

*User Manual*  
*ModeMaster PC™*





*User Manual*  
*ModeMaster PC*  
*M<sup>2</sup> Beam Propagation Analyzer*



27650 SW 95th Ave.  
Wilsonville, OR 97070

This document is copyrighted with all rights reserved. Under the copyright laws, this document may not be copied in whole or in part or reproduced in any other media without the express written permission of Coherent, Inc. Permitted copies must carry the same proprietary and copyright notices as were affixed to the original. This exception does not allow copies to be made for others, whether or not sold, but all the material purchased may be sold, given or loaned to another person. Under the law, copying includes translation into another language.

Coherent, the Coherent Logo, and ModeMaster PC are trademarks or registered trademarks of Coherent, Inc. All other trademarks or registered trademarks are the property of their respective owners.

Patents referenced in this document were active as of the printing date of the manual (see last page for date). The patents referenced herein may have expired. You are advised to check to see if the patents are still active: <http://portal.uspto.gov/external/portal/pair>.

Every effort has been made to ensure that the data given in this document is accurate. The information, figures, tables, specifications, and schematics contained herein are subject to change without notice. Coherent makes no warranty or representation, either expressed or implied, with respect to this document. In no event will Coherent be liable for any direct, indirect, special, incidental, or consequential damages resulting from any defects in its documentation.

### **Technical Support**

#### **In the U.S.:**

Should you experience difficulties with your product, or need technical information, visit our website: [www.Coherent.com](http://www.Coherent.com). You can obtain additional support by either telephoning our Technical Support Hotline at 1.800.343.4912, or e-mailing our Support Team at [support.instruments@Coherent.com](mailto:support.instruments@Coherent.com). Telephone coverage is available Monday through Friday (except U.S. holidays).

If you call outside our office hours, your call will be taken by our answering system and will be returned when the office reopens.

If there are technical difficulties with your laser that cannot be resolved by support mechanisms outlined above, e-mail, or telephone Coherent Technical Support with a description of the problem and the corrective steps attempted. When communicating with our Technical Support Department via the web or telephone, the model and Laser Head serial number of your laser system will be required by the Support Engineer responding to your request.

#### **Outside the U.S.:**

If you are located outside the U.S., visit our website for technical assistance, or telephone our local service representative. Representative phone numbers and addresses can be found on the Coherent website: [www.Coherent.com](http://www.Coherent.com).

Coherent provides web and telephone technical assistance as a service to its customers and assumes no liability thereby for any injury or damage that may occur contemporaneous with such services. These support services do not, under any circumstances, affect the terms of any warranty agreement between Coherent and the buyer. Operating a Coherent product with any of its interlocks defeated is always at the operator's risk.

# TABLE OF CONTENTS

Signal Words and Symbols in this Manual.....	x
Signal Words.....	x
Symbols .....	xi
Preface .....	xii
What's New in ModeMaster PC.....	xii
Export Control Laws Compliance .....	xii
Publication Updates .....	xiii
<b>Section One: Getting Started.....</b>	<b>1-1</b>
ModeMaster PC System Overview.....	1-1
System Components .....	1-1
Installation Procedures.....	1-1
Unpacking Components.....	1-1
Assembling Scan Head to Column .....	1-2
Making the Connections .....	1-4
Connections and Controls.....	1-5
Oscilloscope Traces .....	1-6
Start-Up.....	1-7
Power On Sequence .....	1-7
Initialization .....	1-7
Doublet Wavelength Selection .....	1-9
Singlet Wavelength Selection.....	1-10
Alignment .....	1-11
The ModeMaster PC M2 Live/Alignment Screen.....	1-11
ModeMaster PC Modular Accessories .....	1-18
Installing a New Accessory .....	1-18
Lens Change .....	1-21
Detector Change .....	1-24
<b>Section Two: Reference.....</b>	<b>2-1</b>
Overview of ModeMaster PC .....	2-1
Live/Alignment Window .....	2-2
Menus.....	2-2
File .....	2-3
Open.....	2-4
Save/Save As .....	2-4
File Structure.....	2-6
Print.....	2-6
Print Preview.....	2-7
Print Setup.....	2-7
Recent File .....	2-7
Exit.....	2-7
View .....	2-8

Toolbar .....	2-10
Status Bar .....	2-10
Go To .....	2-10
Alignment View .....	2-10
Propagation View .....	2-10
Pointing View .....	2-10
Customize .....	2-10
Capture .....	2-11
Run .....	2-11
Stop .....	2-11
Focus .....	2-11
Multiple Focus Runs .....	2-11
Move Lens .....	2-12
Clip Level\Knife Edge Conversion Factor .....	2-12
Reset .....	2-12
Special Weights .....	2-12
Analysis .....	2-12
Statistics .....	2-12
Setup .....	2-13
Wavelength .....	2-13
Head .....	2-13
Options .....	2-13
Help .....	2-13
Contents .....	2-14
Using Help .....	2-14
Keyboard Shortcuts .....	2-14
Tutorial .....	2-14
E-mail Tech Support .....	2-14
Website .....	2-14
Tip of the Day .....	2-14
About ModeMaster PC .....	2-14
Toolbar .....	2-15
Status Bar .....	2-16
Graphical Results Area .....	2-17
Properties Panel .....	2-17
Numerical Results Area .....	2-18

<b>Section Three: Operations .....</b>	<b>3-1</b>
Overview of Operations .....	3-1
Global Settings .....	3-1
Clip Level/Knife-Edge Conversion Factor .....	3-2
Knife-Edge Conversion .....	3-3
Special Weights Setup .....	3-4
Special Weights Analysis .....	3-4
Wavelength Selection .....	3-7
Scan Head Setup .....	3-7
M2 Live/Alignment Screen .....	3-8

Status Bar .....	3-11
Focus .....	3-12
Help Messages .....	3-13
Focusing Error Message .....	3-13
Pass to Curve Fit .....	3-14
The Repositioning Remedy .....	3-14
Staying Within the Nomogram Boundaries - Hierarchy of Help Messages ...	3-16
Maximum Gamma Limit .....	3-17
Aberration Limit, $2We/f > (f/\#)$ .....	3-18
Conversion Limit, Knife-Edge M2 Greater than 6.5 .....	3-18
X-Y-R Toolbar Buttons .....	3-19
R-Beam .....	3-19
Properties Panel .....	3-19
Alignment Zoom .....	3-20
Alignment Zoom Indicators .....	3-21
Alignment .....	3-22
Large Font Option .....	3-24
Profile Plot .....	3-24
Width .....	3-24
Delay .....	3-24
Gain .....	3-25
Pinhole Select .....	3-25
Profile Plane .....	3-25
Pinhole .....	3-29
Power Density Plot .....	3-30
Power Density .....	3-30
Maximum Power Density .....	3-33
Beam Propagation Screen .....	3-33
External .....	3-34
Internal .....	3-37
Manual Lens Movement .....	3-39
X Y R Buttons—Beam Propagation Screen .....	3-40
Properties Panel .....	3-40
2D Select .....	3-41
Display Select .....	3-41
3D Plot .....	3-41
Measurement Cursor .....	3-41
Results Panel .....	3-42
Move Lens to .....	3-42
Data Select: External .....	3-42
Data Select: Internal .....	3-44
Data Select: Transform .....	3-45
Pointing Stability Screen .....	3-48
Properties Panel .....	3-50
Mode .....	3-51
Option .....	3-51
Filter .....	3-51

Results Panel.....	3-52
Cursor.....	3-52
Translational Distance (m).....	3-52
Vertical Full Screen .....	3-52
Pointing Stability Run.....	3-53
Hours.....	3-53
Minutes .....	3-53
Second Moments Screen.....	3-54
Knife-Edge Clip Levels Setting.....	3-55
Internal/External Radial Results Area .....	3-56
Properties Panel .....	3-57
Width .....	3-58
Delay .....	3-58
Gain.....	3-58
Truncation.....	3-59
ZeroClip Noise.....	3-59
Background Subtraction .....	3-60
Waist Diameter .....	3-60
Second Moments Setup .....	3-60
Update Second Moments .....	3-63
Multiple Focus .....	3-63
Statistics on Existing Focus Data.....	3-67
<b>Section Four: Tutorial .....</b>	<b>4-1</b>
Start-up: Initialization .....	4-1
Working With ModeMaster PC Files .....	4-5
Retrieving Existing Data.....	4-6
Displaying Existing Data .....	4-9
Power Density Setup.....	4-9
Laser Diode Collimation Process .....	4-11
Pointing Stability Run (Finding the Pivot) .....	4-13
Second Moments Setup .....	4-16
<b>Section Five: Beam Propagation Theory .....</b>	<b>5-1</b>
Overview.....	5-1
Introduction.....	5-1
A Theory of Real-beam Propagation .....	5-2
Useful Equations.....	5-6
Beam Measurements.....	5-7
Knife-edge Diameter Measurements .....	5-9
Theory of Operation.....	5-12
Introduction.....	5-12
Beam Diameter Measurements .....	5-13
Beam Axis Location and Direction .....	5-14
Coordinates and Sign Conventions.....	5-14
The Equivalent Radially-Symmetric Beam .....	5-15
Instrument Axis Alignment .....	5-16

Diffraction-limited Lenses .....	5-16
Azimuthal Adjustment for Locating the Beam Principal Planes .....	5-18
System Modularity: Broadening the Range of Input Beam Wavelengths and Divergences .....	5-19
More Details on the Instrument .....	5-21
Computing M2 in Real-Time (and how $M2 < 0.95$ can result) .....	5-21
Real Time Versus Historical Data .....	5-22
Limiting Effects at the Nomogram Boundaries .....	5-23
The Reference Plane and the Lens Principal Planes .....	5-27
The Transformation Through the Lens to the External Beam .....	5-29
More on Profiles .....	5-31
Optimal Use of the Second Moments Screen .....	5-33
Overview .....	5-33
Definitions .....	5-35
Averaging the Moments from the Left and Right Half-Profiles .....	5-37
Modeling Noise on the Experimental Profile .....	5-37
Truncation Clipping Error .....	5-42
Reducing the Effect of Noise—Background Subtraction .....	5-44
Reducing the Effect of Noise—Truncation Limits .....	5-44
Reducing the Effect of Noise—ZeroClip Noise Option .....	5-45
Checking the Reproducibility of the Second Moment Measurements .....	5-47
Summary of Optimal Use of Second Moment Screen Options .....	5-47
Linear Second Moment Diameter .....	5-48
Conversion Between Beam Diameter Measurement Methods .....	5-49
Diameter Measurement Methods .....	5-49
Diameter Conversions .....	5-50
User Conversion Factor .....	5-53
<b>Section Six: Troubleshooting Tips</b> .....	6-1
<b>Section Seven: Warranty and Service</b> .....	7-1
Warranty .....	7-1
Obtaining Service .....	7-2
Product Shipping Instructions .....	7-3
<b>Appendix A: Specifications</b> .....	A-1
System Specifications .....	A-2
Minimum Computer Requirements .....	A-2
<b>Index</b> .....	Index-1

# LIST OF FIGURES

1-1.	ModeMaster PC Components .....	1-2
1-2.	Making the Connections .....	1-4
1-3.	ModeMaster PC Control/Interface Console Rear Panel .....	1-5
1-4.	ModeMaster PC Signals to Oscilloscope.....	1-6
1-5.	Scan Head Micrometer Adjustments .....	1-15
1-6.	Adjustment Angle Diagram for Focused Condition .....	1-16
2-1.	The Propagation View .....	2-17
2-2.	Properties Window .....	2-18
2-3.	Numerical Results for Propagation Plot Screen .....	2-18
3-1.	Normal Weights Analysis of Distorted Data .....	3-6
3-2.	Data Segmentation for Special Weights Analysis .....	3-6
3-3.	Improved Fit of the Rad Mode Curve.....	3-6
3-4.	Focusing Error Message .....	3-13
3-5.	Effect of Repositioning the Instrument on Internal Rayleigh Range.....	3-15
3-6.	Hierarchy of Post-Focus Nomogram Limits Messages .....	3-17
3-7.	Conversion Limits Message.....	3-18
3-8.	Adjustment Angle Diagram .....	3-23
3-9.	Adjustment Angle Diagram .....	3-24
3-10.	M2 Measurement Planes and Profile Plane .....	3-27
3-11.	Beam Profiling in ModeMaster PC .....	3-28
3-12.	Effect of Second Moments Options .....	3-59
5-1.	Conceptual Relationships Between Real and Ideal Beams .....	5-5
5-2.	Diagram of an Astigmatic Beam .....	5-8
5-3.	Types of Asymmetry .....	5-8
5-4.	Beam Diameter Measurement .....	5-9
5-5.	ModeMaster PC Coordinate System.....	5-15
5-6.	Dewey Doublet Input Lens .....	5-16
5-7.	Focal Length and Principal Plane Separation Variation with Wavelength for the Dewey Doublet .....	5-17
5-8.	ModeMaster PC Modularity Schematic .....	5-20
5-9.	Nomogram Limits.....	5-23
5-10.	ModeMaster PC Nomogram Showing Regions of Useful Operation.....	5-24
5-11.	ModeMaster PC Reference Distances .....	5-27
5-12.	Typical Digitized Profile of a Gaussian Beam .....	5-35
5-13.	Derivation of the Equivalent “Rectified “noise” no .....	5-39
5-14.	Normalized Variance for a Gaussian Mode Versus the Truncation Limit, with NoiseClip On and Off .....	5-41
5-15.	Effect of Second Moment Options .....	5-43

# LIST OF TABLES

3-1.	Properties Panel Functions.....	3-20
6-1.	Troubleshooting Tips.....	6-1
7-1.	Coherent Service Centers.....	7-2

## Signal Words and Symbols in this Manual

This documentation may contain sections in which particular hazards are defined or special attention is drawn to particular conditions. These sections are indicated with signal words in accordance with ANSI Z-535.6 and safety symbols (pictorial hazard alerts) in accordance with ANSI Z-535.3 and ISO 7010.

### Signal Words

Four signal words are used in this documentation: **DANGER**, **WARNING**, **CAUTION** and **NOTICE**.

The signal words **DANGER**, **WARNING** and **CAUTION** designate the degree or level of hazard when there is the risk of injury:

---

#### **DANGER!**

Indicates a hazardous situation that, if not avoided, will result in death or serious injury. This signal word is to be limited to the most extreme situations.

---

---

#### **WARNING!**

Indicates a hazardous situation that, if not avoided, could result in death or serious injury.

---

---

#### **CAUTION!**

Indicates a hazardous situation that, if not avoided, could result in minor or moderate injury.

---

The signal word “**NOTICE**” is used when there is the risk of property damage:

---

#### **NOTICE!**

Indicates information considered important, but not hazard-related.

---

Messages relating to hazards that could result in both personal injury and property damage are considered safety messages and not property damage messages.

## Symbols

The signal words **DANGER**, **WARNING**, and **CAUTION** are always emphasized with a safety symbol that indicates a special hazard, regardless of the hazard level:



---

**This symbol is intended to alert the operator to the presence of important operating and maintenance instructions.**

---



---

**This symbol is intended to alert the operator to the danger of exposure to hazardous visible and invisible laser radiation.**

---



---

**This symbol is intended to alert the operator to the presence of dangerous voltages within the product enclosure that may be of sufficient magnitude to constitute a risk of electric shock.**

---



---

**This symbol is intended to alert the operator to the danger of Electro-Static Discharge (ESD) susceptibility.**

---



---

**This symbol is intended to alert the operator to the danger of crushing injury.**

---



---

**This symbol is intended to alert the operator to the danger of a lifting hazard.**

---

## **Preface**

This manual is the primary source of directions for installing and operating the ModeMaster PC™ Beam Propagation Analyzer.

This manual is accessible online as a Windows help file, available while running the ModeMaster PC software. To access the Windows help version of this manual, press Shift + F1 from within ModeMaster PC.

## **What's New in ModeMaster PC**

ModeMaster PC was designed to provide you with even more functionality through a highly intuitive, easy to use, Windows interface. ModeMaster PC provides all the features of the original ModeMaster, as well as newly added functions and operation options:

- Intuitive Windows® environment
- Multiple print options with complete Windows printer support
- Faster access to data
- Cursor measurements for propagation and pointing stability data
- Save As options for all essential data. Data is saved in tab-delimited text for analysis or viewing by the user interface.
- Function Wizards: Pinhole, Power Density, and Second Moments
- 3D Propagation Plot
- User-defined multiple focus data collection with statistics
- Seamless compatibility with any existing scan head
- Complete pointing stability statistics

## **Export Control Laws Compliance**

It is the policy of Coherent to comply strictly with U.S. export control laws.

Export and re-export of lasers manufactured by Coherent are subject to U.S. Export Administration Regulations, which are administered by the Commerce Department. In addition, shipments of certain components are regulated by the State Department under the International Traffic in Arms Regulations.

The applicable restrictions vary depending on the specific product involved and its destination. In some cases, U.S. law requires that U.S. Government approval be obtained prior to resale, export or re-export of certain articles. When there is uncertainty about the obligations imposed by U.S. law, clarification must be obtained from Coherent or an appropriate U.S. Government agency.

Products manufactured in the European Union, Singapore, Malaysia, Thailand: These commodities, technology, or software are subject to local export regulations and local laws. Diversion contrary

to local law is prohibited. The use, sale, re-export, or re-transfer directly or indirectly in any prohibited activities are strictly prohibited.

## **Publication Updates**

To view information that may have been added or changed since this publication went to print, connect to [www.Coherent.com](http://www.Coherent.com).



# SECTION ONE: GETTING STARTED

In this section:

- ModeMaster PC system overview (this page)
- Preparing for installation (this page)
- Installation procedures (p. 1-1)
- Start-up (p. 1-7)
- ModeMaster PC modular accessories (p. 1-18)

## **ModeMaster PC System Overview**

### **System Components**

The ModeMaster PC Beam Propagation Analyzer includes the following components:

- ModeMaster PC Scan Head
- ModeMaster PC Control/Interface Console
- ModeMaster PC Software
- Power Supply Cable
- USB Device Cable

### **Installation Procedures**

### **Unpacking Components**

1. Remove the Scan Head and Control/Interface Console from their protective container box.
2. Remove the software CD from its packaging, located inside the user manual.
3. Remove the USB cable and power supply cable from its packaging.

Save all the packaging for use while transporting or storing equipment, to ensure that the equipment is adequately protected.



Check to make sure that you have all of the items shown in Figure 1-1, below:



**Figure 1-1. ModeMaster PC Components**

---

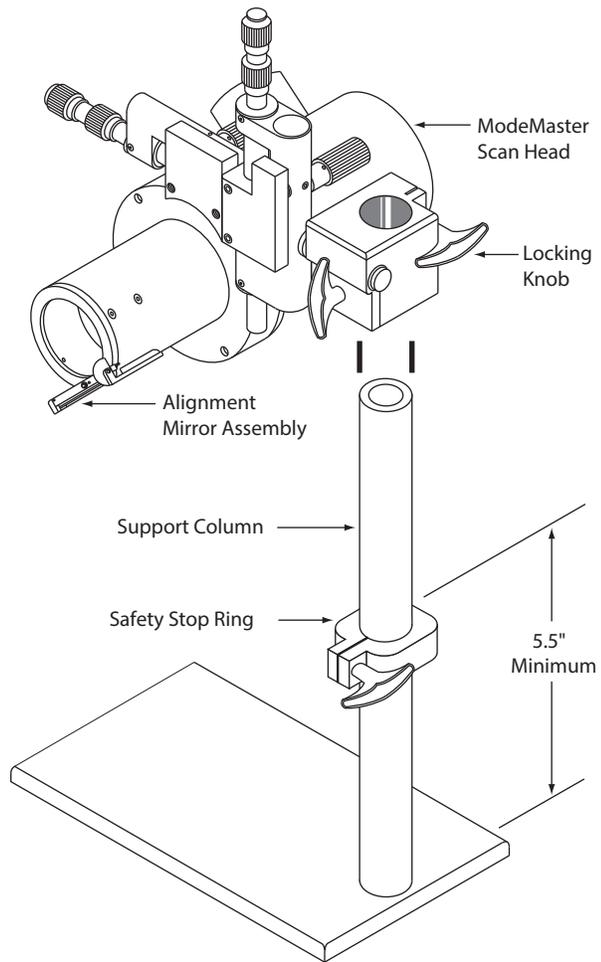
**Laptop computer not included with ModeMaster PC purchase.**

---

## **Assembling Scan Head to Column**

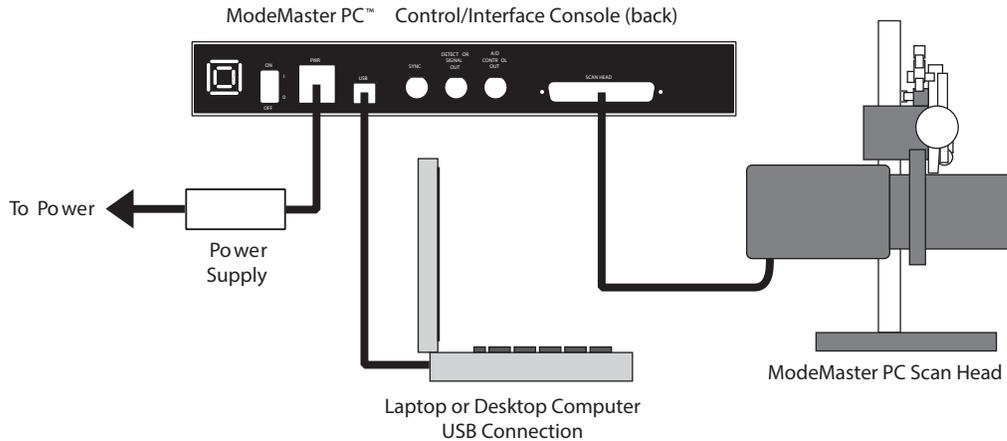
1. Stand is shipped with support column attached to base. If you wish to attach support column directly to an optical table, use the extra long hex driver provided to unscrew the 1/4-20 hex head captive screw in the center of the support column and attach it to the table.
2. First slide safety stop ring onto column and tighten (minimum height above base or table for stop is 5.5"). Slide ModeMaster PC Scan Head onto support column. Tighten locking knob (see the following figure).

3. Rotate alignment mirror assembly back and remove red dust cover and protective foam plug.



## Making the Connections

1. Connect the Scan Head and Control/Interface Console using the provided 37 D-Pin cable.
2. Connect the Control/Interface Console to your laptop or desktop using the provided USB cable.
3. Connect Control/Interface Console to power socket using the provided power supply.

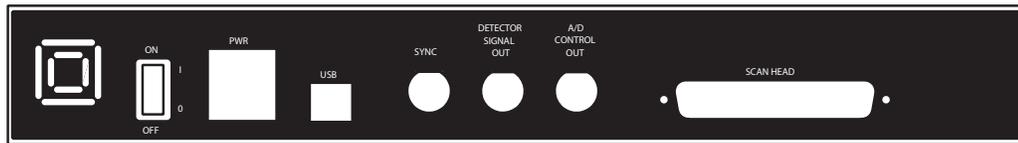


**Figure 1-2. Making the Connections**

4. Attach AC power cord from rear of ModeMaster PC Control/Interface Console to AC power socket. ModeMaster PC senses power and automatically adjusts to use any AC power source from 100-240 VAC, 47-63 Hz, 40 W. ModeMaster PC is shipped with an AC power cord with standard 3 prong plug for U.S. 110 VAC grounded outlets. Replace plug if necessary for compatibility with power outlets in your installation, or replace entire AC cord with one with an IEC 320-compatible connector for the ModeMaster PC and the appropriate plug for your installation.
5. Turn on Console power switch and proceed to “Start-Up” (p. 1-7).

## Connections and Controls

The connections and controls on the rear panel of the ModeMaster PC Control/Interface Console are shown in the following figure:



*Figure 1-3. ModeMaster PC Control/Interface Console Rear Panel*

**POWER OFF/ON** - Switches power Off and On to Control/Interface Console. An LED light on the front panel indicates when the unit is on.

**AC POWER** - ModeMaster PC senses power and automatically adjusts to use any AC power source from 100-240 VAC, 47-63 Hz, 40 watts. ModeMaster PC is shipped with AC power cord with standard 3-prong plug for U.S. 120 VAC grounded outlets.

**USB CONNECTOR** - Connects Control/Interface Console to laptop or desktop using the provided USB cable.

**SYNC** - Provides output of trigger signal for each revolution of the ModeMaster PC Scan Head. Trigger signal is a 1 millisecond, 0-5 volt pulse. Connect to External Trigger on Oscilloscope.

**DETECTOR SIGNAL OUT** - Output of signal from the photocell detector in the ModeMaster PC Scan Head. Connect to Channel 1 on oscilloscope.

**A/D CONTROL SIGNAL OUT** - Output of control signal for A/D Converter. Connect to Channel 2 on oscilloscope.

**SCAN HEAD CONNECTOR** - Connects to Scan Head using the provided DB 37-pin cable.

## Oscilloscope Traces

The direct signal from the ModeMaster PC Scan Head detector can be displayed on an oscilloscope by connecting the SCOPE TRIGGER on the rear of the ModeMaster PC Control/Interface Console to the External Trigger on the oscilloscope, connecting the DETECTOR SIGNAL OUT from the ModeMaster PC Control/Interface Console to Channel 1 on the oscilloscope, and by connecting the Sync Out on the rear of the ModeMaster PC Control/Interface Console to Channel 2 on the oscilloscope—refer to Figure 1-4 (p. 1-6). The A/D Control Out signal shows the segment of the DETECTOR SIGNAL that is digitized and displayed on the Alignment Screen. These signals are often useful in diagnosing problems (for example, noisy laser). An oscilloscope is not required to operate the ModeMaster PC.

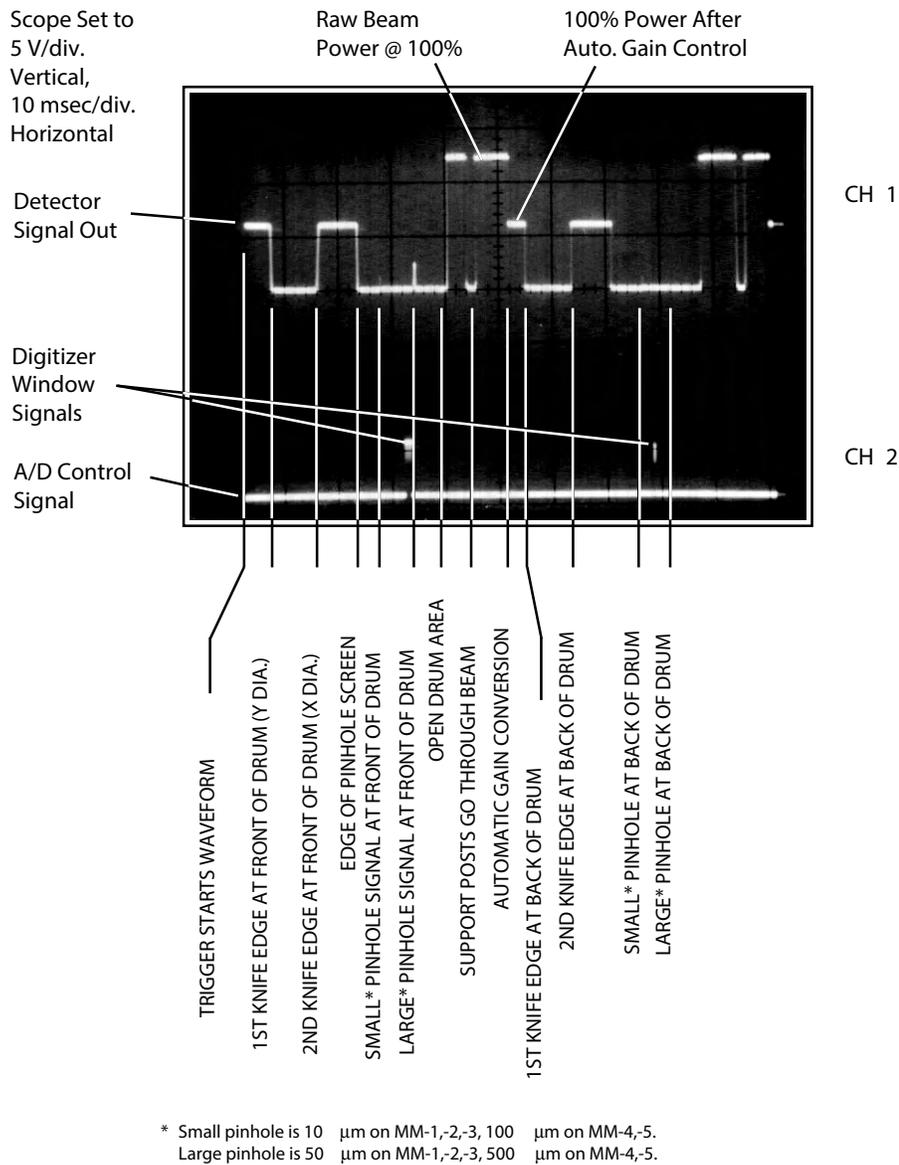


Figure 1-4. ModeMaster PC Signals to Oscilloscope

## Start-Up

### Power On Sequence

1. Make sure all connections are in place.
2. Turn on Control/Interface Console.
3. Wait 5 seconds and then launch ModeMaster PC software.

---

#### **NOTICE!**

**Do not aim laser beam into ModeMaster PC Scan Head when ModeMaster PC is off. Focusing beam on rotating drum when drum is stationary can cause damage even within specified power ranges.**

---



---

#### **WARNING!**

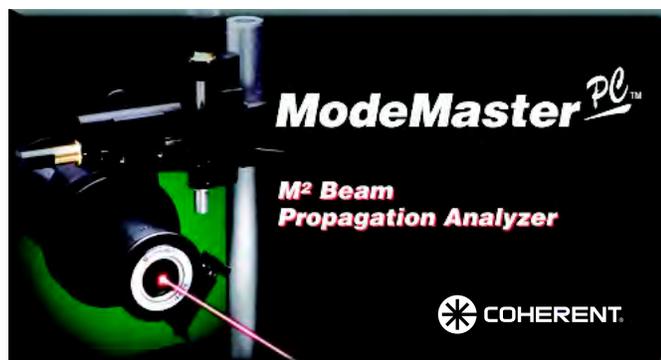
**Alignment should be done with the laser beam at minimum practical power levels. Standard precautions to prevent direct or reflected exposure to the laser beam should be taken.**

---

### Initialization

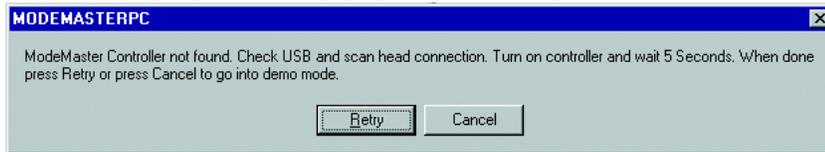
Once you have successfully installed the program and restarted your system, turn on the Control/Interface Console, wait 5 seconds, then double-click on ModeMaster PC icon on your desktop, or choose Programs >>Coherent >>ModeMaster PC from your Start menu.

4. The following screen appears within the ModeMaster PC program window:

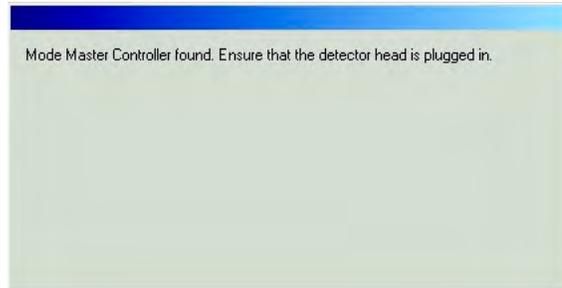


5. The ModeMaster PC Controller not found window will appear if there is a problem with your connection to the controller. Make sure that all connections are secure and correctly connected. Turn on the controller, wait 5 seconds and click

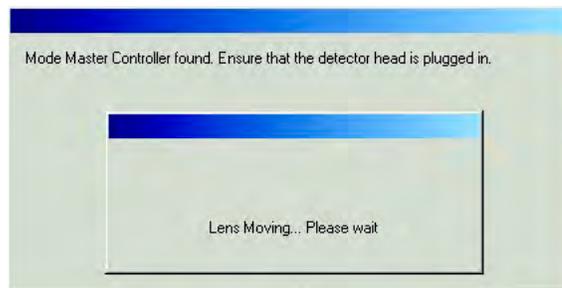
retry to re-attempt connection. If you wish to view ModeMaster PC file data, click cancel.



6. The ModeMaster PC Controller Found window will appear when all components are correctly connected.



7. While the ModeMaster PC initializes, a chattering sound will be heard from the Scan Head. This is made by the positioning of the lens carriage assembly and indicates the Scan Head is operating properly. This process may take a minute.



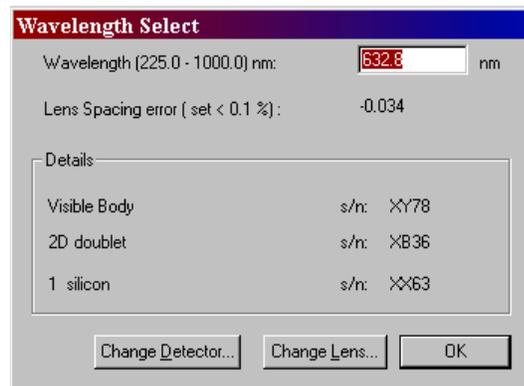
8. After initialization is complete, the ModeMaster PC Reminder screen (shown below) will be displayed for 15 seconds. To continue before fifteen seconds, click OK. The ModeMaster PC will automatically go to the wavelength adjustment screen. You can disable this screen in the future by deselecting the "Show this dialog next time" option. To return this dialog, go to the Setup >> Options menu. This screen will vary depending on whether the ModeMaster PC has a doublet input lens (MM-1, -2, -3 models) or a singlet input lens (MM-1S,-2S, -3S, -4, and -5 models). *For doublet models, proceed to*

“Doublet Wavelength Selection” (p. 1-9). For singled models jump to “Singlet Wavelength Selection” (p. 1-10).



## Doublet Wavelength Selection

9. *ModeMaster PC Wavelength Selection Screen for Doublet Lens Models.* The lens carriage assembly will move to the limit of its travel so that the knurled adjustment ring is protruding from the front of the scan head. For ModeMaster PC models (MM-1, 2, 3) with Dewey Doublet input lenses, the Wavelength Select Screen shown in the following figure will be displayed.



When the displayed wavelength is correct, the lens spacing error is displayed. (If working with a multiline laser, the best compromise is to adjust the wavelength setting to the arithmetic mean of the laser lines.) Turn the knurled adjustment ring on the lens assembly to adjust the lens spacing until the displayed error is less than 0.1. When the current error is less than 0.1, the OK button will come into focus. Valid data cannot be collected with a spacing error greater than 0.1. To change the detector or lens, click on the provided buttons and follow the on-screen commands. When you have met the spacing error conditions at the desired wavelength, click OK to continue.

## Singlet Wavelength Selection

For ModeMaster PC models with singlet input lenses (MM-1S, -2S, -3S, -4, and -5), the Wavelength Selection Screen shown in the following figure will be displayed. Enter the desired value to adjust the wavelength.

---

**For any model, wavelength must be adjusted to within 1% of the actual value in order to make displayed values of  $M^2$  accurate to the published specification.**

---

If working with a multi-line laser, the best compromise is to adjust the wavelength setting to the power-weighted mean wavelength of the laser lines.



## Alignment

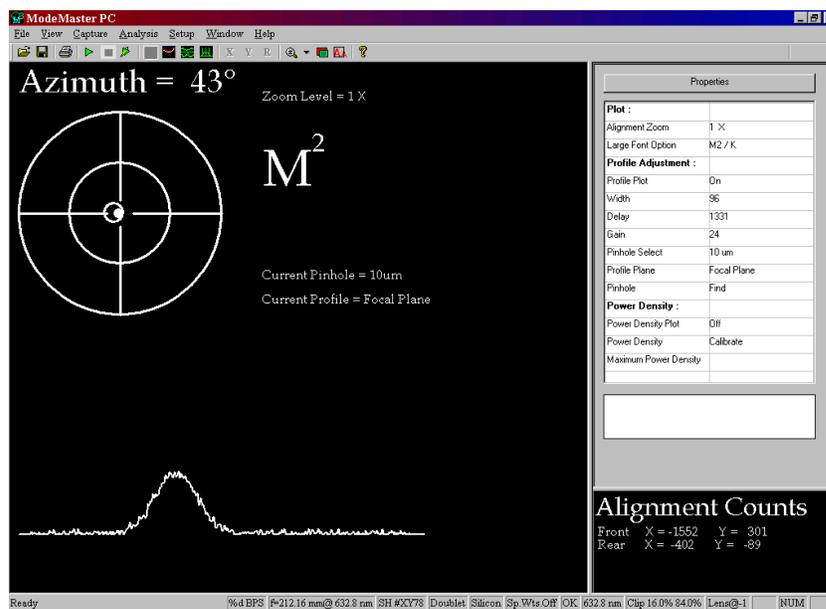
### The ModeMaster PC M2 Live/Alignment Screen

The ModeMaster PC Live/Alignment screen will be displayed. Align the instrument so the circle and dot are located within the center target.

---

**If the laser power into the ModeMaster PC exceeds the specified maximum, the message “the detector is saturated...please reduce the laser power” will be displayed. Reduce laser power or attenuate the beam.**

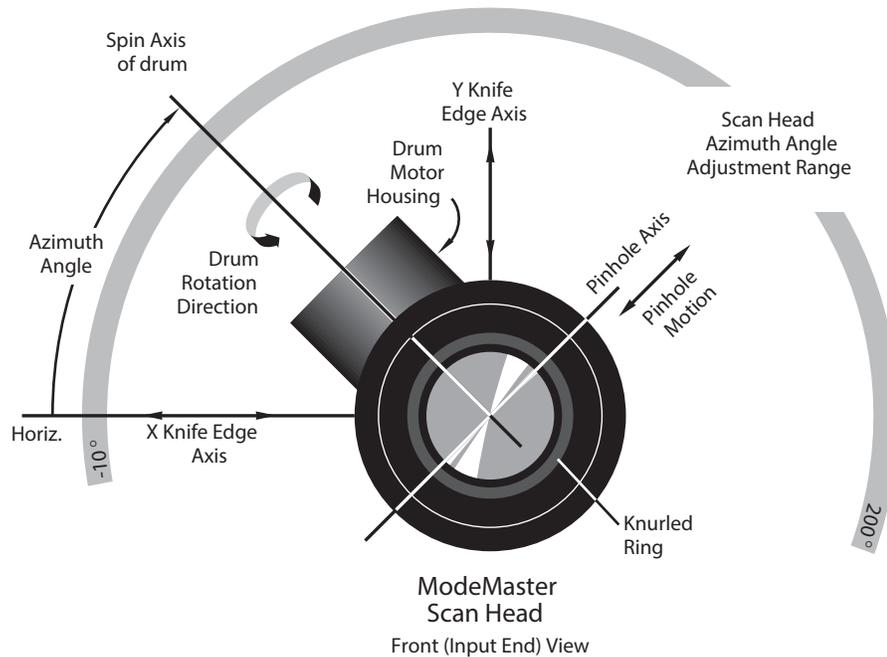
---



1. The following window will appear if the Azimuth angle is not at 45°. If you chose not to show this dialog, use the Setup >> Options menu item to return.



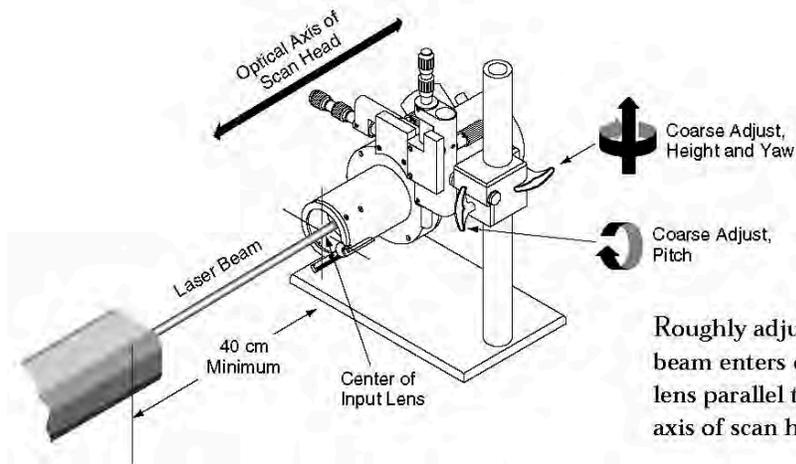
2. Rotate the ModeMaster PC Scan Head body until the azimuth angle on the Live/Alignment screen =  $45^\circ$  (referred to as the “standard azimuth angle”). This will align the scan head so that the knife-edges read the X-axis as horizontal and the Y-axis as vertical. The pinholes will scan across the beam at an azimuth angle of  $135^\circ$ . The azimuth angle is defined as the angle the drum motor makes in relation to horizontal when viewing the input end of the instrument.



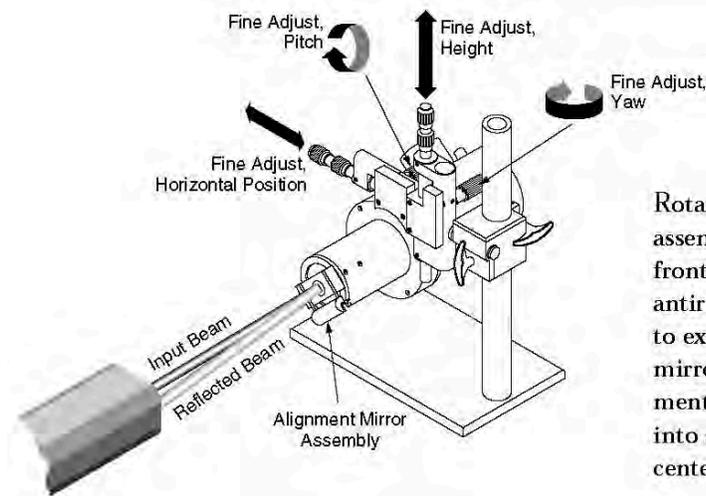
---

**The zero offsets of the alignment targets are calibrated at the factory so that the pinholes cross the beam at a scan head azimuth angle of  $45^\circ$ . Other azimuth angles will result in a less precise initial pinhole alignment.**

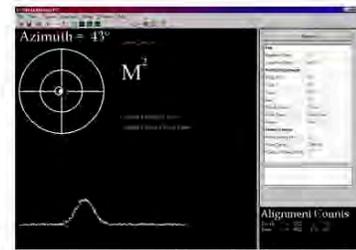
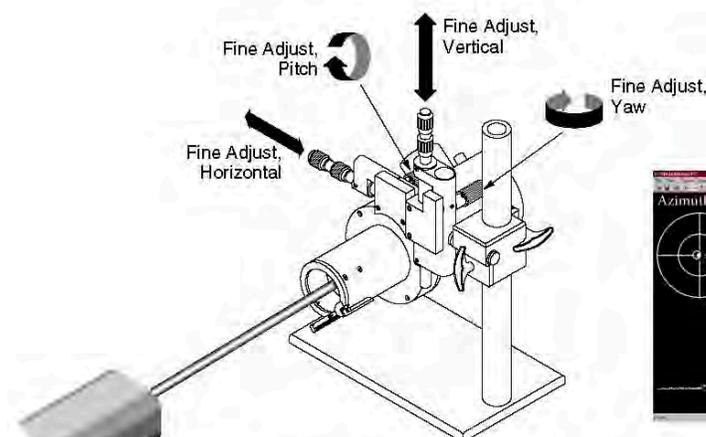
---



Roughly adjust scan head so beam enters center of input lens parallel to optical axis of scan head.



Rotate alignment mirror assembly into place on front of scan head. Slide antireflection cover to side to expose alignment mirror. Use angle adjustments to reflect beam back into source, with the beam centered on the mirror.



Close sliding cover and rotate alignment mirror out of the way. Use micrometer adjustment to center circle and dot in the alignment target on the ModeMaster PC Live/Alignment screen.

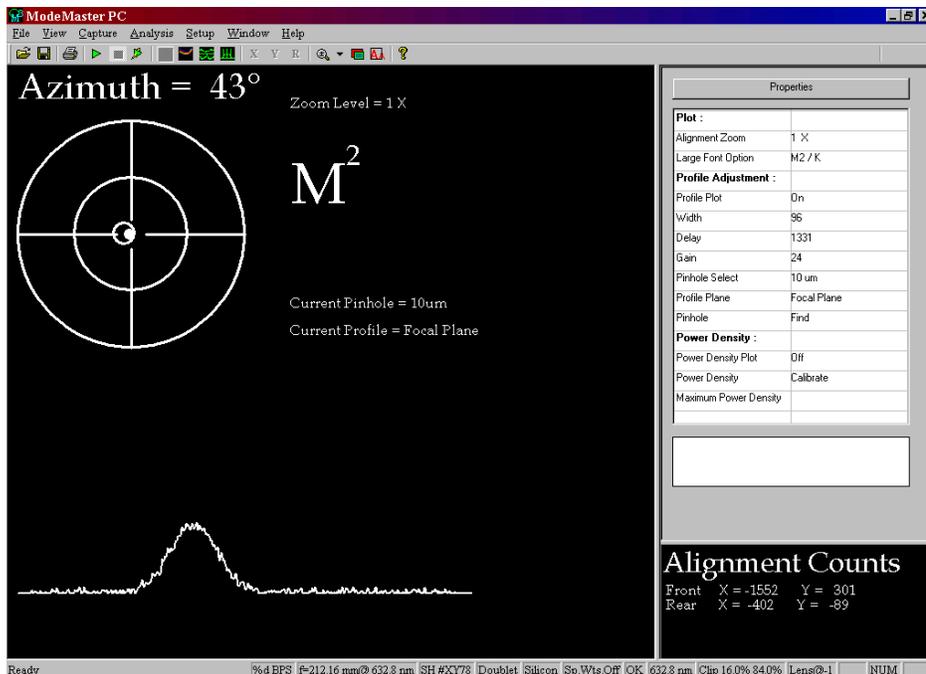
- With the laser at minimum power, roughly align the ModeMaster PC Scan Head so that the beam is going into the center of the input lens approximately parallel to the optical axis of the scan head (see the figure, above). Rotate the alignment mirror assembly into place on the input of the scan head. Slide open the protective cover over the alignment mirror. Adjust the position and angle of the scan head using the micrometer adjustments so that the beam is reflected back to its source with the beam centered on the mirror.

---

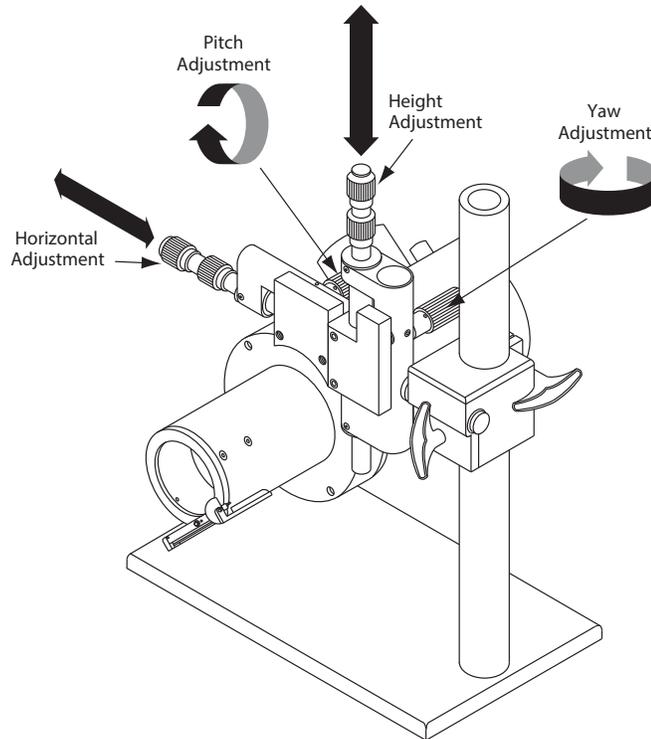
**There are stops at the limit of travel of the micrometer adjustments. Do not try to force adjustments once the stop is reached. If an adjustment limit is reached, re-center the adjustment and loosen the large T-knobs. Manually realign the head so the reflected beam is roughly centered, re-tighten the knobs, and use the micrometer adjustments for final alignment.**

---

- Rotate the alignment mirror assembly out of the way. The Alignment screen should now display the dot (representing the beam position at the back of the rotating drum) and the small circle (representing the position of the beam at the front of the rotating drum) should be within the alignment target on the screen (see following figure). The larger fixed target circle on the Live/Alignment screen represents the approximate outer diameter of the input lens of the scan head. The smaller inner fixed circle represents the approximate region the beam must be aligned within to measure  $M^2$  with precision.



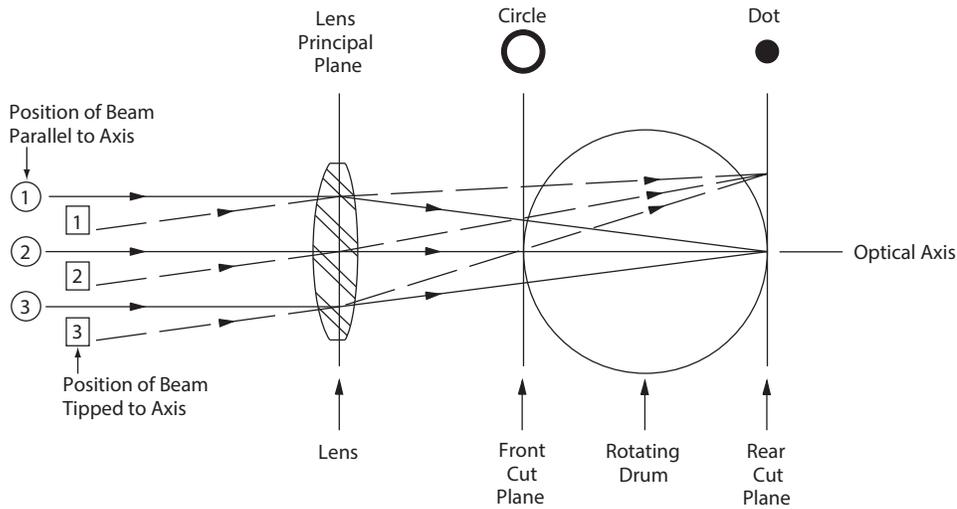
Now, use the micrometer adjustments to bring the small dot symbol within the small circle symbol (adjusts the scan head so the input beam is parallel with the scan head optical axis) and the dot and circle both to the center of the alignment target (adjusts scan head so the input beam is on its optical axis).



**Figure 1-5. Scan Head Micrometer Adjustments**

5. The micrometer adjustments controlling the translation and angular adjustment of the ModeMaster PC scan head will have varying effects on the movement of the front and rear plane beam position indicators, depending on the azimuth angle and the location of the lens within the scan head—refer to Figure 1-6 (p. 1-16). Try each adjustment to find the effect for the current azimuth angle of the scan head. Motion of the beam

position indicators will be easiest to understand and interpret when the scan head azimuth angle is set at 45°.



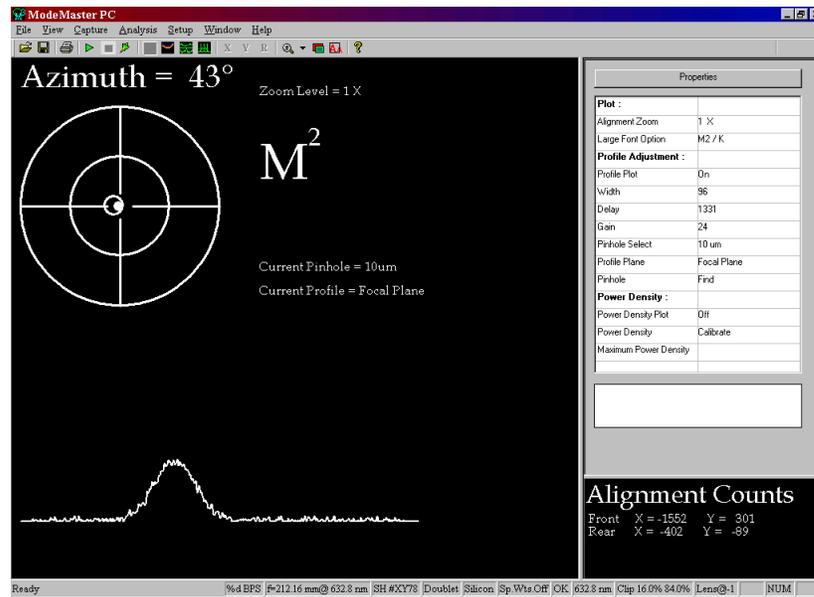
**Figure 1-6. Adjustment Angle Diagram for Focused Condition**

6. Now, align the scan head so the circle is centered in the alignment target, and the dot is centered in the circle (see the following figure).

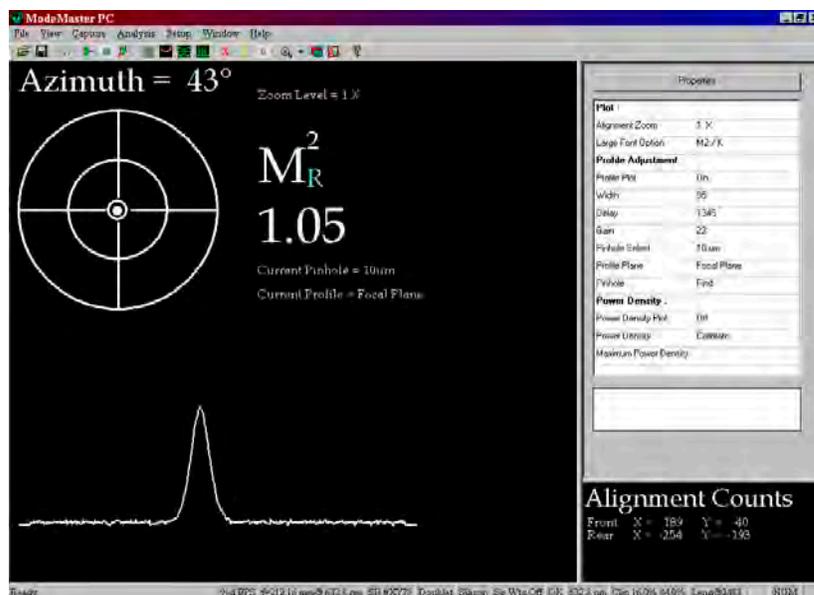


**WARNING!**

The ModeMaster PC Scan Head Knife-edges are coated for high reflection. The diffuse reflection may affect the laser source during a focus run. A slight misalignment of the scan head will produce accurate results without an effect on the laser source. Remove the detector aperture for laser power less than 10% of the maximum rated ModeMaster PC input. The removal of this aperture will provide better beam profile resolution. Always use proper laser eye protection when operating the ModeMaster PC.



- When both the dot and the circle are centered within the target, initial alignment is done. Choose Capture >> Focus (F11). The message “LensMoving...Please Wait” will be displayed, and you will hear the lens assembly in the scan head moving. The Focus command translates the lens assembly through its full travel and gathers beam diameter measurements. The message box will disappear and the Alignment Screen will display values for  $M^2$ , (see the following figure). Focus data is now available.



## ModeMaster PC Modular Accessories

The input lens and the detector on the ModeMaster scan head can be changed to accommodate beams with different characteristics (wavelength, diameter, or divergence). See “Appendix A: Specifications” (p. A-1) for the specific beams that can be accommodated by each model.

When a new lens and/or detector for the ModeMaster PC is ordered, the following items will be received:

1. The lens or detector assembly.
2. A floppy disk with the calibration information associated with the accessory purchased.
3. A Hex driver for removing the required screws for changing accessories.

## Installing a New Accessory

When you receive a new accessory, the first step is to load the accessory calibration data into the scan head. This is accomplished by following the steps listed below.

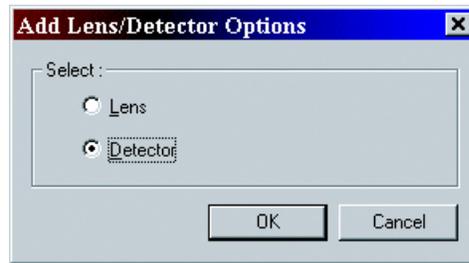
1. Start the ModeMaster PC software and insert the floppy disk included with the accessory.
2. Select Head from the Setup menu.



3. Click on the Add button to install the new accessory.



4. Select the type of accessory that you are installing.

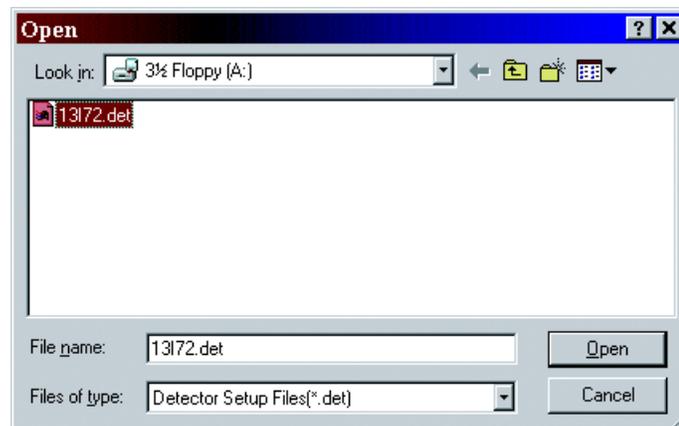


5. The OK button will bring up an open dialog with the serial number of the new accessory shown. Click on the file name shown and then click Open to proceed. The file extension .det (Detector) and .lns (Lens) will dictate the type of accessory that is to be installed. If Lens or Detector was not correctly selected in Step 4, the accessory will not be shown in the open dialog.

---

**If you are not installing the accessory from Drive A:, a message prompting you to place a disk in drive A will be shown. When you select cancel in this dialog, the Open dialog will appear and allow you to select the proper location for the accessory file.**

---



6. When the Open Button is selected, the following message will appear. At this point, the data has been written to the scan head EEPROM. When you restart the ModeMaster PC software, the appropriate default parameters will be reset.



7. The new accessory has now been properly installed into the scan head.

---

**The accessories are contained in the scan head and not the computer. This will allow you to use the scan head on any computer with the ModeMaster PC software.**

---

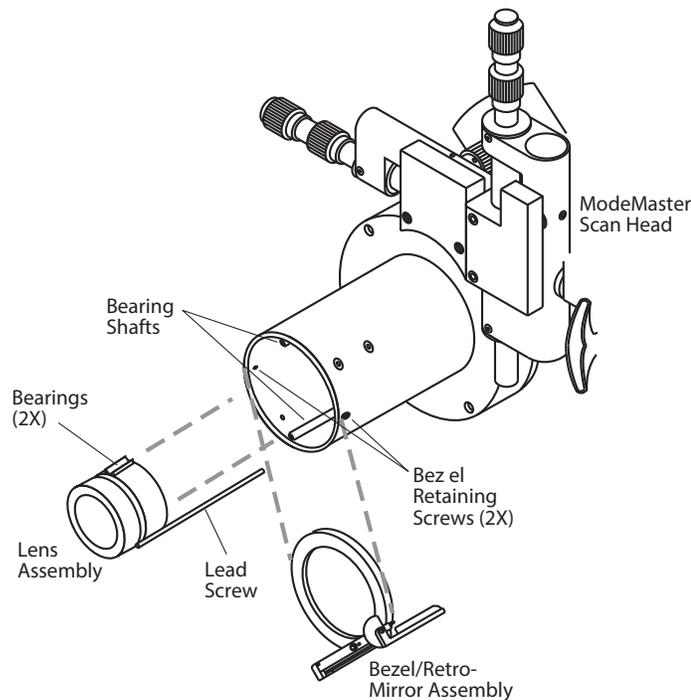
---

**A maximum of three lenses and three detectors can be loaded into a scan head. If the same accessory is loaded multiple times, the data does not overwrite. If you load more than three times, you have to replace one of the previous settings. Note that the setting you are replacing will be deleted in the scan head.**

---

## Lens Change

1. Start the ModeMaster PC software and adjust the scan head angle to 45°.
2. Remove the retro-mirror assembly from the scan head by removing the two flat head screws shown in the following figure. Use the hex tool provided with the accessory lens.



3. Select Head from the Setup menu.

---

**The lens changing process can also be accessed from the Wavelength Setup Dialog.**

---



4. Select Change Lens from the Head Setup dialog. The current lens and detector are displayed in this dialog.



5. When you click on the change lens button, a selection dialog will appear. Click on the drop down arrow to view the list of available lenses. Select the desired lens from the list and click OK.



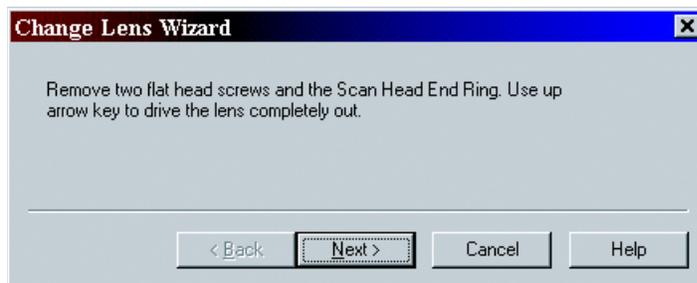
6. The next dialog will prompt you to remove the retro-mirror assembly. With the retro-mirror assembly removed, use the keyboard UP arrow to drive the lens out. Use one hand to grasp the lens as it disengages from the bearing shaft.

---

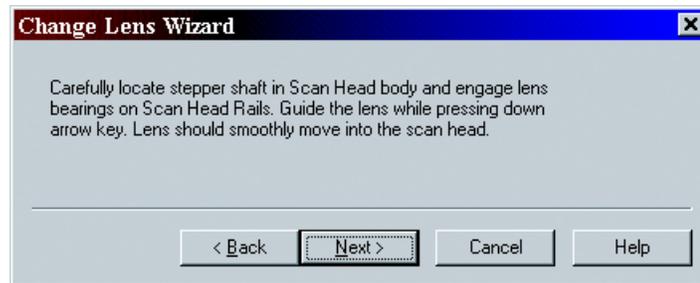
**NOTICE!**

**If you do not grasp the lens as it disengages from the bearing shaft, it can fall out of the head and incur damage.**

---



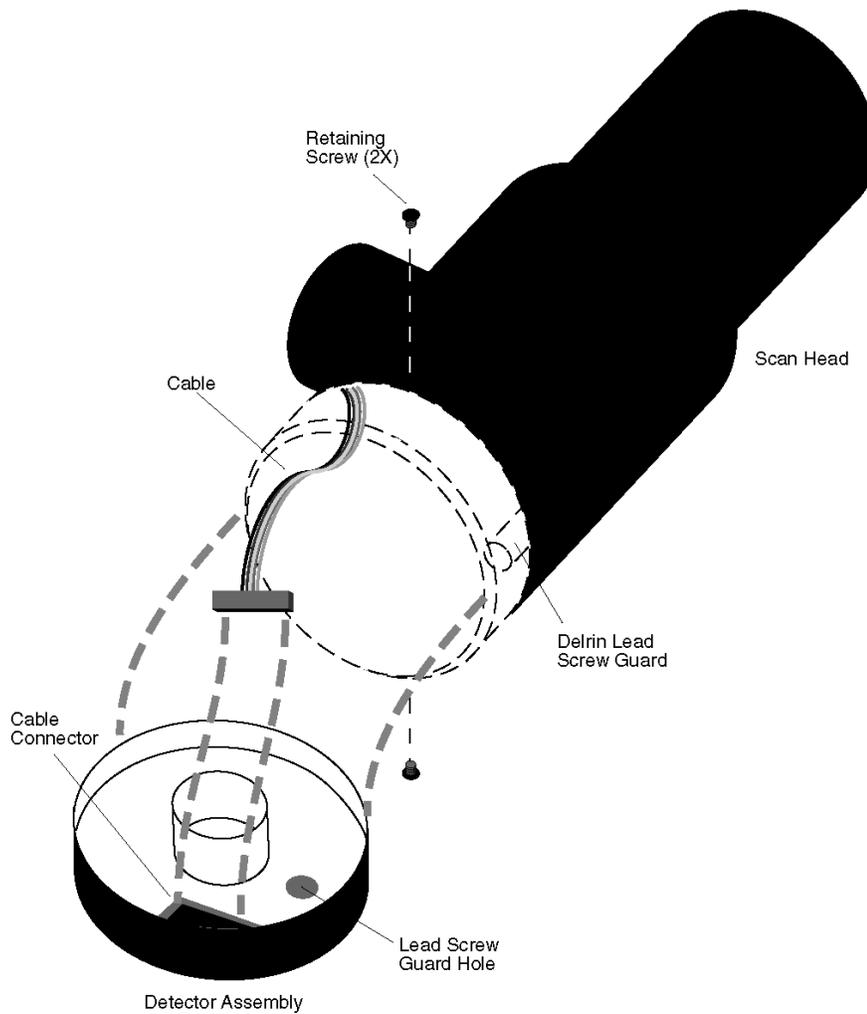
7. The next step will be to install the new lens. Locate the lens lead screw in the stepper motor opening. By looking into the lens tube, this opening will appear as a white plastic component located on the face of the main body. With the lead screw located in the stepper motor, engage the double set of lens bearings on the bearing shaft. Use the keyboard DOWN arrow key to pull the lens into the lens tube as you engage the single spring-loaded bearing set. Continue to move the lens into a central location in the scan head and click next.



8. Complete the lens installation process by replacing the retro-mirror assembly with the two flat head screws. Click Finish. You will then be prompted to restart the ModeMaster PC software to reset default settings associated with the new lens.



## Detector Change



1. Select Head from the Setup menu.

---

**The detector changing process can also be accessed from the Wavelength Setup Dialog.**

---



2. Select Change Detector from the Head Setup dialog. The current lens and detector are displayed in this dialog.



3. When you click on the change detector button, a selection dialog will appear. Click on the drop down arrow to view the list of available detectors. Select the desired detector from the list and click OK.



4. The software has switched off the scan head power. You can now safely change detector assemblies. This is accomplished by removing the two flat head screws at the rear of the ModeMaster scan head. Unplug the existing detector and plug the new detector into the scan head. Replace the two flat head screws and click OK.



5. When you click OK, the power will be restored to the scan head. The software will require a delay to allow the wheel speed to stabilize. When the wheel speed is stable, you will be prompted to restart the ModeMaster PC software to restore the appropriate default settings for the new detector.



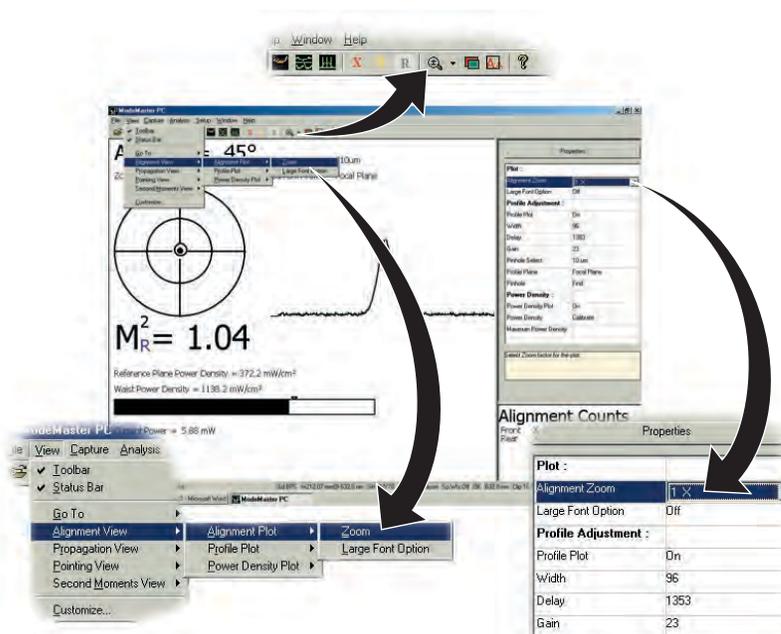
## SECTION TWO: REFERENCE

In this section:

- Overview of ModeMaster PC (this page)
- Live/alignment window (p. 2-2)
- Menus (p. 2-2)
- Toolbar (p. 2-15)
- Status bar (p. 2-16)
- Graphical results area (p. 2-17)
- Properties panel (p. 2-17)
- Numerical results area (p. 2-18)

### Overview of ModeMaster PC

ModeMaster PC controls all functional aspects of the Scan Head and Control/Interface Console through an easy-to-use interface. ModeMaster PC provides a simple point and click solution to a variety of beam analysis options within five different plot and measurement screens. Most of the controls and functions you will use can be accessed either from the Menu Items, Toolbar, or Properties Panel. The following illustration displays this relationship:



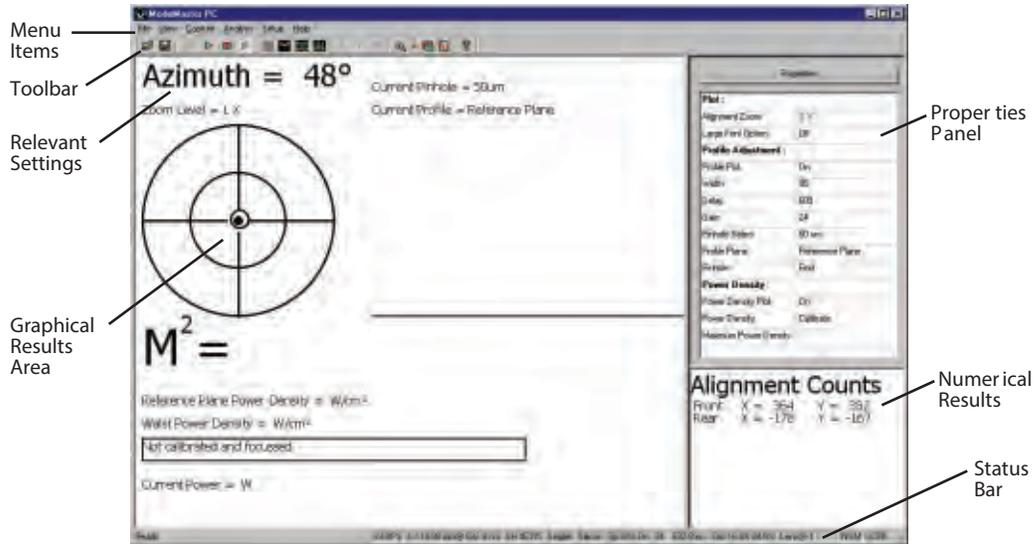

---

**The ModeMaster PC software is optimized to operate at a screen resolution of 1024 x 768.**

---

## Live/Alignment Window

The ModeMaster PC interface is designed to provide a multi-dimensional view of all available analysis functions and controls within a single easy-to-read window. The functions, controls, and readouts change depending on the screen that is currently accessed.



The ModeMaster PC Live/Alignment screen contains the following main elements, which are described in detail in the following subsections.

**Menus:** Contain commands to set up, modify, and use ModeMaster PC.

**Tool Bar:** Contains buttons that provide quick alternative access to Menu, Properties Panel, or Keyboard functions.

**Relevant Settings:** Display of important settings associated with the current screen.

**Graphical Results Area:** Displays numerical and graphical results of analysis. Relevant settings are also displayed.

**Properties Panel:** Contains commands, controls, options, and wizards for displayed data.

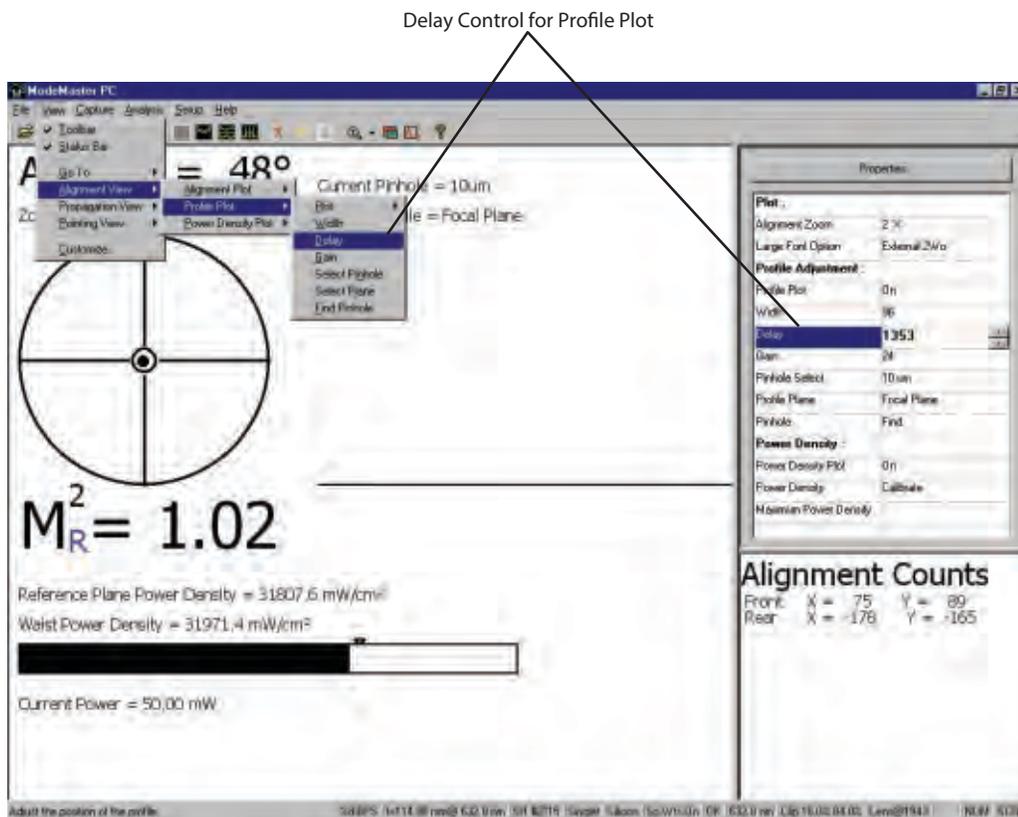
**Numerical Results:** Displays current numerical results.

**Status Bar:** Displays status of current settings and activity.

## Menus

The ModeMaster PC menu system provides all the functionality you will need to setup, modify, and use the ModeMaster PC system. The following is a quick reference of each menu item and its features. ModeMaster PC is designed to provide you with easy access to controls and features via several locations in the interface. Common controls can be accessed from the Menu Items, Toolbar, or Proper-

ties Panel. The ModeMaster PC menu structure contains all controls, settings, and wizards. The following example displays this relationship:



## File

COMMAND	KEY	ICON	DESCRIPTION
Open	Ctrl + O		Access to view ModeMaster PC data files.
Save	Ctrl + S		Saves current data.
Print	Ctrl + P		Prints graphical and numeric results.
Print Preview	None		Displays preview of output before printing.
Print Setup	None		Provides printer configuration options.
Recent File	None		Opens recent or last saved file.
Exit	None		Exist program.

The following subsections further describe the commands in the order they appear on the File menu.

## Open

The Open command opens an existing ModeMaster PC file within your allocated directory. The location of the data files will be [User Path]\Coherent\ModeMasterPC\ Data. The opened file will be displayed on the appropriate screen. Limited display controls will be available for the file data. If changes are detected before closing, the user will be prompted to Save or change the file name. See the appropriate screen for control descriptions.

---

**Some changes effect the numerical results.**

---

---

**If notes file does not contain .txt extension, utilize Windows Explorer. Go to Windows Explorer tools menu. Select Folder Options view tab and then un-check the following item: “Hide extensions for known file types.”**

---

The ModeMaster PC will open files with the following extensions:

- Focus Run Results = Filename.frd
- Pinhole Profile = Filename.prd
- Pointing Data File = Filename.ptd
- Second Moments File = Filename.smd
- Statistics File = Filename.std

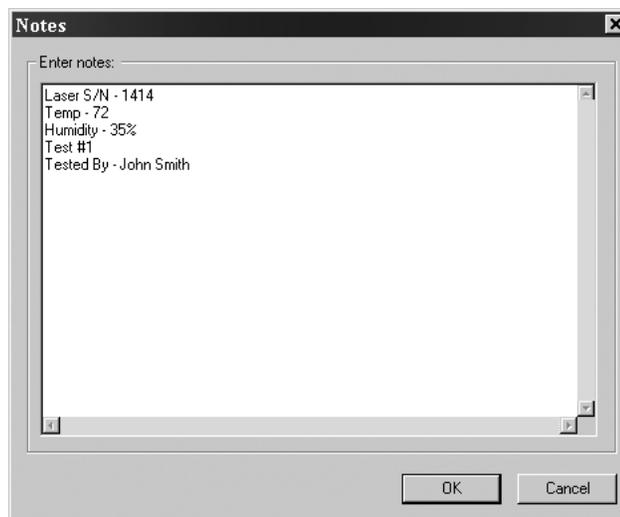
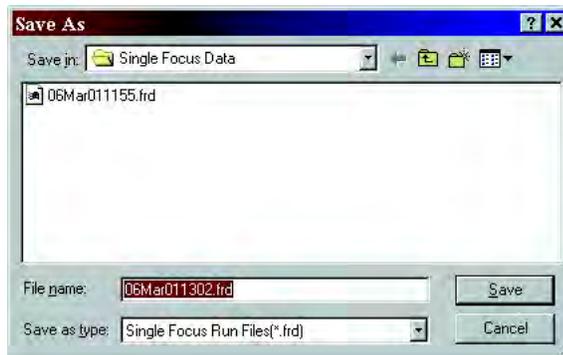
To open an existing file:

- Select File Open
- Press Ctrl + O
- Select the File Open icon. 

## Save/Save As

The Save command saves data based on the current active screen. If new data is being saved or changes have been made to existing data, the Save function will operate in a Save As mode. The Save As operation will confirm the file name and location. The save operation can be utilized to confirm that no changes have been made to existing data. Setup parameters may be required to save new data. If the proper conditions are not met, you will be prompted. The Save operation will prompt the user to attach notes associated with the new file. The notes will be saved with the same file name as the data, with

a .txt extension. The data and notes files will be automatically stored in the same data folder. The ModeMaster PC will provide a Date/Time stamp as a default file name.



To save a file:

- Select File Save
- Press Ctrl = S
- Select the Save icon.



**File Structure**

All data files are saved in easy to export delimited text form. This format will allow for easy analysis with external programs such as Microsoft Excel. Each file will also include the appropriate header information and graphical data points Example of Partial Focus Results in Spreadsheet Form:

Example of Partial Focus Results in Spreadsheet Form:

[HEADER]				
Timestamp	3/6/2001 11:56			
Head S/N	XY78			
Lens Name	2D doublet:vis ir 5 D			
Lens Type	Doublet			
Lens S/N	XB36			
Det Lambda Limits	220		1000	
Det Type	Silicon			
Det S/N	XX63			
Wavelength	632.8			
FocalLength	212.02			
Clip Level Low	16			
Clip Level High	84			
Sp.Wts.	Off			
Type	1			
Azimuth	43			
[EXTERNAL FOCUS RESULTS]				
	X	Y	R	Dim
M_	1.03	1.03	105	-
2Wo	0.807	0.802	0.805	mm
2We	1.463	1.459	1.461	mm
Zo	-1.184	-1.183	-1.183	m
Zr	0.784	0.779	0.781	mm
Divergence	1.03	1.03	1.03	mr
Astigmatism(Zoy/Zox)/Zrr		-0.2	%	
Waist Asymmetry(2Woy/2Wox)		0.994		
Divergence Asymmetry Thetay/Thetax		1		

**Print**

The Print function will initiate a dialog to select the appropriate data for printing. Printed text data will also include the Settings. If the selected data is not available, the user will be prompted appropriately.

- **Report:** This function will print External, Internal, and Transform focus results on a single page.

MODEMASTER(tm) Beam Propagation Analyzer REPORT

Scan Head s/n 1014 Detr-1 silicon s/n 1014  
 Lens-ID doublet: s/n 1014 f=209.72mm @ 514.5nm  
 Clip Levels 16.0%/84.0% (Adjust 2.00)  
 Curve Fit Normal Software Rev. 3.00.00

---

DATA

04-07-93 16:28:19 Azimuth 45 degrees

	X	Y	R
Magd	1.07	1.09	1.08

**EXTERNAL**

2Wc (mm)	1.054	1.053	1.054
2We (mm)	1.592	1.583	1.588
Zc (m)	-1.792	-1.737	-1.764
Zr (m)	1.582	1.547	1.564
Divrg (mr)	0.67	0.68	0.67

Astigmatism (Zcy-Zcx)/Zcr = 3.5%

Waist Asymmetry 2Wcy/2Wcx = 0.999

Divergence Asym Theta y/Theta x = 1.022

---

**TRANSFORM**

Zc* (m)	-1.762	-1.707	-1.734
Gamma	1.12e+002	1.05e+002	1.08e+002
Zc (cts)	2166	2172	2163
hl (mm)	-29.7	-30.0	-29.9

---

**INTERNAL**

2Wi (mm)	0.100	0.103	0.101
2Wd (mm)	0.582	0.578	0.580
Zi (m)	223.63	223.93	223.78
Zr (m)	14.17	14.68	14.43
Divrg (mr)	7.04	6.99	7.01

Astigmatism (Zcy-Zcx)/Zcr = 2.1%

Waist Asymmetry 2Wcy/2Wcx = 1.029

Divergence Asym Theta y/Theta x = 0.992

- **Screen:** This function will print the graphical results pane on the first page and the numerical results on the second page.
- **Second Moments:** This function will print the current Second Moments Results.
- **Statistics:** This function will print the current multiple focus statistics.

## Print Preview

This function will display the selected data in the same form that it will be printed.

## Print Setup

This dialog will allow the user to configure all printers currently installed.

## Recent File

The four previously active files will be listed. Clicking on a file will open and display the results immediately.

## Exit

The exit commands closes the program without prompting you to save the current active data. Make sure to save the desired results by using the Save or Save Profile command first before exiting.

## View

COMMAND	KEY	ICON	DESCRIPTION
Toolbar	None	None	
Status Bar	None	None	
Go To (Screens) - Alignment View - Propagation - Pointing Stability - Second Moments	F6 F7 F8 F9	   	Jumps to Alignment Screen. Jumps to Propagation Screen. Jumps to Pointing Stability Screen. Jumps to Second Moments Screen.
Alignment View - Alignment Plot - Zoom - Large Font Options  - Profile Plot - Plot - On - Off - Width  - Delay  - Gain  - Select Pinhole  - Select Plane  - Find Pinhole  - Power Density Plot - Plot - On - Off - Calibrate  - Reset Maximum	None	 	Accesses Alignment Plot functions.  Zooms alignment plot up to factor 16x. Displays Live Data in larger fonts for Laser Tuning. Access to Profile controls.  Turns Profile Plot On. Turns Profile Plot Off.  Accesses Width adjustment control in Alignment Screen Properties Panel.  Accesses Delay adjustment control in Alignment Screen Properties Panel.  Accesses Gain adjustment control in Alignment Screen Properties Panel.  Accesses Pinhole selection options in Alignment Screen Properties Panel.  Accesses Plane selection options in Alignment Screen Properties Panel.  Accesses Pinhole Wizard in Alignment Screen Properties Panel.  Accesses Power Density Plot functions. Displays the Power Density Plot on Alignment Screen.  Turns Plot Display On. Turns Plot Display Off.  Accesses Power Density Wizard in Alignment Screen Properties Panel.  Accesses Power Density Reset maximum indicator function in Alignment Screen Properties Panel.

COMMAND	KEY	ICON	DESCRIPTION
Propagation View - 2D Selection - Display Selection - Data Selection - 3D Plot - On - Off - Cursor - Internal - On - Off - External - On - Off Move Lens to Internal	None		Accesses Propagation Plot functions in Properties Panel. Accesses 2D selection options in Properties Panel. Accesses Display selection options in Properties Panel. Accesses Data selection options Propagation Screen Properties Panel. Accesses 3D Plot options in Propagation Screen Properties Panel.  Turns 3D Plot On. Turns 3D Plot Off. Accesses Cursor options in Propagation Screen Properties Panel. Displays Internal Diameter Measurement Cursor. Turns Internal Cursor On. Turns Internal Cursor Off. Displays External Diameter Measurement Cursor. Turns External Cursor On. Turns External Cursor Off. Moves lens to internal cursor location. Cursor Position.
Pointing View - Select Mode - Select Option - Select Filter - Cursor - On - Off - Translation Distance - Stability Run - Scale - Duration - Hours - Minutes	None		Accesses Pointing Stability Screen functions. Accesses Mode selection options in Pointing Stability Screen Properties Panel. Accesses Option selection in Pointing Stability Screen Properties Panel. Accesses Filter selection options in Pointing Stability Screen Properties Panel. Displays Cursor. Turns Cursor On. Turns Cursor Off. Accesses Translation Distance selection in Properties Panel. Accesses Pointing Stability Run Wizard in Properties Panel. Accesses Vertical Full Screen selection options in Properties Panel. Accesses Duration selection options. Sets Duration in hours for plot. Sets Duration in minutes for plot.
Customize	None		Accesses color customizing options window.

The following subsections further describe the commands in the order they appear on the View menu.

- Toolbar**                      The Toolbar command displays or hides the Tool Bar.
- Status Bar**                      The Status Bar command displays or hides the Status Bar
- Go To**                              The Go To command allows you to jump to the Alignment Screen, Propagation Screen, Pointing Stability Screen, or the Second Moments Screen.
- Alignment View**                      This menu item provides a list of controls that relate to plot alignment and measurement, such as Profile and Plot Density, as available on the ModeMaster PC Alignment Screen (Live/Alignment Screen). See “Properties Panel” (p. 3-19) for more information.
- Propagation View**                      This menu item provides a list of controls that relate to the Beam Propagation Data, such as Internal or External 2D selection and Cursor Measurement options. Refer to “Beam Propagation Screen” (p. 3-33) for more information.
- Pointing View**                      This menu item provides a list of controls that relate to the Pointing Stability Data, such as Translation Distance Setting and Duration. See “Pointing Stability Screen” (p. 3-48) for more information.
- Customize**                              This menu item launches a color customizing options window where you can set different colors for Plot, X, Y, and R. You can also change the background to white and select a different font. The customizing window also allows you to set the scale of the External Plot to Auto or to a user-defined Manual mode.

## Capture

COMMAND	KEY	ICON	DESCRIPTION
Focus	F11		Starts Focus Scan.
Pause	F12		Pause live data capture.
Resume Live Data	F5		Continue live data capture.
Multiple Focus Runs			Setup Multiple Focus Run Capture.
Move Lens	F2 F3 F4	  	Accesses window to set lens at either X, Y, R, lens Focal Length of the Lens, or a custom location.
Clip Level\Knife Edge			Accesses window to adjust Clip Level percentages and Knife Edge.
Reset			Clears focus scan data and resets optics to a default state.
Conversion Factor			Conversion factors.
Special Weights			Displays Special Weights options window.

The following subsections further describe the commands in the order they appear on the Capture menu.

### Run

Resume Live Data Capture

### Stop

This function will pause Live Data Capture or Stop Multiple Focus Run Process.

### Focus

Initiates the capture of Focus Results. A successful focus run is required for Power Density, Pointing Stability, and Second Moments results.

### Multiple Focus Runs

This function will allow the user to capture multiple focus results and gather statistics. The user can specify the number of focus run and the associated duration. A statistical data file will be automatically generated and displayed in the software. This file is in text format for analysis with external software.

**Move Lens** This command accesses a window to set lens at either X, Y, R, at the Focal Length of the Lens, or a custom location. You can also access this window by double-clicking the Lens position field in the Status Bar after a successful focus.

**Clip Level \ Knife Edge Conversion Factor** This command accesses a window to adjust Clip Level percentages and Knife Edge Conversion factors. The parameters ModeMaster PC uses to calculate beam diameter are set in this window. Three different parameters may be adjusted. See “Clip Level/Knife-Edge Conversion Factor” (p. 3-2) for more information.

**Reset** Clears focus scan data and resets optics to a default state.

**Special Weights** This command accesses a window to change the Special Weights status. The default setting of the Special Weights status is “On” for the recommended divergence of > 1mr. Changing the status to Normal Weighting for Single Lens may cause divergent beam results to have errors. You can also launch this window by double-clicking the Special Weights Status field in the Status Bar.

## Analysis

COMMAND	KEY	ICON	DESCRIPTION
Statistics	F10		Navigation to view statistical results.
Pass to Curve Fit			Forces curve fit data from most recent data scan.

The following subsections further describe the commands in the order they appear on the Analysis menu.

**Statistics** Dialog to open and view statistical results.

## Setup

COMMAND	KEY	ICON	DESCRIPTION
Wavelength	None	None	Displays Wavelength adjustment window.
Head			Displays window for new lens setup.
Controller			Displays window for new Controller setup.
Options			Accesses ModeMaster PC Warnings and Sound settings.

The following subsections further describe the commands in the order they appear on the Setup menu. See “Section Three: Operations” (p. 3-1) for more information.

### Wavelength

This command accesses the Wavelength adjustment window. Wavelength is normally set at the time the ModeMaster PC is turned on and goes through its initialization sequence. If it is necessary to reset the wavelength during operation, this screen can be accessed from the Setup menu.

### Head

This command accesses a dialog for Scan Head Detector/Lens changes and additions.

### Options

This command accesses a window where you can define which Warnings and Sounds are active in ModeMaster PC. For example, you may decide to disable or return the Startup Reminder warnings.

## Help

COMMAND	KEY	ICON	DESCRIPTION
Contents	None	None	Access to all help items.
Using Help			Brief description about using help.
Keyboard Shortcuts			List of keyboard shortcuts.
Tutorial			Description of simple data collection scenarios.
E-mail Tech Support			Opens blank e-mail page for customer questions.
Tip of the Day			List of measurement tips.
About ModeMaster PC			Displays current ModeMaster PC software version.

<b>Contents</b>	This item gives the user access to all software help items.
<b>Using Help</b>	This item provides a brief description about help navigation methods.
<b>Keyboard Shortcuts</b>	This item provides a complete list of Keyboard Shortcuts available to ModeMaster PC.
<b>Tutorial</b>	This item displays a description of simple measurement scenarios. These measurement scenarios will serve as a guide through each measurement screen.
<b>E-mail Tech Support</b>	This item brings up a blank e-mail sheet. The user can list any questions about ModeMaster PC operation and the sheet will be routed to the Coherent Tech Support Team.
<b>Website</b>	This item utilizes your default web browser to link to the Coherent website. Coherent's website may provide additional information and software updates.
<b>Tip of the Day</b>	This window contains a list of quick measurement tips. Feel free to cycle through these tips and learn new methods.
<b>About ModeMaster PC</b>	This item displays the current ModeMaster PC software version.

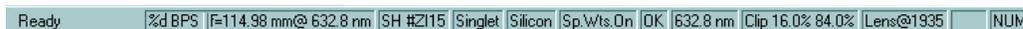
**Toolbar**

The ModeMaster PC Toolbar provides quick access to frequently used functions. The following illustration describes each button.

ICON	COMMAND	KEY
	Open File	Ctrl + O
	Save File	Ctrl + S
	Print	Ctrl + P
	Initiate Focus Run	F11
	Stops live data gathering	F12
	Resumes live data gathering	F5
	Clears focus scan data and resets optics to a default state.	
	Jumps to Alignment Plot View	F6
	Jumps to Propagation Plot View	F7
	Jumps to Pointing Stability Plot View	F8
	Jumps to Second Moments Plot View	F9
	Navigation to view statistical results	F10
	Moves lens to X position	F2
	Moves lens to Y position	F3
	Moves lens to R position	F4
	Zooms in or out up from factors 1x to 16x	
	Customizes color scheme and views	
	Select Large font display option	
	Launch Help menu	F1

## Status Bar

The Status Bar on the bottom of the ModeMaster PC window provides a quick reference point for all critical current settings. Pop up notes also appear when you place your cursor over the field.



SETTING/STATUS	DESCRIPTION
Ready	Indicates the display of current data. File path will be shown for File Data.
F=114.98 mm @ 632.8 nm	Indicates the calculated focal length @ the selected wavelength.
SH #Z115	Indicates the Scan Head serial number.
Singlet	Indicates Lens type.
Silicon	Indicates Detector type.
Sp.Wts.On	Indicates Special Weights status: On or Off. Double-click to edit.
OK	Indicates current Alignment Status.
632.8 nm	Indicates selected Wavelength.
Clip 16.0% 84.0%	Indicates selected Clip Level.
Lens@1935	Indicates current lens position counts. Double-click to edit.

## Graphical Results Area

The graphical results area in the center of the ModeMaster PC program window provides a detailed static or real-time representation of the beam propagation characteristics. The following section will discuss each screen and its features in further detail.

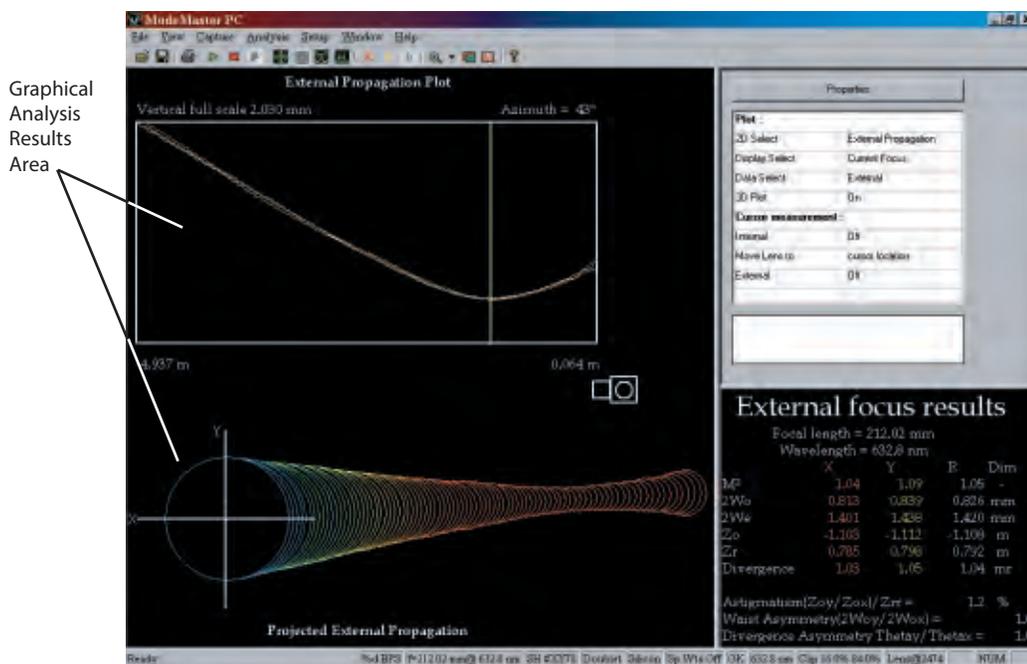


Figure 2-1. The Propagation View

## Properties Panel

The Properties Panel contains ModeMaster PC's main control functions and wizards. The options and controls change depending on the screen or view that is being displayed. Functions and controls are offered in the form of drop-down menus, wizards, and increase/decrease buttons. To activate a button, wizard, or drop

down menu, simply click on the desired function. The following example shows the increase or decrease gain control on the Alignment View screen.

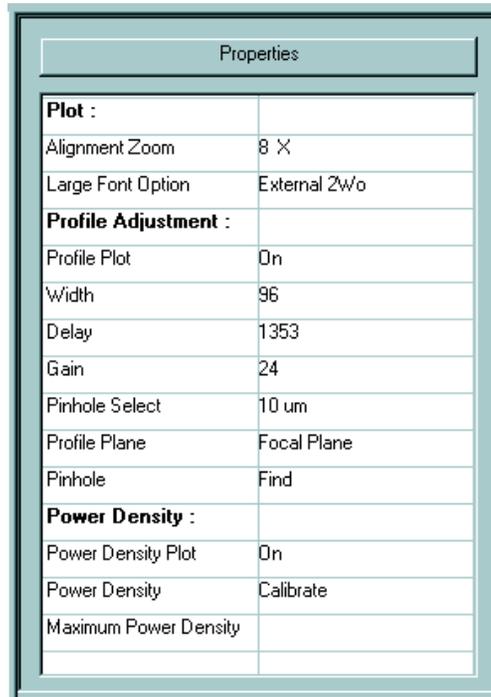


Figure 2-2. Properties Window

## Numerical Results Area

Depending on the screen being viewed, the numerical results area provides either an historical or real-time values display.

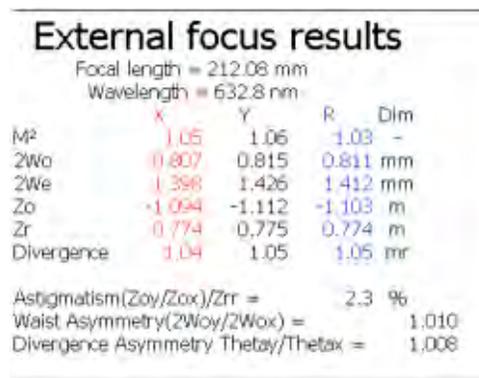


Figure 2-3. Numerical Results for Propagation Plot Screen

## SECTION THREE: OPERATIONS

In this section:

- Overview of operations (this page)
- Global settings (p. 3-1)
- $M^2$  live/alignment screen (p. 3-8)
- Beam propagation screen (p. 3-33)
- Pointing stability screen (p. 3-48)
- Second moments screen (p. 3-54)
- Multiple focus (p. 3-63)

### **Overview of Operations**

The ModeMaster PC interface provides a multi-dimensional view of laser propagation characteristics. The screens associated with these views share this array of presentation. Although ModeMaster PC functionality follows a series of logical steps, the ability to dynamically view different aspects of the beam's character is unrestricted to the user. This section will first discuss the role of Global Settings and then provide a detailed look at the functions and operation of the screens. "Section Four: Tutorial" (p. 4-1) contains a tutorial that will illustrate a basic measurement scenario using ModeMaster PC.

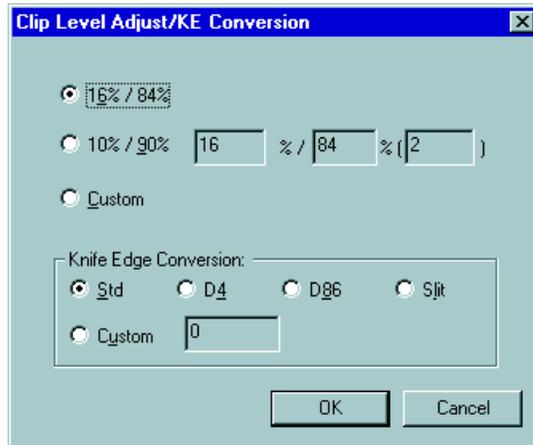
### **Global Settings**

Global settings have broad effects on ModeMaster PC functions. This section discusses the following global settings:

- Clip Level/Knife-Edge Conversion Factor
- Special Weights Analysis
- Wavelength Selection
- Scan Head Setup

## Clip Level/Knife-Edge Conversion Factor

From the Menu items choose Capture and then Clip Level\Knife-Edge Conversion Factor. The following window appears:



Beam diameter measurement is fundamental to the ModeMaster PC propagation data. The Clip Level setting directly effects the raw data collected by the ModeMaster PC. Review “Section Five: Beam Propagation Theory” (p. 5-1), also located in a PDF file on the CD-ROM, for further details. Two standard Clip Level settings plus a user-specified Clip Level, are available in this window.

**Lower Clip Level** is the percentage of maximum power transmitted past the knife-edge at which ModeMaster PC begins (ends) beam width measurement. Minimum value is 1.0%. Maximum value is 49%.

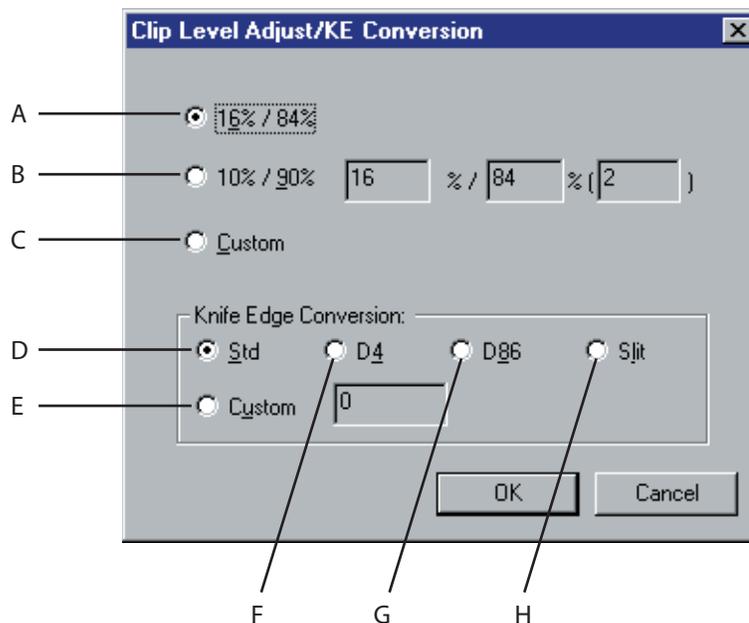
**Upper Clip Level** is the percentage of maximum power transmitted past the knife-edge at which the ModeMaster PC ends (begins) beam width measurement. Minimum value is 51%. Maximum value is 99%.

The **Width Adjust Factor** multiplies the measured width between clip levels to give beam width (2W). Minimum value is 0.20. Maximum value is 20.00.

The default setting for this parameter is 16.0%, 84.0% and 2.00. This setting will return a beam width equal to  $1/e^2$  if the beam is a TEM<sub>00</sub> mode beam. These parameters are saved when the ModeMaster PC is turned off. New Clip Level settings can be selected by choosing Custom and then entering new values to be set. The current Clip Level setting is displayed in the status bar. Changes in Clip Level settings will be in effect on the next focus run.

## Knife-Edge Conversion

ModeMaster PC has built-in algorithms to convert the ModeMaster PC standard knife-edge diameter measurements (and all displayed quantities dependent on them) to second moment diameters,  $D_{86}$  diameters or slit diameters.



- A. Clip level value 16%/84% Width adjust 2.0.
- B. Clip level value 10%/90% Width adjust 1.56.
- C. Click to enter user-defined Clip Level value.
- D. Std. ModeMaster PC's standard knife-edge diameter measurements.
- E. User-entered conversion factor. The value can be entered manually by clicking Custom. Change the value to the desired conversion factor and click OK.
- F.  $D_{4\sigma}$  If selected, knife-edge measurements will be converted to Second Moment measurements using ModeMaster PC's built-in conversion algorithms (valid for lasers with radially symmetrical beams and  $M^2$  of less than 4.0).
- G.  $D_{86}$ . If selected, knife-edge measurements will be converted to the equivalent  $D_{86}$  diameter measurements.
- H. Slit. If selected, knife-edge measurements will be converted to the equivalent slit diameter measurements.

## Special Weights Setup

The Special Weights Analysis option allows recovery of accurate data in situations where beam diameter data is distorted by intermittent noise, vignetting, or other transients during the focus scan. If the Multiple Waist error message appears after the focus scan, inspect the beam propagation screen. If noise appears in the scan data, try setting Special Weights Analysis. To select Special Weights, go to Capture in the menu items and choose Special Weights. Double-clicking the Special Weights item in the Status Bar will also allow you to set Special Weights.



The ModeMaster PC will set the appropriate Special Weighting condition by default. To change the Special Weights status, select the desired radio button and click OK to continue. When Special Weighting is active, a check mark will appear next to the Special Weights Capture menu item. The Status Bar also indicates the current Special Weights status.

## Special Weights Analysis

When the current Special Weighting status is changed, a curve fit will automatically be done on the current data. The data will now reflect the selected Special Weight selection. The designation (Spc Wt) is added to the Propagation Plot label, when Special Weighting is active. To turn Special Weighting off, select it from the Capture menu and choose Normal Weighting, or double-click the Status Bar Special Weight item.

Special Weights is automatically selected as the default curve fit weighting for the S-lens and all three IR lens configurations. These lenses are used with high divergence input beams. The resulting input beam size can vary significantly over the 8 cm of Focus Run lens travel. In Special Weights the beam propagation plot is divided into ten equal segments, as shown in Figure 3-2 (p. 3-6). Recall that the left half of the plot is constructed from beam diameter data acquired at the front side of the knife-edge drum. The right half from beam diameter data acquired at the back cut plane. Special Weights finds the data segment containing the internal waist and uses only this segment and the complimentary segment five segment widths away from the waist segment in the data curve fit. The data in these two segments was collected concurrently (from the front and back

edges of the drum). The equivalent lens travel moves over only one-fifth, i.e., 1.6 cm) of its full range. The distortion of the data due to beam size changes over the 1.6 cm lens travel is much reduced. The 52 locations sampled (1/5 of the full travel number of 260) are still adequate for an accurate curve fit. These locations include the waist, plus a segment several internal Rayleigh ranges  $Z_{r2}$  (internal parameters carry a 2 subscript, external parameters a 1 subscript) from the waist.

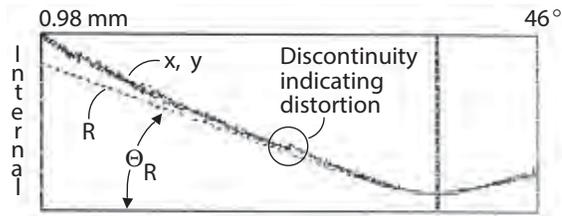
This Special Weights curve fit can therefore also be used to recover an accurate analysis of beam propagation data containing a few noise spikes, if the noise is not present in the two data segments which will be used.

There are two tell tale signs that the change in beam size at the lens over the normal lens travel is too great. The first is a discontinuity in the internal Beam Propagation data right at the middle of the plot. At this point, the data from the front and back edges are spliced—refer to Figure 3-1 (p. 3-6). This midpoint compares data points nominally at the same position in the internal beam (measured by different drum edges), but with the lens at the opposite ends of its travel. Thus this discontinuity is a direct measure of data distortion over the lens travel.

The second is when the Radial Mode propagation plot (user-selected R color) in Normal Weights does not stay between the X and Y propagation plots. The Normal Weight curve fit weights each diameter value of the plot by the inverse of that value. Thus, points near the waist are heavily weighted, with the “strength” of the weighting decreasing as points get further from the waist. This weighting process works well to get an accurate  $M^2$  value. The beam quality ( $M^2$ ), is the ratio of the real beam far-field divergence angle  $\Theta$ , to the gaussian beam divergence angle  $\theta = 4\lambda / \pi(2W_0)$ , utilizing the same waist diameter  $2W_0$  ( $M^2 = \pi 2W_0 \Theta / 4\lambda$ ) are many more points in the propagation plot defining the divergence angle  $\Theta$  than there are in the region around the waist. This inverse-diameter weighting balances out this numerical difference to give the best value of the divergence ratio  $M^2 = \Theta / \theta$ .

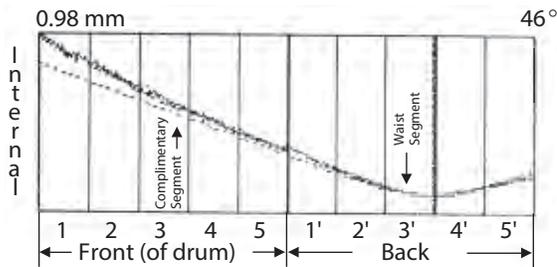
Normal Weights curve fitting to distorted data, gives fitted curves that mainly go through the data points near the waist. The propagation plot shows the measured data for the X, Y plots, while the R-mode plot is theoretically constructed from the curve fit. If the data is distorted, the R-mode plot will not be bounded by the X-, Y-

plots as it should be. When this is the case, switch to Special Weights analysis to use only undistorted data and improve the fit (Figure 3-3, below).



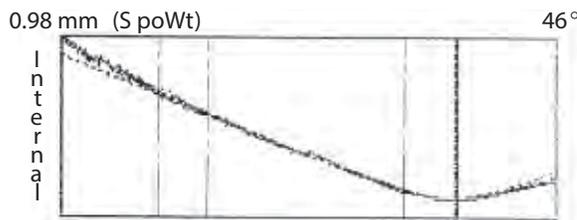
**Figure 3-1. Normal Weights Analysis of Distorted Data**

- (a) Normal Weights analysis of distorted data (note the Rad Mode curve is not bounded by the x, y curves). There is a data discontinuity at the midpoint of the plot where the front and back edge data points are spliced.



**Figure 3-2. Data Segmentation for Special Weights Analysis**

- (b) The data segmentation for Special Weights analysis. Only the data in segments 3 and 3' will be used.



**Figure 3-3. Improved Fit of the Rad Mode Curve**

- (c) Improved fit of the Rad Mode curve through the selected segments after Special Weights analysis.

## Wavelength Selection

The Wavelength Select window appears during the ModeMaster PC startup initialization process. The window also includes wizards that guide you through the installation of alternate lenses or detectors. Refer to “Doublet Wavelength Selection” (p. 1-9) and “Singlet Wavelength Selection” (p. 1-10) for additional information on proper Wavelength Setting.



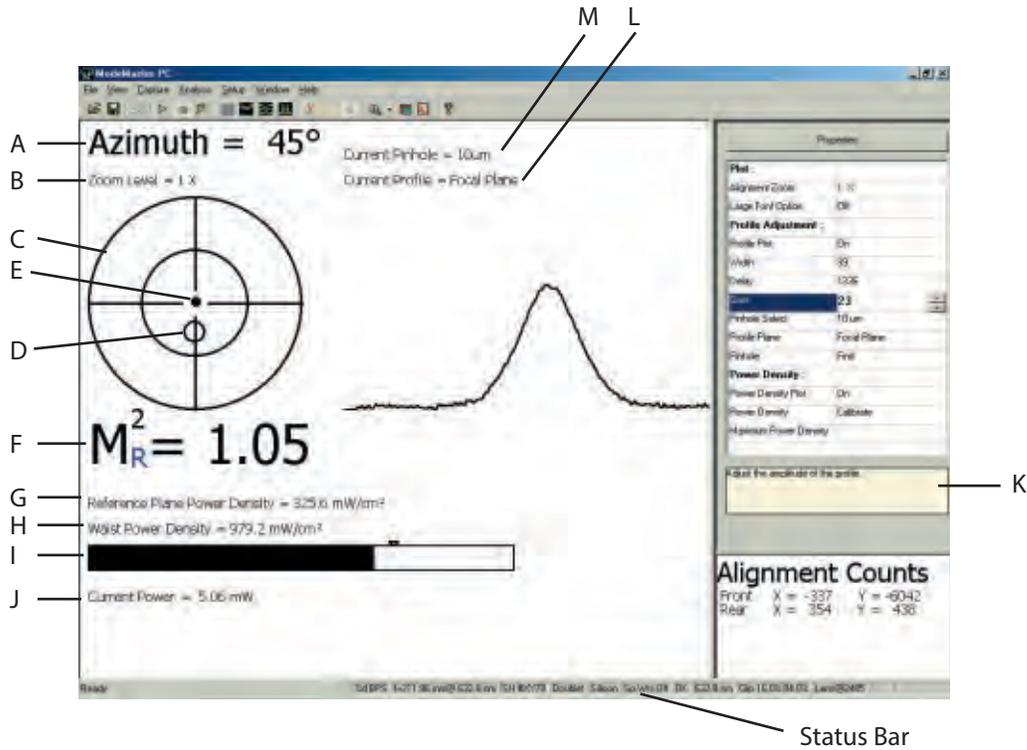
1. Enter the known laser wavelength within 1% and click OK. This must be done in order to provide an accurate value of  $M^2$ .
2. The chosen wavelength will now be utilized in all relevant ModeMaster PC calculations.
3. To change the Wavelength at any time, go to Setup in the menu and then choose Wavelength.

## Scan Head Setup

This dialog will allow the user to select or add a lens or detector. A change lens or detector selection will start a wizard appropriate to the hardware change. The Add button will activate a wizard for adding an additional Scan Head lens or detector. “Appendix A: Specifications” (p. A-1) presents a list of available lenses and detectors. The wizards started from this dialog are self-explained, step-by-step processes, for changing or adding Scan Head hardware.

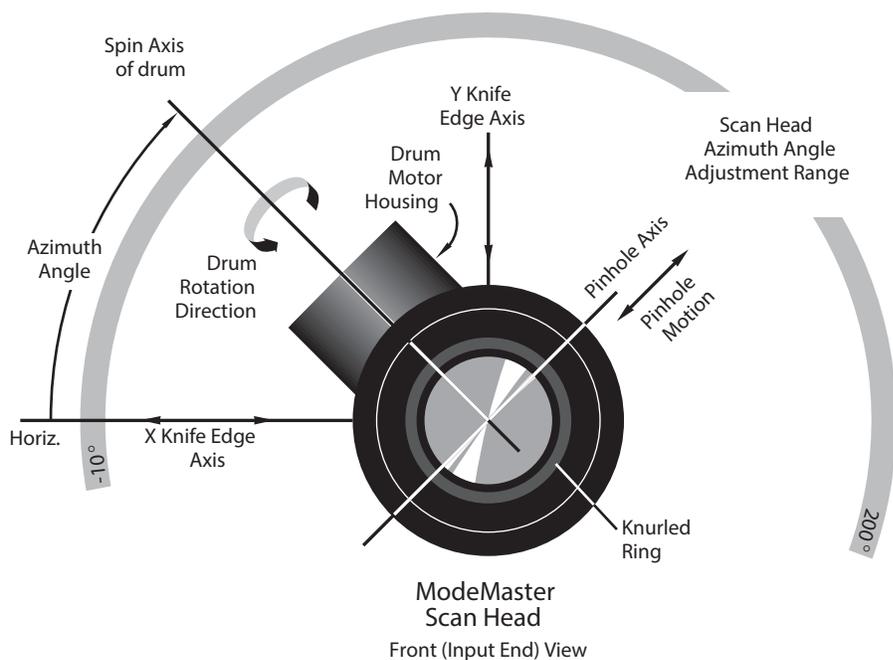
## M<sup>2</sup> Live/Alignment Screen

The M<sup>2</sup> Live/Alignment Screen is shown in the figure below. The following information is displayed on the Live/Alignment Screen:



- A. **Azimuth** - Displays the current rotational angle of the ModeMaster PC Scan Head around the optical axis. The azimuth readout indicates the angle between the drum-motor-shaft axis and the horizontal plane; the pinholes move across the beam perpendicular to the drum-motor-shaft axis. The X and Y knife edge axes are at - 45° and + 45°, respectively, from the drum-motor-shaft axis. Azimuth angle is adjustable by rotating the ModeMaster PC head and is updated immediately on

the Live/Alignment screen. Adjustment range is from  $-10^{\circ}$  to  $200^{\circ}$ .



- B. **Alignment Zoom Level** - Precision alignment is NOT required for accurate propagation data. The Alignment Zoom is a tool for finding the pinholes. Perfect alignment on the 8x zoom level will give you adequate “Find Pinhole” wizard alignment. Precision alignment may cause feedback to the laser source. This feedback may cause the laser to become unstable, resulting in data that is not accurate. If you suspect feedback is effecting your laser source, change the Scan Head alignment within the 1x zoom inner circle and repeat the focus run.
- C. **Beam Alignment Target (Shown at a 1x Zoom Level)** - Large outer fixed circle indicates the relative area over which beams are accepted into the scan head. The smaller (inner) fixed circle indicates the area in which the beam position indicators must be to have valid beam data. If either beam position indicator (Small circle and dot) is located outside of the inner circle, an “Out of Alignment” condition occurs. This condition is indicated by the circle and dot showing well above the Alignment Target and the appropriate error message is displayed. Utilize the alignment counts to restore alignment. A large count value indicates the offending alignment axis. Reduce the count value to restore the valid alignment condition. Large static alignment count values indicate no laser emission. A central status bar panel indicates the

current alignment status (OK or red out of alignment symbol ). Utilize the status bar to verify proper alignment while utilizing other ModeMaster PC screens.

- D. **Beam Position Indicator** (Circle) - Relative beam position on the front rotating drum cut plane is indicated by the moving circle.
- E. **Beam Position Indicator** (Dot) - Relative beam position on the back rotating drum cut plane is indicated by the moving dot.
- F. **M<sup>2</sup>** - Times diffraction limit value. M<sup>2</sup> is the ratio of the divergence of the measured beam to that of the theoretical uniphase, gaussian beam (TEM<sub>00</sub> mode) with the same waist size. A value will not be displayed until a successful focus run has been completed. The M<sup>2</sup> value can only display a Live value for the current plane (X, Y, or R). The current plane subscript is shown in a color that is user selectable through the customize tool bar item. The customize dialog will allow you to change the M<sup>2</sup> to be viewed as K. K=1/M<sup>2</sup>. The Live M<sup>2</sup> value is computed in real time from the focused beam diameter W<sub>O</sub>, with the second diameter 2WD taken on the opposite edge of the scan head drum.

$$M^2 = \left( \frac{\pi W_d W_0}{\lambda D} \right) \sqrt{1 - \left( \frac{W_0}{W_d} \right)^2}$$

For a complete discussion of M<sup>2</sup> theory, see “Section Five: Beam Propagation Theory” (p. 5-1).

---

**Detailed Power Density information is given later in this chapter**

---

- G. **Reference Plane Power Density** - The displayed value is a result of the user-entered power and the calculated beam diameter at the front bezel reference plane. Power per 2W<sub>e</sub> area.
- H. **Waist Power Density** - The displayed value is a result of the user-entered power and the calculated external beam diameter at the laser beam waist. Power per 2W<sub>o</sub> area.
- I. **Power Density Tune Bar** - Graphical tune bar to display current relative Power Density. The tune bar contains a Maximum Indicator. An audio beep also occurs each time a new maximum is displayed.

- J. **Current Relative Power** – The current relative power reading is the result of the user-entered power and the current Scan Head detector output.
- K. **Properties Panel Tool Tips** – This pane will display a description of the currently-selected Properties Panel function.
- L. **Pinhole Plane** – Display of the currently-selected pinhole profile plane. Reference Plane indicates that the current profile display is a front cut plane scan. Focal Plane indicates that the current profile display is a rear cut plane scan.
- M. **Pinhole Size** – The currently-selected pinhole size will be displayed here. For all Silicon and Germanium systems, 10  $\mu\text{m}$  and 50  $\mu\text{m}$  are available for selection. For all Pyroelectric systems, 100  $\mu\text{m}$  and 500  $\mu\text{m}$  are available for selection.

## Status Bar

Ready %d BPS | f=114.98 mm @ 632.8 nm | SH #Z115 | Singlet | Silicon | Sp.Wts.On | OK | 632.8 nm | Clip 16.0% 84.0% | Lens@1935 | NUM

---

**Status bar tool tips provide additional information on Status Bar items. Hold the mouse cursor over the Status Bar item and the tool tip will appear.**

---

**Ready/File Name** – Indicates the current software status. Ready indicates that the software has the capability to collect data. If file data is present, the current file name will be shown in this pane.

**Lens Focal Length** – Displays the calculated focal length of the Scan Head lens at the current wavelength.

**Serial Number** – Displays the current Scan Head serial number.

**Lens** – Displays the current Scan Head lens type.

**Detector** – Displays the current Scan Head detector type.

**Special Weights** – Indicates the current Special Weights Status. Special Weights will be indicated by an “On” condition and Normal Weighting will be indicated by an “Off” condition.

**Alignment Status** – Indicates the current alignment status. “OK” indicates that the current Scan Head alignment will provide accurate Live and Focus Run data. A red circle with a cross (  OUT ) will indi-

cate an out of alignment condition. An out of alignment condition may also be the result of no laser emission. Check for laser output if an unexpected out of alignment condition occurs.

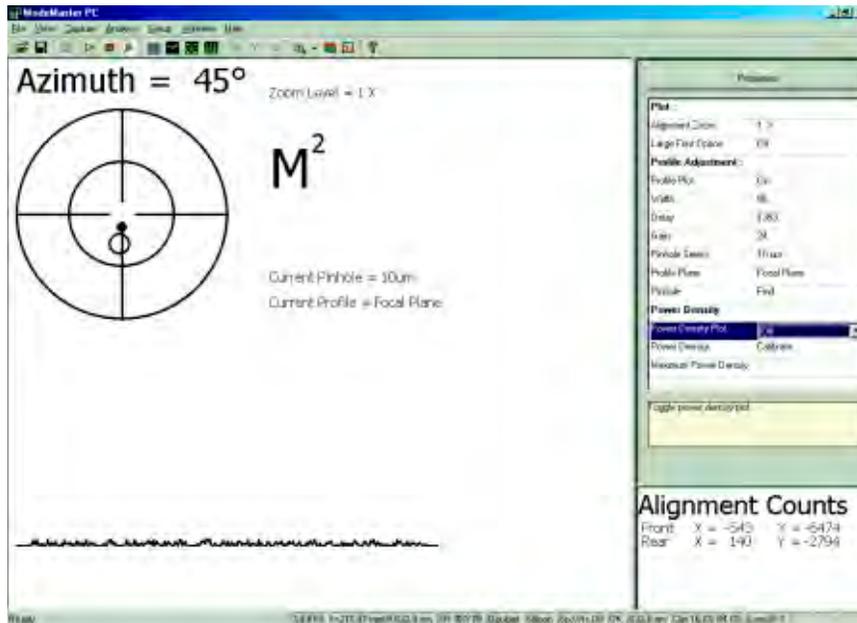
**Wavelength** – Displays the current user-selected wavelength.

**Clip Level** – Displays the current user-selected Clip Level.

**Lens Position** – Displays the current Scan Head lens position in counts. This pane is active after a focus run.

## Focus

When the Live/Alignment screen appears in the condition shown below, current focus results do not exist. Nearly all ModeMaster PC data requires a successful focus run for proper display. Align the scan head to bring the alignment circle and dot inside of the inner circle. For more setup information, review “Section One: Getting Started” (p. 1-1).



Pressing the Focus button (  ) in the toolbar translates the lens assembly through its full travel. The internal beam diameter will be measured within the instrument at 256 planes to produce a beam propagation plot. While the lens assembly is moving the message “Lens moving...please wait” is displayed. When the internal data has been acquired, propagation results are calculated and the lens assembly is moved to the currently-selected focus position. The

focused lens position will be set to locate the internal waist exactly at the rear cut plane. This lens position is essential for most Live data results.

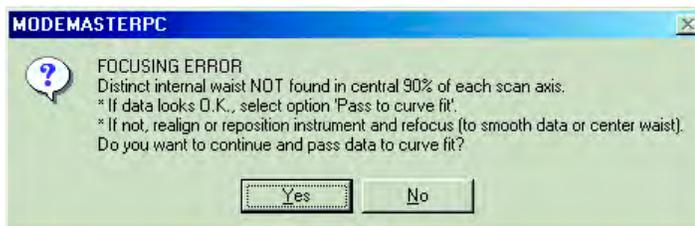


## Help Messages

In ModeMaster PC, help messages have been added to inform the user when the boundaries of the nomogram (which instrument specifications are met) or other instrument limits have been exceeded. The nomogram limits are discussed further under “Theory of Operation” (p. 5-12).

## Focusing Error Message

This first message (shown in Figure 3-4, below) occurs as a result of a Focus Error. The error condition is a result of either multiple waists or no distinct waist found in the central 90% of the internal propagation axis. The multiple waist condition is a result of excessive laser noise or other problems that can generate more than one internal waist. The system looks for waist positions in the stored data by two means. The first is to run a filter over the data. This filter looks for a change in sign of the slope using a digital differentiation algorithm, looking for a minimum point. This is done twice with varying widths for the differentiation interval, in an effort to eliminate noisy data. If a single waist is detected in both the X and Y data, it is then passed to a curve fitting routine to compute the waist size and location. When a multiple waist condition is present, the internal propagation plot can be viewed. If the multiple waist condition is present, the pass to curve fit option can be utilized to calculate data that looks reasonable to the user. If the data is not a pure result of laser noise, the curve fit results are in no way considered to be valid.



*Figure 3-4. Focusing Error Message*

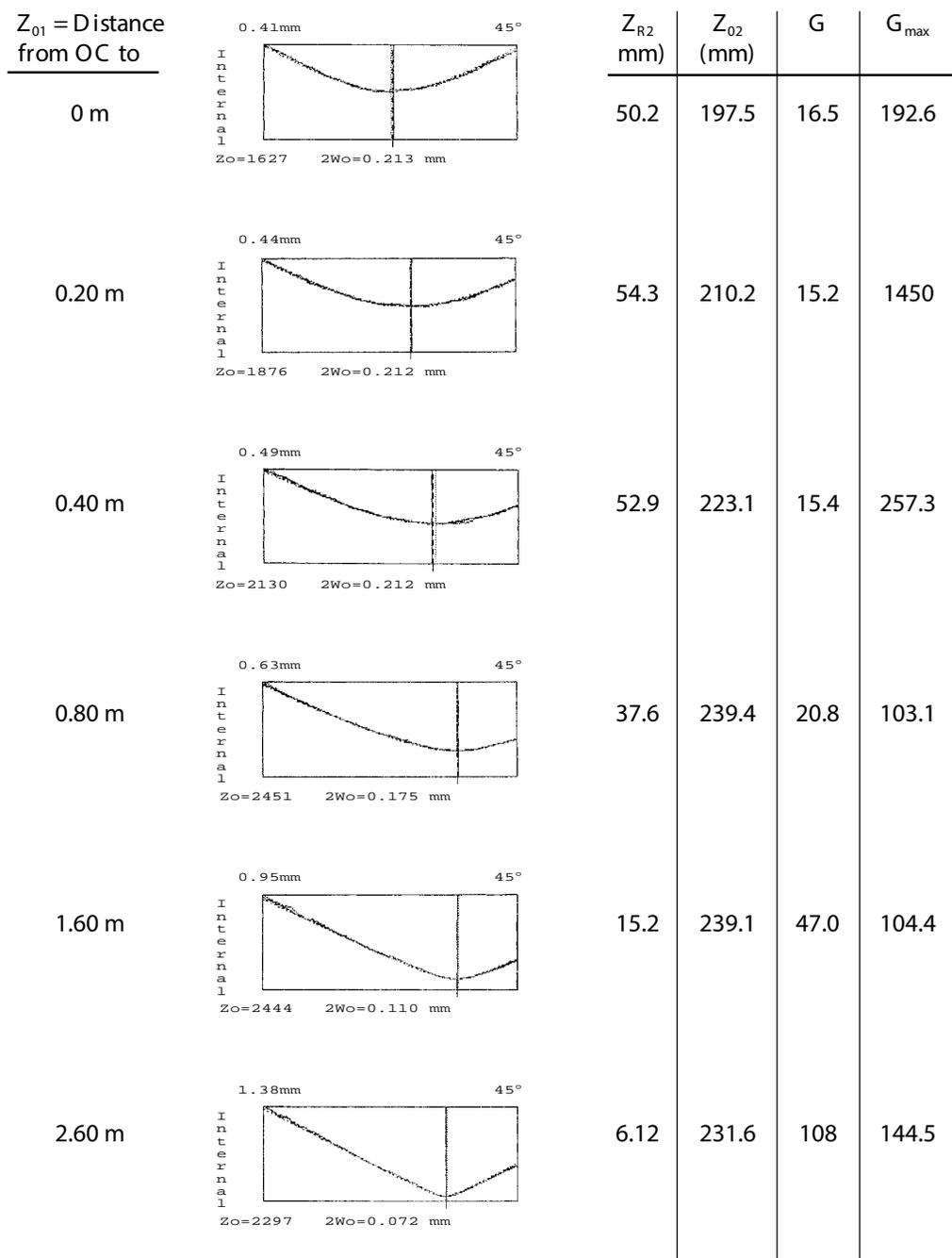
### **Pass to Curve Fit**

This option forces curve fit of data from most recent data scan. This option is presented each time an error condition exists. The user will be presented with the internal propagation data. A visual inspection of this plot will help determine the source of the error condition. By executing the Pass to Curve Fit, the transformation of internal data to external results is completed. This process may produce additional error messages. By reading the error messages and inspecting the resulting data, the cause may be determined. Repositioning the Scan Head or changing the ModeMaster PC Lens, will normally rectify the error condition. The troubleshooting process will consist of executing a focus run, curve fit, and inspection of the data. Identify the offending data parameter and check for a change in that parameter with each subsequent focus run. The Internal Data on the Propagation plot is mainly utilized for the troubleshooting process.

### **The Repositioning Remedy**

A no internal waist condition can be the result of Scan Head location. By viewing the internal propagation plot, a remedy may be obtained. If the waist (on either axis) is just “off screen”, the corrective action may be to reposition the instrument. This is the recommended remedy for several other of the limiting cases below. An example of the effect of repositioning is shown in Figure 3-5 (p. 3-15). Here the distance between the HeNe output coupler plane (where the waist is located) and the ModeMaster PC reference plane B is varied (first column). The Rayleigh range ZR1 for this laser was 0.80 m (external parameters carry a 1 subscript, internal ones a 2 subscript). As the separation between the laser and ModeMaster PC is increased from 0 to 2.6 meters (moving down the figure, a little

over three Rayleigh ranges of change in  $Z_0$ ) notice the changes in the measured internal beam parameters (all values shown are Radial Mode quantities).



**Figure 3-5. Effect of Repositioning the Instrument on Internal Rayleigh Range**

First, the internal Rayleigh range  $Z_{R2}$  decreases, as the ModeMaster PC is moved into regions of larger beam sizes at the lens (resulting in smaller internal focal diameters and Rayleigh ranges). The

internal waist diameters  $2W_{02}$  are listed after  $2W_0$  on each screen of the figure; the  $Z_0$  listed there is the internal waist location  $Z_{02}$  in counts.

Second, the internal waist location  $Z_{02}$  at first moves to the right on the screen, as the lens plane moves away from the flat wave front at the external beam waist ( $Z_{01} = 0$ ) towards the point of maximum wave front curvature at  $Z_{01} = Z_{R1} = 0.80$  m. (This is the region where gaussian-beam waist lens transformation laws are not like geometrical-optics imaging laws.) Then for further increase in separation, regions of flatter wave front curvature are encountered and the internal waist moves (slowly) back towards the middle of the screen, to the left.

Third, the lens transformation constant  $\Gamma$ , given by the ratio of the (fixed) external Rayleigh range to the (varying) internal one,

$$\Gamma = Z_{R1} / Z_{R2},$$

increases with  $1/Z_{R2}$ , but  $\Gamma_{\max}$

$$\Gamma_{\max} = |f^2/16(Z_{02} - f)|, \text{ [in mm]},$$

goes through a minimum at  $Z_{01} = \pm Z_{R1}$  (where the term in the denominator goes through a maximum). Therefore, if the Maximum Gamma Limit message (discussed below) appears, move the ModeMaster PC to change  $Z_{01}$ .

## Staying Within the Nomogram Boundaries - Hierarchy of Help Messages

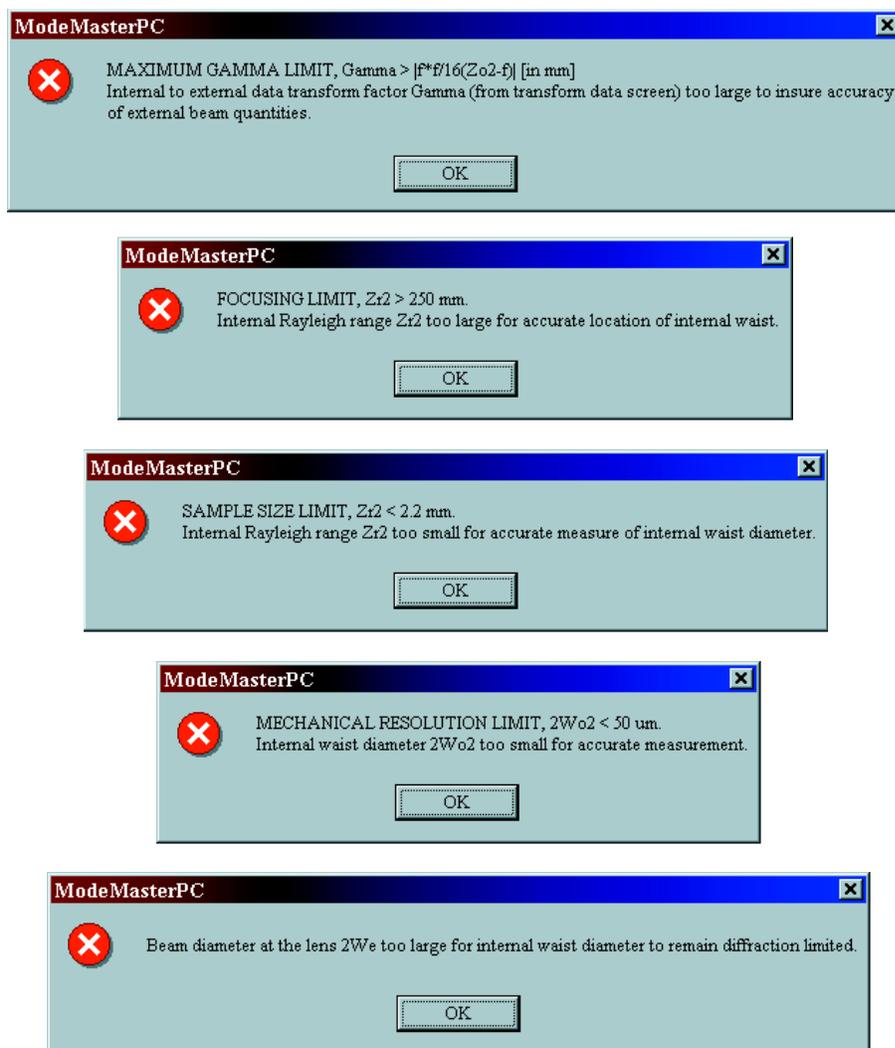
After every successful focus run, the internal data is examined for the presence of the five conditions defining the region of accurate results. If one or more conditions are violated, the topmost help message is displayed in the following hierarchy. Usually the corrective action taken to satisfy the boundary condition for the topmost (generally, the most severe) error takes care of any of the lower ranking problems.

### Message Hierarchy

1. Maximum Gamma limit
2. Focusing limit
3. Sample Size limit
4. Mechanical Resolution limit
5. Aberration limit

These limiting conditions are discussed under "Theory of Operation" (p. 5-12). If one of these messages appears after a focus, change lenses, or reposition the instrument in the direction to reverse

the inequality listed in the message heading. This is the condition that caused the message to appear. Figure 3-5 (p. 3-15) lists the dependencies of internal parameters on instrument position. Refocus the instrument after each change to determine the effect on the data. The full list of messages are shown in Figure 3-6, below.



*Figure 3-6. Hierarchy of Post-Focus Nomogram Limits Messages*

### Maximum Gamma Limit

Multiple ModeMaster PC input lenses require the Gamma limit calculation to take into account the different lens focal lengths. There is a finite error  $\Delta x_2$  with which the factor  $x_2 = (Z_{02} - f)$  is known in  $\Gamma$  calculation:

$$\Gamma = f^2 / [(Z_{02} - f)^2 + Z_{R2}^2]$$

The magnitude of the fractional error  $|\Delta\Gamma/\Gamma|$  this produces is  $(2x_2\Delta x_2/f^2)\Gamma$ . Limiting the fractional error to  $< 1\%$  then gives the Gamma limit criterion. Note that  $\Gamma_{\max}$  is largest at  $x_2 = 0$  since the slope of the  $\Gamma$  vs.  $x_2$  curve is zero and is smallest at  $Z_{02} = Z_{R2}$  since  $x_2$  is largest. Thus to remove the Gamma limit message, move the ModeMaster PC away from the position  $Z_{01} = Z_{R1}$ . Move the Scan Head one input Rayleigh range throw distance between the input waist and the ModeMaster PC reference plane. The upper limit values  $\Gamma_{\max}$  given by the new criterion will usually be less than 1,000 for the lenses with focal lengths less than the Dewey Doublet (lens D), and greater than 1,000 for the lenses with longer focal lengths.

**Aberration Limit,  
 $2We/f > (f/\#)$**

The limiting lens aberration is spherical aberration. This aberration increases rapidly with the aperture over which the lens is used (the beam size at the lens  $2W_e$ ). Hence for each lens, there is a maximum  $f/\#$ , computed in software. The EEPROM constants identify the lens in use, which triggers this message. The beam size at the lens is reduced by moving the ModeMaster PC closer to the input beam waist.

**Conversion Limit,  
Knife-Edge M2  
Greater than 6.5**

This limit message (shown in Figure 3-7, below) comes up when conversions (D4s, D86, or Dslit) are attempted for input beams whose knife-edge measured beam quality exceeds 6.5. As M2 increases, the number of possible Laguerre-Gaussian modes increases in the mode mixture for a given value of M2. The built-in conversions are based on limiting the modes used in the fitted mode mixture. Those observed modes oscillate in actual, stable-resonator lasers, up to  $M_{ke}^2$  ( $M^2$  at knife-edge) = 4.3. The software allows extrapolation a little beyond this, but as the conversion becomes an increasingly unknown, the standard conversions are cut off at an input  $M^2$  of 6.5. User conversion factors can be defined for any input beam, but their reliability is left for the user to determine.



**Figure 3-7. Conversion Limits Message**

## X-Y-R Toolbar Buttons

Pressing the X-Y-R Button ( **X Y R** ) in the Tool Bar rotates the display to show the beam propagation characteristics appropriate for the X axis, the Y axis, or the R-mode axis. The currently-displayed selection is reversed on the tool bar. When the axis is changed, the message “Lens moving...please wait” will be displayed while the lens carriage moves to place the selected beam waist at the cut plane. The X-Y-R lens locations also have direct keyboard access. Simply press the appropriate F-Key and the lens will move to the desired location: X = F2, Y = F3, and R = F4.

## R-Beam

The R-Beam is the equivalent radially symmetric beam. Any beam, regardless of how elliptical its cross-section or how astigmatic it is, can be represented by an R-Beam. For more information, refer to the discussion presented under “Section Five: Beam Propagation Theory” (p. 5-1).

## Properties Panel

The Alignment Screen Properties Panel provides point-and-click access to a variety of alignment and measurement functions.

Properties	
<b>Plot :</b>	
Alignment Zoom	8 X
Large Font Option	External Z/w/o
<b>Profile Adjustment :</b>	
Profile Plot	On
Width	96
Delay	1353
Gain	24
Pinhole Select	10 um
Profile Plane	Focal Plane
Pinhole	Find
<b>Power Density :</b>	
Power Density Plot	On
Power Density	Calibrate
Maximum Power Density	

The following table describes each of the available functions.

**Table 3-1. Properties Panel Functions**

<b>FUNCTION</b>	<b>SELECTION TYPE</b>	<b>DESCRIPTION</b>
<b>Plot</b>		
Alignment Zoom	Drop-Down List	Selects resolution of the current alignment (resolutions of 1x to 16x).
Large Font Option	Drop-Down List	When Profile Plot and Power Density Plot are off, this option displays the selected value in a larger font.
<b>Profile Adjustment</b>		
Profile Plot	Drop-Down List	Toggles Profile Plot On or Off
Width	Increase/Decrease Control	Increases or decreases width of profile from a minimum value of 1 to a maximum value of 100.
Delay	Increase/Decrease Control	Increases or decreases the time delay of the profile in the display from a minimum value of 1 to a maximum value of 1575.
Gain	Increase/Decrease Control	Increases or decreases the height of the profile display from a minimum value of 1 to a maximum value of 12 (Maximum value varies depending on the detector).
Pinhole Select	Drop-Down List	Changes the pinhole from which the profile signal is displayed.
Profile Plane	Drop-Down List	Toggles between Profile and Reference Plane.
Pinhole	Wizard	Launches the “Find Pinhole” wizard.
<b>Power Density</b>		
Power Density Plot	Drop-Down List	Toggles Power Density Plot On or Off.
Power Density	Wizard	Launches Power Density calibration wizard.
Maximum Power Density	Process	Resets Maximum Power Density indicator.

The following subsections further describe the commands in the order they appear within the Properties Panel on the Alignment Plot Screen.

### **Alignment Zoom**

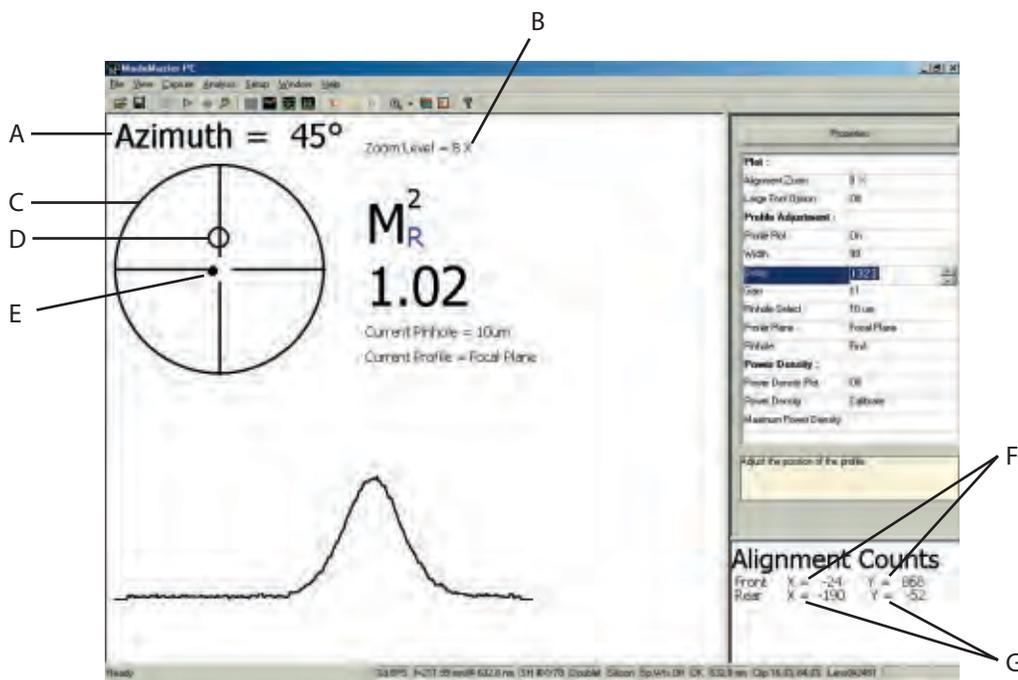
The Alignment Zoom option is used to align the ModeMaster PC Scan head optical axis with the laser beam. High resolution alignment can precisely display the real time motion of the beam axis relative to the instrument optical axis. The graphical view consists

of a target and display of relative distance between the beam axis and the Scan Head optical axis at both the front and the rear cut plane. The High Resolution screen condition is shown in the figure below.

---

**Higher resolution is only required for pinhole alignment and coaxial beam alignment.**

---



### Alignment Zoom Indicators

The following information is displayed within the graphical results and numerical area of the Alignment Screen when the Alignment Zoom option is engaged:

- A. Current azimuth angle of the ModeMaster PC Scan Head.
- B. Resolution of the current alignment screen (resolutions of 1x 2x, 4x, 8x, and 16x are available).
- C. Fixed alignment target. The user may adjust the scan head so that the beam indicators are centered on this target to make the beam and instrument optical axis coincide.
- D. Relative beam position on the front rotating drum cut plane is indicated by the moving circle.
- E. Relative beam position on the back rotating drum cut plane is indicated by the moving dot.

- F. Distance (in counts) between beam axis and instrument axis at the rotating drum front cut plane (1 count = 0.354 micrometers). When the Scan Head is adjusted to a 45° azimuth angle, X is horizontal distance and Y is vertical distance. Value of 0 indicates beam is exactly on the optical axis.
- G. Distance (in counts) between beam axis and instrument axis at the rotating drum rear cut plane. When the Scan Head is adjusted to a 45° azimuth angle, X is horizontal distance and Y is vertical distance. Value of 0 indicates beam is exactly on the optical axis.

## **Alignment**

With the Alignment plot at 2x resolution, both the dot (representing the focal point of the beam at the back of the rotating drum) and the small circle (representing the position of the beam at the front of the rotating drum) should be within the alignment target on the screen.

Now, use the angle and position adjustments to bring the small moving dot within the moving circle (adjust the scan head so the input beam is parallel with the instrument optical axis) and the dot and circle both to the center of the alignment target (adjust scan head so the input beam is on its optical axis).

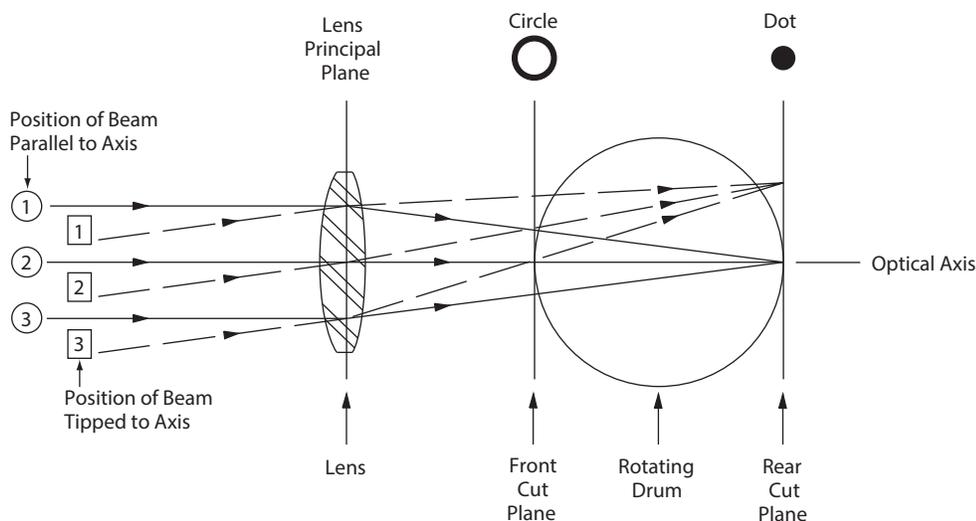
The adjustments controlling the translation and angular adjustment of the ModeMaster PC scan head will have varying effects on the movement at the front and rear cut plane. Resulting movement depends on the azimuth angle (the rotational axis of the drum) and the location of the beam focus within the scan head. Try each adjustment to find the effect for the current azimuth angle. When both the

dot and the circle are centered within the target, increase the resolution to the next higher value. Repeat the process until alignment is complete at highest desired resolution.

---

**Accurate focus data does not require perfect alignment. If your laser source becomes unstable, change the Scan Head alignment and focus again.**

---



**Figure 3-8. Adjustment Angle Diagram**

Two beams may be aligned for coincidence by adjusting the scan head to be aligned with the first beam. Then block the first beam and adjust the alignment of the second beam to center the target indicators.

The Control Panel Alignment Zoom drop-down menu changes the resolution of the display. Minimum resolution is 1X. Maximum resolution is 16x. The tool bar alignment zoom will also have a drop down. Clicking on the magnifier picture will toggle through the zoom ranges. Optimize alignment on 8x zoom prior to beginning Pinhole Wizard. Zoom levels greater than 8x are recommended for coincident beam alignment.

## Large Font Option

The Large Font Option displays a specified value in a font size suited for distant viewing. The Profile Plot and Power Density Plot must be turned off before the values can be displayed. A drop down list of available Large Font items can be selected from the Properties Panel.

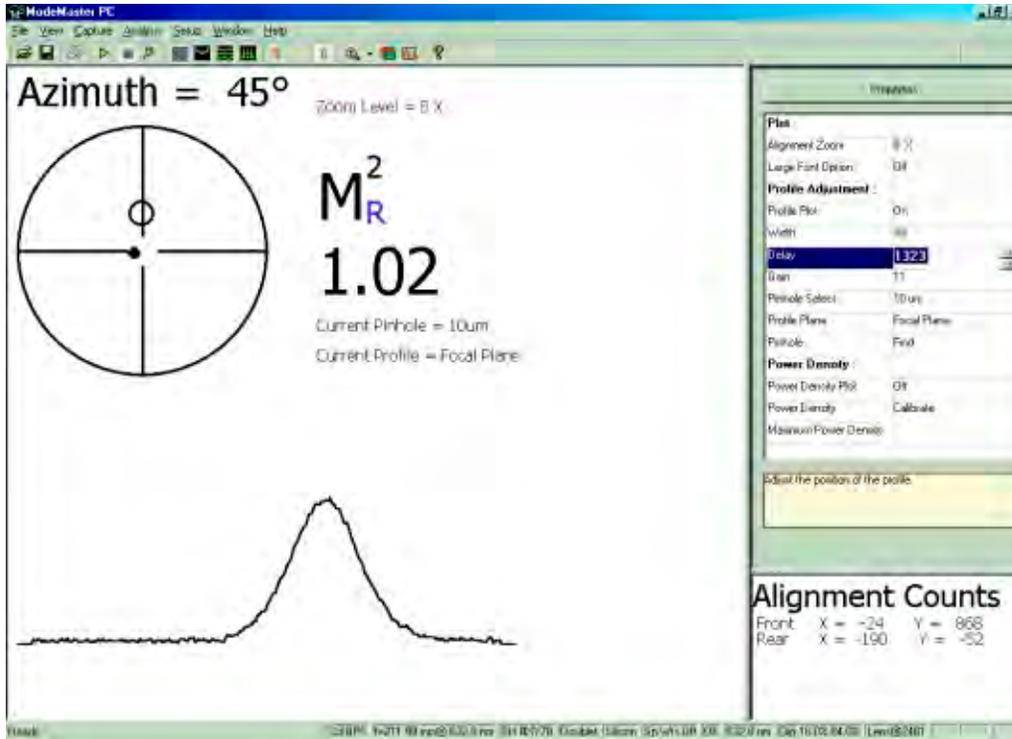


Figure 3-9. Adjustment Angle Diagram

## Profile Plot

This option turns the Profile Plot display “On” or “Off”.

## Width

This control option increases or decreases the width of the profile. Minimum value = 1, Maximum value = 100. The display consists of 512 digitized points. The width adjustment sets the distance between these points. The minimum distance between points with the width set to maximum is 0.5  $\mu\text{m}$ . A profile display width of 512 x 0.5  $\mu\text{m}$  = 256  $\mu\text{m}$ . The width of the profile display can be calculated as follows: Window Width = {101- (width no.)} (0.256mm).

## Delay

This control option moves the profile to either the right or the left side of the window. Minimum value = 1. Maximum value = 1575. The time delay sets the position of the beam profile display. An increase in the delay value by 1 moves the profile by 16.0 microns

to the right. The sensitivity of the delay control is determined by the current display width. A single value change will move the profile by 1/16 of this width.

### **Gain**

This control option increases or decreases the height of the profile. Minimum value = 1, Maximum value = 12 for Si detector, 9 for Ge detector, and 6 for pyro detector. The gain control sets the height of the profile. Each time the gain setting is changed the gain is increased or decreased by 2 times. A larger value results in more detector gain.

### **Pinhole Select**

Changes the pinhole from which the profile signal is displayed. (Between 10 and 50  $\mu\text{m}$  for visible units and between 100 and 500  $\mu\text{m}$  for Pyro units). The control option changes the pinhole label on the screen but does not immediately change the display.

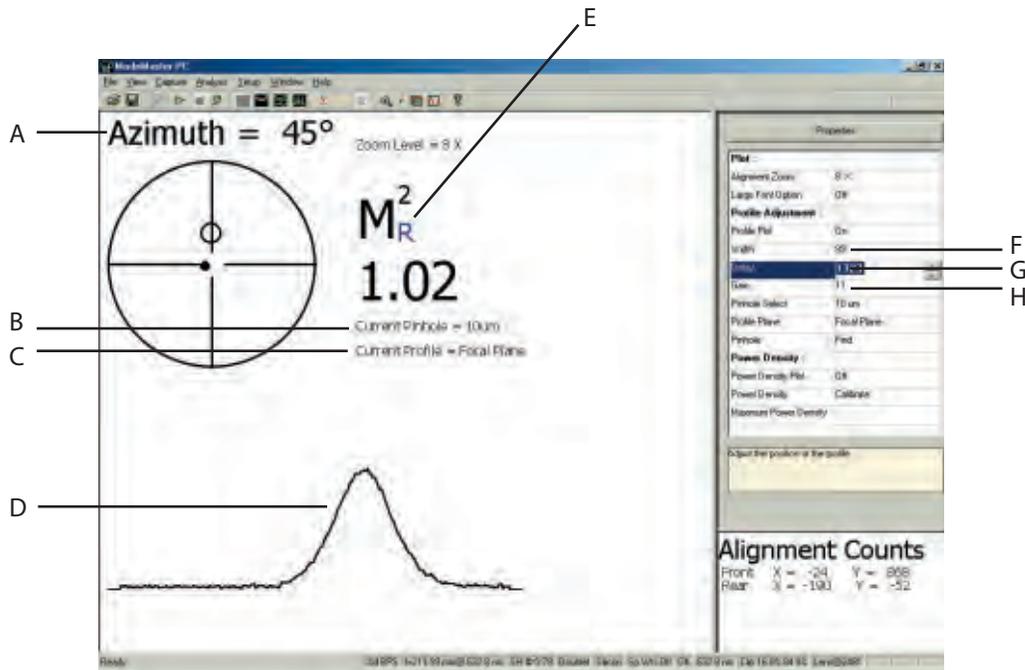
### **Profile Plane**

This option allows you to choose either the Reference Plane or the Focal Plane. The following section discusses both planes.

#### **The Reference Plane**

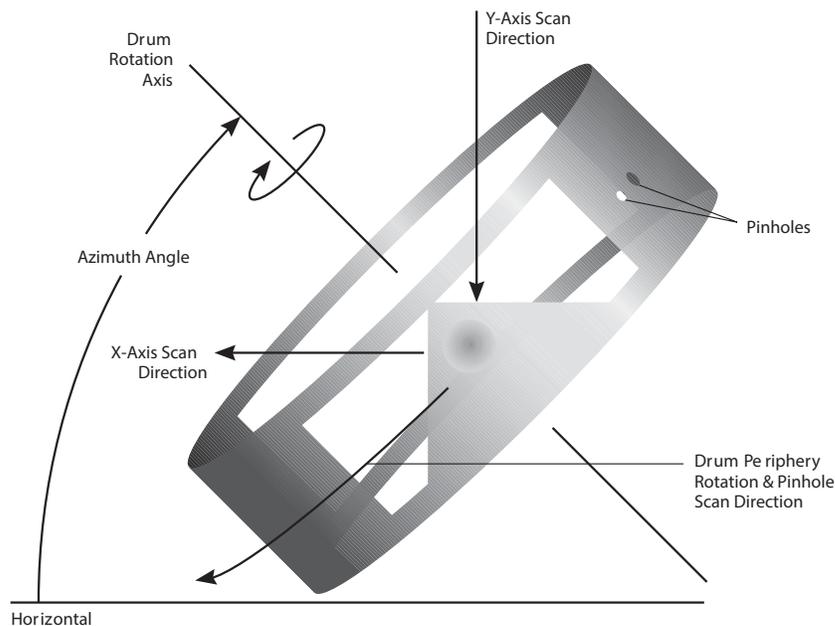
The Reference Plane displays a transverse intensity profile of the beam at the opposite side of the rotating drum from the focal plane. This profile is significant in several ways. To the extent that it is distant from the beam waist, it is representative of the intensity distribution corresponding to the Fourier transform of the field distribution at the beam waist. Considering the intensity profile at the waist to be the “near-field” profile, the profile on this screen is representative of the “far-field” intensity distribution. The more Rayleigh ranges between the two sides of the drum for the internal beam, the more closely this profile represents a true far-field profile. (For a near-gaussian beam, the near- and far-field profiles will have nearly the same shape.) The distances from the reference plane to the lens and from the lens to the front cut-plane of the drum are almost insignificant compared to the respective Rayleigh ranges. This

intensity profile is generally a very close representation of the intensity profile that would be detected at the actual instrument reference plane; hence the name for this plot.



- A. Current azimuth angle of ModeMaster PC scan head.
- B. Pinhole size being used to make the scan (10 or 50  $\mu\text{m}$  for MM- 1, -1S, -2, -2S, -3, -3S, and 100 or 500  $\mu\text{m}$  for MM-4, -5).
- C. Indicates this is the profile at the Reference Plane.
- D. Transverse pinhole profile of the beam scanned at the current azimuth axis ( $45^\circ$  to X and Y axes)—see Figure 3-10 (p. 3-27).
- E.  $M^2$  of beam whose profile is being displayed. The pinhole scan line is at  $45^\circ$  to the direction of the X and Y knife-edge scans—refer to Figure 3-10 (p. 3-27)) When the X and Y axes are set in the principal plane directions, the pinhole generates an R-mode intensity profile (the R-mode plane is always at  $\pm 45^\circ$  to the principal planes).

To see pinhole profiles in the principal planes, rotate the head azimuth angle by  $\pm 45^\circ$  from the azimuth angle.



**Figure 3-10.  $M^2$  Measurement Planes and Profile Plane**

- F. Width of profile in display. Minimum = 1. Maximum = 100. Window Width =  $\{101 - (\text{width no.})\}(0.256 \text{ mm})$
- G. Time delay. Indicates horizontal location of scan within window. Minimum delay = 1. Maximum = 1575.
- H. Gain. Controls vertical scale of display. Minimum = 1. For Silicon detector, maximum = 12. For Germanium detector, maximum = 9. For pyroelectric detector, maximum = 6.

The Pause button (  ) in the Toolbar freezes the profile at the moment the button is pressed. A frozen profile can be stored to a file by utilizing the Save button (  ) in the Tool Bar. When the sample is held, the Resume button becomes active. Pressing the Resume button (  ) releases held data and returns to the normal update rate.

### The Focal Plane

The Focal Plane Profile displays a transverse intensity profile at the internal beam waist. See “Section Five: Beam Propagation Theory” (p. 5-1) for more information on intensity profile significance and interpretation of intensity profiles. Utilize the internal measurement cursor for accurate adjustment of the beam diameter at the pinhole plane.

- A. Current azimuth angle of ModeMaster PC scan head.

- B. Pinhole size being used to make the scan (10 or 50  $\mu\text{m}$  for visible units, 100 or 500  $\mu\text{m}$  for Pyro units).

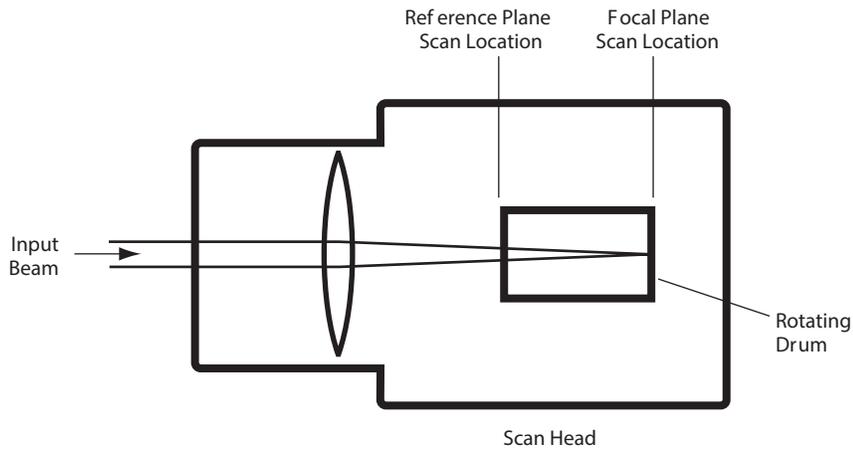
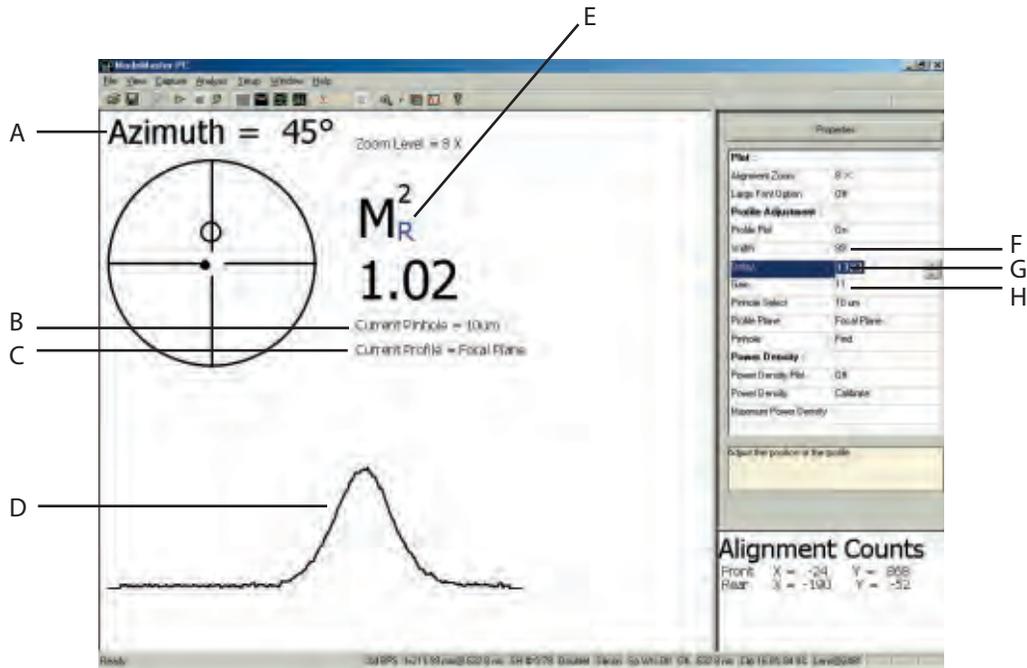


Figure 3-11. Beam Profiling in ModeMaster PC



- C. Indicates this is the profile at the Focal Plane
- D. Intensity profile of the beam measured along the pinhole scan axis shown in Figure 3-10 (p. 3-27).
- D.  $M^2$  for the selected axis.
- E. Width of digitized window. Minimum = 1. Maximum = 100.
- F. Time delay. Controls horizontal location of scan within window. Minimum delay = 1. Maximum delay = 1575.

- G. Gain. Controls vertical scale of display. Minimum gain = 1. Maximum gain = 12 for Silicon detector, 9 for Germanium detector, and 6 for pyroelectric detector.

---

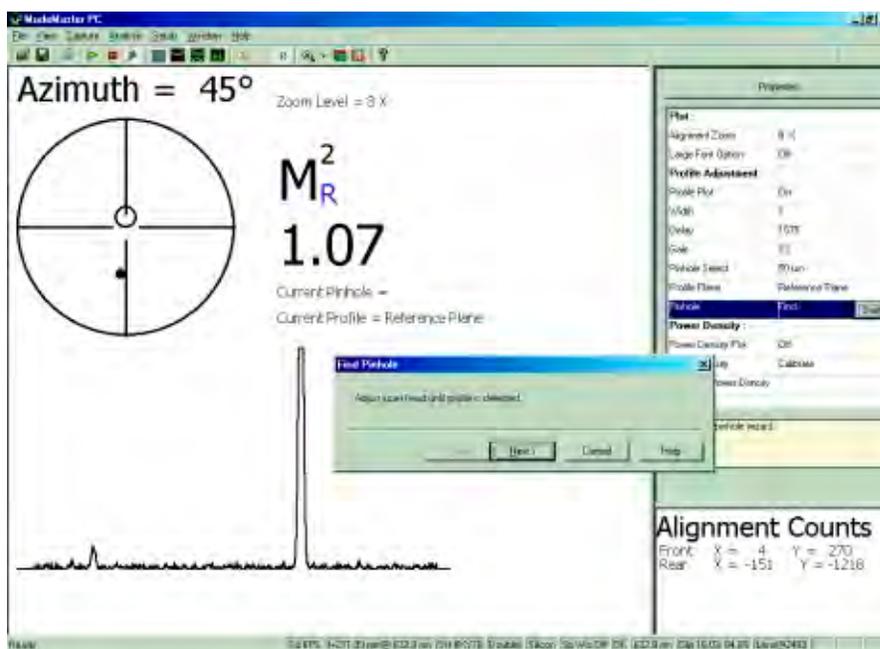
To minimize deconvolution errors in profiling the beam, the pinhole used to scan the beam must be  $\leq 17\%$  of the diameter of the beam being scanned. Therefore, the smaller pinhole is normally used for the Far Field profile that is scanned at the beam's focal plane. For cases in which the signal from the smaller pinhole is not sufficient to produce a usable profile, the larger pinhole can be used—see “Pinhole Select” (p. 3-25). To avoid deconvolution errors if the larger pinhole is used, the scan lens is manually defocused to enlarge the beam diameter to be six times the pinhole diameter at the measurement plane—see “Properties Panel” (p. 3-19).

---

## Pinhole

The Pinhole wizard option is used to locate and optimize the beam profile. Following the wizard completion, final Scan Head and Properties adjustments can be made to optimize the profile display. The wizard guides you through the steps involved.

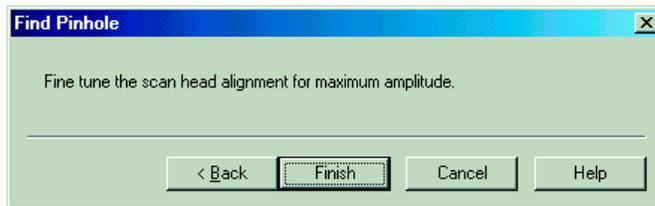
1. Click Find to start the wizard.



2. Once the Find Pinhole Dialog (Full Width) screen is displayed, use the scan head angle adjustments to maximize the signal.



3. Click Next to continue. The following screen prompts you to fine tune the scan head alignment for maximum amplitude. Click Finish when you've completed the fine tuning.



The Pinhole Find wizard does the following:

- Sets width to minimum (100) so that entire scan distance is displayed.
- Sets delay to maximum so that all data is displayed.
- Sets gain to maximum so weakest signal can be seen.
- The final step centers the profile to optimize and continue.

Following the completion of the pinhole wizard, the user can perfect the profile display. This is accomplished with a combination fine scan head angle adjustments combined with changes from the Properties Panel (Width, Gain, and Delay).

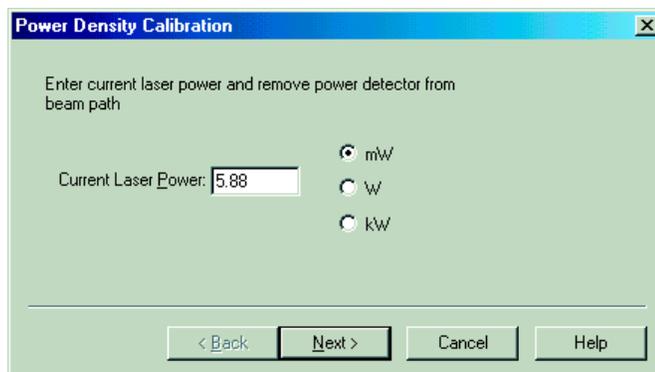
## Power Density Plot

This option turns Power Density Plot “On” or “Off.”

## Power Density

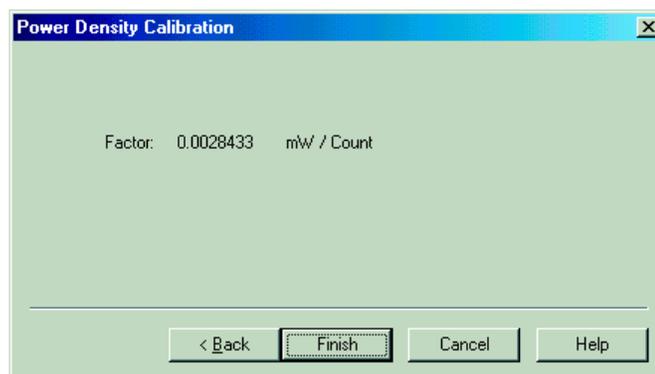
This option launches the Power Density wizard that facilitates the tuning of a laser for maximum power density. By using an appropriate Coherent laser power detector in conjunction with the Mode-Master PC, power density measurements can be made. Note that power density is calibrated only in the R position. The Power Density wizard will set the R plane automatically and prompt the user if focus data is not available.

The first step of the wizard will prompt the user to enter the current laser power. Use the appropriate Coherent power detector to measure the current laser power. Enter this value into the wizard dialog. Verify that the appropriate units are selected. Remove the power detector and click next.



The screenshot shows a dialog box titled "Power Density Calibration" with a close button (X) in the top right corner. The main text reads: "Enter current laser power and remove power detector from beam path". Below this, there is a text input field labeled "Current Laser Power:" containing the value "5.88". To the right of the input field are three radio button options: "mW" (which is selected), "W", and "kW". At the bottom of the dialog, there are four buttons: "< Back", "Next >", "Cancel", and "Help".

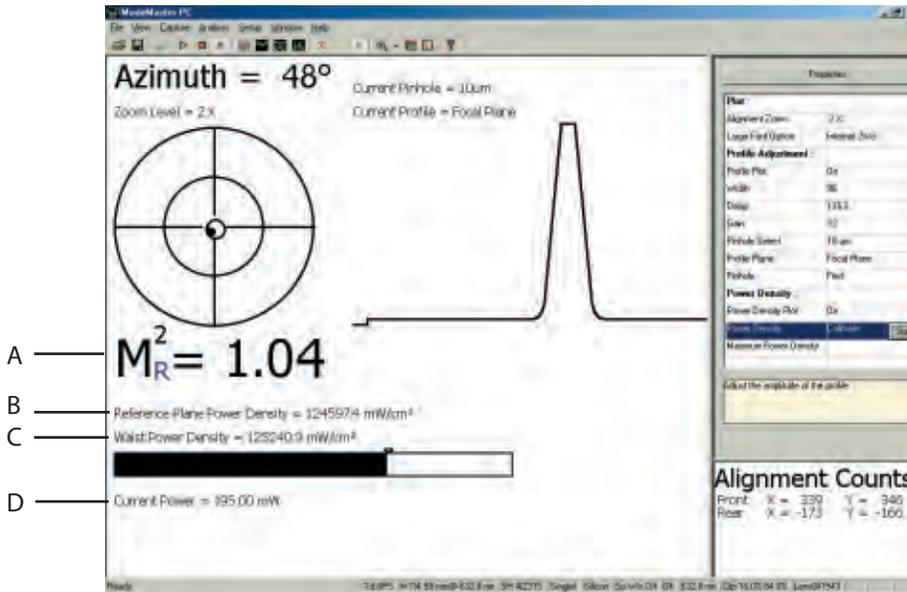
The factor that will be used to convert the ModeMaster PC detector output to calibrated power readings is displayed. This may be used to reproduce the experimental set-up for future comparisons. Click Finish.



The screenshot shows the same "Power Density Calibration" dialog box. The main text now reads: "Factor: 0.0028433 mW / Count". The "Next >" button from the previous step is now disabled and has a dashed border. The "Finish" button is now enabled and highlighted with a solid border. The other buttons ("Back", "Cancel", "Help") remain the same.

The calibrated Power Density plot is shown in the following figure. Power variations in the laser are now followed in real time by the ModeMaster PC detector (using the 100% transmission portions of

the signal). The display must be recalibrated when the optical set-up is changed to alter the fraction of laser power that enters the ModeMaster PC.



The following information is displayed on the Power Density plot after calibration:

- A.  $M^2$  Beam propagation factor for the R-beam whose power density is being measured.
- B. The Reference plane Power Density. This value represents the Power Density at the Scan Head front bezel. This value is a result of Power per Area  $2W_e$ .
- C. The waist power density for the R-beam. The location of the beam waist ( $Z_0$ ) follows the ModeMaster PC sign convention; negative is towards the laser from the ModeMaster PC scan head (the anti-propagation direction).
- D. The current power reading from the detector. This indicator will be blank until the power density calibration is completed.

The power density plot is designed to facilitate tuning of a laser for maximum brightness (power density). The plot displays power density as a pseudo-analog tune bar which provides real-time feedback as laser mirrors are adjusted. The left edge of the bar represents zero and the small triangle above the bar indicates the maximum power density. The tune bar is automatically re-scaled as necessary. If the plot is displayed before a calibration, the bar will show the message “Not calibrated and focused.”

It will often be desirable to use a beam splitter to direct only a fraction of the total power into the ModeMaster PC. If the above calibration is done by placing the detector in the main beam, the ModeMaster PC will then be calibrated to indicate power and intensity for the main beam.

The ModeMaster PC detector is capable of significantly faster response to changing power levels than thermopile detectors.

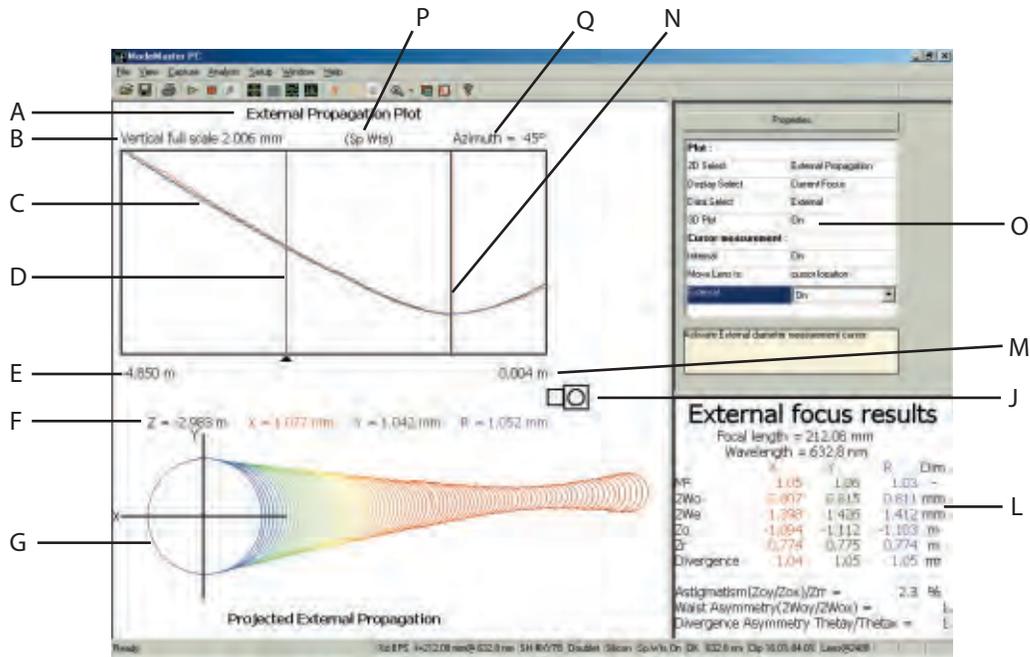
### **Maximum Power Density**

This option allows you to reset the maximum power density indicator. An audio beep will sound each time a new maximum is reached. If the audio beep becomes bothersome, it can be turned off via the Setup >> Options menu item.

### **Beam Propagation Screen**

The beam propagation plot is constructed from 260 internal points collected with each focus run. A focus run consists of the Lens traveling exactly one measurement drum diameter—see “Theory of Operation” (p. 5-12) for more information. As the lens moves the drum knife-edges measure the beam diameter 260 times each focus run. These directly-measured diameters are the 260 points that make up the Internal Propagation Plot. The plot is constructed based on lens position vs. measured diameter. Based on knowledge of the lens and drum parameters, the directly-measured data can be mathematically transformed to map the actual beam that generated the internal data. The external plot is a result of the mathematically-transformed internal plot. The Beam Propagation Plot screen provides a graphic display of the laser beam diameter along the X and Y axes plotted along the travel of the lens assembly (Internal Screen) or trans-

formed into actual distances (External Screen). This section discusses the features of both plots. The following information is displayed on the External Screen:



All data can be stored to a text file. This data can be viewed in the user interface or analyzed with external programs such as Microsoft Excel.

## External

- A. Indicates that the External 2D plot is being displayed.
- B. Vertical full scale (beam diameter axis) displayed in mm. The lowest point on the vertical plot boundary is always zero millimeters. The vertical scale can be set manually by clicking the customize Tool Bar item.
- C. Plots of beam diameter vs. propagation distance. The red profile represents the X axis, the green profile represents the Y axis (horizontal and vertical respectively when the scan head azimuth angle is at the standard 45° angle) and the blue profile represents the R-Beam. The color associated with these plots is also reflected in all of the corresponding data. This color is user-selectable with the customize tool bar button. Color changes may be necessary to view data with laser safety eyewear. The indicated colors correspond to the install defaults. In this manual these curves are referred to as “caustics.”

- D. The Measurement Cursor allows the user to display the diameter vs. distance value for each point on the External Propagation plot. The measurement cursor can be moved with the keyboard arrows or by mouse dragging the arrow indicator. When the cursor is active the Z value indicates the current location referenced to the Scan Head front bezel. The values of X, Y, and R indicate the external beam diameter at the selected location of Z.
- E. Maximum extent of the propagation axis in the negative direction (towards the source) measured from the reference point.

---

**The beam propagation display follows the standard optical textbook convention of light moving from left to right. The beam produced by the source (laser) is therefore represented on this screen as propagating from left to right toward the Mode Master PC the scan head is located at 0.0 m.**

---

- F. Values at cursor's current position. The value is updated when the cursor is moved left or right. The cursor location can be changed with the mouse or keyboard arrow keys.
- G. The 3D Projected External Propagation Plot that is only a projected representation of the beam's characteristic, and not an actual representation.

---

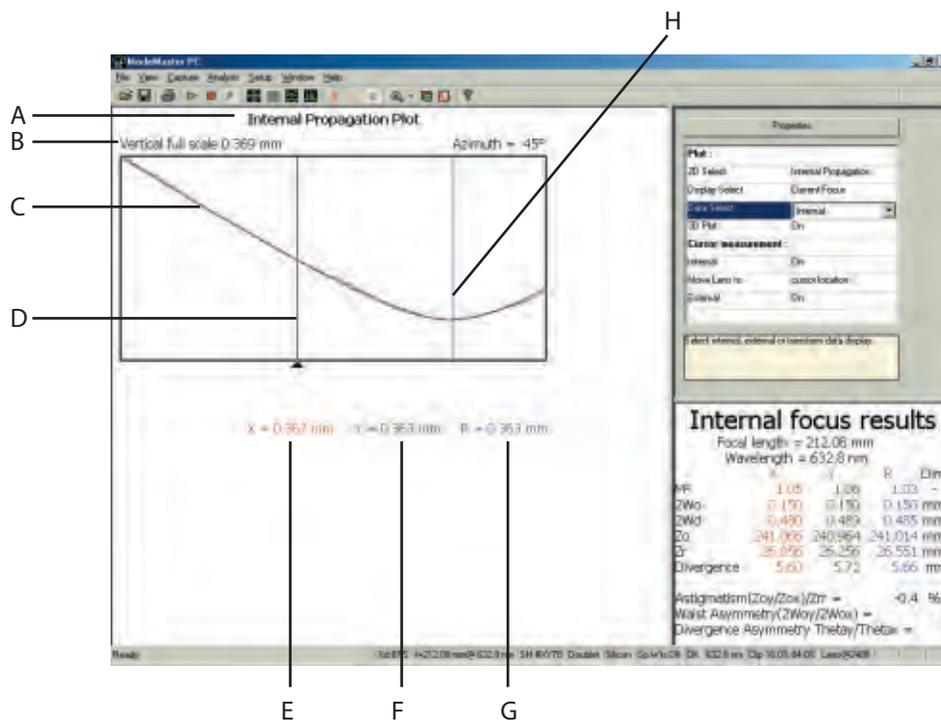
**The 3D Plot is not active when the Internal Propagation Plot is displayed.**

---

- J. Location of Scan Head. The Scan Head symbol indicates current Scan Head position in relation to the Propagation Plot.
- L. Numerical results area which displays live or curve fit focus results.
- M. Maximum extent of the propagation distance axis in the positive direction measured from the ModeMaster PC reference plane (instrument input bezel).
- N. Beam waist positions of the beam in the X (red), Y (green), and the R-Beam (blue) axes. Colors are user-selectable with the customize function.
- O. Beam Propagation Plot Screen Properties Panel.



## Internal



On the internal display, the vertical scale is in units of mm. The horizontal scale represents 3212 counts of the total travel of the lens assembly. The label Internal Propagation Plot at the top of the screen immediately distinguishes it from the external propagation plot.

Information displayed on the internal screen is analogous to that on the external screen. The horizontal scale represents the 3212 counts of the internal travel of the lens assembly.

- Indicates that the internal propagation plot is being displayed.
- Vertical full scale (beam diameter axis) displayed in mm, with the lower plot boundary being zero millimeters.
- Plots of beam diameter vs. lens position. The red plot represents the X axis, the green plot represents the Y axis (horizontal and vertical respectively when the scan head azimuth angle is at the standard  $45^\circ$  angle) and the blue plot represents the R axis. These colors are user-selectable with the Customize tool bar button.
- The Measurement Cursor allows you to manually move the lens. This function is utilized for pinhole profiles. Utilize the measurement cursor to display the desired beam diameter and then select "Move Lens to" option in

the properties panel —review the profile section in the “M2 Live/Alignment Screen” (p. 3-8).

---

**NOTE: Regarding the use of Manual Lens Movement to improve pinhole intensity profiles. This feature should be used when it is impossible to obtain a large enough signal on the profile screens to accurately observe the profile characteristics of a beam using the smaller pinhole (10 microns). To accurately observe the beam profile with a pinhole, it is necessary for the beam diameter to be at least 6 times the pinhole diameter. At that ratio the distortion of the displayed profile due to convolution error is no more than 1% of the beam width. Focused beams whose focused widths are much more than 6 times the small pinhole diameter (of 10 microns) may have insufficient power transmission for a good signal-to-noise ratio on the profile display. This situation can be helped by switching to the larger pinhole diameter using the Pinhole Select option on the Alignment Screen and then defocusing the beam using the manual lens motion. Utilize the internal measurement cursor and the “Move Lens to” selection in the Properties Panel, until it is 6x the pinhole diameter (e.g., for a 50  $\mu\text{m}$  pinhole, 300  $\mu\text{m}$  diameter). This gives the maximum pinhole signal possible, consistent with the 1% distortion criterion.**

---

- E. X value at cursor’s current position. The value is updated when the cursor is moved left or right.
- F. Y value at cursor’s current position. The value is updated when the cursor is moved left or right.
- G. R value at cursor’s current position. The value is updated when the cursor is moved left or right.

---

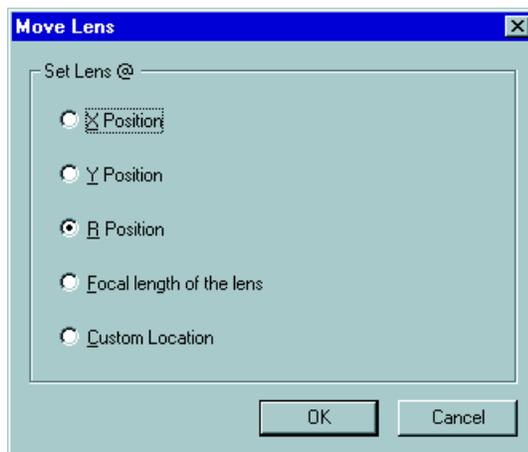
**The beam propagation display follows the standard optical convention of light moving from left to right. The source (laser) will therefore be on the left.**

---

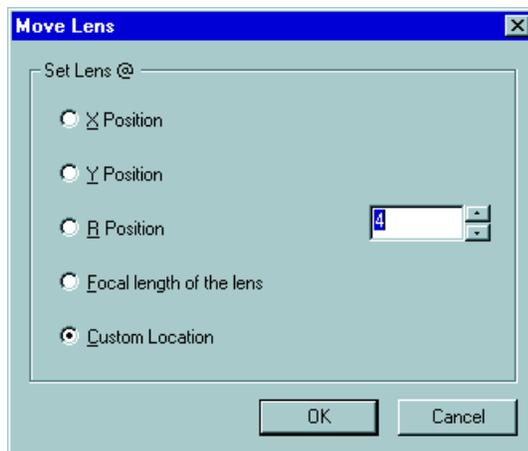
- H. Beam waist position of the X (red), Y (green), and R (blue) axes. These colors are user-selectable with the Customize tool bar button.

## Manual Lens Movement

The Internal Beam Propagation Screen allows you to manually move the lens position using the measurement cursor to measure beam width away from the beam waist. The function can also be accessed by choosing Move Lens from the Capture menu item or double-clicking the current lens position on the status bar. The following window appears.



1. The lens can be set at one of the five options. To move the lens manually, choose Custom Location. An increase/decrease control function appears.



2. Use the buttons to increase or decrease the location.
3. Click OK. The lens will move to the specified location. The current location is shown on the right side of the status bar.

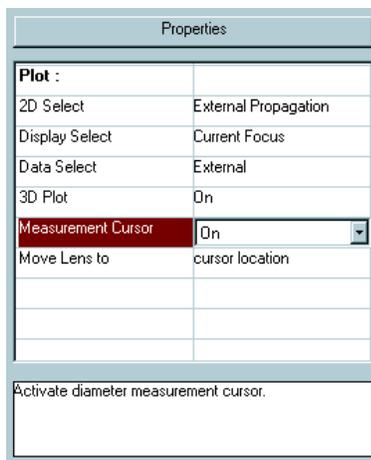
Each time the value is decreased the lens is moved by 25 stepper motor counts toward the front of the scan head (toward the beam source) after clicking OK. The opposite occurs when the value is increased. To return the lens to a standard X, Y, or R position, select the letter on the tool bar or the radio button in the lens move menu item.

## XYR Buttons—Beam Propagation Screen

Pressing the X-Y-R button in the toolbar while on the Beam Propagation Plot screen will move the lens to the appropriate selection. The current lens location will be indicated by the reversed appearance. The current selection will effect the subscript indicating current data on the Live/Alignment Screen and the column of live data on the Propagation Screen. This has no effect on the static Beam Propagation data since the displayed data is historical.

## Properties Panel

The Properties Panel in the Beam Propagation Screen provides point-and-click access to a variety of plot and cursor measurement functions and options. When the selection box is active, a mouse scroll wheel will allow you to toggle through the settings.



The following table describes each of the available functions.

FUNCTION	SELECTION TYPE	DESCRIPTION
<b>Plot:</b>		
2D Select	Drop-down List	Selects Internal or External 2D Propagation plot.
Display Select	Drop-down List	Selects Current Focus or Live.
Data Select	Drop-down List	Selects External, Internal, or Transform data.
3D Plot	Drop-down List	Toggles 3D plot On or Off.
Measurement Cursor	Drop-down List	Toggles Cursor Measurement On or Off.
Move Lens to	Process	Moves lens to internal cursor location.

The following subsections further describe the commands in the order they appear within the Properties Panel on the Beam Propagation Plot Screen.

**2D Select**

This option allows you to select either the Internal or External Propagation Plot. Each plot includes a measurement cursor.

**Display Select**

This selection controls the data display in the results panel. The Current Focus data select will display the static focus run results. The Live data select will display all data that is available for real time display. The X, Y, and R buttons control which column of data is displayed. To utilize Large Font for laser tuning, select the Live/Large Font button from the tool bar.

**3D Plot**

This option toggles the 3D plot on or off. The 3D Projected External Propagation Plot is only a projected representation of the beam's characteristic, and not an actual representation. The 3D Plot is constructed from the X and Y pairs of 2D External Propagation Points. Each 3D Plot Circle represents an ellipse constructed from every third pair of X and Y points. The External 2D Plot is constructed from 260 pairs of transformed Internal Propagation Points. This string of ellipses can only be viewed from one perspective. 3D Plots constructed from noisy laser data will appear distorted. The laser noise spikes will produce invalid ellipses and small ellipses will be hidden behind larger ones. The colors are assigned based on vertical diameter of each ellipse relative to the 2D Propagation Plot. Ellipses constructed from points on the bottom of the 2D Propagation Plot will appear Red. Ellipses constructed from points located on the upper portion of the 2D Plot will appear Blue. The remaining ellipses will be based on a linear translation across a standard color palette between Red and Blue.

---

**The 3D Plot is not active when the Internal Propagation Plot is displayed.**

---

**Measurement Cursor**

This option toggles the measurement cursor on or off. The External Measurement Cursor allows the user to display the diameter vs. distance value for each point on the External Propagation plot. When the cursor is active the Z value indicates the current location referenced to the Scan Head front bezel. The values of X, Y, and R indicate the external beam diameter at the selected location of Z.

## Results Panel

	A	B	C	D
<b>External focus results</b>				
Focal length = 212.08 mm				
Wavelength = 632.8 nm				
	X	Y	R	Dim
E ——— M <sup>2</sup>	1.05	1.06	1.03	-
F ——— 2W <sub>0</sub>	0.807	0.815	0.811	mm
G ——— 2W <sub>e</sub>	1.398	1.426	1.412	mm
H ——— Z <sub>0</sub>	-1.094	-1.112	-1.103	m
I ——— Z <sub>r</sub>	0.774	0.775	0.774	m
J ——— Divergence	1.04	1.05	1.05	mr
K ——— Astigmatism(Z <sub>oy</sub> /Z <sub>ox</sub> )/Z <sub>rr</sub> =			2.3	%
L ——— Waist Asymmetry(2W <sub>oy</sub> /2W <sub>ox</sub> ) =				1.010
M ——— Divergence Asymmetry Thetay/Thetax =				1.008

The Internal Measurement Cursor is utilized for pinhole profiles. Utilize the measurement cursor to display the desired beam diameter and then select “Move Lens to” option—review the profile section in the “M2 Live/Alignment Screen” (p. 3-8).

### Move Lens to

This process moves the lens to current internal measurement cursor position. View the 2D Internal Propagation Plot to utilize this function. Use the X, Y, or R Tool Bar button to return lens to Focus Position.

### Data Select: External

The data gathered in each focus scan of the lens assembly is available in the numerical results area of the Beam Propagation Screen. This is the historical data that results from applying mathematical least-squares curve-fitting algorithm to the beam width data acquired during the last focus scan. Values shown on the External Data screen are more accurate than the real-time values shown on the Alignment screen.

- A. **X Column.** Computed data appropriate for the external (input) beam in the XZ plane. The X plane (XZ plane) is the horizontal plane when the ModeMaster PC Scan Head is adjusted to an azimuth angle of 45°. The column labeled X is the data taken in this plane.
- B. **Y Column.** This column is computed data appropriate for the YZ plane (the vertical plane when the scan head is adjusted to an azimuth angle of 45°).

- C. **R Column.** Rad Mode. The data in this column describes the equivalent radially symmetric mode for the beam. This is the theoretically correct average-value mode for the beam, and is computed from the measured X and Y-axis values. Values are, in principle, independent of the azimuth of the X, Y data set used for the computation.
- D. **Dim.** Dimensions. This column contains the units of measurement for each data item.
- E. **M<sup>2</sup>.** The ratio of the divergence of the beam being measured to that of a theoretical diffraction limited (TEM<sub>00</sub>) beam having the same waist diameter. Theoretical TEM<sub>00</sub> beams have an M<sup>2</sup> of 1 and real laser beams will have a larger M<sup>2</sup> value. The tolerance on the M<sup>2</sup> value is ± 5%.
- F. **2W<sub>0</sub>.** The waist diameter of the beam as determined from knife-edge transmission measurements. Measurement of the waist diameter is affected by parameters set in the Clip Level dialog. The default parameters for the Mode-Master PC are either clip levels at 16% and 84% of full intensity, with a width factor of 2.00, or 10% and 90% clip levels, with a width factor of 1.56, both of which give a value for 2W<sub>0</sub> agreeing with the 1/e width for TEM<sub>00</sub> beams. Measurement is based on rise or fall time of the knife-edge signals as discussed in measurement theory.
- G. **2W<sub>e</sub>.** The beam diameter at the reference plane (front bezel) of the instrument.
- H. **Z<sub>0</sub>.** The distance from the Scan Head Front Bezel reference plane to the beam waist. Negative values indicate waist locations towards the laser (in the antipropagation direction). Positive values indicate waist locations beyond the reference plane (in the propagation direction).
- I. **Z<sub>r</sub>.** Rayleigh range for the input beam,  $Z_r = \pi W_0 / M^2 \lambda$ . This is just the distance along the propagation axis from the beam waist to the plane where the beam width is  $\sqrt{2}$  larger than the waist width.
- J. The full far-field divergence angle of the beam.
- K. **Astigmatism.** Percent astigmatism. As indicated by the formula, this data is normalized to the laser Rayleigh Range.
- L. **Waist Asymmetry.** This is the ratio between the X and Y waist diameters.

M. **Divergence Asymmetry.** This is the Aspect Ratio between the far field divergence angle of the X and Y planes.

		A	B	C	D
<b>Internal focus results</b>					
Focal length = 212.08 mm					
Wavelength = 632.8 nm					
		X	Y	R	Dim
E	M <sup>2</sup>	1.05	1.06	1.03	-
F	2W <sub>0</sub>	0.150	0.150	0.150	mm
G	2W <sub>d</sub>	0.480	0.489	0.485	mm
H	Z <sub>0</sub>	241.066	240.964	241.014	mm
I	Z <sub>r</sub>	26.856	26.256	26.551	mm
J	Divergence	5.60	5.72	5.66	mr
K	Astigmatism(Z <sub>0y</sub> /Z <sub>0x</sub> )/Z <sub>r</sub> = -0.4 %				
L	Waist Asymmetry(2W <sub>0y</sub> /2W <sub>0x</sub> ) = 0.998				
M	Divergence Asymmetry Theta <sub>y</sub> /Theta <sub>x</sub> = 1.021				

**Data Select: Internal**

This screen is very similar in format to the External Data Screen, except that all data is appropriate for the beam transformed by passage through the lens in the ModeMaster PC Scan Head. Use this screen to diagnose data on the External Data Screen, and to verify that the two requirements for valid data are met. Verify that the internal waist diameters exceeds 50 micrometers, and that the internal Rayleigh range is greater than 2.2 mm and less than 250 mm—a detailed discussion of these limits is given under “Theory of Operation” (p. 5-12). The following information is displayed:

- A. **X Column.** Computed data appropriate for the external (input) beam in the XZ plane. The X plane (XZ plane) is the horizontal plane when the ModeMaster PC Scan Head is adjusted to an azimuth angle of 45°. The column labeled X is the data taken in this plane.
- B. **Y Column.** This column is computed data appropriate for the YZ plane (the vertical plane when the scan head is adjusted to an azimuth angle of 45°).
- C. **R Column.** Rad Mode. The data in this column describes the equivalent radially symmetric mode for the beam. This is the theoretically correct average-value mode for the beam, and is computed from the measured X and Y-axis values. Values are, in principle, independent of the azimuth of the X, Y data set used for the computation.

- D. **Dim.** Dimensions. This column contains the units of measurement for each data item.
- E. **M<sup>2</sup>.** The ratio of the divergence of the beam being measured to that of a theoretical diffraction limited (TEM<sub>00</sub>) beam having the same waist diameter. Theoretical TEM<sub>00</sub> beams have an M<sup>2</sup> of 1 and real laser beams will have a larger M<sup>2</sup> value. The tolerance on the M<sup>2</sup> value is  $\pm 5\%$ .
- F. **2W<sub>0</sub>.** The waist diameter of the beam as determined from knife-edge transmission measurements. Measurement of the waist diameter is affected by parameters set in the Clip Level dialog. The default parameters for the Mode-Master PC are either clip levels at 16% and 84% of full intensity, with a width factor of 2.00, or 10% and 90% clip levels, with a width factor of 1.56, both of which give a value for 2W<sub>0</sub> agreeing with the 1/e<sup>2</sup> width for TEM<sub>00</sub> beams. Measurement is based on rise or fall time of the knife-edge signals as discussed in measurement theory.
- G. **2W<sub>d</sub>.** The beam diameter at the front cut plane.
- H. **Z<sub>0</sub>.** The distance from the rear principal plane of the lens to the internal beam waist in millimeters. Positive values indicate waists to the right of the lens principal plane.
- I. **Z<sub>r</sub>.** Rayleigh range of the internal beam,  $Z_r = \pi W_0^2 / M^2 \lambda$ .
- J. The full divergence angle of the internal beam.
- K. **Astigmatism.** Difference between the waist locations of the planes (Z<sub>oy</sub> and Z<sub>ox</sub>) normalized to the Rayleigh range for the R mode (Z<sub>rR</sub>) of the internal beam.
- L. **Waist Asymmetry.** This is the ratio between the X and Y waist diameters.
- M. **Divergence Asymmetry.** This is the Aspect Ratio between the far field divergence angle of the X and Y planes.

### Data Select: Transform

Selecting Transform Data displays the Transform Data Screen shown in the figure below. The Transform data screen simultaneously displays selected beam parameters for both the internal beam and the external beam. Gamma is the factor used in computing the external beam parameters.

The value of Gamma is useful for the following reason. There are small, fixed errors in locating the internal waist which can significantly affect the accuracy of the transform to the external beam values when Gamma is large. It is recommended that when a measurement results in a Gamma in excess of 103, the instrument be moved to a new location, to generate a new focal position and reduce the value of Gamma. Minimum Gamma occurs for the instrument located one Rayleigh range of the external beam away from the external beam waist.

The screenshot shows a window titled "Transform focus results". At the top, it displays "Focal length = 212.08 mm" and "Wavelength = 632.8 nm". Below this is a table with four columns: X, Y, R, and Dim. The table contains two sets of data, one for the XZ plane and one for the YZ plane. Callout letters A through K point to various parts of the screen: A points to the title, E points to the X column header, A points to the Y column header, B points to the R column header, C points to the Dim column header, F points to the M² row, G points to the 2Wo row, H points to the Zo\* row, I points to the Gamma row, J points to the bottom of the window, and K points to the h1 row.

	X	Y	R	Dim
M <sup>2</sup>	1.05	1.06	1.03	-
2Wo	0.807	0.815	0.811	mm
Zo*	1.047	1.065	1.056	m
Gamma	28.80	29.52	29.16	-
M <sup>2</sup>	1.05	1.06	1.03	-
2Wo	0.150	0.150	0.811	mm
Zo	2495	2493	2488	cts
h1	-47.5	-47.4	-47.4	mm

The following information is displayed on the Transform Data Screen:

- A. **X Column.** Computed data appropriate for the external (input) beam in the XZ plane. The X plane (XZ plane) is the horizontal plane when the ModeMaster PC Scan Head is adjusted to an azimuth angle of 45°. The column labeled X is the data taken in this plane.
- B. **Y Column.** This column is computed data appropriate for the YZ plane (the vertical plane when the scan head is adjusted to an azimuth angle of 45°).
- C. **R Column.** Rad Mode. The data in this column describes the equivalent radially symmetric mode for the beam. This is the theoretically correct average-value mode for the beam, and is computed from the measured X and y-axis values. Values are, in principle, independent of the azimuth of the X, Y data set used for the computation.
- D. **Dim.** Dimensions. This column contains the units of measurement for each data item. Note that the units for

$Z_0$  (cts) are counts in the translation of the lens assembly during the focus scan. (Scan goes from 0 to 3212 counts.)

- E. **EXT.** External data. The three rows to the right of EXT on the screen contain best-fit constants characterizing the external (input) beam.
- F.  **$M^2$ .** The ratio of the divergence of the beam being measured to that of a theoretical diffraction limited ( $TEM_{00}$ ) beam having the same waist diameter. Theoretical  $TEM_{00}$  beams have an  $M^2$  of 1 and real laser beams will have a larger  $M^2$  value. When used within the specification limits, the ModeMaster PC lens results in negligible aberration for the internal beam. Therefore the  $M^2$  values for the internal and external beams are identical. The tolerance on the  $M^2$  value is  $\pm 5\%$ .
- G.  **$2W_0$ .** The waist diameter of the beam as determined from knife-edge transmission measurements. Measurement of the waist diameter is affected by parameters set in the Clip Level Dialog. The default parameters for the ModeMaster PC are either clip levels at 16% and 84% of full intensity, with a width factor of 2.00, or 10% and 90% clip levels, with a width factor of 1.56, both of which give a value for  $2W_0$  agreeing with the  $1/e^2$  width for  $TEM_{00}$  beams. Measurement is based on rise or fall time of the knife-edge signals as discussed in measurement theory.
- H.  $Z_0$ . The respective distances from the front and rear principal planes (H1, H2) of the ModeMaster PC lens to the external and internal beam waists. An asterisk is added to distinguish this external waist location  $Z01^*$  measured from the H1 plane, from the value  $Z01$  measured from the bezel reference plane (as appears on the External Data Screen). Note that the internal units for  $Z_0$  (cts) are counts in the translation of the lens assembly away from the start location during the focus run. One count = 0.0509 mm. The scan goes from 0 to 1606 counts, taking data on both front and back cut planes, to produce internal beam caustics covering 0 - 3212 cts.
- I. **Gamma.** Transformation factor. Multiple ModeMaster PC input lenses require the Gamma limit calculation to take into account the different lens focal lengths. There is a finite error  $\Delta x_2$  with which the factor  $x_2 = (Z_{02} - f)$  is known in  $\Gamma$  calculation,

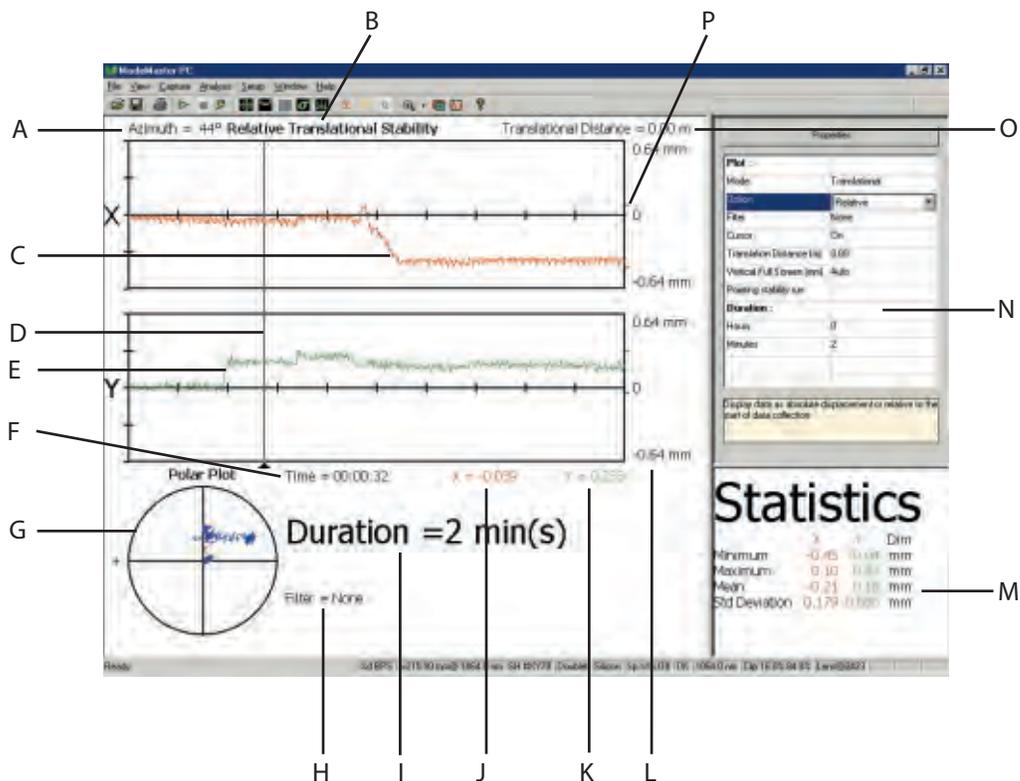
$$\Gamma = f^2 / [(Z_{02} - f)^2 + Z_{R2}^2].$$

The magnitude of the fractional error  $|\Delta\Gamma/\Gamma|$  this produces is  $(2x_2\Delta x_2/f^2)\Gamma$ . Limiting the fractional error to  $< 1\%$  then gives the Gamma limit criterion. Note that  $\Gamma_{\max}$  is largest at  $x_2 = 0$  since the slope of the  $\Gamma$  vs.  $x_2$  curve is zero and is smallest at  $Z_{02} = Z_{R2}$  since  $x_2$  is largest.

- J. **INT.** Internal data. The three rows to the right of INT on the screen contain beam parameters computed from measured beam width data for the beam inside the scan head in the ModeMaster PC Scan Head.
- K. **h1.** Location of the input principal plane H1; this is the distance from the front bezel of the scan head to H1. Negative values indicate H1 lies outside the lens tube, back towards the laser.

## Pointing Stability Screen

The Pointing Stability screen provides easy measurement of fluctuations in beam pointing. This screen includes a complete array of statistical data and a measurement cursor. All data collected can be stored to a text file. This data can be viewed in the user interface or analyzed with external programs such as Microsoft Excel. Select Pointing Stability (  ) from the View menu item or click on the icon in the Toolbar.



---

**Additional information is contained in “Section Four: Tutorial” (p. 4-1).**

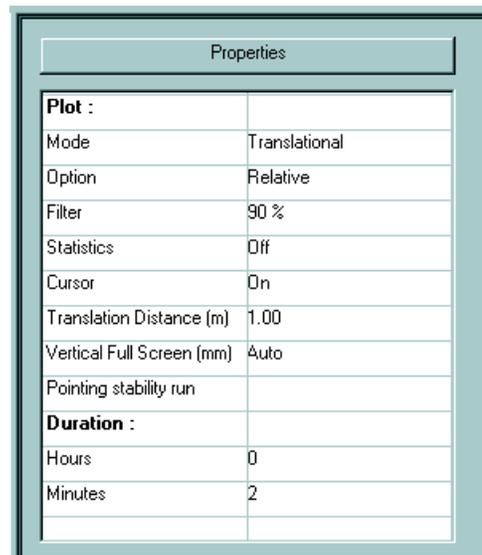
---

- A. Azimuth angle of the ModeMaster PC Scan Head at the start of the run. Angle is not updated during the stability run.
- B. Information being displayed; translational (relative or absolute), or angular (relative or absolute).
- C. Graphic display of beam angular or translational change over time in the X plane (the horizontal plane when the scan head is in the standard 45° azimuth position). Label will be mr in angular mode.
- D. Data Measurement Cursor which indicates characteristics of X and Y plane during the duration of the pointing stability run.
- E. Graphic display of beam angular or translational change over time in the Y plane (vertical plane when scan head is in 45° azimuth position). Label will be mr in angular mode.
- F. Time Values. Indicates current cursor location (hr:min:sec).
- G. Polar Plot. This is a polar view of the combined X and Y data. Note the + sign on the plot. This reference indication will plot the data as if a viewing card were placed in front of the Scan Head.
- H. Displays current filter selection.
- I. Time period data is being collected. Minimum time is two minutes. Maximum time is 24 hours.
- J. Displays X value derived from the current cursor position.
- K. Displays Y value derived from the current cursor position.
- L. The  $\pm$  vertical scale value, with zero at center. The radius of the polar plot circle is determined by the current vertical scale setting.
- M. Pointing Stability Results Panel. The minimum and maximum value correspond to the indicators shown on the strip chart. The mean value represents the average of all points collected. The standard deviation value also

represents a collection of all data. The dimension shown is a result of the user-selected mode of data display.

- N. Pointing Stability Properties Panel.
- O. Translational Distance display. This value is the reference point relative to the Scan Head. This value is the point of view reference. This value does not appear in angular mode.
- P. Min/Max indicators for current graphical plot.

## Properties Panel



The Properties Panel in the Pointing Stability Plot Screen provides point-and-click access to a variety of plot and duration functions and options. Excluding Start, all plot functions can be changed on existing data. A setting change will immediately display the data reflecting the new setting.

The following describes each of the functions available.

FUNCTION	SELECTION TYPE	DESCRIPTION
<b>Plot:</b>		
Mode	Drop-down List	Selects Angular or Translational Mode.
Option	Drop-down List	Selects Relative or Absolute stability.
Filter	Drop-down List	Selects Filter.
Cursor	Drop-down List	Toggles Cursor On or Off.
Translational Distance (m)	Numerical Input Field	Displays data relative to a new location.
Vertical Full Screen (mm)	Drop-down List	Selects Vertical Full Screen option.
Pointing Stability Run	Process	Start pointing stability run.
<b>Duration:</b>		
Hours	Increase/Decrease Control	Set stability run duration in hours.
Minutes	Increase/Decrease Control	Set stability run duration in minutes.

The following subsections further describe the commands in the order they appear within the Properties Panel on the Pointing Stability Plot Screen.

**Mode** This control option changes the pointing stability display from angular (measured in milliradians) to translational (measured in millimeters) and redraws data in new units.

**Option** This control determines the mode of data collection. The Absolute mode will collect and display data directly. The Relative mode will average the first five points collected. The average value will be utilized as a zero reference point for all subsequent data collected.

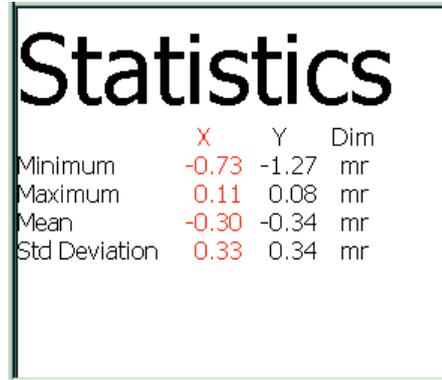
**Filter** Three levels of filtering can be selected to reduce noise and enhance sensitivity. To turn Filtering on, select the desired filter from the drop down list. The filter is an infinite impulse response filter. The Filter's historical weighting value is displayed to the right of each filter selection. Data is filtered on the fly according to the following equation.

$$\theta_i^F = W\theta_{i-1}^F - (W - 1)\theta_i$$

Where:  $\theta_i^F$  : new filtered value  
 $\theta_{i-1}^F$  : prior filtered value  
 $\theta_i$  : current data  
 $W$  : historical weight (shown on Pointing Stability Options screen)

## Results Panel

The minimum and maximum value correspond to the indicators shown on the strip chart. The mean value represents the average of all points collected. The standard deviation value also represents a collection of all data. The dimension shown is a result of the user-selected mode of data display.



	X	Y	Dim
Minimum	-0.73	-1.27	mr
Maximum	0.11	0.08	mr
Mean	-0.30	-0.34	mr
Std Deviation	0.33	0.34	mr

## Cursor

This control option activates the data measurement cursor that reflects characteristics for the X and Y plane throughout the duration of the run. Each value corresponds to the graphical data point at the current time location.

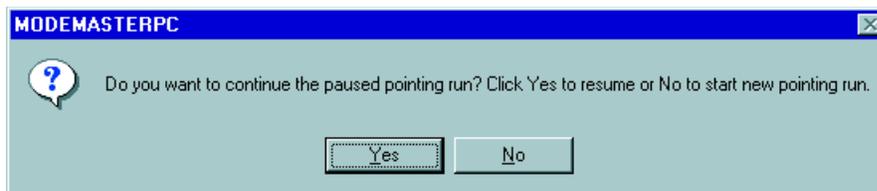
## Translational Distance (m)

This control option changes the distance from the ModeMaster PC reference plane for which translational information is displayed. When this option is selected, the value field to the right becomes available for manual numeric input. By utilizing this function, the user can locate the displacement pivot point. The location of zero displacement will correspond to the pivot point of beam displacement. For further information see “Section Four: Tutorial” (p. 4-1).

## Vertical Full Screen

This control option lets you set the rescale display on auto or manual (during or after a stability run). When auto is selected, the display is rescaled with the scale selected to be the lowest full scale that accommodates the maximum value in the data collection run. All data is redisplayed to the auto scale value. Initial range is minimum ( $\pm 0.01$  mm or mr). Range doubles each time the maximum is exceeded until the maximum range ( $\pm 655.36$  mm or mr) is reached. This option also allows manual setting of display. All data will be redisplayed at the selected display. Maximum range is  $\pm 655.36$  mm or mr. Minimum value is  $\pm 0.01$  mm or mr. When the desired range is selected, the current data will be rescaled.

## Pointing Stability Run



Clicking on Start in this control option executes the pointing stability run. The Start button resets the previous pointing stability run to zero. To stop the run, click the Stop button (  ) in the Toolbar. When the Start button is clicked again the following message will appear:

Click Yes to continue the existing paused run or No to start a new pointing run.

Pausing or freezing the run allows for collected data to be printed or saved. During a run, when the current maximum range is exceeded, the range will automatically be doubled. All data will be redisplayed at the new range each time the range changes.

---

**If the beam is interrupted during a data run, the scale will typically be redisplayed for a high maximum value (interruption of the beam is read as a large displacement). All data collected will be redisplayed at that scale. The actual data may appear to be lost when a high maximum range is used. Data is still collected correctly. By using the manual scale option and setting a low maximum range value after all data is collected, the small-scale data may be redisplayed correctly.**

---

### Hours

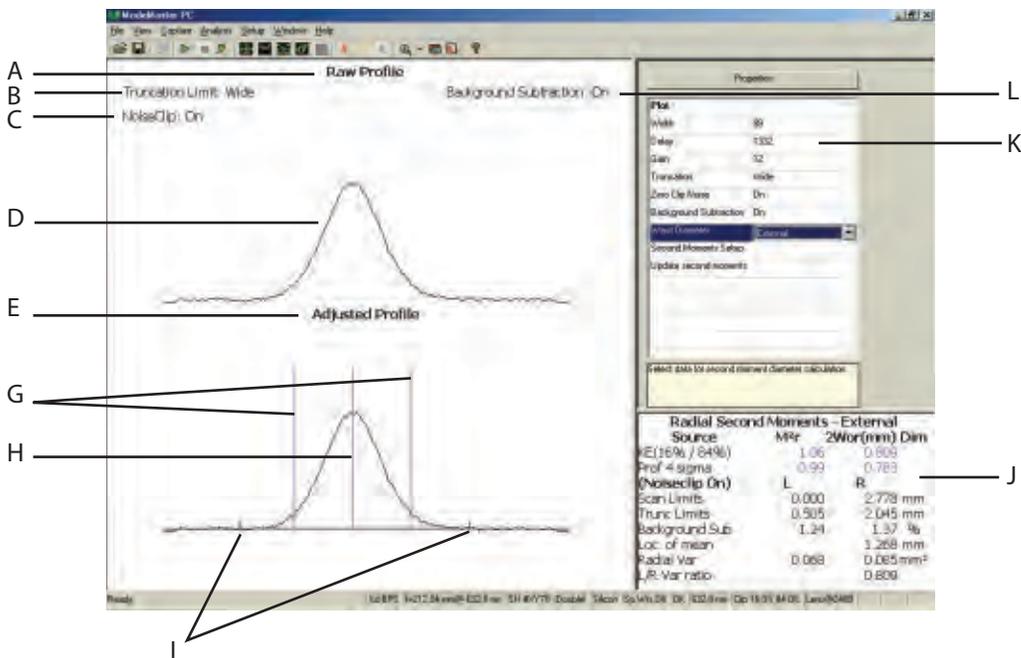
In conjunction or independent of the minutes setting, this control option allows you to manually set the duration time of the run in hours by using the buttons to increase or decrease from 1 to 23 hours.

### Minutes

In conjunction or independent of the hours setting, this control option allows you to manually set the duration time of the run in minutes by using the buttons to increase or decrease from 1 to 59 minutes. The minimum run duration is 2 minutes.

## Second Moments Screen

Measurement of the second moment diameter of a beam is accomplished by selecting Second Moments from the Tool Bar (  ) or choosing the screen from the View menu item. When the screen is first viewed, only a raw profile is displayed. The Second Moments setup process activated from the Properties Panel executes a wizard which guides you through the setup process. The functions integrated in the wizard are also available in the Properties Panel and can be used to set up the measurement in lieu of the wizard. The following Second Moments screen displays the Adjusted profile. This section discusses the functions and indicators of both the Second Moments. For further explanation of Second Moments, refer to “Optimal Use of the Second Moments Screen” (p. 5-33). “Section Four: Tutorial” (p. 4-1) contains additional setup information.



- A. Indicates that the top profile will be utilized for calculated results.
- B. Displays current Truncation limit setting in the Properties Panel.
- C. Displays current Noise Clip setting, from the Properties Panel.
- D. Plot of the Raw Profile. This profile display must be optimized and frozen for data analysis.
- E. Indicates the plot displayed is the Adjusted Profile resulting from the raw profile and the selected settings.

- F. Displays plot of Adjusted Profile points utilized for calculations.
- G. The distance between these markers, equidistant from the mean center location, corresponds to the second moment beam diameter.
- H. Indicates the calculated mean center location of the adjusted profile.
- I. Truncation point markers. These indicators correspond to the user settings.
- J. Numerical Results area for Internal or External Radial Second Moment results.
- K. Second Moments Screen Properties Panel.
- L. Displays current Background Subtraction status. This status display corresponds to the user setting.

### Knife-Edge Clip Levels Setting

The knife-edge clip levels must be set to the standard (16%/84% (2.00)) selection, and the lens position selection must be in the Radial Mode. The second moments calculations done in this screen assume a round beam (both the waist and divergence asymmetries within = -15% of unity). This requirement is appropriate to the Radial Mode lens. For more information, refer to “Clip Level/Knife-Edge Conversion Factor” (p. 3-2).

---

**Because of the large effect noise can have in the calculation of second moment diameter, the measurement set-up must be made carefully to obtain an accurate diameter measurement.**

---

Radial Second Moments - Internal				
	Source	M <sup>2</sup> r	2Wor(mm)	Dim
A	KE(16% / 84%)	1.04	0.150	C
B	Prof 4 sigma	0.98	0.146	D
E	(Noiseclip On)	L	R	
F	Scan Limits	0.000	0.512 mm	
G	Trunc Limits	0.134	0.418 mm	
H	Background Sub	1.35	1.59 %	
I	Loc. of mean		0.276 mm	
J	Radial Var	0.002	0.003mm <sup>2</sup>	
K	L/R Var ratio		0.878	

## Internal/External Radial Results Area

- A. Radial mode  $M^2$  calculated using the standard knife-edge measurements. This beam diameter was made by the ModeMaster PC. Source and will show KE followed by the clip levels used (16% and 84%).
- B. Radial mode second moment  $M^2$  calculated as:

$$M_{4\sigma}^2 = \left( \frac{2W_{4\sigma}}{2W_{KE}} \right)^2 M_{KE}^2$$

Where:

$2W_{4\sigma}$  : Second moment diameter

$2W_{KE}$  : knife-edge diameter

$M_{KE}^2$  : knife-edge  $M^2$

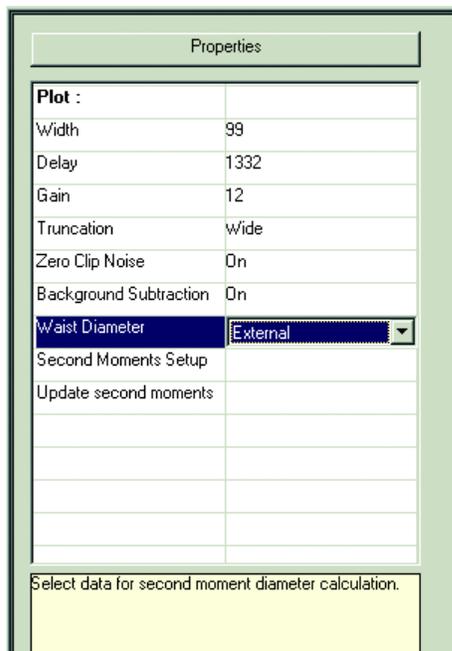
The second moment diameter is calculated as 4 times the standard deviation (s) width of the stored profile. The source of this  $M^2$  value is therefore shown in abbreviated form as “Prof 4 sigma”.

- C. Knife-edge external beam waist diameter.
- D. Second moment beam waist diameter calculated as 4 times the standard deviation width(s) of the stored profile (i.e., source is “Prof 4 sigma”).
- E. Noise Clip status. on or off.
- F. Scan Limits: Left and Right extremes of the displayed part of the pinhole scan, scaled to be appropriate for the external beam.
- G. Trunc Limits: Left and Right truncation points. Only data between these points is used in the calculation of second moment diameter.
- H. Linear background level subtracted from the stored profile. Background levels at the left and right ends of the scan are expressed as a percentage of full scale. OFF will be displayed if Background Subtraction option is off.
- I. Location of Mean: Distance of mean beam center location from left scan limit.
- J. Radial variances: From each half profile (to the left and the right of the mean), the radial variance is calculated, and the results are displayed here in units of (millimeters)<sup>2</sup>.
- K. Left/right variance ratio: This ratio (of the two values displayed in J.) should be within  $\pm 15\%$  of unity if the profile being analyzed has sufficient symmetry to be

treated as around beam, as required for valid second moment calculations.

## Properties Panel

The Properties Panel in the Second Moments Plot Screen provides point-and-click access to a variety of plot functions and options.



FUNCTION	SELECTION TYPE	DESCRIPTION
<b>Plot:</b>		
Width	Increase/Decrease Control	Adjusts the width of the profile using increase/decrease control.
Delay	Increase/Decrease Control	Adjusts the position of the profile using increase/decrease control.
Gain	Increase/Decrease Control	Adjusts the amplitude of the profile using increase/decrease control.
Truncation	Drop-down List	Selects Truncation type.
Zero Clip Noise	Drop-down List	Toggles Zero Clip noise On or Off.
Background Subtraction	Drop-down List.	Toggle Background Subtraction On or Off.
Waist Diameter	Drop-down List.	Selects data for second moment diameter calculations.
Second Moments Setup	Process	Launches Second Moments setup wizard.
Update Second Moments	Process	Updates Second Moments to use the new profile plot.

The following section describes the functions in the Second Moments Properties Panel in further detail.

**Width**

This option adjusts the width of the selected profile. Use the increase or decrease button to change the width of the plot. Same function as the Live/Alignment screen.

**Delay**

This option adjusts the delay of the selected profile. Use the increase or decrease button to change the delay of the plot. Same function as the Live/Alignment screen.

**Gain**

This option adjusts the amplitude of the selected profile. Use the increase or decrease button to change the amplitude of the plot. Same function as the Live/Alignment screen.

## Truncation

Toggles between wide truncation limits (1.9 knife edge beam diameters,  $3.8 W_{orKE}$  between limits) and narrow truncation limits (1.6 knife edge beam diameters,  $3.2 W_{orKE}$  between limits).

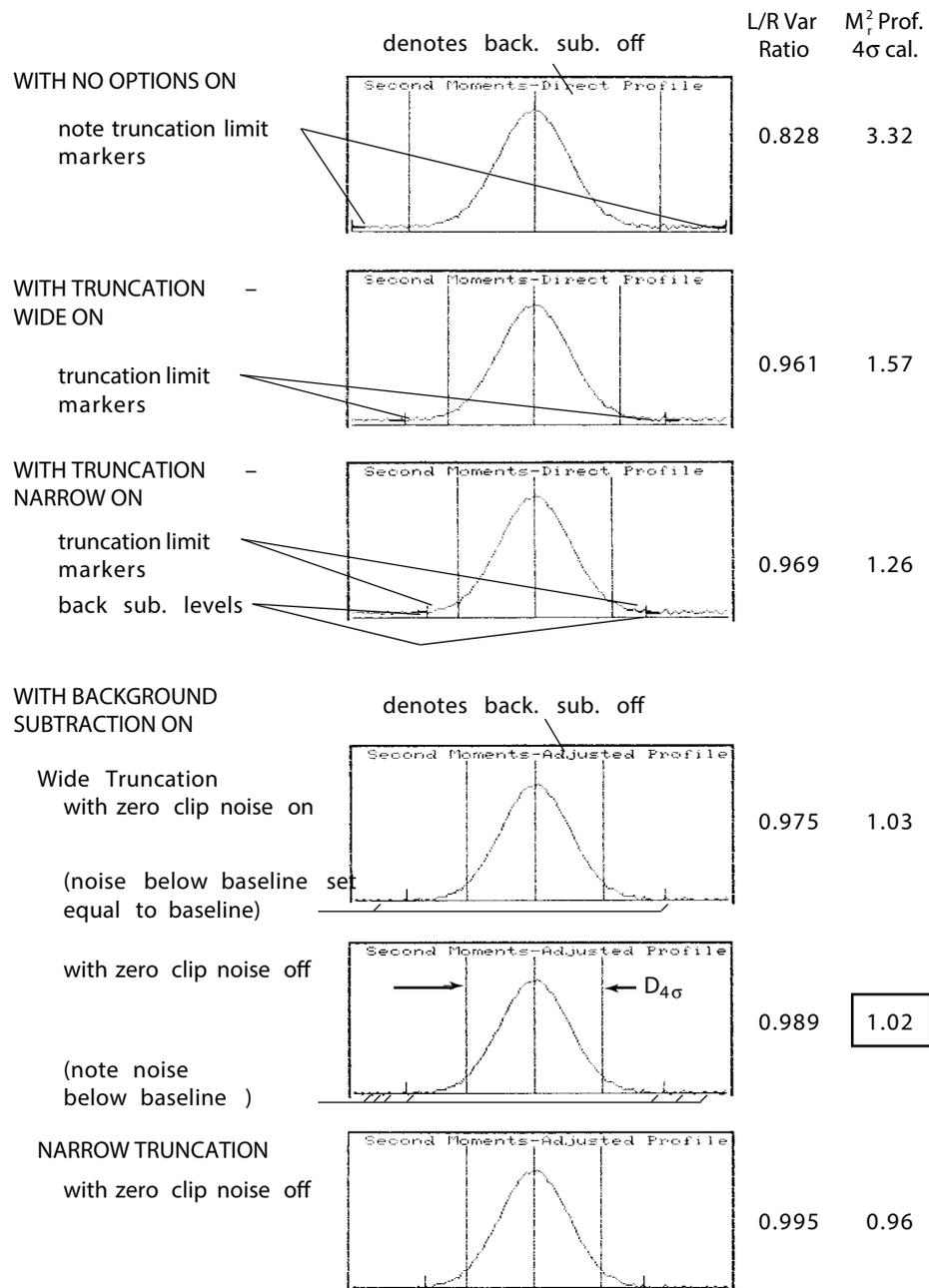


Figure 3-12. Effect of Second Moments Options

## ZeroClip Noise

This option toggles the ZeroClip noise option on and off. When on, any irradiance data with a negative value (after background subtraction) is set to zero (refer to Figure 3-12, above).

## Background Subtraction

This option toggles Background Subtraction option on and off. When Background Subtraction is on, a linear baseline is calculated for the profile and subtracted from the data before second moment calculations are done. Every profile contains 512 sample points. The left endpoint of the baseline is the average of the twenty sample points to the left of the left truncation limit. The right endpoint is the average of the twenty sample points to the right of the right truncation limit. These end points are connected in a straight line to form the baseline—refer to Figure 3-12 (p. 3-59).

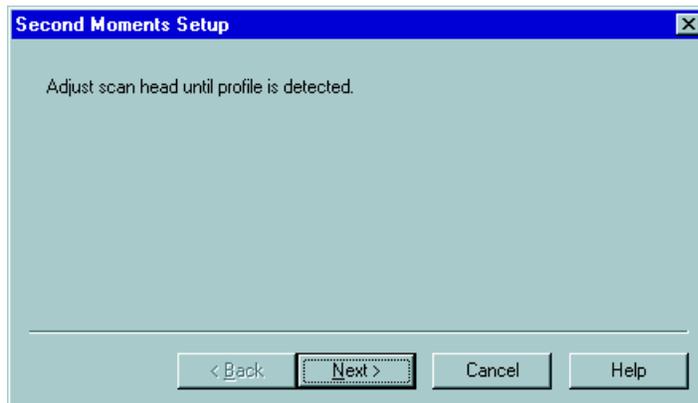
## Waist Diameter

This option selects whether the second moment diameter is calculated on the measured internal data or on the measured data transformed to the external beam (diameters scaled by the square-root of the radial mode transformation constant, gamma).



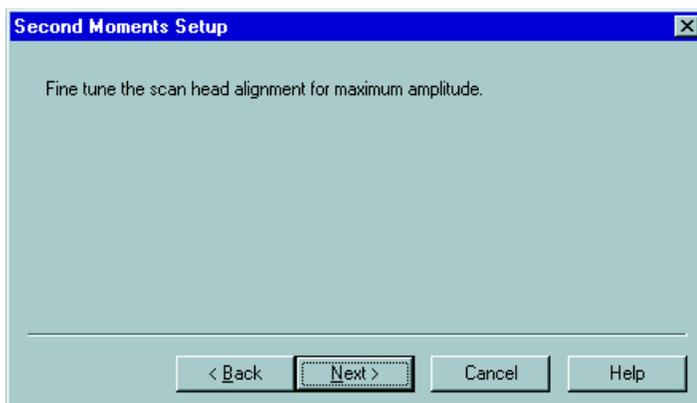
## Second Moments Setup

This option launches the second moments setup wizard. When Start is pressed, the following window appears.

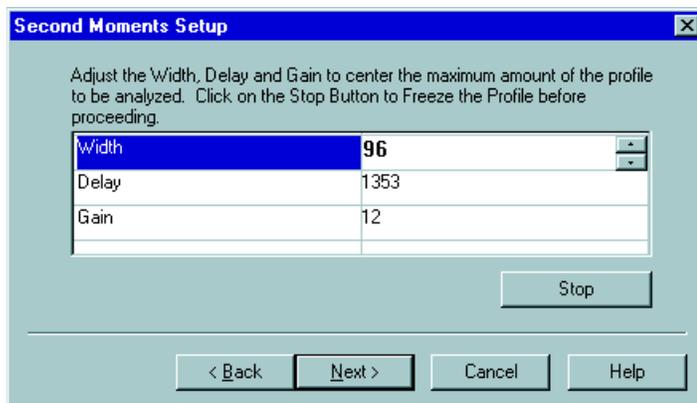


1. Click OK to confirm the currently set clip levels. If the clip levels are not set at 16% and 84% the dialog shown un “Waist Diameter,” above appears. To change clip levels go to Capture in the menu items and choose Clip Level\Knife Edge Conversion Factor.
2. Adjust the scan head until the profile is detected. This function is equivalent to the first step on the Find Pinhole Wizard

utilized on the Live / Alignment Screen. Click Next to continue.



3. Fine-tune the scan head alignment for maximum amplitude. This function is equivalent to the second step on the Find Pinhole Wizard utilized on the Live / Alignment Screen. Click Next.

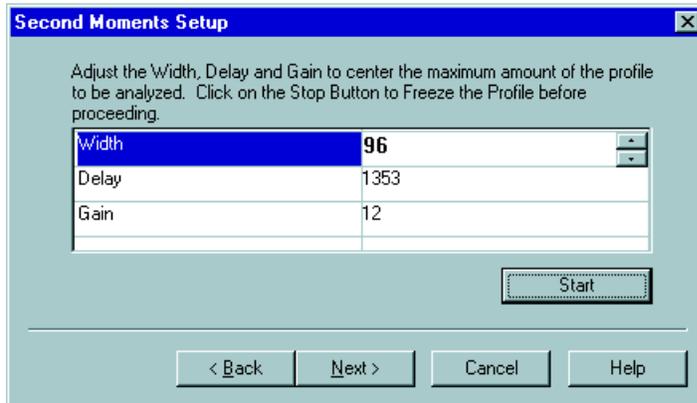


4. This step asks you to adjust the Width, Delay, and Gain to center the maximum amount of the profile to be analyzed. If you have not yet clicked the stop/pause button to freeze the profile, you can click Stop within this window before continuing. The following message if you continue without first freezing the profile by clicking Stop in the wizard or on the Tool Bar.

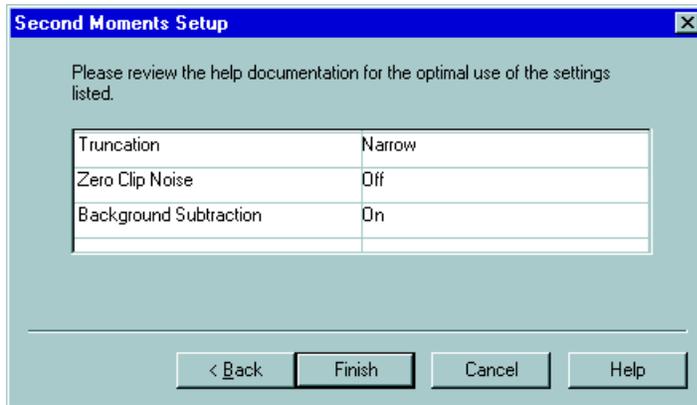


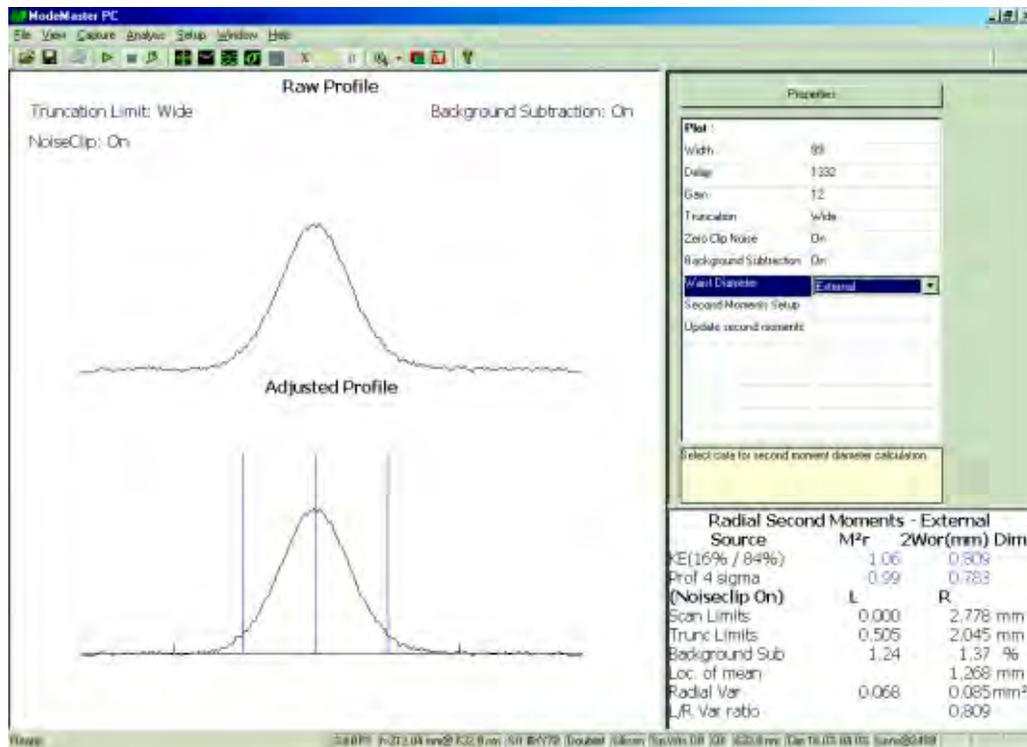
5. Click OK and then STOP to freeze the profile. Notice that the STOP button changes to START once it is pressed, allowing

you to resume the current run. The profile appearance should now be in the form that is ready for calculation. Click Next to continue.



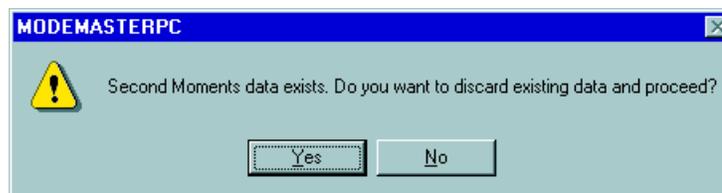
6. This step asks you to set the Truncation limits as well as allows you to turn Zero Clip Noise and Background Subtraction on or off. Refer to the preceding section for more information on optimal use of these settings, as well as “Section Five: Beam Propagation Theory” (p. 5-1). Click Finish once you have entered your settings. The lower portion of the Second Moments graphical screen displays the Adjusted Profile.





### Update Second Moments

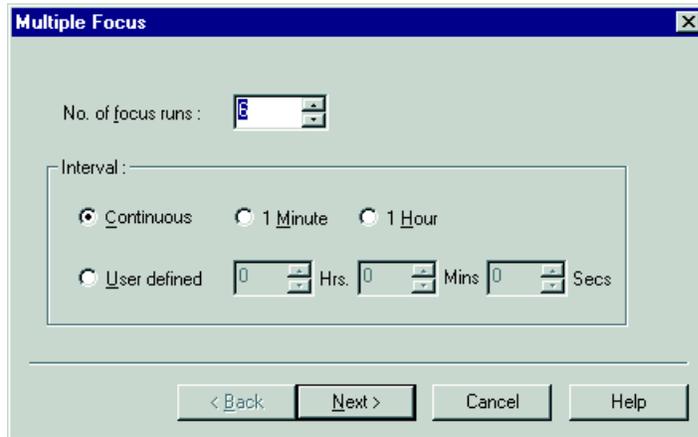
This process updates Second Moments to use the newly adjusted plot. The following message appears to confirm your request. Click Yes to continue or No to cancel. This function is available to proficient users who do not need to utilize the wizard function. Any time a frozen profile is present, new results will be calculated.



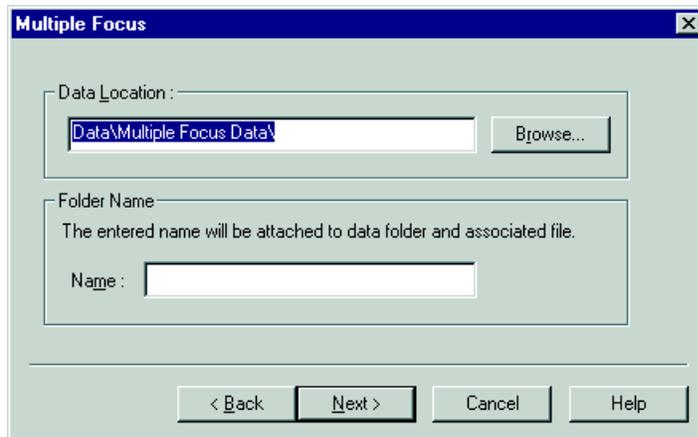
### Multiple Focus

The multiple focus process will allow you to collect multiple focus runs at a user-specified interval. The data will be stored in a user-specified folder and the statistical results will be displayed. The Min, Max, Mean, and Std Dev value will be displayed for each focus run data parameter. The multiple focus setup wizard will begin by displaying a dialog to set the number of focus runs and the interval. The dialog will default to 6 runs at a continuous interval. The

maximum number of runs is 100. Standard deviation data will not be available for less than 5 focus runs. The minimum user-specified interval will be 1 minute.

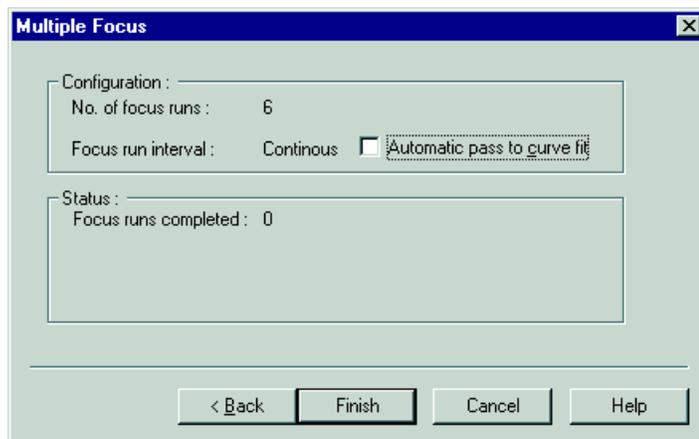


The next dialog will allow you to specify the data location and the folder name for the data file set. Each multiple focus run session will generate individual focus data files (.frd) for each focus run. The user-specified folder also contains a notes file (.txt) and the statistics file (.std). All files are in text format and can be viewed in the user interface or with external programs, such as Notepad or Microsoft Excel.

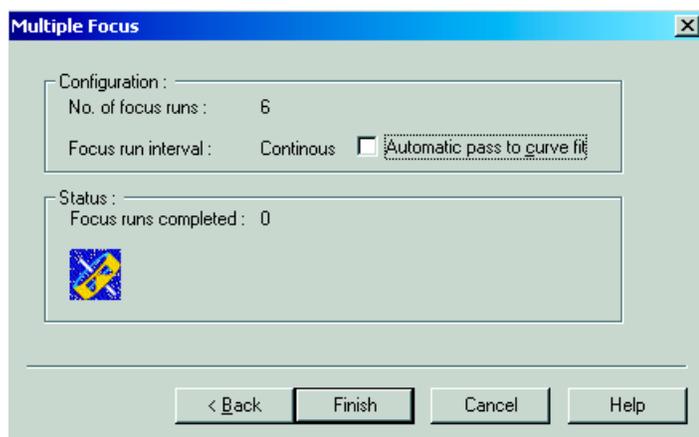


The final dialog box will confirm the number of focus runs and the interval. The check box in this dialog is utilized for automatic Pass to Curve Fit. The automatic Pass to Curve fit will be utilized with noisy lasers that normally create a multiple waist condition. When the box is checked and a Multiple Waist Condition is detected, the Focus Data will automatically be calculated and utilized in the

Statistics. Focus runs that create error conditions will not be utilized for statistical analysis. Note the number of runs from the setup and compare this value to the number focus runs in the statistics file.

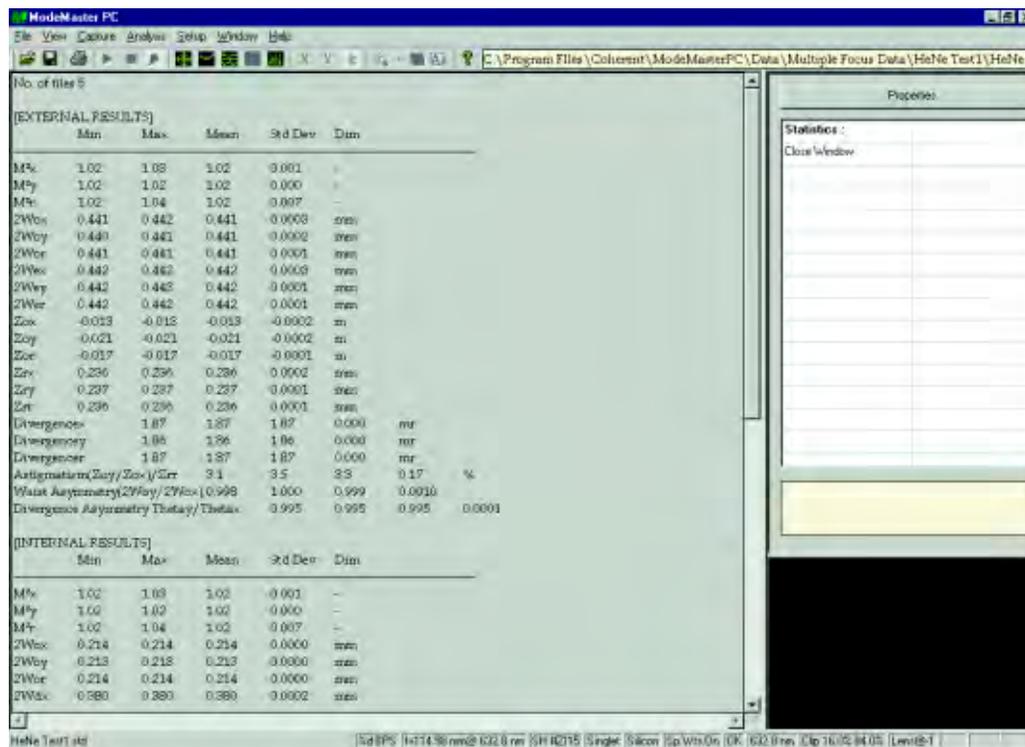
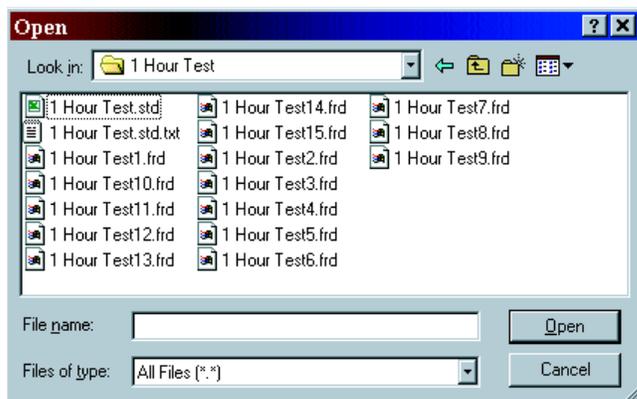


The finish button will start the multiple focus process. The stop button (  ) will interrupt the data collection process after the current focus run. A statistics file will still be created for the data currently collected.



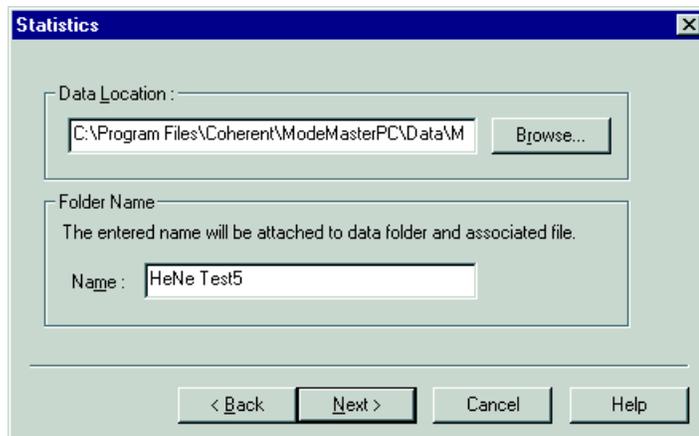
A Folder will also be created for the Statistical data collected. Each statistical folder will be located in the Multiple Focus data folder. Each folder will be labeled with the unique name that you entered during the Multiple Focus Setup process. The name 1 Hour Test is utilized for this example. The statistical folder will contain files with the same name that was assigned to the folder. The file with the .std extension will contain the statistical results. The file with the .txt extension will contain the user notes. The remaining files will have the .frd extension.

These files will contain the folder name followed by a number. These are the individual focus brun files. The number will correspond to the order in which the data was collected. Any one of these folders can be viewed in the user interface by utilizing the Open () tool bar item.

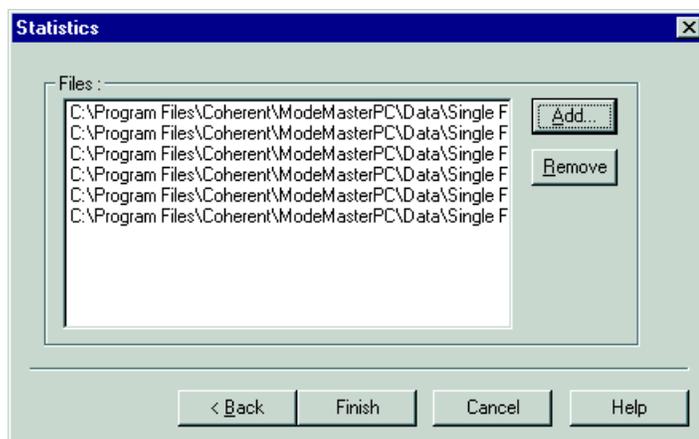


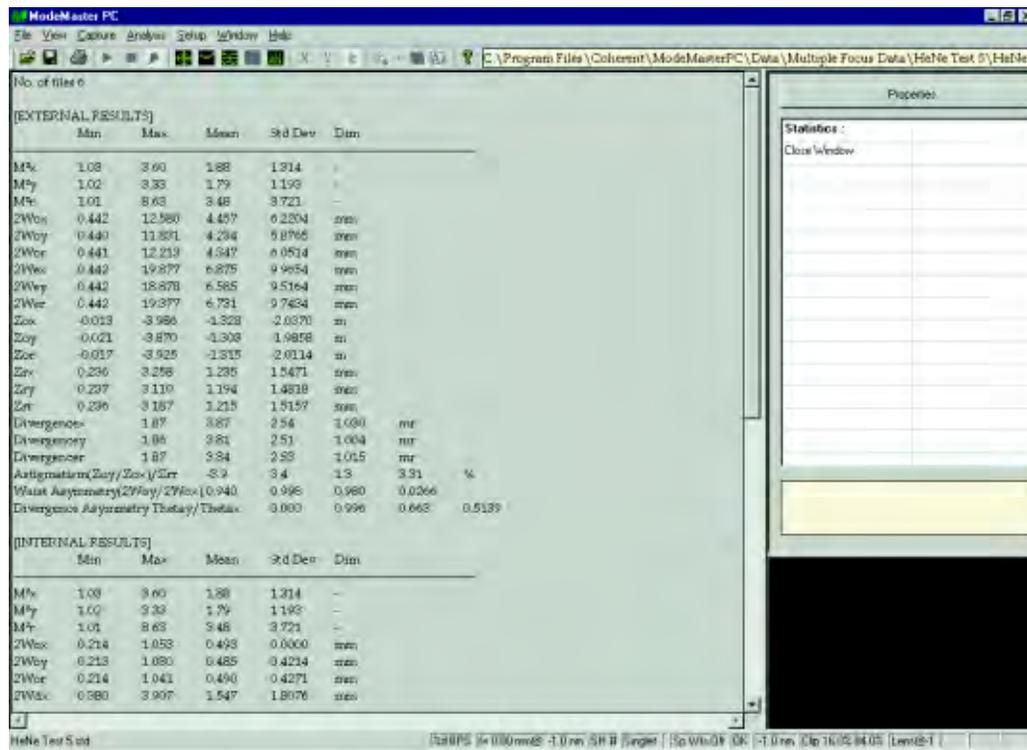
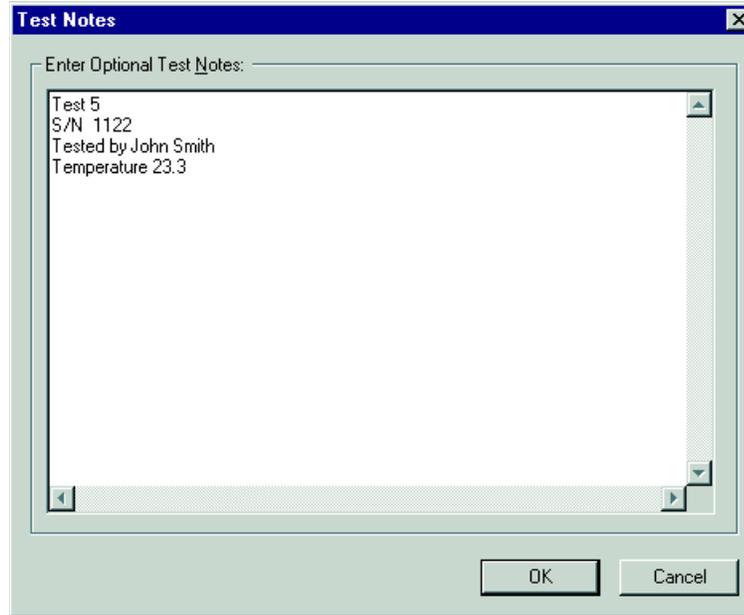
## Statistics on Existing Focus Data

Statistical Data can also be collected on existing data. By selecting Statistics from the analysis menu, a wizard will guide you through the process. The first dialog will allow you to select the path and a name for the new statistics data.



The second step will allow you to browse, select, add, and remove up to 100 Single Focus Data Files (.frd). The Finish button will allow you to enter Notes that will be contained in the new Statistics Folder. When the optional notes are complete, the new statistics file will be displayed. To return to active ModeMaster PC operation, select any Screen Button (  ).





## SECTION FOUR: TUTORIAL

This chapter applies the material discussed in Chapter 2 and 3 in the form of a Tutorial that illustrates a step-by-step scenario of a basic measurement with ModeMaster PC. Refer to the previous chapters for detailed information on the functions that are discussed. The Tutorial will cover the following:

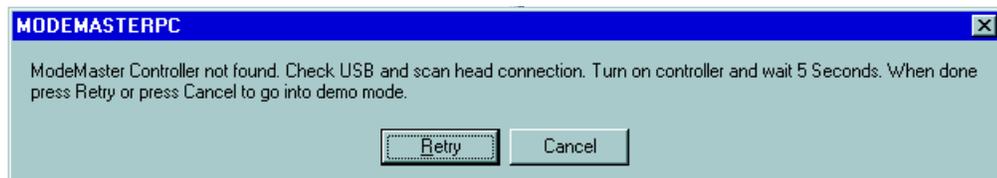
- Start-up: initialization (this page)
- Working with ModeMaster PC files (p. 4-5)
- Retrieving existing data (p. 4-6)
- Displaying existing data (p. 4-9)
- Laser Diode Collimation process (p. 4-11)
- Pointing stability run (finding the pivot) (p. 4-13)
- Second moments setup (p. 4-16)

### **Start-up: Initialization**

Launch ModeMaster PC from your Programs menu or double-click the icon on your desktop.

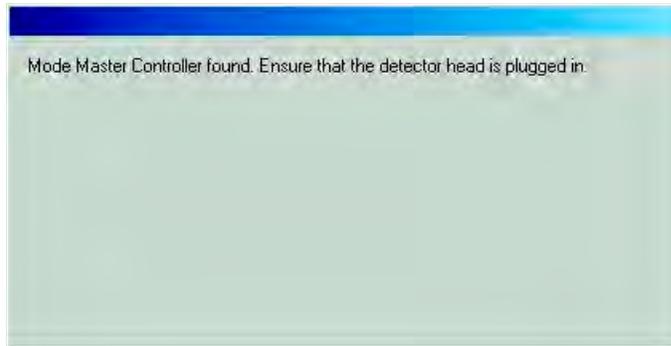
#### 1. **ModeMaster Controller not found**

If this window appears there is a problem with your connection to the controller. Make sure that all connections are secure and correctly connected. Turn on the controller, wait 5 seconds, and click retry to reattempt connection. This delay is required to establish USB communication between the host computer and the Control/Interface Console. If you wish to view file data only, click cancel and Utilize the Open () tool bar item to analyze previously saved data files.



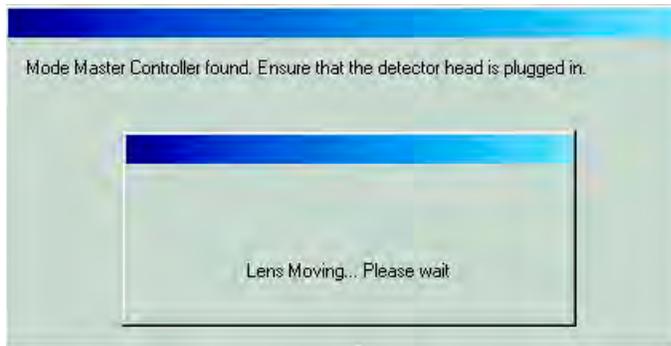
## 2. ModeMaster Controller Found

The following window will appear when the Scan Head Communication is properly established.



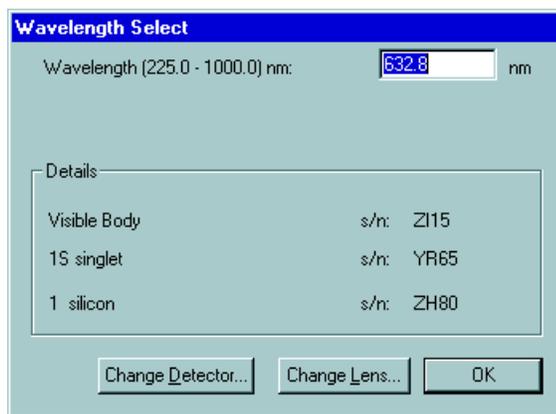
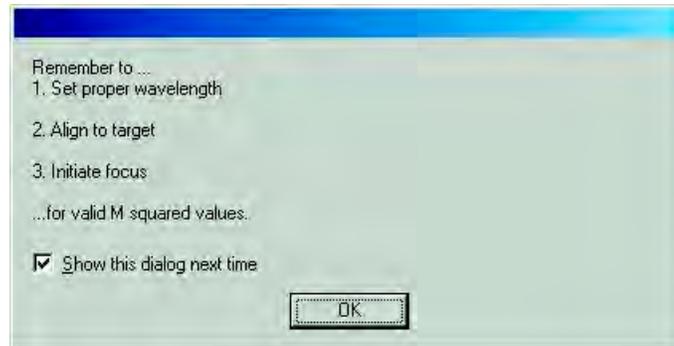
## 3. ModeMaster Initialization Screen

While the ModeMaster initializes, a chattering sound will be heard from the Scan Head. This sound is made by the initializing of the lens carriage assembly at the zero position. The sound is also an indication that the Scan Head is operating properly. The Scan Head initialization process will take approximately 30 seconds. If the Scan Head is not properly connected, a two-step wizard will appear to guide you through the Live connection process.



#### 4. ModeMaster Reminder Screen

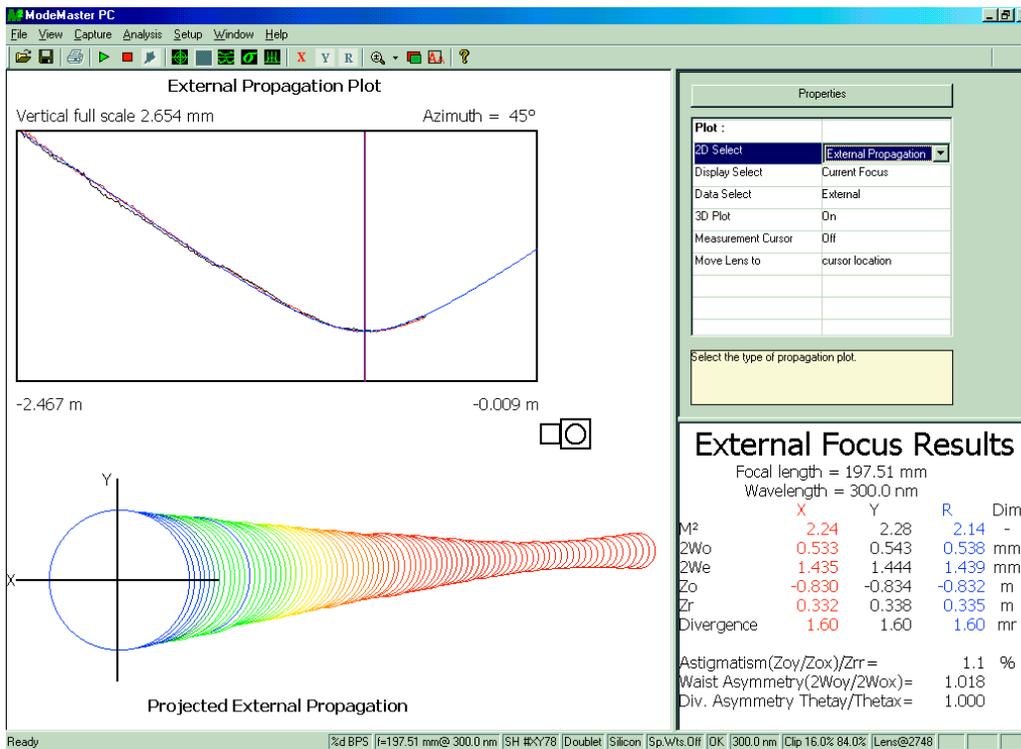
After initialization is complete, the reminder screen (shown below) will be displayed for 15 seconds. Click OK. The ModeMaster PC will automatically go to the wavelength adjustment screen.



- a. Enter a wavelength between the range specified on the screen.
- b. Click OK to view the Live/Alignment Screen. The software will also check for exact X and Y knife edge plane orientation. A 45° Azimuth value will orient the knife edges to cut the beam at the normal X (horizontal) and Y (vertical), relative to the Scan Head base. If the Scan Head is not exactly at 45°, the following message will appear. The “Remember to” and the “Azimuth” reminders can be removed from the start up process by clicking on the check box. These messages can be returned through the Setup >> Options menu item.



- c. The Live/Alignment Screen will now be shown.
- d. If you have difficulty obtaining the proper alignment condition, refer to “Alignment” (p. 1-11).
- e. Press Focus (  ) or F11 to initiate a focus run. A successful focus run is essential to display results. For more information, refer to “Focusing Error Message” (p. 3-13).
- f. A quick check of the Propagation Screen will confirm the successful focus results. The system is now ready to gather a wide variety of data unique to the ModeMaster PC. You are now in control of one of the most powerful laser measurement tools known.



## Working With ModeMaster PC Files

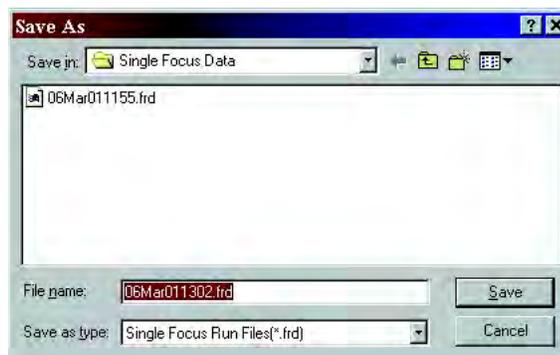
The ModeMaster PC includes the capability to Store and Retrieve data in text file format. The integrity of this process must be maintained to view data within the user interface. Do not change any information or the file extension to view results with the User Interface. Each type of file will have a unique extension. The file can have any name or location as long as the extension is not altered.

- .frd** Focus Run Data
- .prd** Profile Data
- .ptd** Pointing Stability Data
- .smd** Second Moments Data

The ModeMaster PC installation will generate properly labeled folders for each type of data. The actual data will be stored in a text format and can be viewed or analyzed with external programs, such as Microsoft Excel. For further detail, see “Section Two: Reference” (p. 2-1).

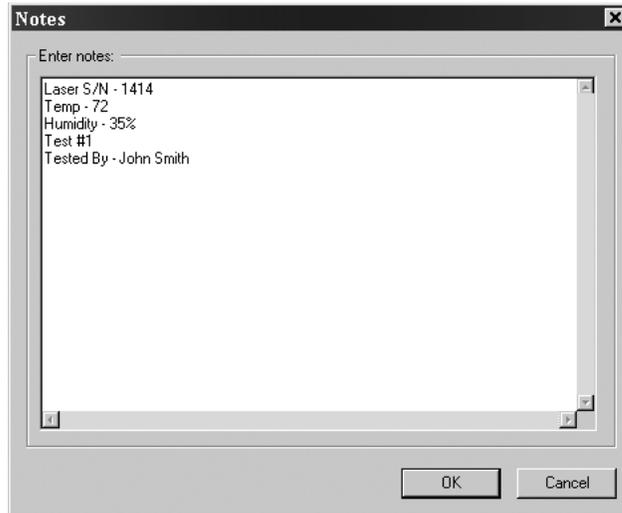
To save a ModeMaster PC data file, follow these steps.

1. Execute a Focus Run and verify the data to be saved. It is essential that you are currently viewing the data to be saved.
2. Click on the Save (  ) tool bar icon or press Ctrl+S. The screen currently viewed will dictate the data to be saved. The file extension and the appropriate file location are automatically assigned. A date and time stamp will automatically be assigned as a default file name. The file name and location can be changed by the user at any time. The proper file extension will automatically be assigned.



3. By selecting the Save button you will be presented with the opportunity to attach notes associated with the test conditions. The notes will be saved as a separate .txt file. The ModeMaster PC will automatically assign the data file name to the .txt notes file.

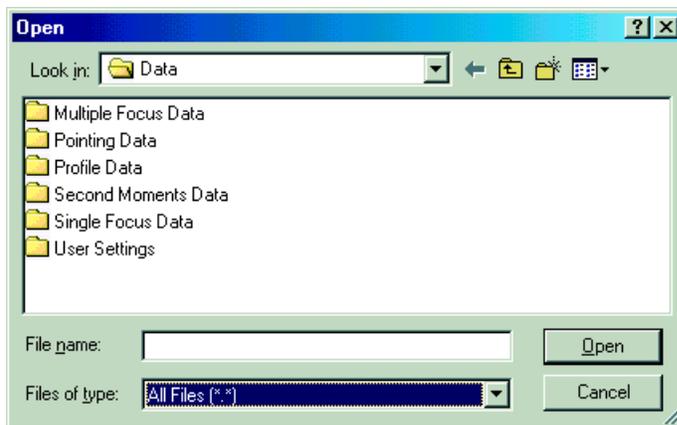
4. Click on the OK button in the notes file and finish the process. The cancel button will bypass the Notes file creation process.



## Retrieving Existing Data

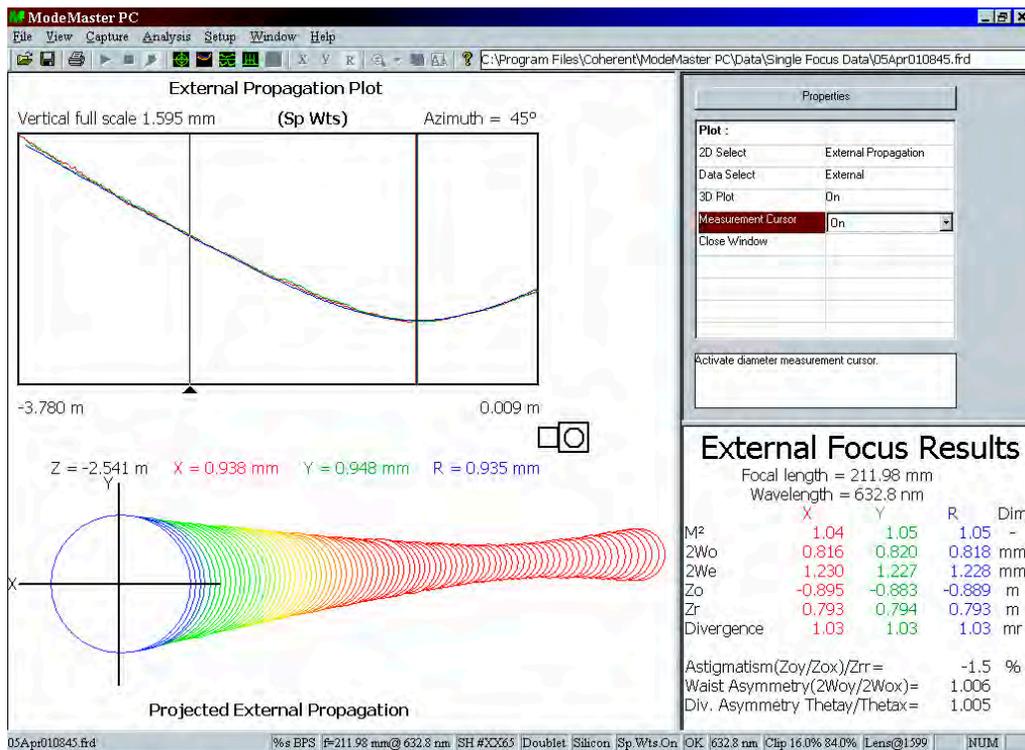
To retrieve ModeMaster PC data files, follow these steps:

1. Click on the Open (  ) tool bar icon or press Ctrl+O. The following dialog will appear:



2. The ModeMaster PC will present the following dialog. The displayed folders contain the data appropriate to the name. Double-click on the desired folder to view the file names that it contains.
3. Double-click on any individual file name and the ModeMaster PC will automatically display the desired file. A typical file

display is shown below. The file name will appear in the Status Bar and the complete path will appear adjacent to the Tool Bar.



- ModeMaster PC data files can also be viewed with applications such as Notepad or Microsoft Excel.
- The appropriate header information is attached to each ModeMaster PC data file. This header information will provide the additional information needed to analyze data externally. All ModeMaster PC data files contain the data points associated with the Plot. These points will allow you to reconstruct the

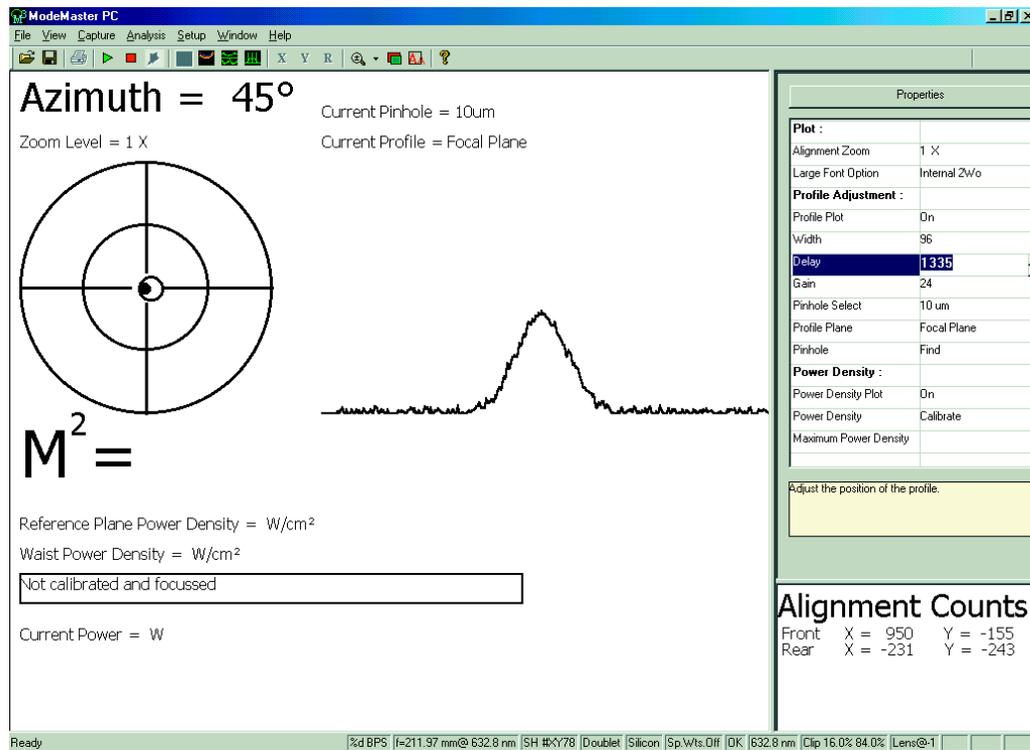
ModeMaster PC plots with the Chart Wizard in Microsoft Excel. A partial ModeMaster PC data file is shown below.

[HEADER]				
Timestamp	3/6/2001 11:56			
Head S/N	XY78			
Lens Name	2D doublet:vis ir 5 D			
Lens Type	Doublet			
Lens S/N	XB36			
Det Lambda Limits	220	1000		
Det Type	Silicon			
Det S/N	XX63			
Wavelength	632.8			
FocalLength	212.02			
Clip Level Low	16			
Clip Level High	84			
Sp.Wts.	Off			
Type	1			
Azimuth	43			
[EXTERNAL FOCUS RESULTS]				
	X	Y	R	Dim
M_	1.03	1.03	105	
2Wo	0.807	0.802	0.805	mm
2We	1.463	1.459	1.461	mm
Zo	-1.184	-1.183	-1.183	m
Zr	0.784	0.779	0.781	mm
Divergence	1.03	1.03	1.03	mr
Astigmatism(Zoy/Zox)/Zrr		-0.2	%	
Waist Asymmetry(2Woy/2Wox)			0.994	
Divergence Asymmetry Thetay/Thetax		1		

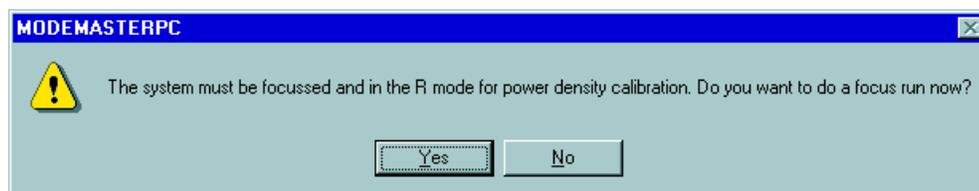
## Displaying Existing Data

### Power Density Setup

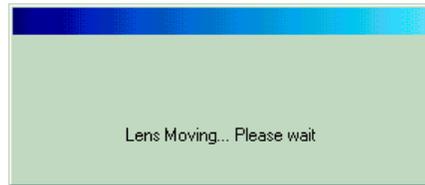
Once you have initialized the system, the  $M^2$  Alignment Screen will be the first screen to appear. At this point, however, Power Density is not yet calibrated.



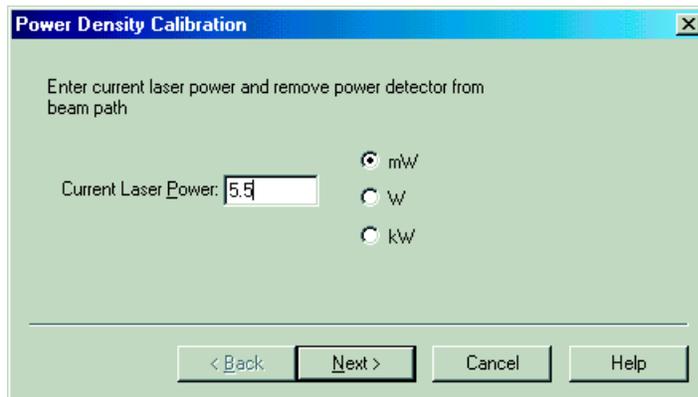
1. From the Properties Panel window, click on the Start button in the Power Density option.
2. The following window appears if you are attempting to calibrate without first focusing the system.
3. Click Yes to start a focus run.



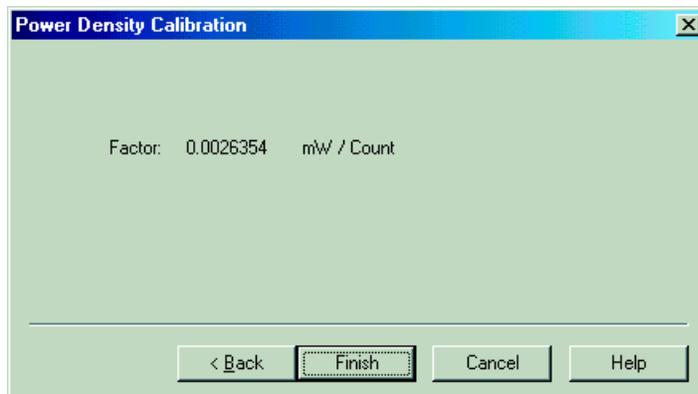
- The following window appears, indicating that the lens is moving. After the window disappears, click the Power Density Start button again.



- The following window appears. Center the proper Coherent Power detector in the beam path. When the power reading is stable, enter the value in the Power Density Calibration dialog. Verify that the proper units are selected.
- Remove the detector and click next to continue the Power Density calibration process.

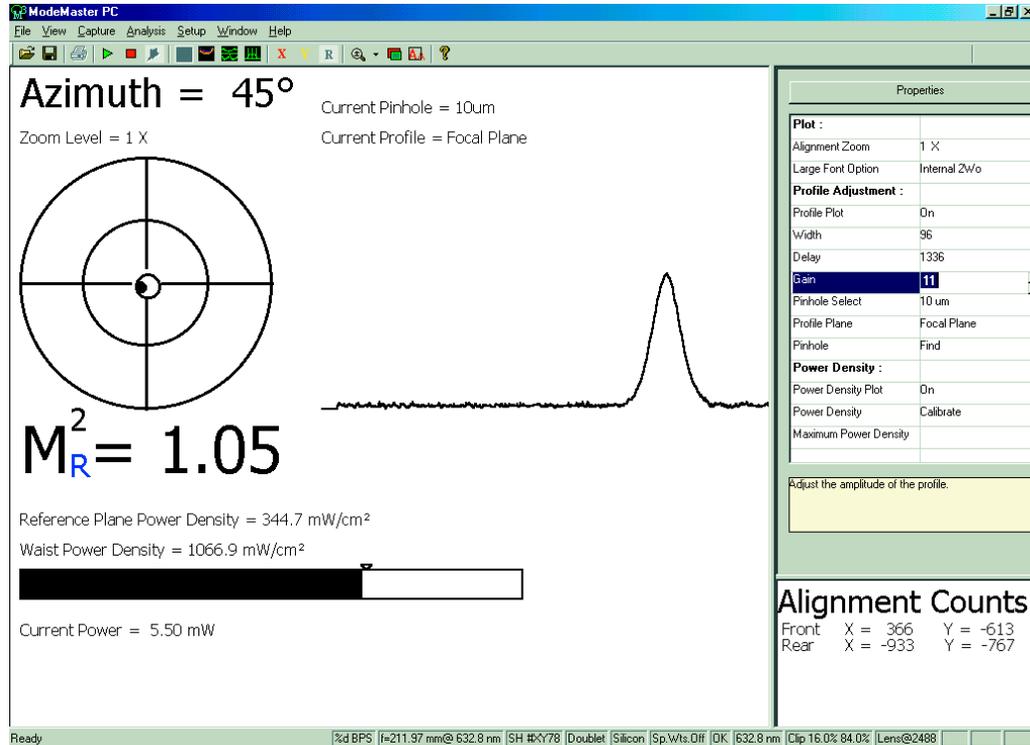


- The following screen appears displaying the factor for future reference.
- Click Finish to complete the calibration process.



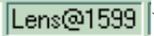
- The M2 Home Screen will now display the current calibrated Power Density. The numerical values indicate the Power Density at the beam waist and the Scan Head Front Bezel

Reference Plane. You can utilize the Maximum Indicator combined with the Audio Beep, to Optimize the Laser Power Density. The maximum laser power does not necessarily correspond to the maximum power density. The Properties Panel contains an item to reset the Maximum indicator as needed.

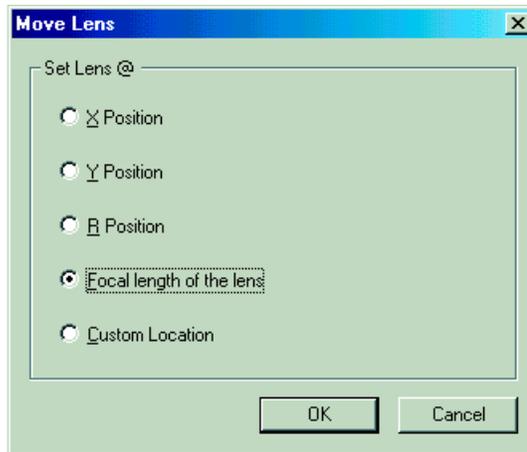


## Laser Diode Collimation Process

The ModeMaster PC is one of the most powerful and easy to use Laser Diode collimation tools available. Based on the current wavelength setting, ModeMaster PC knows the exact Scan Head Lens focal length. The Scan Head Stepper Motor has the ability to locate the lens principle plane **exactly one focal length** from the rear knife edge cut plane. By utilizing the Live Large Font () tool bar button and selecting the 2Wi value, the collimation process is ready to begin.

1. Double-click the Lens Position panel () on the status bar, located at the bottom right-hand corner of the screen. The following dialog will be displayed.

2. Select the focal length of the lens radio button.



3. The OK button will locate the principle plane of the Scan Head Lens at exactly one focal length from the rear knife edge cut plane.



**ModeMaster PC**

File View Capture Analysis Setup Window Help

Azimuth = 45° Zoom Level = 1 X

Int 2Wi

X - 0.355 mm

Y - 0.370 mm

Properties	
<b>Plot :</b>	
Alignment Zoom	1 X
Large Font Option	Internal 2Wi
<b>Profile Adjustment :</b>	
Profile Plot	Off
Width	96
Delay	1353
Gain	12
Pinhole Select	10 um
Profile Plane	Focal Plane
Pinhole	Find
<b>Power Density :</b>	
Power Density Plot	Off
Power Density	Calibrate
Maximum Power Density	

Alignment Counts		
	X	Y
Front	-852	-460
Rear	1736	-917

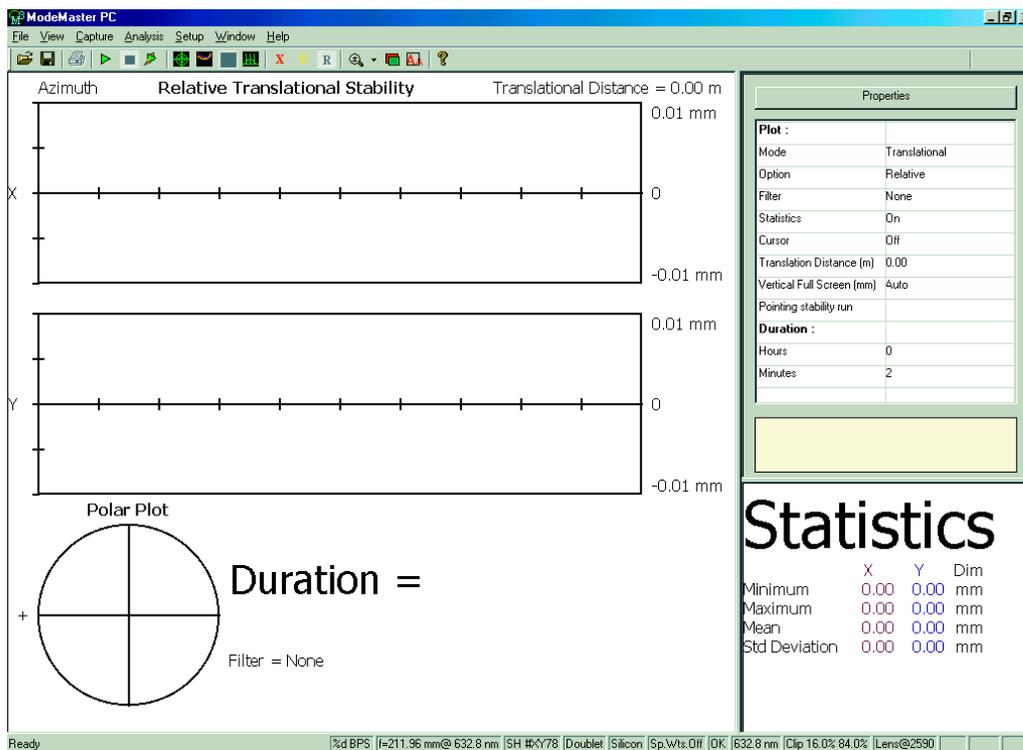
Ready | %d BPS | f=212.20 mm@ 632.8 nm | SH #K78 | Doublet | Silicon | Sp.Wts: Off | OK | 632.8 nm | Clip 16.0% 84.0% | Lens@-1

- The 2Wi display will provide three digits of precision. A minimum value of 2Wi will correspond to optimum collimation.

## Pointing Stability Run (Finding the Pivot)

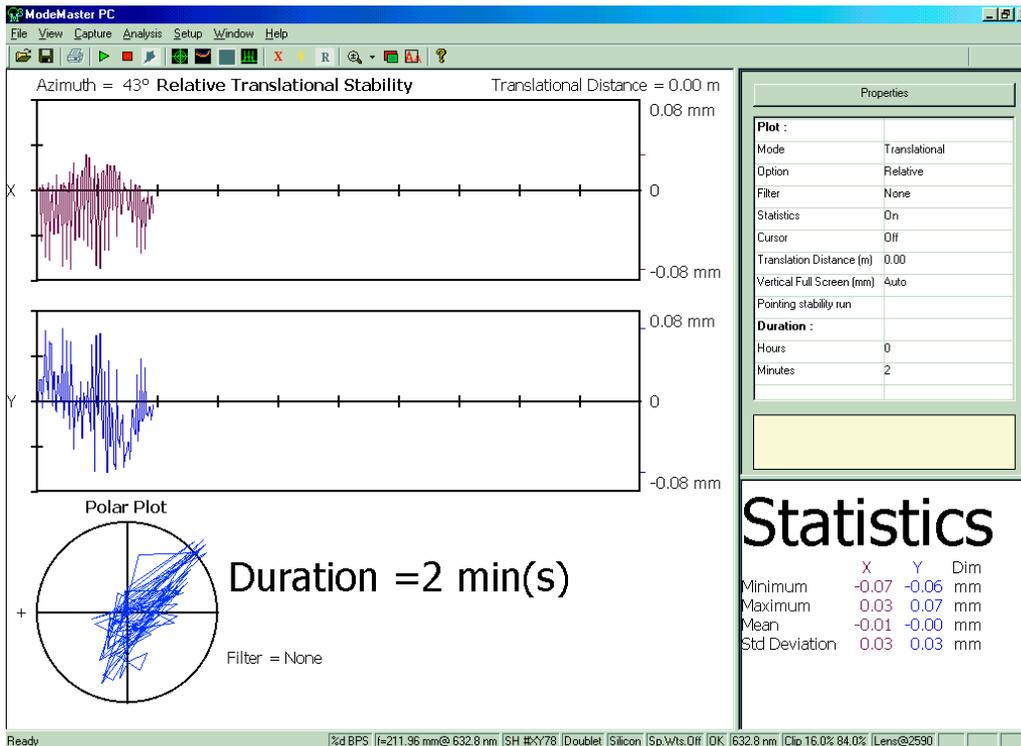
The ModeMaster PC Pointing Stability Screen provides the unique ability to find the source of a pointing error. Many optical applications require a stable beam pointing requirement. After setting up the optical delivery system, an error in pointing is detected. This error could be the result of thermal effects, mechanical mounting, etc. Standard methods of finding the source of the error can be extremely tedious and time consuming. The ModeMaster PC can accomplish this task in a couple of minutes. The only tools required are a ModeMaster PC and a meter stick.

- Click on the Pointing Stability Screen tool bar button (  ). In the Properties Panel, choose the following settings. For this case, a 2-minute run has been chosen. If you are dealing with a thermal situation or any long term transient, you may want to set the run for a longer duration. If noise is an issue, select the filter. The filter can be applied before, during, or after the run.

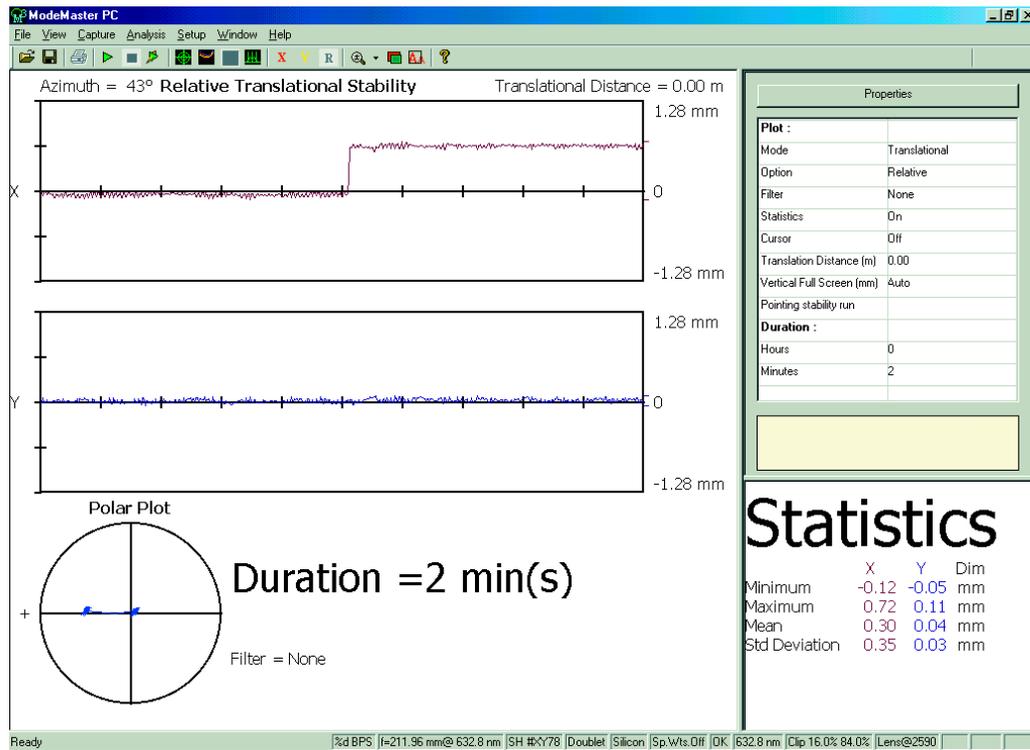


Properties	
<b>Plot :</b>	
Mode	Translational
Option	Relative
Filter	None
Statistics	On
Cursor	Off
Translation Distance (m)	0.00
Vertical Full Screen (mm)	Auto
Pointing stability run	
<b>Duration :</b>	
Hours	0
Minutes	2

- Click on the Resume Live Capture (  ) button in the toolbar or F5. The ModeMaster PC will begin to plot the data from left to right. With the scale set to auto, the ModeMaster PC will display any changes in pointing on the most sensitive scale available. Note the .08mm scale value.

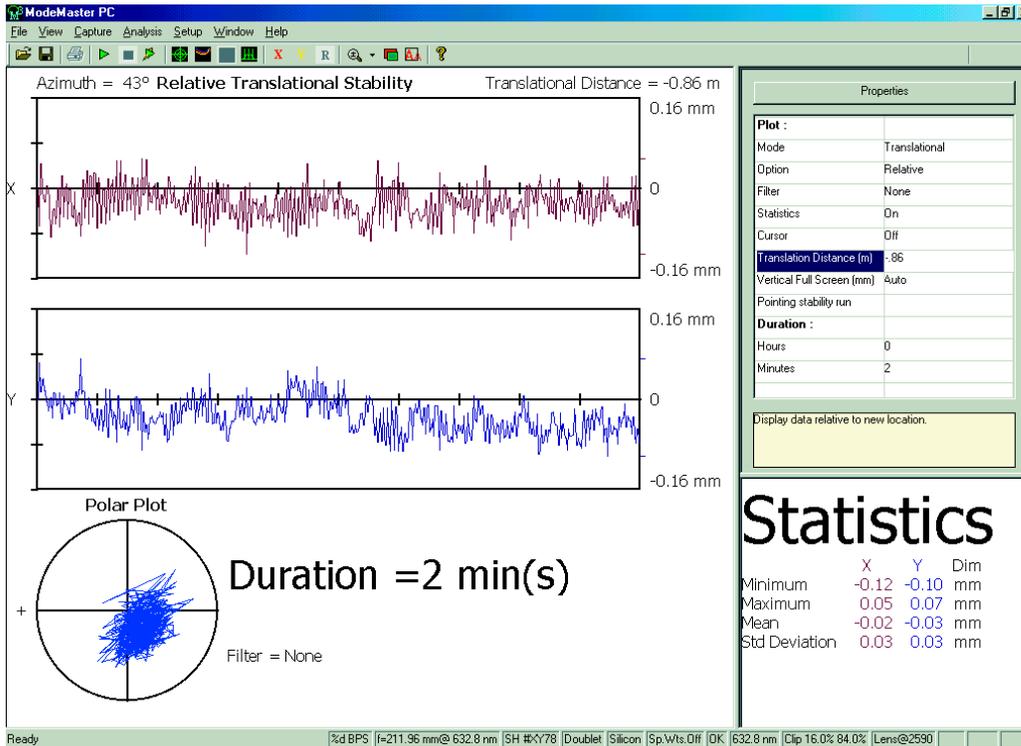


- For demonstration purposes, a weak, negative lens has been placed 0.86 meters from the Scan Head front bezel (reference position). During the course of the two-minute run, the beam was displayed slightly by shifting the lens. The following figure shows the displacement that occurred on the X axis only. The separate X and Y data can also give clues as to the type of problem that may be encountered.



- Once the data has been collected, you can now find the source of your displacement. By measuring the distance from the Scan Head Front Bezel to each optical element, you can now find the source. By utilizing the Translation Distance selection, enter the distance to each element as a negative number. If the offending plot goes to zero or close to zero, you have found the offending element. If the plot does not indicate a near zero displacement, check the next element.
- A distance of -0.86 meters was entered and the value is reflected above the right-hand corner of the X plot (Translational Distance = -0.86 m). The X plot now indicates a near-zero displacement and the situation can be resolved. After a change is made, the same procedure can be performed to verify the solution.

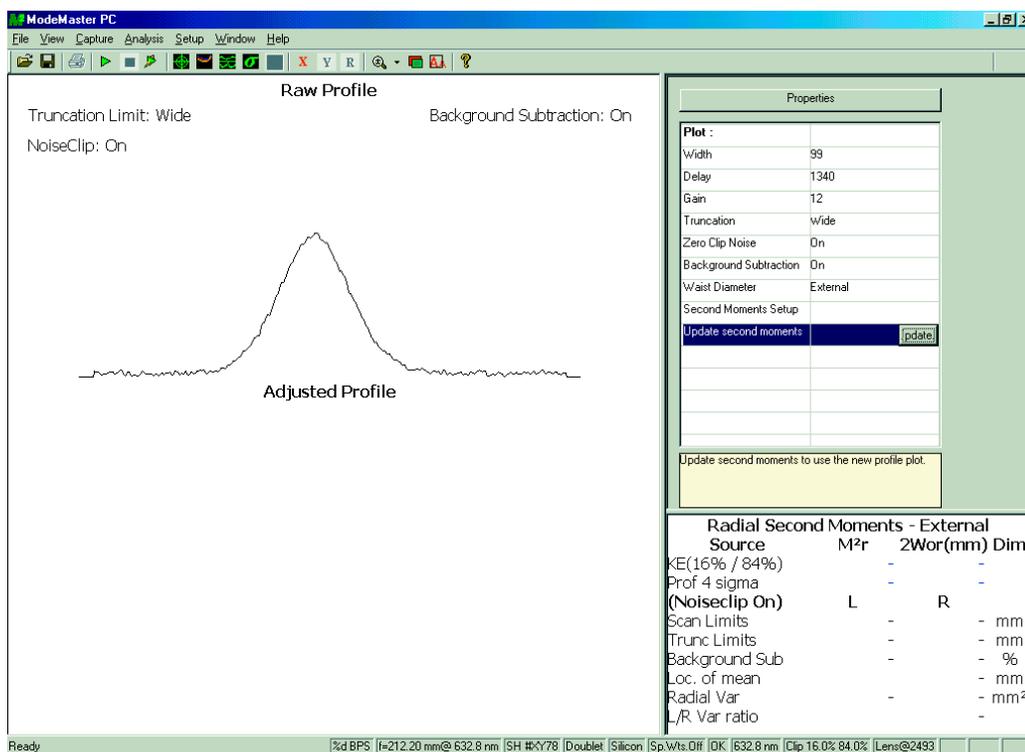
- The Pointing Stability Data can be saved by selecting the Save Button (  ) in the toolbar.



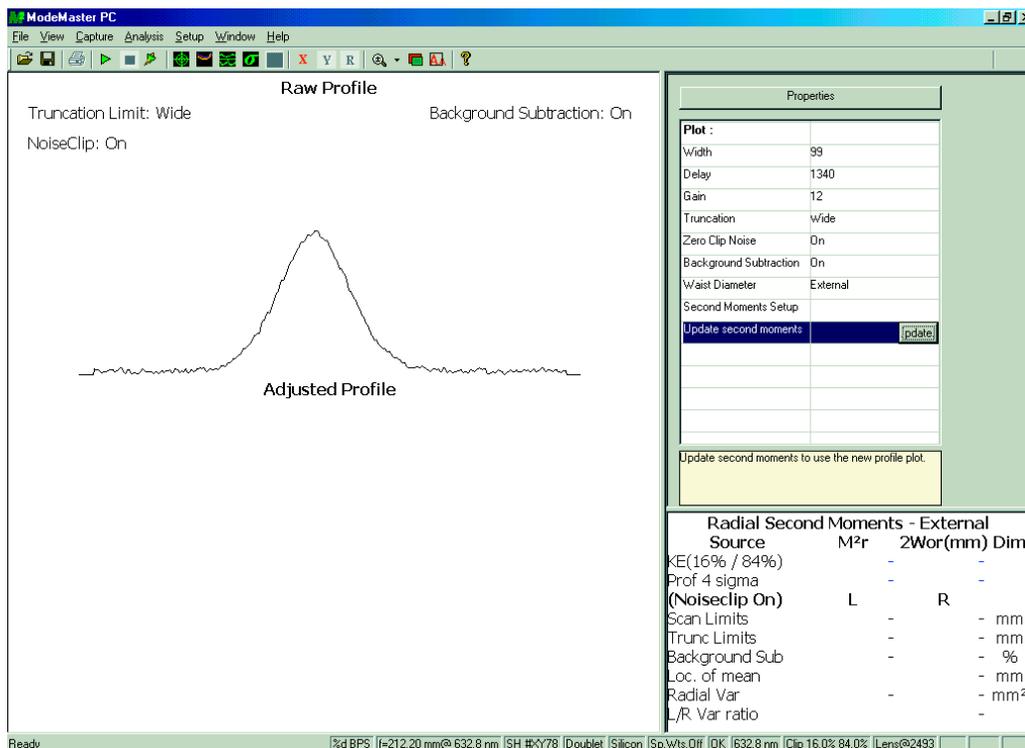
## Second Moments Setup

- Click the Second Moments icon in the Toolbar. The following illustrates how to set up Second Moments. The Second Moments Setup Wizard will guide you through the process, step-by-step. As you become proficient, steps can be done with the Properties Panel.
- Adjust the Scan Head alignment to optimize the raw profile shown at the top of the screen.
- Utilize the Width, Gain, and Delay Properties Panel controls. The ability to analyze the profile accurately is dependent upon the user setup. The Proper Raw Profile setup process will consist of the following:
  - Maximize the profile amplitude utilizing the Gain Control. The profile should maintain maximum amplitude without clipping the top.
  - Maximize the width of the profile with the Width Control. It is essential to maintain a similar amount of baseline as shown below. The calculation requires a zero reference.
  - Center the profile with the Delay Control.

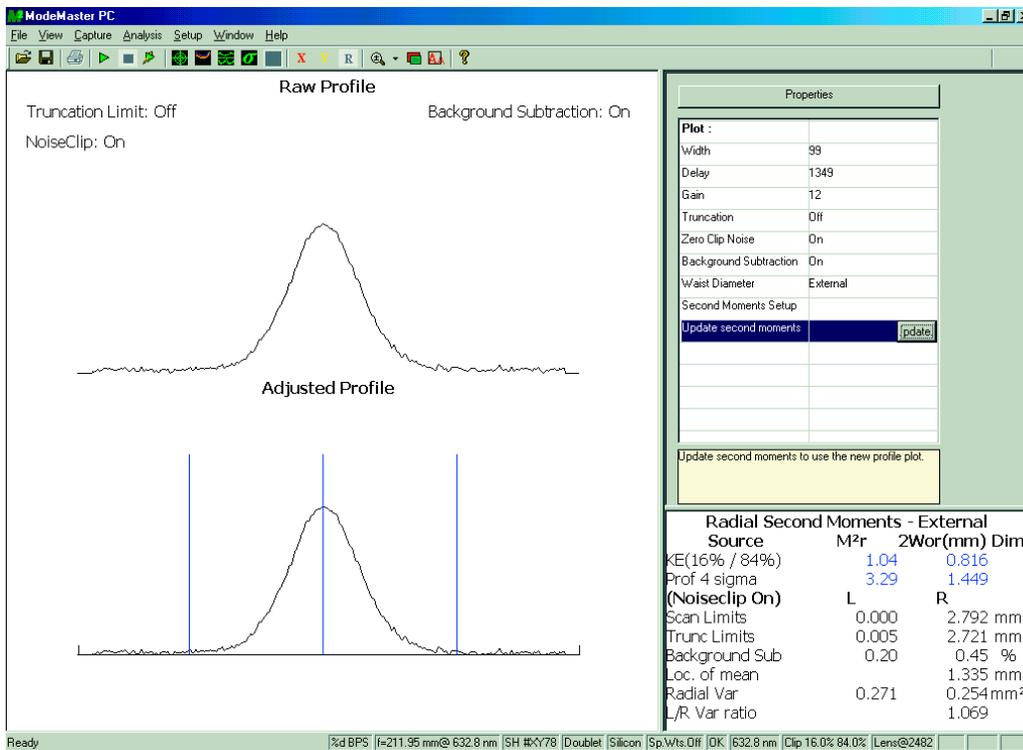
- d. Click the Pause button (  ) in the Toolbar or press F12.



4. When the Profile is frozen, the analysis process can be conducted. Press the Update Second Moments Button to display the Adjusted Profile and the associated results.

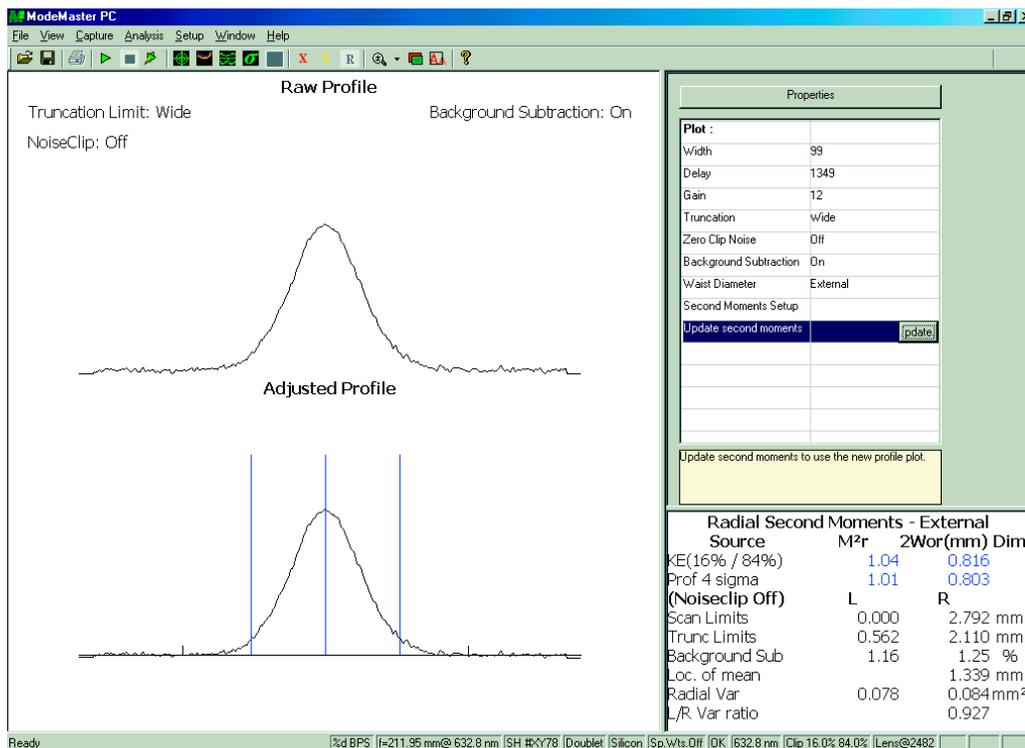


5. By leaving the Raw Profile frozen on the screen, the effect of various setup parameters can be analyzed. Simply change a parameter setting and click on the Update Second Moments Button. This process is available for the Truncation, Zero Clip Noise, and Background Subtraction settings.
6. The Truncation markers are shown as small tick marks at the profile baseline. The Truncation sets the window for analysis. Any data outside the markers will not be analyzed. The Wide Truncation setting corresponds to 1.9 Knife Edge Diameters and the Narrow Corresponds to 1.6 Knife Edge Diameters. The screen below shows the data effect associated with turning the Truncation Limits Off. As you can see, the  $M^2$  (Prof 4 sigma) value increased dramatically.



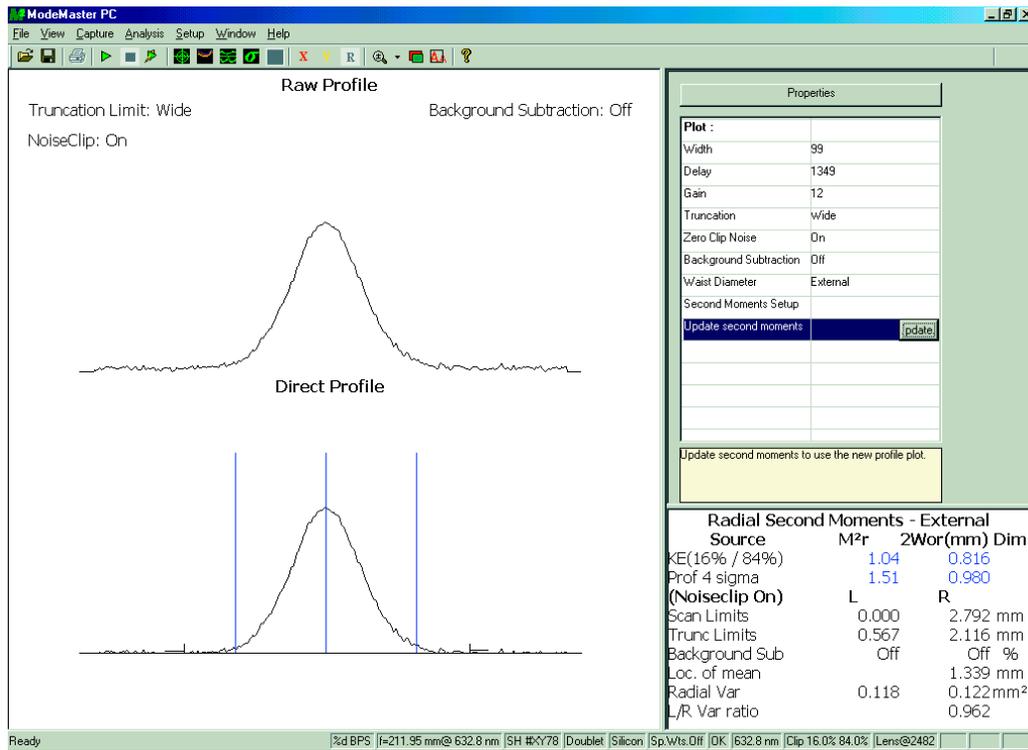
7. The Zero Noise Clip will analyze the data and set any negative value to zero. This setting will keep the undesired noise from effecting the calculation. The effect of turning the Zero Clip

Noise off and returning the Truncation setting to Wide is shown below.



- The Linear Background Subtraction will calculate a linear baseline for the profile and subtract it from the data before calculation. The effect of Background subtraction is shown below with the Zero Noise Clip On and the Truncation set at Wide.

- The Second Moments data and profiles can be saved by selecting the Save Button (  ) in the tool bar.



## SECTION FIVE: BEAM PROPAGATION THEORY

In this section:

- Overview (this page)
- Introduction (this page)
- A theory of real-beam propagation (p. 5-2)
- Useful equations (p. 5-6)
- Beam measurements (p. 5-7)
- Knife-edge diameter measurements (p. 5-9)
- Theory of operation (p. 5-12)
- Optimal use of the second moments screen (p. 5-33)
- Conversion between beam diameter measurement methods (p. 5-49)

### **Overview**

Beam waist size, waist location, far-field divergence angle, and beam axis location and angle are the most basic and fundamental parameters describing the propagation of real laser beams. This information is useful in the engineering development of lasers and beam delivery systems, and provides a meaningful way to monitor, compare, and control quality both in the manufacture and in the application of laser devices. The  $M^2$  parameter, derived from the product of waist size and divergence angle, measures how closely a beam approaches the theoretical perfection represented by a gaussian,  $TEM_{00}$ , beam. This times-diffraction-limit number is useful both because it can be compared with its universal absolute minimum value of unity, and because it does not change throughout any aberration-free optical system. This latter property can be used, for example, to detect the presence of an aberrating optical component by finding a higher  $M^2$  value for the beam after transmission through that element.

### **Introduction**

A beam propagation theory that characterizes the location and width of intensity distributions should require only information that is available from intensity and power measurements. For example, in the interest of expedient measurements, information about phase or phase distortion of the component waves making up the beam

should not be needed. The theory should be unambiguous about what constitutes the central axis of the beam and about what constitutes the “width” of an intensity distribution. The latter will be especially helpful since beams, unlike the apertures through which they pass, do not lend themselves to width measurements of the kind that can be made with calipers and micrometers.

## A Theory of Real-beam Propagation

A theory proposed by Prof. A. E. Siegman and only recently published<sup>1</sup> appears to succeed against all these requirements. He shows that if one defines the axis of a paraxial beam of light at any plane, by the mean location,  $(\bar{x}, \bar{y})$  of the (normalized) intensity distribution,  $I(x, y)$  and the mean angular orientation,  $(\bar{\theta}_x, \bar{\theta}_y)$ , where

$$\bar{x} = \int x I(x, y) dx dy \quad (1)$$

$$\bar{\theta}_x = \int \theta_x I(\theta_x, \theta_y) d\theta_x d\theta_y \quad (2)$$

(for the x-plane, and by analogy for the y-plane) then the locus of such centers for a beam in free space is a straight line. This rigorously-defined line is then a suitable and locatable propagation axis for the beam. While this result may seem obvious and trivial, it is not. The center of a real, not necessarily symmetrical, beam would generally be, except for Siegman’s work, ambiguous and/or difficult to locate.

The theory also shows that beam width and divergence angle can be unambiguously defined and measured as the standard deviations (again for just the x-plane)  $\sigma_x$  and  $\sigma_{\theta_x}$ , rigorously defined in statistical analysis as

$$\sigma_x^2 = \int (x - \bar{x})^2 I(x, y) dx dy \quad (3)$$

$$\sigma_{\theta_x}^2 = \int (\theta_x - \bar{\theta}_x)^2 I(\theta_x, \theta_y) d\theta_x d\theta_y \quad (4)$$

Converting these results to full width,  $2W$ , and full divergence angle,  $\Theta$ , equivalent to what would be measured between  $1/e^2$  levels for a perfect gaussian beam requires multiplication by 4.

$$2W = 4\sigma \quad (5)$$

$$\Theta = 4\sigma_\theta$$

---

1. A. E. Siegman, M. W. Sasnett, T. F. Johnston, “Choice of clip levels for beam width measurements using knife-edge techniques,” IEEE Journal of Quantum Electronics, Vol. 27, pp. 1098-1104, April 1991

As Siegman shows, it follows from (3), (4), (5) and the Fourier transform relationship linking  $I(x, y)$  to  $I(\theta_x, \theta_y)$  that beam width varies along the propagation axis,  $z$ , according to

$$(2W)^2 = (2W_0)^2 + \Theta^2 (z - z_0)^2 \quad (6)$$

where  $2W_0$  is the width of the beam at its narrowest place, called the waist and located at  $z = z_0$ .

It should be noted that the derivation of (6) is perfectly general for any paraxial beam and is not based on Laguerre-gaussian or Hermite-gaussian field distributions. So it is comforting to realize that it reduces to the same propagation equation familiar from gaussian beam theory. It is important to note that the perfection represented conceptually as a gaussian beam can only be approached, but never actually attained. This is because any real beam source will have at least a finite aperture through which the beam is emitted that will truncate the lateral extent of the distribution. There are other likely detractors from perfection that will cause the wave fronts to be less than perfectly spherical. Approaching  $M^2 = 1$  can be thought of as analogous to the attempt to reach an absolute temperature of zero Kelvin.

From the same analysis leading to (6), it can be shown that the product of beam waist width,  $D_0$ , and divergence angle,  $\Theta$ , has a fundamental lower limit that can only be approached by a laser beam as its intensity approaches a purely gaussian distribution and its phase fronts approach perfectly spherical form. That fundamental limit is

$$2w_0 \theta = \frac{4 \lambda}{\pi} \quad (7)$$

where the lower case symbols,  $2w_0$  and  $\theta$  indicate waist width and divergence angle for the ideal gaussian beam and  $\lambda$  is the wavelength. Real beams will have diameter-divergence products that are higher than this fundamental limit by a factor  $M^2$ , the times-diffraction-limit number. For real laser beams

$$2W_0 \Theta = \frac{4 \lambda}{\pi} M^2 \quad (8a)$$

Re-writing (8a) in terms of the ideal beam parameters and grouping terms as shown below makes it possible to conceptualize several relationships between ideal and real beams.

If the relationship is that both beams have the same size waists, but the real beam diverges faster, then it must diverge faster by the factor  $M^2$

$$2W_0 \Theta = 2 w_0 (M^2 \theta) \quad (8b)$$

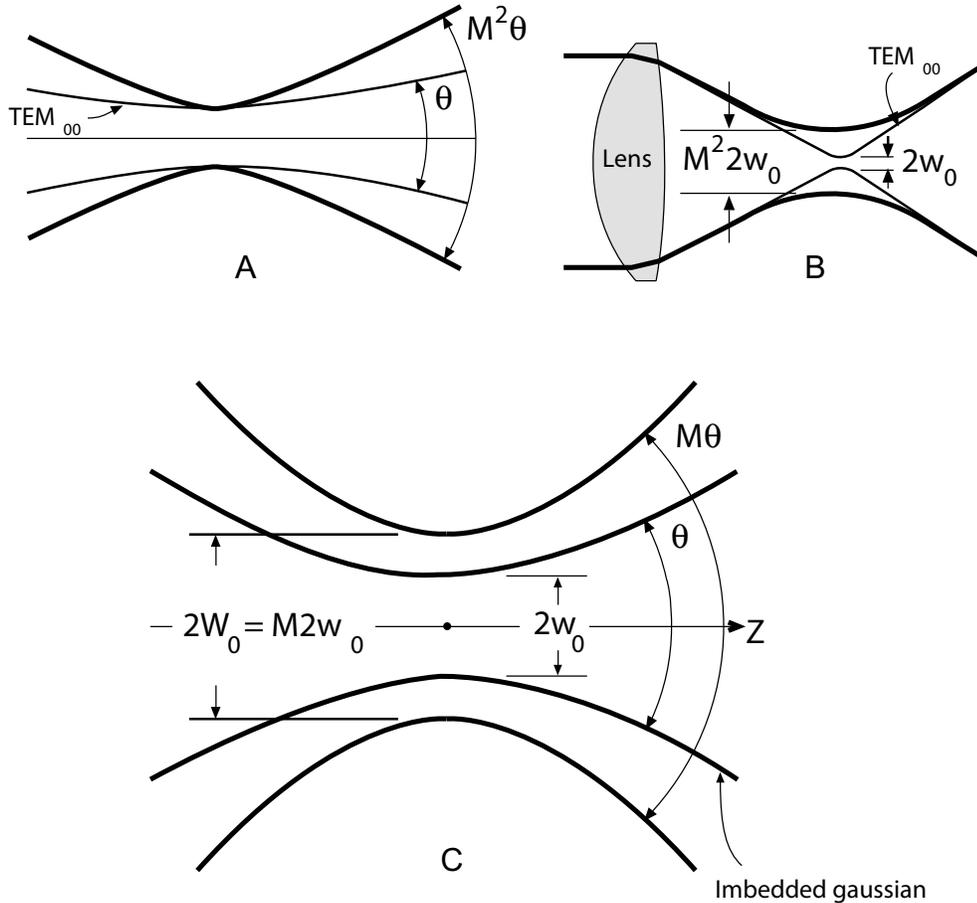
If both have the same divergence angle but the real beam has a larger waist, then it must be larger by the factor  $M^2$

$$2W_0 \Theta = (M^2 2w_0) \theta \quad (8c)$$

If the real beam is everywhere larger than the ideal beam by  $M$  ( $=\sqrt{M^2}$ ), then the divergence angle must also be larger by the same factor

$$2W_0 \Theta = (M 2w_0) (M \theta) \quad (8d)$$

These conceptualizations are shown in Figure 5-1, below. Figure 5-1(C) is of particular interest as it illustrates the concept of what might be called the “imbedded gaussian beam”; important because it represents the relationship between the fundamental and higher order modes of a geometrically-stable laser resonator.



**Figure 5-1. Conceptual Relationships Between Real and Ideal Beams**

A characteristic distance, that will be seen to be the Rayleigh range, may be defined as

$$Z_R = \frac{2W_0}{\Theta} = \frac{\pi (2W_0)^2}{4M^2\lambda} \quad (9)$$

By dividing both sides of (8d) by  $\Theta$  and simplifying, one can show that the Rayleigh range for any real beam is identical to the Rayleigh range for its imbedded gaussian beam. This is important because it means that ray matrix (ABCD matrix) methods can be used to model the propagation of real beams as well as gaussian beams.<sup>1</sup>

1. J. Snyder, “Algorithm for Fast Digital Analysis of Interference Fringes,” Applied Optics, Vol. 19, pp. 1223-1225, April 1980

## Useful Equations

The following is a summary of equations useful for computing beam properties. Two of the important propagation-related properties of any laser beam are beam width,  $2W$ , and wavefront radius of curvature,  $R$ , both of which change with distance along the propagation axis. Using (9) allows (6) to be re-written in a more familiar form

$$2W(Z) = 2W_0 \sqrt{1 + \left[ \frac{(Z - Z_0)}{Z_R} \right]^2} \quad (10)$$

This is the basic equation that allows beam diameter at any location,  $z$ , to be computed from known values of waist diameter,  $D_0$ , and waist location,  $Z_0$ , and  $M^2$ , using (9) to determine  $Z_R$ .

$$R(Z) = (Z - Z_0) \left\{ 1 + \left[ \frac{Z_R}{(Z - Z_0)} \right]^2 \right\} \quad (11)$$

Alternatively, if the width and position of the beam waist are not known, but beam width,  $D_Z = 2W_Z$  and wavefront radius of curvature,  $R_Z$ , at some arbitrary plane,  $Z$ , along the propagation path are known, a related set of equations are used to compute the beam waist properties.

$$2W_0 = \frac{2W_Z}{\sqrt{1 + \left[ \frac{\pi (2W_Z)^2}{4M^2 \lambda R_Z} \right]^2}} \quad (12)$$

$$Z_0 = \frac{R_Z}{1 + \left[ \frac{4M^2 \lambda R_Z}{\pi (2W_Z)^2} \right]^2} \quad (13)$$

Equations 12 and 13 are useful, for example, to determine the size and location of the new waist created after a beam passes through a lens. If the lens is thin there will be no significant change in beam width but the wavefront radius of curvature on the exit side of the lens,  $R_2$ , will be different and related to the wavefront radius on the entrance side of the lens,  $R_1$ , and the lens focal length,  $f$ , by

$$\frac{1}{R_2} = \frac{1}{R_1} - \frac{1}{f} \quad (14)$$

## **Beam Measurements**

The conceptualizations expressed in Figure 5-1 (p. 5-5) and equation 8 are the basis for three strategies for making beam propagation measurements. Of these, the first two require exactly the same set of measurements and differ only in the thought process behind the calculation of  $M^2$ . The third method is distinguished from the other two by not requiring a direct measurement of divergence angle. The methods are:

1. Locate and measure the diameter of the real-beam waist and then measure its far-field divergence angle. If the beam was ideal and had the same size beam waist, its divergence angle would be smaller than that of the real beam by the factor  $M^2$ . Therefore  $M^2$  is just the ratio of the real and ideal divergence angles

$$M^2 = \frac{\pi 2W_o \Theta}{4 \lambda} \quad (15)$$

Beam propagation is now fully characterized (for this plane). It would be sufficient to just use the divergence angle and not compute  $M^2$ , but since  $M^2$  remains invariant throughout any aberration-free optical system, and because it can be easily compared with its universal minimum value of unity, it will be the more generally useful parameter.

2. Again, locate and measure the waist diameter, then measure the divergence angle. If the beam was ideal and had the same divergence angle, according to (8c) it would have a smaller width at the waist. The ratio of real to ideal waist width is just equal to  $M^2$  as expressed in (15).
3. Locate and measure the width of the real beam waist and then find the location along the propagation axis where the beam is  $\sqrt{2}$  larger. This distance, one Rayleigh range, is by-arrangement of (8)

$$Z_R = \frac{\pi 2W_o^2}{\lambda} \quad (16)$$

and permits direct calculation of the waist size of the imbedded gaussian beam. The ratio of real to imbedded waist width is  $M (= \sqrt{M^2})$  and the characterization is complete.

The above analysis treats only a single plane and a complete characterization will, in general require measurement of the three beam parameters in each of two principal planes for a total of six parameters. Figure 5-2, below, shows an artist's conception of the three-dimensional nature of beam size vari-

ation for an astigmatic beam. Other possibilities for asymmetry are shown in Figure 5-3 (p. 5-8). (a) in that figure represents a cylindrically- or radially-symmetrical beam. Other possibilities, not shown, would be combinations of the three kinds of asymmetry.

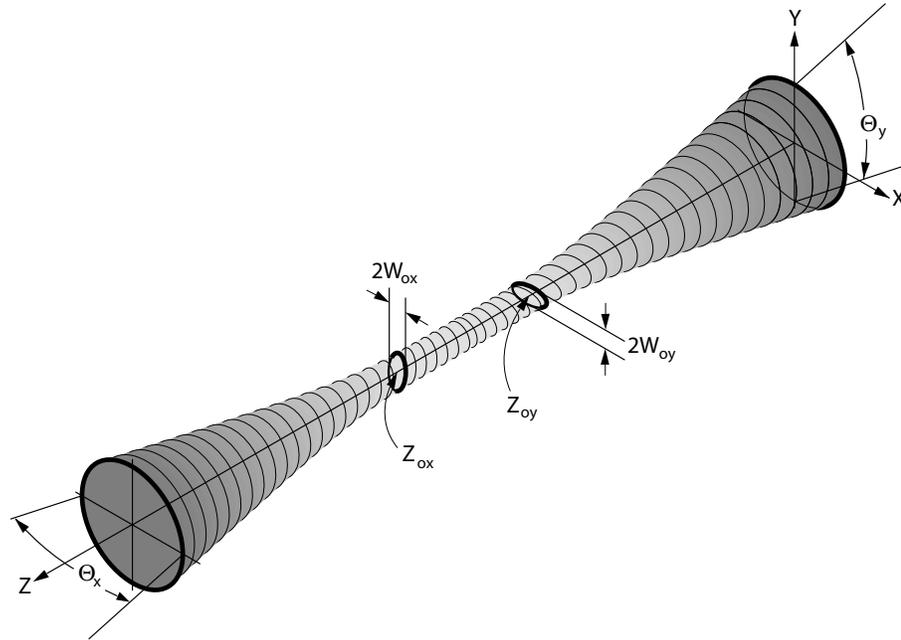


Figure 5-2. Diagram of an Astigmatic Beam

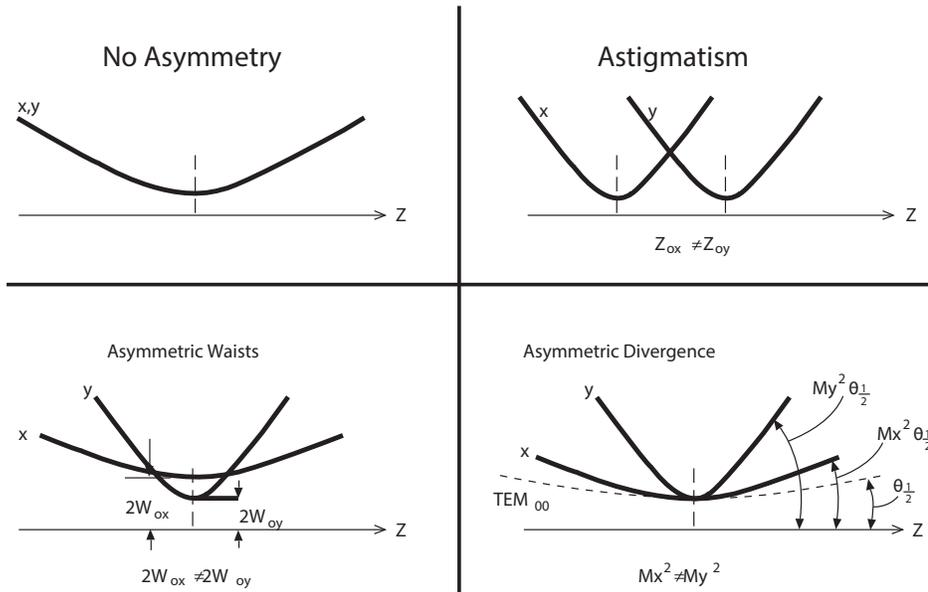


Figure 5-3. Types of Asymmetry

The first (two) of these strategies are used by the ModeMaster PC for both rapid, real-time measurements in the usual situation where the beam waist position is known and not changing; and for measurements with archival-quality accuracy that do not have to be done at high rates and where waist location is part of the measurement. In the former case, the minimum measurement consists of two beam widths (in each transverse plane), one at the waist and one that is at least a Rayleigh range away from the waist. In the latter case, the availability of many beam width measurements that can be used for least-squares curve fitting permits accurate beam characterization even with active sources of noise.

## Knife-edge Diameter Measurements

It is perhaps under appreciated that there is no wide agreement, even on the definition of beam diameter, for a general multimode beam. Of the five or six definitions that have been proposed, most suffer from generating an artificial discontinuity in the defined diameter, under continuous adjustment of the relative mode mixture in the beam or under continuous change of the azimuth direction for the diameter measurement along the cross section of a multi-lobed beam. International committees have reviewed this situation and were given the responsibility of recommending workable standards. The use of knife-edge measurements

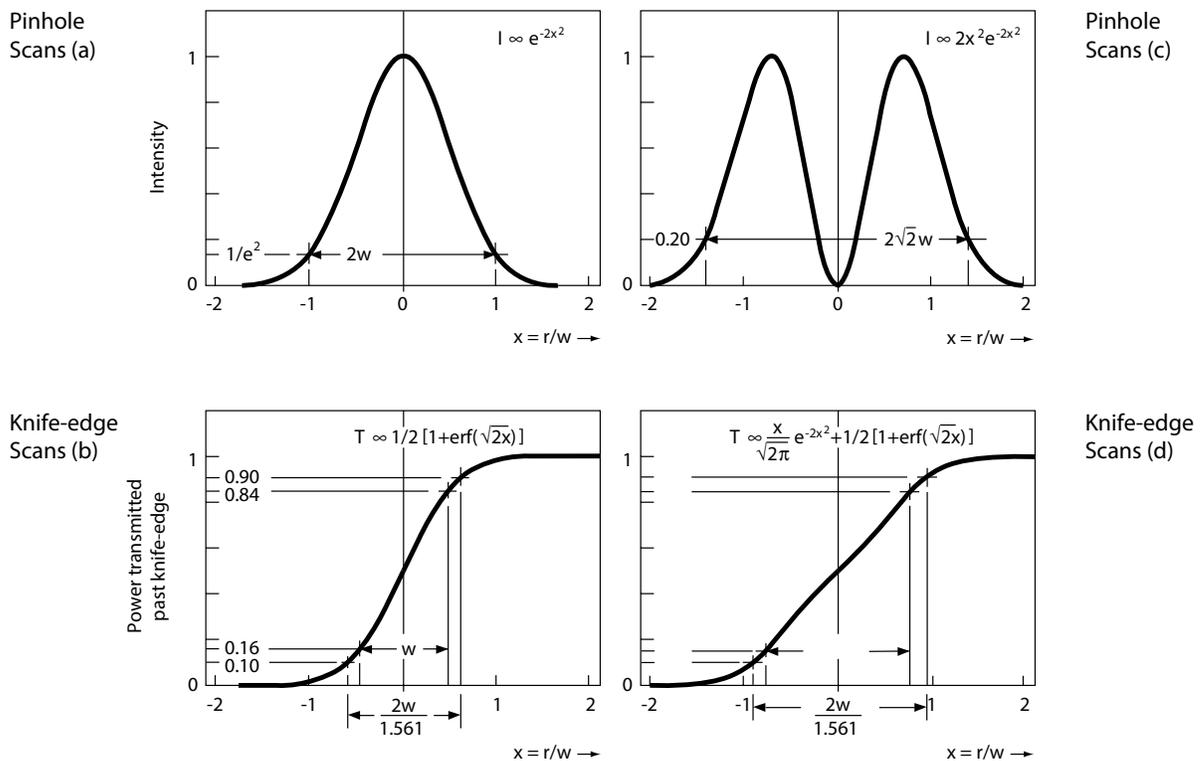


Figure 5-4. Beam Diameter Measurement

(which suffer no such discontinuities) came out as a strongly recommended candidate.

Figure 5-4, above, illustrates the principal of the knife-edge diameter measurement and relates it to the  $1/e^2$  diameter definition for a pure, fundamental  $TEM_{00}$  mode<sup>3</sup> (for which there has been wide agreement). The rule for that definition, is to take a pinhole scan across the center of the beam, locate the peak (100%) intensity value, drop down to 13.5% ( $1/e^2$ ) and “clip” the profile on both sides there; the distance between these two clip points on the profile is the  $1/e^2$  diameter denoted by  $2w$ .

The term and the method is derived from the gaussian intensity profile of this mode;  $w$  is the radial width scale parameter in  $x = r/w$  so that when  $x = +1$ , the relative intensity function of Figure 5-4 (a) is  $I \approx \exp(-2x^2) = 1/e^2 = 0.135$  and the width between these points is  $2w$ .

The same diameter results if instead of scanning a pinhole across the beam, a knife edge cuts the beam and the transmission past the edge (a knife edge profile) is recorded. The mathematical analysis of this signal is a little more complicated, involving an integration over the gaussian function, but the result may be expressed in terms of the tabulated “error function” (given the symbol “erf”) and is shown in (b) in Figure 5-4 (p. 5-9). This transmission signal yields the beam diameter by the rule of first locate the 100% transmission value; drop down to 84.1% and clip the signal there; then drop down to 15.9% and clip the signal again; the distance between these clip levels is exactly  $w$ , so multiply that distance by 2 (the “width adjust factor”) to get the beam diameter  $2w$ .

This is the traditional way to analyze a knife edge signal to get a diameter which has been in the literature for decades. In connection with his development of  $M^2$  theory, Prof. A.E. Siegman has proposed a useful improvement. He first provides a mathematically sound definition for the diameter of a general mixed high order mode based on the square-root of the variance of the mode’s intensity distribution (like the “standard deviation” definition valid for any mathematical distribution function). For the fundamental mode, his variance-based definition and the traditional  $1/e^2$  definition of width are identical. The variance definition has the nice property that if the pure modes are ordered with the fundamental mode first, the donut mode next, and so forth up the radially symmetric  $TEM_{mnq}$  family, then the diameters of the modes (relative to the fundamental mode) increase as  $1, \sqrt{2}, \sqrt{3}$ , etc. and the  $M^2$  values increase as  $1, 2, 3, 4$ , etc. For many reasons, this seems to be the natural definition for higher order mode diameters. Siegman then points out that two degrees of freedom are obtained if both the clip levels and the width adjust factor are freely chosen (rather than arbitrarily picking an

integer width adjust factor as was done in the past). Then the knife edge width definition can be made to agree exactly with the variance-based width definition for two modes, which he picks to be the first two (the fundamental and donut modes). As the order of the mode or mixture of modes increases, a difference between the knife edge and variance-based beam widths is generated, but it is usually less important to have the high precision on high order mode beam widths.

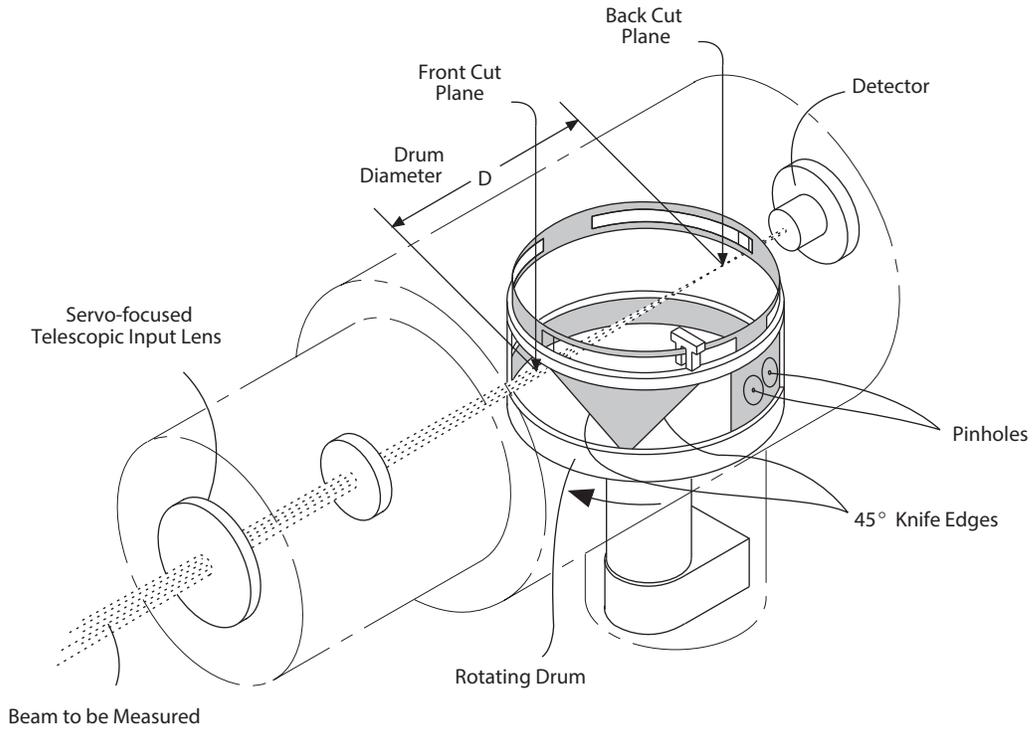
The ModeMaster PC uses either the older 16%/84% (2.00) definition or the newer 10%/90% (1.561) definition as its default value (selected in the Clip Level Dialog). Both definitions are graphically shown in (b, d) in Figure 5-4 (p. 5-9) and compared to the variance-based width definitions used with pinhole profiles in (a, c) in Figure 5-4 (p. 5-9).

Knife-edge transmission signals are preferred by the experimentalist because of their favorable properties:

1. There are no deconvolution errors with a knife-edge (as there are with slits or pinholes, whose widths can affect the measurement) as long as the edge is straight over the scale of the diameter of the beam.
2. Knife-edge signals work with the full beam power, which enhances the signal-to-noise ratio in their detection.
3. The overlaid circular diffraction patterns (from the laser's mode limiting aperture) which distort near field pinhole scans, are averaged out (with minima canceling maxima in the interference pattern) due to the geometrical difference of a straight edge crossing a circular pattern.

Another development coming out of Prof. Siegman's work, which is implemented in the ModeMaster PC software is called the R- or "rad mode." It shows that if only radially symmetric questions are asked about the beam properties, only three constants are needed to define the beam, and these are independent of azimuth. Chief among these "radially symmetric questions" would be to ask what the transmission of the beam is through a round aperture shape there or at what azimuth the beam cross section was clipped by the aperture. Thus for beams with strong asymmetry, astigmatism, or asymmetric divergence, the rad mode becomes the theoretically best average value against which to measure their nonsymmetrical properties. The values for the rad mode constants for beams measured with the ModeMaster PC are computed from the X, Y plane constants and are displayed under the R column of the Data Screens.

## Theory of Operation



## Introduction

An instrument for fully characterizing beam propagation should be capable of measuring and displaying the following information:

Waist location	Waist diameter
Divergence	Times-diffraction-limit ( $M^2$ )
Intensity profiles	Principal axes
Beam axis location and angle	Beam axis stability

The ModeMaster PC is of an instrument class known as **beam propagation analyzers**. The figure above shows a schematic diagram of the ModeMaster PC Scan Head. Briefly described, it consists of an enclosure or body that can be rotated over a  $200^\circ$  range in azimuth angle about the optical axis. Within the front section of the body is a lens that transforms the input beam into a beam that has both a beam waist and a fully developed far-field divergence angle within the measurement area of the instrument.

Central to the function of the instrument is the rotating drum that carries two knife-edges oriented at  $\pm 45^\circ$  to the plane of the drum. After the beam is aligned along the instrument axis, width measurements are made by measuring rise and fall times of the detector signals as the knife-edges scan across the beam in the two mutually

perpendicular transverse directions, both at front (near the lens) and rear planes where the beam intercepts the periphery of the drum. The drum rotates at 10 revolutions per second.

## **Beam Diameter Measurements**

During the data collection cycle, the lens moves over its 81.5 mm (= drum diameter) travel range while width data at 260 planes for each of the front and back planes is recorded. Because the input beam is nearly collimated, the beam diameter at the lens is essentially fixed. The focused internal beam can therefore be treated as being 'attached' to the lens that carries it along the Z axis as the knife-edges measure its X and Y widths at a total of 260 planes. It takes about 25 seconds to collect these widths, after which least-squares curve fits to the width vs. distance data are calculated. These curve fits yield waist width, waist location and divergence for the two orthogonal planes of the focused beam as it is inside the instrument. The same parameters are then computed for the original beam (external to the instrument), by making use of the known focal length and principal plane location for the lens. This beam data from the curve fits together with other derived beam parameters including  $M^2$ , Rayleigh range, waist asymmetry, and astigmatism for both the internal and external.

After the beam is characterized, the lens moves under processor control to the location that positions the internal beam waist at either the front or back measurement plane. This permits real-time viewing of beam waist width and  $M^2$ . Waist location data is updated only after each data collection cycle.

The knife-edge measurement technique is particularly well suited for this application where speed and accuracy are both important. The detector signal, generated as the power transmitted past the knife-edge, is compared with upper and lower clip levels to generate the beam width measurements. Compared to acquiring data for a full intensity map and then computing the means and standard deviations according to equations 1 through 4, this technique is much faster, as might be expected. Less obvious is the fact that with proper interpretation, width data generated this way can have relatively small errors—see Footnote 1 (p. 5-2). It also helps the accuracy that the knife-edge has no width, so there is no possibility for convolution error. Such errors would occur, for example, with moving slit or moving pinhole methods when the slit or pinhole size is more than 10 to 20% of the beam width. This is an important consideration in this application since a large range of beam widths must be accommodated. During the data collection cycle, beam size in the measurement planes may vary by a factor of from 2 to 5 or more.

## Beam Axis Location and Direction

The other function of the moving knife-edges is to measure the beam axis location and pointing angle. It is assumed that intensity distributions of interest will be at least close to symmetrical so the beam axis is just the location of the knife-edge at which half of the total power in the beam is transmitted to the detector. This is not the same as the centroid or mean location of the intensity distribution, but the only signal processing required to locate the axis in this way is a simple comparison against a level set, in this case, at half the maximum detector signal level. These locations are sensed in both the X and Y directions at both the front and back planes of the drum. This beam position data at both locations yields the angular orientation of the beam at rates up to  $10 \text{ sec}^{-1}$ . This is one of the important capabilities of the instrument and recordings of beam orientation relative either to the initial axis orientation or to the instrument axis can be made for periods of from 2 minutes to 24 hours. Beam axis information is also important to the user as feedback during initial alignment of the instrument.

## Coordinates and Sign Conventions

The coordinate system used for the ModeMaster PC screens is shown in Figure 5-5 (p. 5-15). The origin (O) of the coordinate system is taken at the center of the input bezel plane B of the instrument, with the instrument optical axis as the Z-axis. Light is shown propagating from left to right (the standard optical textbook convention) in the +Z direction, so that beam waist locations  $Z_{01}$  on the instrument side of the bezel plane are positive, and locations back towards the laser are negative. A vertical beam displacement above the optical axis is taken as in the +Y direction. Then in order to have a right-handed coordinate system, a beam displacement in the +X direction away from the axis must be to the left when looking towards the input plane B of the instrument as shown. The circle and

dot target indicators of the Home and Alignment screens then move in the same sense as the beam spot would when viewed on a card (when the scan head is at the standard 45° setting).

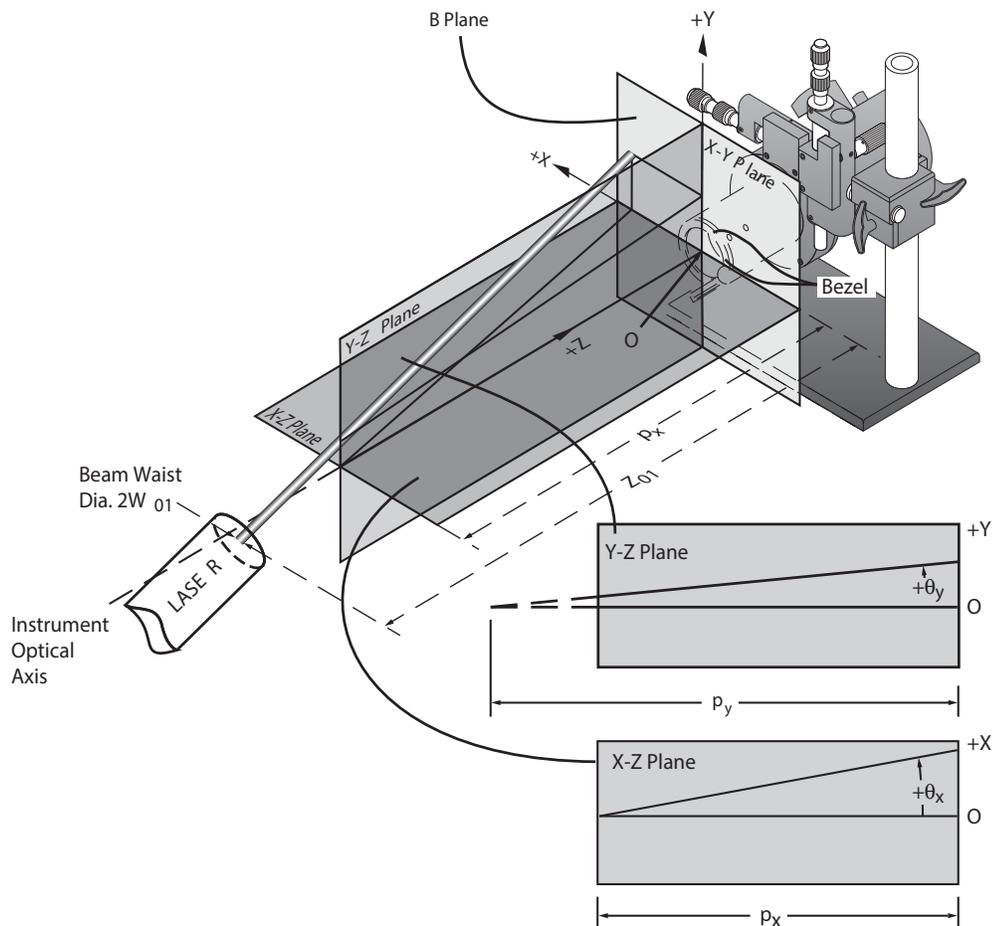


Figure 5-5. ModeMaster PC Coordinate System

---

**For the X and Y data shown on the data screen to agree with the planes shown in Figure 5-5, above, the ModeMaster PC scan head must be at the standard azimuth setting of 45°.**

---

### The Equivalent Radially-Symmetric Beam

A development coming out of Prof. Siegman’s work, which is implemented in the ModeMaster PC software is called the “R” or “rad” mode. It has been shown—see Footnote 1 (p. 5-2)—that if only radially symmetric questions are asked about the beam properties, then only three constants are needed to define the beam, and these are independent of azimuth. Chief among these “radially symmetric questions” would be to ask what the transmission of the beam is through a round aperture at some propagation distance (such

as a lens), without specifying the beam cross sectional shape there or at what azimuth the beam cross section was clipped by the aperture. Thus for beams with strong waist asymmetry, astigmatism, or divergence asymmetry, the rad mode becomes the theoretically best average value against which to measure their nonsymmetrical properties. The values for the rad mode constants for beams measured with the ModeMaster PC are computed from the X, Y plane constants and are displayed under the R column of the Data Screens.

## Instrument Axis Alignment

The instrument support is fitted with X, Y translational adjustments as well as angular adjustments. These four adjustments permit the instrument optical axis to be superposed on the input beam axis by using the targeting information displayed on the console. This insures that the input lens operates at minimum aberration. When used on-axis (within  $\pm 0.5^\circ$ ) with monochromatic laser beams, the most significant remaining aberration to be corrected in the lens design is spherical aberration as will be discussed in the following section.

## Diffraction-limited Lenses

The lens models designated with an -S (short focal length singlet lens) are for use up close to the waist in small waist diameter, high divergence beams and because of the small beam diameter at the lens, spherical aberration is negligible. For larger, low divergence beams, spherical aberration has been nulled out using an air-spaced doublet (telephoto) design, designated with a -D, as shown in Figure 5-6 (p. 5-16). For input beams that produce focal spot diameters greater than 50 micrometers, residual lens aberrations will make a negligible contribution to the measurement of this focal spot diameter.

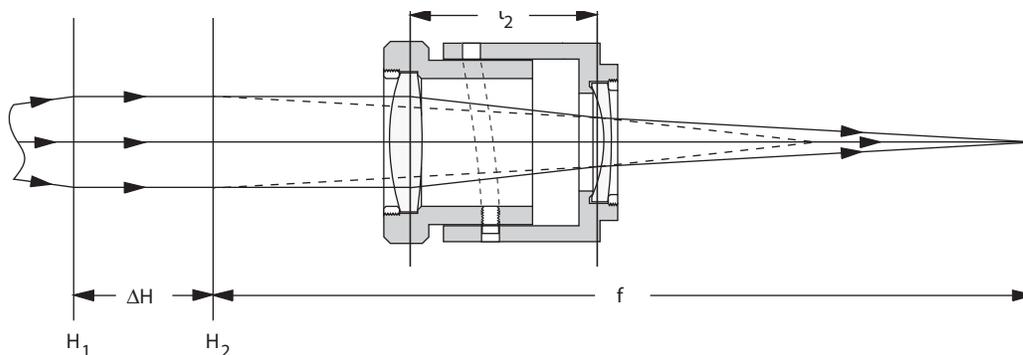
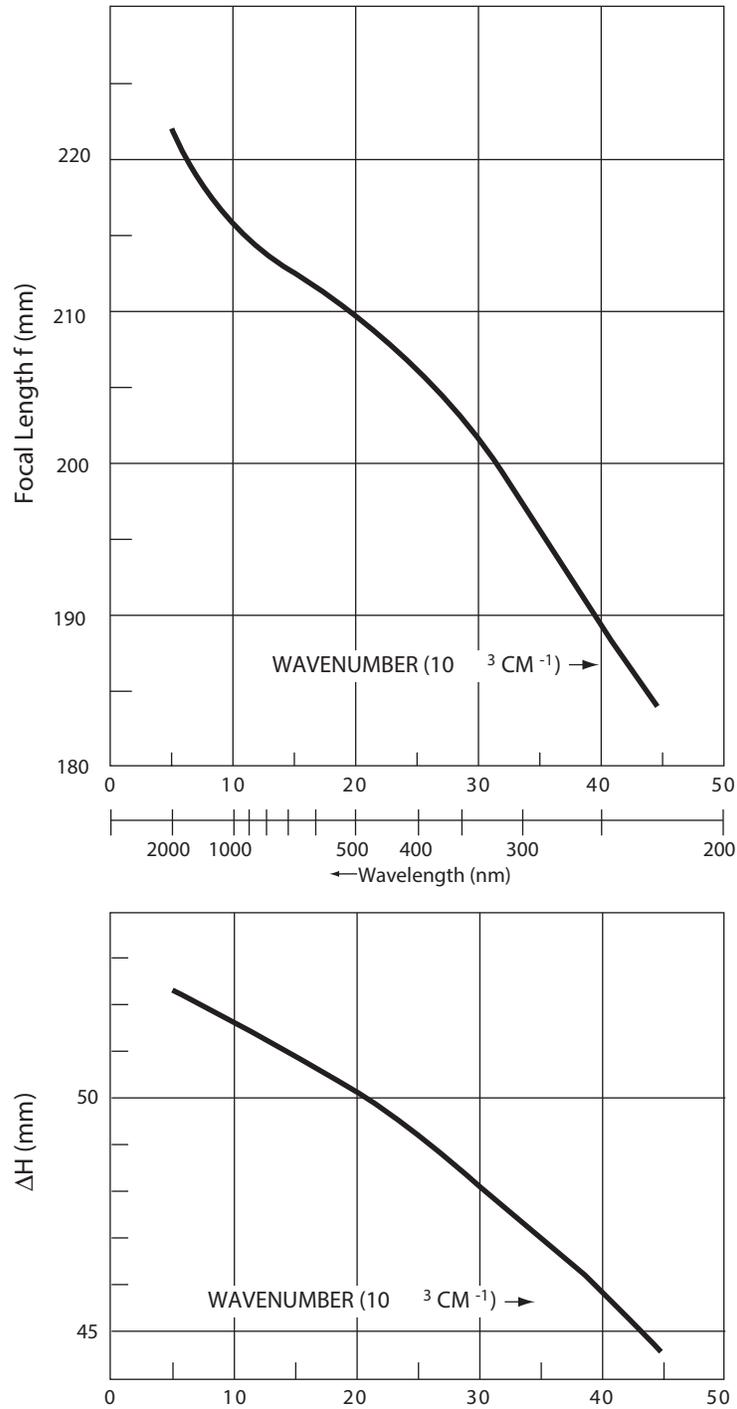


Figure 5-6. Dewey Doublet Input Lens



**Figure 5-7. Focal Length and Principal Plane Separation Variation with Wavelength for the Dewey Doublet**

It can be shown that since both elements of the doublet are of the same (silica) glass, the low aberration properties built in at the initial design wavelength are maintained over the full wavelength range if the spacing  $t_2$  between the elements is scaled proportionally to  $1/(n-1)$ , where  $n$  is the index of refraction of silica. This patented,

computer-designed lens, created specifically for this beam measurement application, is named the Dewey Doublet after its designer, David Dewey of Coherent, Inc.

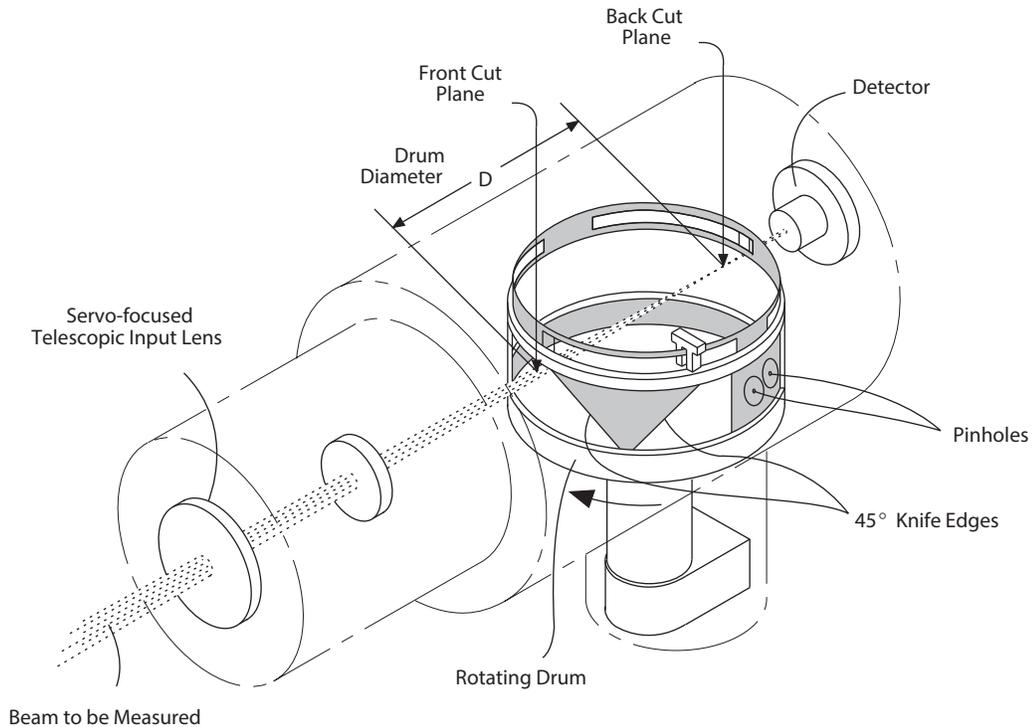
The focal length for the -S lens is about 115 mm. For the -D lens focal length is about 200 mm and varies with element spacing as shown in Figure 5-7 (p. 5-17). The exact focal length is computed by the instrument each time the wavelength (element spacing) is adjusted. For all of the lenses, actual lens geometry data measured during their manufacture is used to compute their individual exact focal lengths.

### **Azimuthal Adjustment for Locating the Beam Principal Planes**

As discussed above, the most general beam will have different and independent values for waist width, waist location, and divergence angle in two orthogonal principal planes transverse to the propagation direction. So, in general at any plane along the propagation axis there will be two different transverse beam widths. These beam principal planes are not to be confused with the lens principal planes to be discussed later.

The instrument mount permits its rotation in azimuth about the beam axis, and the cylindrical drum-motor housing oriented at right angles to the instrument axis (pointing downward in the figure below) is an obvious indicator of the azimuth angle. It is the angle that the axis of this motor housing makes with respect to the tabletop that is displayed on the ModeMaster PC screens. At 45° azimuth the two knife-edges produce horizontal and vertical scans through the beam.

Note that the scanning direction of the pinholes is at right angles to the drum-motor axis and therefore at  $45^\circ$  to the scanning direction of the knife-edges.

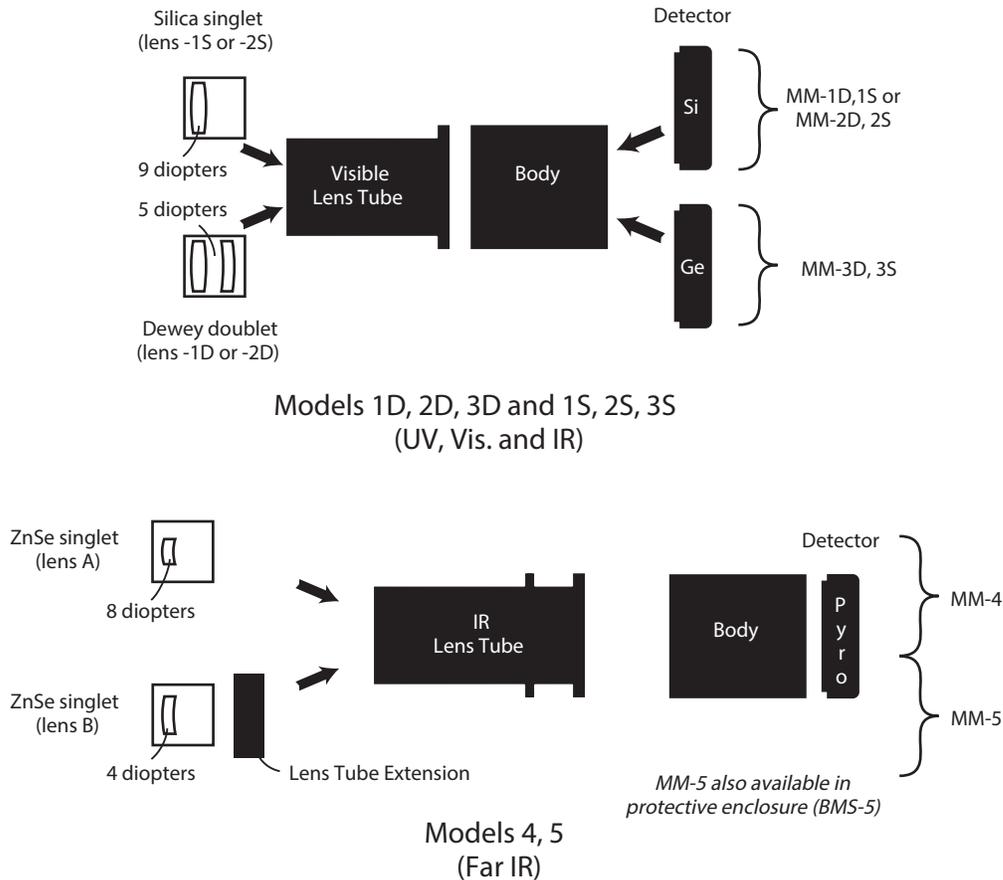


**System  
Modularity:  
Broadening the  
Range of Input  
Beam  
Wavelengths and  
Divergences**

A relatively large 225 to 2000 nm wavelength coverage is obtained from the Dewey Doublet and S-lenses by making the lens elements from UV grade silica glass. Single-layer broadband anti-reflection coatings with two different coating thicknesses are available. The -1 coating centers the minimum reflection zone in the UV-visible range, and the -2 coating centers the minimum reflection zone in the visible-near IR range. Single-layer AR coatings have the property that outside of their operating bandwidth they become “absentee,” that is, the surface reflectivity merely returns to the value for the uncoated glass. Thus either -1 or -2 lenses can be used throughout the UV-IR range and in the worst case there would be only an 8% loss of transmission. This simple, durable construction gives these lenses the ability to function with visible or near IR laser light power of up to 25 watts. The silica lenses are user interchangeable, broadening the range of input beam parameters that can be measured. The silica lenses are used with either silicon (225 to 1000 nm range) or germanium (800 to 1800 nm range) detectors and are user interchangeable to cover 225 to 1800 nm wavelength input beams with the same scan head.

For measurement of CO<sub>2</sub> laser beam characteristics at the 10.6 micrometer wavelength there are two instrument configurations both of which use a single-element, pyroelectric detector and zinc selenide singlet lenses to provide diffraction-limited performance in accommodating the wide range of beam diameters and divergences found with this laser. The -4 and -5 configurations use 1.5 inch diameter 5 inch and 10 inch focal length lenses, respectively. These two lenses can be interchanged to broaden the instrument capability.

The following figure summarizes the interchangeability of parts between various ModeMaster PC Scan Head models. Prior to shipment, supporting data is installed in the ModeMaster PC software for all lenses and detectors included in that shipment. Each accessory lens and detector ordered later is shipped with a Floppy Disk that contains the constants appropriate for that accessory. The procedure for installation of the accessory is described under “Section Three: Operations” (p. 3-1).



**Figure 5-8. ModeMaster PC Modularity Schematic**

After the data is installed in ModeMaster PC memory for each accessory, the user can change lenses or detectors using the Change Lens or Change Detector wizard, which are described under “Section Three: Operations” (p. 3-1). This informs the instrument

about its current configuration. A list of available detectors, by model number, and a list of available lenses, by model number. The ModeMaster PC console is universal and may be used with any scan head configuration.

## More Details on the Instrument

### Computing $M^2$ in Real-Time (and how $M^2 < 0.95$ can result)

From its definition, Equation (8a), the beam quality  $M^2$  cannot be less than unity (as that would imply a beam divergence less than the diffraction limit). Understanding how a reading of less than one can come about, thus gives insight into the internal workings of the ModeMaster PC.

After the focusing cycle, the lens is positioned to put the transformed waist on one of the drum cut planes, normally the rear cut plane (as most input beams are divergent; convergent beams will be automatically focused on the front cut plane). The position of the lens then is a measure of the transformed waist location  $Z_0$ . This is one of the three constants needed to specify the propagation properties of the beam in each of two orthogonal planes. The waist diameter  $2W_0$  measured at that cut plane gives the second constant, and the diameter measured at the front cut plane  $2W_D$  gives the third constant. The third constant is the diameter of the beam expanded over a precisely known propagation distance  $D = Z - Z_0$  away from the waist, where  $D$  is the diameter of the drum ( $= 81.48$  mm). For this case, assuming this is the X-axis, Equation (10) specializes to:

$$W_D^2 = W_0^2 \{1 + (M^2 \lambda / \pi W_0^2)^2 D^2\} \quad (17)$$

which in turn yields an expression for  $M^2$  in terms of measured quantities:

$$M^2 = (\pi W_D W_0 / \lambda D) \{1 - (W_0 / W_D)^2\}^{1/2} \quad (18)$$

Note that this is just the form expected from the identification of  $M^2$  as the ratio of the real beam divergence to the normalizing Gaussian divergence. The divergence determined from measurements at the waist and at distance  $D$  from the waist is:

$$\Theta = 2 \{(W_D^2 - W_0^2) / D^2\}^{1/2} \quad (19)$$

and the divergence of the normalizing gaussian of waist diameter  $2W_0$  is:

$$\theta = 2\lambda/\pi W_0 \quad (20)$$

Ordinarily the waist diameter is much smaller than the diameter on the opposite side of the drum so that the square root term in Equation (18) is nearly unity. Thus the real time  $M^2$  value displayed on the  $M^2$  Alignment Screen which is computed from Equation (18) is given very nearly as the product of the diameter measured at the back cut plane, times that measured at the front cut plane (times a known constant  $\pi/\lambda D$ ). This simple result is a convenient way to remember what actually is being measured and computed on the real-time update screens. These measurements are obtained once per drum revolution, or at a 10 Hz update rate; sufficiently fast for laser adjustment.

Equation (18) is only valid if the transformed beam waist is positioned at one of the cut planes. If for any reason the internal beam is not properly focused on one of the cut planes, then the curly bracket term in Equation (18) may drop considerably as the beam diameters on either side of the drum can then approach each other. This will produce on the real time display the output  $M^2 < 0.95$ ; do not panic, a beam with lower divergence than a diffraction limited beam has not been measured; this simply means some change has put the beam out of focus, and a focus scan should be initiated.

## Real Time Versus Historical Data

The focusing cycle takes roughly thirty seconds to complete, which is a long time to wait for a response in adjusting a laser. "Real time" response is provided on the Live/Alignment screen (but the numerical results will differ by several percent from the more accurate, curve-fit, Data Screen values). The internal waist location is only obtained upon a focus scan (it is not real-time updated). That is usually all right in that the waist location of a laser is fixed by the laser resonator and the intermediate optics in the beam, and only changes if the resonator mirror is changed or an optic is moved. A deliberate change in the experiment is required so that the user making the change knows when a new focus command is required.

The real time display  $M^2$  value is essentially determined from two diameter measurements, instead of the 256 measurements used for the numerical values. Thus the numerical result can be expected to have error bars *one-eleventh* the error bars of the real time results. The moral is clear: use the real time measurements for convenient peaking of the laser and experiment, and the numerical values for the final, best data. The instruments' accuracy specifications apply to these numerical results.

### Limiting Effects at the Nomogram Boundaries

For each ModeMaster PC model, there is a nomogram defining a region in input beam divergence vs. wavelength space where the instrument operates properly and meets all specifications. It is useful to know what defines the boundaries of this operating space, to know what to watch out for (which specifications are in jeopardy) when operating near a limit.

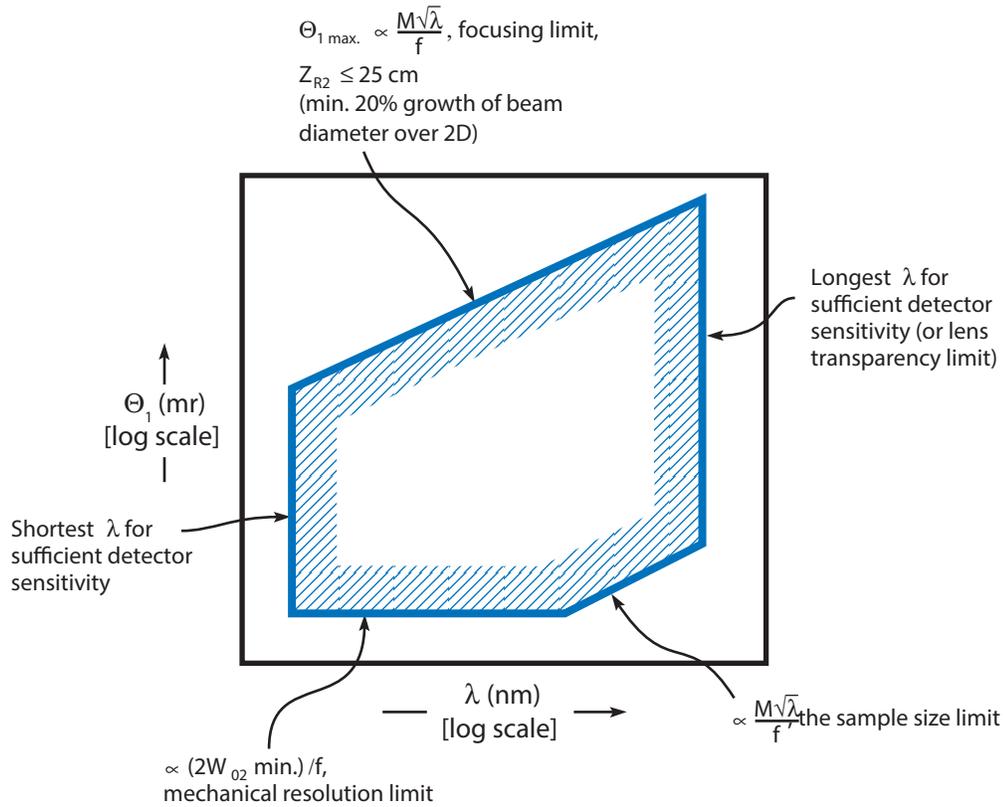


Figure 5-9. Nomogram Limits

### Wavelength Limits

The various limits are depicted in Figure 5-9, above. The wide wavelength limits are reached due to the drop-off of detector response, or due to the reduced transparency of the lens material, both of which produce a reduced, noisy detector signal. The same is true if the input power level is insufficient or the amplitude noise on the input beam is large. Poor signal-to-noise ratios give erratic internal beam diameter measurements (noisy caustics on the beam propagation screen) and  $M^2$ ,  $2W_0$ , and  $Z_0$  determinations of reduced

precision. Repeating the same measurement several times should reveal the degree of precision attained when operating near one of these limits.

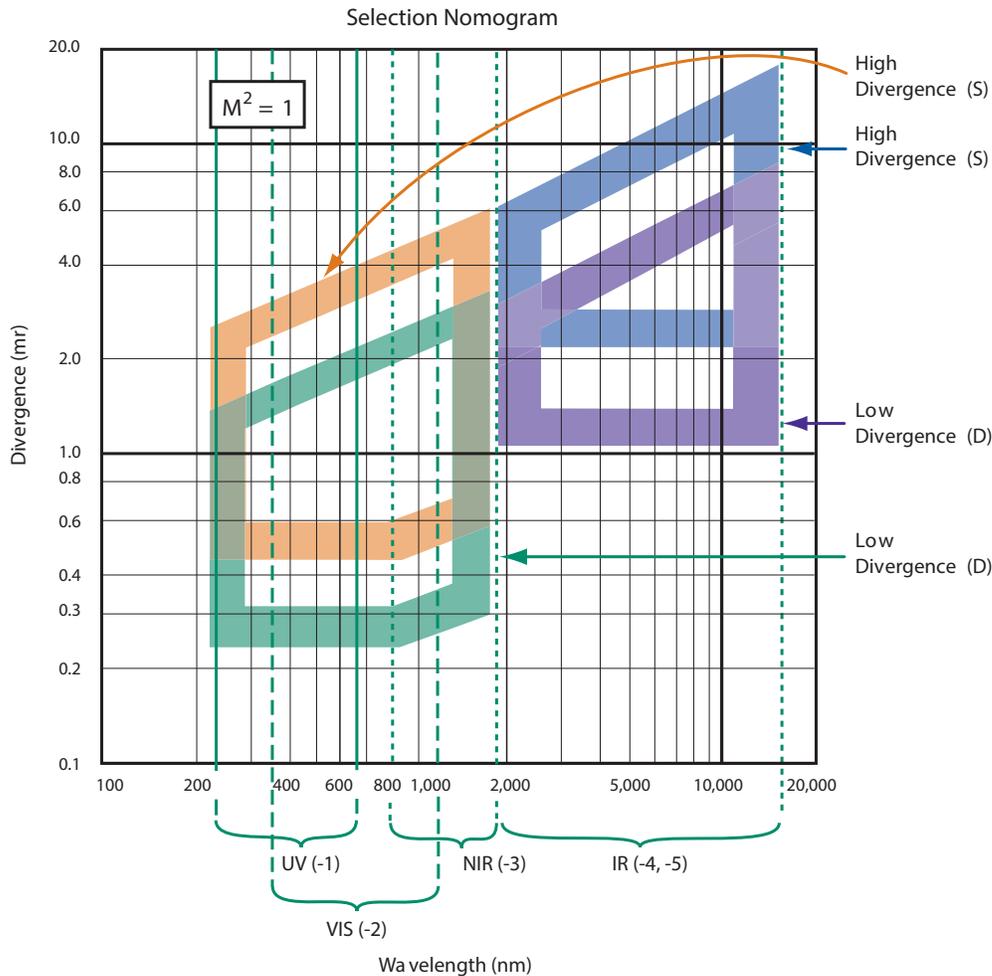


Figure 5-10. ModeMaster PC Nomogram Showing Regions of Useful Operation

### Focusing Limit

The upper divergence limit,  $\Theta_{1max}$ , termed the “focusing limit”, is fixed by the requirement for a 20% minimum growth in internal beam diameter (across the measured portion of the transformed beam of length of two drum diameters) for the internal waist location  $Z_{02}$  to be determined with adequate precision. (Since the drum diameter is 8.15 cm, this is equivalent to requiring the Rayleigh range of the transformed beam to be  $Z_{R2} \leq 25$  cm.) With less diameter change than this, the error in  $Z_{01}$  may exceed  $\pm [(0.08) |Z_{01}| + 4$  cm]. (Note that the Internal Data numerical results screen shows the internal Rayleigh range  $Z_{R2}$ , etc., when needed to check the approach to a nomogram boundary.)

Other types of focusing problems will become more common near the “focusing limit”. Two algorithms are used sequentially when analyzing the internal beam propagation data to determine that there is only one transformed beam waist found (on each axis) and where it is located. The double tests are intended to alert the user to a potential problem in the focus data, and permit an intelligent remedy to be chosen. Thus if the first test fails, operation ceases until the user looks at the data and selects to pass the data on to the next step.

First, a digital filter is passed over the data, which is essentially a digital differentiator, and then the number of zero-slope regions found are counted for each orthogonal axis. There should be one zero-slope point on each caustic, at the waist location. If no zero-slope point is found (on either axis) a “No Waists Found” condition is returned, and if more than one is found (on either axis) the “Multiple Waists Found” condition is returned. In either case, the user should examine the transformed beam caustics to determine the problem. Noisy data can trigger “no-” or “multiple-waists”, with the remedy of increasing the input power or reducing the amplitude noise on the beam. If an evident waist is there in the noise, the user can select “pass to curve fit” under the Analysis menu item, which will manually turn-on the second algorithm to do a least-squares curve fit to a hyperbola to extract from the data the best waist location, diameter, and  $M^2$ .

Step discontinuities in the data can trigger the error messages; these can result from stray reflections glinting on to the main beam at some point in the lens travel during the focus scan, and the remedy is to realign the instrument.

The caustic data may look clean, but show a slope that never reaches zero; the waist is located “off screen” on either end of the lens travel limit. Within the region of the transformed beam sampled in the focus scan, there was no waist (on that axis). To remedy this, move the ModeMaster PC Scan Head relative to the input beam waist, to bring the transformed waist on screen. (Another alternative is to install a different focal length ModeMaster PC lens, if available, if operating space is constrained.)

A more subtle variant of the situation just described, is that the internal beam caustics may look clean, with both waists showing, but at least one waist is located near the limits of the lens travel (on either end of the caustic plots). The digital filter uses data that spans a finite width of about 10% of the full lens travel range to calculate the slope, and it cannot find a waist that is within half a filter width of the ends of the plot. The remedy in this case, is to select “pass to curve fit” under the Analysis menu item, as this second analysis algorithm should have no problem in fitting this data.

### Mechanical Resolution Limit

The lower divergence limit boundaries are of several types. For the typical nearly-collimated input beams used with the ModeMaster PC, with the input waist within a Rayleigh range of the input lens, the focal diameter  $2W_{02}$  inside the instrument is related to the input beam divergence  $\Theta_1$  by:

$$\Theta_1 = 2W_{02}/f \quad (21)$$

where  $f$  is the effective focal length of the ModeMaster PC lens. Thus the horizontal portion of the lower boundary, independent of wavelength, is just the mechanical resolution limit of the instrument (e.g., fifty microns for the Dewey Doublet) where the focal diameter gets too small to be measured with the required precision. Reducing the beam size at the lens to raise  $2W_{02}$  is the only remedy.

### Sample Size Limit

The portion of the lower boundary that slopes proportionally to the square root of wavelength, termed the sample-size limit, results from the finite step size (distance the lens is moved) between samples (measurements) of the diameter of the transformed beam in a focus scan. If the transformed beam Rayleigh range drops below 3.5 times the step size (of 0.625 mm in the ModeMaster PC, requiring  $Z_{R2} > 2.2$  mm) it is possible that the actual waist diameter will be “stepped over” (or straddled) in sampling the beam. This leads to erroneous values of waist diameter and  $M^2$  from the curve fit. (The divergence, given from the measurement of many far field points as the ratio

$$\Theta = (4\lambda/\pi)(M^2/2W_0) \quad (22)$$

is still correct, but there are proportional errors in  $2W_0$  and  $M^2$ .) The limits on the minimum internal Rayleigh range above will keep the measurement error in the internal waist diameter under 1%, and all effects on other specifications will then be negligible. To increase the internal Rayleigh range when near this limit, move the ModeMaster PC Scan Head to decrease the beam size at the input lens.

### Aberration Limit

The portion of the lower boundary that slopes proportionally to wavelength, termed the aberration limit, results from the increase in lens aberration blur circle diameter (due to spherical aberration) as the input beam fills a larger aperture of the lens. Smaller input divergences, simply filling a larger aperture of the lens. The nomogram for each model is drawn at the limit where the blur circle diameter is

less than 1% of the diffraction-limited spot diameter, and the effect on all specifications will then be negligible. Reduce the beam size at the lens to gain more margins when operating too close to this limit.

### The Reference Plane and the Lens Principal Planes

For the user's convenience in mechanically referring propagation distances measured in the laboratory to the ModeMaster PC, the plane defined by the bezel ring —B in Figure 5-11 (p. 5-27)—a the front of the lens tube of the Scan Head is designated the Reference Plane and is the origin for the propagation axis Z of the external beam. External beam waist locations are displayed on the Beam Propagation screens and are measured from this (fixed) plane. The Profile at the Reference Plane Screen also gives the beam diameter at plane B, to facilitate comparison of beam diameters measured with other instruments to the diameter determined with the ModeMaster PC. For optical calculations, however, it is more convenient and conventional to have distances measured from the lens principal planes, which move with the lens. (These are defined below, and are *not* to be confused with the *beam* principal planes discussed earlier). This second coordinate system is used for most of the ModeMaster PC's internal calculations, and if an auxiliary input lens is used with the ModeMaster PC the formula for accounting for the extra lens will be simpler if distances are referenced to the lens principal planes. For these purposes distances relative to the lens principal planes are used on the Internal and Transform numerical results.

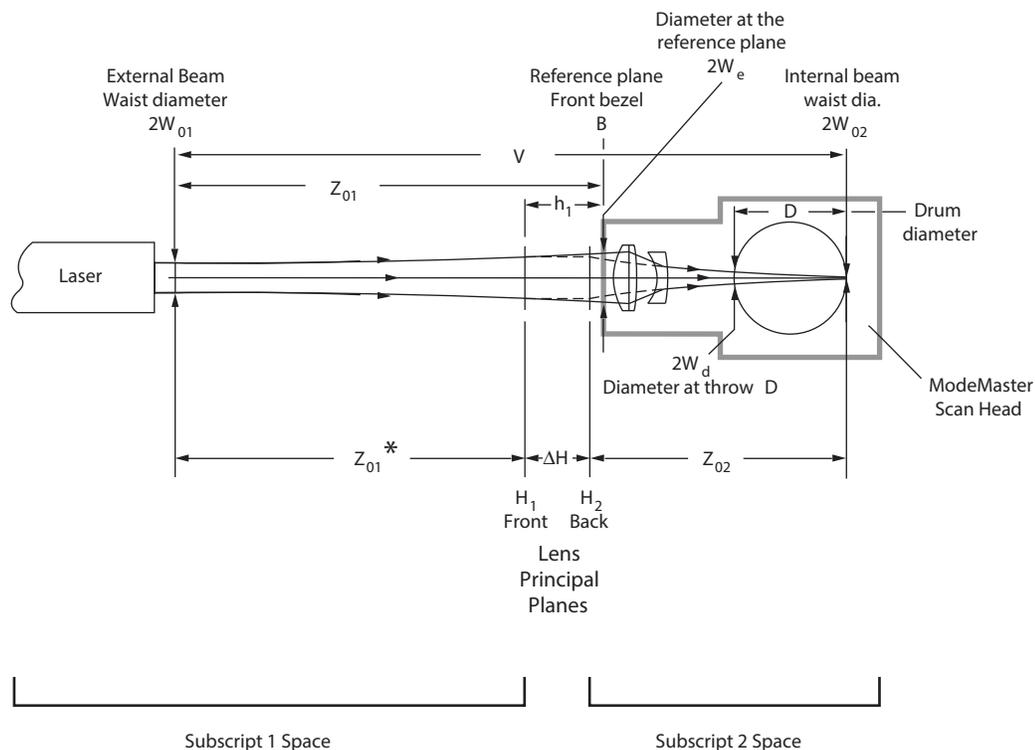


Figure 5-11. ModeMaster PC Reference Distances

Figure 5-11, above, shows that the connection between the two distance references is:

$$Z_{01} = Z_{01*} + h_1 \quad (23)$$

where  $Z_{01}$  (on the External focus results), is the distance from the bezel B to the external beam waist;  $Z_{01*}$  (on the Transform focus results) is the distance from the front principal plane  $H_1$  to the external beam waist, and  $h_1$  is the B to  $H_1$  distance and is given on the Transform focus results. The standard optical convention that light always moves from left to right is assumed here, putting the laser to the left of the ModeMaster PC; then a negative quantity means a distance to the left of the respective origin. For example, in the Dewey Doublet the  $H_1$  to B distance is always less than 10 cm in magnitude, and negative values mean that  $H_1$  is outside the lens tube.

### Lens Principal Planes

For those unfamiliar with the principal plane representation of a thick lens, a review in a standard optics book is recommended, such as Hecht<sup>1</sup>, Jenkins and White<sup>2</sup>, or Melles Griot<sup>3</sup>. This representation gains the analytical simplicity of thin lens object and image distance behavior, at the expense of having to keep track of the slight movement (with wavelength, or interlens spacing) of the principal planes  $H_1$ ,  $H_2$  of an “equivalent thin lens” from which the object and image distances are measured. A singlet lens, in which the thickness of the lens is much less than the focal length, can be considered already as “thin”, and the lens principal planes will be close together and near the midline of this lens. In a telephoto design such as the Dewey Doublet, the “principal planes”  $H_1$ ,  $H_2$  of the equivalent single (thick) lens are well spaced away from either telephoto element—see Figure 5-6 (p. 5-16).

The construction for finding the back principal plane  $H_2$  (with parallel rays as input) is indicated by the dotted lines shown in Figure 5-6 (p. 5-16) and Figure 5-11 (p. 5-27); essentially the converging rays in the focal region are extended back towards the front of the lens to find the plane  $H_2$  where an equivalent thin lens could be placed to produce the same plane of focus. This defines the effective focal length of the telephoto combination of lenses and shows one of its advantages: a long focal length is achieved (about 20 cm in the ModeMaster PC lens) in a physical space that is shorter than the focal length. A similar construction can be done—see the

---

1. E. Hecht, Optics, Addison Wesley, Reading, Massachusetts, 1987, Section 6.1

2. F. Jenkins and H. White, Fundamentals of Optics, 4th Edition, McGraw-Hill, New York, New York, 1976, Chapter 5

3. Melles Griot, Optics Guide 4, 1988, Section 1

optics texts with parallel rays on the right in Figure 5-6 (p. 5-16), traced backwards through the telephoto lens pair to a focus to find the front principal plane  $H_1$ , where an equivalent thin lens could be placed to produce this new focus. The rules are, that the source (on the left, light always moving from left to right) or object distances are measured from  $H_1$ , and the image or focal distances are measured from  $H_2$ . Between the two planes the rays are shown as parallel to the axis, regardless of the angles with which they enter and exit from the principal planes, in an optical “no man’s land.”

This leads to the rather odd looking diagram of Figure 5-11 (p. 5-27) (dotted beam traces) defining the lens principal plane distances used on the Internal and Transform focus results in the numerical results area. Whenever both external and internal beams are considered together, subscripts “1” denote the external space, and subscripts “2” the internal space. It sometimes will be helpful to know the physical location of the back principal plane  $H_2$ , obtained by subtracting the principal plane separation  $\Delta H$  given for the Dewey Doublet in Figure 5-7 (p. 5-17) from the front principal plane location  $H_1$ . The variation of the telephoto focal length with wavelength is also shown in Figure 5-7 (p. 5-17).

## **The Transformation Through the Lens to the External Beam**

### **The Transformation Equations**

An important property of the  $M^2$  value of a beam is that it remains unchanged for passage of the beam through a non-aberrating lens. The ModeMaster PC lenses are specially designed to have negligible aberrations for laser beams meeting the input beam requirements (lying within the nomogram) for the instrument, so the  $M^2$  value measured for the internal beam, is the correct value for the external beam as well.

The external beam’s waist diameter and location are gotten from those of the internally measured beam, by the mathematical inversion familiar from Kogelnik and Li’s<sup>1</sup> work for the transformation of a gaussian beam in passage through a lens. This uses the effective focal length  $f$  of the lens, the internal waist location  $Z_{02}$  measured from the back lens principal plane, and the internal Rayleigh range (computed in the curve fit) which for a multimode beam is:

$$Z_{R2} = \pi W_{02} / M^2 \lambda \quad (24)$$

---

1. H. Kogelnik and T. Li, “Laser Beams and Resonators,” Applied Optics, Vol. 5, p. 1550, October 1966

This generates from the internal measurements the transformation constant gamma, which gives the external beam waist diameter and location in terms of the internal ones (the  $M^2$  values being the same):

$$\Gamma = f^2 / [(Z_{02} - f)^2 + Z_{R2}^2] \quad (25)$$

$$W_{01} = (\Gamma)^{1/2} W_{02} \quad (26)$$

and

$$Z_{01*} = - \{ f + \Gamma [Z_{02} - f] \} \quad (27)$$

In reporting  $Z_{01*}$  from Equation (27) the minus sign in front of the curly brackets has been added to agree with the sign convention choices made for the ModeMaster PC, that distances to the left (towards the source) of the scan head are negative, to the right positive, and light always moves from left to right.

### The External Beam Propagation Plot

To construct the External Beam Propagation Screen via these results, first the external beam waist diameter and therefore Rayleigh range are calculated from Equation (26). Then points in the diameter data array for the transformed beam positioned  $\beta$  internal Rayleigh ranges away from the internal waist, are plotted  $\beta$  external Rayleigh ranges away from the external waist, with the diameter values scaled according to Equation(26). This is preferred to just showing a perfect hyperbola computed from the best fit  $M^2$ ,  $Z_0$ , and  $2W_0$  values, as the scaled experimental data presentation allows a visual estimation of the of the fit properties.

### Operation at $\Gamma > 1,000$ Not Recommended

The value of  $\Gamma$  from the last focus run is listed on the Transform Data Screen (as Gamma) and should be used for the following reason. There are small, fixed errors in locating the internal waist and knowing precisely the (wavelength dependent) lens focal length. Ordinarily these small errors are of no concern, but for perfectly plane input wavefronts (which focus at  $Z_{02} = f$ ) the first term of the denominator of Equation (25) should go to zero but may not due to the measurement error. If also the internal waist diameter simultaneously approaches the minimum limit, a noticeable error in  $\Gamma$  may result. This can only occur for large  $\Gamma$ . It is recommended that when a measurement results in a  $\Gamma$  in excess of  $10^3$ , the instrument be moved to a new location, to generate a new focal position and reduce the value of  $\Gamma$ . Minimum  $\Gamma$  occurs for the instrument located one Rayleigh range of the external beam away from the external beam waist (this puts the most curved wavefront at the lens to move the focus to its maximum distance away from  $Z_{02} = f$ ).

**More on Profiles****Pinhole Alignment**

The targets on the Home (or Alignment) Screen are used for initial alignment to get the tracks of the scanning pinholes to cross the transformed beam. This simultaneously aligns the optical axis of the ModeMaster PC to the beam, because of the precision construction which places the pinhole tracks along the instrument optical axis. The foils carrying the knife-edges and pinholes are photolithographically formed to define a precision geometry including positioning reference marks. These position references are picked up when the pinholes are laser-drilled in the foil, giving well-defined mechanical pinhole positions.

Final alignment is done by using the Find Pinhole Wizard that sets the electronic window to center appropriately on the pinhole signal. With the signal located and in view, the mechanical adjustments are peaked to center the pinhole track precisely across the center of the beam.

A subtlety to be aware of is that the effect of a mechanical adjustment of course changes as the azimuth setting is changed. At  $0^\circ$  azimuth, the drum carrying the pinholes is spinning in the vertical plane, about a horizontal axis. Thus turning the vertical tilt screw, moving the instrument axis in the vertical plane, does nothing to peak the pinhole signal but only makes a change to the signal delay seen on screen. The pinhole is already moving vertically, and this varies the timing of this vertical scan. At this azimuth the horizontal tilt screw is effective in peaking the pinhole signal.

At  $90^\circ$  azimuth this effect reverses, and the pitch adjustment must be used to peak the pinhole signal. A glance at the azimuth-defining axis (the drum motor housing), with recall that this is the spin axis of the drum as shown in Figure 5-6 (p. 5-16), will make obvious at any azimuth the appropriate tilt axis for signal peaking.

**Avoiding Retro-reflections**

When the ModeMaster PC axis is perfectly aligned to the beam, and the lens is focused on one of the drum cut planes, the retro-reflections from the drum in the plane containing the spin axis form what is known optically as a “cat’s eye”. The incident collimated beam is reflected back through the lens and is returned as a collimated beam to the source. This can perturb the laser oscillation (the output coupling of the laser becomes a sensitive, interferometric function of the reflectivities and spacing of the output mirror and the ModeMaster PC) to produce a “broken-up”, noisy pinhole signal. This is characterized by a sharp improvement in the pinhole scan (the noise disappears) with a slight tilt of the instrument alignment, which gives one way to eliminate the effect. Other ways to avoid the retro-reflection effect are to put an aperture near the laser source to

block the cat's eye beam, or to add an attenuator between the source and the ModeMaster PC. The retro-reflected beam is reduced by two transits of the attenuator before returning to the source and the perturbation effect disappears quickly.

For systems used with the carbon dioxide laser, the initial alignment retro mirror is supplied only for use with a coaxially aligned visible HeNe tracer beam. Retro-reflections from a high-power, invisible ten-micron laser are not considered safe, and a multi-watt ten-micron beam incident on the retro mirror may crack the glass in any event.

### **Interpreting Near Field (Reference Plane) and Far Field (Focal Plane) Profiles**

Two pinhole intensity profile screens are available with the ModeMaster PC. The Profile at the Focal Plane displays the signal generated by the pinhole traversing the transformed beam at the waist, and the Profile at the Reference Plane displays the signal generated by the traversal at the opposite side of the drum,  $D = 8.15$  cm from the waist. The data on the beam from the focus scan is used to generate scale factors, to project the (knife edge) beam widths measured in real time at these two cut planes, to the widths appropriate to the screen labels. Since the profile taken at the focus of the lens is equivalent to one taken many Rayleigh ranges from the waist of the external beam, in the "far field", the appropriate width for the Focal Plane Profile is that of the divergence of the external beam (in milliradians).

The profile taken at the opposite of the drum is displayed as the Reference Plane Profile, and the scale factor used adjusts the measured width to that of the beam at the reference (bezel) plane B of Figure 5-11 (p. 5-27). A fair question to ask, is how representative is that transform beam profile, of the profile a scanning pinhole placed directly in the external beam at B would generate. Most often the ModeMaster PC will be used at a distance around 0.5 to 1 meter from the laser; and for many lasers this will put the point B within a Rayleigh range of the external beam waist. The Reference Plane Profile is thus a "near field" profile.

Profiles measured close to the waist of most lasers show diffraction ripples<sup>1</sup>, interference maxima and minima due to the overlaying of the pure mode content of the beam with the diffraction wave generated by the mode-limiting aperture in the laser resonator. A rather small fractional power content in the diffraction wave can cause surprisingly large modulations<sup>7</sup> of the profile, and the phase of the interference effect—whether the ripple adds or subtracts to the

---

1. A. E. Siegman, Lasers, Sections 17.1, 18.3, 18.4, University Science Books, Mill Valley, California, 1986

unmodulated form—varies rapidly with slight shifts in the distance of plane B from the laser. Under these (typical) conditions, the answer to the question posed above, is that there is no profile that fully represents that of the near field of the beam in either external or internal space. Since both are contaminated with diffractive overlay noise, the profile at D from the transformed beam waist is as good a representative as any other.

Note that the ModeMaster PC lens can be positioned manually which permits the near field profile variations with change of distance along the transformed beam to be examined simply and reproducibly by pushing buttons (with the same effect as if the ModeMaster PC were moved several meters in the external beam). It is useful in such studies to know the physical width at the internal cut planes corresponding to the window width across the full profile display (between the ends of the trace). This is obtained by converting the width code number (running from 1 to 100) given on screen using:

$$\text{Window Width} = \{101 - (\text{width no.})\} (0.256 \text{ mm}) \quad (28)$$

Similarly, the gain code number given on screen can be used to tell the relative scales of two profiles at different gains, using the fact that each change in (gain no.) by + 1 corresponds to a signal amplifier gain increase by + 1.5 times.

The delay code number given on screen can be used to tell the displacement of a profile feature at the knife-edges. Each integer change in (delay no.) by + 1 corresponds to a 16-micrometer displacement, moving the feature to the right on screen. To give the delay control the proper “feel”, the change in (delay no.) with each button push depends on the current window width setting, being 1/16 of the window width per push.

## **Optimal Use of the Second Moments Screen**

### **Overview**

Of several possible ways of defining and measuring beam diameter and beam divergence, a very natural choice is to base it on the second moment of the beam irradiance and intensity distributions. (In the SI system of units, irradiance is the power per unit area

measured in watts/meter<sup>2</sup> and intensity is the radiant power per unit solid angle measured in watts/steradian). Positive consequences of this choice are:

1. The simple quadratic propagation law, Equation (6), follows from this definition as a consequence of the Huygens-Fresnel principle and the Fourier transform relationship that it implies between the spatial and angular distributions of field amplitude for freely-propagating light.
2. The pure Laguerre-gaussian modes, that make up beams emitted from geometrically-stable laser resonators, have integer values of  $M^2$  starting with unity for TEM<sub>00</sub> mode and increasing with higher mode order. For beams made up of mixtures of L-G modes, the  $M^2$  value is just the power-weighted sum of  $M^2$  values for the component modes.
3. The diameters of arbitrary intensity profiles become unambiguous and easily calculable.

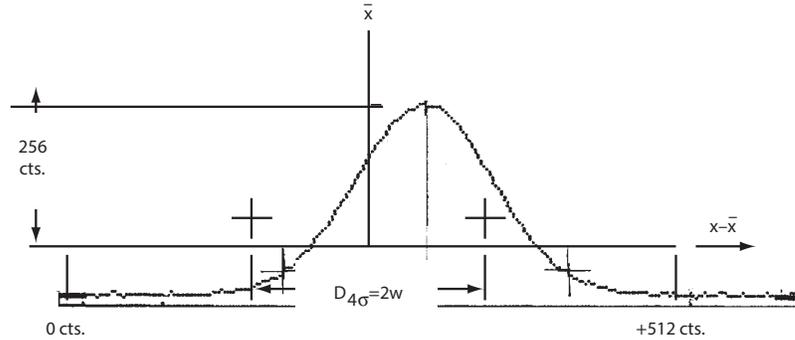
For these reasons second moment-based diameter has attracted strong interest from groups including an international committee working on standardization of beam geometry measurements. We have therefore made this measurement method available to ModeMaster PC users.

There are disadvantages, however, to relying only on the second moment diameter. A true second moment calculation requires integration over the entire range of the transverse coordinate and it converges to a finite result only when the distribution function decays quickly enough with increasing distance from the center. The irradiance distributions for theoretical Laguerre-gaussian modes exemplify functions for which there is a successful measure of width. Here the exponential function multiplying the Laguerre polynomials ensures that the second moment integral converges to a finite result. The Airy function is an example of a theoretical distribution that does not have a finite second moment unless the integration is truncated by reducing the limits of integration to some finite range of transverse coordinate.

Experimentally recorded irradiance distributions have the additional problem that even if the signal is well behaved, noise is always present and can have a major effect on the second moment calculation. That is the subject of this section—how to best use the options built into the ModeMaster PC Second Moments screen, to control the effect of noise on the end result. A model is developed which assumes a constant level of white noise over the full width of a digitized gaussian profile, and the generalizations to an arbitrary profile are indicated. With this model the quantitative effects of background subtraction, truncation of the scan width and noise rectification on

the second moment are examined. A summary near the end of the section then lists the steps, in sequence, to make optimal use of these options for noise control.

## Definitions



**Figure 5-12. Typical Digitized Profile of a Gaussian Beam**

Assume a typical digitized pinhole profile for a gaussian beam as generated by the ModeMaster PC, of 256 counts peak height, centered in the scan, and width 40% of the 512 count digitized width, or  $2W = 205$  counts—refer to Figure 5-12, above. The theoretical gaussian profile is of the form:

$$E(x, y) = const. \times E_0 \exp [-2 (x^2 + y^2) / w^2] \quad (29)$$

Here  $E_0$  is the peak signal height in counts, and the constant converts the units from counts to  $W/m^2$ . For use in the definition of second moment width given in Equation (3), the profile must be normalized to unit power, that is, the constant determined from:

$$\begin{aligned} P &= const. \iint_{-\infty}^{+\infty} E(x, y) dx dy = const. \times 2\pi E_0 \int_0^{\infty} \exp [-2r^2/w^2] r dr \\ &= const. \times 2\pi E_0 (w^2/4) \int_0^{\infty} e^{-u} du \end{aligned} \quad (30)$$

where the substitutions  $2(x^2 + y^2)/w^2 = 2r^2/w^2 = u$  and  $r = x - \langle x \rangle$  have been made, it being assumed that the profile was taken along the x-axis, with  $\langle x \rangle$  the mean value of  $x$  defined below. The last

integral evaluates to unity, giving for the volume of the gaussian the quantity  $\pi w^2/2$  and the value of ( $const. \times E_o$ ) as  $2P/\pi w^2$ . The second moment of this distribution is then:

$$\begin{aligned} \langle r^2 \rangle &= const. \times E_o (1/P) 2\pi \int_0^\infty r^2 \exp[-2r^2/w^2] r dr \\ &= (2/\pi w^2) 2\pi (w^4/8) \int_0^\infty u e^{-u} du = w^2/2 \end{aligned} \quad (31)$$

as radial coordinates are most convenient for the integration and again the last integral evaluates to unity. The radial variance  $\sigma_r^2$  is here equal to the second moment  $\langle r^2 \rangle$  because by choice of coordinates the mean value of r is zero. As Siegman<sup>1</sup> shows, in radial coordinates the second moment diameter of the beam is  $2\sqrt{2}$  times the standard deviation (square root of the variance) or:

$$D_{4\sigma} = 2\sqrt{2} \sigma_r = 2\sqrt{2} (\langle r^2 \rangle)^{1/2} = 2\sqrt{2} (w/\sqrt{2}) = 2w \quad (32)$$

As expected the “diameter from the  $4\sigma$  profile calculation” given by (3) for this gaussian beam, is the traditional 1/e<sup>2</sup> beam diameter.

For a higher-order-mode,  $2\sqrt{2}$  times the square root of the radial variance *defines* the second moment radial diameter  $D_{4\sigma}$ . From this, a radial second moment beam quality  $M_{4\sigma}^2$  can be derived, once the diameter of the embedded gaussian mode associated with the higher order mode is known, as the beam quality is just the square of the ratio of these two diameters. The standard knife-edge diameters measured by the ModeMaster PC gives this as  $2W_{ke}/M_{ke} = 2w$ , which is evaluated at either the external or internal waist, and from which the “beam quality from the  $4\sigma$  profile calculation” is given as:

$$M_{4\sigma}^2 (profile) = (D_{4\sigma}/2W_{0ke})^2 M_{ke}^2 \quad (33)$$

The radial second moment beam quality is thus proportional to the radial second moment  $\langle r^2 \rangle$ .

---

1. A.E. Siegman, “New Developments in Laser Resonators”, SPIE V.1224 (16-18, Jan. ‘90)

## **Averaging the Moments from the Left and Right Half-Profiles**

Assuming the pinhole scan goes through the center of the beam along the X-direction, the actual profile recorded is of the form  $E(x)$ , with  $x$  running over the 512 sample points of the digitized interval  $L$ . For the radial integral Equation (31) this is converted to radial form by first finding the mean value  $\langle x \rangle$  of the distribution:

$$\langle x \rangle = \frac{\int_0^L xE(x) dx}{\int_0^L E(x) dx} \quad (34)$$

and then treating the right and left halves of the profile, divided at the mean, as independent radial profiles in Equation (31) with  $r = x - \langle x \rangle$  and  $E(x - \langle x \rangle) = E(r)$ , the fact that the integration stops at the profile limits instead of extending to infinity being handled by the fact that for a centered profile, the intensity should fall to zero (and remain zero) at the extremes.

This gives two values for the radial variance, which will differ if the profile is not symmetrical about the mean or the mean is not centered in the full width of the profile. The ModeMaster PC averages the two variances as the best estimate of the true value, takes the square root of this average and multiplies the result by  $2\sqrt{2}$  the final answer for  $D_{4\sigma}$ . The right and left variances and their ratio are listed on the Second Moments screen. If the ratio is not within  $\pm 15\%$  of unity, the assumption that the input beam is round is probably not appropriate and hence the validity of doing a radial variance calculation based on a single profile scan is questionable.

## **Modeling Noise on the Experimental Profile**

The two preceding sections make use of the gaussian irradiance profile to show how second moment beam diameters are computed. This work can be extended to include the real-world effects of having:

1. Higher order modes contributing to the profile.
2. Noise present in the recorded profile data.
3. An offset between the zero-level of the detection system and the true dark level. This offset is often referred to as the background.

Both noise and a non-zero background level can cause very significant errors in the calculated second-moment diameter. Strategies employed in the ModeMaster PC for controlling these problems are examined in this section. These strategies are listed with brief descriptions in the following table.

<b>MODEMASTER PC OPTION</b>	<b>FULL NAME</b>	<b>DESCRIPTION</b>
Background Sub	Background Subtraction	Subtracts the background level from the profile to make set the dark level of the detection system to zero.
Trunc Limits	Truncation limit-narrow	Reduces the limits of integration for second moment calculation to less than the scan width. Limits are $1.9 W_{ke}$ on either side of the mean.
(NoiseClip Off/On)	Zero-level noise clipping	After the background subtraction, any profile data with negative values is set to zero.

The following parts of this section describe the effects and interactions of these options and discuss their proper use for obtaining high accuracy second moment beam diameters.

Examination of the noise on typical profiles shows it to be of high frequency and uniform amplitude over the width of the digitized scan. This can be modeled, when the ZeroClip Noise option is On, as a constant fractional level  $n_o/E_o$  of noise added to the gaussian signal. (The actual noise, after background subtraction, has peaks of heights about  $\pm 2n_o$  relative to the Background Sub level, or a peak-to-peak height of  $4n_o$ , with a mean of zero. The noise clip option sets the negative-going signal equal to zero, leaving the posi-

tive half unaltered. The  $+ 2n_0$  positive half peaks, covering half the interval, average to a constant amplitude “rectified noise equivalent” of height  $n_0$ , as shown in the following figure.

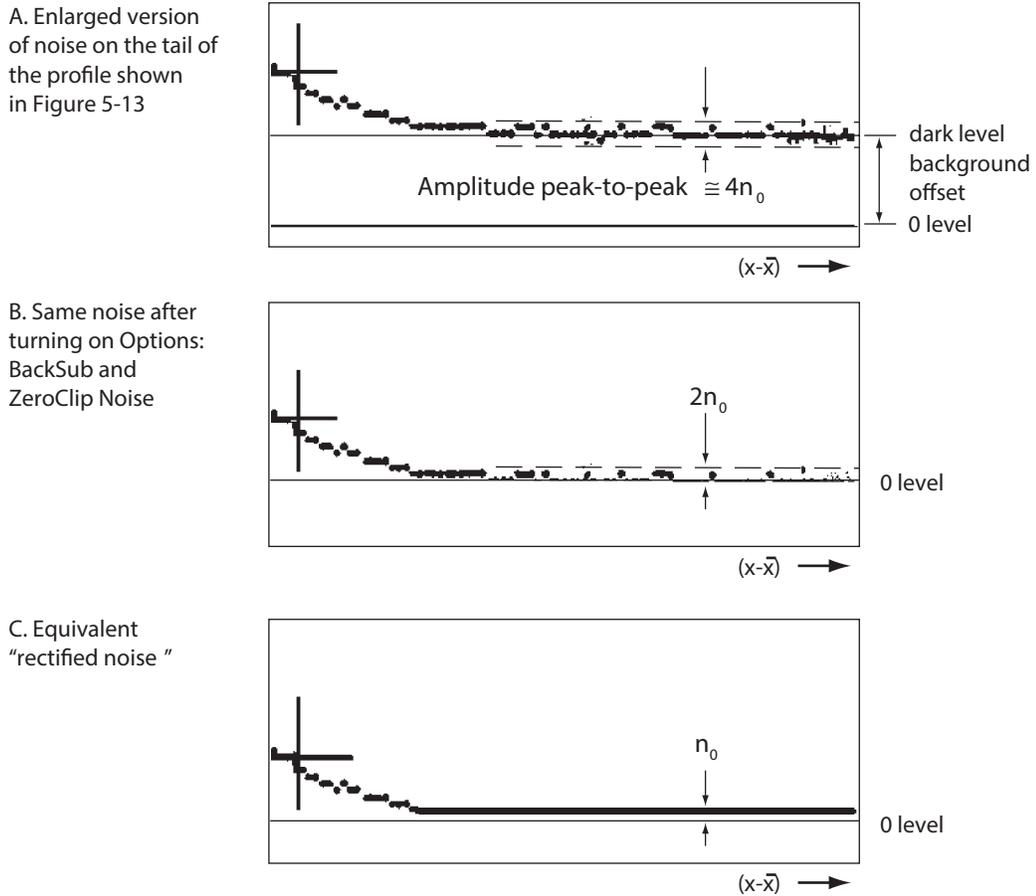


Figure 5-13. Derivation of the Equivalent “Rectified “noise”  $n_0$

This uniform noise case is the easiest to model, and the other experimental situations, with ZeroClip Noise Off or Background Sub Off, may be understood by appropriate choice of  $n_0$  from this model.) To denote where the integration is truncated (stopped), it is convenient to use the knife-edge signal waist radius  $W_{0\ ke}$  to give a normalized truncation radius as:

$$\rho = (x_{truncation} - \langle x \rangle) / W_{0\ ke} = r_{truncation} / W_{0\ ke} \quad (35)$$

This truncation normalization is used in the ModeMaster PC for both higher-order modes and gaussian beams. For the gaussian beam being modeled,  $W_{0\ ke} = W_0 = W$  (since the profile is taken at the

internal waist location); then the integration variable is  $u = 2r^2$  and the truncated, noisy variance for the gaussian profile of Figure 5-12 (p. 5-35) is calculated as:

$$\langle r_{n\rho}^2 \rangle = \text{const.} \times E_0(1/P)2\pi \int_0^{\rho^2} \left[ \exp(-2r^2/w^2) + n_0/E_0 \right] r^3 dr \quad (36)$$

$$= (2/\pi w^2)2\pi(w^4/8) \int_0^{2\rho^2} u \left[ e^{-u} + n_0/E_0 \right] du \quad (37)$$

or the normalized experimental variance is:

$$\langle r_{n\rho}^2 \rangle / (w^2/2) = \left[ 1 - (2\rho^2 + 1) \exp(-2\rho^2) + 2\rho^4(n_0/E_0) \right] \quad (38)$$

This result is plotted in the following figure, which when correctly interpreted, explains the interactions between the options available on the Second Moment screen and leads to strategies for their optimal use.

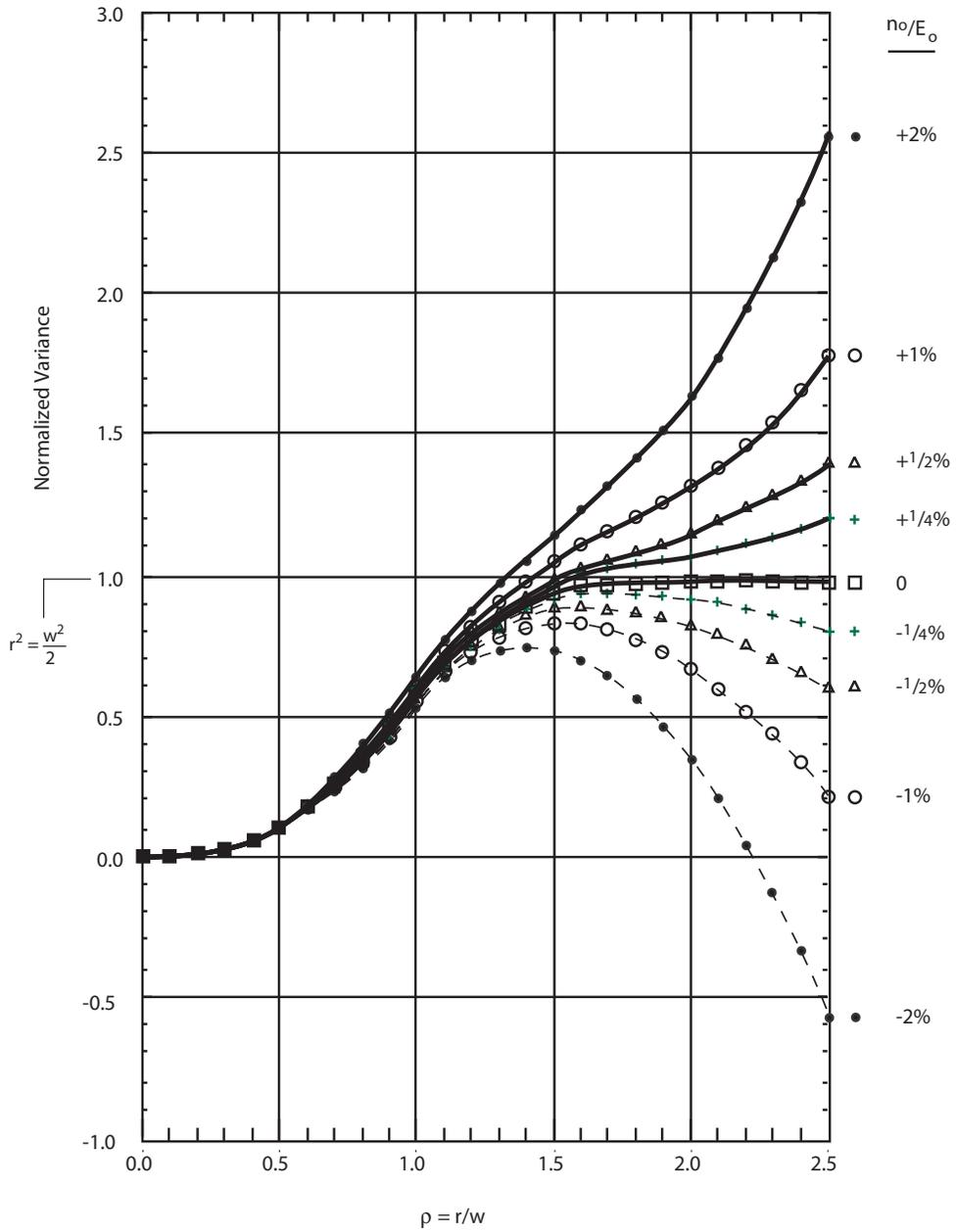


Figure 5-14. Normalized Variance for a Gaussian Mode Versus the Truncation Limit, with NoiseClip On and Off

## **Truncation Clipping Error**

Consider first the case when the noise is negligible,  $n_o/E_o = 0$ . The radius (measured in beam radii  $w$ ) where the integration is truncated is  $r$ ; as this increases from zero the variance grows as a sloping S-shaped curve towards the correct value of unity as more of the gaussian profile is included in the integration. The second term on the right hand side of Equation (38) is seen to give the fraction of the variance clipped by a premature truncation of the calculation; for the ModeMaster PC's Narrow truncation of  $\rho = 1.6$  the clipping error is -3.7%, and for the Wide truncation of  $\rho = 1.9$  the clipping error is -0.5% of the variance. In Figure 5-15 (p. 5-43), the observed values of  $M_r^2$  (prof.  $4\sigma$  calc.) for a gaussian profile are displayed, with various choices of second moment options, and the  $M^2$  value of 1.02 for Wide truncation is seen to drop to 0.96 for Narrow truncation. Clearly the Wide choice (the default value) is preferable for near-gaussian profiles. In the (unrealistic) noise-free case, the truncation point needs only to be greater than  $\rho = 1.9$ .

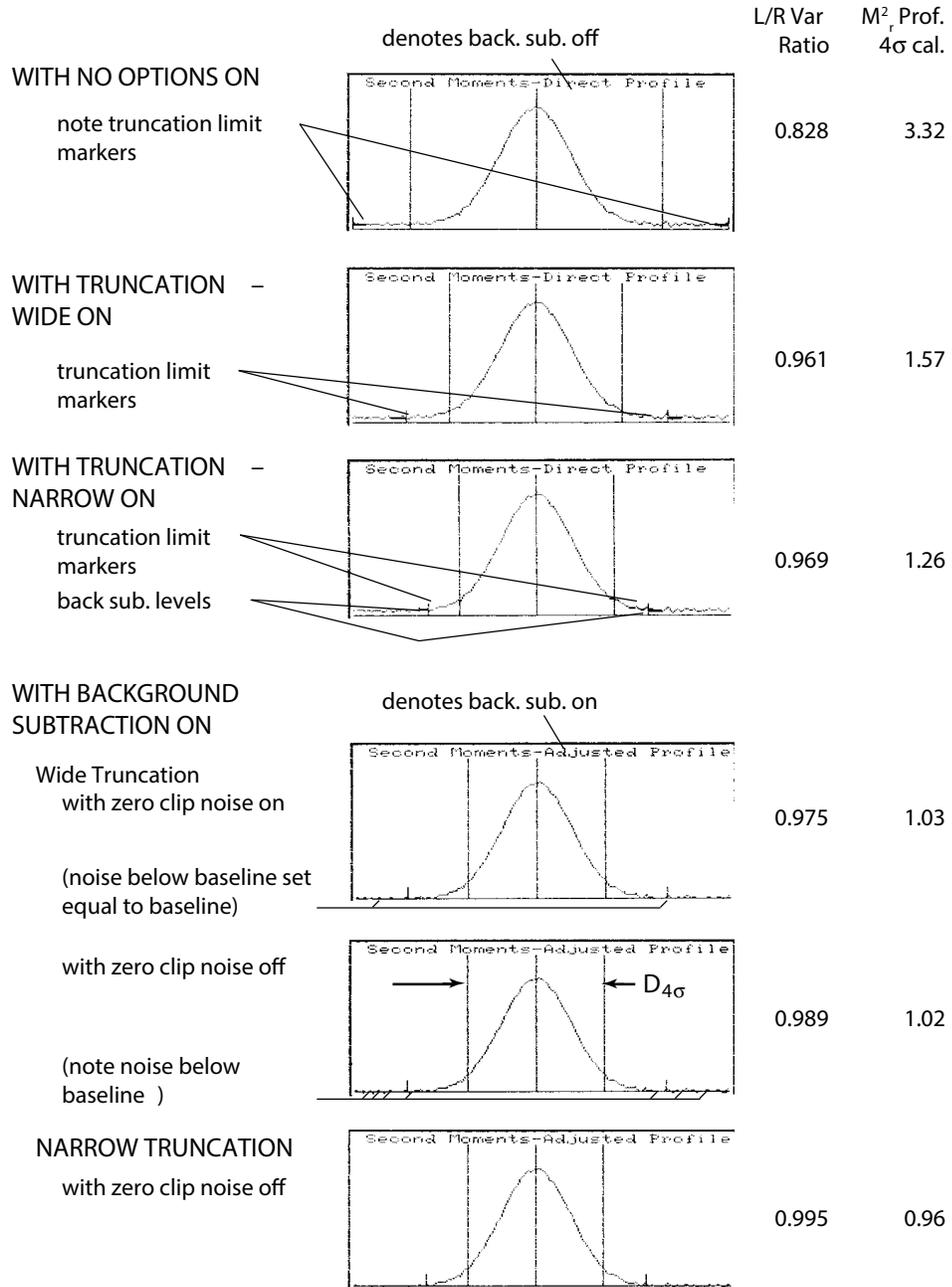


Figure 5-15. Effect of Second Moment Options

## Reducing the Effect of Noise—Background Subtraction

The pinhole profile background units is deliberately set at around +2% to +3% of full scale, to prevent clipping of negative-going (preamplifier) noise spikes before digitization and to preserve the full waveform for later noise averaging. With the Background Sub option Off, calculating the normalized variance to a truncation point  $r$  of a gaussian profile with this level of noise gives results similar to the  $n_0/E_0 = 2\%$  curve of Figure 5-14 (p. 5-41). At the maximum  $r = 2.5$  of that plot the normalized variance (here the same as the  $M^2$  from the profile) is 2.6, similar to the experimental value of  $M_{4\sigma}^2 = 3.3$  observed in this case for similar data in Figure 5-15 (p. 5-43) (top row). Clearly this background must be subtracted to get anywhere close to the correct value of  $M^2 = 1$ . In the ModeMaster PC, this is done with the Background Sub Option turned On (the default state).

The background level that is subtracted is the straight line drawn between end points located at the truncation limits, of heights equal to the average height of the twenty sample points immediately to the outside of the truncation limits (but always within the digitized width—given as the Scan Limits on the Second Moments screen). The average heights of these points is listed in percent of the 256 count full scale height on the Background Sub line of the Radial Second Moment screen.

## Reducing the Effect of Noise—Truncation Limits

After background subtraction, the next most effective way to reduce the effect of noise is to not include unnecessary noise in the calculation, and stop (truncate) the radial integration, as  $\rho$  increases from 0, in Equation (31) or (38), at the point where the signal has effectively dropped to zero.

With the Truncation option turned Off, the limits of the Right, Left variance integrations, Equation (31), are the values of  $r$  from 0 (at the mean) to the ends of the full width of the digitized window at  $-\langle x \rangle$  and  $L - \langle x \rangle$ . The mean location depends somewhat on the integration interval and the second moment calculation. Thus, when Truncation Wide or Narrow is turned On, moving the integration end points to  $r = +1.9$  or  $+1.6$ , respectively, the mean position within the new integration interval is recomputed before the second moment calculation is done. This iterative process of finding the mean is only done twice (i.e., the truncation limits are **not** moved after finding the new mean). Occasionally, if the original profile is not centered well within the digitized window, this will result in truncation limits that are noticeably not symmetrical about the final mean location, which is the mean that is displayed. If it seems unreasonable in switching between Wide and Narrow that the truncation of a noise spike causes a large change in  $M_{4\sigma}^2$ (profile), check to see if the mean location has shifted.

To avoid truncation clipping error (discussed above), the Wide truncation (the default choice) should be used for near-gaussian profiles. The truncation limits are set by Equation (35) in proportion to the measured knife-edge width  $2W_{o\ ke}$ , and for h.o.m. profiles this will tend to overestimate  $D_{4\sigma}$ . Also, higher order mode profiles drop to zero on the wings more quickly than do gaussians, so in the multi-mode beam case the Narrow truncation limits are likely to be appropriate. Viewing the location of the truncation markers relative to where the profile descends into the noise will help in deciding which truncation limits to use. The Narrow setting may be used to move the truncation point off of a particularly noisy area on the baseline, if this causes an erroneous Background Subtraction height. Another approach will be to just record a new profile.

To best illustrate the effect of different truncation limits, the results for  $M_{4\sigma}^2$  and the L/R variance ratio in Figure 5-14 (p. 5-41) are shown with Background Sub Off of changing from integration over the full window width, to Wide limits, to Narrow limits (upper half of the figure). The beam quality drops from 3.3 to 1.3 while the variance ratio approaches unity. These changes are about what is expected theoretically from Figure 5-14 (p. 5-41), with these changes in truncation limits for  $n_0/E_0 = 2\%$ . With the Background Sub On, reasonable values near unity are found for the beam quality for Wide truncation (and the L/R var ratio is closer to 1). Going to Narrow truncation in this case drops the measured beam quality below unity, due to truncation clipping error, as expected for a near-gaussian profile.

**Reducing the Effect of Noise—ZeroClip Noise Option**

Figure 5-15 (p. 5-43) shows that with Background Sub and Truncation On, there is a slight improvement in the measured beam quality by turning Off the NoiseClip option. In principle, the best  $M_{4\sigma}^2$  (profile) value is obtained with NoiseClip Off, as this permits the effects of the positive and negative noise spikes on the wings of the profile to average to near zero.

The effect of having this option On is shown in Figure 5-13 (p. 5-39). With background being subtracted, when in the integration a negative going spike is encountered, its amplitude is set equal to zero, while positive spikes are untouched and included in the calculation as found. In effect, the peak-to-peak noise on the wings of the signal is rectified and reduced by 1/2, to give the “equivalent rectified noise” level  $n_0$  of the model, yielding Equation (38).

The first use of this option for near-gaussian profiles, therefore, is to quantitatively estimate the signal-to-noise level  $n_0/E_0$  of a profile. This is done by varying the truncation limits, observing the changes in  $M_{4\sigma}^2$ . This is possible if the values of  $r$  at the various truncation

limits are reasonably obvious; if a match is found then the truncation clipping error and effectiveness of the zero-averaging of the noise (by turning NoiseClip Off) can be determined.

The main use of the ZeroClip Noise option, however, is to aid in the process of experimentally adjusting the beam parameters to minimize noise, to get the best second moment diameter. For example, cleaning dust off input optics can reduce amplitude noise by reducing the light scattered with beam pointing fluctuations. Other examples of beam noise reduction are the changing from current regulation to light regulation in an argon ion laser, and raising the excitation of almost any laser to operate further above threshold. If these changes inadvertently increased the noise on the profile, and NoiseClip was Off, subtraction of large negative noise spikes could give a false indication that the experimental change was in the right direction; when averaging high noise in the wings there is no bound positive or negative on where the variance calculation might go. With the noise rectified with NoiseClip On, reducing noise settles the variance result in towards a minimum; there is a definite lower bound (viz., the correct answer for the variance). The default value of NoiseClip is On, as it is assumed that initial step in using the Second Moments screen is minimizing beam noise.

While there is no certain bound on the variance with noise averaging, it is reasonable to assume, in the NoiseClip Off case that the average, constant level noise term would not be more than  $-n_0/E_0$  below the correct variance level out in the wings. That is, if the final term in Equation (38) is given a negative value (for  $n_0 < 0$ ), and the resulting equation plotted for the same magnitudes of  $n_0$ . There are obtained pairs of curves at different  $|n_0|$  values that set bounds for the noise-averaged variance as a function of the truncation limit.

Nevertheless, it is clear from Figure 5-15 (p. 5-43) that noise levels must be quite low to get reasonable accuracy for a second moment variance. For truncation at  $r = 1.9$ , an equivalent rectified noise level of less than 0.2% (less than 0.8% peak-to-peak amplitude) is required to be reasonably assured of 5% accuracy in the  $M_{4\sigma}^2$ (profile) result. The final use of the ZeroClip Noise option is thus to observe the change, when the option is toggled Off to get the final, best answer for the second moment beam quality. If the  $M_{4\sigma}^2$  value decreases slightly, by less than 5%, then a good job has been done on reducing beam noise and there can be confidence in the second moment results obtained.

## Checking the Reproducibility of the Second Moment Measurements

It is advisable in any measurement subject to significant error from noise to check the reproducibility of the final result by repeating the measurement. Ten different profiles from the same  $M^2 = 1$  beam were stored (by pressing Stop on the Second Moments screen) and analyzed under two different signal-to-noise ratio conditions. The standard deviation to mean ratios ( $+\sigma/m$ ) of the resulting beam qualities compared with those of ten knife-edge measurements of the same beams. The table below gives the comparison.

M2 Meas. $\pm\sigma / m$ from:	High S/N $\approx 50$ ( $n_0/W_0 \approx 0.5\%$ )	Low S/N $\approx 10$ ( $n_0/E_0 \approx 2.5\%$ )
K.E.	$\pm 0.49\%$	$\pm 0.53\%$
Profile	$\pm 2.5\%$	$\pm 5.4\%$

Three important conclusions can be drawn from the above table.

1. A range of  $> 10\%$  will commonly be observed in measurements of second moment beam qualities as the signal to noise levels required to do better will often not be available.
2. The logic for the choice of knife-edge based measurements as the main measurement means in ModeMaster PC is amply demonstrated as the error bars are one-fifth that for the direct second moment measurement.
3. The validity of having conversions from knife-edge measurements, to second moment measurements is demonstrated. With a  $+ 2\%$  diameter accuracy for the conversion ( $+ 4\%$  for  $M^2$ ) and  $+ 0.5\%$  for the basic knife-edge measurement, the converted value is expected to be as accurate as the direct second moment in the low signal-to-noise case while being a lot less trouble and considerably faster.

## Summary of Optimal Use of Second Moment Screen Options

1. In activating the screen from the Focal Plane Profile screen, always HOLD the highest, widest, best centered profile, to eliminate as much noise from the data at the start as possible.
2. Take steps to reduce the noise on the beam with NoiseClip On (and Background Sub On, with a fixed value of Trunc) by looking for a minimum value of  $M_{4s}^2$  (profile) as the experimental parameters affecting noise are varied.
3. Always use Background Sub On for the final data.
4. Always use Trunc Limits On at the narrowest setting with acceptable truncation clipping error for the final data (usually

the Wide setting for  $M_{ke}^2 < 2$ , going towards the Narrow setting for  $M_{ke}^2 > 3$ ).

5. Use NoiseClip Off for the best final answer, and look for a less than - 5% change of  $DM^2/M^2$  upon turning NoiseClip Off.
6. Check the reproducibility of the final answer by repeating it several times and computing the normalized standard deviation of the answers.

## Linear Second Moment Diameter

It is also possible to interpret the experimental profile  $E(x)$  as a one-dimensional scan across a (possibly asymmetric) two dimensional beam cross-section, and to calculate this *linear* second moment diameter. (Presumably, a second scan along the orthogonal direction  $y$  would then be used to complete the characterization of the beam, described by a mixture of Hermite-Gaussian modes.) This second moment is calculated with the transverse dimension weighted only as the square (as opposed to the use in Equations (31) and (38) of cubic weighting), and normalized as in Equation (34) (which gives the mean  $\langle x \rangle$ ), and the second moment diameter is four times—see Figure 1 (p. 5-2) the square root of the variance:

$$\sigma_x^2 = \langle x^2 \rangle - \langle x \rangle^2 = \int_0^L [x - \langle x \rangle]^2 E(x) dx \bigg/ \int_0^L E(x) dx \quad (39)$$

$$D_{4\sigma} = 4\sigma_x \quad (40)$$

Because of the lower weight of the transverse dimension in this calculation, the linear second moment result is not as sensitive to noise as the radial second moment. The ModeMaster PC uses the same truncation limits (and other options settings) for the linear calculation, as are set-up for the radial calculation. (Caution: For beams that are highly out-of-round, the radial truncation limits may not be the most appropriate for the linear calculation. If a large internal beam diameter can be achieved, using the full digitized width (Trunc Off) and the Width setting will give more control over the linear integration limits.

## **Conversion Between Beam Diameter Measurement Methods**

### **Diameter Measurement Methods**

Accuracy and speed are of central importance in any measurement device and they generally interrelate such that speed can be traded off for increased accuracy and vice versa. For example, in the presence of noise, greater accuracy can be achieved by making more measurements and averaging the results. A well designed instrument therefore makes use of methods that are inherently as fast and accurate as possible so there is wide latitude to make these trade-offs without subjecting the user to frustrating delays for unreliable results. Available and generally-accepted methods for making the beam diameter measurements needed to analyze beam propagation include the following:

- Moving knife-edge
- Moving pinhole
- Moving slit
- Variable diameter aperture

Each method has its own speed and accuracy characteristics that depend in different ways on whether or not the measurement can be made “on-the-fly,” how the raw data is processed, sensitivity to the various noise sources and whether or not there are fundamental accuracy problems with laser beams comprising mixtures of higher order cavity modes. For example, use of a moving pinhole requires that the scan line first be well centered in the beam. After it is aligned the data it produces can be collected and processed to compute the most basic and fundamental measure of beam diameter—the second-moment diameter. This computation requires significant time compared with processing the same data “on-the-fly” to immediately determine beam diameter as the distance traveled by the pinhole between locations where it transmits  $1/e^2$  (13.5%) of the maximum transmitted power. If the beam is made up of higher order modes or if the irradiance distribution has significant “lumpiness” these diameters can be very different from the second moment diameter. On the other hand, detector noise or a non-zero dark level can produce large error in the second moment diameter and have rela-

tively little effect on the  $1/e^2$  diameter. Accurate second-moment diameters can be determined under these conditions, but only at the expense of more computer processing time.

Like the moving pinhole, measurement of the power transmitted past a moving knife edge allows on-the-fly measurement of beam diameter as the distance traveled between set lower and upper transmitted power levels. Unlike the pinhole, the knife-edge does not require precise alignment in the beam. Also, since the knife-edge has zero width, there is no measurement error resulting from convolution of the irradiance profile with the aperture width as in the case of the moving pinhole or slit. Because of this and because the knife edge allows the same maximum power to reach the detector, regardless of the beam diameter being measured, it will be able to measure a much wider range of beam diameters than the pinhole or slit. Because of the inherent integration performed by the knife-edge, its results are even more reliable in the presence of noise than the pinhole or slit methods. The moving knife-edge does not, however, provide data from which second-moment diameters can be computed (for circular or elliptical irradiance distributions).

It is sufficient to say that there are many factors affecting the choice of a beam diameter measurement method. Current widespread use of all of these methods indicates there is no “best” method. The moving knife-edge was selected for use in the ModeMaster PC because of its speed, ability to accommodate a wide range of diameters and its insensitivity to both Master PC measurements with those from other methods is sometimes important, the capability has been provided for conversion of the knife-edge results to results equivalent to each of the other methods. For ModeMaster PC users, the most important of these is the conversion of knife edge results to equivalent second-moment diameters.

## **Diameter Conversions**

Knife-edge measured beam diameters and corresponding parameters including  $M^2$  and divergence angle may be accurately converted to the values that would come from the other methods. These conversions are accurate to within  $\pm 2\%$  for beams produced by lasers that generate mixtures of Laguerre-gaussian modes (circular rather than rectangular symmetry) in a geometrically-stable resonator. Accuracy of the conversions has been experimentally verified for these conditions. Use of the conversions under other conditions is unproved but may also provide acceptably-accurate results. The ModeMaster PC user with the important ability to check the accuracy of the second-moment conversion results and modify the conversion if necessary to improve accuracy. (The user-defined conversion is described in the section following this one.)

The measured diameter of a perfect gaussian beam, the  $1/e^2$  diameter, is identically the same for all of the measurement methods and the conversion algorithm used in the ModeMaster PC makes use of this fact. A consequence of this is that, unlike diameter, divergence and  $M^2$ ; the Rayleigh range for any beam will have the same value, regardless of the measurement method used to characterize the beam. (This assertion is readily proved by expressing the Rayleigh range in terms of beam waist diameter and beam quality,

$$Z_R = (\pi / 4\lambda) (2W_0)^2 / M^2, \quad (41)$$

and recalling that the diameter of any real beam is  $(2w)\sqrt{M^2}$ , where  $2w$  is the diameter of the underlying pure gaussian beam). Much more obvious is the fact that waist location is also unaffected by the choice of diameter measurement method.

Experimental results were taken to derive the conversion factors, initially with an ion laser that could be operated with beam quality values (as measured by the knife edge,  $M_{ke}^2$ ) between 1 and 4.5. This showed that there is a linear relationship between the square roots of the second-moment-beam quality,  $M_{4\sigma}^2$ , and the square root of the knife-edge beam quality  $M_{ke}^2$ . Subsequent measurements on other lasers of other types (all with stable resonators) showed similar linear relationships. It appears that as  $M^2$  increases (with increase in the mode-limiting aperture in the resonator), higher order modes are added into the beam in a characteristic sequence (primarily by adding the  $TEM_{0n}^*$  modes—Laguerre-Gaussian designation—which have the lowest diffraction loss of the pure modes at a given value of  $M^2$ ). The characteristic sequence of this restricted set of modes is such that the linear conversion rule provides accurate second moment diameters. Once the characteristic mode set was identified, conversions were calculated theoretically to go from  $M_{ke}$  to  $M$  values determined by slit or variable-aperture diameter measurements. These were linear as well, and were also confirmed by experiment (to the same  $\pm 2\%$  accuracy). This makes it possible to emulate second-moment, slit, and variable-aperture based measurements, by linear conversion of the directly measured knife-edge beam quality and diameter.

Because all the methods give the same result at  $M^2 = 1$ , the linear the relationship can be expressed using only a single constant if it is written in the following way:

$$M_{4\sigma} - 1 = c (M_x - 1) \quad (42)$$

Here  $M_{4\sigma}$  is the second moment result and  $M_x$  is the result from method “x”. One way to view the form of Equation (42) is as a transformation from the  $\{M_x, M_{4\sigma}\}$  coordinate system to the  $\{M_x - 1,$

$M_{4\sigma} - 1$  system where plots of  $M_{4\sigma}$  vs.  $M_x$  will all pass through the origin, so only a slope  $c$  and no offset term is required to relate the two variables.

Since the diameter,  $2w$ , of the pure gaussian underlying any mode is fixed and independent of the method used to measure beam diameters, it will always be true that:

$$\frac{D_x}{M_x} = 2w = \frac{D_{4\sigma}}{M_{4\sigma}} \quad (43)$$

Here  $D_x$  is the diameter of the real beam as measured by method “x” and  $D_{4\sigma}$  is the second-moment diameter of the real beam. Combining Equations (42) and (43) yields:

$$D_{4\sigma} = \frac{D_x}{M_x} [c(M_x - 1) + 1] \quad (44)$$

This equation allows computation of second-moment diameters from the measurable quantities  $D_x$  and  $M_x$  together with the value of  $c$  appropriate for the measurement method used. An exactly similar form (with a new value of  $c$ ) can be used for conversion between any two diameter measurement methods which are linearly related. The following table shows the values of  $c$  used by the ModeMaster PC to convert its knife edge-measured results to those that would be obtained by the other methods.

Knife-Edge Diameter to:	$c$
Second-Moment Diameter	0.808
Slit Diameter	0.848
Variable-Aperture Diameter	0.660

The variable aperture diameter (for a round beam) is the circular aperture diameter, which when centered on the centroid of the beam, transmits 86.5% of the beam. It is also called the  $D_{86}$  diameter.

**User Conversion  
Factor**

An important capability in ModeMaster PC allows the user to directly measure second-moment diameters of irradiance profiles recorded on the “Beam Profile-Focal Plane” screen. These diameters may be compared with the results from the standard conversion of knife-edge diameters to second moment diameters and if necessary the user can enter a conversion factor,  $U$ , to replace the default value. The value of  $c$  in Equation (44) that will convert the current knife-edge radial diameter, listed on the Second Moments screen, to the  $D_{4\sigma}$  listed just below and determined from the current profile.

This feature is provided to cover lasers with beams that are not expected to follow the standard sequence of mode additions on which the built-in conversion factors are based. Beams with large  $M_{ke}^2$  (greater than 6.5), high astigmatism, or large waist or divergence asymmetry such as are sometimes generated in unstable resonators are examples. The user then need only carefully set-up and check-out a profile for second moment analysis (low noise, unity variance ratio, proper truncation, reproducible results, etc.) at one time, and install that User  $U$  value. Then the user knife-edge conversion gives accurate second moment results, even with decreased signal-to-noise on the profile or other changes, so long as the laser is operated near the conditions for which the user conversion factor was defined.



## SECTION SIX: TROUBLESHOOTING TIPS

*Table 6-1. Troubleshooting Tips (Sheet 1 of 2)*

<b>PROBLEM</b>	<b>PROBABLE CAUSE</b>	<b>SOLUTION</b>
Controller not found.	USB Cable is not firmly connected. USB Driver is not working properly. Controller power is not on.	Inspect Windows Device Manager to verify proper USB operation. Verify that the Controller Green LED indicator is on.
Scan Head is not detected.	The Measurement wheel may not be turning. Scan Head may not be properly connected to the controller.	Verify that the wheel is rotating by looking through the Scan Head input lens. Verify that the 37-Pin Scan Head connector is securely attached to the Control/Interface Console.
File Results do not display in the User Interface.	File extension is incorrect or data has been altered.	Use Notepad or Excel to view the File. Verify the correct File extension .frd (Focus Data), .prd (Profile Data), .ptd (Pointing Data) or .smd (Second Moments Data). Verify that the Results or Results Structure have not been altered.
Live Results do not appear on the Screen.	Focus data is not available. Lens is not at the X, Y or R Position.	Check Propagation Screen and Verify that External Focus Data is available. Click on X, Y or R tool bar button to locate lens at a focus position.
Gamma Message appears after a focus run.	Laser input beam divergence is outside of current Scan Head Lens capability. Scan head location is not appropriate to laser waist location.	Verify the input beam specifications in the back of the manual (manual .pdf is included on the installation CD). Reposition the Scan Head. Review "Maximum Gamma Limit" (p. 3-17).
Pointing Stability Data does not display properly.	Noise Spike may have caused the auto-scale to increment dramatically.	Utilize the Pointing Stability Properties Panel "Vertical Full Screen" selection to reduce the scale manually. Continue to reduce the scale and view the data until the desired resolution is achieved.
ModeMaster PC screens do not display completely.	Display resolution is not set for 1024 x 768.	Go to the Control Panel and select Display. Use the Settings tab to set the Screen Area at 1024 x 768 pixels.
Notes files do not display the.txt extension.	Windows is not set to view this file type.	Tools menu. Select the "Folder Options" tab and then un-check "Hide extensions for known file types"
The Multiple Focus rotating icon displays many white pixels.	Display color is not set to High Color 16 Bit.	Go to the Control Panel and select Display. Use the Settings tab to set the Screen Colors to High Color (16 Bit).
Cannot view Profile.	Scan Head alignment is not adequate.	Pinhole "Find" button on the PropertiesPanel. Follow the wizard prompts.

**Table 6-1. Troubleshooting Tips (Sheet 2 of 2)**

<b>PROBLEM</b>	<b>PROBABLE CAUSE</b>	<b>SOLUTION</b>
Unable to obtain proper alignment with Near-Ir laser source.	Scan Head alignment is not adequate.	Utilize the Scan Head Flip Mirror and an IR viewing card to obtain adequate alignment. Place IR card close to laser source and adjust Scan Head alignment to reflect the beam on the card. Review “Alignment” (p. 1-11) for additional alignment information.
Focus Error “Multiple Waist Condition”	Excessive Laser Noise or the Scan Head is Misaligned.	If the data looks OK select “Pass to Curve Fit.” Utilize “Special Weights for better numerical results.”
Focus Error “No Waist Condition”	The scan head was unable to establish a focus at a cut plane, due to excessive wavefront curvature.	Verify that the Input beam is within the divergence range for the current scan head lens. If the Input beam is within range, reposition the instrument to a different location and run the focus again.
M <sup>2</sup> Value is not Correct.	Wavelength setting does not match the laser source. Clip Level setting is not appropriate to the input laser source.	Set the Wavelength within 1% of the input laser source. Review “Section Three: Operations” (p. 3-1) as well as “Theory of Operation” (p. 5-12) for Proper Clip Level Setting.
Doublet Lens Error Spacing value does not respond.	Lens contacts are not positioned properly in the scan head.	Verify that the Lens is extended outside the barrel. Apply gentle side pressure to the knurled lens carrier and check for dramatic change in current lens spacing error value.
Focus Results are not consistent.	Reflective Feedback from ModeMaster to Laser Source.	Adjust current alignment away from the exact center of the Alignment Target. Focus Again.
USB connection not detected with Windows 98.	Operating system is not optimized for USB operation.	Windows 98 may not detect the ModeMaster PC USB connection properly. Resolve this condition by unplugging the USB cable at either end and reconnect with the ModeMaster PC power ON. Restart the ModeMaster PC software to resume normal operation.
The following error message appears when you start the ModeMaster PC software. MODEMASTERPC.EXE file is linked to missing export MFC42.DLL.	Older versions of Windows 98® with other applications utilizing this file, may cause the conflict.	Go to support.microsoft.com and download a current version of MFC42.dll. The new version will not cause conflict with existing applications.

## SECTION SEVEN: WARRANTY AND SERVICE

In this section:

- Warranty (this page)
- Obtaining service (p. 7-2)
- Product shipping instructions (p. 7-3)

### **Warranty**

The seller warrants to the original Buyer each item manufactured by it to be free from defects in material and workmanship for a period of time and under such conditions as specified in the Seller's warranty for the individual product, or for twelve (12) months from delivery if a warranty for the individual product is not specified. Major sub-systems manufactured by other firms but integrated into the Seller's systems are covered by the original Manufacturer's warranty. The Seller's liability under valid warranty claims is limited to repair or replacement at the Seller's plant or the Buyer's location, all at the option of the Seller.

**The foregoing warranty is exclusive and in lieu of all other warranties, whether written, oral or implied and shall be the Buyer's sole remedy and the Seller's sole liability on contract or warranty or otherwise for the product. The Seller disclaims any implied warranty or merchantability or fitness for purpose.**

All claims under warranty must be made promptly after occurrence of circumstances giving rise thereto, must be received within the applicable warranty period by the Seller, and shall be subject to the terms and conditions stated herein. Such claims should include the product serial number, the date of shipment, and a full description of the circumstances giving rise to the claim. Before any products are returned for repair and/or adjustment, authorization for the Seller for the return and instructions as to how and where these Products should be shipped must be obtained. Any product returned to the Seller for examination and/or warranty repair shall be sent prepaid via the means of transportation indicated as acceptable by the Seller. The Seller reserves the right to reject any warranty claim on any item that has been shipped by non-acceptable means of transportation. When any product is returned for examination and inspection, or for any other reason, the Buyer and its shipping agency shall be responsible for all damage resulting from improper packing or handling, and for loss in transit, notwithstanding any defect of non-conformity

in the Product. In all cases, the Seller has sole responsibility for determining the cause and nature of failure, and the Seller's determination with regard thereto shall be final.

If it is found the Seller's Product has been returned without cause and is still serviceable, the Buyer will be notified and the Product returned at the Buyer's expense. In addition, a charge for testing and examination may, in the Seller's sole discretion, be made on products returned.

## Obtaining Service

In order to obtain service under this warranty, Customer must notify the Company of the defect before the expiration of the warranty period and make suitable arrangements for the performance of service. The Company shall, in its sole discretion, determine whether to perform warranty service at the Customer's facility, at the Company's facility or at an authorized repair station.

If Customer is directed by the Company to ship the product to the Company or a repair station, Customer shall package the product (to protect from damage during shipping) and ship it to the address specified by the Company, shipping prepaid. The customer shall pay the cost of shipping the Product back to the Customer in conjunction with annual recalibration and repair; the Company shall pay the cost of shipping the Product back to the Customer in conjunction with product failures within the first twelve months of time of sale or between annual recalibrations.

A Returned Material Authorization number (RMA) assigned by the Company must be included on the outside of all shipping packages and containers. Items returned without an RMA number are subject to return to the sender.

For the latest Customer Service information, refer to our website: [www.Coherent.com](http://www.Coherent.com).

Detailed instructions on how to prepare a product for shipping are shown under "Product Shipping Instructions" (p. 7-3).

**Table 7-1. Coherent Service Centers**

LOCATION	PHONE	FAX	E-MAIL
USA	1.800.343.4912	503.454.5777	info_service@Coherent.com
Europe	+49-6071-968-0	+49-6071-968-499	info_service@Coherent.com
International	503.454.5700	503.454.5777	info_service@Coherent.com

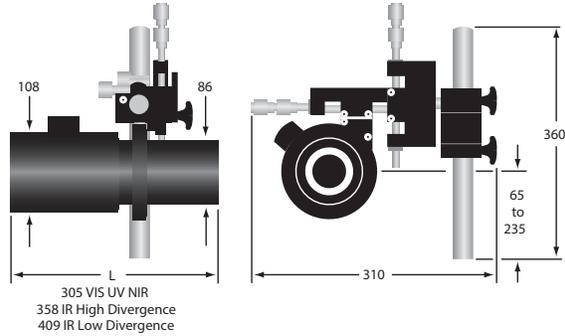
## **Product Shipping Instructions**

To prepare the product for shipping to Coherent:

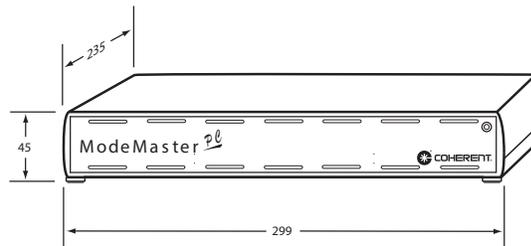
1. Contact Coherent Customer Service for a Return Material Authorization number—refer to Table 7-1 (p. 7-2) for contact information.
2. Attach a tag to the product that includes the name and address of the owner, the person to contact, the serial number, and the RMA number you received from Coherent Customer Service.
3. Wrap the product with polyethylene sheeting or equivalent material.
4. If the original packing material and carton are not available, obtain a corrugated cardboard shipping carton with inside dimensions that are at least 15 cm (6 in.) taller, wider, and deeper than the product. The shipping carton must be constructed of cardboard with a minimum of 170 kg (375 lb.) test strength. Cushion the instrument in the shipping carton with packing material or urethane foam on all sides between the carton and the product. Allow 7.5 cm (3 in.) on all sides, top, and bottom.
5. Seal the shipping carton with shipping tape or an industrial stapler.
6. Ship the product to:  
Coherent, Inc.  
27650 SW 95th Ave.  
Wilsonville, OR 97070  
Attn: RMA # *(add the RMA number you received from Coherent Customer Service)*



# APPENDIX A: SPECIFICATIONS



Scan Head Precision Mount



Control/Interface Console

STANDARD CONFIGURATIONS	UV LOW Divergence	UV HIGH Divergence	VIS LOW Divergence	VIS HIGH Divergence	NIR LOW Divergence	NIR HIGH Divergence	IR HIGH Divergence	IR LOW Divergence
Model Name	-1	-1S	-2	-2S	-3	-3S	-4	-5
Catalog Number	33-1843	33-2106	33-2221	33-2239	33-2387	33-2395	33-2429	33-2437
Spectral Range	0.22-0.68 $\mu\text{m}$		0.34-1.00 $\mu\text{m}$		0.80-1.80 $\mu\text{m}$		1.80-15 $\mu\text{m}$	
Detector Type	Silicon				Germanium		Pyroelectric	
INPUT BEAM REQUIREMENTS	AT TEST WAVELENGTH							
Test Wavelength <sup>a</sup>	351 nm		514 nm		1.06 $\mu\text{m}$		10.6 $\mu\text{m}$	
Minimum Power <sup>b</sup>	7.5 mW <sup>c</sup>		2.5 mW <sup>c</sup>		2.5 mW		400 mW	
Maximum Power <sup>b</sup>	10 W <sup>c</sup>		25 W <sup>c</sup>		2.5 W		20 W	
Noise	<2% RMS and <5% peak-to-peak							
Min. Divergence (mrad)	0.24	0.46	0.24	0.46	0.25 <sup>e</sup>	0.47 <sup>e</sup>	2.7	1.3
Max. Divergence (mrad) <sup>d</sup>	1.7	3.2	2.0	3.6	2.7	5.0	14	7.2
Max. Beam Dia. (mm) <sup>f</sup>	25	12	25	12	25	12	12	25

- Wavelength dependent quantities are input power levels, and minimum and maximum divergence: see notes b, e, f.
- Power levels are proportional to the inverse of the spectral response of the detector. The silicon detector peaks at 900 nm, and is at half peak sensitivity at 510 nm and 1050 nm. The germanium detector peaks at 1500 nm and is at half peak sensitivity at 1100 nm and 1650 nm. The pyroelectric detector has a flat spectral response.
- These limits may be reduced by a factor of 10 (higher sensitivity) by user-removal of the light restricting aperture in front of detector.
- The maximum divergence limit is fixed by the inability to accurately locate the internal waist when the internal beam diameter growth (over the span of the drum) is too slight. Limits shown are for  $M^2 = 1$  and test wavelength; limits scale as the square root of  $M^2$  (Test wavelength).
- Minimum divergence in this wavelength range scales as the square root of  $M^2$  (Test wavelength).
- Diameters are approximate, divergence takes precedence in choosing options. Refer to nomogram.

## System Specifications

### Accuracies:

Waist Diameter:  $\pm 2\%$

Waist Location:  $\pm 8\%$  of input beam Raleigh Range

Beam Quality -  $M^2$ :  $\pm 5\%$

Divergence:  $\pm 5\%$

Beam Translation:  $\pm [5\% \text{ of Waist Diameter} + 0.1 \text{ mm}]$

Pointing Angle:  $\pm [5\% \text{ of Divergence} + 0.04 \text{ mrad}]$

**Azimuth Angle Readout:**  $\pm 2^\circ$  (10-200°)

**Knife Edge Clip Levels:** User adjustable 0% to 100% in 1.5% steps.

**ModeMaster PC Control/Interface Console Update Rate:**  $<8 \text{ Hz}$  ( $M^2$ , divergence, power density, waist diameter, profiles)

**Analog Outputs:** Detector signal output, 0-13V maximum. A/D Control Signal Out, 0-5V pulse. Trigger (syncs to drum rotation), 0-5V pulse.

**Power:** 100-240 VAC, 47 to 63 Hz, 40W maximum.

## Minimum Computer Requirements

- 233 MHz or faster processor
- Microsoft® Windows 2000®, Windows Vista®, Windows XP®, or Windows 7® operating system
- CD-ROM drive
- 32 MB of RAM (64 MB recommended)
- 30 MB of free hard disk space
- USB port
- Serial communication port (for remote operation)
- 1024x768 screen resolution

# INDEX

## A

- Aberration limit,  $2We/f > (f/\#)$  help message 3-18
- About ModeMaster PC (help menu) 2-14
- Alignment (properties panel) 3-22
- Alignment view (view menu) 2-10
- Alignment zoom (properties panel) 3-20
- Alignment zoom indicators (properties panel) 3-21
- Analysis menu 2-12

## B

- Beam measurements 5-7
- Beam propagation screen 3-33
  - External 3-34
  - Internal 3-37
  - Manual lens movement 3-39
  - Properties panel 3-40
    - 2D select 3-41
    - 3D plot 3-41
    - Display select 3-41
    - Measurement cursor 3-41
  - Results panel 3-42
    - Data select (external) 3-42
    - Data select (internal) 3-44
    - Data select (transform) 3-45
    - Move lens to 3-42
  - X Y R buttons—beam propagation screen 3-40

## C

- Capture menu 2-11
- Clip level-knife edge conversion (capture menu) 2-12
- Components, unpacking 1-1
- Contents (help menu) 2-14
- Conversion between beam diameter measurement methods 5-49
  - Diameter conversions 5-50
  - Diameter measurement methods 5-49
  - User conversion factor 5-53
- Conversion limit, knife-edge M2 greater than 6.5 help message 3-18
- Customize (view menu) 2-10

## D

- Data collection (setup menu) 2-13
- Delay (properties panel) 3-24
- Display existing data 4-9
  - Power density setup 4-9

## E

- E-mail tech support (help menu) 2-14
- Exit (file menu) 2-7

- External beam propagation screen 3-34

## F

- File menu 2-3
- File structure (file menu) 2-6
- Focus (capture menu) 2-11

## G

- Gain (properties panel) 3-25
- Global settings 3-1
  - Clip level/knife-edge conversion factor 3-2
  - Knife-edge conversion 3-3
  - Scan head setup 3-7
  - Special weights
    - Analysis 3-4
    - Setup 3-4
  - Wavelength selection 3-7
- Go to (view menu) 2-10
- Graphical results area 2-17

## H

- Head (setup menu) 2-13
- Help, using 2-14

## I

- Installation procedures 1-1
  - Assembling scan head to column 1-2
  - Connections and controls 1-5
  - Making the connections 1-4
  - Oscilloscope traces 1-6
  - Unpacking components 1-1
- Instructions, product shipping 7-3
- Internal beam propagation screen 3-37

## K

- Keyboard shortcuts (help menu) 2-14
- Knife-edge diameter measurements 5-9

## L

- Large font option (properties panel) 3-24
- Laser diode collimation process 4-11
- Limited warranty 7-1
- Live/alignment window 2-2

## M

- M2 live/alignment screen 3-8
  - Focus 3-12
  - Help messages 3-13
    - Aberration limit,  $2We/f > (f/\#)$  3-18
    - Conversion limit, knife-edge M2 greater than 6.5 3-18
    - Maximum gamma limit 3-17

- Staying within the Nomogram boundaries - hierarchy of help messages 3-16
  - Properties panel 3-19
    - Alignment 3-22
    - Alignment zoom 3-20
    - Alignment zoom indicators 3-21
    - Delay 3-24
    - Gain 3-25
    - Large font option 3-24
    - Maximum power density 3-33
    - Pinhole 3-29
    - Pinhole select 3-25
    - Power density 3-30
    - Power density plot 3-30
    - Profile plane 3-25
    - Profile plot 3-24
    - Width 3-24
  - R-beam 3-19
  - Status bar 3-11
  - X-Y-R toolbar buttons 3-19
  - Manual lens movement beam propagation screen 3-39
  - Maximum gamma limit help message 3-17
  - Maximum power density (properties panel) 3-33
  - Menu
    - Analysis 2-12
      - Statistics 2-12
    - Capture 2-11
      - Clip level-knife edge conversion factor 2-12
      - Focus 2-11
      - Move lens 2-12
      - Multiple focus runs 2-11
      - Run 2-11
      - Special weights 2-12
      - Stop 2-11
    - File 2-3
      - Exit 2-7
      - File structure 2-6
      - Open 2-4
      - Print 2-6
      - Print preview 2-7
      - Print setup 2-7
      - Recent file 2-7
      - Save/save as 2-4
    - Help 2-13
      - About ModeMaster PC 2-14
      - Contents 2-14
      - E-mail tech support 2-14
      - Keyboard shortcuts 2-14
      - Tip of the day 2-14
      - Tutorial 2-14
      - Using help 2-14
      - Website 2-14
    - Setup 2-13
      - Data collection 2-13
      - Head 2-13
      - Options 2-13
      - Wavelength 2-13
    - View 2-8
      - Alignment view 2-10
      - Customize 2-10
      - Go to 2-10
      - Pointing view 2-10
      - Propagation view 2-10
      - Status bar 2-10
      - Toolbar 2-10
  - Menus 2-2
  - ModeMaster PC modular accessories 1-18
    - Detector change 1-24
    - Installing a new accessory 1-18
    - Lens change 1-21
  - ModeMaster PC system overview 1-1
  - Move lens (capture menu) 2-12
  - Multiple focus 3-63
    - Statistics on existing focus data 3-67
  - Multiple focus runs (capture menu) 2-11
- N**
- Numerical results area 2-18
- O**
- Obtaining service 7-2
  - Open (file menu) 2-4
  - Optimal use of the second moments screen 5-33
    - Averaging the moments from the left and right half-profiles 5-37
    - Checking the reproducibility of the second moment measurements 5-47
    - Definitions 5-35
    - Linear second moment diameter 5-48
    - Modeling noise on the experimental profile 5-37
    - Overview 5-33
    - Reducing the effect of noise—background subtraction 5-44
    - Reducing the effect of noise—truncation limits 5-44
    - Reducing the effect of noise—zeroclip noise option 5-45
    - Summary of optimal use of second moment screen options 5-47
    - Truncation clipping error 5-42
  - Options (setup menu) 2-13
  - Overview
    - ModeMaster PC 2-1
    - Operations 3-1
- P**
- Pinhole (properties panel) 3-29
  - Pinhole select (properties panel) 3-25
  - Pointing stability run (finding the pivot) 4-13
  - Pointing stability screen 3-48
    - Properties panel 3-50

- Cursor 3-52
- Filter 3-51
- Hours 3-53
- Minutes 3-53
- Mode 3-51
- Option 3-51
- Pointing stability run 3-53
- Results panel 3-52
- Translational distance (m) 3-52
- Vertical full screen 3-52
- Pointing view (view menu) 2-10
- Power density (properties panel) 3-30
- Power density plot (properties panel) 3-30
- Preface xii
- Preparing for installation 1-1
- Print (file menu) 2-6
- Print preview (file menu) 2-7
- Print setup (file menu) 2-7
- Product shipping instructions 7-3
- Profile plane (properties panel) 3-25
- Profile plot (properties panel) 3-24
- Propagation view (view menu) 2-10
- Properties panel 2-17
- Properties panel beam propagation screen 3-40
- Publication updates xiii
- R**
- Real-beam propagation theory 5-2
- Recent file (file menu) 2-7
- Results panel beam propagation screen 3-42
- Run (capture menu) 2-11
- S**
- Save/save as (file menu) 2-4
- Second moments screen 3-54
  - Internal/external radial results area 3-56
  - Knife-edge clip levels setting 3-55
  - Properties panel 3-57
    - Delay 3-58
    - Gain 3-58
    - Width 3-58
  - Truncation 3-59
    - Background subtraction 3-60
    - Second moments setup 3-60
    - Update second moments 3-63
    - Waist diameter 3-60
    - ZeroClip noise 3-59
- Second moments setup 4-16
- Service, obtaining 7-2
- Special weights (capture menu) 2-12
- Specifications A-1
  - Minimum computer requirements A-2
  - System specifications A-2
- Start-up 1-7
  - Alignment 1-11
  - The ModeMaster PC M2 live/alignment screen 1-11
  - Doublet wavelength selection 1-9
  - Initialization 1-7
  - Power on sequence 1-7
  - Singlet wavelength selection 1-10
- Start-up - initialization 4-1
- Statistics (analysis menu) 2-12
- Status bar 2-16
- Status bar (view menu) 2-10
- Stop (capture menu) 2-11
- System
  - Components 1-1
- T**
- Theory of operation 5-12
  - Azimuthal adjustment for locating the beam principal planes 5-18
  - Beam axis location and direction 5-14
  - Beam diameter measurements 5-13
  - Coordinates and sign conventions 5-14
  - Diffraction-limited lenses 5-16
  - Instrument axis alignment 5-16
  - Introduction 5-12
  - More details on the instrument 5-21
    - Computing M2 in real-time (and how M2 less than 0.95 can result) 5-21
    - Limiting effects at the Nomogram boundaries 5-23
    - More on profiles 5-31
    - Real time versus historical data 5-22
    - The reference plane and the lens principal planes 5-27
    - The transformation through the lens to the external beam 5-29
  - System modularity - broadening the range of input beam wavelengths and divergences 5-19
  - The equivalent radially-symmetric beam 5-15
- Tip of the day (help menu) 2-14
- Toolbar 2-15
- Toolbar (view menu) 2-10
- Troubleshooting tips 6-1
- Tutorial (help menu) 2-14
- U**
- Updates, publication xiii
- Useful equations 5-6
- W**
- Warranty 7-1
  - Limited 7-1
- Wavelength (setup menu) 2-13
- Website (help menu) 2-14
- What's new in ModeMaster PC xii
- Width (properties panel) 3-24
- Working with ModeMaster PC files 4-5





