breadth of face can be taken advantage of, the principal limiting factors being speed and backlash. In the case of indifferently moulded gears, the usual rule of assuming all the load to bear on one corner of the tooth, due to the inequalities of the casting, must be adhered to.

Moulded teeth, being thinner than cut teeth of the same pitch to allow for the necessary extra clearance, their strength is consequently less, but thickness of tooth being a factor in the calculations for the determination of pitch and face, the difference in thickness is of course automatically compensated for, but what is not always taken sufficiently into consideration is the liability of moulded teeth to brittleness; the smaller the teeth the greater the degree of hardness and brittleness. This is usually compensated for up to about 4in. cir. pitch by employing an empirical formula: P. varying as p2b (where P. equals load, p equals cir. pitch, b equal breadth of face), the assumption being that 4in. circular pitch is the minimum at which the metal of the moulded teeth is equal to the metal of teeth cut from solid blanks.

The best way to approach the design of the one direction gears, in view of the many commercial advantages moulded gears possess when running under ordinary factory conditions, is to assume this type and throw the onus of proof of superiority upon the cut type, whether they be straight tooth, helical or worm gears. Superiority to be gauged by the net financial effect upon the industry in which they are employed.

Experience teaches that reciprocating gears should be avoided as much as possible, but where essential it is generally found to be to the best advantage to use those made out of the best material, with well-cut teeth, care being taken to keep the momentum of the parts actuated by the gear as low as the best of materials and skilful design will permit. The author has obtained some very satisfactory results by the use of some of the modern nickel steels in continuous running reciprocating gears reversing 540 times per minute.

Industrial considerations call for the use of abnormal gears much more frequently than is generally supposed by engineers who have only a limited experience in the design of industrial machines. Where gears are liable, even only very occasionally, to be fouled with bits of a more or less incompressible nature, extra clearance below the working depth of the teeth will often make the difference between comparative failure and complete success. Expedience sometimes makes it advisable to design the gears to run at variable depths to permit of some amount of adjustment of a business part of the machine. Pinions are called for, with teeth a long way below the number requisite, to fulfil the requirements of either sound theory or quite ordinary practice, and worm gears are required to run where it is quite impracticable to provide adequate lubrication for the sliding action of this class of reduction gear. Perhaps the situation is best described by a draftsman accustomed to machine tool-makers' practice, who, when engaged by the author to work up some alterations to a machine, declared that by all the laws of theory and practice the machine was unworkable, yet the machine in question was a particularly good one of its class, and a very profitable one to the proprietor.

FACTOR OF SAFETY AND SHOCK.

The question of factor of safety of the different mechanisms and members often arises in complicated and variable forms, to an extent that would at first seem incredible to the engineer without previous experience in this particular branch of the profession.

But quite frequently it is found that machine makers, even in the design of their specialities, have not devoted sufficient attention to this point, although calculation, ordinary observation, and lengthy trial tests under normal conditions may seem to shew the machine to be of a good type, and of ample strength for the normal duty it is to perform.

Unfortunately, the ordinary duty of many machines employed in some industries cannot be taken as even an approximate basis for design. The conditions under which they must necessarily be worked render them more or less liable to occasional shock of a specially severe nature, such as might be caused by the material being operated fouling the mechanisms or jamming. The design must, of course, provide for this shock, but it does not always follow that increasing the strength of the parts subjected to the abnormal stress, or reducing the momentum responsible, is either technically or financially the best way of overcoming the difficulty, and especially so where the stresses are greatly in excess of normal full load.

In cases where the introduction of a design, sufficiently strong to withstand only very occasional severe shocks, would impose an undesirable feature upon the industry concerned, "fusing" can sometimes be resorted to with advantage, i.e., the judicious insertion of a cheap, easily replaced, and comparatively weak part in the mechanism or structure subjected to the shock. The author has on several occasions successfully remedied the difficulty of breakdowns due to jamming by reducing the width of the belt. Though somewhat foreign to the subject in hand, it might not be altogether out of place to mention here that it is not always safe to assume, when considering the adoption of a positive drive, say, by a geared motor, of a machine hitherto driven by a belt, that the same results will be obtained in the working of the machine. Belt-slip and elasticity have not infrequently a beneficial effect on the running, not always appreciated at its full value.

The factor of safety to be used in any particular case must, of course, be determined by judgment and experience, on which the nature of the assumptions must have some influence. In structural work, engines, cranes and other classes of engineering where failure is liable to have disastrous consequences, accidents of a most remotely possible nature must be ensured against by a very real factor of safety, based, moreover, on assumptions, which, where there is any doubt, err on the side of liberality. Most industrial machines, however, by their failure do not entail the disastrous consequences of the nature already referred to, and therefore, while a reasonable margin of safety is desirable, it would be absurd to go to the extremes just mentioned. The designer must use his judgment and experience in each particular case to determine the value of the factor of safety that will best suit the interests of the manufacturer, always, of course, bearing in mind not to encroach below absolutely safe limits, where failure would be liable to inflict bodily injury. It is occasionally found that where some function of a machine must be prejudiced if what would be ordinarily considered a reasonable factor of safety is to be secured, it is of advantage, as weighed in the financial balance, to stress some of the materials involved close up to their limit of proof elasticity. This, of course, necessitates accurate assumptions and a knowledge of the grade of materials available for renewals in the locality in which the machine will be worked.

As in other branches of engineering, the continual improvements that are being made in the mechanical properties of materials, and particularly of steel, make possible to-day what was almost undreamt of a very few years ago, and it behoves those interested in industrial machines to be ever on the alert to avail themselves of any advantage these improved materials might have in any section of their work.

Choice of materials is also occasionally determined by some limitations imposed by the industry. A year or so ago the author, quite contrary to all the accepted rules of the game, introduced some bearing surfaces, mild steel against mild steel; indeed, so glaring was the departure from ordinary practice that some difficulty was experienced in persuading the firm selected to make them, in taking on the job, in case they might injure their reputation. Yet this mechanism has turned out an unqualified success. It is not of course suggested that mild steel bearing on mild steel is either good practice or desirable, but the instance mentioned serves to show that the engineer must not enslave himself to any hard and fast principle, but retain an open mind and judge each set of conditions upon its own merits relative to its financial bearing on the industry.

LIFE AND WEAR.

The life of a machine, properly measured, is that length of time a machine fulfils unimpaired the functions it was originally designed to serve. There must be no gradual falling off in either the quality or quantity of product from the day it is installed to the day it is discarded, but there may be in some instances a little latitude permissible in the way of increased maintenance costs as the machine ages. Machines should therefore be designed so as to permit of the ready renewal and adjustment of all parts subjected to wear or liable to damage, whether from the working of the machine or extraneous sources, and such parts should not be cast or forged solid with complicated or expensive parts where it can possibly be avoided.

Some machine makers, and notably some of the American makers who specialise, seem to take a special delight in embodying in one casting as many functions of the machine as the ingenuity of the designer and founder will allow, with little heed as to how the efficiency of the machine is to be maintained when breakage or wear necessitate repair. These makers usually lay claim to the advantages of the greater rigidity so attained, and often can quite truthfully point to some record-breaking performance in support of their claims. Machines con-

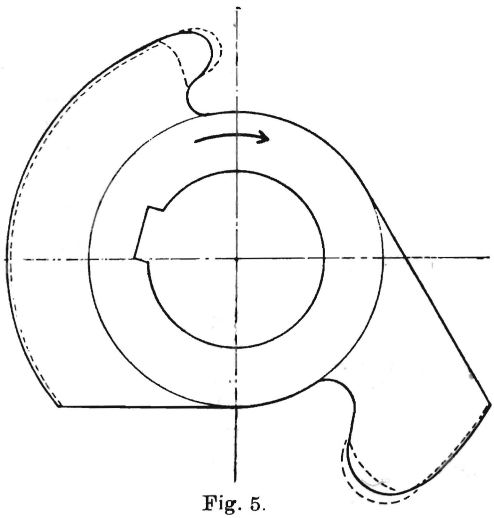

Fig. 5.

structed on these lines are obviously cheaper to construct when made in large quantities, but they are a poor asset to the manufacturer on account of the long periods they must run in a shabby condition, to the detriment of the quality and output, or if this is to be avoided, long stoppages and expensive repairs are required for only trivial adjustments, more than wiping out the advantages of any previous record-breaking feats. Most industrial machines entail a lot of wear, and what a manufacturer requires is to be able to deal with each little defect from this cause as it arises, in a speedy and workmanlike manner, at an expense commensurate with the nature of the repair itself, without having to take adrift a large proportion of the entire machine.

This important question of providing facilities for adjusting for wear frequently has a considerable effect on the form the design takes. For illustration, take the simple case of a cam in a position difficult of access for its removal, the said cam being subjected to heavy wear

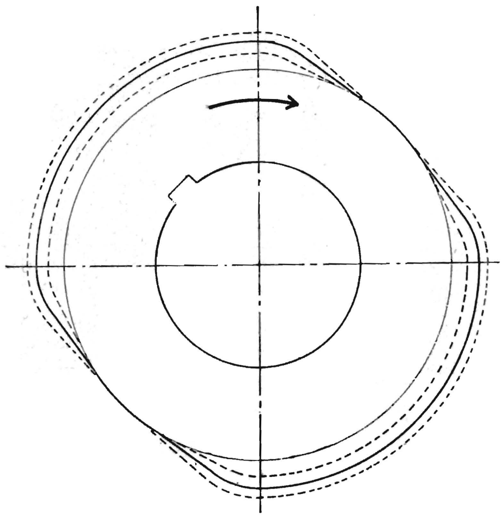

Fig. 5.

on its lifting face, necessitating frequent renewals. It might here be found of advantage to go to some trouble to provide accommodation for a cam larger in diameter than requisite for the work, to permit of a detachable portion of the face being checked in and securely bolted to the cam disc, thereby expediting renewals, and reducing their cost (Figs. 4 and 5).

There is more or less latitude allowable in the extent, timing, and acceleration of most movements, and where these are effected by parts open to considerable wear, and no means are available for adjusting for this wear without renewing the worn parts as in the case of a cam, it is advisable to investigate the maximum and minimum limits of variation permissible, and then to arrange matters so that when the parts are new they work at or near the higher limits, and as wear takes place the lower limit is approached.

Discussion.

MR. W. H. GRIEVE (in proposing a vote of thanks to Mr. Sykes for his interesting paper), said: Mr. Sykes's paper is more or less a statement of facts, as far as I am concerned, and it opens up the big question of policy in machine design—whether in designing machinery, efficiency and long life, or comparative inefficiency and cheapness of manufacture should be the deciding factor in manufacture or selection of machinery.

It is, of course, impossible to have any hard and fast rule to bind all cases, so variable are the requirements and the nature of the work to be done.

The differences of opinion on such an important subject have always been an interesting study to me; these appear to be more or less international, and I think that, when one comes to analyse the question, the reason is obvious. I am referring more particularly to machinery for railway construction and the methods adopted in that important branch of engineering.

The two schools are represented by the British and American systems, and it is most important for us in Australia—I still refer to railway construction—to know how far we should adopt each system. In many ways the conditions in Australia are similar to those appertaining in America and other new countries, and it is of the greatest importance that we should benefit by the experience of other countries, and (if I may be allowed to diverge slightly), it is essential that our Government en-