Nano Peen™ Technology

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INTRODUCTION

Peterson Spring has developed and refined a peening technology for highly stressed springs that greatly enhances fatigue life by as much as 35%. Previously it was not possible to shot peen small springs that had outside diameters under 3 mm with wire sizes below 0.5 mm and/or very tight pitch spacing (less than 0.3 mm between the spring coils). Peterson Spring has industrialized a production process and methodology to manufacture small critical springs with a beneficial residual compressive stress. This innovation will allow springs to be made more efficiently (smaller) to carry more load and have higher cycle life for demanding applications such as fuel systems, medical, aerospace, and military uses.

Challenges to proper shot peening of small springs include:

- Presenting springs reliably to the shot stream
- Obtaining complete shot peen coverage at the inside diameter
- Obtaining repeatable shot peen intensity
- Obtaining significant residual compressive stress without significantly distorting the spring
- Media selection to obtain all of the above without requiring passivation (for stainless steel springs)
- Do all of the above with an economical process suitable for production volumes of springs

Solution to these challenges grew out of the Nano Peen™ process technology developed in 2005 for Peterson Spring's high-performance racing valve springs. This process establishes beneficial residual compressive stresses of high magnitude in addition to modifying and smoothing the wire surface. A direct result is superior fatigue strength under high amplitude cyclic stresses. The media size used is appropriate for small wire diameter springs and also for springs with tight coil spacing. For stainless steel springs, modified media prevents a need for a secondary passivation operation. The greatest modifications pertain to spring containment and presentation to the shot stream. This allowed for duplicating the racing benefits of the Nano Peen process for small wire diameters and tight pitch gap stainless steel springs.

Engine valve springs (wire diameters typically between 3 to 6 mm and pitch gaps greater than twice the wire diameter) are peened single or multiple times with shot sizes typically ranging up to 0.8 mm. Smaller diameter fuel injector springs have also been shot peened with cut wire shot sizes of 0.3 or 0.45 mm. Up until now, critical small wire springs (d < 1 mm) could not be economically or reliably shot peened with the current technology in the marketplace without distorting or damaging them. Springs with very tight pitch spacing could not be economically or reliably shot peened because peening media cannot get between the coils to provide the beneficial residual stress where it is needed most—at the inside diameter (ID).

A batch process for shot peening is common practice in the industry as it utilizes the law of large numbers to achieve a certain level of uniformity and consistency over time. Other processes, methods, and technology are possible but not economically viable when taking into account part handling, cycle time or controlling and documenting the process parameters to requisite automotive standards. Economic viability limited the options to a batch type process in which hundreds if not thousands of springs could be peened in a single batch. Uniformity is evaluated for a given batch size by conducting such tests as saturation testing, and coverage studies. A batch system with the size and type of media needed for the Nano Peen™ process narrowed the delivery method to an air propelled system. The air pressure and subsequent velocity transports the very small media to the work piece transferring kinetic energy to the spring surface and thereby imparting the beneficial residual compressive stress.

In order for the media to be effectively efficient, it needs to be similar in hardness to the object being peened; otherwise the media will not fully transfer its kinetic energy to the spring in the form of a plastic deformation dimple on the surface of the wire. This resulting dimple can only be imparted if the shot peen media is spherical (or near spherical) in shape; else the resulting impact with the spring wire could create a detrimental surface indentation. Sharp-edged media could potentially scar the spring wire surface and leave a damaging early fatigue stress raiser where crack propagation can initiate. Glass beads have been used in the past on other parts, springs included, to improve the surface residual stress but this media is limited as it is brittle and will shatter when used at higher velocities on high-hardness parts. Shards from the shattered glass beads impart detrimental sharp bottomed indent surface stress raisers.

The targeted industry and customers for this process utilize stainless steel spring wire. This narrowed media selection to a media type that would not require passivation after shot peening. Carbon steel shot was not considered as an option. Several sizes and types of media were evaluated and the one with the best combination of features (shape, size, hardness) was selected.

When conducting preliminary trials on a production air blast machine, small wire springs escaped the basket and ended up in the shot reclamation system. This would become the most difficult challenge with this process—containing parts without trapping them. The force of the high-pressure media stream blew springs out of the basket and everywhere else in the cabinet. The bulk of development focused on the basket and mating component design to retain parts without trapping parts or restricting shot reclamation. Several iterations and significant creative modifications achieved the goals with a custom basket system solution.

The final steps for the production intent system was to incorporate the necessary failsafe controls for the process variables and to continuously monitor and document these parameters for each batch of parts run through the system. By adding the necessary transducers, sensors and machine code, each batch of parts can be documented that they received the correct recipe and that all parameters are within specification.

RESULTS

Tests used to establish process parameters included saturation tests using Almen strips and coverage evaluation using black light with fluorescent paint. SEM photographs, residual stress measurements and fatigue testing were used to quantify the results.

Two different springs were selected to demonstrate the benefits of the Nano Peening process. Cycle testing was conducted on a special test spring with wire diameter of 0.41 mm and pitch gap of 0.5 mm to demonstrate fatigue strength improvement of Nano Peening. Cycle testing and residual stress testing conducted on a larger spring with wire size of 0.56 mm and pitch gap of 0.32 mm compared Nano Peen with a more conventional shot peen and illustrated benefit for springs with tight pitch gap.

The first spring design tested was a small wire spring (d = 0.3 mm) which previously went un-peened based on the size of the wire relative to the traditional media size. The readily available media size of 0.3 mm propelled at this wire size with enough velocity to impart compressive residual stress would damage and distort the spring. Nano Peen media size was sufficiently smaller than the spring wire size to impart beneficial residual stress to the wire surface; enhancing the fatigue life without any dimensional distortion (bending or bowing of the spring).

Reliable evaluation of shot peen coverage on valve springs only requires low power magnification and an optical microscope is sufficient. With smaller shot, smaller spring wire and lighter intensity shot peening, evaluation of coverage under the optical microscope becomes more challenging. Electron microscopy allows for assessment of the degree of surface texture modification caused by light intensity shot peening. By its very nature, this is a qualitative evaluation.

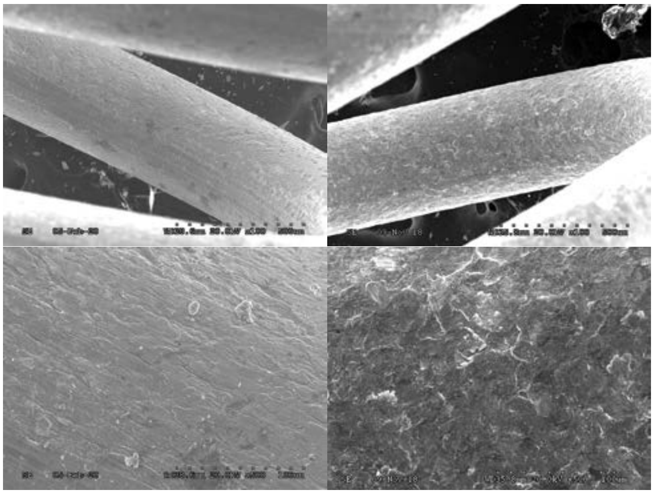

Figure 1 - Comparison views of the inside diameter of a 17-7 PH stainless steel (d = 0.41 mm, pitch gap = 0.5 mm) spring. Images at left show the residual wire drawing surface texture of an unpeened spring, while images at right show inside diameter after Nano Peen.

SN fatigue curves are generated by testing springs at various stress amplitudes—in this case, 35 springs at each stress range. A custom fatigue test fixture cycled peened and unpeened springs at the same time. The Nano Peen process increases the 10 million cycle endurance limit by ≈35% over non-peened springs.

Figure 2 – Test fixture capable of cycling 70 springs simultaneously.

Nano Peening can also peen the inside diameter of spring designs with very little space between spring coils. Tight pitch gap restricts access to the inside diameter. A good rule of thumb for media size as it relates to pitch gap is for the media to be 1/3 the size or smaller of the pitch gap to allow comprehensive, full and complete peening at the spring inside diameter, where applied stresses are highest. For the example in Table 1 (next page), cut wire shot of the recommended size is not readily available. Using cut wire shot results in complete shot peen coverage on the outside diameter, but insufficient coverage on the inside diameter. Extending the cycle to obtain full coverage on the inside diameter can result in distortion

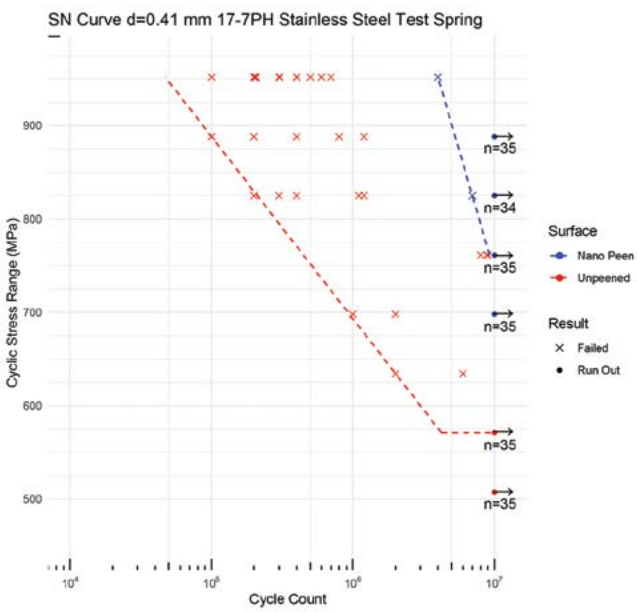

Figure 3 – SN curve for 17-7 PH stainless steel (d = 0.41 mm, pitch gap = 0.5 mm).

of the ground end coil tips and/or uneconomical throughput. Nano Peen achieved complete and full shot peen coverage on inside and outside diameter. Residual stress results (Table 1) demonstrate the improvement of Nano Peen over standard cut wire shot sizes.

Table 1

Residual stress measurements on springs with wire diameter of 0.56 mm and pitch spacing of 0.32 mm. The smaller Nano Peen media results in superior residual compressive stress at the spring inside diameter.

	Residual Stress Measured at Inside Diameter
Unpeened	-28 MPa
Standard Peen (0.3 mm cut wire)	-186, -62, -214 MPa
Nano Peen	-517, -476, -476 MPa

A single multi sample fatigue fixture running both peened versions (standard peen vs. Nano Peen) of the same spring (wire size 0.56 mm, pitch gap 0.32 mm) generated first failures with an order of magnitude difference. First failure for the standard peen was recorded at 600,000 cycles, while first failure for the Nano Peened parts occurred at 6,000,000 cycles.

CONCLUSION

With inspiration from our racing technology and innovation from our engineering group, it is now possible to economically and reliably enhance the fatigue life of high-tensile stainless steel springs with both wire diameters and pitch gaps as small as 0.3 mm.