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THE TESTING OF THE OPTICAL PERFORMANCE OF INFRARED LENSES DURING CO_2 LASER RADIATION

Bekir Sami YILBAŞ
E.Ü. Mühendislik Fakültesi, KAYSERİ

SUMMARY

The application of CO_2 laser in machining the focusing element is very important, since the thermal characteristics of an focusing material influence the effects that a high energy radiation of a particular wavelength may have on the component. If the absorption coefficient of the material is high witnin the range of wavelenght of interest then temperature change will be significant. The consequence of this is a thermal strain on the focusing element producing a distortion of its geometry. This will cause the undesirable features of aberration and loss of transmission. In the present sutudy, the testing of thermal effects on the focusing element was carried out using a Michelson interferometer.

CO_2 LASER IŞIMASI SIRASINDA INFRARUJ MERCEKLERİN OPTİK PERFORMANSLARININ TESTİ

ÖZET

CO_2 laserin takım tezgahı olarak kullanılmasında odaklama elemanı çok önemlidir, zira belirli bir dalga boyundaki yüksek enerjiye sahip ışıma odaklama malzemesi ısıl özelliklerine etki eder. Eğer malzemenin soğurma katsayısı büyük (ışıma dalga boyunda)ise sıcaklık değişimi önemlidir. Böylece odaklama malzemesinde meydana gelen ısıl uzamalar odaklama malzemesi geometrisini değiştirir. Bu arzu edilmeyen aberasyonu ve iletim kayıplarına neden olacaktır. Bu çalışmada odaklama elemanın ısıl etkiler neticesindeki optik performasyonu ile ilişkili testler Michelson interferometresi kullanılarak yapıldı.

1- INTRODUCTION

In many engineering works welding and thermal cutting processes are involved. In order to carry out these processes some sort of heat source is required. Arc-welding, soldering, brazing, oxy-acetylene flame and laser beams can be used in these processes.The use of laser beams for engineering purposes requires the use of optical components which bring the beam into a focus in order to concentrate it on a small area on a workpiece to be welded or cut. The most useful and commonly used optical element for focusing radiation is the lens.

Characteristics such as dispersion, reflectivity, mechanical, physical and chemical properties determine the suitability of a material for use as an optical element. Availability and cost are also, often a serious consideration. The thermal characteristics of an optical material influence the effects that high energy radiation of a particular wavelenght may have on the component. If the absorption of the material is high within the range of wavelength of interest then temperature change will be significant. The consequence of this is a thermal strain on the element producing a distortion of its geometry. Other properties of the material which will also be effected by the temperature change and stress are the refractive index, and transmission. The defects of aberration and loss of transmission will obviously cause difficulties in the production of microwelds and cuts.

The thermal affects causing a distortion and aberration in the focusing element can be measured in such a way that, if a focusing element, such as a lens, is introduced between the beam splitter and one of the mirrors such that the mirror is at the focal plane of lens, the field of view will still contain fringes which may be made straight, parallel and equidistant if all the optics, including the lens test are perfect. Any imperfection in the lens is revealed by a distortion of the fringe pattern.

In the present study, interferometric technique was employed to analyse the imperfections and aberration caused by the temperature rise in the focusing element.

2- CHOICE OF THE METHOD FOR EXPERIMENTATION

In making a choice of method for the investigation of the performance of where "u" is object distance and "v" the image distance from the optical element "f" is the focal length.

From Figure (1), it is known that rays from infinity are brought to focus at the focal point of the lens. That is the image of object at infinity appears at the focus. This becomes the object for the mirror, and the image formed by the mirror will again become an object for the lens. Hence the final position of the image formed by combined system can be found.

For the mirror:

$$\frac{1}{s-f} + \frac{1}{V_m} = \frac{2}{r} \tag{2}$$

$$V_m = \frac{r(s-f)}{2s-2f-r} \tag{3}$$

$$U_L = s - V_m \tag{4}$$

substituting from 3,

$$U_L = s - \frac{r(s-f)}{2s-2f-r} \tag{5}$$

Using the lens formula:

$$\frac{1}{V_L} = \frac{1}{f} - \frac{1}{U_L} \tag{6}$$

and substituting from 5 into expression 6 then:

$$V_L = \frac{2s^2f - 2sf^2(1+r/f) + rf^2}{2s^2 - 2sf\ (2+r/f) + 2f\ (r+f)} \tag{7}$$

Equation 7 can be used to obtain the calibration curve for corresponding change in "s" to change in "f".

Figure (2) shows the importance of choosing a value of initial separation (about which the separation is to be varied) very close to the sum of "r" and the nominal focal length of lens. Rapid change of V_L occurs for a small change in "s" around this value and so it is expected that relatively large changes of diameter of fringes with changes in "s" to be found.

The fringe diameters can be calculated as:

Let "r_n" be the radius of the n th order fringe and "α_n" the corresponding angular deviation of beam to bring about that fringe. "1" denotes the distance from the lens to the screen. "V_L" is conjugate point of a point at infinity with the lens-curved mirror system and separation "s". Assuming small angles:

$$\alpha_n = \frac{n\,\lambda}{r_n} \tag{8}$$

and $$\alpha_n = \frac{r_n}{|V_L - \ell|} \tag{9}$$

therefore,

$$r_n = \quad n \ |V_L - \ell| \tag{10}$$

In the present study $\ell = 49.5$ cm and $\lambda = 10.6$ μm.

Table II presents some of the results obtained with equation 7 and 10 and the corresponding experimental resultes.

4- EXPERIMENTAL SETUP

The layout of the experimental apparatus is given in figure (3). The equipment used basically consisted of a CO_2 laser, the beam splitter a plane mirror and the lens (under investigation) with accompanying curve mirror and lastly a screen. The optical characteristecs of the lens and the mirrors are given in Table I.

CO_2 laser used in the present experiment delivers 1 KW - 10 KW output power with a beam diameter of 2.54 cm.

The arrangement of the various components was such that the parallel beam coming from the laser would strike the beam splitter at 45^o, so two beams at right angles would then take origins at the position of the beam splitter. The curved mirror and the lens were mounted on the optical bench such that they were on the same optical axis and both arranged such that the transmitted beam from the beam splitter struck the lens normally while mirror was placed in such a position that the reflecth the reflected beam from beam splitter struck it normally too. The screen was on the other side of the beam splitter as the plane mirror and parallel to the mirror. This was to anable interference on the screen of the reference beam reflected back from the plane mirror and the beam from the lens-curved mirror arrangement.

5- DISCUSSION

When the equipment had been set up and the laser operating well, fringes appeared on the screen. Before photographs of these fringes were taken from which measurments were to be made, time was allowed for thermal equilibrium to be achieved. This was to ensure that measurment were made under the same conditions and any results obtained could be referred to these conditions. A photgraph of the fringe pattern was taken of each setting of separation of the lens-curved mirror arrangement while the separation was noted. Figure (4) shows typical fringe patterns obtained for s = 19.2 cm.

The amount of agreement between the predicted fringe diameters and the experimental values can be seen in Table II confirms the reliability of the lens-curved mirror technique to give a quantitative assessment of an optical component when transmitting an infra-red radiation a number of factors have to be considered. Compatibility with the aims of the experiment, the expense and availability must be considered.

Fizeau interferometer was discarded on the basis of the very accurate work required [1]. The Foucault test (Schlieren paterns) was also rejected because it involved the observation of the focal point. The intensity of radiation would not permit a direct observation at a focal plane [2]. The holographic interferometric techniques would allow a direct study of the lens surface but would not give any information about the overall change of optical performance as factors like the refractive index would be involved [3].

The Michelson interferometer therefore seemed to be compatible with the aims of the present investigation, and also readily available. Any impervection in a lens would be shown by a distortion of the fringe pattern, while a change of focal point would be manifasted by the fringe separtions.

3- RELATIONSHIP BETWEEN CHANGE IN SEPARATION OF LENS-CURVED MIRROR ARRANGEMENT AND CHANGE OF FOCAL LENGTH

If a lens is restricted circumferentially then on heating it up the lens will become thicker and consequently the focal length will change depending on the shape factor of the lens. The effect of shortening of focal length will be to make the emergent beam become less divergent if it is already divergent or if convergent initially to become more convergent. The measurement can therefore be based either on a count of the fringes passing across a point in the field of view on the screen or by measurements on circular fringes obtained.

Restricting the incident beam to the paraxial region of the lens an approximate relationship can be worked out between "f" and "s" (Figure (1)) using the formula,

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

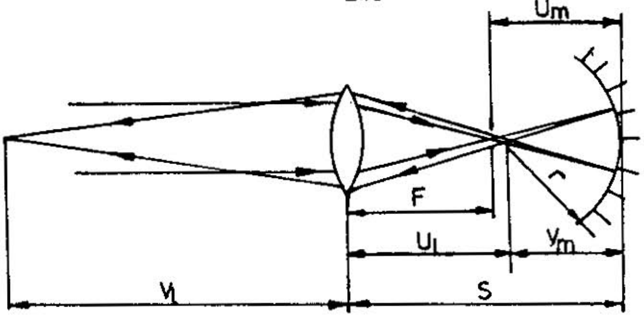

Fig.1- Formation of object at infinity by a lens-curved mirror system.

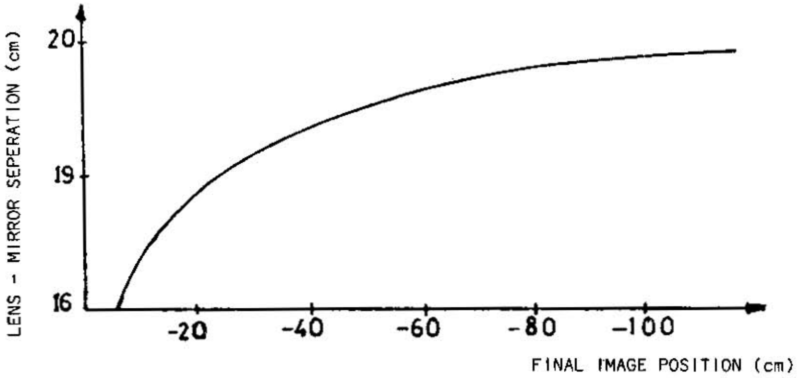

Fig.2- Position of a image of a point at infinity formed by a lens-curved mirror system against separation.

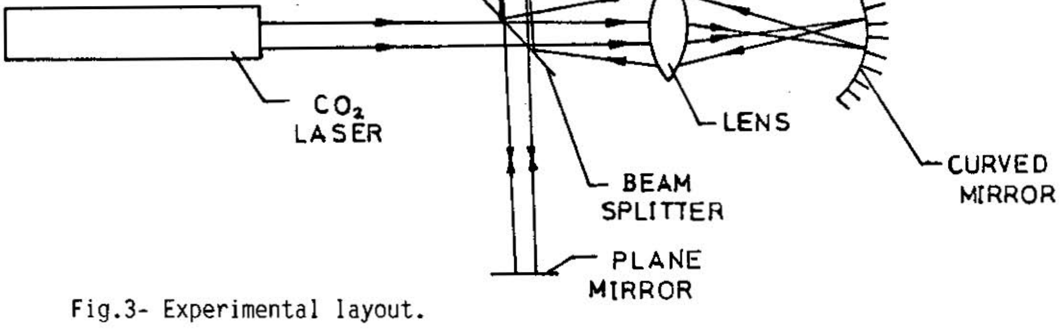

Fig.3- Experimental layout.

aberration of a lens under working condition.

The discrepancies as shown in Table II may be in fact not be as much as that. The equation 7, from which the predicted values were computed, breaks down as one leaves the paraxial region of the lens. For this reason, the difference between calculated diameters of fringes and the experimentally obtained values can be expected to be increasing as high order fringes are being considered. This trend was also confirmed by the results shown in Table II.

Furthermore, the inaccuracy at wich the fringes' diameters were measured from the interferograms could account for some of the discrepancies between the predicted and experimental values. The instrument used to do the measurment was accurate to ± 0.05 cm. Intrinsic errors also come in as the determination of when the indicator of the instrument was at the centre of the light area of the interferogram was exclusively for the operator to decide.

By treating the change of diameter of each fringe appearing on the screen when lens condition change separately, different of corresponding separation, "s" should be obtained and consequently different changes of focal length. These changes will hence indicate quantitatively the extent of aberration caused by the heating up of the lens.

6- CONCLUSION

A method of measuring the diameters of circular fringes produced by a lens and curved mirror arrangement in a Michelson interferometer has been investigated. Measurment of fringe diameter changes has been shown to be a useful technique for observing quantitatively a temperature or strain-induced change in performance of the lens.

It was also shown that for a change of focal lenght of aens in a lens-mirror arrangement the separation between the lens and the mirror would have to change in an opposite manner to bring about the equivalent

LENS MATERIAL	GERMANIUM
FOCAL LENGTH	10.6 cm.
RADIUS OF MIRROR	10.6 cm.
INITIAL SEPERATION	19.0 cm.

Table I- Optical Characteristics of lens and curved mirror.

S (CM)	FIRST	FRINGE	SECOND	FRINGE	THIRD	FRINGE
	D_p	D_E	D_p	D_E	D_p	D_E
18.6	0.52	0.56	0.74	0.88	0.9	1.13
18.8	0.53	0.56	0.75	0.90	0.92	1.12
19.0	0.56	0.57	0.79	0.93	0.96	1.14
19.2	0.58	0.60	0.82	0.97	1.00	1.21
19.4	0.62	0.62	0.88	1.04	1.07	1.30

Table II- Fringe diameters with seperation is given. D_p represents the predicted values while D_E represents the experimental values.

Fig.4- A typical photograph of fringes.

effect to the image formed by the system had the focal length of the lens not changed.

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NOMENCLATURE

u	Object distance	(m)
v	Image distance	(m)
f	Focal length	(m)
s	Seperation	(m)
V_m	Final position of the image formed by the combined system	(m)
r	Radius of the curved mirror	(m)
V_L	Final image position of object at infinity from lens	(m)
$_n$	Angulan deviation of beam to bring about the fringe	(rad)
n	Number of fringes	
l	Distance between the lens and the screen	(m)
	CO_2 laser wavelength	(m)
r_n	Fringe diameter	(m)