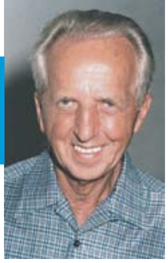

ACADEMIC STUDY

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# Essential Elements of Shot Peening

**INTRODUCTION**

Shot peening is a very important metalworking process– mainly used to substantially improve the fatigue life of components. There is now such a wealth of information about the process that often one cannot "see the wood for the trees". This British idiom carries a dictionary definition: "If someone **can't see the wood for the trees**, they get so caught up in small details that they fail to understand the bigger picture." This article explains shot peening in terms of six essential elements as illustrated in fig.1. on page 26.

**1** Components, such as trailer leaf springs, are subject to cyclic loading.
**2** Cyclic loading leads to corresponding cyclic stressing.
**3** Cyclic stressing can lead to fatigue failure - if the stresses and number of cycles are high enough. Stresses must be tensile for cracks to grow.
**4** The incidence of fatigue failure is often reduced by shot peening.
**5** Shot peening induces a "magic skin" of compressively-stressed, work-hardened, material. The thickness of this skin depends upon the peening intensity.
**6** Coverage is the amount of shot peening that is applied. Coverage is the percentage of the component's surface that is indented.

Specifying an appropriate shot peening treatment involves inter-related decisions. These are summarized in fig.2.

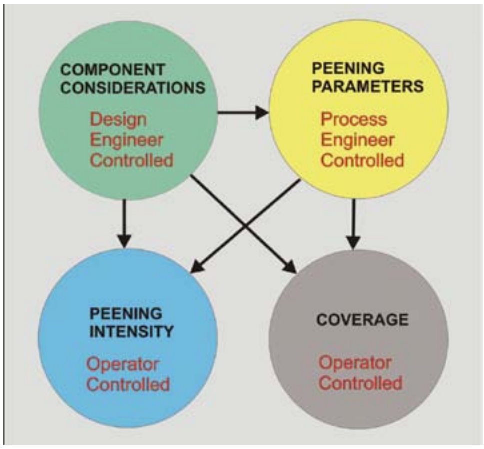
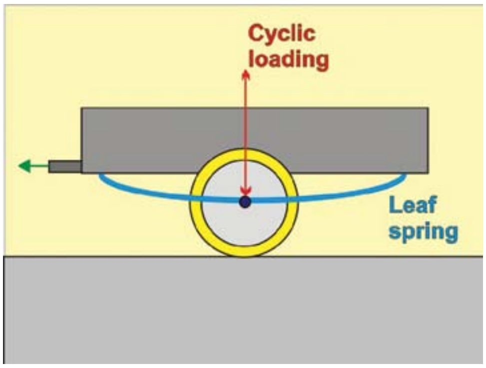



*Fig.2. Shot Peening Decision-making.*

Generally speaking, the customer is responsible for component considerations and setting of peening parameters – intensity and coverage. Customer decisions may involve experts such as design and process engineers. The peening company's operators are responsible for applying the customer's specified peening intensity and coverage levels.

**1 CYCLIC LOADING**




Cyclic loading occurs in almost all engineering components but most significantly (for shot peening) in auto and aero components. This loading has four distinguishing features:

1. Frequency of occurrence,
2. Variability,
3. Magnitude and
4. Type of loading.

**1. Frequency of Occurrence**

Sometimes the loading is obvious as with compression springs and leaf springs. Other times cyclic loading is much less obvious as with an aircraft fuselage (alternately pressurized and de-pressurized in flight). Springs may be cyclic loaded trillions of times, whereas an aircraft fuselage (landing gear, etc.) may only be cyclic loaded a few thousand times – in the same period of time. The frequency of loading can therefore vary enormously. This has an effect on component design. Some components have to be designed to withstand thousands of cyclic loadings whereas others have to be designed to withstand trillions of loadings.

**2. Variability**

Component loading can vary substantially. An empty truck

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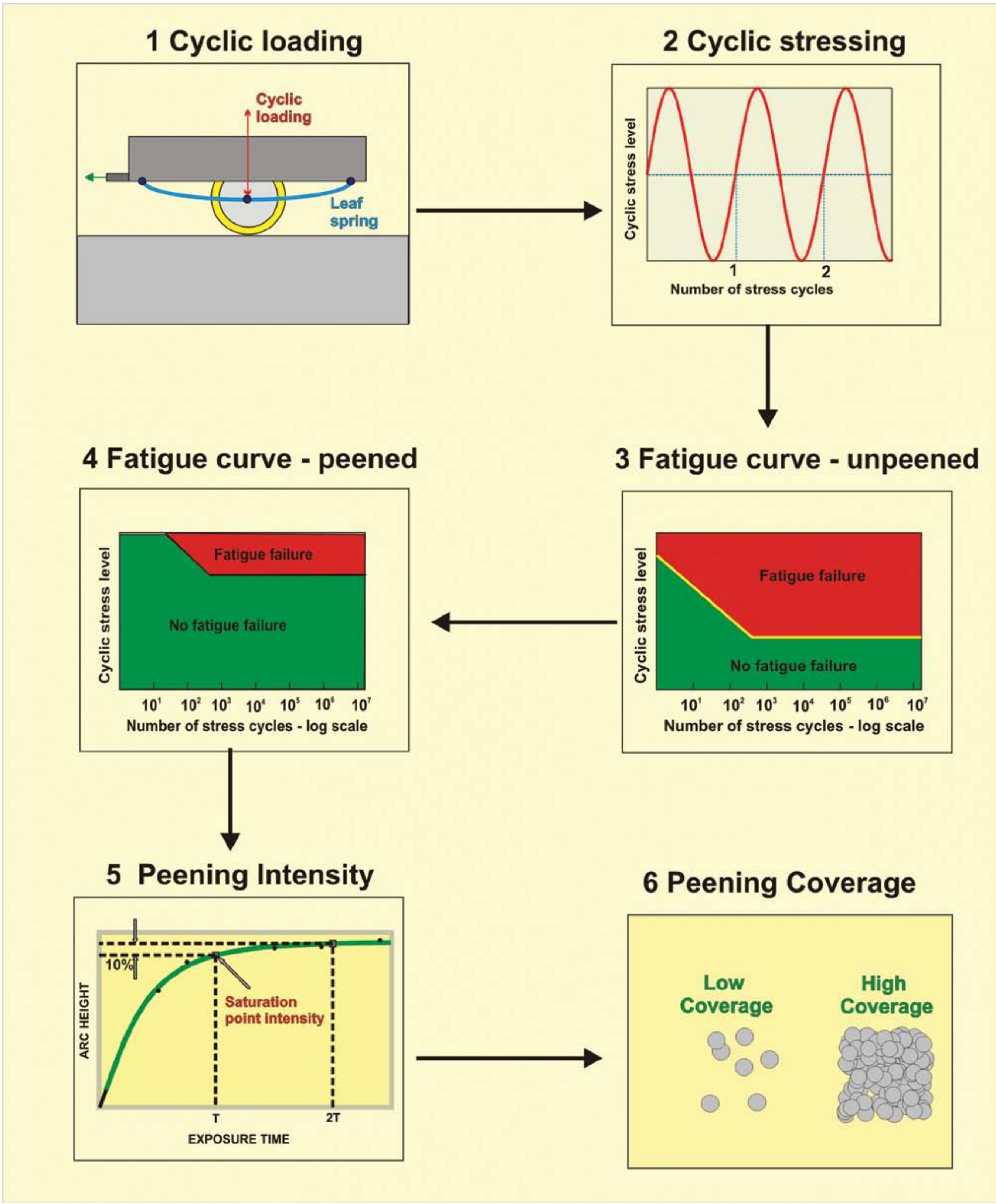



Fig.1.Shot Peening considered in terms of six essential elements.

imposes lower cyclic loads than does a fully-loaded truck. A trailer being pulled along a smooth tarmacked road will experience lower loads than when pulled on a pot-holed mountain track. An aircraft making a heavy landing imposes higher loading than with a normal landing. This variability adds a complication to component design and to the effectiveness of shot peening in preventing failure.

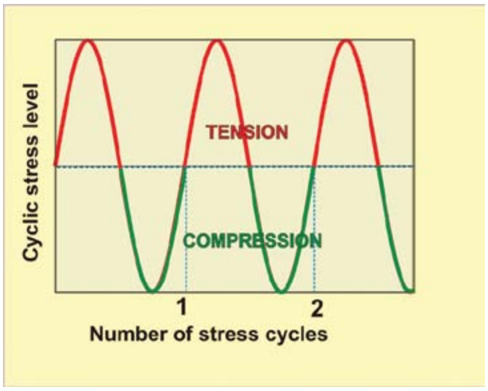
**3. Magnitude**

The magnitude of the cyclic loads affects how long a component will last before it fails. Larger loads equate with shorter component lives in terms of the number of cycles that can be withstood. Estimating the magnitude of cyclic loads is a subject in its own right!

**4. Type of loading**

The 'black and white' extremes of cyclic loading are 'push-pull' and 'repeated bending'. All components have a proportion of each type of loading. Shot peening works best when the cyclic loading is mainly repeated bending.

**2 CYCLIC STRESSING**




Cyclic loading of any component gives rise to corresponding cyclic stressing. The stress may vary between tension and compression as shown above. It is the tension part of stressing (shown in red) that can cause fatigue failure.

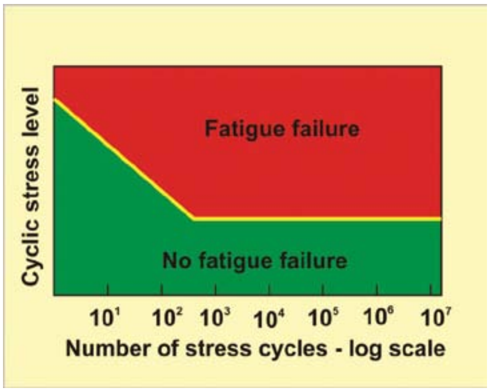
Stressing of components is normally "elastic stressing" because the stress disappears if the load is removed. Applying a tensile load to a component means that it must stretch. Conversely a compressive load compresses the component. The amount of stretching or compression is called the "strain". For elastic stressing of components there is a linear relationship between stress and strain. This relationship is a cornerstone of mechanics, being known as "Hooke's Law" (published in 1660). The ratio of stress to strain is the elastic modulus, E, of a material.

The number of stress cycles that are applied in service varies enormously according to the type of component. Components can be designed to withstand an expected number of known stress cycles before they fail due to 'fatigue'.

In the nineteenth century, component design in the UK lead to the phrase "Victorian Engineering". Components were designed with such a huge margin of safety, and therefore low stress levels, that some of them are still working in the twenty-first century! Such over-engineering cannot normally be tolerated in modern transport vehicles – the corresponding weight penalty would make them uneconomic.

An important element of cyclic stressing is "stress-amplification". If a component contains a notch then the derived stresses are amplified. The degree of amplification depends on the sharpness of the notch. That is why smooth "fillets" are normal for areas such as axle-to-flange. Shot-peening has to minimize the effect of its dimples which are themselves stress-amplifiers.

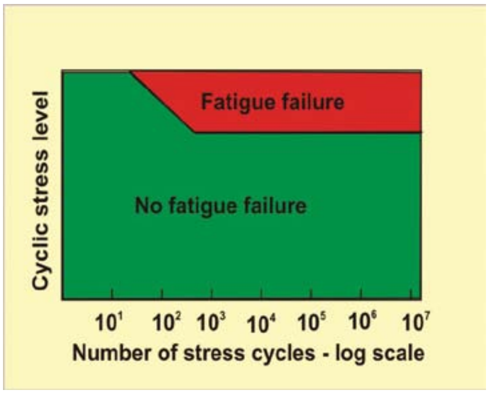
**3 FATIGUE CURVE – UNPEENED**




Metals have an inherent ability to withstand cyclic stressing. This is generally represented in the form of a fatigue curve. For ferritic materials the general shape of a fatigue curve is shown above. The first thing to notice is its simplicity – just two straight lines separating failure from survival. That is because a 'log scale' has been used for indicating the number of stress cycles that have been applied. A log scale is necessary because of the huge range of applied stress cycles that may be encountered – say tens to many billions – depending on the component's application.

For ferritic materials the number of cycles to failure decreases with increase in cyclic stress level. Below a certain stress level fatigue failure never occurs. That stress level is called the "fatigue limit". In the diagram shown this occurs at about 500 stress cycles, but that number will vary considerably with type of material and type of testing. The main objective with shot peening is to raise the fatigue limit stress level. Imagine a ferritic component that is repeatedly stressed to just above its fatigue limit. Fatigue failure will occur when a critical number of stress cycles have been applied. If the cyclic stress level never exceeds the fatigue limit then fatigue failure will never occur.

**4 FATIGUE CURVE – PEENED**



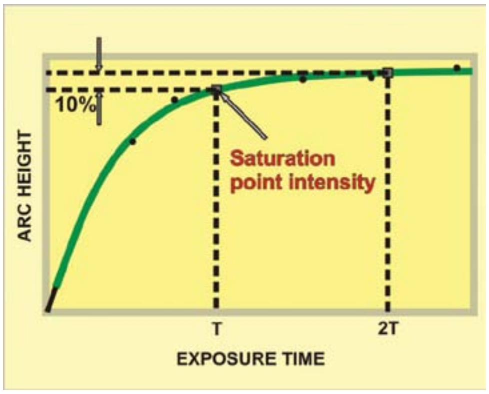

The general effect of shot peening is to raise the cyclic stress level that can be withstood for any given number of applied stress cycles. This raising of the stress level is illustrated above – compare it with the fatigue curve for the same material in the un-peened state.

Impacting shot particles plastically-deform the surface of a component. This generates a work-hardened, compressively-stressed surface layer on the component. It is this surface layer that improves the fatigue resistance of components. Fatigue cracks can only form and grow during the tension part of applied stress cycles. The stress applied to a component is greatest at the surface – especially in bending. Compressive residual stress at the surface reduces the applied tensile stress by the same amount.

The reason for compressive stress in the surface layer being effective is not always obvious. As an analogy, consider a rubber sleeve being stretched over the handle of, say, a cricket bat (hockey stick, etc.). The rubber sleeve is in tension. Now imagine cutting a slit into the surface. As the cut is made, the tension will pull the slit open. If, however, the rubber sleeve was somehow in compression, then that compression would keep the slit closed.

Peening intensity directly controls the thickness of the work-hardened, compressively-stressed surface layer.

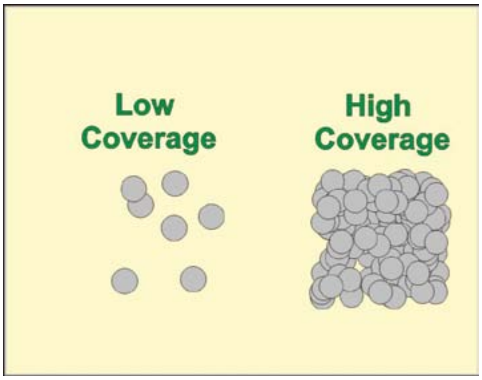
**5 PEENING INTENSITY**




"Peening intensity" is a quantity that is directly related to the depth of the compressed surface layer. The greater the peening intensity value, the greater will be the thickness of the compressed, work-hardened layer. Estimation of the peening intensity value requires that a set of standard steel strips, Almen strips, have been peened for different amounts. The induced bowing of the strips allows a curve to be plotted – arc height versus amount of peening. Peening intensity is defined as the arc height at a point on the curve that is increased by 10% when the amount of peening is doubled.

The effect of bombarding particles depends on the angle of impact. Imagine a machine gun firing at a vertical steel plate. The bullets will make certain impacts on the plate's surface. If we now incline the plate at an angle the impact effect will be reduced. This phenomenon is utilized in battle tank design! If Almen strips are inclined at an angle to the shot stream then the impact effect will similarly be reduced, lowering the measured peening intensity.

**6 PEENING COVERAGE**




"Peening Coverage" is defined as the percentage of the peened surface that is dented by impacting shot particles. The percentage of coverage increases with the amount of peening that has been applied to a given area of the component. Small amounts of peening impart a low percentage of the area that has been indented. Conversely, large amounts of peening will produce a high coverage – as shown above.

An analogy to the evolution of peening coverage is that of repeated bombing runs over a target area. Imagine one bomber drops seven identical large bombs that explode, producing craters that correspond to the low coverage shown. It is quite possible that one bomb explodes so that its crater partly overlaps a previous crater – as shown. The total area of the seven craters is now slightly less than seven times the size of an isolated crater. A second bombing run over the same target area will produce a greater proportion of overlap. The greater the coverage with craters the less will be the new crater area that will be created by an extra bombing run. This represents an example of "The Law of Diminishing Returns". Note that even with a large number of bombing runs it is probable that a tiny proportion of the target area will be un-cratered.

**DECISION-MAKING**

Decision-making depends on where the customer/peener is on the spectrum of shot-peening knowledge. At one end of the spectrum, a single person has to bear all of the responsibility armed with only an elementary knowledge of what shot peening is all about. At the other end, the customer/peener has a team that includes design engineers, process engineers, computer experts, staff trained at shot peening workshops, etc. The complexity and value of the components involved directs the optimum position on the spectrum.

The several elements of shot peening that have been outlined in this article combine to highlight the enormous complexity of the decisions that have to be made. Three essential decisions have to be made:

**1 Peening Media**

**2 Peening Intensity** and

**3 Peening Coverage.**

**1 PEENING MEDIA**

The most popular shot peening media are cast iron shot, cast steel shot, cut steel wire shot, glass beads, ceramic beads and stainless steel shot. These share some common characteristics: near sphericity, high hardness, durability and reasonable cost.

Choice of peening medium depends mainly on the component's composition. Ferritic steel components are normally peened with either cast iron, cast steel or conditioned cut steel wire shot – all of which are themselves ferritic. Peening stainless steel components with ferritic shot invites the danger of galvanic corrosion. Dissimilar metals and alloys have different electrode potentials, and when two or more come into contact in an electrolyte, one metal acts as anode and the other as cathode. Aluminum alloy components, being relatively soft, normally require the use of glass or ceramic beads – which also obviate the galvanic corrosion problem.

There are strict specifications governing the quality and size of peening media. Shot deteriorates in use because of size reduction due to wearing and shape problems occurring due to fracturing on impact. There is a direct connection between the specified size of shot and the peening intensity that can be induced. Sieving is employed to control the size range for each grade of shot. Media sizes vary from about 0.2mm diameter up to about 3.4mm diameter. Most peening is carried out with media less than 1.0 mm diameter.

The customer decides on the size and type of media that have to be employed.

**2 PEENING INTENSITY**

Customer specification of the peening intensity to be applied to a particular component is of critical importance. This requires that peeners must apply an intensity that lies between upper and lower limits, e.g., 0.20 – 0.26mm using A strips. A limiting range is necessary because peening intensity is very difficult to control to within precise limits. The optimum mean intensity that should be applied depends on a large number of factors – type of material, type of loading, thickness of component, etc. – so that its selection has to be carefully determined.

A shot stream striking a component's surface 'head on' will have a higher intensity than if it strikes at an angle. Customers often specify that their required peening intensity must be measured, for certain locations, with strip holders at an appropriate angle to the shot stream. For those locations only, the shot stream must be accelerated.

The 'magic skin' of work-hardened, compressively-stressed material can be up to about 1 mm in thickness. Charts are available that indicate how this thickness varies with applied peening intensity and component composition. As a rough guide: the skin depth is approximately two-thirds of the Almen A intensity value for steels.

Optimizing the intensity to be specified is complicated by the number of factors that affect component life improvement. As long ago as 1958, Fuchs advised that an intensity range of 0.25 to 0.35mm using A strips (0.010 – 0.014" A) was appropriate for general applications. He also detailed some of the complicating factors such as component thickness, material, notches and possibility of sub-surface crack initiation. These indicate that the optimum intensity varies considerably. Even after taking into account the several complicating factors, there is no substitute for practical assessment of component life improvement.

**3 PEENING COVERAGE**

Customers must specify the amount of coverage that they require to be applied to their components. Again there is no substitute for practical assessment if optimum coverage is to be specified. One school of thought assumes that 'more is better'. This has resulted in rather vague requirements such as "300% coverage" – being three times the amount of peening that produces a nominal "100%" coverage. Another school of thought believes that the optimum coverage for most applications is less than a nominal "100%".

It is generally recognized that it is very difficult to measure changes in coverage above 98%. Hence it is accepted that a value slightly less than 100% is to be regarded as "full coverage".

**DISCUSSION AND CONCLUSIONS**

This article has presented a 'Big Picture' of shot peening especially in terms of the decisions that have to be made about the several important parameters. Of necessity, simplifications have had to be included. There is extensive literature that provides the theoretical and practical implications of parameter change.

In the majority of practical applications, shot peening is proposed because premature component failure has occurred. Again, there is a wealth of literature detailing the substantial improvements to component life brought about by applying shot peening. As an 'add-on' process, it is normally more economical than having to either change component dimensions and/or component material.

**Editor's Note: The online library at www.shotpeener.com is a great resource for articles on the benefits of shot peening. For example, a search for "benefits of shot peening" gives 86 articles.**

**The website is also the place to download Dr. Kirk's free Curve Solver and Coverage Predictor programs.**