by fringe width, which varied between 0·004 cm⁻¹ and 0·018 cm⁻¹, so it is possible that separations of one or two $\Delta\bar{\nu}$ may not have been detected. This, however, would not explain those lines which did not fit into a mode family as their widths were in general not broad enough to contain multiplets. No family of modes extending over a range of wavenumber greater than 18 $\Delta\bar{\nu}$ has been found. That modes separated by higher multiples of $\Delta\bar{\nu}$, but disguised by overlapping of orders in the Fabry–Perot pattern, were not present was confirmed by carrying out a number of trial shots with an interferometer spacing of 2 cm and 0·1 cm. The former spacing would have brought to light members of a family of axial modes over a range of about 40 $\Delta\bar{\nu}$, and the latter, which produced fringes the widths of which were at the limit of instrumental resolution, served to show that over a range of about 800 $\Delta\bar{\nu}$ no more modes were present.

The occurrence of single unrelated lines and more than one family of axial modes in a single giant pulse may be due to different parts of the laser oscillating independently. It is interesting to note that if the fringes are considered as arising from single modes, the observed widths are consistent with mode lifetimes of between 2 and 8 n sec.

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ENGINEERING

Reversed Plastic Flow during the Unloading of a Spherical Indenter

THE process of indentation of a metal surface by a hard spherical indenter has been examined in considerable detail by Tabor[1] and others. If the indenter makes contact with the surface over a circular area of radius a under the action of a load W, the mean contact pressure $p_m = W/\pi a^2$. Tabor showed that plastic yielding begins beneath the surface of the metal when p_m reaches the value 1·1 Y (where Y = yield stress of the metal in simple tension). As the load is increased and a marked plastic indentation develops, the mean pressure approaches a value which is independent of the load given by:

$$p_m = cY \tag{1}$$

where c has a value of approximately 3. This is the state of affairs in a Brinell hardness test.

After the load and indenter are removed the indentation remains, although its curvature is slightly less than that of the indenter itself. The change in curvature is attributed by Tabor to elastic recovery of the material during unloading and his measurements are consistent with this view. If the unloading process is elastic then reloading to the same load should produce no further plastic deformation. Tabor observed no increase in the size of the impression during five repeated applications of the same load. He concluded, therefore, that the deformation after the first application of load was entirely elastic.

Some recent experiments made by Tyler, Burton and Ku[2], in which an impression has been observed to grow in size under the action of a load repeated many times, have led to Tabor's conclusions being re-examined. It is the purpose of this communication to show, on theoretical grounds, that reversed plastic yielding would be expected during the unloading of an indenter, and hence that repeated loading would cause a continuous cycle of plastic deformation.

When the load is first applied the mean contact pressure is given by equation (1), but no exact theory predicts the distribution of this pressure over the contact surface. Tabor[1] quotes the approximate analysis of Ishlinsky to demonstrate that the actual pressure distribution will not differ greatly from the elliptical distribution of Hertz for elastic contact. The unloading process may then be thought to consist of the subsequent application of an equal negative pressure to the contact surface.

At the end of the loading process the material beneath the surface, lying on the axis of symmetry, will be in a state of plastic flow, so that by the Tresca maximum shear criterion of yield:

$$\sigma_z - \sigma_r = Y \tag{2}$$

where σ_z is the stress (compressive) acting normal to the surface and σ_r is the stress (also compressive) acting parallel to the surface.

To represent unloading we apply a Hertzian distribution of tension to the surface having a maximum intensity:

$$p_0 = \frac{3}{2}\,p_m = \frac{3}{2}\,cY \tag{3}$$

If the unloading process were perfectly elastic this surface tension would result in a maximum principal stress difference at a point beneath the surface on the axis of symmetry the magnitude of which is given by the Hertz theory, that is:

$$(\sigma_z - \sigma_r)_{\max} = 0{\cdot}62p_0 = 0{\cdot}92cY \tag{4}$$

in which σ_z and σ_r are both tensile.

To find the state of stress corresponding to complete unloading we superpose the stresses given by equations (1) and (4), having due regard for sign, with the result:

$$\sigma_z - \sigma_r = (1 - 0{\cdot}93c)Y \tag{5}$$

Now reversed yielding would be expected if $\sigma_z - \sigma_r$ in this equation exceeds $-Y$, that is, if:

$$c > 2{\cdot}15 \tag{6}$$

As Tabor has shown by many tests, c has a value lying between 2·7 and 3. We would therefore expect reversed yielding to occur in a small region beneath the surface during unloading from the fully plastic state. This yielded region will be fully contained and will not make a noticeable change in the surface profile, which explains why it was not detected by Tabor's profile measurements.

By the same argument, a second loading to the same maximum load will cause a reversal of yield in the subsurface region. Under cyclic loading, therefore, we would expect a repeated cycle of plastic deformation. This could lead to either a progressive enlargement of the indentation or failure by a fatigue process.

The foregoing argument is based on the assumption that the metal has an equal yield strength in loading and unloading. Actually the Bauschinger effect will make reversed yielding during unloading even more certain.

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