Laser Beam Expanders

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Laser Beam Expander Theory

Diffraction

Perfect Gaussian Laser beams are often characterized by a parameter known as beam divergence. Divergence is the angular spreading of light waves as they propagate through space. Even a perfect unaberrated ray of light will experience some beam divergence due to diffraction effects. Diffraction is the effective bending of light rays caused by truncation from an opaque object such as a knife edge. The spreading arises from secondary wavefronts emitted from the edge of truncations. These secondary waves interfere with the primary wave, and also themselves, sometimes forming quite complicated diffraction patterns.

Diffraction makes it impossible to perfectly collimate light, or to focus it to an infinitely small spot size. Fortunately diffraction effects can be calculated. Consequently theory exists which predicts the degree of collimation and spot size for any diffraction limited lens.

Now consider a beam waist (S_o) such as that emerging from a low power TEM_{oo} gas laser (figure 1). We are considering a low power laser so that it can be assumed

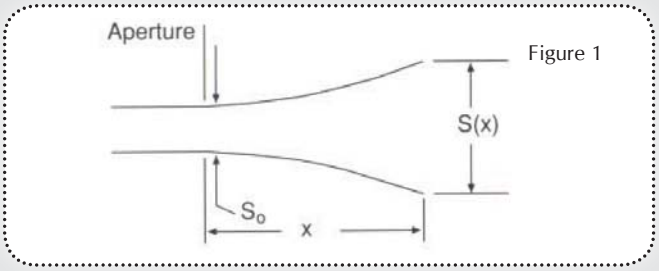

Figure 1

to be diffraction limited and free of any thermal lensing effects. It can be shown that the curvature, or spreading, of the waist due to diffraction can be expressed as follows:

$$S(x) = S_o[1 + (\lambda x/\pi S_o^2)^2]^{1/2}$$

where x is the distance from the waist source and l is the laser wavelength. If $lx/pS_o^2 >> 1$, then:

$$S(x) = \lambda x/\pi S_o$$

Using this approximation we can then write the beam divergence angle due to diffraction as:

$$\theta = S(x)/x = \lambda/\pi S_o$$

q is also known as the far field divergence.

Improving Divergence

The far field beam divergence defines the best collimation for a given beam diameter. It also illustrates that zero beam divergence or perfect collimation can never be achieved, because doing so would require and infinite beam diameter. However this equation does suggest a means of improving divergence.

Consider a collimated beam of light with a beam divergence of q and a beam diameter of S_0. Clearly, if the beam diameter were to be increased, the far field divergence would be decreased by the inverse proportion i.e. by 1/< where M is the expansion ration. This is precisely the advantage of expanding laser beams. In addition, lower divergence allows for better focusing of Gaussian beams (see Bestform Laser Lenses). With this improvement in mind we now describe several ways of expanding collimated light.

Galilean Beam Expanders

The most common type of beam expander is derived from the Galilean telescope (figure 2) which usually has one negative input lens and one positive output lens. The input lens presents a virtual beam focus at the output. For lens expansion ratios (1.3x-20x) the Galilean

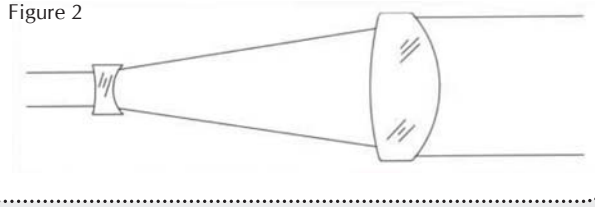
Figure 2

telescope is most often employed due to its simplicity, small package size and low cost. Designs can usually be obtained having minimal spherical aberration, low wavefront distortion and achromaticity. Limitations are that it cannot accommodate spatial filtering or larger expansion ratios.

Keplerian Beam Expanders

In cases where larger expansion ratios or spatial filtering is required, Keplerian design telescopes are employed. The Keplerian telescope has a positive input element presenting a real beam focus to the output elements. In addition, spatial filtering can be instituted by placing a pinhole at the focus of the first lens.

Achromatic (Dual Wavelength) Beam Expanders

Special Optics Achromatic (Dual wavelength) beam expanders provide diffraction limited collimation at both 1064nm and 532nm simultaneously. The air spaced designs enable usage in high power Nd:YAG applications. The use of high efficiency antireflection coatings on all interior surfaces also ensures low reflection loss.

Specifications:

Wavefront Distortion ..... < 1/4 Wave
Transmission ..... > 97%
Coating Damage Threshold 500 MW/cm2
Useable Spectral Range 0.500-1.100nm

Features

- Adjustable Lens Spacing
- Low Insertion Loss
- Dual Wavelength Correction

Achromatic (Dual Wavelength) Beam Expanders

Model	Expansion Ratio	Input Aperture (mm)	Output Aperture (mm)	Dimensions O.D. x Length (mm)	Wavelength Range (nm)
52-25-5XA	5.0X	5.0	25	31.75 x 122	532 & 1064
50-40-5XA	5.0X	8.0	40	50.80 x 142	532 & 1064
52-25-10XA	10.0X	2.5	25	31.75 x 140	532 & 1064
50-80-10XA	10.0X	8.0	80	102.0 x 332	532 & 1064
52-25-5XAP	5.0X	5.0	25	31.75 x 140	700 - 900
50-45-5XAP	5.0X	8.0	45	57 x 165	700 - 900

High Power Beam Expanders

Special Optics High Power beam expanders are specifically designed with a convex first surface, which diverges the return reflection from the first lens surface and prevents any damage backstream of the beam expander.

Note: Low Power beam expanders may have a return reflection that is not suitable with high power lasers.

Specifications:

Wavefront Distortion ..... < 1/4 Wave
Transmission ..... > 97%
Coating Damage Threshold 500 MW/cm2
Useable Spectral Range ..... 248 - 1550 nm

Features:

- Adjustable Focus for Collimation
- Diffraction Limited Design
- Large Input Apertures
- High Transmission
- No Focused Retro-reflections

High Power Beam Expanders

Model	Expansion Ratio	Input Aperture (mm)	Output Aperture (mm)	O.D. x Length @1064 nm (mm)
52-25-2X-λ	2 X	7.0	15.0	34.9 x 72
52-25-4X-λ	4 X	7.0	30.0	44.5 x 127
52-51-7X-λ	7 X	7.0	51.6	66.7 x 172
52-71-5X-λ	5 X	14	71.6	85.7 x 248
52-71-10X-λ	10 X	7.0	71.6	85.7 x 248
52-71-20X-λ	20 X	3.5	71.6	85.7 x 248

Please replace λ in model number with working wavelength when ordering

IR Beam Expanders

Special Optics IR beam expanders have adjustable lens spacing and use Zinc Selenide lens elements that enable low insertion loss over a spectral range from 9.0 to 10.6 microns. We offer both an IR beam expanders and IR Variable beam expander.

Specifications:

Wavefront Distortion ..... < 1/4 Wave
Transmission ..... > 97%
Coating Damage Threshold 100 MW/cm2

Features:

- Adjustable Lens Spacing
- Low Insertion Loss
- Zinc Selenide Lens Element

IR Beam Expanders

Model	Expansion Ratio	Input Aperture (mm)	Output Aperture (mm)	Dimensions O.D. x Length (mm)	Wavelength Range (microns)
53-25-2X-λ	2X	12.5	25	38.1 x 83	9.0 - 10.6
53-25-3X-λ	3X	4.0	15	31.75 x 83	9.0 - 10.6
53-25-5X-λ	5 X	5.0	25	44.5 x 109	9.0 - 10.6
53-25-10X-λ	10 X	2.5	25	38.1 x 147	9.0 - 10.6
53-50-2X-λ	2 X	25	50	69.9 x 147	10.6
53-50-5X-λ	5 X	10	50	69.9 x 147	10.6
53-50-10X-λ	10 X	5.0	50	69.9 x 147	10.6
53-76-5X-λ	5 X	14.4	72	85.7 x 230	10.6
53-76-10X-λ	10 X	7.2	72	85.7 x 230	10.6

Please replace λ in model number with working wavelength when ordering.

Large Output Beam Expanders

Special Optics line of large output beam expanders provide diffraction limited performance over the entire 100 mm aperture, and deliver low wavelength distortion and high transmittance over a broad spectral range. They feature adjustable focus for collimation at various wavelengths, broadband antireflection coatings, large output and input apertures and a diffraction limited Galilean design. Wavefront distortion is standard at less than 1/2 wave, but 1/4, 1/8, or 1/10th wavefront distortion can be achieved upon request. Custom systems have been designed to provide output beam diameters of over 200mm as well as input beam diameters that exceed 100mm. Note: 1/4, 1/8 or 1/10th Wavefront Distortion can be achieved. Please call or email us for this request.

Specifications:

Wavefront Distortion ..... < 1/2 Wave
Useable Spectral Range .....400-1650 nm
Transmission ..... > 92%
Coating Damage Threshold ....500 MW / CM2
Dimensions .....15″ x 5 1/2″

Features:

- Adjustable Focus For Collimation At Various Wavelengths
- Diffraction-Limited, Galilean Design
- Large Output & Input Apertures
- Broadband AR Coated For High Transmission

Large Output Beam Expanders

Model	Expansion Ratio	Input Aperture (mm)	Output Aperture (mm)
50-100-5X-λ	5X	20	100
50-100-10X-λ	10X	10	100
50-100-20X-λ	20X	5	100
50-100-40X-λ	40X	2.5	100

Please replace in λ model number with working wavelength when ordering

Low Power Beam Expanders

Special Optics low power beam expanders incorporate a high performance optical design that is optimized for use with our F-Theta Scanning lenses. Optimum energy throughput is achievable with a maximum input aperture of 11mm. The maximum output aperture is 47mm. Ideal for integration for a variety of applications, these beam expanders are available in a selection of magnifications ranging from 2X – 26X. All Special Optics beam expanders offer diffraction limited performance and have focus adjustment for collimation at various wavelengths, divergence correction, and focusing.

Specifications:

Wavefront Distortion ..... < 1/4 Wave
Transmission ..... > 97%
Coating Damage Threshold 500 MW/cm2
Useable Spectral Range .....248 - 1550 nm

Features:

- Adjustable Focus for Collimation at Various Wavelengths
- Diffraction limited design
- Large input apertures
- High Transmission
- AR Coated
- High Damage Threshold

Low Power Beam Expanders

Model	Expansion Ratio	Input Aperture (mm)	Output Aperture (mm)	Length @ 1064 nm(mm)	Availability
50-25-2X-λ	2 X	11.0	22	89	In Stock for 820-1220nm
50-25-3X-λ	3 X	7.3	22	108	Call
50-25-4X-λ	4 X	5.5	22	118	In Stock for 1064nm
50-25-4.5X-λ	4.5 X	4.8	22	126	Call
50-25-5X-λ	5 X	4.4	22	122	Call
50-25-6X-λ	6 X	3.6	22	128	Call
50-25-7X-λ	7 X	3.1	22	131	Call
50-25-8X-λ	8 X	2.7	22	138	In Stock for 1064nm
50-25-10X-λ	10 X	2.2	22	140	Call
50-25-12X-λ	12 X	1.8	22	141	Call
50-25-18X-λ	18 X	1.3	22	145	Call
50-51-4X-λ	3.9 X	11.7	47	203	Call
50-51-7X-λ	6.8 X	6.7	47	239	Call
50-51-10X-λ	10.2 X	4.7	47	253	Call
50-51-20X-λ	20.6 X	2.3	47	267	Call

Please replace λ in model number with working wavelength when ordering.

Motorized Zoom Beam Expander

For automated applications, Special Optics developed motorized versions of our zoom beam expanders. Our Motorized Zoom beam expanders combine our proprietary 5 lens-element optical designs from our manual zoom beam expanders, with built-in adjustment motors for controlling lens groups. With our motorized systems, both expansion ratio and focus can be controlled independently from a remote location via controller electronics and software running on the Windows platform and LabView.

Special Optics Motorized Zoom beam expanders typically employ a proprietary 5 lens-element design with 3 lens groups to reduce the internal focus. Also, we use fused silica lenses on the two input groups. As a result, high damage thresholds can be achieved.

Beam wander is critical in any zoom lens so we employ a proprietary "rail" design which allows for minimal beam wander while maintaining diffraction limited performance over the entire expansion range. Custom designs have been built which produced wander of less than 0.1 mrad.

With Special Optics Motorized Zoom beam expanders, variable magnification levels can automatically be set ranging from 2X-8X, 2X-10X, 1X-4X, and 1X-5X. This variability helps to reduce machine set up times and provides flexibility to equipment for a wide range of jobs. Laser protection class is also maintained as continuous opening of the machine is no longer required.

These beam expanders are also ideal for general laboratory research.

Specifications:

Expansion Range	2x-8x Continuous or 1x-4x continuous
Input Aperture	10mm Max
Output Aperture	30mm
Beam Wander	0.15 mRad for 1-4X Beam Expander, 0.3 mRad for 2-8X Beam Expander
Wavefront Distortion	< 1/4 Wave @ 633 nm
Usable Wavelength Range	see table below
Field of View	+ / - 0.5 Degrees
Transmission	> 95%
Damage Threshold UV & VIS-NIR models	< 100 MW/cm2
Damage Threshold IR (CO_2) models	20 kW/cm2 pulsed wave, 1kW/cm2continuous wave
Expansion Change Time	< 5 seconds
Usable Temperature Range	-10 to +50 Celsius

Features:

- RS232 Serial interface
- One motor control box
- Default expansion settings pre-programmed
- User-controlled focus adjustment
- Users can define custom expansion settings
- Compact 2" outside diameter for standard optical mounting
- Windows compatible
- Developed in LabViewTM
- GUI (.DLL) can be addressed from C++ or other languages (1-4X Beam Expander Only.)

Design:

- Diffraction-limited design
- 5 element design reduces internal focus
- Continuous zoom and focus adjustments
- Mechanicals specifically designed to minimize beam wander

Motorized Zoom Beam Expander

Model Number	Standard Wavelength Ranges	Availability
VIS-NIR 56C-30-2-8X-λ VIS-NIR 56C-30-1-4X-λ	450-675, 600-900, 800-1200, 1100-1600 nm	Call Call
UV 61C-30-2-8X-λ UV 61C-30-1-4X--λ	248-425 nm	In Stock for 355nm Call
IR (CO_2) 53C-30-2-10X-λ IR (CO_2) 53C-30-1-5X-λ	9.3 or 10.6 um	Call Call

Please replace λ in model number with working wavelength when ordering.

UV Beam Expanders

Special Optics UV beam expanders use UV grade Fused Silica lenses that permit high energy transmission with low insertion loss over a usable spectral range from 248nm to 355nm. These beam expanders have adjustable lens spacing and no focused retro-reflections.

UV Beam Expanders

Specifications:

Wavefront Distortion ..... < 1/4 Wave
Transmission ..... > 97%
Coating Damage Threshold ....500 MW/cm^2
Useable Spectral Range .....0.248 - 0.355 nm

Features

- No Focused Retro-reflections
- Adjustable Lens Spacing
- Low Insertion Loss

UV Beam Expanders

Model	Expansion Ratio	Input Aperture (mm)	Output Aperture (mm)	Dimensions O.D. x Length (mm)	Wavelength Range (microns)
61-25-4X-λ	4X	6.25	25	31.75 x 120	0.248 - 0.355
61-25-7X-λ	7X	3.5	25	31.75 x 134	0.248 - 0.355
61-25-10X-λ	10X	2.5	25	31.75 x 141	0.248 - 0.355
Please replace λ in model number with working wavelength when ordering.					

UV Variable Beam Expander

Specifications:

Wavefront Distortion ..... < 1/4 Wave
Transmission ..... > 95%
Coating Damage Threshold 100 MW/cm2
Useable Spectral Range .....0.248 - 0.351 nm

Features:

- Compatible to Standard Computer Controlled Actuators
- Minimal Internal Focus for High Power Use
- Large Input and Output Apertures
- Replaces Several Fixed Wavelength Devices
- Non-Rotating Lens Elements, Eliminating Beam Wander
- Fused Silica Lens Elements

UV Variable Beam Expander

Model	Expansion Range	Max. Input Aperture (mm)	Max. Output Aperture (mm)	O.D.(mm)	Max. length (mm)	Availability
61-30-2-8X--λ	2-8X	10	30	37.6	167	In Stock for 325nm
Please replace λ in model number with working wavelength when ordering.						

Variable Zoom Beam Expanders

For applications where the exact expansion ratio required is not known, Special Optics offers both manual and motorized zoom beam expanders. Our proprietary diffraction limited 5-element design, allows for continuous expansion selection from 2X to 8X. Fused silica lenses are used on the two input groups to allow for high damage thresholds. Both expansion ration and focus can be controlled independently so that diffraction limited performance can be maintained at any single wavelength from 488-1300 nm.

Special Optics Variable Zoom Beam Expanders are ideal to compensate for varying optical path lengths. They allow you to match the beam diameter of the laser to the aperture of the optical system. They typically employ a proprietary 5 lens-element design with 3 lens groups to reduce the internal focus. Also, we use fused silica lenses on the two input groups. As a result, our zoom beam expanders tolerate a very high damage threshold.

With Special Optics zoom laser beam expanders, variable magnification levels can easily be set ranging from 2X-8X, 2X-10X, 1X-4X, and 1X-5X. This variability makes Special Optics Beam Expanders ideal for easier set ups on OEM machines, provides flexibility to equipment and are ideal for general laboratory research.

Choose from VIS, IR, or UV variable beam expanders.

VIS Beam Expanders

Specifications:

Wavefront Distortion ..... < 1/4 Wave
Transmission ..... > 95%
Coating Damage Threshold .... 100 MW/cm^2
Useable Spectral Range .....450-1100 nm

Features:

- Diffraction-limited design
- 5 element design reduces internal focus
- Continuous zoom and focus adjustments
- Mechanicals specifically designed to minimize beam wander
- Reduce machine setup times

VIS Beam Expanders

Model	Expansion Range	Max. Input Aperture (mm)	Max. Output Aperture (mm)	O.D. (mm)	Max. length (mm)
56-30-2-8X-λ	2-8X	10	30	37.6	167
56-45-2-8X-λ	2-8X	10	45	66.7	163

Please replace λ in model number with working wavelength when ordering.

Variable Zoom Beam Expanders

IR Variable Beam Expanders

Features:

- Adjustable Lens Spacing
- Low Insertion Loss
- Zinc Selenide Lens Elements

IR Variable Beam Expanders

Model	Expansion Range	Input Aperture (mm)	Output Aperture (mm)	Dimensions O.D. x Length (mm)	Wavelength Range (microns)
53-26-2-10X-λ	2-10X	10	26.5	48.0 x 180	9.3 or 10.6

Please replace λ in model number with working wavelength when ordering.

UV Variable Beam Expanders

Specifications:

Wavefront Distortion ..... < 1/4 Wave
Transmission ..... > 95%
Coating Damage Threshold ....100 MW/cm^2
Useable Spectral Range .....0.248 - 0.355 nm

Features:

- Compatible to Standard Computer Controlled Actuators
- Minimal Internal Focus for High Power Use Large Input and Output Apertures
- Replaces Several Fixed Wavelength Devices
- Non-Rotating Lens Elements, Eliminating Beam Wander
- Fused Silica Lens Elements

UV Variable Beam Expanders

Model	Expansion Range	Max. Input Aperture (mm)	Max. Output Aperture (mm)	O.D. (mm)	Max. length (mm)	Availability
61-30-2-8X-λ	2-8X	10	30	37.6	167	In Stock for 325nm

Please replace λ in model number with working wavelength when ordering.

Beam Expanders Accessories

Special Optics offer several accessories for our line of beam expanders including Alignment Apertures, Threaded Adaptors, and Vee Block Mounts.

Alignment Apertures

The Model 60-16-1.5 Alignment Aperture has a 1.5 mm central hole and screws into all 50-25 and 50-51 Series Beam Expanders. This removable aluminum plug is extremely useful in the initial centering and alignment of the beam expander.

Model	T Thread (inches)
60-16-1.5	1″ 32 TPI
60-17-1.5	1.1/8 32 TPI

Threaded Adaptors

These Threaded Adaptors, compatible with 50-25 and 50-51 Series Beam Expanders, are useful for mounting the beam expander directly to the laser or other threaded optical components.

Model	Thread (B.E. Side)	Thread (Laser Side)
60-16-30	1″ - 32 TPI	1″ - 32 TPI
60-16-51	1″ - 32 TPI	2″ - 32 TPI

Vee Block Mounts

The Vee Block Mounts are stable non-adjustable mounts which are used with the 50 and 52 Series Beam Expanders. Model 60-16-25 is suggested for barrel diameters between 25 and 45 mm, and Model 60-16-26 is suggested for diameters between 46 and 80 mm.

Model	A	B	C	D	E	F	G
60-16-25	1.25	1.00	1.25	2.00	1.63	0.716	0.147
60-16-26	2.25	1.63	2.25	3.25	2.75	1.13	0.187

Custom Lens Quote

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Special Optics excels at the rapid design and production of custom precision lens assemblies. We would be happy to work up a custom quote to fit your specific needs. To receive your quote, please complete all applicable fields in the page below and fax 973-366-7407 or email to specopt@aol.com.

Customer Information:			
Name:		Phone Number:	
Company:		Fax Number:	

General Information:			
Wavelength Range:		Power Density:	
Wavefront Distortion:		Overall Dimensional Restrictions:	
Achromatic or Apochromatic:		Coating Required:	
Input Divergence:		Distance Between Scan Mirrors:	

Please quote design and manufacture of a custom lens to the following performance specifications below. It is not necessary to fill in all specifications, indicate the determining specifications only.

Focusing Lenses	
F#:	
Input Clear Aperture:	
Focal Length:	
Spot Size:	
Working Distance:	

Collimating Lenses	
Source Size:	
Numerical Aperture:	
Working Distance:	
Output Beam Diameter:	

Beam Expanders	
Input Clear Aperture:	
Expansion Ratio:	
Input Divergence:	

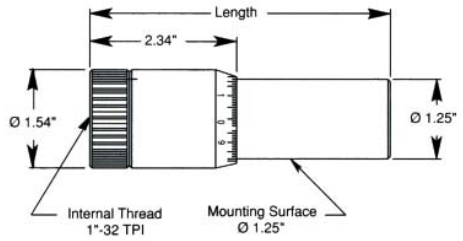
Imaging Lenses	
Source Size:	
F#:	
Object Distance:	
Focal Length:	
Resolution:	
Object NA:	
Image Distance:	

Scanning Lenses	
Scan Field Size:	
Spot Size:	
Input Beam Diameter:	
Focal Length:	
Front Working Distance:	
Back Working Distance:	
Distance Between Scan Mirrors:	

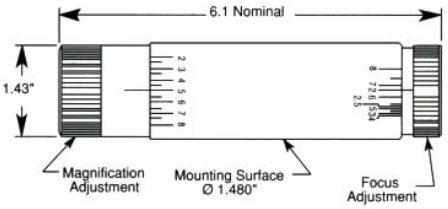
Special Notes or Requirements:

Special Optics, 315 Richard Mine Road, Wharton, New Jersey 07885
Tel 973.366.7289 Fax 973.366.7407 www.specialoptics.com E-mail sales@specialoptics.com

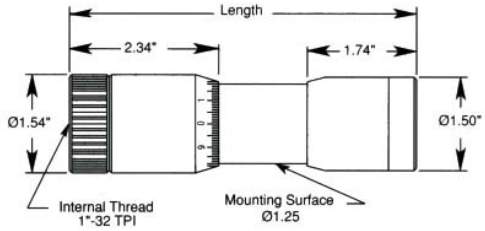
Beam Expanders Outline Drawings



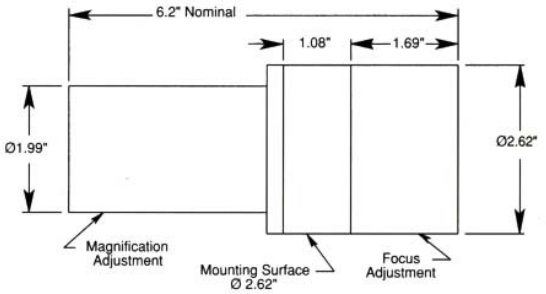
50-25 Series



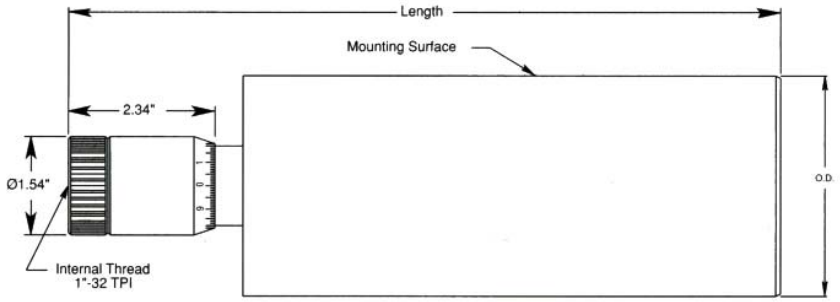
56-30-2-8X



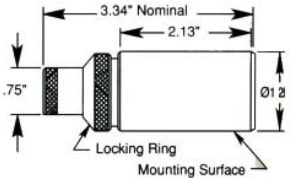
50-25-12X & 50-25-18x models



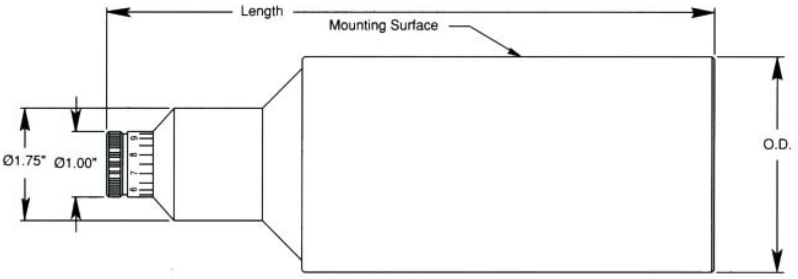
56-45-2-8X



50-51 Series



53-25-3X & 3.5X



52-71 Series