Serial No._______________

INSTRUCTION MANUAL & WAVELENGTH TABLES

FOR

MODEL 16-A

CO_2 LASER SPECTRUM ANALYZER

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1.0 INTRODUCTION

The CO_2 Laser is capable of lasing at a large number of wavelengths between 9.1 and 11.3 microns. Macken Instruments' CO_2 Laser Spectrum Analyzer is an instrument designed to simultaneously monitor and visually display all wavelengths within this range. This display is accomplished through the use of a calibrated thermal sensitive screen which darkens at points corresponding to the wavelength(s) at which the laser is operating. The calibrations also identify the CO_2 molecular transition(s) responsible for laser action.

The Spectrum Analyzer is calibrated at the factory and, with normal handling, should never need to be adjusted. However, provisions have been made for checking the calibration and adjustment. As part of the initial inspection of the Spectrum Analyzer, one may wish to check the calibration of the instrument using the procedure described in Section 9.0. Before attempting this check, one should at least read Sections 4.0 and 6.0 to obtain a working knowledge of the instrument

C A U T I O N

It is possible to damage the Thermal Sensitive Screen if the slit is opened too wide when working with laser beam power densities in excess of 25 watts/cm^2. All tests should start with the variable slit in the "closed" position. The correct slit opening is the minimum opening which presents a good visual display.

2.0 SPECIFICATIONS

Following is a list of the specifications for the Model 16A CO_2 Laser Spectrum Analyzer

Wavelength range	9.1µ to 11.3µ
Resolution	.003µ to (3.0 cm^{-1})
Calibration accuracy	Section II for inspector's report
Maximum continuous power	75 watts (Section 5.1)
Maximum pulsed energy	Section 5.4
Minimum continuous power (focused)	0.01 watts (Section 5.2)
Minimum pulsed energy (focused "T" laser)	0.1 Joule (Section 5.4)
Damage Limits	Section 6.3
Fluorescent screen response Time	¼ second
Grading efficiency	90% horizontal polarization
	30% vertical polarization
Optical design	¾ meter modified Ebert
Total optical path length	2.3 meters
Acceptance angle	2.5° horizontal
	1.5° vertical
Slit width	adjustable-closed to 0.6mm
Weight	21 pounds (9.5KG)
Length	18 inches (46cm)
Width	9.9 inches (25cm)
Minimum height	6.5 inches (16.5cm)
Elevation of slit	2.5 to 3.8 inches (6.3 to 9.6cm)
Electrical power	115V, 50 to 60 Hz, 10 watts
(See label)	or 220V, 50 Hz, 10 watts
CE Mark	CE mark (certified)
12C1502 vibrational	00°1 - 02°0
rotational lines	P2 to P62 and R2 to R60
identified	00°1 - 10°0
	-P2 to P56 and R2 to R60
	-$01^1 1 – 11^1 0$
	-P19 to P45

3.0 OPTICAL DESIGN

The CO_2 Laser Spectrum Analyzer is an infrared grating spectrascope designed to be used with CO_2 lasers. The optical design of the instrument is basically an Ebert Mount using a plain grating and a spherical mirror. This well-known design has been modified so that the display screen can be located near the top of the instrument. Also, folding mirrors are used to reduce the length. The Spectrum Analyzer has a ¾ meter dispersive distance and the overall optical path length within the instrument is 2.3 meters or 7-1/2 feet. The long path length and the compact design restrict the optical acceptance angle of the instrument to 1-1/2° in a vertical plane and 2.5° in the horizontal plane. Positioning the instrument so that the laser light does not enter within this acceptance cone will not create incorrect readings but simply cause the light to miss some element in the optical path and never reach the display screen.

Figure 1 is a side view if the Spectrum Analyzer showing the essential components of the instrument. The laser beam enters from the left striking the slit area. The portion of the beam which passes through the slit will strike the beam monitor if the monitor is turned to the "in" position or will pas unobstructed to the calibrated scale when the beam monitor is in the "out" position. Progressing past this point, the light then strikes the flat mirror, which folds the optical beam and introduces a slight vertical angular component to the direction of the light beam. The beam then strikes the concave mirror which collimates the divergence introduced by the diffraction grating. The grating is rigidly mounted in the flat mirror and held at a fixes angle by a wedge. Only the light which is diffracted into the first order of the diffraction grating continues on to strike the curved mirror for a second time which focuses the image on the display screen. Each laser wavelength leaves the grating at a unique angle and is imaged at different points on the wavelength scale. The light which is reflected off the grating into other diffraction orders strikes the cover of the Spectrum Analyzer and is absorbed.

4.0 COMPONENTS

There are three functions the user must perform when operating the Spectrum Analyzer. These are (1) controlling the input laser power; (2) positioning the instrument; and (3) reading the laser wavelength. The components that are used when performing these functions are:

- 4.1 Control of input laser power
  - 4.1.1 Variable slit
- 4.2 Positioning
  - 4.2.1 Adjustable legs
  - 4.2.2 Alignment marks
  - 4.2.3 Beam Monitor
- 4.3 Wavelength readout
  - 4.3.1 Hinged viewing lid
  - 4.3.2 Ultraviolet light
  - 4.3.3 Thermal sensitive screen
  - 4.3.4 Calibrated wavelength scale

4.1 CONTROL OF INPUT LASER POWER
4.1.1 VARIABLE SLIT

The front of the Spectrum Analyzer contains a hole ¼ inch in diameter which is surrounded by several alignment marks. The laser light is directed into this hole where it encounters the variable slit. The light which does not pass through the slit is reflected off the slit at an angle so that it is absorbed. The adjustment control for the variable slit is contained at the rear of the instrument. The slit can be adjusted from an opening of approximately 600µ to “closed”.

The slit performs two functions. First, it restricts the area the light can enter the instrument to a thin line at a known location. The light that reaches the display screen is actually an inverted image of the light which has passed through the slit.

Second, the slit controls the amount of light that enters the instrument and ultimately gets focused on the display screen. Although the screen is capable of handling wide range of power densities, it is possible to damage the screen if too much laser power is allowed to enter the instrument. Therefore, when first positioning the Spectrum Analyzer, the slit control knob at the rear of the instrument should always start in the closed position. Turning the opening until the maximum width is obtained at the “open” position. During normal operating conditions, the slit will seldom have to be opened beyond the half-open position and usually will be operated in the vicinity of ¼ open.

4.2 POSITIONING THE SPECTRUM ANALYZER

This section deals with the components designed to assist the user in positioning the Spectrum Analyzer. The laser beam must bot strike the slit area and enter the Spectrum Analyzer within the 1-1/2° x 2-1/2° acceptance angle.

4.2.1 ADJUSTABLE LEG

The positioning of the Spectrum Analyzer requires an elevation control to place the slit at the height of the laser beam. The slit height can be adjusted from an elevation of 2-1/2 inches to 3-3/4 inches using the screw-type adjustable legs. If greater heights than this are required, blocks or lab jacks can be used under each of the three feet to place the instrument at an elevation within the adjustment range of the legs. The legs can also be entirely unscrewed to permit lower mounting of the instrument. However, one must be careful not to inadvertently unscrew the legs during adjustment.

4.2.2 ALIGNMENT MARKS

To help in the positioning of the Spectrum Analyzer, alignment marks are provided. In the front of the Spectrum Analyzer, there are horizontal and vertical alignment marks around the slit that are used when making measurements to position the front of the instrument. At the rear of the Spectrum Analyzer, there is a red dot that is also an alignment mark. When the instrument is properly positioned, the laser beam would pass through the red dot. Therefore, this dot can be used in determining the elevation and transverse position of the rear of the instrument.

4.3.3 Beam Monitor

The Beam Monitor is a small thermal sensitive screen located within the Spectrum Analyzer several inches behind the slit. This screen can be rotated into place so that it intercepts and displays the light that has passed through the slit. Use of the Beam Monitor greatly simplifies the positioning of the Spectrum Analyzer so that the input light can enter within the acceptance angle of the instrument.

The Beam Monitor is viewed by lifting the hinged lid all the way open, then looking straight down into the instrument. Its positioning is controlled from the rear of the Spectrum Analyzer. When the knob is turned into the “in” position, the Beam Monitor has been rotated into the path of the laser beam. When the ultraviolet lamp within the Spectrum Analyzer is turned on, the Beam Monitor is illuminated so that it can provide a thermal display of the transmitted laser light.

When using the Beam Monitor, the slit would normally start in the closed position. The slit is then slowly opened until the fluorescing surface displays a dark line. This is an image of the light which has considerably broader than the slit width because of diffraction spreading. The position of the front of the Spectrum Analyzer can be checked by slowly moving the front from side to side until the best image is obtained. Adjustment of the rear of the Spectrum Analyzer is accomplished by introducing the proper vertical and horizontal translations required to move the dark thermal image until it is centered on the fluorescent green dot located on the Beam Monitor. These adjustments of the rear of the instrument should be made using the front leg of the Spectrum Analyzer as pivot point is located under the slit, it will introduce a minimum of translation to the sit. Once the slit image has been centered on the dot, the slit should be closed. The Beam Monitor should then be turned to the “out” position which moves in out of the optical path. The slit can now be slowly reopened until the wavelength indications appear on the fluorescent display screen.

4.3 WAVELENGTH READOUT

4.3.1 HINGED VIEWING LID

The wavelength scale is viewed by opening the hinged viewing lid at the top of the Spectrum Analyzer. A friction sliding mechanism allows the lid to remain at any desired angle. Under normal viewing conditions, this lid would only be opened wide enough to permit comfortable viewing of the wavelength scale.

Under some circumstances, it may be desirable to completely remove the gray Spectrum Analyzer cover to obtain wide angle viewing of the display screen. With the cover removed, the background illumination must be kept low enough not to interfere with the fluorescent display. When the instrument is not in use, the cover should be replaced.

4.3.2 Ultraviolet Light

The Spectrum Analyzer contains an ultraviolet light to illuminate the thermal sensitive screen and the fluorescent calibrations on the wavelength scale. When the instrument is to be used, this light is turned on by depressing the button at the rear of the Spectrum Analyzer. The self-starting fluorescent light requires about 5 seconds to turn on after this button has been depressed. The fluorescent lamp should be turned off when the Spectrum Analyzer is not in use.

The ultraviolet light emits only "longwave" ultraviolet radiation. This light is completely safe and will cause no damage to eyes or skin. Should the bulb ever burn out, it can be replaced with a F6T5 BLB bulb usually available through a local lighting distributor. The self starter within the ultraviolet lamp is a 6 watt FS-5 starter and is usually available locally; however, both of these replacement components are available through Macken Instruments.

4.3.3 FLUORESCENT THERMAL SENSITIVE SCREEN

The conversion of infrared radiation to a visible image is made possible through the use of a fluorescent thermal sensitive display screen. This is a membrane containing a phosphor which fluoresces yellow when illuminated by ultraviolet light. The intensity of the fluorescence decreases with increasing temperature. Therefore, when a portion of this screen is struck and heated by a laser beam, it appears to turn dark. If excessive amounts of laser light strike this screen, the membrane can become too hot and be damaged. This can always be prevented if the following precaution is taken: The power density required to turn a portion of the screen completely black. Therefore, if the slit opening is adjusted to find the point at which a line just becomes black, then this is a safe operating level. Other less intense lines, of course, can still be seen as lower contrast images.

Should the screen ever become damaged, the tension in the membrane is not sufficient to propagate a tear. A new fluorescent surface is available by rotating the fluorescent thermal sensitive screen to expose the half of the screen that is normally obscured by the upper part of the wavelength scale. To rotate the plate, the display screen is removed by unfastening the two outside mounting screws on the front of the Spectrum Analyzer. The bar holding the fluorescent thermal sensitive screen can then rotated 180° and remounted on the plate. When replaced, a new area of the screen will have been exposed without affect the calibration of the instrument.

4.3.4 CALIBRATED WAVELENGTH SCALE

The Spectrum Analyzer is calibrated both in wavelength and in vibrational-rotational line designation. A scale containing fluorescent markings surrounds the display screen. The portion of the scale below the fluorescent thermal sensitive screen indicates the wavelength-rotational lines. The 00°1-02°0 vibrational transition and 00°1-10°0 transition both are split into P and R rotational branches. In the $01^1 – 11^1 0$ transitions, only the P branch has been observed to lase.

These vibrational branches have been alternately colored to simplify the recognition of the different rotational groups. The arrows below the P and R designations indicate the direction of increasing numerical value for that vibrational branch. Particular care should be taken when reading rotational line designations in the R branches since these branches have increasing numerical values from right to left. For both the 00°1 - 02°0 and the 00°1 - 10°0 transitions, there are only even numbered rotational lines and therefore there are only five divisions per decade. The $01^1 1 – 11^1 0$ transitions have both even and odd rotational line designations and therefore there are ten divisions per decade.

There is some overlapping of the transitions in the eleven micron region between the P branch of the 00°1-10°0 transition and the P branch of the $01^1 1– 11^1 0$ transition. Confusion in this overlap region is eliminated by using two different fluorescent colors for these different transitions. At 11.016μ there is a transition which is particularly strong for this region of the spectrum. This occurs because there is a coincidence between the P-56 lines of the 00°1-10°0 transition and the P-23 line of the $01^1 1– 11^1 0$ transition. This line is marked using both colors. The majority of the laser transitions have sufficient separation between them. So it is not difficult to determine which transition is being indicated. However, a a few of the R branch transitions are closely spaced and must be read by positioning yourself perpendicular to the portion of the wavelength scale being examined.

4.3.5 CARBON BAR DISPLAY SCREEN

A rectangular carbon display bar screen has been included with the Spectrum Analyzer. This carbon bar can be used to greatly increase the sensitivity of the Spectrum Analyzer when it is used with TEA, Q switched, or other pulsed lasers. The high peak power of these lasers produces a visible flash on the carbon screen to designate the laser wavelengths. The minimum detectable energy using the carbon bar and focusing the light on the slit is about 0.003 joules per line.

This carbon bar is designed to replace the standard thermal sensitive display screen supplied with each Spectrum Analyzer. To replace the standard screen with the carbon bar:

1. There are four round head screws on the front of the Spectrum Analyzer. Remove the two outside screws and carefully lift out the display screen/mounting bar unit.
2. Detach the display screen from the mounting bar by removing the two inside screws.
3. Insert the carbon bar into the Spectrum Analyzer in the volume previously occupied by the standard display screen. Attach the mounting bar to the Spectrum Analyzer, thereby retaining the carbon bar. Areas of the carbon bar that are repeatedly being struck by the most intense of the rotational lines may, in time, decrease in sensitivity. If it is desired to restore the initial sensitivity, the surface of the carbon bar can be rotated, or the surface can be sanded with fine sandpaper.

Be sure to store the thermal sensitive display screen in a safe (preferably dark) place. Storage in a plastic bag is recommended.

After using the carbon bar, some carbon dust may remain on the back of the wave scale. This residual carbon should be cleaned off before the membrane bar is attached to the Spectrum Analyzer.

5.0 OPERATIONAL LIMITS

5.1 MAXIMUM CONTINUOUS POWER

The maximum power dissipation limit for the Spectrum Analyzer has been computed to keep the instrument from becoming too hot when being used with high power beams. Excessive temperature will cause the display screen to lose fluorescence in the same way as the heat from the laser beam causes the screen to darken. Also, the temperature gradients produced within the metal cause a temporary misalignment of the optical components due to thermal expansion of the case. This misalignment does not affect the calibration, but is confined entirely to a vertical translation of the image at excessive input powers. This effect occurs only when the bottom of the instrument is at a different temperature from the upper part of the instrument.

The maximum long-term power dissipation of the Spectrum Analyzer is 75 watts, but much higher power lasers can be used for short periods of time. If higher power laser beams are to be used with this instrument, the recommended procedure is to partially block the laser beam with two fire bricks or two metal reflectors to make a crude slit. This will transmit only the center section of the laser beam and reduce the power that must be dissipated by the Spectrum Analyzer to an acceptable level. The instrument should be allowed to cool when the bottom of the instrument feels warm to the touch.

5.2 MINIMUM CONTINUOUS POWER DENSITY

The minimum average power density that can be seen depends on the polarization, number of wavelengths present and collimation of the beam. A convenient rule is that about 2 watts/cm^2 are required for each rotational line if horizontally polarized light is used. The vertically polarized light requires about 3 times this value. Normally, multi-mode lasers do not run in more than three lines simultaneously so the minimum power density requirement is that the laser beam should at least be visible as a dark image on a #7 surface of Macken Instruments' Thermal Image Plate. Naturally, if the laser beam is visible on a less sensitive surface, the laser exceeds the minimum power density.

If the output beam from the laser is less than the minimum power density, then it will be necessary to focus the laser beam to achieve the minimum power density. Section 7 describes the details of this procedure.

5.3 DAMAGE LIMITS

The laser beam power density that is capable of damaging the display screen with the slit wide open is about 25 watts/cm^2 for horizontal polarization and somewhat more than this for vertical polarization. Power densities as high as 1000 watts per square centimeter can be used with this instrument provided: a) the necessary attenuation is achieved by controlling the slit width, and b) the maximum long term power dissipation capabilities of the instrument are not exceeded.

The power density which can damage the screen is about ten times the power density required to produce a dark image. As the damaging power density is approached the image on the wavelength display screen broadens to several times its normal width. Therefore, there is always adequate indication of possible damage. If one simply works with the minimum slit width which produces a good display, this will always be within the safe range. Should the display screen ever be damaged, it is possible to flip the screen to obtain the new surface as described in Section 4.3.3.

Replacement screens (model 16-RDS) and beam monitors (model 16-M) are available from Macken Instruments, Inc.

5.4 PULSED LASER LIMITS

A rectangular carbon bar display screen has been included with this Spectrum Analyzer. This carbon bar can be used to greatly increase the sensitivity of the Spectrum Analyzer when it is used with a TEA, Q switched, or other pulsed lasers. The high peak power of these lasers produces a visible flash on the carbon screen to designate the laser wavelengths. The minimum detectable energy using the carbon bar and focusing the light on the slit is about .003 Joules per line (See directions in Section 4.3.5).

The carbon bar cannot be permanently damaged by too high a power input, but under extreme circumstances it would be possible to damage the diffraction grating with too high a pulsed power. However this damage occurs when the pulsed energy input exceeds 1000 times the energy required to produce a visible flash. It is recommended that the variable slit be used to control the input power to the Spectrum Analyzer. The slit can be opened gradually between pulses to find the optimum viewing conditions.

The carbon bar may lose sensitivity in certain areas after repetitive shots. This occurs when loose carbon particles on the surface of the bar have been vaporized. This effect can be used to advantage when there are several lines running simultaneously. In this case, the stronger lines will eventually have reduced intensity, making all lines more comparable in intensity.

To restore the original sensitivity to the carbon bar, merely rub the carbon bar lightly with fine sandpaper. Be careful to avoid getting carbon dust inside the instrument.

6.0 OPERATING INSTRUCTIONS

This section gives a step-by-step procedure for setting up and using the Spectrum Analyzer. These steps are actually quite simple and once one becomes familiar with the instrument, it is possible to set it up for use in a couple of minutes. The steps are as follows:

1. Using the criteria set for in Section 5.2, decide whether the laser beam has sufficient power density to be detected unfocused. If focusing is required, read Section 7 at this point.
2. Measure the beam's height and position above the table at the point where the front of the Spectrum Analyzer is to be placed.
3. Block the laser beam.
4. Place the Spectrum Analyzer on the table and elevate the slit to the height of the laser beam. Position the rear of the Spectrum Analyzer so that the projected path of the laser beam would approximately pass through the red dot at the rear of the instrument.
5. Open the hinged viewing hood to its maximum open position.
6. Turn on the ultraviolet lamp by depressing the button at the rear of the instrument. This lamp has a self-starter and will come on approximately 5 seconds after the button has been released.
7. Turn the slit control knob at the rear of the Spectrum Analyzer to "closed" position. Turn the Beam Monitor knob to the "in" position.
8. Using an imaging device, check to see that the beam is going to strike the slit area. (The ideal device is Macken Instruments' Beam Probes, Model series 23 which are thin thermal imaging surfaces that can be placed right up against the front of the Spectrum Analyzer, or one of Macken Instruments' Thermal Image Plates. If crude devices are used, be careful not to allow any smoke products to coat the slit area.)
9. View the fluorescing Beam Monitor by looking straight down through the opening in the cover. If overhead light provide excessive external illumination on the Beam Monitor so that the surface fluorescence does not dominate the reflected room light, then it will be necessary to position oneself so that a shadow is cast on the Beam Monitor.
10. Slowly open the slit by turning the control knob until a darkened image of the light that has passed through the slit appears on the Beam Monitor. If no image has appeared when the slit is wide open, then either the front of the slit is not positioned within the laser beam or the beam is too low a power density to be used without focusing. Usually, translating the front of the Spectrum Analyzer will quickly locate the laser beam if it is in the vicinity of the slit. If the laser beam does not fill the full length of the slit, it is advisable to check to see if the beam is vertically centered on the slit. This can be accomplished either by holding a small wire horizontally across the center of the slit and noting the pattern on the Beam Monitor, or by blocking the upper half of the slit and noting the effect on the Beam Monitor.

CAUTION

Translating the slit into the laser beam with the slit wide open can allow too much power to strike the Beam Monitor. Therefore, search patterns should start with the slit nearly closed and then greater openings can be used. Remember – the proper slit opening is the minimum opening which will produce a dark image.

11. Once the slit is positioned in the center of the laser beam, the rear of the Spectrum Analyzer must be translated so that the dark beam image can be centered on the fluorescent dot

appearing on the Beam Monitor. The front leg is used a pivot point for these motions. The elevation of the rear of the Spectrum Analyzer and pivoting it about the front leg. With the beam image centered on the dot, the Spectrum Analyzer is properly aligned.

12. Close the slit, then turn the Beam Monitor to the "out" position.
13. Lower the hinged viewing lid so that it is at a comfortable height but provides shading of the display screen.
14. Slowly open the slit width until the dark wavelength indications appear on the yellow display screen. Once again, the proper slit opening is the minimum opening that provides dark lines. When the lines turn "black", this is about a factor of 10 lower power density than the damage limit of the screen.
15. Slightly translate the rear of the Spectrum Analyzer to peak up the intensity of the display screen.
16. Reading the calibrated scale is accomplished by positioning oneself perpendicular to the screen to avoid parallax. The front surface of the calibrated scale is approximately .030 inches away from the display screen. For further information about the calibrated scale, consult section 4.3.4. The exact wavelength for each of the rotational lines is given in section 12 of this Manual. Also, comments on the accuracy of the calibration of your particular instrument are contained in the Inspector's Report in Section 10.
17. If the laser beam does not fill the full length of the slit, then darkened lines will be smaller than the width of the display screen. The position of the darkened lines can be elevated on the display screen by lowering the front of the Spectrum Analyzer. This will have no effect on the calibration accuracy.

7.0 FOCUSING THE LOWER POWER LASER BEAMS

When the power density of the laser beam is too low to be seen on the Beam Monitor with the slit wide open, then it is necessary to increase the power density on the slit by focusing. In order not to exceed the acceptance angle of the Spectrum Analyzer and waste laser energy, the F number of the focused beam should be between 15 and 40. This is to say that the ratio of the focal length of the lens to the laser beam diameter is between 15 and 40. To accomplish this, either lenses or mirrors can be used.

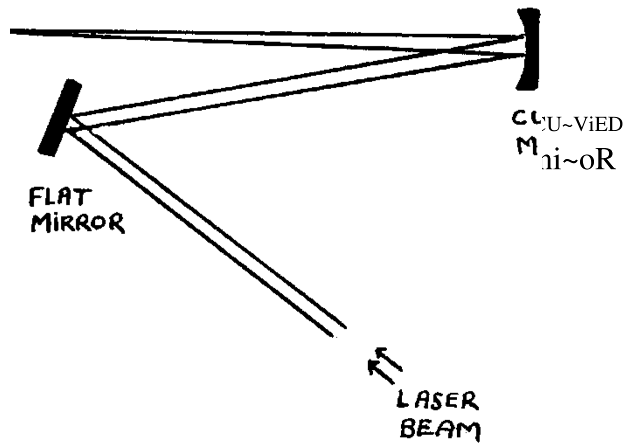
Figure 2 shows two possible optical setups that can be used with a focusing mirror. Layout A has a slightly smaller spot size than Layout B because the mirror is used more nearly on axis. In Layout B, the beam should pass as close as possible to the edge of the Spectrum Analyzer to minimize the angle between the incident and reflected beams. When focusing is required, one must be careful not to inadvertently produce a power density that could damage the thermal sensitive screen. If the total laser power is greater than 0.1 watt, it is possible to damage the display screen if the slit is opened too wide. For alignment of the Spectrum Analyzer using a focused beam, the general procedures outlined in Section 4.2 should be followed.

When very low laser beam powers are displayed, polarization of the laser beam can have an important affect on the intensity of the display. The efficiency of the diffraction grating varies considerably depending on whether the light is polarized parallel or perpendicular to the to the grating lines. For this particular grating, light polarized in the horizontal plane is reflected with greater than 90% efficiency, while light polarized in the vertical plane is reflected with approximately 30% efficiency. Normally, with higher power laser beams, this difference is compensated for by empirically determining the proper slit opening for a particular polarization. However, when very low power laser beams are to be displayed, the best results are obtained with horizontally polarized light.

If a laser beam is vertically polarized and it is not possible to rotate the laser 90°, then the plane of polarization can be rotated using a half wave plate of a material such as cadmium sulfide.

Another method is to introduce an optical arrangement such as shown in Figure 3 that uses two mirrors to rotate the plane of polarization 90°. To accomplish this, the light beam must undergo two reflections, one in a vertical plane and one in a horizontal plane so that the resultant beam emerges at a 90° angle to the incident beam and at a different elevation. This polarization rotation results purely from geometric considerations and even images are rotated 90° when they undergo this type of double reflection.

(A)



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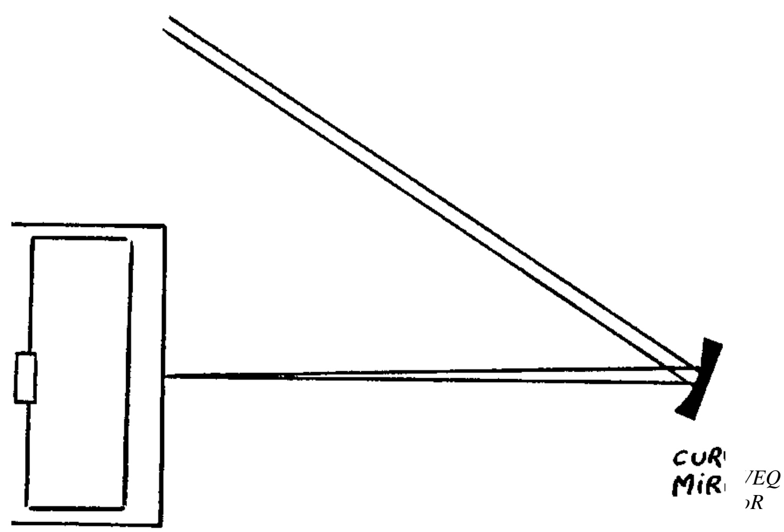

Figure 2 - Suggested Focusing Methods

8.0 EXTERNAL DETECTORS

The CO_2 Laser Spectrum Analyzer can be used as a monochrometer so that external detectors can monitor an individual rotational line. To do this, the thermal sensitive screen is removed by unscrewing the two outside screws on the front of the Spectrum Analyzer. Removal of the screen permits the laser beam to pass through the open area of the wavelength scale and come out into the working area in front of the Spectrum Analyzer. Different long wavelength infrared detectors may require different mounting techniques, however, a typical setup is shown in the photograph on the third page of the Spectrum Analyzer data sheet (Section 12.0). To select a single wavelength from the complete spectrum which passes thorugh the instrument, it is necessary to restrict the area captured by the detector using either a slit or a small area detector. One simple, but effective, slit is provided with the Spectrum Analyzer. This slit is meant to slide into the elongated opening on the from of the Spectrum Analyzer that usually contains the thermal sensitive screen. This slit should be lined up to allow the transmitting of the particular rotational line desired. The divergence of the light that is transmitted through the slit depends somewhat on the width of the input slit, but is approximately 40 milliradians. For other cases, such as monitoring multiple wavelengths or for scanning applications, special adapters should be constructed that could bolt onto the front of the Spectrum Analyzer using 6-32 screw holes which are normally used to support the display screen.

9.0 CALIBRATION

The model 16A CO_2 Laser Spectrum Analyzer is calibrated at the factory and should never need adjustment. However, it is quite simple to check the calibration and to make minor adjustments if they should ever be necessary.

To check the calibration, a helium neon laser is used in place of the CO_2 laser beam. The HeNe laser is aligned by following the same instructions given for the CO_2 laser in Section 6. With the helium neon laser, there is no danger of damaging the display screen, but for calibration, the adjustment knob should be set at approximately ¼ open.

When the HeNe laser is sent into the instrument, it will produce three different diffraction spots on the thermal sensitive phosphorous screen. Obviously, these spots will be visible without the need for an ultraviolet light; however, it may be useful to turn on the ultraviolet light to illuminate the wavelength scale. These three spots are the 15^{th}, l6th, and 17thd diffraction orders of the HeNe laser beam when it reflects off the diffraction grating. One will note that the 16^{th} and 17^{th} diffraction orders are considerably brighter than the 3^{rd} spot which is the 15^{th} diffraction order because of the blazing of the grating. When used to display CO_2 laser lines, this type of intensity differential is not present because the longer wavelength greatly broadens the peat efficiency of the grating. The use of reflective optics in the analyzer assures that the three spots from the HeNe laser correspond exactly to the positions which would be obtained with a wavelength 15, 16, 17 times the HeNe laser wavelength has brought into the Spectrum Analyzer. However, since the wavelengths commonly used to designate CO_2 laser transitions are given as vacuum wavelengths, it is necessary to use the vacuum wavelength (.6330µ) of the HeNe laser in determining the calibration points. Therefore, the 15^{th} diffraction order of the HeNe laser should lie at a wavelength calibration 15 times .6330µ or 9.495µ. Similarly, the 16^{th} and 17^{th} diffraction orders should like at wavelengths 10.128µ and 10.761µ. Since the rotational line designations are the more exacting calibrations on the scale, the HeNe light that has entered the center of the slit should be imaged in the upper portion of the display screen near the rotational line calibrations. The three spots on the display screen can be moved in vertical plane by raising and lowering the front slit using the adjustable leg at the front of the instrument. The calibration marks therefore can also be given in reference to the rotational line scale. The 17^{th} diffraction order at 10.761µ should appear between P34 (10.740µ) and P36 (10.763µ) separated from P36 by about 10% of the total distance. The other marking of concern is the 15^{th} diffraction order which is located at 9.495µ between P12 (9.488µ) and P14 (9.504µ). This mark is separated from P14 by about 50% of the total distance.

In the event that these HeNe laser calibration points appear to be very slightly off, then the decision must be made whether they are off enough to cause an error in reading which rotational line is lasing. Normally, the highest accuracy commonly required demands that the distinction between R40 and R42 must be made in the 00°1 - 02°0 transition when a grating is used to force the laser to lase at this short a wavelength. Without a grating, however, the most common transitions are near P20 and R20 of the 00°1 - 10°0 transition which are not so closely spaced.

If adjustments are required, the simplest adjustment is obtained by sliding the wavelength scale after loosening the screws that hold it in place. When tightening these screws, one must be careful not over-tighten or else some bowing of the metal scale may take place at the center. Should larger corrections be necessary, these could be made by adjusting the angle of the flat mirror that holds the diffraction grating. To make these adjustments, the two lock nuts must be loosened on one of the four screw standoffs. Then, using as a pivot, the screw diagonal to the one that has been loosened, corrections can be made using the screw adjustments on the other two legs. In adjusting these legs, one should make corrections in increments of 1/6 or less revolutions. After rotating the nut on the one side of the mirror mount, the nut on the reverse side should be rotated the same amount. Once the proper position is found using this technique, the nuts on the fourth leg are once more tightened to give added rigidity.

If the Spectrum Analyzer has undergone some serious damage that could require a considerable amount of adjustment to re-calibrate, the adjustments may have to include some translation of the rear mirror to obtain the proper separation between the three diffraction orders. Under these circumstances, the Spectrum Analyzer could be returned to Macken Instruments for a check out and re-calibration.

10.0 INSPECTION REPORT

Each Spectrum Analyzer has been individually calibrated and tested. Since the wavelength scale is not custom made for each instrument, production considerations at times do not make it possible to obtain a perfect match at all parts of the spectrum between the observed and calculated position of each individual rotational line. Therefore, this section is included to permit the inspector to comment on the characteristics of each instrument.

Model Number 16A______________

Serial Number __________________

Date Tested ____________________

Methods of calibration used: Initial calibration was made using the 15th, 16th and 17th diffraction orders of a NeNe laser (see Section 9.0). This calibration was then checked using a CO_2 laser equipped with a diffraction grating capable of obtaining 112 wavelengths between 9.13 and 11.1µ.

Inspector's Comments:

11.0 WARRANTY

Macken Instruments, Inc., makes no warranty, expressly or by implication except as set forth below. Macken Instruments warrants that the products delivered hereunder will be in substantial conformity with applicable specifications and will be free from defects in material and workmanship. Macken Instruments' obligation under this warranty shall be limited to (at its option) repairing, replacing or granting a credit at the prices invoiced at the time of shipment for any of said products that shall within one year after shipment be returned to the factory of origin (transportation charges prepaid) and that are, after examination, disclosed to Macken Instruments' satisfaction to be thus defective. This warranty shall not apply to any of such products that shall have been subjected to physical, optical, or electrical abuse or misuse. Macken Instruments shall not be liable for special or consequential damages of any nature with respect to any products or services sold or rendered hereunder.

12.0 WAVELENGTH TABLE

A number of authors have reported on the wavelengths obtainable from CO_2 lasers *. The most complete tabulation is given by Laures (1) and this is used as the basis for the following table and the calibrations on the Spectrum Analyzer scale. The bale also includes calculated wavelength values which may be more accurate than the measured values.

The naming of the vibrational bands and rotational line designations are according to the commonly used notation presented in Herzberg (2). There is some confusion in naming the vibrational band responsible for the transitions between 11 and 11.3µ. Laures and Schein (3) refer to it as the $01^11 – 03^10$ band, but the correct designation is $01^1 – 11^10$ as substantiated by Hartmann (4) and Meyer (5).

The strong transition at 11.016µ has been identified as a superposition of the P56 line of the 00°1 - 10°0 band and the P23 line of the $01^11 – 11^10$ band. Meyer concludes that the line centers for these two transitions are separated by 30MHz but pressure broadening causes an overlap. On the Spectrum Analyzer scale this double line is designated using two colors on the calibration mark.

Figure 4 shows a graph of the relative gain between different rotation lines. The envelope of these laser gain curves is a combination of the data presented by Laures, Hanst (6), Djeu (7) and observations made at Macken Instruments. Actually, the relative shape of these curves depends on the laser gas temperature and the composition. Variations are therefore to be expected. This gain cure does not necessarily represent the amount of power that can be extracted from each line. Collision cross coupling of the rotational lines allows nearly the full power to be extracted from any line that has sufficient gain to be considerably above threshold.

*The best guide to these articles is contained in a CO_2 laser bibliography by Robinson and Johnson (8). This bibliography references approximately 50 articles listed under the following categories: wavelength tabulation, wavelength selection, line competition, line strength, and Isotopes.