SHOT PEENING GIVES PARTS HIGHER FATIGUE LIFE
For Diesel And Gas Turbine Components

Shot Peening Gives Parts Higher Fatigue Life

By Gerald Nachman

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One of the prerequisites of early fatigue failure of turbine blades, crankshafts, connecting rods, leaf springs, piston rings and pins, to cite a few examples, is present from the moment these components are manufactured. This is residual surface tensile stress, unavoidably induced in most metal and alloy parts by machining, grinding and, to an extent, by plating and other finishing and forming operations. Residual surface tensile stress creates microscopic surface fissures or "stress risers" between the metal grain boundaries. As the components undergo cyclic loading during operation of the equipment, the risers enlarge and propagate inward until premature fatigue failure results.

The phenomenon of stress corrosion which also originates at the stress risers, requires a more or less corrosive environment. It proceeds whether or not the untreated part is in actual use. Never-before-used parts held in inventory are subject to continuous stress corrosion. Most typically, in the case of gas turbines and diesels, unprotected parts are being cyclically loaded in a mildly corrosive atmosphere. Premature failure is caused by fatigue, the continual progression of an initial stress riser, aggravated to greater or less extent by corrosion. Coating or plating the surfaces covers over the stress risers preventing atmosphere contact and corrosion, but does not hinder fissure progression and fatigue. Controlled shot peening, especially of those areas most likely to be affected, is a means of preventing both fatigue and corrosion failure.

Controlled shot peening includes those carefully monitored procedures involving uniform impacting of a metal surface with spherical steel shot and/or glass beads, thereby producing a result not unlike that of hundreds of thousands of minute peening hammers impacting with blows of precisely equal intensity. What controlled shot peening does, is to convert the tensile stressed surface layer into a compressively stressed one, one which will remain compressively stressed after loading. This is illustrated by the three diagrams in figure 1. The resulting compacted layer of metal, several thousandths of an inch deep, prevents origination and/or propagation of stress risers.

Chrome plated piston rings of 9254 alloy steel, hardness 45 Re, for example, used to present a fatigue problem found to be caused by the plating process itself. Controlled shot peening prior to plating increased fatigue strength from 85,000 to 150,000 psi or 76%. Peened sub-surfaces of plated components also prevent propagation, to the base metal, of minute cracks which originate in the plating, as a fatigue crack will not propagate into the compressively stressed zone. On forged steel crankshafts for six cylinder diesel engines used in heavy equipment, shot peening, by one manufacturer, of the journal fillets (hardness 24-27 Re) increased the fatigue limit from 51,000 to 65,400 psi, or 24%. In testing the effect of shot peening on modular iron cast shafts of the same design (hardness 255 Br), the fatigue limit was found to be increased from 38,000 to 50,000 psi or to about the same value as that of unpeened forged shafts. One particular manufacturer of gas turbine systems specifies controlled shot peening on the dovetail portion of hot gas pass buckets, fillets on compressor blades in the platform-to-airfoil areas and of certain key rotating elements subject to vibratory and other high cycle fatigue stresses. Shot peenedfoils and roots of turbine blades as well as disks are standard with a number of leading turbine producers. A British engine company uses shot peened detuner leaf springs on their large marine couplings. Another's power system incorporates controlled shot peening of such gearbox parts as planet gears, pinions, idler gears, output wheels and mainshafts.

Experience shows that controlled shot peening of blades already fatigue-damaged through loading will extend their life, at the same stress level, over
those of unpeened new blades, or will permit opera-
tion at higher stress levels. If the fatigue damage
does not progress far too fast, that is, if the minute
cracks representing fatigue damage have not penet-
trated too deeply, controlled shot peening will, in
effect, eliminate them and place the surface layer
under compression. Surface stress riser formation
will be prevented just as in the case of a peened
new blade. At just what point should shot peening
be undertaken is the case of operating compo-
ments which already exhibit fatigue damage? Since
shot peening inhibits the possibility of surface in-
sure initiation and/or propagation, the earlier in
the life span that it is done, the better. The danger
in waiting too long is that crack propagation might
extend so far as to make shot peening ineffective
in extending fatigue life. The curves in figure 2
illustrate the value of controlled shot peening in so
rejuvenating fatigue-damaged Inconel 718 steel compo-
nents that they can be operated at considerably
higher stress levels than can (no fatigue damage)
unpeened items.

Curve A represents the stress levels accommodated
by new, unpeened specimens without fatigue dam-
age while curve D that of the same, but fatigue-
damaged specimens which were not shot peened.
The latter could be operated at approximately 5%
higher stress level. In other words, shot peening
more than compensated for the loss due to fatigue
damage. Even more dramatic is the difference
peening makes in fatigue-damaged blades, amount-
ing to about 10% increase in allowable operational
stress level.

Inconel 718C turbine blades with grinding indica-
tions on their shanks have considerably lower
fatigue resistance than the same blades without
such indications, as shown in curves W and X,
figure 3. However, if the former are shot peened
prior to going into service, their allowable stress
level, as represented by Y, is higher than that of
the unpeened blades without grinding indications.

In grinding hardened steel, the high surface tensile
stresses induced by this operation may approach
the ultimate strength of the material. The condi-
tion is often disregarded by manufacturers as long
as grinding cracks do not appear in the finished
product. However, the excessive surface stress
sharply reduces fatigue life. Controlled shot peen-
ing is an effective means of correcting the situation,
as the curves in figure 4 show.

Shot peened surfaces help resist fatigue failure to a
considerably greater degree than will unpeened,
smooth, polished surfaces. Though the appearance
of the shot peened surface is far from displeasing
(it is actually desirable, in many cases) a skinner
surface but with the desirable effects of shot peen-
ing is sometimes required. In those cases, shot peen-
ing is accomplished first, followed by lapping, hon-
ing or polishing up to a carefully predetermined
degree of material removal. The most critical areas
of connecting rods are the fillets next to the holes,
but the rods are usually shot peened all over in
except in the holes. The bar graph in figure 5 shows
that peened rods whose surfaces were subse-
quently scratched had 40% higher stress endurance
limit than unpeened, but unpeened samples.

Shafts and axles of all sizes are shot peened to
improve their fatigue life. One particular shaft,
in order to provide protection for the equipment it
brove, was designed with a groove which caused the
shaft to fail at a certain overload point. The
groove, however, caused premature fatigue failure.

Since shot peening was instituted, the part no
longer fails in fatigue, yet provides the proper
overload protection. Pioneered by the automotive
industry, shot peened coil springs have been in use
for long periods of time. Springs with wire dis-
ameters as large as three inches have been success-
fully peened. The Goodman diagram in figure 6
shows the additional stress permissible on the
peened springs.

Control is the hybird of shot peening to insure
uniformity over every portion of a surface confi-
guration, to insure quality uniformity in terms of
steel shot and glass beads. Also, shot peening is a
specialized, precision process for which conven-
tional peening and blasting equipment is largely
unsuitable. A test program is required to estab-
lish peening parameters and the cost of the opera-
tion for a given component. One company whose
only business is shot peening for others, both on
individual job and contract bases, is Metal Im-
provement Company of Traveneck, New Jersey, a
subsidiary of Curtis-Wright Corp. They are quali-
fied and equipped to undertake the necessary engi-
neering recommendations as well as to process
parts at their ten U.S. and two European locations.
Metal Improvement also has trained crews for
assignments in the field.

Since surface tensile stress is largely unpredictable,
and, for all practical purposes, immeasurable by
the design engineer, it is seldom taken into ac-
count. The classic approach to the problem of pre-
mature fatigue failure is an often costly redesign
involving changes in material, configuration and
dimensions. If the cause of the trouble is surface
tensile stress, as it is often found to be, then elimi-
nation of other physical factors as well as after
careful testing, controlled shot peening can save
the high cost of redesigning the part. Peening it-
self, costs comparatively little, frequently amount-
ing to less than 1% of the total cost of the item.

In this same regard, the added fatigue strength
derived from peening could well allow thinner sec-
tions, less costly materials, and a less costly design.
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