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SHOT PEENING OF SPRINGS

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Introduction

Each year hundreds of millions of springs are shot peened. They range in size from hydraulic relief springs which fit into a thimble to the giant coils which cradle launching installations. In quantity of manufacture they range from millions of automobile valve springs to single flexure pivots for special scientific instruments. All have one thing in common: the peening process is carefully controlled to produce the desired results and the improvement in spring performance repays the efforts of proper shot peen processing.

The various process controls and shot peen specifications necessary to insure dependable results have been developed since 1929 when the process was originally discovered in connection with springs.

Origin

According to J. O. Almen[1] shot peening was discovered by O. Burkhardt and J. P. Heiss who were trying to improve the fatigue durability of valve springs. Broken valve springs were quite common in those days before peening. Burkhardt and Heiss suspected that particles of scale which adhered to the wire might be a cause of failures and they asked for a thoroughly cleaned batch of springs. When the order was delivered they were horrified to find all the springs bruised and roughened by shot blasting, which had been used for cleaning. They would have rejected these springs as obviously unfit because of the rough surface, but had no other springs to test and so proceeded to test these while waiting for a properly cleaned batch of springs.

To the surprise of the experimenters, the entire batch of shot blasted springs out-performed all previous samples. It seemed incredible to the suppliers as well as to the engineers at Buick that shot blasting could improve springs, so they decided to repeat the tests. Again the shot blasted springs proved superior and in 1930 the process was specified for all Buick valve springs.

In time research showed why these springs were superior, and how the blasting process should be modified to produce far better results. The expression "shot peening" was introduced to distinguish the controlled process for improvement of spring performance from the haphazard blasting which had led to the original discovery.

It is interesting to note in passing that practical springmakers were soon convinced that peening could accomplish large improvements in spring performance.[2] Academic circles were more dubious at first, but eventually recognized the powerful effect of residual stresses and today shot peening is discussed in the text books on strength of materials.

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Applications in Design and Manufacturing

Shot peening is used to improve the fatigue durability of parts made from both ferrous and non-ferrous metals. The part may have an area of localized high stress. These highly stressed areas are usually unavoidable because of limiting dimensions or the configuration of mating parts. The hook on an extension spring is a good example.

Operating speeds of assemblies and service loads are continually being increased without any basic design changes, causing higher stress levels and lesser fatigue durability. The automotive industry's recent 50,000 mile guarantee will put greater demands on fatigue endurance and quality.

A C-shaped spring[3] of 1/8" x 5/16" wire had inadequate service life.

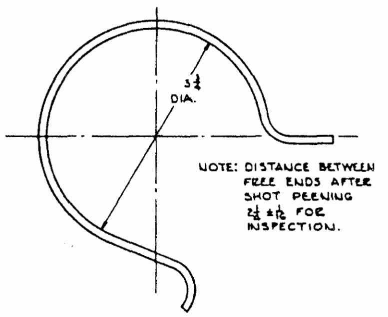


FIG. 1 — Oil Tool Spring

Fatigue tests showed an average life of 7200 cycles, with failures starting on the outside of the "C", which is the tension side. Shot peening (to .014 A) increased the life to 24,000 cycles when applied all over the

[1] J. O. Almen: "Effect of Residual Stresses on Rolling Bodies"; S.A.E. Preprint No. 467A, Jan. 8, 1962.

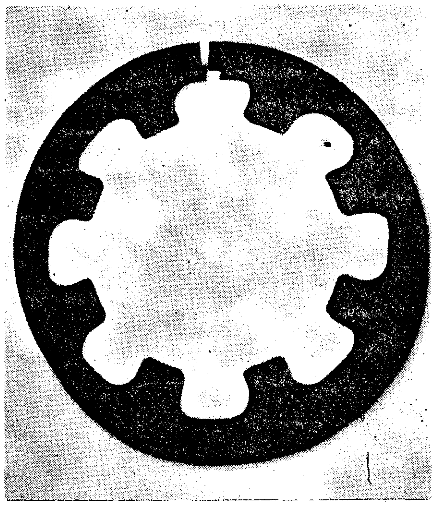
[2] F. P. Zimmerli: "Heat Treating, Setting, and Shot Peening of Mechanical Springs"; Metal Progress, 1952.

[3] "Multiply Spring Life without Changing Design," by C. W. Oicles & F. K. Landecker; Iron Age, Dec. 21, 1950.

spring while the spring is held in a partly loaded position. Other peening processes gave the following results:

Peening	*Average Life*
None	7,200 cycle
Outside only	12,500 cycle
All over	18,000 cycle
Strain Peened	24,000 cycle

Mattel Inc., the toy maker, uses an extension spring which is shot peened inside and outside to .012 A intensity to assure the long life expected of high quality products. Here too,



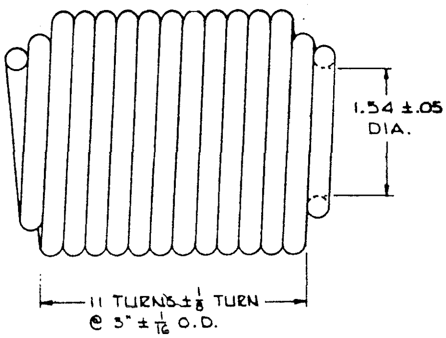


FIG. 2 — Extension Spring

peening one side only had been tried first and was changed to peening both the inside and outside after tests showed how much this increased the fatigue life.

Areas of stress concentration are often incurred in the manufacturing process. In one case shot peening increased the life of a wire form (5/32" oil tempered wire) by 10 times when the part was failing at an unavoidable tool mark. The life of a Belleville spring was greatly increased with shot peening when cause of failure was traced to a very poor surface condition resulting from a shearing operation. An electrical contactor made from phosphor bronze was required to pass a 2 million life cycle test. Failure was caused by a crease which was necessary for conformance to mating parts. Shot peening lowered the critical surface stress level and enabled the part to meet its life

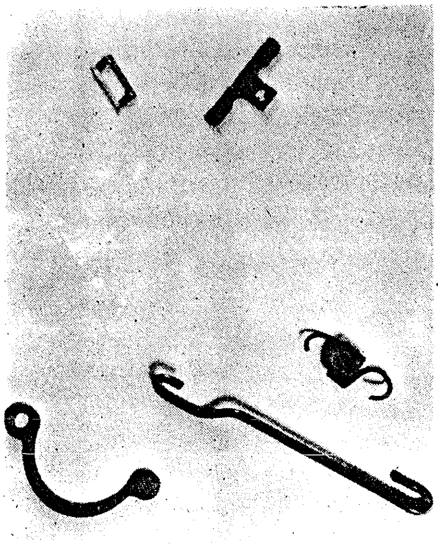


FIG. 3

cycle requirement. Plating usually diminishes the fatigue durability of a part. This damaging effect will be eliminated if the part is shot peened before plating. A corrosive atmosphere will accelerate fatigue failure. Again, shot peening will negate this damaging effect.

Shot peening is, and should be, used both as a manufacturing and a design tool to provide the best part at the most economical cost.

Mechanics of Fatigue and Shot Peening

Fatigue is a phenomenon which occurs in dynamically loaded parts which must withstand many cycles of loading. The cycle life is a function of stress. This is shown graphically by the typical S-N Curve in Figure 4.

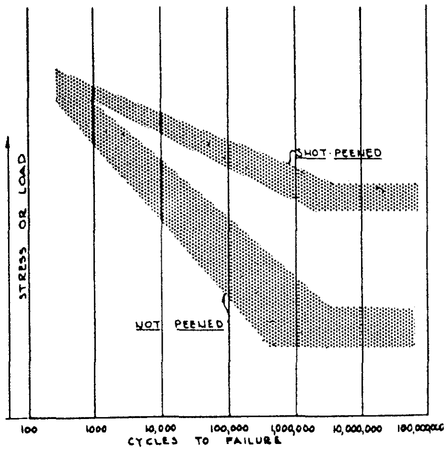


FIG. 4 — S-N Curve

Stress is plotted over life; note that the scale for life is logarithmic. If tests are plotted on such a chart we obtain a scatterband, narrower at the short life end. On such a chart the effect of shot peening is shown by longer life at a given stress level or by higher load for a given life. This is more important for springs than for structural members, because in springs an increase of 30% in permissible stress gives a saving in active material or weight of 40%. (The active material required is inversely proportional to the *square* of the permissible stress.) The S-N curves (which really are scatterbands) flatten out at a stress which may be perhaps 50% of yield strength for parts without stress raisers, much lower for parts with stress raisers.

One fortunate aspect of fatigue is that the crack causing failure will only propagate in material fibres which are stressed in tension. Secondly, fatigue cracks almost always originate at the surface of a part. These points of origin are usually traceable to a poor surface condition or a configuration responsible for localized areas of high stress. All of these conditions are usually present in most springs.

Shot peening improves the fatigue durability of springs and other dynamically loaded metal parts by inducing a layer of compressed fibres on the surface of these parts. This layer results from the impingement of regular spherical steel particles on

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the metal surfaces. The steel shot plastically deforms the surface fibres, creating a layer of residual compressive stress extending from the surface toward the core. The magnitude of the induced stress is highest near the surface and diminishes toward the core. This is illustrated in Figure 5,

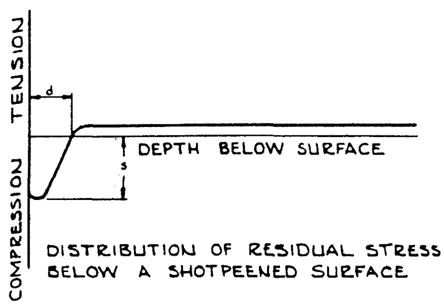

FIG. 5 — Distribution of Residual Stress Below a Shot Peened Surface

which shows a typical residual stress pattern in a shot peened part. The magnitude, S, of the induced stress is a function of the strength of the treated material, essentially independent of the shot peening variables commonly defined as intensity. On the other hand, the depth, D, to which the compressive stress extends is controlled by the shot peening process, and can be as much as .040″.

It should be noted that the residual compressive surface stress is accompanied by a balancing tensile core stress as shown in Figue 5. Because of this tensile core stress, it is possible to "over-peen". By "over-peening" we mean a condition where the magnitude of the core stress added to the working stress of the part, gives a resultant stress which could produce failure of the part from the core. In general, there should be little concern for "over-peening" if intensities are specified in accord with sound practices discussed in later paragraphs. On the thinner sections, the magnitude of core stress can be controlled by the shot peening intensity.

Heating after Peening

Since the effect of shot penning depends on the compressed surface layer one hesitates to disturb this layer by heat. But other considerations may make heating after peening desirable and a suitable compromise must then be achieved.

Heating after shot peening is used mainly to avoid setting, or loss of load after a few cycles of loading and unloading. The same compressive stresses which improve resistance against fracture by 30% would decrease the resistance against loss of load by perhaps 5%.

The usual compromise is to heat springs of music wire or of pretempered wire for ½ hour at about 450°F. Note that this treatment is separate from the stress-relief at 750°F. which must be done before shot peening to remove undesirable coiling or forming stresses. Otherwise the desirable effects of peening would be completely destroyed.

Even the lower temperature of 450°F. should not be applied for too long a time, because it is close to the temperature at which the resistance against fracture would begin to decrease[2]. In trying to explain the effect of moderate heat we assume that it relieves only the highest peaks of compressive stress without decreasing the more moderate but very useful stresses at slightly deeper layers of the compressed skin.

Fatigue Evaluation of Springs

Some users of springs specify shot peening as a matter of course. They know from long experience that springs designed to their specifications won't last unless they are peened. Automotive valve springs and suspension springs are good examples of such practice. Other users consider shot peening as cheap insurance: they specify it whether needed or not, because the time and effort of testing cost more than the peening. Small volume high quality jobs such as instrument springs and aircraft springs fall in this class. For a third class of applications tests on the necessity of peening are sound economy. It is for this class that the following notes on testing are intended.

In conducting tests on peening it is absolutely essential that the test loads should simulate service loads. If it is necessary to speed up testing it must be done by applying more cycles in a shorter time, never by increasing loads beyond those encountered in service.

With load cycles of 100 pounds a certain spring may last perhaps 130,000 cycles without peening and 10 million cycles when properly peened. If one attempts to speed up testing by increasing the load to 150 pounds the average life of both peened and unpeened springs will probably be the same, perhaps 1,000 cycles, and individual unpeened springs may last longer than some peened springs. These relations conform to the S-N scatterbands shown in Figure 4. The test "accelerated" by imposing higher loads will give a completely misleading picture. The reason for this is simple: the higher load produces local yielding at points of high stress. When a spring yields the effect of peening may disappear.

This does not mean that when springs fail by excessive settling or yielding we cannot improve their performance by making use of peening. In these cases we must use a harder material, one of higher yield strength, and we can use peening to overcome the "brittleness" which often goes with hardness unless peening is used.

Those who have been in the spring business before 1940 will remember that R_c 42 was considered a high hardness (for unpeened springs). Today steel springs are heat treated to R_c 52 and perform without trouble because they are shot peened. Improved alloys and production practices have of course contributed to this, but tests show that shot peening is necessary to make high hardness springs practical.

Controlling Shot Peening

The Almen strip is the basic control tool in shot peening. It measures the effect of peening by the curvature produced on a standardized strip of spring steel which is peened on one side only. Holding fixture and gage

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used for measuring the curvature are also standardized. This is a very practical method, developed 30 years ago by J. O. Almen and still unsurpassed.

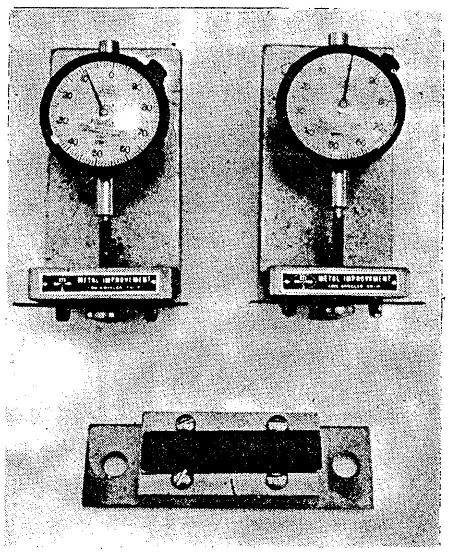

FIG. 6 — Almen strips, gage and holding fixture.

There are three standard thicknesses of strips, called N, A and C strips. For most spring jobs the A strips will be used. For springs of small wire or section under .050", the N strip would be preferred, and for very heavy springs one might use the C strip to control the higher peening intensity.

The most important quality of any peening job is SATURATION. A surface is saturated at a given intensity when additional peening produces no further improvement.

An intensity given as .008 A means that an A strip (.051" thick) will show an arc height of .008" over the standard chord of 1.250" when peened to saturation, and that the peened part is hit by at least as much shot per square inch as the strip.

A sloppy operator can produce the required arc height by exposing the strip for a shorter time to a shot stream of greater potential intensity, but this will produce only inferior protection against fatigue. Only saturation of peened springs and of the measuring strip guarantees a satisfactory peening job.

Shot Peen Processing

There are a number of ways in which the mechanical process of shot peening is accomplished. Regardless of the method of accelerating and directing the shot, the work is handled either as individual pieces or in some manner of batch processing.

The choice between one at a time and batch methods is one of economics. Since batch processing involves random treatment of the parts without any control of the part to shot pattern relationship, the use of this method is limited. It is important that all areas of a part to be shot peened are easily accesible if batch processing is to be used. For example, a close wound spring that will not allow the shot to pass between adjacent coils cannot be batch processed because there is no assurance of getting proper shot peening coverage and saturation on the inside diameter of the coils. Parts that tangle severely or springs that screw together can be batch processed but the handling of this type of work must be given special consideration. Automotive engine valve springs and small diesel injector springs (1/4" O. D. x 1" long) are good examples of parts that can be well shot peened at nominal expense with batch methods.

Individual handling allows one to shot peen a part with a great deal more precision and control of the shot peening variables. This type of handling will vary widely, from highly automated tooling which feeds the parts through the shot peening cabinet to the simple procedure of placing the part into and removing it from the cabinet one piece at a time. Again, production lot sizes and economics dictate methods employed. An interesting example of one at a time automated processing involved the previously discussed extension spring. The machine was equipped with automatic indexing stations. The station outside the cabinet allowed the operator to load and unload; the station inside rotated the spring while it was peened by external and internal nozzles. The whole process cycle including nozzle oscillation, speed of rotation, time exposures, etc. was automatically controlled to assure maximum peening quality.

There are basically two methods of accelerating the peening shot and directing it toward the surfaces to be shot peened. These are shown sche-

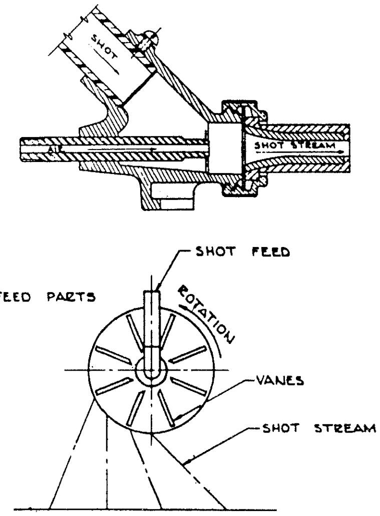

FIG. 7 — Methods for Shot Peening

matically in Figure 7. In wheel machines the shot is fed into the center of the impeller and accelerates as it travels the length of the impeller vanes. In air machines the shot is fed to the entrance of a nozzle and is accelerated through the nozzle by air.

Each system has its application. Controlled shot peening of internal surfaces can be accomplished only by air machines. The air nozzle system allows simple and accurate direction of the shot pattern. The shot peening variables can be very precisely controlled with the air nozzle system. Control of the centrifugal wheel principle is limited but it does deliver the shot at a very high rate.

In summary, the air nozzle system combined with individual part handling allows the shot peening to be done with the highest degree of control and level of quality assurance. The tolerance on the specified intensity should be increased with centrifugal wheel processing whether individual or batch.

In all cases the quality condition of the shot used in the shot peening

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operation is of paramount importance. The best mechanical shot peening system can be no better than the condition of the shot used in the process. What starts out as a shot peening operation will soon grow into a crude blasting operation unless the shot charge is continually conditioned and reclassified.

Shot Peening Specifications

In specifying shot peening the designer or spring maker should consider these factors which determine the fatigue improvement shot peening will accomplish and the economies that can be realized: Choice of Almen intensity, those areas requiring peening, areas requiring masking, shot size, and processing sequence.

Figure 8 provides suggested peening intensities for various section thicknesses. A minimum intensity should be specified for every part. On section thickness or wire diameters less than .250", a maximum intensity should also be specified. An intensity tolerance of ± .002" is considered commercial practice.

The peening intensity of thin sections becomes critical for the reason of core stresses which was previously discussed. The trapped stresses resulting from peening can also cause warpage or deformation of very thin sections if the peening intensity is too high or the process is poorly controlled. On these special applications of thin sections it would be well to rely on the experience and judgement of those skilled in the art. Whenever a selected or especially critical area of a part is intended to be shot peened, this should be so indicated on the blueprint. For example, the hook end of an extension or torsion spring is often the critically stressed area and the only area requiring shot peening. If this is indicated the cost of shot peening can usually be lessened, sometimes significantly.

One consideration in specifying intensity and selecting shot size may be the distance between coils or size of fillet radii in formed parts. A general guide in this case is that the shot size (in nominal diameter) should be no larger than ½ of the smallest fillet radius or ¼ the smallest opening through which the shot must pass.

Machining or cold forming applied to shot peened surfaces will destroy the effect of peening and should be avoided. Also, any heat treatment of the part after peening at temperatures above the stress relieving temperature will in a similar manner void the benefits that shot peening can accomplish.

Inspection and Process Quality Control

Inspection and controls are vital to the shot peening process. An accumulation of fatigue test results has indicated that the importance of these controls cannot be overemphasized.

First and perhaps foremost is that all parts must be shot peened to saturation. This can be verified by visual inspection, but only if the shot is of uniform size and shape, and harder than the part. Visual inspection is usually done with a 10X glass and will show complete or 100% coverage of the part if the original surface has been obliterated by overlapping peening dimples.

The condition of the shot used in the peening process must be under continuous surveillance because as it circulates in the machine it continually wears and fractures into smaller and irregular particles. To get consistent and proper fatigue benefits from shot peening the shot must be continuously classified to meet the size specification. Of perhaps greater importance is the need to eliminate all non-spherical or irregular shapes from the shot charge. Poor quality shot will show on the peened part as nicks and roughness.

An example of the importance of these controls is a 5/32" diameter wire form which had been "shot peened" with inadequate coverage and shot of very poor condition. The fatigue improvement of this part was about a 60% increase in fatigue life. When the same part was properly shot peened, not haphazardly blasted, the fatigue life improvement was 700%.

A major automotive company was concerned over a wide variance in the fatigue life of a number of component parts. An investigation revealed the greatest single factor was inconsistent shot peening quality. Those parts shot peened under controlled conditions were far superior to the same parts that were processed without proper respect for the conditions that assure shot peening quality.

In conclusion we would like to quote the late F. P. Zimmerli, Chief Engineer of Associated Spring Corp., who wrote, "This process (shot peening), which adds more life to springs than any alloy steel or heat treatment has been able to do, is of the greatest importance to the spring industry".

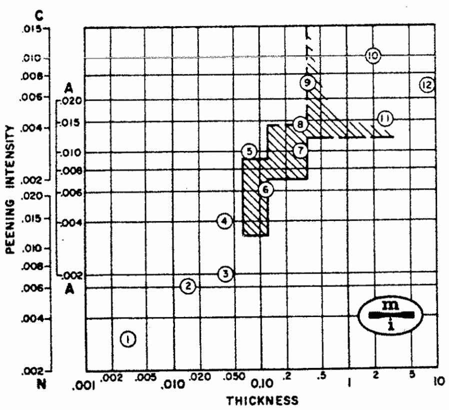

CHART POINT	PART	APPROXIMATE SIZE	ALMEN INTENSITY	REMARKS (ROCKWELL C HARDNESS)
1	STEEL TAPE	0.003 THICK	.003N	—
2	STEEL FINGER	0.015 THICK	.006N	52
3	COIL SPRING	0.040 WIRE DIA.	.007N	—
4	VALVE PLATE	0.040 THICK	.004A	FOR COMPRESSOR
5	TUNING BRACKET	0.075 THICK	.010A	40; SOUND EQUIPMENT
6	BUCKET	0.120 THICK	.006A	CAST STEEL; SHANK
7	GEAR	32" O.D 170 TEETH	.010A	58
8	LEAF SPRING	0.3 THICK	.014A	47; PEENED ONE SIDE ONLY
9	GEAR	14" O.D. 60 TEETH	.007C	25
10	TORSION BAR	2" O.D.	.010C	50
11	CRANK PIN	2.7" O.D.	.015A	50
12	SHAFT	8" O.D.	.007C	36; WITH KEYWAYS & FILLETS

THE SHADED AREA CORRESPONDS TO MIL S-13165A

FIG. 8