studies concerned the effects of changes in incentive payment systems in a factory and a repair works. All the studies showed the importance of considering the total factory situation, the relevance of the incentive payment system to the nature and organization of the work, and the social effects produced by these systems.

Satisfaction with a system appeared to be related to the understanding of it, and this depended on the workers' ability to explain it to themselves.

In the two studies of changes in payment systems it was found that improved morale and satisfaction followed the change, but it was not possible to attribute this to the alteration alone. There was evidence that improved output may accompany increased satisfaction, but different performances by comparable working groups were attributed more to the size and stability of the groups. Social conflicts arose in group systems if there was equal regard for unequal effort.

In addition to these investigations, essential incidental studies have been carried out on methodological problems in order to facilitate work in this field. Among these are a study of the dangers of using crude absence-rates available in industry; examinations of the use of linear and verbal self-assessment scales in the assessment of attitude; consideration of possible extensions of the paired comparison technique in measurement of opinion and in measurement of agreement of opinion; a study of the different methods of measuring understanding and remembering of verbal material and the development of rank correlation methods.

Papers have also been published on accidents in industry, and on the effects on skill and performance of machine design, environment and technological change.

CONTACT STRESSES

So many engineering devices, such as toothed gears, rolling bearings and the wheel itself, operate by the transmission of large forces between surfaces in contact over a relatively small area that a knowledge of the local stresses set up in the region of such contacts is obviously of wide interest. Yet the symposium, organized by the Stress Analysis Group and held at the Institute of Physics on May 14, appears to have been the first in Britain to be devoted specifically to the topic of "Contact Stresses". An explanation for the neglect of the subject probably lies in the mathematical difficulties involved in obtaining a theoretical solution to even the simplest problem in contact stress. Apart from the inspired, and now classical, theory of elastic contact presented by Hertz in 1881, there have been until recently very few contributions to the theoretical structure of the subject so beloved of academic investigators. In consequence, the engineering designer has been obliged to develop his own empirical rules and to conduct his own comparative tests to avoid the undesirable consequences of excessive contact stresses: pitting, scuffing, fretting or simple wear.

The past few years, however, have seen considerable advances in the theory of contact stresses. A number of solutions have been found, arising, as so often is the case, from investigations in other fields, to the problem of contact of both ideally elastic and ideally plastic solids under the action of various systems of forces. The basis for more fundamental and revealing studies of the mechanism of surface breakdown under contact loads appears to have been laid, and it is likely that more satisfactory explanations of pitting and other surface failures are not too remote. Even the study of metallic friction and wear, which has attracted scientific work of high quality over a number of years, has benefited from recent theoretical studies.

The present symposium gave encouraging evidence of this trend. The extent to which the problems are common ones was striking. Speakers whose papers arose from interests as diverse as railways, toothed gearing, ball-bearings and rubber tyres described phenomena which were basically similar and to which the academic contributions were relevant.

Contact-stress problems can be divided broadly into two categories, one of contact between surfaces having no relative movement, and the other to include contact between rolling or sliding solids. The first session was devoted to stationary contact, and naturally the papers were concerned with various extensions to the Hertz problem of two ideally elastic bodies under the action of a purely normal force. Mr. C. Storey (Constructors—John Brown, Ltd., Leatherhead) recalled Hertz's assumption that the undeformed profile of the solids in contact could be taken to be parabolic, and showed how the theory could be improved for spherical surfaces. The correction appears to be significant only where there is close conformity between the surfaces, as for a ball-ended pivot in a spherical seating.

Perhaps the most valuable recent contribution to elastic contact theory is due to Mindlin[1] and his associates, who have found the surface tractions and displacements at a contact where a tangential force and a twisting couple are applied in addition to a normal force. They have shown that in consequence some slip is inevitable at a periphery of the contact area. Explicit calculations of the internal stresses in these circumstances have not been made, so that the experimental work of Mr. E. Ollerton (Nottingham) is particularly valuable. He described a photoelastic investigation of the contact stress-field under the action of a normal and tangential force (less than the limiting friction force). The observations with a two-dimensional model as the tangential force approached its limiting value were shown to compare favourably with the theoretical analysis of Poritsky[2]. With smaller tangential forces and also with a three-dimensional model, an attempt was made to deduce the surface stresses to compare with Mindlin's theory, but at the present stage of development of the technique the comparison is rather inconclusive.

The work of Bowden and Tabor[3] on metallic friction has shown that the intimate contact of metal surfaces is to a large extent a plastic phenomenon. In the most lightly loaded contacts the surface asperities are crushed plastically so that the subsequent application of a tangential force, however small, must cause further plastic flow. Dr. D. Tabor

(Cambridge) discussed this process, referring to the experiments on adhesion carried out by McFarlane and Tabor[4] and to the measurements of initial tangential displacement by Courtney-Pratt and Eisner[5]. In both these investigations the behaviour of a single asperity was simulated by using small, heavily loaded contacts in soft metals so that their real and apparent areas of contact coincided. The application of a tangential force to a contact already stressed to the yield pressure in compression causes an immediate increase in the area of real contact. The predominant plastic deformation, therefore, initially brings the surfaces closer together, while the tangential displacements are of an elastic order of magnitude, as their agreement with Mindlin's elastic theory shows. As the tangential force is increased, the contact undergoes large, irreversible, plastic deformation in the tangential direction until, at a point determined by the cleanliness of the surfaces, the junction breaks, and complete sliding occurs. In the context of a meeting on contact stresses it is relevant to ask how the essentially plastic behaviour of individual surface asperities can be related to the overall properties of a contact in which the forces are transmitted through a large number of asperities, while the main body of the material is stressed within its elastic limit—the usual situation found in engineering practice. Is an elastic theory of any value? The experiments of Johnson[6] suggest that the deformation of the contact as a whole can be predicted very closely by an elastic theory. The explanation seems to lie in the fact that if contact is maintained through a large number of junctions their tangential plastic deformation is 'controlled' (in the sense used in plasticity theory) by the strains in the hinterland which remain elastic. Thus two solids first pressed into apparently elastic contact and then sheared undergo normal and tangential displacements given by Mindlin's theory. Over the central area of contact, where the normal pressure is high and the tangential tractions low, the solids are locked together. Towards the edges of the contact area, where Mindlin predicted slip, the asperities may be expected to shear plastically in the manner of Courtney-Pratt's model, through a displacement sufficient (yet no more than sufficient) to relieve otherwise infinite elastic stresses in the body of the material.

The second session was devoted to papers on rolling contact. Experimental investigations of the tangential stresses and relative movements at the contact surface of a rolling pneumatic tyre were reviewed by Mr. V. E. Gough (Dunlop Rubber Co., Ltd., Birmingham). The importance of tangential surface stresses was emphasized since these provide both the driving force and also the controlling forces of a wheeled vehicle. The amount of slip between the tyre and the ground determines the wear-life of the tyre. It was shown that the area of contact is divided into two regions: a forward region where there is no relative movement with the ground, and a region at the sides and trailing edge of the contact area where slip occurs. If the plane of the wheel is inclined at an angle to the direction of rolling, which would arise from the side-slip when rounding a corner, the tangential tractions at the contact surface provide a transverse 'cornering' force. In addition, due to the fact that the slip occurs at the rear of the contact area, this force exerts a self-aligning torque tending to rotate the plane of the wheel into the direction of rolling. Measurements of the cornering force and self-aligning torque as a function of the slip (or yaw) angle show that these quantities increase in proportion to the slip for small angles to a maximum value, after which they decrease gradually. The maximum value corresponds to the transition from partial slip to complete sliding of the tyre on the ground.

The similarity in behaviour of a rolling tyre and a rolling solid is striking. In a later paper, Dr. K. L. Johnson (Cambridge) showed pictures of the contact area of a solid rubber ball rolling on a 'Perspex' sheet. The patterns of slip are almost identical: slip begins at the sides and trailing edge and spreads forwards as the tangential tractions are increased. Experiments with steel balls rolling on steel tracks exhibit similar relationships between the slip motion, or 'creep' as it is frequently called, and the tangential forces and twisting moments. Conditions similar to those obtaining in the case of a tyre rounding a corner occur in angular-contact ball-bearings, where, due to rolling around a curved track, the balls have an angular velocity of 'spin' relative to the races on which they roll, and tangential forces are brought into play by virtue of the 'creep' motion. It follows that in such a bearing the steady-state rolling path of the balls lies between surfaces of the races which are not parallel at the two points of contact, a result which is contrary to the usual assumption in ball-bearing design.

Messrs. A. A. Milne and A. M. Nicholson (Mechanical Engineering Research Laboratory, Glasgow) and also Dr. A. W. Crook (Associated Electrical Industries, Ltd., Aldermaston) were indirectly interested in the life of rolling contacts—the former in rolling bearings and the latter in toothed gears—so that their papers dealt with the breakdown of the rolling surfaces under the continuous application of heavy loads. Milne and Nicholson described some experiments using a modified four-ball machine[7] in which a single rotating ball rolls on three others. The kinematics of the motion were analysed and it was shown that there is a large angular velocity of spin between the rotating and the rolling balls, in consequence of which slip occurs at the sides of the contact area. The majority of the pitting cracks are observed at the edges of the rolling track and on the slower moving surface. The conclusion that, where rolling is accompanied by sliding or even local slip, pitting is more likely to affect the slower moving surface now seems to be fairly well established. As Mr. Milne observed, the cycle of stress experienced by the slower moving surface is one of tension followed by compression, which is consistent with the theory of crack propagation by trapped lubricant proposed by Way[8].

The paper by Dr. Crook suggested that another significant mechanism might be involved. Experiments on rolling mild steel disks under loads sufficiently large to exaggerate the amount of plastic flow were described[9]. He showed that two disks rolling under a purely normal contact force produce plastic shearing of a relatively undeformed surface layer, forward, in the direction of rolling, relative to the main body of the disk. The effect is independent of the presence of a lubricant. Running the disks at different speeds introduces frictional tractions at the contact surfaces, acting in the direction of rolling on the slower surface and opposed to it on the faster one. The effect of these tractions, as might be expected, is to accentuate the plastic flow of the slower surface and restrict or reverse that of the upper surface depending upon the coefficient of friction. In any event, it appears that the slower moving surface experiences much larger plastic deformations than the faster one, which under lighter loads and with less ductile materials would be likely to lead to a shorter fatigue life.

The papers on rolling contact made it clear that stresses and distortions in rolling contact are likely to differ from those in a stationary contact under the same forces. Dr. Johnson explained this difference in terms of the different stress history of a surface element in the two cases. If either slip or plastic flow takes place, a difference in sequence of loading leads to a difference in the overall stress pattern. In particular, it was shown that slip at the contact surface begins at the trailing edge of the contact area and not at the leading edge. A method of approach to the theoretical problems of rolling contact was suggested in which the process is viewed as one of 'steady-flow' in the manner of hydrodynamics. This involves using the Eulerian co-ordinate system[10] in which the contact region appears as a stationary pattern of elastic distortion through which the material of both surfaces flows at a steady rate.

Taken as a whole, the symposium gave a valuable co-ordinated view of the present state of research into contact problems in Britain. K. L. JOHNSON

PAPERS PRESENTED AT THE SYMPOSIUM

Andrews, H. I., "Contact Stresses on Railways and Wheel and Rail Problems".
Ollerton, E., "Contact Stresses between Toroids under Radial and Tangential Loads".
Tabor, D., "Effect of Tangential Stresses on Plastically Loaded Contacts".
Storey, C., "Point Contact Effects—the Relevance of Hertz's Theory".
Gough, V. E., "Tyre to Ground Contact Stresses".
Milne, A. A., and Nicholson, A. M., "Pitting Failure—Some Studies in the Modified Four-ball Machine".
Crook, A. W., "Some Experiments upon Sub-surface Deformation in a Disk Machine".
Johnson, K. L., "The Rolling Contact of Elastic Solids viewed as a Steady-flow Process".

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THE METROPOLITAN-VICKERS IRRADIATION LABORATORY

THE opening on May 29 of the new Irradiation Laboratory at the Metropolitan-Vickers Barton works was performed by Mr. H. West, director of electrical engineering in the Company. In a short address he reminded his audience that the scientific and engineering contributions made by Metropolitan-Vickers to the development of high-vacuum equipment and particle accelerators have been prominent in keeping Britain to the forefront in this field. An inspection of the new laboratory certainly gave strong support to his claim.

The principal item of equipment in the laboratory is the 4-MeV. linear accelerator, which produces the beam of irradiating electrons. There is nothing fundamentally new about this unit; it has been adapted from the accelerator developed by the Company for its 4-MeV. X-ray machines which are already installed in several hospitals in Britain. The electrons, bunched together into small clusters and travelling in a hollow corrugated' wave-guide, are accelerated by a radio-frequency field which is produced by the propagation of radio-frequency power of short wave-length (usually 10 cm.) along the wave-guide. The design of the wave-guide is such that the velocity of propagation of the radio-frequency field matches that of the accelerating electrons, so maintaining the phase relationship between field and beam and ensuring the continuous acceleration of the electrons along the whole length of the wave-guide. A radio-frequency feedback system is used to increase the energy of the beam, which is released in pulses of 2 μsec. duration at a rate of between 50 and 500 pulses per sec. The power of the beam is of the order of 500 watts, corresponding to a mean beam current of 125 μamp. At the output end of the accelerator an alternating field fans out the electrons so that they scan an area of 12 in. × $\frac{3}{4}$ in. as they emerge from an aluminium foil window.

The construction of the laboratory itself leaves nothing to chance in the matter of safety. A system of interlocked doors ensures that access to the treatment room (surrounded by massive concrete walls with 4-in. steel plates at strategic locations) or to the accelerator room automatically renders the apparatus harmless. All the control equipment is centralized and is well clear of any radiation or high-voltage hazard. Articles to be irradiated may be mounted either on a variable-speed continuous conveyor belt or a specially designed work-table, both of which are operated by remote control.

The property which makes irradiation a useful process is the disruption which it causes, particularly in large molecules. When biological systems are irradiated, three types of change may occur. Slight irradiation will lead to no obvious damage to the organism, but through the agency of gene mutation may promote the evolution of new genetic types. This offers the interesting possibility that, by exposing quantities of seed to radiation, the probability of producing mutations and of occasionally finding some improved plant strain may be greatly increased. Greater doses of radiation may render sterile the irradiated organism. A suggested application of this property is the improvement of the storage properties of some vegetables, such as potatoes, by preventing them from sprouting.

However, the most fascinating possibilities seem to arise from the utilization of the lethal effects of very large doses of radiation as a bacteriocide. Foodstuffs which normally deteriorate through bacterial infection have their keeping properties much improved