THE OPTICAL STUDY OF PERCUSSION FIGURES

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ABSTRACT

The application of optical interference methods to the study of the small local deformations occurring in impact is indicated as likely to lead to an extension of our knowledge of such deformations. As an illustration of the usefulness of the method, interference photographs showing the surface deformations produced by the percussion of a polished steel ball on a thick glass plate are reproduced. The photographs show the percussion figure to consist of three distinct regions.

a. A central area which remains plane and practically undisturbed except for a small permanent lowering of its level.

b. A narrow annular region of fracture showing severe injury to the surface.

c. A sudden elevation of the surrounding surface which slopes down gradually to the general level of the plate at the outer margin of the area of internal fracture.

As is well-known, a theory of the elastic deformations produced when two solid bodies with curved surfaces are pressed into contact was developed by Hertz,[1] and applied by him to a consideration of the phenomena occurring during the impact of such bodies. The theory takes no account of the *irreversible* deformations such as actually occur in practice under sufficient static pressure or in elastic collision, and of the consequent dissipation of energy; it does not therefore completely describe the phenomena. Nevertheless the theory serves as a first approximation and is a useful guide in attempting to understand the behavior of imperfectly elastic materials in hardness or impact tests. In special cases, as for instance when the impact velocities are very low,[2] or when no energy loss occurs except that due to production of vibrations in the impinging bodies,[3] Hertz's theory fits the facts tolerably well or at any rate can be suitably modified. It is more difficult adequately to take into account the effect of inelastic deformations on the course of the phenomena of impact, particularly because the element of time enters in the problem in a somewhat complicated way. Nevertheless it may be hoped that an exact experimental knowledge of the subject may pave the way for further developments in theory.

It occurred to the writer that an application of optical interference methods might be useful in extending and making more precise the

[1] Hertz, Miscellaneous papers, English Translation, p. 146.

[2] C. V. Raman, Physical Review, 2nd Series, *12*, p. 442, 1918.

[3] C. V. Raman, Physical Review, 2nd Series, *15*, p. 277, 1920. See also, J. Okubo, Tohoku Univ. Sc. Reports, *11*, pp. 445-461, Dec. 1922.

knowledge of the local deformations occurring in impact. The interference lines between the deformed surface and an optical flat would form an accurate contour map which could easily be measured up and interpreted, and the sensitivity of the method would be such that deformations as small as 10^{-5} of a centimeter could be accurately determined. In the case of metallic surfaces, a difficulty which presents itself is that the reflecting power of a polished metallic surface is usually much higher than that of an optical flat of glass or fused quartz, and the visibility of the fringes between them is therefore somewhat low. This may however be overcome by half-silvering the lower face of the optical flat and thus making the reflecting power of the two boundaries of the air film nearly equal. Work on these lines has been undertaken by Mr. Kedareswar Banerjee, a research student under the writer's direction, and the results obtained will be reported in due course. As an indication of the usefulness of the method suggested in the study of the deformations produced by elastic impact, the writer wishes to present three interference photographs obtained by him showing the effect of the collision of a polished steel ball 2 cm diameter on the surface of a thick glass plate. The percussion figure obtained in this case was described by the writer some five years ago in a communication to Nature.[4] Its remarkable character is brought out in a striking way when an optical flat is laid on the deformed surface, and the interference fringes between the contiguous faces are observed in monochromatic light. Figs. 1, 2 and 3 are photographs obtained in this way, (magnification about five diameters), a quartz mercury lamp with quinine sulphate filter being the source of light used. In Fig. 1, the two surfaces were nearly parallel, in Fig. 2, somewhat more inclined to each other and in Fig. 3 further inclined still.

An inspection of the photographs shows three distinct regions in the percussion figures. Firstly, there is a central area, nearly circular which, apparently, is unaffected by the impact as is shown by the fringes passing through it in Fig. 3 being straight and parallel. Secondly, there is a narrow annular region of fracture full of a net-work of irregular fringes, showing severe injury to the surface. Thirdly, and just beyond this, there is a sudden elevation of the surface, of about four wave lengths, which slopes down first quickly, and then more slowly, to the original level of the surface at the edge of an area which sets the limit to the percussion figure. Closer examination reveals another remarkable

[4] C.V. Raman, "Nature," Oct. 9, 1919.

feature, namely, that the central area of the percussion figure, though it remains plane and apparently undisturbed has, in reality, been *depressed below* the original level of the surface by an appreciable fraction of a

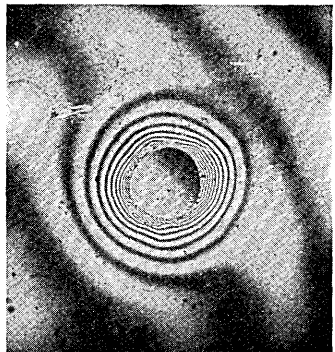

FIG. 1. *Percussion Figure: Interference pattern with test-plate nearly parallel to surface of glass block.*

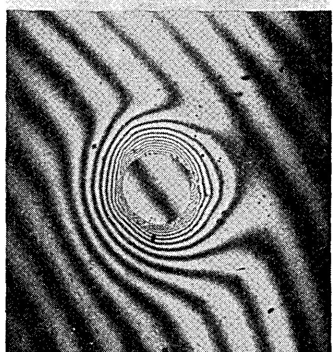

FIG. 2. *As in Fig. 1, but with the test-plate not parallel to surface.*

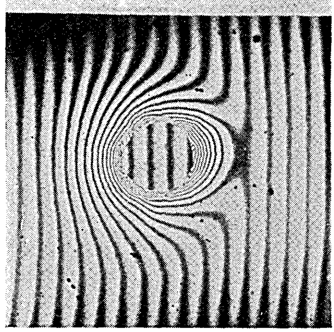

FIG. 3. *As in Fig. 2, but with still larger tilt of test-plate.*

wave length, as shown by the fact that the course of the fringes outside the percussion area and within the central circle are distinctly out of register. This feature will be evident on a scrutiny of all three photographs and has been found to be an invariable feature of the percussion figures produced even on very thick glass plates by the impact of steel balls.

An explanation of these features on Hertz's theory of impact may be ventured, though some points still remain obscure. The nature of the stress distribution in the case of a sphere resting on a plane has been worked out by S. Fuchs[5] who has given a diagram of the lines of principal stress. Near the central compressed area both the principal stresses are pressures, and the glass stands the compression without giving way. There is a narrow annular region surrounding the central area where one set of principal stresses are pressures and the other set are tensions. The shearing stresses are a maximum in this region and the glass gives away, the circular crack spreading obliquely inwards into it for a considerable region. When the crack forms, the surface of the glass on its outer side is raised up and dips down slowly to the edge of the area covered by the extension of the internal fracture-surface. The small permanent depression of the central area remains, however, a mystery. It does not seem possible that it can be due to any actual flow of the glass during the impact, as the time available is all too short for such flow to occur, and as, moreover, there is no sign of the area in contact with the sphere acquiring any appreciable curvature, as could reasonably be expected if viscous flow occurred. Accepting the reality of the phenomenon, the only explanation of it that the writer can offer is that, at the instant the crack starts and spreads inwards, part of the material which has shifted its position outwards under the intense compressive forces remains outside it and is unable to return. The level of the central area is thus permanently lowered when the stress is removed. Further studies of the phenomenon under large static stresses would be of interest.

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[5] S. Fuchs, Physikalische Zeitschrift, p. 1282, 1913.