Indian J. Phys. **64B** (2), 106-115 (1990)

Determination of normal displacement of warren beams by holographic methods

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Received 11 July 1989, accepted 1 December 1989

Abstract : It is evident enough to rate the technique of holographic interferometry with paramount importance as one of the advanced tools for material testing and evaluation. Its nature of non-contact testing nosed itself ahead of many conventional testing methods. In the present paper normal displacements of warren beam structures have been found by adopting the double exposure holographic interferometry technique in which an interferometric comparision of the deformed object with undeformed object has been usually done. Three types of warren beam structures have been studied and the experimental results were compared with the theoretical predictions. The deviation of inferred results has been discussed critically and comprehensively.

Keywords : Holographic interferometry, double exposure holographic interferometry, the holodiagram, warren beams, partitions.

PACS Nos : 07.60.Ly, 42.40.kw

1. Introduction

Holography by its very nature provides a three dimensional information of the object. When interferometry combines with holography, a technique of holographic interferometry will result and which enables one to compare the object's texture and deformation interferometrically even without touching the object directly. In the double exposure holographic interferometry two holograms will be recorded, one before deformation of the object and the other after straining the object, on the same photographic plate without any change in its position. On reconstruction, the two wave-fronts corresponding to the two conditions of the objects will emanate from the processed plate i.e. hologram and will interfere with each other resulting in a characteristic fringe pattern that accounts for the deformation.

Abramson (Abramson 1969) has devised an easy method for recording hologram and Vest (Vest 1979) explained the theoretical process of double exposure

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*Present Address : Department of Physics, V R Siddhartha Engg. College, Vijayawada-10, India holography. Powell and Stetson (1965) have reported the deformation and displacement results of some diffusely reflecting objects after realizing the engineering application of holographic interferometry. The displacement analysis in double exposure holographic interferometry has been reported by Venkateswara Rao and Maxwell (1973) by means of simple mathematics. Several other researchers have reported their results with their own interpretation (Ennos 1968, Luxmore and House 1970, Eoone 1970, Wilson 1970, Srimannarayana 1978).

The advantages of using holographic interferometry for non-destructive testing include its excellent sensitivity and high accuracy. This feature even permits the use of low level stressing during inspection. It does not rely on data acquisition by either point by point determinations or scanning processes. But three dimensional images of interference fringe fields can be obtained on the entire object surface. It permits comparison of the responses of an object to two different levels of stress or other excitation. This differential type of measurement contrasts with absolute types, which are made without a frame of reference. The double exposed interferograms can be reconstructed at any later stage to produce three dimensional replicas of the previously recorded test objects. The general change in the shape of the test object is portrayed by the fringe pattern itself. Keeping all these advantages in mind, study of warren beams has been taken up using holographic interferometry method.

The present investigation has been concentrated on the studies of warren beam structures. Generally, the strength and rigidity of hollow machine frames such as, lathe beds (warren beam structures) are increased by incorporating ribs and partitions. These stiffening members are especially needed when the operating conditions of the machine unit do not allow the frame to be completely closed with two sides open. Badawi and Thronley (Badawi and Thronley 1966) have investigated warren-type beam of optimum proportions, box-section beams without and with holes at different positions, double-laced warren-type beams by contributing importance to both static as well as dynamic characteristics.

For arriving at possible theoretical results, the static assumptions include (i) the resultant of the external forces is a couple which either lies in or is perpendicular to the plane of symmetry of the cross section and (ii) the beam is under equilibrium. The geometrical assumptions are (i) the longitudinal axis of the beam is straight, (ii) the beam has constant cross section throughout its length, (iii) a plane normal to the longitudinal axis of the beam remains the same before and after bending of the beam and finally (iv) the beam bends without twisting. Also it is assumed that the material of the beam is homogeneous and isotropic and the stresses do not exceed the elastic limit of the material.

2. Design and theoretical formulation

For a beam of constant cross section, deflection is given by (Madhava Rao 1973)

$$Y = K_1 \frac{Pl^3}{EI} \tag{1}$$

where

K_1 = numerical constant depending upon type of loading and type of mounting.

I = moment of inertia of the section about an axis perpendicular to the plane of bending.

where

$I = K_2 t h^3$

and where

K_2 is again a numerical constant depending on shape of profile.

Therefore,

$$Y = K_1 \frac{Pl^3}{E(K_2 t h^3)} \tag{2}$$

Further, rigidity C is defined as

$$C = \frac{P}{Y} = K_3 E t h^3 / l^3 \tag{3}$$

where K_3 is a constant.

From eq. (3) it is obvious that considerable increase in rigidity can be attained by increasing the dimension of cross section (h) or by reducing the length (l), as these quantities appear in eq. (3) in the 3rd power. By increasing the wall thickness (t), rigidity increases only linearly.

The total deflection of the warren beam due to the force P is given by (Badawi *et al* 1963)

$$\delta = \frac{PL^3}{12EI_w} + \frac{PL^3}{2A_d E \sin^2\theta \cos\theta} \tag{4}$$

where

L = length of the beam

E = Modulus of elasticity

A_d = Cross sectional area of the lacing diagonal (mm^2)

θ = lacing angle

$I = \mathrm{Am}\, \frac{b^2}{2}$ (mm^4)

where Am is second moment of area of the beam and b is its breadth.

3. Experimental procedure

Warren beam models of dimensions shown in Figure 1 were designed and fabricated from commercial perspex. The dimensions of the warren beams are given by 300 mm length, 100 mm width, 100 mm height, and the partitions are of thickness 6 mm, as shown in Figure 1. Three types of warren beams, viz. without partitions, with straight or transverse partitions and with diagonal partitions were fabricated for the present work, in which studies of normal displacements was given importance. For that purpose, the loading apparatus should be such that it allows only normal loading. The loading apparatus designed and fabricated for warren beams is shown in Figure 2, in which the vertical plate C

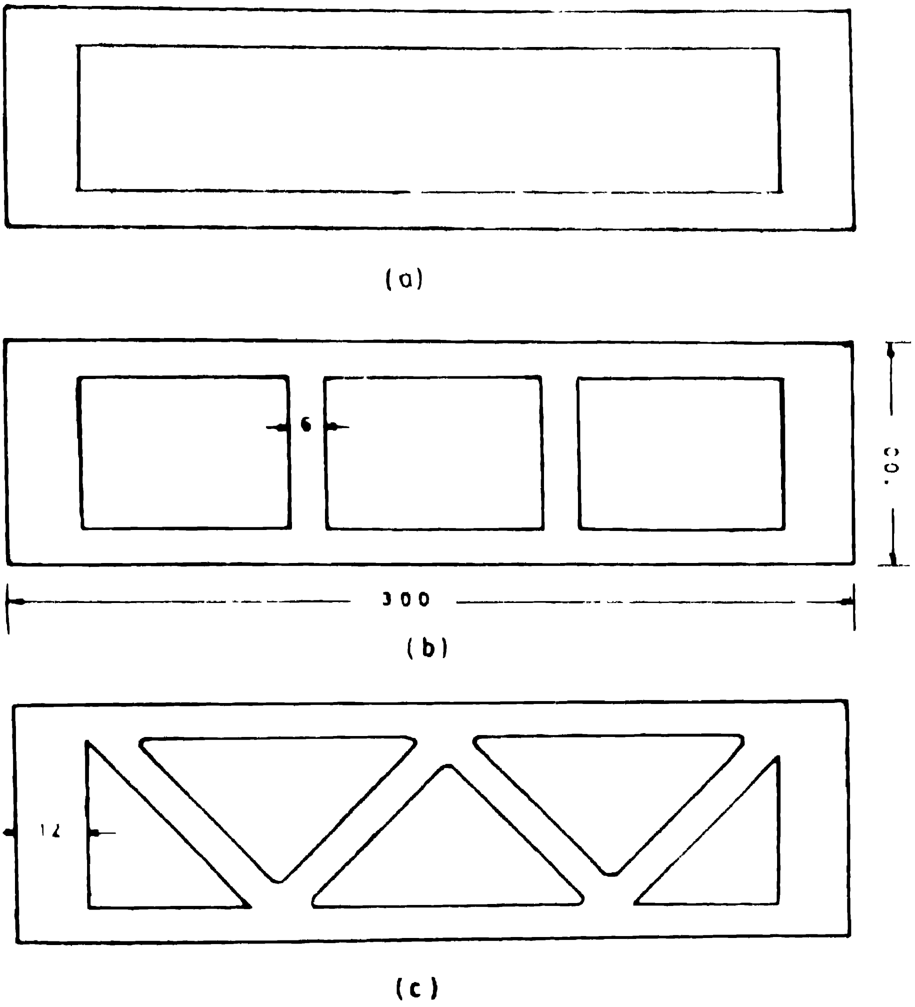

Figure 1. Warren beams : (a) without partitions ; (b) with transverse partitions ; (c) with diagonal partitions. All dimensions are in mm.

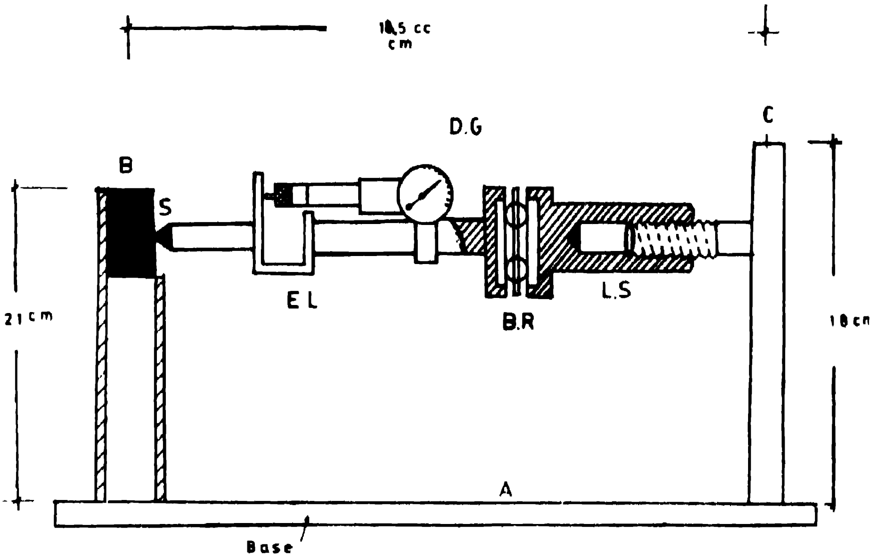

Figure 2. Loading apparatus for warren beam : S specimen, AC – mild steel plates, B – U channel, EL elastic loading member, DG – dial gauge, BR – ballrace, LS – loading screw.

was rigidly fixed to bottom plate A of greater thickness. Two U-channels which were provided with nuts and bolts were welded on the base plate. The warren beam was fixed in the U-channel plates B-B. The load is applied normally, by means of a pre-calibrated U-ring and dial gauge arrangement, at the centre of the beam.

The experimental set-up for recording the hologram is shown in Figure 3(a), where the holodiagram method (Abramson 1981) was followed. A 15 mW He-Ne

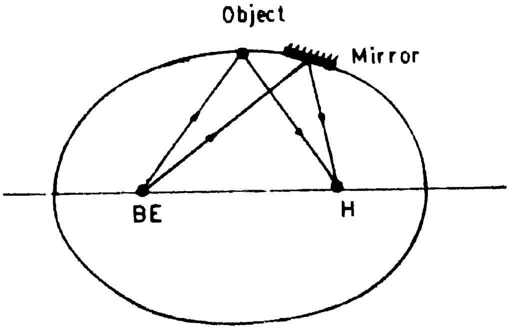

Figure 3(a). Recording of hologram

laser was used as the source of illumination. The laser beam was expanded by means of a beam expander (BE) which was placed at one of the two foci of the ellipse whose K value is 1.1033. The warren beam, fixed in the loading apparatus, was placed on the periphery of the ellipse (object). A mirror was placed adjacently to the object for producing reference beam. The photographic plate holder was located at the second focus of the ellipse, so that the path lengths of the beam from beam expander to the photographic plate via the object as well as mirror were equal.

The first hologram was recorded with no load on the specimen and the second hologram was also recorded on the same photographic plate with a test load of 0.01568 Kgf. After processing the photographic plate, it was subjected to reconstruction as shown in Figure 3(b). On reconstruction the two wave fronts emanating from the double exposed hologram produced an interference fringe pattern characteristic of the strain the object experienced. Similarly, double exposed holograms were recorded with other test loads of 0.03136 Kgf and 0.06272 Kgf for the same specimen. Likewise, the two other warren beams were also strained by the test loads and their corresponding holograms were recorded. On reconstruction each hologram yields its corresponding characteristic fringe pattern. The fringe contours for the test load of 0.03136 Kgf corresponding to the three warren beams are shown in Figure 4.

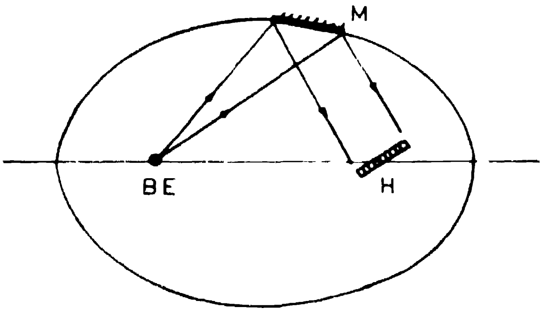

Figure 3(b). Reconstruction of hologram.

The normal displacement for different test conditions was determined using the equation given by

$$d = nK\frac{\lambda}{2}\cdot\frac{1}{\cos\alpha} \qquad (5)$$

where

n = the number of dark fringes between the fixed point and the point under study,

λ = wavelength of He-Ne laser,

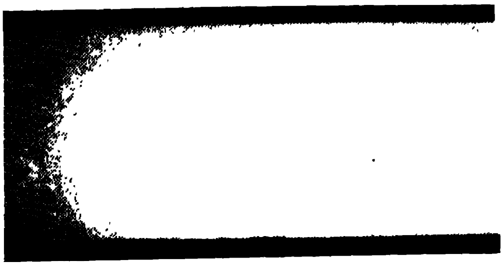

Figure 4(a). Without partitions fringe pattern.

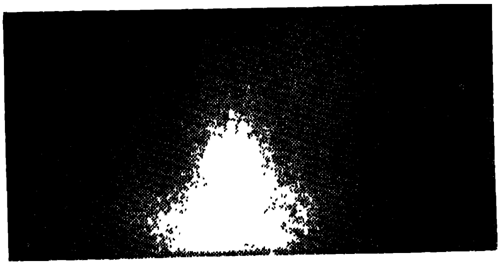

Figure 4(b). With straight partitions fringe pattern.

Figure 4(c). With diagonal partitions fringe pattern.

$K = \frac{1}{\cos\theta}$, where θ is the semi-angle between illumination and observation directions. ($\theta = 25$ in the present studies)

and

α = the angle between the normal to the object surface and the normal to the periphery of the ellipse.

In the present studies $\alpha = 0$ is used.

Hence

$$d = nK \qquad (6)$$

4. Results and discussion

Three different interferograms were recorded for loads 0.01568 Kgf, 0.03136 Kgf and 0.06272 Kgf for each beam. Considering the fringe contours corresponding to the load of 0.01568 Kgf, the contour spacing and their extension towards the edges were totally different for the three different warren beams. The contour spacing corresponding to the warren beam with transverse partition configuration was very much less (from the photographs) relative to that of the beam with diagonal partitions. When deformation is greater the fringe spacing will be lesser and more number of fringes occupy the deformed surface. The same feature was observed with the other loads of 0.03136 Kgf and 0.06272 Kgf. From this characteristic feature of contour spacing and contour (fringe) distribution it is clearly evident that the configuration of diagonal partitions provides greater strength to the warren beam than that of transverse partitions. The most interesting result observed was that no fringe pattern was overlaid the testing surface of the warren beam without partitions. This may be justifiably said that there is no inter-connection between the two parallel members of the beam, for the two members act as two different cantilevers and hence the load applied on the rear member may not be transferred to the testing surface.

From the foregoing discussion, it was evident that among the three warren beams studied, the beam with diagonal partitions was more strong and accepts greater stress over the other two beams. Transverse partitions contribute very little to the increase of rigidity when compared to diagonal or inclined partitions. This may be due to the lacing angle maintained in the diagonal partition configuration.

The characteristic orientation of deflection of each warren beam against three different testing loads was shown in Figure 5. The non-linearity due to the beam

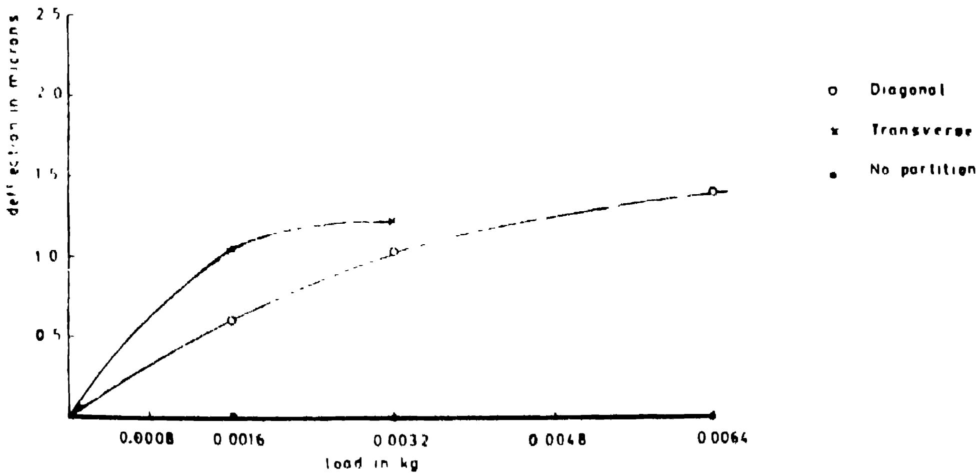

Figure 5. Load vs deflection.

is restrained at both the ends with respect to horizontal moments (Frisch Fay 1962). The results are shown in the Table 1.

Table I. Normal displacements of three warren beams under different loading conditions.

Sl. No.	Load in Kgf	Specimen	Deflection due to bending 10^{-4}	
			Theoretical	Experimental
1.	0.01568	Beam with no partitions	Not available	Nil
		Beam with no partitions	0 2534	0 6981
		Beam with transverse partitions	0 757	1 047
2	0 03136	No partitions	Not available	Nil
		Diagonal partitions	0 5068	1 047
		Transverse partitions	1 514	1 2217
3	0 06272	No partitions	Not available	Nil
		Diagonal partitions	1 01	1 3963
		Transverse partitions	3.28	Fringes could not be counted

5. Conclusions

From the observation of the results, it was quite evident that the beam without partitions did not behave like a single solid beam. Between the other two beams, the one with diagonal partitions has more strength than the beam with straight partitions. Hence, it may be concluded justifiably that for lathe beds, the warren beam of diagonal partition configuration is more suitable relative to the other two beams.

Acknowledgments

One of the authors, Ch Venkata Srinivas, is grateful to the Department of Science and Technology, New Delhi, for extending financial support in the form of Junior Research Fellowship. He is also thankful to Dr R L N Sai Prasad for his assistance in the experimental work.

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