AGMA
109.13
June 1964

SHOT PEENING IN GEAR DESIGN 1964

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Presented at the 48th Annual Meeting
of the
AMERICAN GEAR MANUFACTURERS ASSOCIATION
The Homestead, Hot Springs, Virginia
June 7-10, 1964

INTRODUCTION

Increased fatigue strength due to shot peening has been firmly established by extensive fatigue tests on a wide variety of machine parts. Although the process is used very extensively on leaf springs, coil springs, torsion bars and, in fact, practically every type of machine part, this paper is limited to its application for gears. Peening can be used not only to increase beam strength but also to increase pitting resistance. By utilizing the increased beam strength in design, improvement in noise characteristics has been achieved. It is likely that the same procedure can be employed to improve scoring resistance.

BEAM STRENGTH

Shot peening is an excellent means of increasing beam strength of all types of gears in which high load carrying capacity is required. As evidence of the effectiveness of peening, it is used today as an integral part of production in many industries. Upgrading the capacity of a given gear design has become common practice. Many thousands of gears are being shot peened in the automotive and aircraft industries. This does not mean that its use is limited to these industries, but they are chosen as examples.

The extensive use of peening is increasing in spite of the fact that in a good many cases its full benefit is not being realized. A gain in fatigue strength can be obtained even though the peening conditions are poorly chosen for the particular application, and even though the operating conditions of the peening machine are poorly controlled. In spite of this combination, sufficient increase in fatigue strength may be obtained to justify the use of shot peening in that particular application. However, with a more advantageous choice of specifications and good control, we might expect a much greater increase in fatigue strength of the parts peened. Moreover, it is quite possible that this greater increase may be obtained at no increase, or even a decrease in the cost of the peening operation.

Unfortunately, it is a rather common concept that the gain in fatigue strength obtained with a particular peening machine in production is representative of a fixed benefit that can be derived from the process, without regard to whether the full value of peening is obtained. For example, a relatively moderate gain may be experienced which is sufficient to avoid fatigue problems, and the stamp of approval is given peening, but for a relatively low gain in fatigue strength.

Such a concept may be likened to the statement that the fatigue strength of a gear can be increased by heat treatment. This statement would immediately raise the question, "What kind of heat treatment?" A metallurgist involved in the manufacture of gears would want to know a great deal about the required performance of the gears before specifying a heat treatment. He would also want to know the size and configuration of the gear blank. If the gears are to be carburized he would select a case depth in keeping with the tooth thickness. After having specified the heat treatment, he would then be vitally concerned with its control because he knows that lack of control can result in inadequate life.

This does not imply that the parameters of quality in a peening operation are the same as those in a heat treat operation. There is an implication, however, that the peening conditions should be chosen to fit the requirements of increased fatigue strength of the particular application involved. It is doubtful if anyone today would send a pair of gears into the shop with the specification "heat treat", but it is not uncommon to see a blueprint with the specification "shot peen the areas indicated."

In order to realize the true advantages of shot peening, it is important to appreciate the influence of a number of factors involved in the process. In general, inspection of a peened part will reveal little information relative to the quality of the peening job. Examination of the surfaces may reveal whether or not the coverage is uniform, but beyond that, it has little value. The control of quality depends upon the control of the process itself, rather than upon inspection of the parts peened.

The benefit derived from a peening operation will depend to a great extent upon the depth of the residual compressive stress at the peened surface, and the distribution of the residual stresses just below the surface of the most highly stressed areas. A great deal of investigation has been made on the distribution of the residual stresses produced by shot peening, and the results have greatly aided in the interpretation of results obtained. However, for the most part, it is impractical to determine the distribution of the residual stress in each application. In lieu of this time-consuming measurement, qualitative means have been established which can be used effectively in specifying and controlling the operation, if proper care is exercised in their use.

ARC HEIGHT

Probably the most tangible measurement in a shot peening operation is the height of arc on a standard Almen specimen as measured on a standard Almen gage (1)*. The specimen itself is a standard strip of spring steel ¾″ wide and 3″ long. It is available in any of three thicknesses:

The N strip;	.031 ± .001
The A strip;	.051 ± .001
The C strip;	.094 ± .001

A strip of the appropriate thickness is fastened to a standard Almen block by means of 4 screws as shown in Figure 1. The strip is mounted on a fixture so that its surface simulates a tangent to the root circle of the gear to be peened. It is then subjected to the blast in the same cycle as the gear. When it is removed from the block, the strip will have a curvature, the shot peened side being convex. The extent of this curvature is measured as arc height.

*Numbers in parentheses designate reference at end of text.

Figure 2 shows the measurement of a peened A strip having an arc height of .019″. Note that the non-peened side of the specimen is toward the dial indicator. Conventionally, the arc height is expressed as the gauge measurement, followed by the designation of the strip on which it is measured. For example, the measurement shown in Figure 2 is expressed as .019A. The A strip is used for arc heights from .006″ to .024″. Below this range, the N strip is used, and the C strip is used for greater impact.

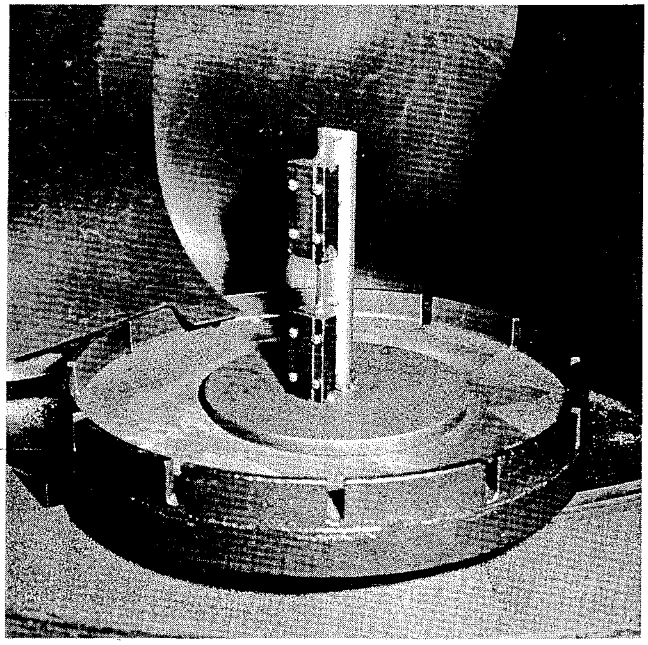


Figure 1 — Almen A Strips Mounted on Standard Almen Blocks.

Under controlled conditions, an increase in arc height is indicative of an increase in depth of the residual compressive stress. As discussed in a later paragraph, it is important to exercise control of the peening operation if arc height is to be used effectively.

For beam strength, the specifications for arc height should be chosen in relation to the tooth thickness at the root. Wherever possible, it is good practice to determine by fatigue tests the arc height most suitable for a particular application, taking into account the desired increase in fatigue strength in relation to the overall cost of the gears being produced. However, the following tabulation can be used as a guide.

TABLE I

Root Thickness	Arc Height
$\frac{1}{16}$	.012N
⅛	.008A
¼	.014A
⅜	.018A
½	.021A
⅝	.007C
¾	.008C
⅞ or greater	.010C or greater

It is important to recognize that the maintenance of the specified arc height is not in itself sufficient to assure the desired fatigue strength increase. A large difference in fatigue strength improvement can result by peening identical parts with the same arc height, depending upon how that arc height is obtained. This will be discussed further in a later paragraph.

A peening specification should contain a requirement for coverage. This can be referred to as

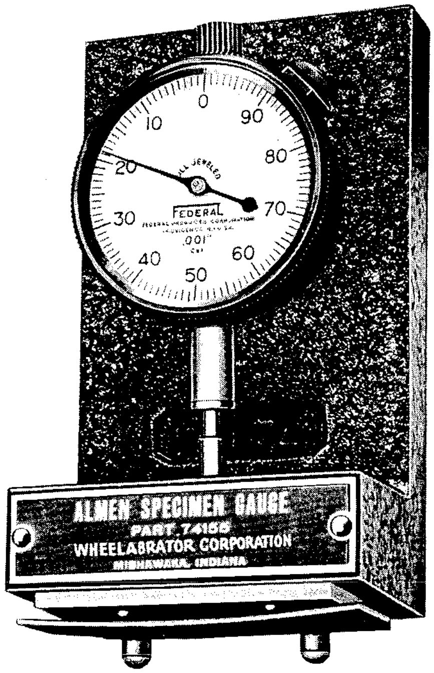


Figure 2 — Standard Almen Gage for Measuring Arc Height of Almen Test Strips

the percentage of the surface area which has been indented, or as a multiple of the exposure time required to obtain a coverage of 98%. The value of 98% is chosen as one unit of coverage because the exposure time at which 100% coverage is obtained is an indeterminate value. This is because coverage approaches 100% as a limit as the time is increased indefinitely.

Coverage can be measured by means of a polished Almen strip as described in AGMA 101.05 (2). This method is used primarily as a means of setting up the machine conditions to obtain a given coverage. Once the desired coverage is established for a given setup, it is a matter of maintaining the shot size, shot velocity, shot flow rate, exposure time (or conveyor speed) and the position of the work in the blast. If these conditions are duplicated in a given machine the arc height and coverage should consistently fall within the specifications.

Coverage is sometimes specified as "visual", which implies that the surface of the part as inspected with a magnifying glass shows no visible surface that has not been indented by the blast. This is adequate when 98% coverage is required.

CONTROL OF SHOT SIZE

In addition to a specification for arc height and coverage there should be a specification for control of shot size. Primarily this means control of the uniformity of size in the machine. It has been demonstrated both in the laboratory and in the field that if the shot striking the work is not uniform in size, the gain in fatigue strength is likely to be less than that obtained with uniformly sized shot, even though the arc height and coverage specifications have been met. When peening gears in continuous production, it is essential that the machine be equipped with a good separator which continuously removes broken or undersized shot and an adding device which automatically replenishes the spent shot so that a high percentage of shot in the machine falls within the S.A.E. specification for new shot (1). For quality and economy, this should be 80-85%.

It should be mentioned that in many cases the undersized shot removed from the peening machine through the separator can be reused in a blast cleaning machine.

HOW MUCH INCREASE IN FATIGUE STRENGTH? HOW MUCH IS REQUIRED?

It was stated previously that the gain in fatigue strength is not a fixed value. The extent to which it can be increased will be influenced not only by the peening conditions used but also by the stress to which the gears will be subjected. Figure 3 shows an SN diagram for carburized and hardened automotive type gears, non-peened and shot peened. These lines are characteristic of shot peening in that the lines diverge towards the higher number of cycles.

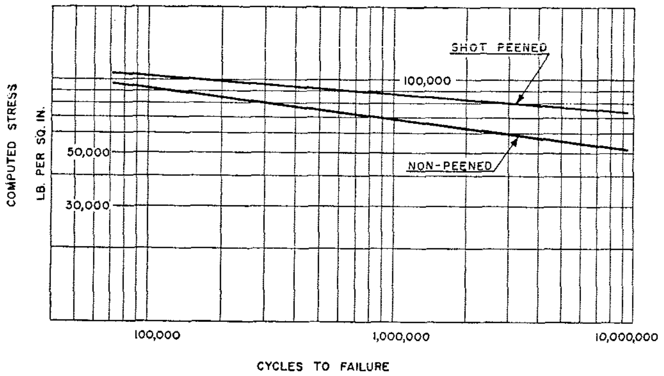


Figure 3 — Fatigue Chart of Carburized Automotive Type Gears, Shot Peened and Non-Peened.

The SN diagram for shot peened gears is based on a coverage of approximately 98%, with reasonably good control of shot size. Figure 3 is the same chart as that published in 1953 (2). Since that time, a number of tests on non-peened gears and gears peened at 98% are in agreement with the relative values shown. With multiple coverage, that is, with gears exposed for a multiple of the time required for 98%, a much greater increase in fatigue strength can be obtained.

For example, referring to Figure 3, with a life requirement of 1 million cycles, shot peening shows an increase in fatigue strength of a little more than 25% in terms of stress. In a dynamometer test, non-peened gears failed at somewhat less than 1 million cycles. Identical gears shot peened with a coverage of 7, showed no failure after 1 million cycles at 60% higher stress.

A coverage of 7 indicates an exposure of 7 times that required to obtain 98%. The term "exposure time" is used here as a convenient comparison. An increase in the rate of shot flow is equivalent to a corresponding increase in exposure time.

Note that in this example, for a given life the gain in fatigue strength with a coverage of 7 is more than double that obtained with a coverage of unity (98%). It should be mentioned also that the arc height was considerably less than that indicated for the tooth thickness in Table I.

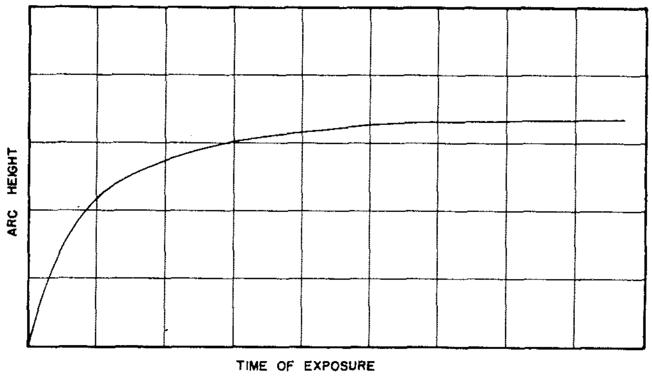


Figure 4 — Arc Height — Exposure Curve.

Further tests on gears peened in regular production with multiple coverage have shown a considerably greater increase in fatigue strength than that indicated in Figure 3.

It is interesting to note that this additional increase in fatigue strength is obtained even beyond the exposure time at which the arc height ceases to increase. Figure 4 illustrates a curve of arc height versus time under constant machine conditions. Note that the curve rises rapidly and then develops a "knee", finally reaching a point beyond which no further increase in arc height is obtained. Figure 4 is a qualitative example, inasmuch as the exact shape of this curve will be influenced by a number of factors, including shot flow rate, the manner in which the specimen is presented to the blast, etc.

These results with multiple coverage are in agreement with laboratory tests which, under controlled conditions, show a gradual increase in fatigue strength with increased coverage well beyond the knee of the arc height-time curve, provided two conditions are met:

1. The arc height is not excessive for the thickness.
2. The applied stress is not close to yield strength.

If the arc height greatly exceeds that which is appropriate for the tooth thickness (see Table I) there is not likely to be any additional gain in fatigue strength beyond that obtained at 98%

coverage. It is believed the reason for this limitation is the fact that a residual compressive stress in the surface layer is of necessity balanced by a corresponding residual tension stress at a greater depth, but of a lower magnitude. If the arc height is excessive, the sub-surface tension stress reaches a value of sufficient magnitude that any additional increase in arc height or coverage will result in no further gain in fatigue strength.

The second limitation for multiple coverage occurs at very high working stresses. If the repeated stress in service or during a fatigue test is sufficiently high to cause a gradual slight yielding of the material, multiple coverage is not likely to be effective in further increasing fatigue strength. It is believed that the reason for this limitation is that the yielding is most likely to occur at a depth where the resultant tension stress (residual stress plus applied stress) is maximum. The effect is somewhat similar to that obtained in a spring which is pre-set after peening. The slight yielding will result in a redistribution of the residual stress and may be considered similar to the effect of increased coverage. Since the redistribution of residual stress automatically occurs during the repeated application of the load, multiple coverage is not likely to result in additional increase in fatigue strength. This limitation is likely if the life of the non-peened part is in the neighborhood of 10,000 to 15,000 cycles or less.

In either of the above instances, additional coverage is not detrimental, but it serves no purpose.

It should be pointed out that the existence of this "pre-setting" condition at high stresses emphasizes the importance of caution when running accelerated fatigue tests on peened parts by increasing the stress to accelerate failure. Such accelerated fatigue tests can completely obscure the influence of coverage, unless the applied stress during the test is comparable to that encountered in actual service.

PITTING

Until recently, data on pitting resistance as influenced by shot peening have been relatively meager. The data which were available appeared to indicate that in cases where shot peening was used for increasing beam strength alone, there was no evidence of increased pitting resistance. More recent work has indicated that shot peening is capable of increasing pitting resistance provided the arc height is sufficiently high to produce a substantial compressive stress at the depth of maximum shear stress.

This reasoning is based on the fact that when the maximum stress occurs at the surface, shot peening is effective in increasing fatigue strength regardless of whether the stress is tension, compression or shear.

The above statement with regard to tension stress is evidenced by general acceptance of peening for fatigue strength in bending.

With regard to shear stress, there is equal acceptance of the process for torsion bars and coil springs, in which maximum shear stress occurs at the surface.

With regard to compressive stress, the late Prof. H. F. Moore, of the University of Illinois, has reported a pronounced increase in fatigue strength by peening rail steel specimens which failed at the surface when subjected to a stress range of from 2000 p.s.i. compression to 100,000 p.s.i. compression (3).

But in peening specifically for beam strength alone, the lack of positive gain in pitting resistance indicates that pitting is not due to surface stresses but rather due to subsurface shear stress.

In accordance with this reasoning, for increased pitting resistance the arc height should be chosen to insure a substantial residual compressive stress in the region of maximum shear stress. With the possible exception of course pitch gears, this suggests a considerably greater arc height for pitting resistance than for beam strentgh.

In support of the above analysis, at least one automotive plant is shot peening gears in regular production for the express purpose of increasing pitting resistance. In this application, a much heigher arc height is used than that indicated in Table I for increased beam strength. Both pitting resistance and beam strength are increased.

For a laboratory test, one gear was peened in accordance with the calculated depth of maximum shear stress under maximum applied load. An increase of 30% in horsepower was obtained for a life of 10 million cycles. Since the contact stress varies directly as the square root of the load, this would represent an increase of 14% in stress. The test was made in the laboratory of a commercial gear manufacturer.

No attempt will be made here to cover the calculation of depth of maximum shear stress for various types of gears, but the following basic equation can be applied:

Depth of maximum shear stress (4)

$$= .78 \sqrt{4P' \left(\frac{1 - v_1^2}{E_1} + \frac{1 - v_2^2}{E_2}\right) \frac{R_1 R_2}{R_1 + R_2}}$$

in which

P' = load per inch of contacting cylinders, pounds per inch.

R_1, R_2 = radii of curvature of contacting cylinders, inches.

E_1, E_2 = Moduli of elasticity, p.s.i.

v_1, v_2 = Poisson's ratio.

Assuming $E_1 = E_2 = 30{,}000{,}000$ and $v_1 = v_2 = .3$ for steel in both members, this can be reduced to

$$\text{Depth} = .000217 \sqrt{\frac{P' R_1 R_2}{R_1 + R_2}}$$

For spur gears, P′ can be taken as load per inch of face and R_1, R_2 can be taken as the radii of curvature at the pitch point.

$$R_1 = R \sin \phi$$
$$R_2 = r \sin \phi$$

R, r = pitch radii of pionion and gear, inches

ϕ = normal pressure angle.

For an internal gear the radius of curvature R_1 is negative.

For helical gears, the radius of curvature of each member is taken normal to the tooth profile at the pitch line and is equal to the radius of curvature in the plane of rotation divided by the cosine of the base helix angle. The load is taken normal to the teeth, distributed over the total length of contact lines (5).

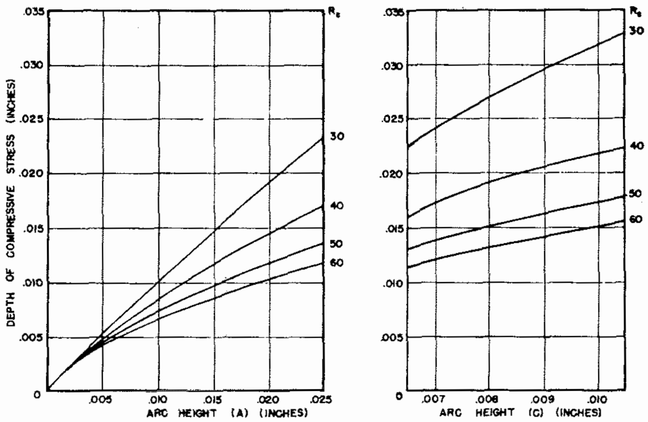


Figure 5 — Depth of Compressive Stress vs. Arc Height with Cast Steel Shot.

Since the calculated depth of shear is a function of the square root of the unit load and since the depth need only be an estimate, it is not necessary to determine the precise load distribution.

For bevel gears, the radii of curvature should be taken normal to the tooth profile at mid face. For load distribution see AGMA 215.01 (5).

Having determined the depth of maximum shear stress, reference can be made to Figure 5 to determine arc height for a relatively high compressive stress at the point of maximum shear. The values shown in Figure 5 have been estimated on the basis of residual stress measurements (6). From experience to date, it appears that this can be obtained when the depth of the residual compression stress from Figure 5 is about .005″ deeper than the calculated depth of maximum shear. The above peening conditions are chosen with complete disregard for beam strength.

Disregarding the rule for beam strength does not imply a lack of increase in bending fatigue strength. If the arc height required for pitting resistance is appreciably greater than that shown in Table I, it means only that the gain in beam strength will be in accordance with the SN diagrams in Figure 3 and multiple coverage is not likely to result in *additional* gain. However, since both pitting resistance and beam strength are increased, we can expect a substantial increase in utilization of material, and the increase in the transmitted load permitted by the gain in pitting resistance is not likely to result in beam failure.

When peening for pitting resistance, the same type of equipment is used as that for beam strength. However, the preferable position of the gears relative to the blast may in some cases differ. In peening for beam strength, the blast should be in such a direction that the shot will strike the root fillet at the maximum angle of impact. For pitting resistance, on the other hand, the blast should be directed so that the maximum angle of impact is obtained on the tooth profile in the neighborhood of the pitch line.

GEAR NOISE

In a recent publication (7), in addition to increased beam strength, shot peening in combination with a phosphate treatment indicated an improvement in noise characteristics of automotive rear axle gears. It is conceivable that such direct benefits in noise characteristics may be peculiar to a specific type of gear.

But in the general sense, assuming that no benefit in noise level results directly from shot peening, a modification of the tooth design can be made, utilizing the increased beam strength to provide a choice of tooth design more favorable to quiet gears.

An example of this procedure is one in which an automotive manufacturer changed the design of transmission gears from 10 pitch to 14 pitch. Fatigue tests were run to make certain that the 14 pitch gears provided adequate beam strength. The 14 pitch design was adopted for production, and the manufacturer reported an attractive reduction in the noise level of the production gears. He also stated that this change would not have been possible without shot peening, because beam failures would have been inevitable.

SCORING

A large number of scoring tests have indicated little if any direct influence of shot peening on scoring resistance. That is, in a given gear set, there appears to be no change in the scoring tendencies due to shot peening. This is not surprising because of the nature of scoring, which is a function of the heat generated at the tooth surfaces. It is reasonable to believe that this would be independent of the presence of residual stresses at the surface.

However, if the process is incorporated into the design of gears, the increased beam strength can be utilized to provide a more flexible choice of diametral pitch and tooth proportions for reducing the possibility of scoring.

Whereas no actual data have been obtained in which scoring resistance has been increased by the incorporation of shot peening in the design of gears, the possibilities of such a procedure are apparent.

FLEXIBILITY IN DESIGN BY VIRTUE OF SHOT PEENIING

The foregoing discussion cites the advantages which can be obtained directly or indirectly when dealing with any of four major problems involved in the performance of gears. Probably one of the most effective uses to which shot peening can be applied is in more effective utilization of material, thereby reducing production costs through saving in material. If the process is incorporated into the design of gears, the increased fatigue strength can be utilized to reduce the size and weight of the entire gear box (2). A common concept has prevailed for a number of years which may be illustrated by the expression "we like to keep shot peening as an 'ace in the hole'. If we encounter failures in production with a particular design, then we can fall back on shot peening." But this concept assumes that the process is capable of a single degree of increased fatigue strength.

Actually shot peening can be incorporated into the design of a set of gears without the necessity of foregoing this "ace in the hole."

For example, assume a pair of gears is required to withstand 100,000 cycles of load without failure. Referring to Figure 3, it would be reasonable to allow an increase of 13% in beam strength for shot peening with a coverage of 98%. If, for any reason, it becomes necessary to provide additional beam strength, it would be necessary only to increase the degree of coverage. This would require nothing more than an increase in exposure time or in shot flow rate or both. By using this procedure, another 13% increase in beam strength could be obtained in addition to that already utilized.

Another example would assume the required life is one million cycles. In this case, an increase of 25% in beam strength could be assumed at 98% coverage, with the option of an additional 25% if necessary by using multiple coverage.

The above discussion is based on the assumption that the contact stresses are not sufficiently high in the new design that pitting is likely to occur. With the reduced center distance, we can expect an increase in tangential load and a decrease in radii of curvature. Each of these factors will result in an increase in contact stress, but as a function of the square root in both cases. Even so, however, it is advisable to check the contact stresses in the new design in order to determine the most advantageous peening conditions. If the contact stress is quite low, then pitting failures are not likely, and peening conditions can be chosen for increased beam strength even to the extent of using multiple coverage if desired. However, if the contact stresses indicate that pitting might be a problem, then the conditions of peening should be chosen in relation to depth of maximum shear, thereby limiting the gain in beam strength to that shown in Figure 3.

Sufficient data are not available on pitting failures to develop SN diagrams as in the case of beam strength. However, from the data available, it appears that the gain in pitting resistance is somewhat comparable to that obtained in beam strength, in terms of applied load.

As in any problem in design, all other components of the gear box should be checked for adequate capacity. For example, if the gear center distance is reduced, a reduction in the size of the housing may logically follow. Bearing capacity should also be checked, because of the resulting increase in tangential load.

The most effective use of shot peening in the design of gears will be influenced by the type of production for which the gear design is scheduled. In an application in which repetitive units are required in high volume, fatigue tests can be run on experimental units in order to more accurately establish the maximum reduction in size and weight at the least cost in the overall production of the gears.

On the other hand, in an application involving the manufacture of a few units, such fatigue tests on the actual design may be impractical, and therefore, a somewhat more conservative design might be in order.

Finally, it should be mentioned that shot peening is simply a means of increasing fatigue strength and basically its use does not obviate the necessity of control of all manufacturing processes involved in the manufacture of a pair of gears and their environment. The overall quality of a power transmission unit will inevitably depend upon the accuracy of cutting the gears, control of heat treatment, design and tolerances involved in the housing, deflections in the shaft, housing and bearings, and all other factors normally encountered.

EFFECTIVE UTILIZATION OF THE BLAST

In order to obtain the maximum benefits of shot peening, particularly in cases involving its use for reducing production costs, it becomes apparent that efficient utilization of the process itself is important. Shot peening does not fall in the category of a high-cost process. But even so, it is only logical to eliminate any factors from a process which might add unnecessary cost.

Earlier the importance of a good separator for removing broken and undersized shot was cited. This arises from the fact that any shot which is appreciably undersized relative to new shot adds nothing to the gain in fatigue strength accomplished by the full sized shot. Since this undersized shot is ineffective it is apparent that it displaces effective shot in the blast, thereby reducing the efficiency of the operation. In spite of its ineffectiveness, however, it may increase the arc height and result in a false indication of the quality of the peening job.

The economy of maintaining uniformity of shot size is not always obvious. If the undersized shot is not removed until it is appreciably decreased in size the shot usage will automatically decrease.

This decrease will be obvious in the operation of the machine. But not so obvious is the fact that the gain in fatigue strength of the gears is likely to decrease also.

The arc height should be measured periodically at intervals depending upon production conditions. Where the required coverage is 98% or less an appreciable accumulation of undersized shot will usually be reflected in a decrease in arc height. But where multiple coverage is used a deterioration of shot size may be extensive before a decrease in arc height occurs, and therefore the shot should be checked periodically by a screen analysis.

This does not imply that large shot in itself is more effective than small shot, but rather that the shot size should be uniform for good control and economical operation. The implication is "do not mix shot sizes in a peening operation."

Other things being equal, the arc height varies directly with the sine of the angle of impact. For this reason, with a given size and velocity of shot, the maximum arc height will be obtained when the shot strikes the work at right angles. Right angle impact is not necessary for a good peening job, but in a given area of the work the angle of impact should be as uniform as practicable.

It is apparent that in peening a gear the most practical approach is to rotate the gear about its axis in the blast. For gears of small diameter, this inevitably results in a range of angles of impact as the shot strikes the root fillet. It follows then that complete coverage with respect to the maximum impact may not be obtained until the coverage is well beyond 98%. This may be part of the explanation for the greater effectiveness of multiple coverage in gears.

SHOT FOR PEENING

The size of shot for a given application depends upon the arc height required and upon the velocity of the shot.

Since the number of pellets per pound of shot varies inversely with the cube of their diameter, for a given weight of shot striking the work a great deal more coverage is obtained with small shot than with larger shot (at a reduced velocity to obtain the same arc height). This is confirmed by extensive testing which has demonstrated that the highest production rate is obtained by using the smallest shot size with which the desired arc height can be achieved. Obviously, this tends to reduce labor cost.

Because of its durability, steel shot is the most common type in use for peening. A good grade of steel shot with a hardness of 42-50 Rockwell C is entirely capable of peening gears of all hardness ranges including fully hardened gears (60 Rockwell C).

EQUIPMENT FOR SHOT PEENING

The most obvious requirement of a peening machine is the means for accelerating the shot. This may be in the form of an air nozzle or a centrifugal wheel. There are two types of air nozzles; the induction or suction type, in which the shot is mixed with compressed air as it expands from a jet in the nozzle, and the direct pressure type, in which the shot enters the air stream under pressure and travels with it through a hose and through the nozzle. The induction type can be operated by a gravity feed from an overhead hopper, or the shot can be raised to the nozzle by the inherent suction of entrainment in the nozzle. It is capable of delivering a relatively small quantity of shot. The direct pressure type is capable of delivering greater quantities of shot at a somewhat higher velocity, using the same air pressure.

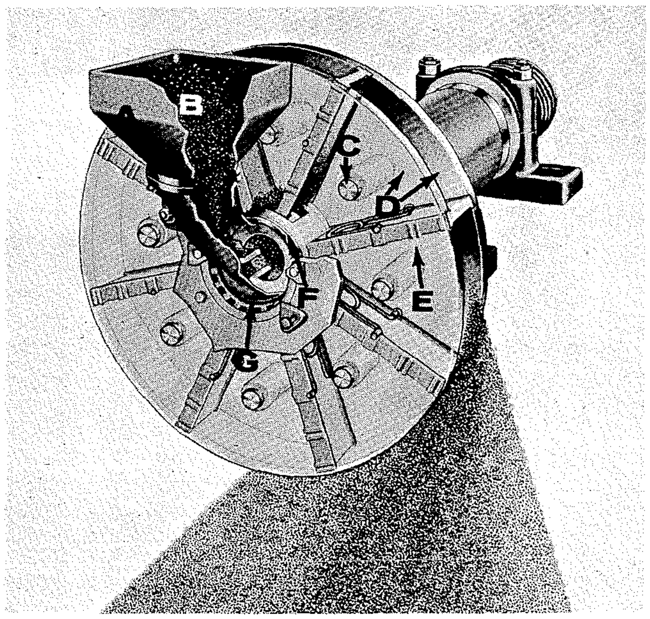


Figure 6 — Phantom View of Wheelabrator.

Key to Parts:

(A) Shot feed funnel.
(B) Shot.
(C) Spacers between side plates.
(D) Special steel side plates.
(E) Cast alloy blades, locked in place by spring holding device for ease of removal.
(F) Cast alloy control cage (stationary in operation).
(G) Cast alloy impeller (rotates with wheel). This unit carries the shot to the opening in the control cage where it discharges to the bladed section of the wheel.

The centrifugal wheel accelerates the shot by centrifugal and radial forces as shown in Figure 6. The angular position of the control cage is adjusted to give the desired direction of the blast stream.

An air nozzle is used in cases involving low volume production in which the existing supply of compressed air is sufficient for adequate volume of air at the required pressure.

When volume production is involved, the centrifugal type is much more economical because it is capable of delivering a far greater volume of shot at a fraction of the power required for air nozzles. For example, a standard Wheelabrator will throw a little more than 300 pounds of shot per minute at a cost of 15 H.P. With the direct pressure

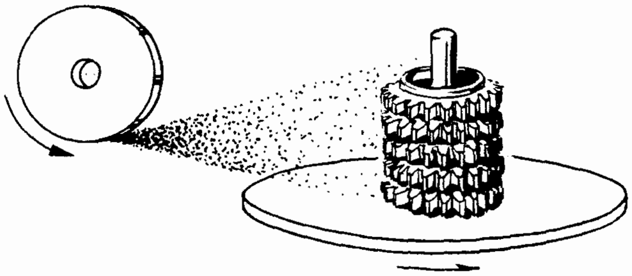


Figure 7 — Indexed Arrangement for Peening Spur and Helical Gears.

type of air equipment, five 3/8" nozzles will be required to throw the same quantity at 80 pounds per square inch pressure at a cost of 190 H.P. This example is for comparison only and does not imply the limit of capacity of the wheel. Wheelabrator units of widely varying capacity are available to suit various requirements.

WORK HANDLING EQUIPMENT

The type of work handling equipment depends upon the size and type of the gears and upon the volume of production required. In general, a gear should rotate about its own axis at a uniform speed while exposed to the blast to insure uniform coverage on all teeth. Its speed of rotation is not critical, it being necessary only to obtain a high enough speed to insure uniform coverage on all teeth.

For gears of moderate size, it is very advantageous to rotate the gears in the blast in an indexed position as shown in Figure 7 for spur and helical gears. The gear is placed on a horizontal rotating table, and the wheel is located to direct the main stream of the blast in a horizontal direction. This is particularly effective for high volume production for gears of relatively short over-all length. In this arrangement, gears can be stacked one on top of the other to a height of 10 or 12" and peened simultaneously. An advantage of this arrangement is that the blast strikes the work at any given height at a constant angle. The difference in arc height at various levels is negligible. This is a highly efficient method, and gears can be peened in high volume production even at multiple coverage at low cost. The machine employing this arrangement is similar to the multi-table setup shown in Figure 8, except that the wheel is mounted on the side of the machine to obtain a horizontal blast.

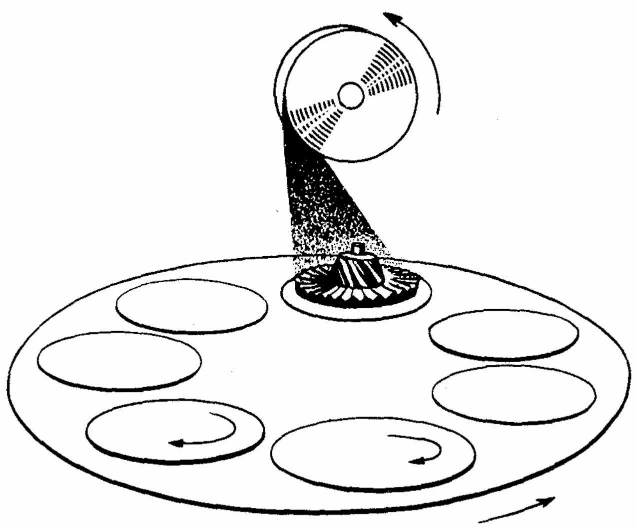


Figure 8 — Indexed Arrangement for Peening Bevel Gears.

Figure 8 shows a similar arrangement for peening bevel gears. In this case, the wheel is mounted in the roof of the cabinet, and the blast angle is adjusted to strike the work substantially at right angles to the root cone. In many cases, the gear and pinion of a pair are peened simultaneously in matched sets. In peening gear and pinion simultaneously, it is economical to direct the blast so that the angles of impact with the root cones are substantially equal. Thus, the efficiency of rotating in an indexed position is maintained with little loss of arc height.

Figure 9 — Loading matched set of Bevel Gears on Multi-Table Machine.

Figure 9 illustrates the operation of a multi-table machine of the type shown in Figure 7 and Figure 8. The gears are loaded at the front of the machine where the individual tables are free to rotate but are not driven. As soon as the individual table enters the blast zone, it is automatically rotated at constant speed as it approaches the indexed position.

For large gears with a wide face, (spur, helical, or herringbone type) the gear is rotated about its own axis as it passes axially through the blast. For increased beam strength, the center of the blast is located directly in line with the gear axis. Except in very coarse pitch, large diameter gears, this provides an adequate angle of impact at the root fillet. Figure 10 illustrates a peening application for marine gears. This machine is capable of peening gears up to 200 inches in diameter. Due to its size, the gear in this case rotates in an indexed position and the wheel travels vertically to obtain uniform coverage on the entire face width, using a blast directed horizontally. For coarse pitch gears (1 DP or coarser) it may be advantageous to displace the

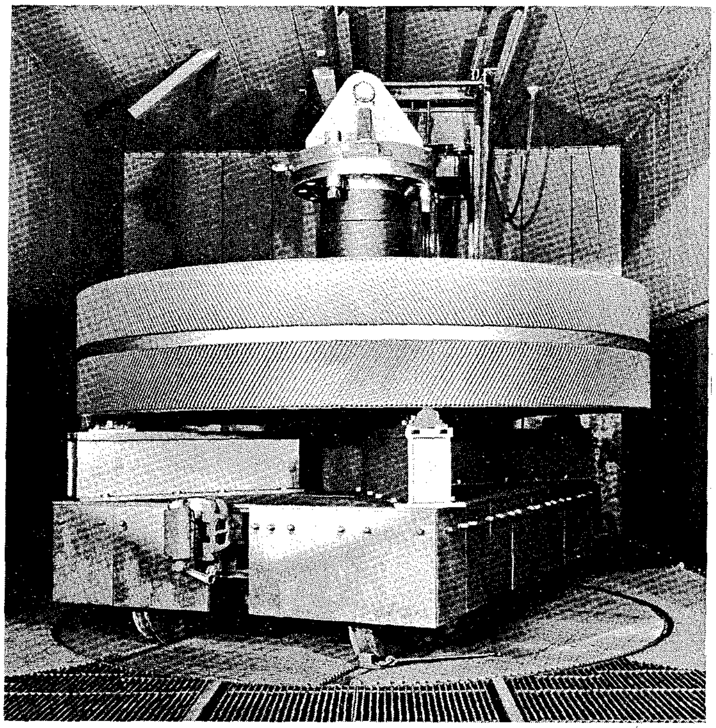
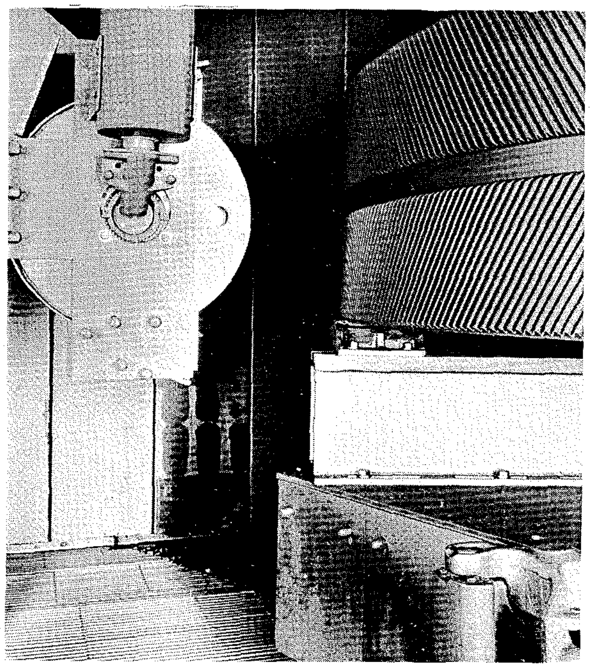


Figure 10 — Peening Machine for Marine Gears up to 200 Inches in Diameter (courtesy, General Electric Co., Lynn, Mass.).



blast from the axis in order to obtain a greater angle of impact at the root fillet. For such a gear designed to drive in one direction only, it is sufficient to peen the drive side of the teeth, whereas if the drive is in both directions it may be necessary to peen both sides of the fillet by turning the gear end for end for an additional pass.

In peening for pitting resistance, it may be advisable to displace the blast from the axis in order to obtain a greater angle of impact on the tooth profile.

Positioning the blast as described above does not necessarily involve a difference in the type of equipment, but only in the positioning of the blast relative to the work.

The above illustrations show some of the typical arrangements for peening gears of similar configuration, in which a variety of gears of the same type can be peened in the same machine. For peening various types and configurations of gears, it may be advisable to consider special equipment.

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