TEMPORARY ADJUSTMENT IN LASER EQUIPMENT

M. Nabil Aly Shoukry
Transportation Engineering Department, Faculty of Engineering,
Alexandria University, Alexandria, Egypt.

ABSTRACT

A straightforward solution is presented for determining the location of the beam waist which is considered to be an element of utmost importance in temporary adjustment of laser equipment. A basic formula is used and the specific value of the image-distance parameter (v) can be easily obtained through curves or directly by the main equation itself.

INTRODUCTION

The extremely rapid development of lasers has made the laser surveying instrument a most reliable and dominant tool in engineering surveying applications. Users and designers of laser equipment need not be optical engineers in order to use or design a practical system. A basic knowledge about the laser beam propagation through simple lenses will prove adequate for the design or selection of an optimized laser surveying instrument.

The scope of this paper involves an orientation for the estimation of the positioning of the laser beam waist in laser equipment which is analogous to the sharpness of the images in classical surveying equipment. Such an orientation is considered to be the prime element in temporary adjustment of instruments.

Laser Beam Optics

From the surveying point of view, the low angular divergence of the laser beam is considered as one of its most important characteristics. This divergence can be reduced by expanding and collimating the beam. As a laser beam propagates from an instrument, it converges to a minimum spot size, the waist, then expands symmetrically beyond this point. At a relatively large distance from the laser the angular divergence of the beam is inversely proportional to the waist size and, the wider the beam is on exit from an instrument, the larger the waist is and the less the beam diverges. Consequently, to reduce the divergence of the laser even further, the waist size is made larger by placing a converging lens at a distance equal to its focal length away from the output mirror (HeNe laser) or diode (semiconductor laser), Figure (1). The disadvantage with this system is that the focal length f of the converger lens must be very long in order to obtain a sizeable beam diameter. This may be overcome however, by using a beam expander lens arrangement, Figure (2), the effect of which is to increase greatly the beam collimation and its diameter.

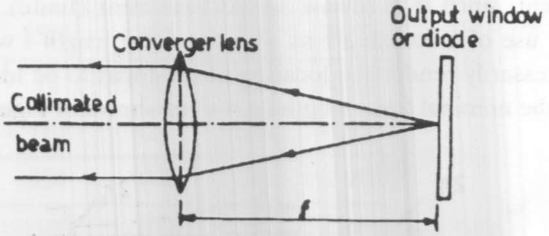

Figure 1.

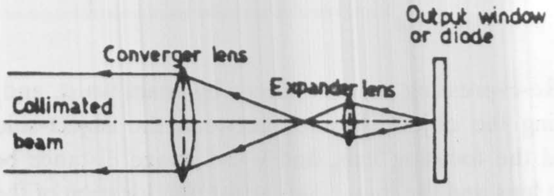

Figure 2.

Users of simple convergent lenses are often concerned about the ability of such a lens to form an inverted image of a distant scene. From optical principles, the relationship between object distance u, image distance v and focal length f, is given by

$$\frac{1}{u}+\frac{1}{v}=\frac{1}{f} \qquad (1)$$

For laser optics a correction factor is included. This may be illustrated by considering a fundamental-mode laser beam, whose characteristic parameters φ and S_R are shown in Figure (3).

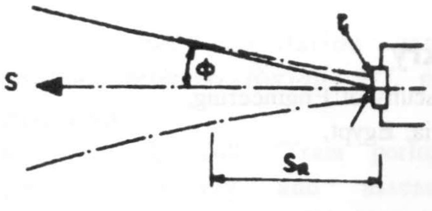

Figure 3.

The angular divergence of the laser beam with the wavelength λ is defined by

$$\phi = \frac{\lambda}{\pi r_1} \tag{2}$$

where r_1 is the width of the laser beam at the beam waist. The laser beam is considered parallel only to a certain extent, since φ is always larger than zero (finite). Thus, the use of a focusing lens with the focal length f will not necessarily render the location of the focus to be identical to the nominal focal length ($u \neq v$) as shown in Figure (4).

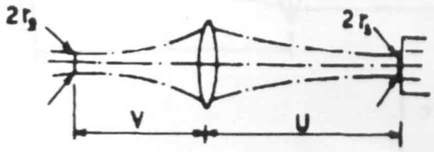

Figure 4.

Re-expressing the term focus by beam waist, and with u being the object distance between the object-side waist and the focusing lens, and v the image distance between the lens and the image-side waist, the location of the latter can be obtained from the formula

$$v = f + \frac{(u-f)\,f^2}{(u-f) + S_R^2} \tag{3}$$

where S_R is the Rayleigh length of the laser indicating the distance from the beam waist at which the cross-sectional area has doubled, and is given by

$$S_R = \frac{\pi r_1^2}{\lambda} \tag{4}$$

The correction factor involved in equation (3) includes f, u and S_R (and accordingly λ). Equation (3) may be r written in the following form so as to furnish the le equation of laser geometrical optics.

$$\frac{1}{v} = \frac{1}{f} + \frac{1}{u}\left[\frac{1}{1 + S_R^2/u(u-f)}\right]$$

of significance, is the focal length and the object distanc ratio to the Rayleigh length. The correction factor adde to the object distance, enables to locate the beam waist at the geometrical image distance or not, meaning that the application of the geometrical optics (eq. 5) is possibl or not.

By introducing the parameters u′, v′ and S'_R where u′ = u/f, v′ = v/f, $S'_R = S_R/f$, the fundamental equation (5 can be expressed in the general form

$$v' = \frac{v}{f} = 1 + \frac{(u'-1)}{(u'-1)^2 + (S'_R)^2}$$

By substituting in eq. (6) for values of u′ ranging from 0.02 to 8.0 and S'_R from 0.01 to 3.0, the different values of the image distance v′ are obtained as a function of u′ and S'_R. Using a software grapher version 1.75, eq. (6) can be represented by a family of curves, Figure (5), which show the relationship between the parameters u′ and v′ at constant S'_R.

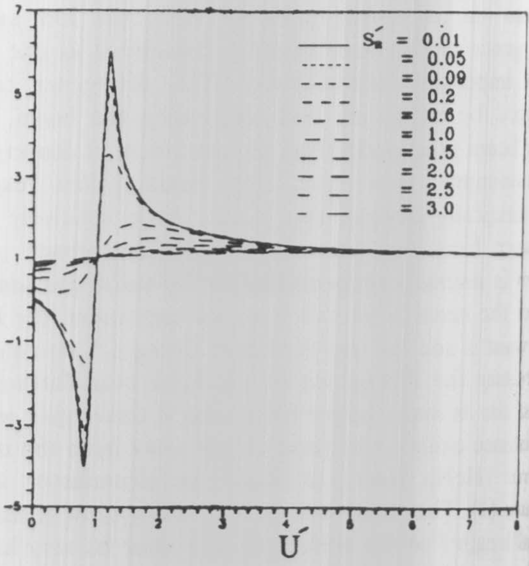

Figure 5.

Table 1.

Laser source	f = 400 mm		f = 800 mm		f = 1100 mm		f = 1500 mm	
	u	v	u	v	u	v	u	v
GaAs	4	264	8	264	11	220	15	172
	40	268	80	248	110	165	150	68
	200	304	400	256	550	0	750	-540
	400	400	800	800	1100	1100	1500	1500
	800	540	1600	1336	2200	1980	3000	2820
	2000	488	4000	992	5500	1375	7500	1875
HeNe	4	320	8	392	11	363	15	300
	40	324	80	392	110	341	150	225
	200	352	400	472	550	352	750	0
	400	400	800	800	1100	1100	1500	1500
	800	480	1600	1200	2200	1837	3000	2700
	2000	480	4000	992	5500	1365	7500	1875
CO_2	4	2	8	-6.4	11	-9.9	15	-13.2
	40	-6	80	-88	110	-121	150	-165
	200	-352	400	-776	550	-1078	750	-1485
	400	400	800	800	1100	1100	1500	1500
	800	796	1600	1600	2200	2200	3000	3000
	2000	500	4000	1000	5500	1375	7500	1875

In the case of incident parallel light, the beam waist will necessarily be in the focal plane when $S_R = 0$, thus yielding the general geometrical optics equation:

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v} \qquad \text{i.e.} \quad v' = \frac{u'}{u'-1}$$

As shown from eq. (6), this occurs if $u' = u/f = 1$. This means that $v = f$ or $v' = 1$. Also, the beam waist may be located in the lens itself with no further focus if $v' = 0$. Finally, any negative values of v' indicate an invalid location of the beam waist.

Thus, in accordance to the foregoing, a comprehension of the ratios of f to u and to S_R is quite essential. This may be appropriately illustrated as follows. Consider a gallium arsenide (GaAs) laser of wavelength $\lambda = 905$ nm is used with a focal length f = 1100 mm, and the width of the laser beam at the beam waist $r_1 = 0.4$ mm. Therefore, from eq. (4)

$$S_R = 550\,\text{mm} \quad \text{and} \quad S'_R = \frac{S_R}{f} = 0.5$$

If the distance of the lens from the laser is u = 550 mm, therefore

$$u' = \frac{u}{f} = 0.5, \quad \text{and accordingly} \quad v' = \frac{v}{f} = 0,$$

meaning that the beam waist lies directly in the lens. Should the object distance u be changed to, say 1650 mm, therefore

$$\frac{u}{f} = 1.5\ , \quad \text{and} \quad \frac{v}{f} = 2\ , \quad \text{thus } v = 2200\,\text{mm}.$$

If a shorter or longer focal length is used, different results are obtained as shown herein after. Thus, for incident parallel light, the object distance of the lens from the laser will affect the beam waist location.

Considering three different laser active materials such as gallium arsenide (GaAs), helium-neon (HeNe) and carbon dioxide (CO_2) of wavelengths λ = 905 nm, 633 nm, 10.6 μm respectively, and if r_1 = 0.4 mm, Table (1) shows the different values of the beam waist distance v from the lens obtained as a function of the laser-lens distance u and with a variation of the focal length f from 400 mm to 1500 mm. As is apparent, immensely varying results are obtained.

CONCLUSION

In almost all surveying instruments, the position of the beam waist v is commonly located in the focal plane of the length; i.e. by calculating S_R, S'_R and u', Figure (5). can be used to obtain v' and accordingly v. If not located in the focal plane, the beam waist can be determined by employing either eq. (3) or (6).

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