PRODUCT NEWS: TEC AND X-RAY DIFFRACTION

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X-Ray Diffraction Impacted by TEC's Contribution

History

Wilhelm Röntgen discovered x-rays in 1895. I wonder what he would think if he knew the number of people's lives he impacted. In 1912, Sir William Henry Bragg gave us the equation for x-ray diffraction. X-ray diffraction is the scattering of x-rays by crystal atoms, producing a diffraction pattern that yields information about the structure of the crystal, such as the distance between the planes of atoms.

Now we could do some really useful things with Röntgen's x-rays! As we travel through history, the next exciting discovery for me was residual stress measurement in 1925. My son, who often accompanies me when I give technical presentations for TEC, proclaimed that I should know all about this discovery since I was probably there when it happened. (My dad didn't come along until 1927, and my mom made the scene in 1930.) Over the course of 30 years, we were given the basics for changing the world—the world of residual stress measurement. It took about another 50 years to see the next big change in this field. In the 70s, position-sensitive detectors were developed that could identify an entire diffraction peak without having to step scan through the large angular range required by other detectors. Position-sensitive detectors gave rise to the small, portable systems we know and love today.

Technicians with Warren-Robbins and TEC are measuring the fuselage on a C-5 transport with a TEC 1630. The computer is recording and analyzing data for rapid and precise results.

X-Ray Diffraction Residual Stress Measurement

To understand residual stress measurements by x-ray diffraction, we need to understand residual stresses. If I push, pull, twist, or bend a part, I'm putting an applied load on the part. When I let go, if I've been successful in plastically deforming the part by pushing or pulling, there will be new residual stresses left in my part. Let's say you put a paperclip on a few pages of paper. The paperclip is basically in its original shape with no significant increase in residual stresses when you remove it from the papers. However, if I then need that paperclip to retrieve Play-dough from my computer keyboard, I can plastically deform it into a hook. The process of plastically deforming the paperclip has now changed its residual stresses. And when I imparted residual stresses into the paperclip, I changed it at an atomic level—I changed the distance between the paperclip's atoms.

X-rays are useful because they can tell us how much distance lies between atoms of the paperclip. Think of these atoms as lying in sheets stacked on top of each other, then imagine these sheets as being connected with springs and that you can change the distance between the sheets by pushing or pulling on the outer layers. X-rays don't care if you push or pull, they simply measure the distance between the sheets. I can tell how much residual stress is in my paperclip simply by measuring the distance between the sheets. If the sheets are pushed together, we have a compressive stress. If the sheets are pulled apart, we have a tensile stress. In the real world, tensile stresses are generally bad since they are pulling things apart. Compressive stresses are usually good because they tend to hold parts together. We can measure both types of stresses using x-ray diffraction.

TEC's Role in the Industry

Being at the right place at the right time has advantages. TEC was a leader in building position-sensitive detectors when Northwestern University was developing PARS (Portable Apparatus for Residual Stress). TEC obtained the manufacturing rights from Northwestern University to develop a commercial, portable x-ray diffraction system. Not only did we then develop a commercial system, but we eliminated the guitar strap used by the graduate students to hold the system in place while making measurements. Radiation safety officers around the world probably breathed a sigh of relief with this improvement. The software was developed so that even a Ph.D. could operate it.

After potential users were surveyed, TEC decided that a portable diffractometer with a long umbilical cord would best serve the military and commercial customers. The umbilical cord was attached to a transportable cart, affectionately known as the tank. Our tank was designed to withstand a nuclear blast or airport baggage handlers, whichever was deemed the most destructive. Actually, we wanted a rugged design that would survive the environment of a Naval Air Depot or industrial complex. We may have outdone ourselves since our first commercial unit, delivered in April 1984, is still working today at Redstone Arsenal.

We spent much of the 1980s refining our 1600 series in an applications lab. We teamed with several well-known leaders in residual stress and retained austenite measurements to develop systems that would take what the real world would throw at it. Industry and the military would send us samples to see what new and exciting heights could be reached with a portable system. Some of the samples required cherry pickers and scaffolding to reach these heights. We eventually plunged to great depths when we went underground to inspect a structure underneath a dam. While developing new applications, we were constantly asked if we offered measurement services to compliment our products. In 1989, our services lab was inaugurated with a marathon trip to measure the space shuttle's solid rocket booster casing. Our crew of four with our trusty 1610 system worked round the clock for a couple of weeks to measure the infamous tang and clevis areas of the casing.

In the mid-90s, TEC embarked upon a major design change to the 1600 series. The TEC 4000 was born out of this effort. The basis for the TEC 4000 was to do everything the 1600 could do plus additional applications. Nine different peak-fitting routines was just the start. The 4000 could operate equally well in two orientations, and much of the operation was automated. We have found that even the computer-challenged individual was able to successfully operate this new system.

As we entered the 21st century, TEC decided to make another giant leap and developed MAX (Miniature Apparatus for X-rays). MAX is so small it can fit inside a six-inch opening. It's almost as fast as a speeding bullet. We haven't tried to see if it can leap tall buildings with a single bound, but its residual stress measuring capability is just as amazing. The progression of the 1600 to the 4000 to MAX is similar to the progression of a mainframe computer to a desktop to an iPad.

Practical Applications

When x-ray diffraction residual stress measurements were first made on laboratory-type diffractometers, one had to cut a quarter-sized plug out of the part, take it to the lab, and then wait eight hours or so to get a result. Unfortunately, cutting the plug out of the part not only destroyed the part, but probably relieved most of the stresses that we needed to measure. When the centerless diffractometers with position-sensitive detectors were invented, parts could be measured without sectioning. Not only did we save the part, but we could measure stresses in a fraction of the time—minutes instead of hours. Field measurements were also possible, which opened up the door for a truly useful non-destructive evaluation tool. So, where have we gone with this unique capability?

The aerospace and automotive industries have a real need for these measurements. Both groups have engines with moving parts, lots of bearings, transmissions, and structural members. These parts have been machined, cast, welded, forged, rolled or ground along with other manufacturing processes. Some of the parts have been carburized, nitrided, coated, anodized, heat treated or otherwise enhanced. A good portion of the parts have been cold worked, burnished, or shot peened. Each of these processes changes the residual stress in the part.

When we fly or drive, we prefer that our planes and vehicles have those good compressive stresses in all the critical places to make sure we arrive at our destination safely. Not only are we able to measure the parts when they are manufactured, but in many cases, we can also measure the parts after they are assembled. After all, if there is a suspect part, who wants to dismantle the entire assembly just to see if an improperly processed part accidently made it onboard?

Many failures can be attributed to bad stresses at or near the surface of the part. Usually these stresses are tensile ("pulling apart") stresses. Fatigue, stress-corrosion cracking, and overload are examples of failures where tensile stresses are generally the culprit. Luckily, we can often do something to the part to change the tensile stresses into the more desirable compressive stresses.

A favorite method for *The Shot Peener* magazine's readers to change bad tensile stresses into good compressive stresses is shot peening. Shot peening is the process of blasting a part with small beads of metal or ceramic in a controlled manner to put a sample's outer layers into compression. Because the beads hit the surface much like a hail stone hits your car hood, the stresses are uniform in all directions around the indentation. In other words, a very, very small crater is formed and the distance from the bottom of the crater to the top rim is the same all the way around the crater.

Let's use the analogy from the top. When the shot hits the sample, the springs holding the sheets of atoms gets so tightly compressed that they can only spring back part way. Because the springs aren't the same height as before shot peening, the sample will show a compressive stress. Not only are the top layers of atoms affected, but many layers beneath the top are also in compression. Because the atoms in the very top sheet don't have a layer of atoms above them, they can relax a bit more than the layers that have atoms above and below. When we use x-rays to measure the stress at and near the surface of a shot peened part, we will find that the compressive stresses at the surface are not as compressive as the stresses just beneath the surface. It is often this profile of compressive stresses at the surface followed by more compression just beneath the surface that protects a part from failures.

Conclusion

X-ray diffraction has come a long way since Röntgen first discovered those powerful rays. Thanks to the development of x-ray diffraction followed by the development of the residual stress measurement technique, we have learned how to look at the stresses that can cause or prevent failures. TEC, with its roots in position-sensitive detectors, has developed a line of diffraction systems that has allowed Man (or Woman) to boldly go where no x-rays have gone before. TEC continues to search for the truth in x-ray diffraction residual stress measurements.

Come and share the journey with us. ●