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Shot Peening in Relation to Gear Tooth Scoring

by J. C. Straub
Wheelabrator Corp., Mishawaka, Ind.

Shot peening is recognized as a means of increasing fatigue strength of machine parts. Long accepted as a means of correcting fatigue failures, the possibilities of its use in the design of machine parts generally appear to be underestimated. Although used primarily for increasing fatigue strength, if incorporated into gear design, shot peening can be used to avoid other types of failure. Scoring resistance may be increased by use of a finer pitch, but at the expense of bending strength. Shot peening may provide the necessary fatigue strength to accomplish this end.

Test results have indicated an increase of as much as 50 per cent or more in allowable stress in applications requiring a long service life.

The object of this article is to discuss the possible influence of shot peening on scoring tendencies of gears. Directly, shot peening appears to have little influence on the scoring tendencies of a given physical pair of gears. However, it is suggested that the increase in fatigue strength resulting from shot peening can permit a change in the tooth design to favor scoring resistance.

TYPES OF FAILURE IN GEARS

Gear tooth failure can be classified into three major types:

1. Bending failure, or tooth breakage. This is a fatigue type of failure caused by high bending stress in the root fillet. It is the most serious type because a broken tooth usually renders the gears inoperative.
2. Pitting. This is also a fatigue type of failure but occurs on the working profile of the tooth due to high contact stresses. It is not as serious as bending failure because although a moderate noise may develop after the initial stages, the gears can usually be run for an extended period before complete failure occurs.
3. Scoring. This is not a fatigue failure, and may occur early in the life of the gears. It is a welding of the tooth surfaces due to high contact stresses in combination with high sliding velocity. It is characterized by radial scratches on the profiles, somewhat similar to the seizing of a journal bearing.

RELATIONSHIP OF DESIGN FACTORS IN THE THREE TYPES

For effective utilization of material in the design of gears, all three types of failure should be considered. If the power is transmitted at a high torque and low speed, scoring resistance may not be a problem. On the other hand, if the power is to be transmitted at high speed, scoring resistance may be an important factor in the design. However, if size and weight of the transmission are to be reduced, it becomes more and more important to consider all three types of failure and to achieve a balance in the design. Resistance to bending failure depends at least in part on the tooth thickness. In contrast, both pitting and scoring are the result of a surface condition and are not influenced directly by tooth thickness. The latter types of failure are strongly influenced by the radii of curvature of the tooth profiles in the area of contact, since contact stress increases with decreasing radii of curvature.

During World War II, a PVT formula for computing scoring resistance was developed on the basis of a large number of tests on carburized and hardened spur gears in aircraft engines, lubricated with mineral oil (1).

More recently, a calculation of "flash temperature" has been used for determining scoring resistance (2) which appears to agree with test results on tractor, aircraft and marine gears (3). These methods differ in their approach to the problem, but in either case the calculation involves the radii of curvature and the sliding velocity of the teeth.

It is quite evident that an excellent tooth design of itself will not guarantee satisfactory performance of a pair of gears. Other factors must be carefully consid-

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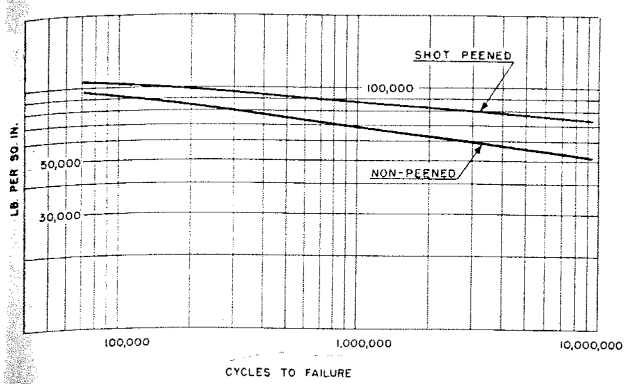

g. 1. Fatigue chart of carburized automotive type spur and helical ears, shot peened and non-peened.

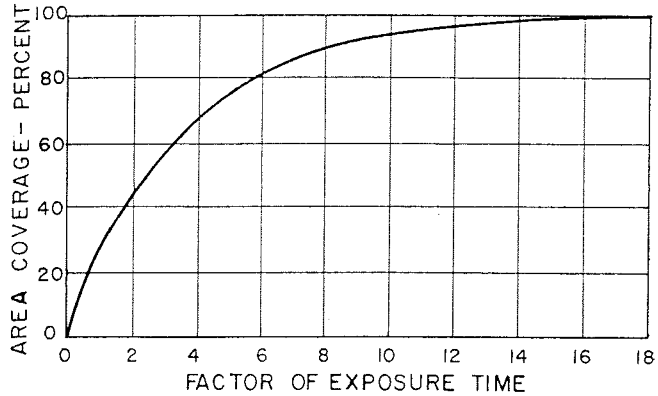

Fig. 2. Relationship between area coverage and exposure time.

red in the light of resistance to all types of failure. he capacity for trouble-free performance of a pair of ears will depend also upon the accuracy of manufacıre, material, heat treatment, mountings, type of luricant and method of applying it to the teeth, proısion for dissipation of heat and other factors.

In some of the elements of gear tooth design, there no conflict between scoring resistance and bending trength. For example, in a pair of gears with a high atio, scoring resistance can be improved by the use of ng and short addendums. Such proportions may perıit adequate tooth action and at the same time avoid ontact in the region where contact stress and sliding elocity would be high. This procedure is also advangeous for bending strength because such proportions ill normally result in a proportionately greater thickss of the pinion tooth, which will be required to unrgo a greater number of stress cycles than the gear oth.

This "compatibility" does not occur in all of the ements of the design of the teeth. For example, a arse pitch may be used where high bending strength required, because of its advantage in a greater tooth ickness. However, this means greater tooth heights r an adequate number of teeth in contact and results tooth action at a greater distance from the pitch int. Consequently, since the sliding velocity varies rectly with this distance, greater sliding velocity is countered, as well as the likelihood of high contact resses.

The above factors suggest a fine pitch for scoring sistance. But this would lead to low resistance to nding failure. Therefore, if the bending strength can increased by shot peening it would permit the use a finer pitch for greater scoring resistance.

HOW MUCH GAIN IN FATIGUE STRENGTH BY SHOT PEENING

If an increase in fatigue strength can provide a degn tool permitting its use for the prevention of scor, the next question is—to what extent can fatigue rength be increased by shot peening? For such data be useful in design, it is necessary to consider the crease in allowable stress for a given life. For indefinitely long life, an increase of 50 per cent or more in the endurance limit stress is not unusual.

For shorter life requirements involving higher stresses, the gain in endurance limit stress is more moderate. This is illustrated by Fig. 1 which shows an SN diagram plotted on a log-log scale for shot peened and non-peened spur and helical gears. The gears from which this chart was derived were of the automotive type, carburized and heat treated to approximately 60 Rockwell C. The stresses are computed on the basis of a method developed for automotive gears (4). Each line on the chart represents the average life of a large number of gears. Note that the two lines diverge toward the right. For example, for an expected average life of 100,000 cycles the allowable stress is increased by approximately 10 per cent. For a life requirement of 1,000,000 cycles the increase in allowable stress is somewhat more than 25 per cent. For a life requirement of 10,000,000 cycles, the increase in allowable stress is almost 50 per cent.

The chart in Fig. 1 does not necessarily represent the optimum results which can be achieved by shot peening. This will be further discussed in a later section.

A specific example of the extent to which shot peening can be used to permit the designer to use a fine pitch is one which was recently applied in automotive gearing. In this particular case, a finer pitch was desired by the manufacturer for the purpose of improving noise characteristics. Shot peening permitted a change from 10 pitch to 14 pitch in production, using the same center distance and face width. The manufacturer stated that, in his opinion, this change would not have been possible without shot peening.

APPLICATION OF SHOT PEENING TO GEARS

As in other machine parts, shot peening of gears should be the last operation insofar as the highly stressed areas are concerned. Although the effect of the process is to impose a residual compressive stress on the surface by virtue of a lateral expansion of the surface layer, there is little if any change in the tooth profile, except for an increase in the surface roughness.

In hardened gears, this increase in roughness is very slight. A great number of gears are being peened in regular production today, and the majority of manufacturers makes no attempt to reduce the surface roughness after shot peening. In some cases however, in very large gears, the teeth are cut with a protuberance hob to provide some undercut. The gears are then carburized, heat treated, shot peened, and ground. Thus, the undercut allows the tooth profiles to be ground without disturbing the shot peened surface at the root of the tooth.

Shot peening is effective in increasing fatigue strength of both hardened gears (60 Rc) and gears of machinable hardness.

If it seems necessary to achieve a high degree of surface finish on the working profiles, this can be accomplished on gears of machinable hardness by shaving after peening. Gears of high hardness can be honed (5). Both of these procedures permit the profiles to be processed to the required finish without disturbing the peened surface at the roots of the teeth.

CONTROL OF SHOT PEENING

Since shot peening utilizes the same general type of equipment as that for blast cleaning, one is often confused with the other. Probably the greatest distinction between the two processes lies in the method of inspection. In a blast cleaning operation, the quality of the job is appraised by the cleanliness of the parts after processing. But since the goal of shot peening is an increase in fatigue strength, it will be apparent that visual inspection is not likely to reveal the quality of the peening job, except for the determination of whether the required areas have been struck by the blast.

Control of the peening operation consists in a sense of appraising the blast itself. For this purpose standard Almen test strips and equipment have been standardized by the SAE (6). A thin strip of spring steel is fastened with screws to a solid block and passed through the blast, simulating the work. The lateral expansion of the surface results in a curvature of the test strip when it is removed from the block, the peened side being convex. The degree of curvature is then measured as arc height on a standard cordal distance. A thin strip "A" is used for light impact, and a thicker strip "C" is used for heavy impact. The arc height is designated in thousandths of an inch with the suffix "A" or "C" depending upon the strip used. Thus ".014 A" designates .014″ arc height using an "A" strip, as measured on a standard Almen guage.

Specifications for a peening job are based on arc height and some measure of coverage. In establishing such specifications, the arc height should be in keeping with the thickness of the part in the location of maximum stress, as well as the overall requirement of a particular job. It is not practical to generalize on the ideal arc height for all applications because of the wide variation in requirements. Wherever possible, it is good practice to establish by fatigue tests the mos effective arc height for a particular job in the light c the overall requirements. The following tabulation i based on a large number of fatigue tests, and can b used as a guide in establishing appropriate arc heigh for a given thickness in the parts to be shot peened.

Thickness of Part	*Arc Height*
1/16 inch	.004 A
1/8 inch	.008 A
1/4 inch	.014 A
3/8 inch	.018 A
1/2 inch	.021 A
5/8 inch	.007 C
3/4 inch	.008 C
7/8 inch or greater	.010 C or greater

Having set up the specifications it is important, fo best results at lowest cost, to obtain the required ar height with uniformly sized shot. Fatigue tests hav indicated that, if a high percentage of undersized sho is permitted to accumulate in the peening machine, th expected fatigue strength may not be achieved, eve though specified arc height is obtained. For this reason a peening machine should be equipped with a separato capable of removing broken or undersized shot in con tinuous operation as soon as possible after it become smaller than the original size. Obviously, it is neces sary to provide for uniform replacement of the broke shot with new shot by means of an adding device.

In many cases where there is blast cleaning equip ment in the same plant, it is quite practical to use thi undersized shot in the cleaning operation.

For efficient operation the shot should strike th work at a reasonably uniform angle of impact. If, fo example, a large portion of the shot strikes the work at right angles, then any shot which strikes the same area at an angle appreciably less than 90° is ineffec tive in the same way as undersized shot. This does no mean that the shot must strike at right angles, bu rather that the angle of impact should be uniform.

COVERAGE

Coverage in shot peening is related to the degree of exposure to the blast. It may be defined as the pro portion of a given area of the work which has receive impact of the peening blast.

In any peening operation with constant conditions there is a definite relationship between coverage and exposure time, as shown in Fig. 2 (7). The horizonta scale is relative and can be expressed in terms of time or number of passes under given conditions.

Note that coverage approaches 100 per cent as the exposure time is increased indefinitely. For this reason it is convenient to refer to 98 per cent as a finite meas ure of approximately "full coverage."

FATIGUE STRENGTH AS INFLUENCED BY COVERAGE

Fatigue tests have indicated that, provided the arc height is not excessive for the thickness of the part, the fatigue strength increases with increased coverage. In many cases it increases gradually, even after the exposure time far exceeds that required to obtain 98 per cent. This appears to be especially true in peening parts of irregular shape such as gear teeth. For example, gears peened with an exposure of three times that required to obtain 98 per cent coverage give results well above the chart for peened gears in Fig. 1. This is referred to as a coverage of 3. Gears peened with a coverage of 6 to 8 show even greater increase.

In order to utilize shot peening to best advantage, it is important to select a degree of coverage which is best suited to the requirements of the particular job. If shot peening is incorporated in the design of gears, it is likely that the purpose is to reduce the cost of production of such gears (8). Such being the case, it is only natural to reduce costs to the practical minimum. It is important, to specify a degree of coverage in accordance with the economics of the gears in question. For example, with gears involving a very high production rate, the cost of manufacturing the gears may be relatively small. In such a case, it might be economical to specify a coverage in the neighborhood of 98 per cent, or possibly even less. The fatigue tests mentioned above have shown a more gradual increase in average life after a coverage of about 80 per cent is obtained. Reference to Fig. 2 will reveal that the exposure time required to obtain 80 per cent coverage is less than half that required for 98 per cent. Consequently the additional increase in fatigue strength at full coverage may, in some cases, not be warranted. It should be mentioned, however, that where high production rates are involved, the capacity of a wheel type machine may be so high that the conveyor speed through the peening machine is limited only by the capacity for handling the gears to and from the machine. A coverage of 3 is not uncommon in high volume production of relatively low cost gears.

There are applications in which the cost of manufacturing the gears is sufficiently high that the cost of shot peening is insignificant, even though a coverage of 6 or 8 is specified. In this case, a much greater increase in fatigue strength can be obtained at negligible cost.

CHOICE OF SHOT SIZE

The size of shot best suited for a given application depends upon the arc height and coverage to be obtained.

For steel gears, it has been the author's experience that a small shot at high velocity will result in about the same increase in fatigue strength as a larger shot at correspondingly lower velocity, provided the same arc height and coverage are used. However, as mentioned earlier, whatever shot size is used, it is important to maintain uniformity of size for efficient operation.

Since the number of shot particles per pound varies inversely as the cube of their diameter, it follows that coverage is obtained much faster with smaller shot. This of course means that the shot velocity must be higher to obtain the same arc height. However, in spite of the fact that shot usage per hour increases considerably with shot velocity, the increased production compensates for it, so that the shot usage per part peened is about the same. The end result is that the most economical operation can usually be obtained by using the smallest uniformly sized shot with which the required arc height can be obtained.

TYPE OF SHOT

As in the case of selection of shot size, the type of shot should be selected on the basis of lowest operating cost for efficient operation. It has been demonstrated (7) that it is not necessary that shot for peening gears with a hardness of 60 Rc have the same hardness as the work. Equally good results have been obtained by peening fully hardened work with cast steel shot (42-50 Rc) and with chilled iron shot (60 Rc). A good grade of cast steel shot has a far greater resistance to breakage and therefore is much more economical. In addition, the maintenance cost of a peening machine is much less with steel shot because of the lack of sharp edges which are prevalent in chilled iron shot as it breaks down.

Cut wire shot can also be used if its hardness is sufficiently high and uniform. However, its use is usually limited to the larger sizes because of the increase in cost per pound as the size decreases. This conflicts with the economy of using smaller sizes for faster coverage.

When steel shot is used for peening it is important that new shot be run in for a short period before peening the parts. This is because of the work hardening of the shot itself, and is evidenced by an increase in arc height after new shot has been run in. This pertains only to starting a machine with all new shot. After the machine has been in operation for a few hours, the amount of new shot for make-up is a negligible percentage of the shot in circulation.

EQUIPMENT FOR SHOT PEENING

To insure an adequate peening job, the work should pass through the blast in a mechanically controlled cycle, so that all critical areas will be uniformly covered.

The equipment for accelerating shot is generally of two types—one which utilizes compressed air and the other a rotating bladed wheel. Air equipment may be of the induction type which accelerates the shot within the nozzle itself, or direct pressure type in which the shot is added to the air stream under pressure.

The induction nozzle is sometimes used in applications which require very few small parts to be peened. The direct pressure type is capable of throwing more shot at a higher velocity and therefore can be used in cases where more parts are required. In applications involving a reduction of cost by shot peening in design,

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: COURSE PROGRAM
ıt. from p. 94)

The practical approach to maintenance and lubrication of ball and roller bearings.

Short discussion and distribution of Gulf Oil Corp. manual "Bearings and their Lubrication."

SEALS AND PACKINGS: E. W. Fisher, Major Product Eng. Dept., Garlock Packing Co., Palmyra, N. Y.

A survey of this field covering mechanical seals, gaskets, packings and stuffing boxes, and emphasizing the details of lubrication and maintenance.

PLANT VISITATION

1:30 P. M.-4:30 P.M.

Lackawanna Works of Bethlehem Steel Company. Busses leave Statler Hotel entrance at 1:30 p.m. Guided tour of the Lackawanna Works with emphasis on lubrication applications.

ırsday, April 23, 1959

0 A.M.-12:00 Noon

PLANT LUBRICATION & ORGANIZING A PLANT LUBRICATION PROGRAM: Charles L. Pope, Eastman Kodak Co., Rochester, N. Y.

An informal discourse on the subject of lubrication of industrial machinery as it pertains to the purchasing agent, operator, maintenance man and the role of the plant lubrication engineer in organizing a plant lubrication program.

QUESTION AND ANSWER PANEL:

Questions submitted on cards all during the course will be answered at this time.

) AFTERNOON SESSION

NOTE: Lubrication course students will be permitted to attend any technical session of their choice.

Factors Affecting Hi-Temp Gear Operation

(Cont. from p. 103)

and case carburized gears. This band seems to be pretty well established for this combination. The silicone oil when run with case carburized gears, produced about the same scoring resistance as the MIL-L 7808C oil test. The same silicone oil when run with nitrided gears, gave a much improved performance.

Large amounts of valuable information have been gathered from investigations and test stand operations. Plans are underway to continue on the various programs until a more complete understanding of all the factors that affect high temperature gear operation have been obtained.

Actually, the high temperature gear test facility has been a worthwhile and vital link in the progress made to date. The results from running full sized aircraft gears seem to produce extreme realistic results. It is expensive and time-consuming but completely necessary.

Shot Peening in Relation to Gear Tooth Scoring

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the volume of production is usually such that the natural choice is the wheel type of equipment. This is because of the fact that the wheel type is capable of accelerating many times as much shot, to the same velocity, with an expenditure of a fraction of the horsepower required in the compressed air types.

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