Laser Shock Peening

Bombarding metal parts with tiny metal or ceramic beads seems like a crazy way to improve those parts' performance, but shot peening is a proven method of improving the fatigue life of metal parts, especially those that are prone to surface fatigue failures. Now, there's an even more unusual tool—lasers—to perform the same function, only better.

Laser peening can extend the service life of some parts, including gears. The extension of service life can be anywhere from 3–10 times the extension given by normal shot peening, according to industry experts, because laser peening puts compressive stress much deeper into the part.

The concept of using lasers to introduce residual stresses into a part's surface of a part was invented at Battelle of Columbus, OH, in the late 1960s and early 1970s. But it really didn't become practical for production use until the late 1990s, as the technology improved and commercial companies began to develop it.

One of those companies, LSP Technologies Inc. of Dublin, OH, was founded in 1995 by former Battelle employees and has done work for the U.S. Air Force. Another company, Metal Improvement Co. Inc. of Paramus, NJ, has worked with Lawrence Livermore National Laboratory of Livermore, CA, to develop laser peening.

"We think that laser peening, based on recent advances, is a technology that is going to see widespread use," says Lawrence Livermore physicist Lloyd Hackel.

Metal Improvement Co. is developing laser-peened gears for engine transmissions. According to James Daly, senior vice president of the company, construction, mining, farming, marine and over-the-road tractor truck transmission components are being required to have their guaranteed service lives extended.

"One or a few problem gears can represent a lifetime limitation," Daly says. But laser peening those gears could extend the lifetime of the entire transmission and be a very cost-effective step in quality improvement.

LSP Technologies is also working extensively with gears, including ring and pinion sets and other automotive drivetrain gears, says president Jeff Dulaney.

Laser peening is more effective than shot peening, and it's beginning to be used on gears, including this automotive ring and pinion set processed by LSP Technologies Inc.

How it Works

When most people think of lasers, they think of them as a tool for cutting through metal, but that's not how laser peening works. In fact, light from the lasers never touches and never heats the part surface. Instead, the lasers are used to generate a shock wave that causes compression at the part surface.

The part to be laser peened is coated with an opaque, absorptive material—a special paint or tape that will vaporize when exposed to a pulse of laser energy. The part is also covered with a thin layer of translucent material, which is usually water. A pulsed laser beam passes through the water and strikes the paint or tape, causing a small thickness of the material to vaporize. The vapor absorbs the remaining laser light, creating plasma, which is trapped in a small gap between the absorption material and the water layer. The trapped plasma builds to a pressure of up to 100,000 atmospheres (about 1.5 million pounds per square inch) and creates a compressive shock wave, part of which runs into the metal surface.

A pulsed laser beam creates a shock wave that causes beneficial compressive stresses in the roots of these gear teeth. Photo courtesy of Metal Improvement Co. Inc.

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That part of the shock wave causes plastic deformation of the part surface, leaving compressive residual stresses that prevent cracks from growing and thus improve the part's fatigue life.

According to Dulaney, the LSP Technologies laser-peening process creates compressive stresses at depths ranging from 0.040" to 0.060". According to Daly, Metal Improvement Company's laser peening creates compressive stresses to depths of 0.040" to 0.080". In both cases, the compressive stresses are significantly deeper than through shot peening. This extra depth provides even greater protection against surface-related failures, such as fatigue cracks and corrosion cracking.

Laser peening can be used in conjunction with normal shot peening, Dulaney says. An entire part is typically shot-peened, and then the areas of high stress concentration, which are prone to fatigue cracking, are further treated with laser peening. Those areas include the roots of gears, says Hackel.

Applicability

Because laser peening is more expensive and takes longer than normal shot peening, it's been used mostly for expensive, highly critical parts. One of the biggest applications to date has been the laser peening of the leading edges of the blades of aircraft turbines. Normally, these parts are shot-peened to improve their performance. Laser peening increases the performance even further. According to Dulaney, that increased performance amounts to savings of millions of dollars per year for the U.S. Air Force.

Both the cost of laser peening and the amount of time it takes are decreasing, which should open the applicability of the process to many more parts, says Daly.

In addition to aerospace turbines and gears, the organizations involved in this technology have begun targeting products as diverse as oil drilling equipment; medical implants, such as hip joints; marine and rocket engine parts; automotive crankshafts and connecting rods; and tooling and dies.

Circle 300

A New Heat-Treating Process

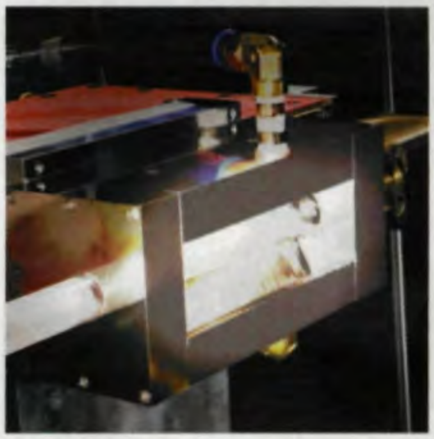
A new heat-treating process could harden internal gear teeth using a lamp that can radiate 3,500 Watts per square centimeter, with a brightness that rivals the sun's.

The lamp could harden internal gear teeth by being slid into and pulled out of a gear's opening.

The high-intensity plasma arc lamp consists of a cathode, an anode, a clear quartz tube, argon gas and deionized water. The lamp's power is generated by circulating the gas and water through the tube, from the cathode to the anode, around the electric arc between those two electrodes.

The water is pushed against the tube's inner walls while the gas is ionized along the centerline. The gas then emits large amounts of radiant energy, which pass through the water and quartz.

The process is being developed by Vortek Industries Ltd. of Vancouver, Canada, and Oak Ridge National Laboratory, located in Oak Ridge, TN.



Capable of radiating 3.5 kW/cm², Oak Ridge National Laboratory's plasma arc lamp glows brilliantly as it hardens steel without hardening the entire workpiece. The lamp's hardening ability could be used on internal gear teeth.

At Oak Ridge, Craig Blue is the technical lead in the Infrared Processing Center, in the laboratory's Metal & Ceramics Division. He holds a doctorate in materials science, with a specialty in radiant/infrared processing of materials.

"We can get full hardness in our material," Blue says. "We can harden steel at up to a meter per minute."

The lamp can run from 2% to 100% of its radiant output and can continuously vary that output, changing the power level in less than 20 milliseconds. Thus, the lamp can compensate for different thicknesses of metal and thereby provide a constant case hardness.

Such radiant heating has very high heat transfer efficiences because there's no intermediate material to absorb heat between the lamp and the workpiece.

Also, radiant heating can be precisely controlled and isn't affected by processing atmospheres.

Blue's processing facility has been operable since spring 1999 and consists of the high-intensity plasma arc lamp, an industrial robot and PC-based controls.

The lamp was invented about 29 years ago by Vortek Industries.

"Up until about the last three years, it had very limited use," Blue says of the lamp. "Because of its relatively short life." He explains that the life was measured in hours.

But, according to Blue, Vortek extended the lamp's life to hundreds of hours by further developing the lamp's anode and cathode.

The cost is $300,000 for the machinery, with a 300,000 Watt lamp. Blue says the cost is similar to induction heat treating.

Since it became operable, Blue has tested his process to determine possible applications, including heat treatment of flat-stock powder metal parts.

But, he hasn't used his process on gears, so he has no data about heat-treating them. But, he does have data about heat-treating steel, and gears are steel.

"Then you're just talking about geometry," Blue says.

Besides not developing his process for gears, he also hasn't talked to anyone about developing it for gears.

If a gear manufacturer came to him, though, Blue says he might develop his process for gears. Also, the laboratory has programs for working with commercial organizations to develop processes they need.

Blue estimates it would take a year to develop his process to heat-treat gears.

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