Spring manufacturers recognize that their product is perhaps the most important component in an assembly, in terms of life performance. However, it is usually the last component designed — after all the other engineered parts take up the majority of the space in an assembly. Now it is up to the spring manufacturer to make a spring from a small-diameter wire, that fits into a small space, with expectations for it to perform like a spring twice its size. In other words, the customer wants a “four pound package” to fit into a “two pound space.” As a result, manufacturers often add shot peening to the spring to give them the “extras” they need, in terms of loads and life cycles.

Unfortunately in many cases, the design engineer adds a shot peening specification that he has used successfully in the past. What he may not realize is that what worked in the past may not be optimum for the material chosen, the surface hardness of this material, the diameter of the wire, and the desired load and life improvements, to name a few considerations.

However, recent innovations in the shot peening industry make the engineer’s selection more precise in optimizing a specification. These include the following:

- A computer software program called “Peenstress,” which permits a reasonable prediction of residual stress curves.
- A coupon system called “Milam” that makes possible actual X-Ray diffraction curves to monitor production shot peening.
- Although not new, a fluorescent tracer system called “Peenscan” to verify proper peening coverage in the critical area of springs, such as the I.D. of compression springs.

A Review of Shot Peening

Springs are the most commonly shot peened part. Although the origins of the technique go back more than 60 years in the automotive industry, today all types of springs – compression, extension, torsion, leaf, Belleville and so
Recent technology takes the guesswork out of shot peening specification and verification

by James L. Wandell
Metal Improvement Co.

on – are peened for fatigue life and load improvements. All sizes, from 0.008-inch diameter wire used for torsion springs on electrical dimmer switches, to 3.5-inch diameter rod used for springs on coal pulverizing equipment, are successfully shot peened. The peening process is relatively inexpensive and has proven to increase operating life by five to 10 times or more when compared to unpeened springs.

A spring subjected to a large number of stress cycles frequently will fail sooner than anticipated. The origin of spring failures can usually be traced to a couple of things that involve tensile stress:

1. Surface defects, such as a tooling mark, creating a stress riser.
2. Residual surface stresses as a result of the forming operation.

The common denominator is tensile stress. Usually, springs are thermally stress relieved after forming to ensure complete stress relief. Theoretically, the surface is at zero stress. However, in practice, is there such a thing as a “perfect” stress relief? Perhaps some residual tensile stresses remain at surface. Or, even if the surface is stress-free, as soon as the spring is loaded in service, tensile stresses immediately reappear at the surface. It is a well known fact that fatigue failures initiate at a surface in tension as a crack. It propagates through the cross section from cyclic loading, and the part fails when there is insufficient cross section to handle the load. It is also a well known fact that fatigue cracks will not initiate or propagate in a surface in residual compressive stress.

Shot peening is the process whereby the material’s surface is bombarded with round or spherical media, producing a thin layer of high-magnitude residual compressive stress. The magnitude of the compressive stress historically has run in excess of 50 percent of the ultimate tensile of the material peened. Each shot particle, with controlled shape and of uniform size, acts as a peening hammer to cold work the surface and produce compressive stresses. Now when a spring is loaded, the tensile stress created by the applied load must first overcome the residual compressive stress before the resultant stress becomes tensile. Therefore, a
peened spring will live longer than an unpeened spring at design stress levels, or achieve the same life at higher stress levels.

Figure 1A, page 76, shows a distribution of the compressive stress in a typical peened surface with no external load applied. Due to a compressive stress induced at the surface, an offsetting tensile stress has been developed in the core. For the part to remain in equilibrium, the two areas in the region of compressive stress must be equal to the corresponding core area in the region of tensile stress. In other words, the sum of the moments around the neutral axis must equal zero.

Figure 1B, page 76, shows the resultant stresses with an external bending load applied. The resultant stresses at any depth must equal the algebraic summation of the residual and applied stresses as shown by both the dotted lines. The resultant stress shown by the solid line remains in compression, even though the section is under design load. Even if a higher stress were applied, the resultant curve would shift to the left, perhaps into tensile stress. However, the tensile stress at surface will be far lower than if the surface had not been peened, or significantly higher if the surface was originally in tensile stress.

Peenstress

Given the possibility for premature failure of springs (with design restrictions adding to the potential) it is of utmost importance that the first choice of shot peening parameters be the correct one. As previously noted, a specification that worked in the past may not be the best specification for a new application. Optimizing the effects of shot peening is achieved by careful selection of the composition, hardness and size of the peening media; the transferred energy at impact (which con-

<table>
<thead>
<tr>
<th>Description</th>
<th>Test duration</th>
<th>Fatigue Strength</th>
<th>Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Millions of Cycles</td>
<td>Not Peened</td>
<td>Peened</td>
</tr>
<tr>
<td>Music Wire, 0.039 in. dia.</td>
<td>0.4</td>
<td>120,000 psi</td>
<td>190,000 psi</td>
</tr>
<tr>
<td>Oil Tempered, 0.207 in. dia.</td>
<td>10</td>
<td>85,000</td>
<td>120,000</td>
</tr>
<tr>
<td>Hot Colled 1095, 1/4 in. dia.</td>
<td>2</td>
<td>60,000</td>
<td>90,000</td>
</tr>
<tr>
<td>Beryllium Copper, 0.148 in. dia.</td>
<td>10</td>
<td>40,000</td>
<td>78,000</td>
</tr>
<tr>
<td>Stainless 18-8</td>
<td>10</td>
<td>80,000</td>
<td>120,000</td>
</tr>
<tr>
<td>S-816</td>
<td>10</td>
<td>55,000</td>
<td>100,000</td>
</tr>
</tbody>
</table>

Table 1: Increases in fatigue strength in helical springs.
trols the depth of the compressive layer); the percentage of coverage; and part material and geometry. The many combinations of the factors make the correct choice a difficult one – one that is often inadequate.

It is for this reason that Peenstress was developed. Peenstress is a computer program that is capable of predicting the residual stresses introduced by controlled shot peening in most of today’s engineering metals. These include mild- and high-strength steels, stainless steels, carburized and carbonitrided steels, aluminum alloys, titanium alloys, and nickel alloys. Peenstress operates as follows:

1. Upon entering the program, select a material from the metals and alloys in the Peenstress library. Nearly 100 materials are currently in the program library, and more can be programmed as needed (see Fig. 2, bottom right).

2. Select a geometry related to that of the component to be peened. For springs, the program offers round bar and asks for O.D. dimensions.

3. Peenstress asks the user to indicate which Almen strip will be used (N, A or C), the type of media (steel, glass, ceramic or other), the actual intensity (arc height) and the shot size.

4. The program calculates the shot velocity required to produce the selected Almen arc height or intensity.

5. Peenstress uses this shot velocity in all subsequent calculations.

6. The first calculation is the determination of the elastic deformation caused during the actual peening on a “massive body” of the selected alloy at the previously chosen peening parameters. This is a complex calculation, but the program does it all.

7. Peenstress uses material-behavior laws for steady and cyclic loading to determine the elasto-plastic deformations on the massive body and the corresponding residual stress, in both magnitude and depth, as shown in Fig. 3, page 00.

8. The program can be accessed in English, French, German and Spanish, and can be run in metric or English units of measure.

The Peenstress program will finally print out a stress curve as shown in Figure 4, page 00. It shows the magnitude of the residual stress distribution, the depth profile beneath the surface for the material and the shot peening parameter that was selected. The curve can be used to read the magnitude of compressive stress at the surface and at depth, which can be used in load calculations. Peening parameters may then be adjusted, if necessary. Most significantly, the user can do all this on a computer screen without having to resort to very expensive and time-consuming X-Ray diffraction, or even laboratory and field testing many variables.
Testing is still recommended, however, but can be reduced to a few selected data points.

In short, Peenstress is useful in optimizing the peening parameters on springs made from all sizes of wire. This is preferable to the old “what worked before should work again” approach. In some cases, the use of Peenstress software may even reduce the cost of the process.

**Gains Through Shot Peening**

Significant improvements in both fatigue life and strength have been gained as a result of shot peening. Fig. 5, page 78, illustrates a Goodman diagram showing the allowable fatigue strength, with and without shot peening, of helical springs made from 0.207-inch diameter wire. As one can see, there is a significant additional stress permissible on the peened springs versus the unpeened springs. For example, a spring with an initial or minimum stress of 60 ksi could operate safely with a maximum stress between 60 ksi and 95 ksi in the unpeened condition. In the peened condition, that same spring can now operate safely well over 120 ksi, an increase of permissible stress of more than 30 percent over the unpeened spring.

The same holds true for helical springs made from a variety of materials. Table 1, page 78, refers to helical springs made from various metals. Music wire springs show an increase in allowable operating stresses of 58 percent, from 120,000 to 190,000 psi. Such increases in allowable operating stresses, which run up to 95 percent as noted in the table, can offer tremendous increases in operating life.

**Milam**

How can you be assured that the types of improvements noted will be consistent, other than through positive controls of the shot peening process? Peenstress gives the spring manufacturer an optimization of the actual process. A new system, Milam, offers a quality-control measurement of the residual compressive stress profiles through actual X-Ray diffraction on a more economical and timely basis. It makes X-Ray diffraction readings of residual stress profiles more economical than in the past, and they can be available in days rather than weeks.
The Milam system actually offers three alternatives for its use. The first employs coupons that are ¼ inch wide by 3 inches long by ¼ inch thick, essentially the same size as a standard Almen strip. The coupons are designed to fit on a standard Almen block and can therefore be used on an existing Almen fixture, an example of which is shown in Fig. 6, page 00. In this way, the Milam coupons are placed to represent the critical areas of the part to be peened. The Milam coupons are made from the same material as the parts, heat treated (if required) along with the parts and supplied by the customer. They are shot peened after Almen strip verification and just before the parts are processed. Thereafter, the parts are periodically shot peened per the customer’s request.

The second alternative is to test the actual parts, such as small springs, rather than the coupons. The parts must be able to fit in a 2-inch-wide, 2-inch-long, 1.5-inch-thick envelope.

The third method consists of testing large parts that have been cut up so that the critical areas for X-Ray diffraction can fit into the envelope. Both of the last two alternatives lack the convenience of the coupons but work well if the spring manufacturer prefers to use actual parts rather than coupons.

After shot peening, the coupons or parts are tested by X-Ray diffraction. Because of their standard size, the coupons or parts can be etched and X-Rayed at successive depth levels for residual stress readings in a very expeditious manner. This accounts for the quick processing and economical cost of the Milam system. The recorded profiles are then reviewed and evaluated with a copy forwarded to the customer (see Fig. 7, page 79). These profiles can be recorded as Statistical Process Control (SPC) data. In the spring industry where SPC is required, this can be an advantageous tool.

The Shot Peening Process

Efficient and effective shot peening depends on a number of factors, such as type, hardness and diameter of the shot used; nozzle pressure or wheel speed; duration of the peening cycle for proper coverage; distance from the shot delivery system; and impingement angle. Many years ago,
J.O. Almen at General Motors developed a method for determining the intensity level for a given peening setup. This involves measuring the intensity, or kinetic energy, of the shot stream on a target location, which simulates the critical surface.

When a flat strip of spring steel (an Almen strip) is clamped to a block and exposed to a stream of shot, it will be uniformly curved convex to the side being peened (see Fig. 8, page 79). The height of the arc serves as a measure of the kinetic energy and is read in thousandths of an inch. Almen developed three strips, all ⅛ inch wide by 3 inches long. An N strip is 0.031 inch thick, an A strip is 0.051 inch thick, and a C strip is 0.094 inch thick. These represent three ranges of intensities – low, medium and high, respectively. The height of the arc will vary with shot velocity and time exposure to the shot stream.

Arc height is not considered intensity saturation obtained on the Almen test strip. Saturation is said to occur when doubling the time exposure will not further increase the arc height by more than 10 percent (see Fig. 9, page 79). It occurs just beyond the knee of the curve. Developing this curve for each new part is important to ensure that saturation occurs within the intensity range specified for the part. For instance, if through Peenstress an optimum peening intensity of 0.012 Almen A is developed, then the knee of the saturation curve will fall within an intensity range of 0.010 - 0.014 inch.

**Shot Integrity**

Perhaps the most important aspect of shot peening is the integrity of the shot. Cast steel shot is the most commonly used for peening and is available in different degrees of hardness. The selection of shot hardness depends on the hardness of the material being peened. Regular hardness of shot ranges between 45-55 HRC. This is suitable for peening springs with a nominal hardness of 50 HRC and below. A harder shot range, 55-65 HRC, should be used for material above 50 HRC. MIL-S-13165C recommends harder shot on any material over 200,000 pounds per square inch. On springs made from metals such as music wire, chrome vanadium and chrome silicon, a hard shot should be used for optimization of the peening process. This will result in a higher magnitude of compressive stress and, therefore, greater fatigue life (see Fig. 10, page 80).

Another aspect of shot integrity is the shape of the shot. Most commercially available shot meets MIL-S-851 or ASM-2430 specifications. Metal Improvement recommends the use of shot meeting the requirements of MIL-S-13165C or AMS 2431, which requires close screening tolerances and shape control. Military specification clearly defines acceptable and non-acceptable shapes. Acceptable shapes are either round or spherical; non-acceptable include any broken or sharp-cornered particles that can damage or abrade a surface. It is important that shape tolerance be maintained throughout the peening process. Shot will fracture over a period of time. As it fractures, two things can be affected:

1. The mass of the shot will be lower, which has a direct effect on the kinetic energy which, in turn, determines depth of the compressive stress
2. More importantly, the sharp corners of the broken particles can damage the surface of the part.

**Coverage**

Another control factor in the peening process, and a most important one, is coverage. A properly peened surface is overlapping and uniformly dimpled (Fig. 11, page 80). Overlapping dimples must completely obliterate surface discontinuities for proper coverage. It is extremely difficult, if not impossible, to inspect certain areas with an approved 10-power magnifying glass to determine if full coverage has been achieved. For example, it is very difficult to inspect the critical inside diameter area of a closely wound compression spring. Also difficult to inspect is a large surface area or a hardened area, where dimpling may not be as

---

**SPECIALTY SPRING STEEL**

*The “Admiral Nippers”™ give that little extra.*


---

SPRINGS, Winter 1998 83
pronounced as on a soft surface. In these cases, the results of visual inspection with a 10-power magnifying glass are open to subjective interpretation. Military specification MIL-S-13165C, paragraph 6.11 method “b” recommends “visual examination using a 10-power magnifying glass in conjunction with an approved liquid tracer system.” The specification further refers to one paragraph, 6.17.4, that further defines the tracer system as a “liquid coating material which removes at a rate proportioned to peening coverage.”

Several years ago, the Peenscan process was developed. It employs Dyescan fluorescent tracer liquid, a dye that fluoresces under ultraviolet light. Parts are brushed, sprayed or dipped into the liquid and allowed to dry. Dyescan forms a fluorescent elastic coating that is removed at a rate proportional to the percentage of shot peening coverage. The tracer liquid coating responds to all peening intensity ranges. Low angle of shot impingement or low shot peening coverage will not remove all the tracer coating. After the surface has been shot peened, and full coverage has been achieved, inspection under the UV light should indicate no remaining traces of the Dyescan material. This is completely objective, and no doubt or question will remain as to whether full coverage has been achieved. If inspection indicates remaining Dyescan traces, one or more of the peening parameters has changed, resulting in incomplete coverage.

For example, Peenscan is a very valuable coverage verification tool on the I.D. of compression springs (see Fig. 12, page 80.) Since this is the critical area where most fatigue cracks initiate on this type of spring, full coverage is essential on the I.D. for the added performance that peening will give the part. Occasionally, it is not possible to deliver shot to the I.D. from an external source on a tightly wound spring. To facilitate coverage, special I.D. equipment with rotating, oscillating lance-type nozzles is used. In this case, Peenscan becomes invaluable for coverage verification, along with the use of a borescope.

**Summary**

Springs respond more dramatically to shot peening than most mechanical parts. Efficient peening will often allow a spring to be used for infinite life at 50-70 percent higher stress levels than an unpeened spring.

With today’s demands for higher performance in smaller packages, it is essential to specify precisely the right peening parameters. Optimum results can only be obtained by the proper specification of shot size and intensity for each application. Peenstress now takes the guesswork out of the process, offering an effective tool in selecting optimum parameters for a given part’s geometry and material.

---

**BENNETT MAHLER**

- Single head and tandem models in 8", 14", 18", 24", 30" & 36" sizes
- “Behind-center” grinding path featured on most models
- Simple, repeatable head tilt for easy setup

**NIMSCO INTERNATIONAL MACHINERY SYSTEMS CO.**

5328 Tremont Avenue, P.O. Box 2709
Davenport, Iowa 52809
Tel: 319/386-9590 Fax: 319/386-9593

**CRASH GRINDERS**

---

84 SPRINGS, Winter 1998
Milam permits affordable X-Ray diffraction readings with timely turnaround. It offers quality control a valuable tool for SPC. In all cases, residual stress modeling should be verified by X-Ray diffraction or other validation methods.

Equally important is positive controls of the peening process for its repeatability and reliability. Maintaining shot integrity, in terms of size, shape and hardness, is essential for maintaining a consistent kinetic energy to induce uniform depth of compressive stresses. Proper coverage in the critical areas of parts and coverage verification add to process reliability. Peenscan can make verification effective in a process-control and cost evaluation.

References


James L. Wandell is currently the manager of technical services for Metal Improvement Co. in Addison, IL. He has been with the company for 13 years, expanding and developing shot peening services and sales in the Midwest. Previously, he worked in the metals industry for 20 years at the mill and service center levels.

He has been a featured speaker at American Society of Metallurgists, Society of Automotive Engineers and other industry functions. He also has written several technical papers on shot peening and presented peening seminars to OEMs. He may be contacted at (630) 543-4950.

Metal Improvement Co. developed the Peenscan technology and engaged the services of Lambda Research, an independent laboratory, to create the Milam system. In addition, the company collaborated with ENSAM, a French advanced engineering school, to develop the Peenstress computer program.

---

UG-30
ULTRAGRIND DOWN FEED