

## Letters to the Editor

### Eliminating the diffraction halo effect in speckle photography

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A method to eliminate the diffraction halo effect in speckle photography is derived which does not demand any knowledge of the halo intensity distribution. Both maxima and minima positions in Young's fringe pattern may be used. Experiments are performed to verify the applicability of the proposed procedure.

#### 1. Introduction

Speckle photography has now become a common technique for non-destructive strain analysis in static and dynamic problems [1]. The method is based on the correlation of two random patterns (both coherent and incoherent ones may be used) of an object recorded on the same photo emulsion before and after the object is affected. The specklegram is then optically processed by a whole field or (more often) by a pointwise filtering. The last procedure consists in illuminating a small region of the speckle photograph at normal incidence with a converging beam of laser light. In the Fourier plane where the beam comes to focus a diffraction halo appears modulated by a parallel equispaced fringes similar to Young's fringes. The displacement vector of the point of consideration is determined from the spacing and the angle of these fringes.

It has been found that the halo intensity variation changes the slope of the fringes and as a result the minima move to the edge of the pattern and the maxima — to its centre. So the values determined from maxima or from minima positions turn to be different from their real values [2]–[4]. The effect is significant when the fringe density is low, *i.e.*, near the lower limit of measurable displacement  $d_{\min}$ , and experiments with laser speckle photography show that measured displacement values less than  $5d_{\min}$  and  $3d_{\min}$  when using maxima and minima, respectively, are highly inaccurate and necessitate compulsory corrections to obtain reliable results [5].

Different methods are suggested to correct the results and to remove the diffraction halo effect for the occasion when displacements and vibrations are measured [6]–[9]. Most of them are based on theoretical models for diffraction halo intensity distribution. But the actually observed halo profile may be quite different from the predicted one. This is valid especially in white light speckle photo-

graphy where the diffraction halo is affected by many factors that usually cannot be taken into account. In all these cases the above-mentioned procedures are inapplicable.

The experimentally observed diffraction halo shape also may be used to correct the results. In this case, some additional experiments are necessary to obtain the real halo function [10]–[12].

In this work, we present a simple method to eliminate the diffraction halo effect in speckle photography. Both maxima and minima positions in Young's fringe pattern may be used and no assumptions about the halo intensity distribution are needed.

## 2. Method for removing the diffraction halo effect

The light intensity distribution in the Fourier plane with point by point filtering is

$$I(x) = I_0(x) \cos^2 \frac{\pi x d M}{\lambda L} \quad (1)$$

where  $x$  is the coordinate in the direction perpendicular to the fringes,  $I_0(x)$  is the diffraction halo intensity distribution,  $d$  is the displacement in the object plane,  $\lambda$  is the wavelength used for filtering,  $L$  is the distance between the specklegram and the Fourier plane, and  $M$  is the magnification factor. Here we assume that the image is integrated along lines parallel to the fringes to create a one dimensional function. As the fringe positions are slightly affected by the visibility factor  $v$ , here we accept  $v = 1$ .

The displacement values are usually obtained using  $n$ -th maximum position  $x_n$

$$d = \frac{\lambda L n}{M x_n}, \quad n = 1, 2, 3, \dots, \quad (2)$$

or  $n$ -th order minimum position  $x_n^0$

$$d = \frac{\lambda L (n + 1/2)}{M x_n^0}, \quad n = 0, 1, 2, 3, \dots, \quad (3)$$

hence:

$$d \frac{x_n}{n} = \text{const} \quad \text{or} \quad d \frac{x_n^0}{n + 1/2} = \text{const}, \quad (4)$$

for maxima or minima positions, respectively.

As we have already seen, this is valid only for constant intensity halo or when the displacements are sufficiently big.

Let us assume that

$$d \frac{x_n}{n} f(x_n/n) = \text{const} \quad (5)$$

where  $f(x_n/n)$  is a correcting function.

This function may be different according to the specific experimental conditions and it can be estimated by processing a number of double exposed specklegrams recorded with known displacement values and appropriate approximation.

### 3. Experimental results

The validity of the proposed procedure was verified experimentally for white light speckle photography, where the diffraction halo is much more sensitive. A plane white object with an artificially created speckle pattern was illuminated with a flash lamp and imaged by an ordinary 35 mm camera. Between the two exposures a camera translation of a known value perpendicular to the optical axis of the lens was introduced. The specklegrams were analysed by pointwise filtering using a scanning slit whose width was chosen so as not to influence the fringe visibility. The correcting function was estimated by polynomial approximation of different degree and using different number of initial values from first maxima positions.

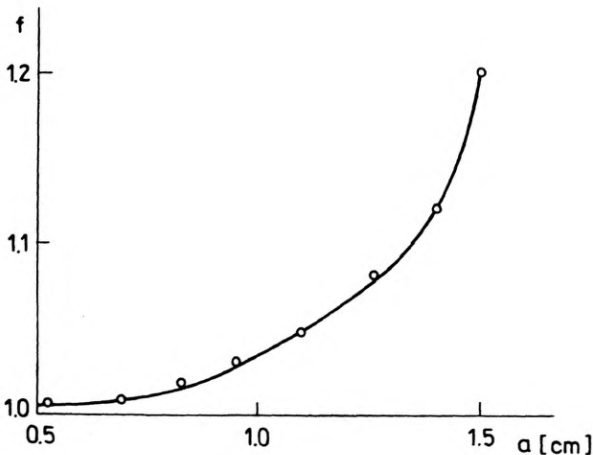


Fig. 1. Experimentally determined correction function versus the first maximum position:  $\circ$  — points used for polynomial approximation

Figure 1 shows the experimentally determined correction function versus the first maximum position. To obtain it known displacement values in the range of 300–700  $\mu\text{m}$  are introduced to the recording camera. It is seen that the values calculated by means of Eq. (2) need corrections up to 20%.

An approximation by polynom of the 4-th degree based on the points marked in Fig. 1 seems to be good enough to be used for corrections which can be seen in Fig. 2. Two curves are presented in the figure — the values calculated by means of Eq. (2) and the real displacement values against the maxima positions. The values estimated using the procedure described are plotted so well and they agree very well with the real displacement values.

The procedure described could be useful in a variety of practical situations. We applied it when investigating in-plane strain of the models of thin-wall structures

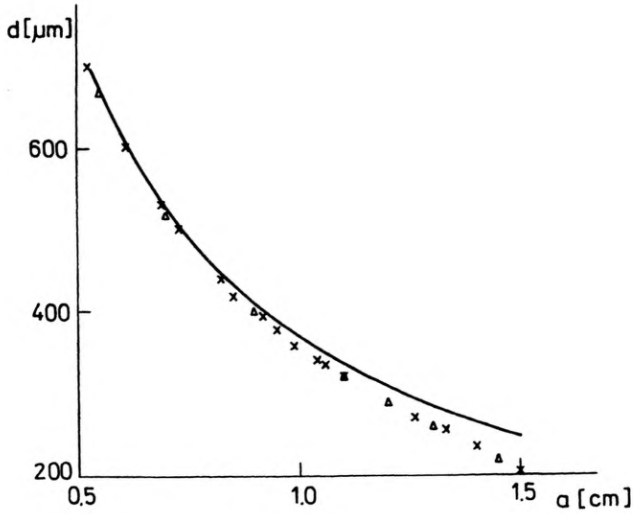


Fig. 2. Displacement values versus the first maximum position. — — calculated by means of Eq. (2),  $\times$  — real values,  $\Delta$  — corrected by means of polynomial approximation

by white light speckle photography which was performed simultaneously with their engineering testing. Displacements in a wide range of a great number of points had to be measured and models were loaded many times. No one of the known methods seemed to be suitable to correct lower displacement values influenced by the diffraction halo slope. We need not to discuss here in detail the experiments and shall only note that in several points of the model the vertical components of the

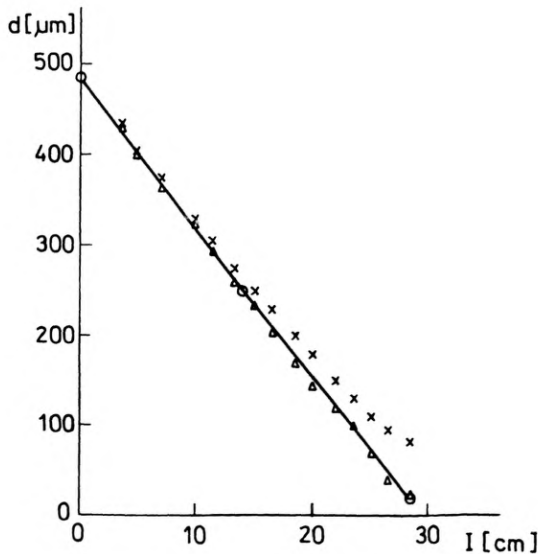


Fig. 3. Comparison between uncorrected ( $\times$ ) and corrected ( $\Delta$ ) displacement values

displacement vector were measured independently. Before the models were loaded known lateral displacements were given to the recording camera and were used afterwards for polynomial approximation.

An example of the results is presented in Figure 3, where the vertical displacement components are plotted against the model length. It is seen that polynomial approximation permits obtaining trustworthy displacement values.

#### 4. Conclusions

The proposed procedure eliminates the diffraction halo effect in speckle photography in a very simple way. Although we prefer to use for it maxima positions, minima may be used in the same way. It should be noted that no information about the halo shape is needed and hence it may be applied without any restrictions in most practical cases of speckle photography.

#### References

- [1] JONES R., WYKES C., *Holographic and Speckle Interferometry*, Cambridge University Press, Cambridge 1983.
- [2] KAUFMANN G. H., *Appl. Opt.* **21** (1982), 3411.
- [3] VIKRAM C. S., VEDAM K., *Appl. Opt.* **20** (1981), 3388.
- [4] SHAKNER C., NIRALA A. K., *Appl. Opt.* **33** (1994), 2125.
- [5] GEORGIEVA J., *Appl. Opt.* **25** (1986), 3970.
- [6] KAUFMANN G. H., *Appl. Opt.* **20** (1981), 4277.
- [7] VIKRAM C. S., *Opt. Lett.* **7** (1982), 374.
- [8] JOENATHAN C. J., SIROHI R. S., *Appl. Opt.* **25** (1986), 1791.
- [9] VIKRAM C. S., VEDAM K., *Appl. Opt.* **22** (1985), 2242.
- [10] GEORGIEVA J., *Appl. Opt.* **28** (1989), 21.
- [11] HUNTLEY J. M., *J. Phys. E: Sci. Instrum.* **19** (1986), 43.
- [12] HUNTLEY J. M., *Appl. Opt.* **28** (1989), 4316.

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