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# HOLOGRAPHIC INVESTIGATION OF THE ELASTIC DEFORMATION OF DEFECTIVE GOLD SOLDER JOINTS

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A holographic method using an He-Ne gas laser was described. The interference fringes in double-exposure holography were used to study the elastic deformation of soldered gold structures. The investigation was performed on ten specimens, defects having been produced artificially in the soldered joints of five, and on ten three-unit dental bridges, five of which already had superficial defects in the soldered joints. The specimens were loaded and double-exposure holograms were taken. The elastic deformation was determined from the holodiagram and calculations of the number of interference fringes. The results indicate a greater elastic deformation at small loads in the specimens which had defects in the soldered joints.

Soldered joints in dental gold alloy constructions have to fulfil the mechanical properties required of the castings. These properties may be altered by the presence of defects in the joints e.g. porosities, gold-solder interface, imperfections in the solder (*El-Ebrashi et al.*, 1968). Under a bending load, solder is likely to have a lower proportional limit than cast alloy (*Skinner*, 1958) but it is not entirely clear to what extent the elastic deformation of the joint is influenced by defects. In particular, more has to be known about the influence of the size of the defect. The elastic deformation of soldered structures under a bending load has been measured previously from the angular deflection but this does not distinguish between the deformation of the joint and the deformation of the castings. Neither does it define the position of the deformation in the specimen, which is of importance when analysing a soldered structure.

The purpose of the present investigation was (1) to develop a method for analysing the elastic deformation of soldered constructions (in a non-contact

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and non-destructing test) with special reference to the location of any deformation, and (2) to make a quantitative evaluation of this deformation in constructions made from dental gold alloy.

## MATERIAL AND METHODS

I. Thirty samples of dental gold alloy (C-gold, type III) were prepared to the specifications in ADA no. 5 as follows: circular acrylic disks ($6 \times 2$ mm) were invested, cast, bench cooled for 1 min and quenched in water. The samples were soldered together in threes using a gas-air flame (J.S.* 820 hard solder) to give ten specimens simulating dental gold bridges. In five of these specimens a 0.17 mm carbon wire was placed in the joint before soldering to prevent the casts from being fused by the solder in the place of the wire. These five specimens are referred to as series A, the other five as series B. Care was taken to ensure that the specimens were all the same length.

II. Ten equivalent three-unit gold alloy bridges (C-gold, J.S.*) were selected from the preclinical work of dental students. Five of these (series C) had visible superficial defects in the soldered joints and the other five (series D) had no visible defects. The casts had been soldered together by a standardized method using JS 820 gold hard solder. No heat treatment was given to the bridges after soldering.

III. A thirteen-unit gold alloy bridge (C-gold, J.S.*, type III) constructed for a clinical case was mounted in an articulator. The gold alloy castings had been joined with J.S. 830 hard solder. Four amalgam dies functioned as abutments to the bridge in the stone model. The model of the lower jaw made from hard stone. Experiments were performed with this construction to observe its behaviour during small changes in loading.

*Laser technique in dentistry.* Laser technique has been applied in dentistry to produce crevices in enamel and dentin by means of pulsed ruby laser and $CO_2$-gas laser (*Goldman et al.*, 1965; *Morrant*, 1965; *Scheinin* & *Kantola*, 1969) but little work has been published on the use of low-energy laser to study the deformation of metallic dental appliances. The technique of using the monochromatic, coherent laser beam for obtaining a three-dimensional image is known as *holography*.

The holographic method was invented by *Gabor* in 1948 but remained a scientific curiosity until the development of the He-Ne gas laser in 1962. Using this light source, *Leith* and *Upatnieks* obtained holograms of a much

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higher quality than was possible with conventional light sources. In 1965 *Powell* and *Stetson* discovered interference fringes on the holographic image of an object that moved during exposure of the hologram. Several methods were soon developed for utilizing this measuring technique, which was termed *hologram interferometry*.

The deformations caused by forces acting on an object can be measured by using either double-exposure holography or real-time holography. With the former, the two holographic images interfere so that the object is seen covered by an interference pattern that reveals how each point on the object surface has been dipslaced between the two exposures. Real-time holography presents the same type of information but the holographic plate is exposed once only and is then developed, fixed and replaced in its original position, after which the holographic image is made to interfere with the real object.

The sensitivity of hologram interferometry depends on the wavelength of the illuminating light, the direction of illumination and the direction of observation. If illumination and observation are both perpendicular to the object surface, each dark fringe represents a displacement between exposures of half the wavelength in a direction normal to the surface. In all other cases the sensitivity of the method is lower. Denoting the angle between surface normal and the line of illumination $\alpha$ and the angle between surface normal and the line of observation $\beta$, the displacement $d$ can be calculated from the formula

$$\mathrm{d} = \mathrm{n} \, \frac{2}{\cos\alpha + \cos\beta} \, \lambda \tag{1}$$

were $n$ is the number of dark fringes and $\lambda$ is the wavelength of the light (0.6328 $\mu$m for an He-He gas laser). The line of sensitivity bisects the angle $\alpha + \beta$.

The trigonometric calculations can be avoided by using a diagram of the type reproduced in Fig. 1. Here the ellipses represent loci of constant path length for the light transmitted from the source $A$ to the observer $B$ via the object $C$ and the circles represent loci of constant distance separating adjacent ellipses. In this case the displacement $d$ is calculated from the formula

$$\mathrm{d} = \mathrm{n} \cdot \mathrm{k} \cdot \frac{\lambda}{1} \tag{2}$$

where $k$ is found in the diagram. The direction of sensitivity is normal to the ellipses. A more detailed description of this method had been published by *Abramson* (1969).

*Holographic procedure.* The specimens, held in a screw-vice, were illuminated by divergent laser light from a Helium-Neon gas laser (wavelength

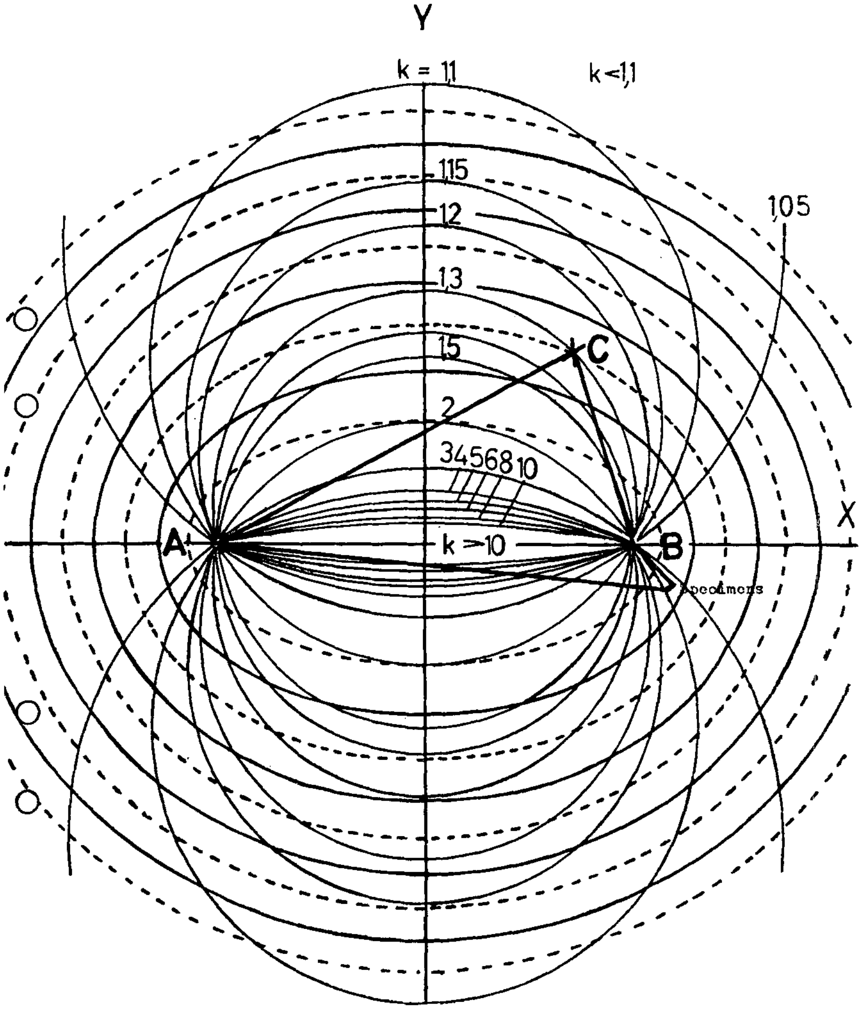


Fig. 1. The holodiagram made by ellipses of constant path length for the light passing from A to B via the object C. The position lines of constant distance between ellipses are formed by arcs of circles named k-lines.

0.6328 $\mu$m, output 60 mW). The divergent beam also illuminated a mirror, which directed a reference beam towards the photographic plate, located in front of the specimens. The plates were Agfa Gevaert, Scientica 10E75, $9 \times 12$ cm, resolution 2 800 lines/mm, exposure time approx. 1 sec. One specimen from series A was placed next to one of series B and both were loaded in the same way using a equivalent force (Fig. 2). To determine a

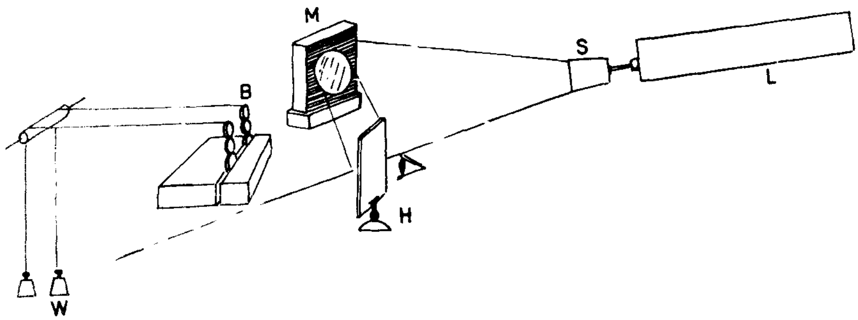


Fig. 2. The holographic arrangement. The letters denote L — Laser, S — Spatial filter H — Holographic plate, M — Mirror, A, B — Specimens, W — Weights.

suitable load, a hologram was exposed, developed, fixed and replaced in the original set-up and observations were made of the interference fringes obtained when the specimen was loaded (real-time technique, see above). Suitable fringe separation occured at a load difference of 0.2 kp. Double-exposure holograms were then made with and without this load of 0.2 kp between the two exposures, the procedure being repeated for each of the five pairs of specimens in series A and B. After the plates had been developed, the interference pattern caused by the deformation could be studied in the hologram when this was illuminated by the same reference beam as during the recording. The holographic images were recorded with a conventional camera, making it possible to study the interference fringes on photographs.

The three-unit dental gold bridges (series C and D) were examined in the same way, the bridges being painted white first to reduce the bright reflection. In this sereies, load differences of 0.1 and 0.2 kp were used between the two exposures. For the experiments with the thirteen-unit bridge mounted in an articulator, a metal rod was placed between two teeth in the upper and lower jaws and a load difference of 0.5 kp was applied between the two exposures of the holographic plate.

*Evaluation*. As mentioned briefly above, if the object is illuminated and viewed from the same direction and parallel to its movement, the distance between two interference fringes represents a displacement of half the wavelength of the laser light, in this case $\frac{1}{2} \cdot 0.6328\,\mu m$. Otherwise the distance between two fringes represents a greater displacement. The recording and evaluation of holograms were simplified by the use of the holodiagram (Fig. 1). Ellipses with foci at $A$ and $B$ were drawn such that the light which passes from $A$ via an object $C$ located anywhere on the ellipse, to $B$ has a constant path length. The arcs termed k-lines in the diagram are loci for constant sensitivity to deformation perpendicular to the ellipses. The k-values can be used to compensate for the change of sensitivity due to the geometrical set-up employed while recording the hologram. The dark fringes in the hologram were interpreted as follows. The geometrical set-up used while recording the hologram was inserted in the holodiagram and the k-value was read off for the point on the object at which the displacement was to be determined. The number of dark fringes ($n$) in the hologram was counted between this point and a fixed, light region. The deformation $d$ (in $\mu$m) could then be calculated from formula 2.

The deformation data will be correct if the direction of displacement is perpendicular to the ellipses. If it runs in any other direction, the result is a component of the real displacement (perpendicular to the ellipses). Given this other direction, the real displacement can be calculated from the formula

$$d_{real} = d/\cos \alpha \qquad (3)$$

where $\alpha$ is the angle between the known direction and a normal to the ellipse.

In the present study, the k-value for the specimens and the three-unit bridges was 1.08 and the distance between two interference fringes thus corresponded to a displacement of $1.08 \cdot 0.6328/2 = 0.34\,\mu$m. For the thirteen-unit bridge the k-value was about 1.04 and the inter-fringe distance corresponded to a displacement of $0.33\,\mu$m. The closer the interference fringes, the greater the displacement of the object.

*Errors of the method.* The position of the objects was selected in such a way that the error in determining k-values amounted to approximately 1 per cent. The evaluation of the interference fringes was impeded by the presence of speckle. The errors of the holographic method have been discussed previously by *Robertsson & Harvey* (1970).

## RESULTS

The holographic method produced images of a satisfactory quality for evaluating the deformation of the specimens at the loads used.

Calculations based on the holograms showed that elastic deformation was greater in the group with artificial defects in the soldered joints (Table III, Fig. 3). The findings for the dental bridges indicated that the holographic method is suitable for studying small deformations in objects of varying size and shape. From the holograms it appeared that elastic deformation diminished with the distance from the point of attachment to the application of the load, not linearly but in the form of a curve (Fig. 4).

The dimensions of the soldered joints in the tree-unit bridges (Table II)

Table I.

*Dimensions of the soldered joints studied in the 3-unit specimens. A-series without B-series with artificial defect. W and H denote width and height of the soldered joint (in mm)*

| Specimen n:o | A-series | | | | B-series | | | |
|---|---|---|---|---|---|---|---|---|
| | I | | II | | I | | II | |
| | W | H | W | H | W | H | W | H |
| 1 | 2.7 | 1.9 | 3.2 | 1.9 | 2.7 | 1.9 | 2.6 | 2.0 |
| 2 | 3.1 | 2.0 | 3.1 | 2.0 | 3.1 | 2.1 | 3.4 | 2.0 |
| 3 | 3.3 | 1.9 | 3.3 | 2.0 | 2.8 | 2.0 | 2.6 | 2.0 |
| 4 | 3.2 | 1.9 | 3.2 | 1.9 | 2.7 | 1.9 | 2.7 | 2.0 |
| 5 | 3.2 | 1.9 | 3.2 | 2.0 | 3.2 | 2.0 | 3.4 | 2.0 |
| $\bar{x}$ | 3.1 | 1.9 | 3.2 | 2.0 | 2.9 | 2.0 | 2.9 | 2.0 |

Table II.

*Dimensions of the soldered joints studied of the 3-unit dental gold bridgeconstruction. A-series without B-series with superficial defects of the joint. W and H demote width and height of the soldered joint (in mm)*

| 3-unit bridge-construction no. | C-series | | | | D-series | | | |
|---|---|---|---|---|---|---|---|---|
| | I | | II | | I | | II | |
| | W | H | W | H | W | H | W | H |
| 1 | 3,9 | 2,8 | 4,4 | 2,9 | 5,0 | 3,1 | 5,2 | 3,0 |
| 2 | 3,9 | 2,5 | 3,7 | 2,4 | 3,6 | 3,0 | 3,8 | 3,1 |
| 3 | 3,7 | 2,6 | 4,3 | 3,4 | 5,1 | 4,2 | 4,7 | 3,6 |
| 4 | 4,2 | 3,5 | 5,1 | 3,4 | 4,6 | 3,5 | 4,5 | 3,1 |
| 5 | 3,8 | 3,2 | 2,8 | 2,5 | 4,6 | 2,7 | 4,5 | 2,1 |

Table III.

*Deformation of the specimens with a load of 0.2 kp. A and B denote without and with porosities in the soldered joints respectively. $\overline{X}$ and S.D. denote mean value and standard deviation*

| Specimen | Group A | | Group B | |
|---|---|---|---|---|
| No | Number of fringes | Deformation ($\mu$m) | Number of fringes | Deformation ($\mu$m) |
| I | 36 | 12,4 | 33 | 11,0 |
| II | 23 | 7,6 | 29 | 9,7 |
| III | 25 | 8,3 | 32 | 10,7 |
| IV | 22 | 7,3 | 26 | 8,7 |
| V | 25 | 8,3 | 28 | 9,3 |
| $\overline{X}$ | 26,2 | 8,7 | 29,6 | 9,9 |
| S.D. | 5,6 | 1,9 | 2,4 | 0,8 |

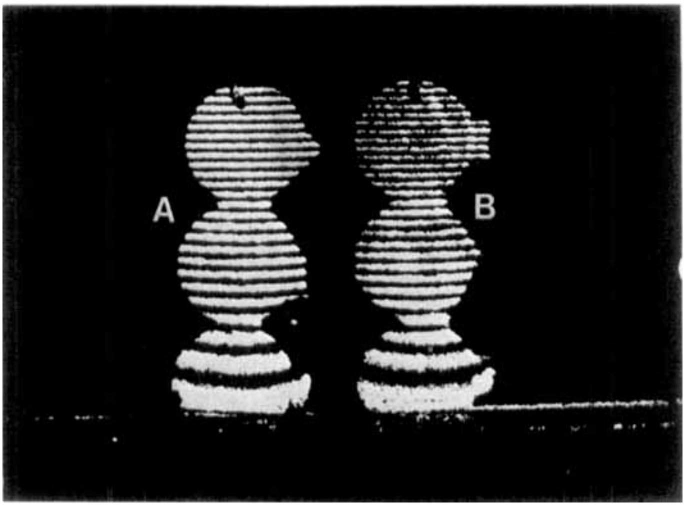


Fig. 3. Hologram demonstrating the elastic deformation of the soldered specimen. The number of interference fringes indicate a larger deformation in B (with) than in A (without defect in the soldered joint).

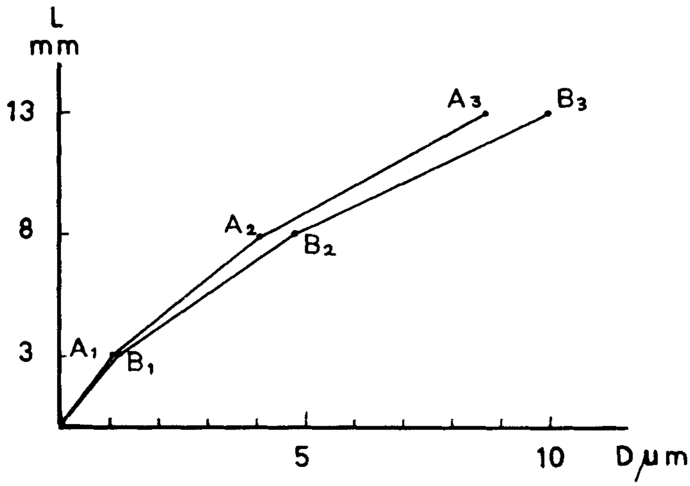


Fig. 4. A graphic curve of the mean deformation in the series A (without) and B (with defects in the soldered joints). The deformation per mm decreased with the distance from the point of attachement. L. Length of the specimen deformed.

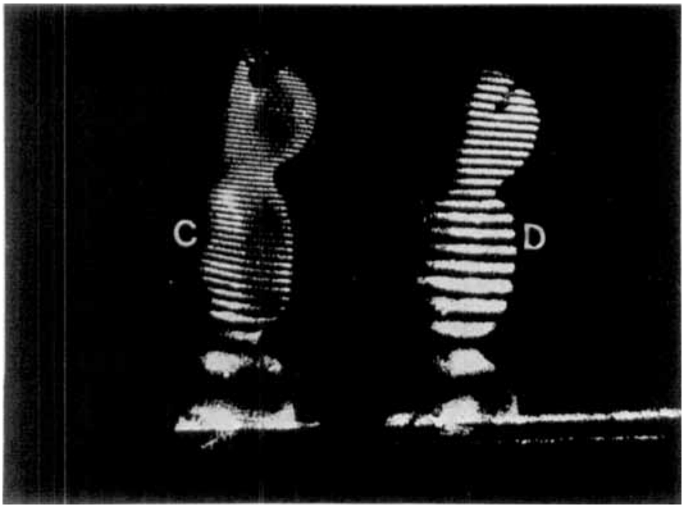


Fig. 5. The influence of dimensions of the soldered joint on the elastic deformation. The hologram demonstrated a less deformation of construction D than in C. The soldered joints of D had larger dimensions but with defects.

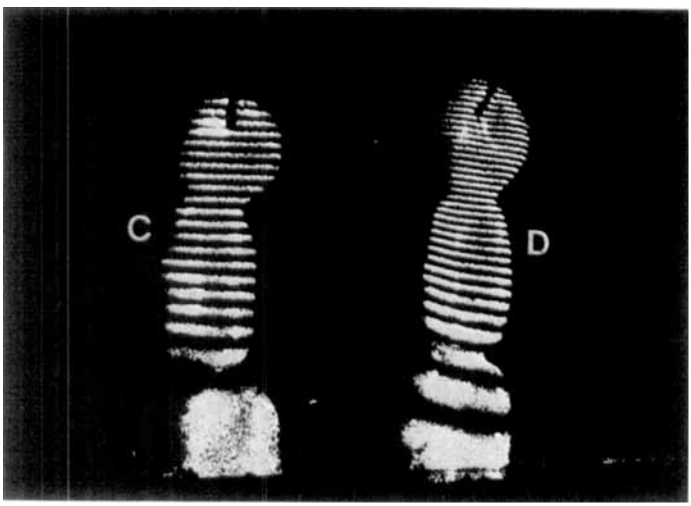


Fig. 6. The influence of defects in the soldered joint on the elastic deformation. The hologram of two constructions indicated a larger deformation of D (with defect). The dimensions of the solderings were equivalent in C. and D.


Fig. 7. Hologram demonstrating the deformation of a soldered 13-unit bridge mounted in an articulator. The loading point (Q) deformed especially the loaded unit (U) in an outwards direction.

varied too much to permit comparisons as regards deformation between the series with and without superficial defects (C and D). But it was possible to study the influence of two factors on this deformation. The influence of the dimensions of the soldered joint is demonstrated in Fig. 5, the elastic deformation being greater at 0.1 kp as well as at 0.2 kp in bridge D II than in C II, the latter having larger dimensions (H values) in its soldered joints (cf. Table II).

The influence of defects in the soldered joint is illustrated in Fig. 6, which shows a comparison between two bridge constructions with equivalent values for the dimension of the soldered joints. The D construction has a larger number of interference fringes, indicating greater elastic deformation.

The experiment with the 13-unit bridge construction demonstrated the possibility of using the holographic method to study deformations of a large dental bridge. The hologram indicated a deformation of the whole construction, especially at the loading point (Q) into the gold unit, which was bent outwards (Fig. 7).

Little use has been made of holography to study the elastic deformation of dental appliances. Using a holographic method, it is possible to investigate the magnitude of this deformation continuously in the entire specimen. The deformation is registered without mechanical gauges and the errors associated with these. The deformation is recorded in the hologram, which can be filed for secondary studies as a document of the experimental procedure.

Elastic deformations of less than 0.32 $\mu$m could not be analysed with the He-Ne laser apparatus. As the deformation arises from a difference in loading, the size of the load can be chosen between zero and the specimen's elastic limit. But the difference in load between the first and second recordings should be selected to give a suitable fringe separation. The experiments demonstrate that this selection has to be based on the size, shape and material of the specimen.

The quality of the holograms obtained of the castings and soldered specimens of dental gold material indicated that the method is appropriate for studying elastic deformations in these objects. The gold surface should not be polished, as this only enhances reflections in the holographic image. A bright metallic surface can be made dull by painting.

It will be seen from the results that specimens with defects in the soldered joints displayed a greater elastic deformation under the small loads applied. The size and location of the deformation could be seen distinctly in the holograms (Figs. 3 and 5). The deformation displayed a parabolic and not a linear increase with the distance from the point of attachment to the application of the load. The location of interference fringes showed that the elastic deformation increased more in the soldered joint situated at the point of attachment. Deformation was also observed, however, in the cast parts of the specimens.

It is clear from the present study that the elastic deformation of soldered structures made from dental gold alloy increases if the soldered joints are defective, the increase being detectable at small loads (0.2 kp). The result is indenpedent of the value of the first load as long as the load does not exceed the proportional limit of the material. Thus the difference of deformation is only due to the difference in load between the first and second exposure of the hologram (Tool Engineers Handbook, 1949).

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