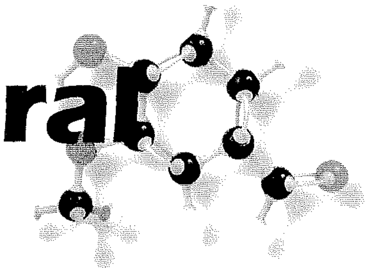
Annihilating Structural Uncertainties



Imagine the benefits to aviation maintenance, nuclear power plants, oil refineries—any industry that is dependent on structural integrity—if a detection process could detect fatigue, embrittlement, and defects at the atomic level; find damage before cracks appear; work on a variety of materials; and predict remaining life of expensive components. What would the value be to the shot peening industry if a process could measure shot peening intensity, quantify the subsurface compressive stress and monitor its long term effects on structural integrity?

A fundamental advancement in nondestructive testing that identifies strutural integrity, fatigue, and embrittlement problems at the atomic level.

Photon Induced Positron Annihilation (PIPA) is a new non-destructive, patented evaluation technology developed by scientists at the U.S. Department of Energy's Idaho National Engineering and Environmental Laboratory and licensed exclusively by Positron Systems. According to Scott Ritchie, Director of Operations at Positron, "PIPA provides the ability to measure compressive residual surface stresses/strains induced by shot peening at any Almen intensity in a range of materials, including single crystal alloys, and to quantify the relaxation of this surface residual stress due to thermal and mechanical effects." "This technology offers the potential to evaluate existing operational damage in components and assess suitability for continued operation, optimizing maintenance and parts replacement schedules and leading to significant cost savings", he added.

Positron Systems has been marketing PIPA for commercial use for the past two years as a nondestructive testing method superior to any other traditional technique. Because PIPA is unlike any other nondestructive test, Positron is committed to customer education. The company welcomed the opportunity to share with us some frequently asked questions and answers that will explain the new process.

Q. How does PIPA work?

A. The base process begins by using a linear accelerator to inject a material with a high-energy photon beam. With the rules of physics in play, these photons knock off neutrons from atoms creating positrons within and throughout the bulk material or component. These same positrons are trapped at atomic level lattice defects where the atomic charge is the least positive creating an attractive potential. The positrons then "annihilate" with low momentum electrons in the material. The gamma spectrometry response of the positron annihilation is measured, resulting in a highly quantitative and accurate atomic analysis. From the gamma spectrometry analysis, and Positron Systems analytical methods, quantifiable fatigue or embrittlement damage estimates are produced. Data can be obtained not only for the concentration of defects, but also the type and size of defects using the coincidence lifetime technique.

Q. What are you actually measuring by this method?

A. The gamma ray energy being produced by these annihilations is measured using gamma-ray detectors and associated electronics. The annihilation energy level in defects is distinct from the annihilation energy level in non defect areas. The gamma-ray energy is analyzed and quantified using both standard and Positrons' methods to determine the quantity of energy produced near the annihilation energy (511 KeV) and away from that energy (Doppler Broadening). In addition, coincidence techniques can be used to quantify the positron lifetime in the material using two detector systems.

Measurements can be performed to detect a variety of fatigue and embrittlement types. Fatigue detection is possible for, but not limited to, thermal, mechanical, wide-area, and corrosion assisted. Embrittlement detection is possible for, but not limited to, hydrogen, neutron, and thermally enhanced. The technology can accurately quantify the effects of surface treatments such as shot peening and the extent of surface and subsurface stress relaxation induced by operational damage or heat treatments.

Q. What are the main advantages of PIPA over conventional NDT methods?

A. PIPA can quantify fatigue or embrittlement life at any point during the operational period of a component including prior to crack initiation. PIPA can also estimate the percentage of remaining life and crack propagation direction. Further, PIPA works in a variety of materials and is not sensitive to complex part geometries. No other techniques have this ability. PIPA has the capacity to address maintenance, surveillance, and replacement planning issues that were previously left to chance.

Q. How is PIPA different from other NDT methods?

A. Unlike any other method, PIPA looks at the atomic structure of materials and provides a quantitative measure of fatigue or embrittlement damage. This type of analysis can be done at any point during the operational life of the component. PIPA is also the only method capable of estimating remaining life. All other techniques (e.g., x-ray, ultrasonic or eddy current) require a physical flaw to be present. If physical flaws are already present, the component may already be near its failure point. PIPA allows you to eliminate this uncertainty and plan ahead.

Q. How thick a material can be tested?

A. The analysis is performed at depths of up to 3.5 inches (for titanium). Depending on available access, measurements can be performed from both sides of the object, allowing for a combined measurement volume of 7 inches. If the outer or inner 3.5 inches have no significant fatigue or embrittlement damage, then the bulk component is not likely to fail in any near term scenario.

Q. What surface area is covered?

A. The surface area analyzed can be varied based upon the collimation of the detector system. The maximum area that can be analyzed in one shot is on the order of 4" x 4". Smaller areas can be assayed. It is anticipated that potentially high fatigue zones would already be identified. Several measurements would be performed to characterize these specific areas in comparison with no fatigue zones.

Q. How long does it take to run a test?
A. Testing and Analysis varies significantly, and can only be determined on a case-by-case basis. The timing depends on a number of variables, such as, material type, size, and what analysis method the customer wants us to perform. PIPA is a process capable of providing a wide range of valuable data, from a "go/no-go" test to actual fatigue estimates and a quantifiable remaining life analysis. Once the setup is complete, laboratory measurements can be performed in 15-20 minutes. For the optimized measurement system (i.e. on-site systems), already fine-tuned to achieve a higher flux, it is anticipated that quantitative data can be obtained within 4-6 minutes. Analysis time will vary depending upon the complexity of measurements and the resulting data. Continuous scanning capability is planned for the future.

Q. How accurate is the measurement?
A. The gamma spectrometry measurements are quantitative and reproducible to less than a 1% uncertainty.

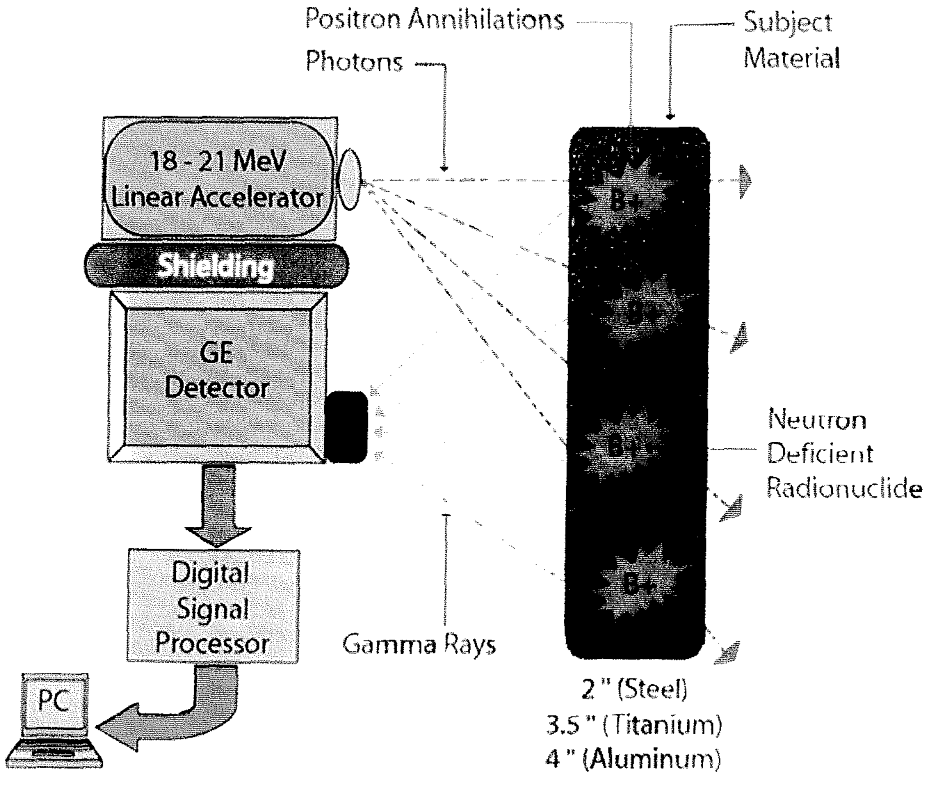
Q. How accurate is the life estimate?
A. The accuracy of the fatigue or embrittlement estimate is based on the type of analysis used. This is somewhat dependent on the material type, damage in the specimens, similarity of operational periods, and other factors. For a detailed analysis, the uncertainty can be reduced to < 5%. For a rapid estimate of damage, measurements are taken from damaged locations and undamaged locations on the same component, with uncertainties on the order of 15%.

Q. How is the fatigue life measurement calibrated?
A. There are several calibration methods. The first method is based on the analysis and comparison of non-damaged sections with known damaged sections from the same component. The second method is based on the use of standardized fatigue damage comparisons for differing material types being developed by Positron Systems. The third method involves using specimens from components with similar operational scenarios and known histories. The fourth method uses the standard ASTM fatigue specimens developed with similar stress-strain curves to the actual operational scenario. Methods 1-3 provide the most accurate and useful data.

Q. Does it require a physicist to operate?
A. Following the initial setup and training for a specific application, an operator could be a technician-grade individual. The analysis of the measurement output is expected to be automated using proprietary and off the shelf software.

Q. Where else has this method been used and what were the results?
A. Measurements using this technique have been performed on a number of material types and specimens with different fatigue levels, such as aluminum, stainless steel, iron, nickel-based superalloys, copper, composites, polymers, gallium arsenide, and titanium. Sample types include ASTM prepared stainless steel samples with differing compositions and fatigue histories, thermally fatigued aluminum specimens,

A Summary of PIPA



Photon Induced Positron Annihilation (PIPA) involves penetrating materials with a photon beam. This process creates positrons, which are attracted to nano-sized defects in the material. Eventually, the positrons collide with electrons in the material and are annihilated, releasing energy in the form of gamma rays. The gamma ray energy spectrum creates a distinct and readable signature of the size, quantity and type of defects present in the material.

Details of Process

PIPA works by generating positrons inside a bulk material or component being examined, followed by annihilation of those positrons with electrons in the material. The gamma spectrometry response of the positron annihilation is then measured and is highly quantitative and accurate.

Positron annihilations produce 511 KeV gamma rays; however, the total energy released includes the momentum energy of the electron with which the positron annihilates. Positron annihilations in defective material occur with low-momentum free electrons. Consequently, the gamma-ray energy produced is at or near the 511 KeV.

From these gamma spectrometry response data and Positron Systems' analytical methods, quantifiable fatigue or embrittlement damage estimates are produced. Data can be obtained not only on the concentration of defects, but also the type and size of defects by using the coincidence method.

titanium aircraft wing spars, turbine blades, turbine rotors, pump housings, high strength steel wire, aircraft structural components, power generation components, aircraft bearings, rail sections and rail wheel sections, mechanically fatigued nickel-based alloy specimens and golf clubs. The results indicate that even with blind specimens, Positron Systems can quantify the fatigue damage and provide an accurate estimate of fatigue life.

Q. Are there safety concerns?

A. As with any radiation examination technology, safety precautions are necessary. Because PIPA requires the use of a high-energy photon beam, there are relatively high radiation fields (5000 R/hr) directly in front of the positron generation system. The beam is shielded to limit lateral radiation exposure. In addition, an exclusion area and automated shutdown feature (i.e., laser fence shutdown) are used to prevent potential exposures in the area where measurements are being performed. It is expected that in a field measurement configuration a 4 meter radius exclusionary area will be required while the linear accelerator is on. The process is not expected to be disruptive in a maintenance depot or manufacturing environment. Other derivative technologies require smaller or no exclusionary area. There is no residual radiation or material damage.

Q. How portable is it?

A. Currently, measurements are performed using a laboratory based system. Mobile systems are being designed. The technologies will be available in configurations from cart mounted size down to equipment that can be hand carried. As an example, one version of the technology can be configured to use through borescope access ports. For the base PIPA technology the largest component measures approximately 2' x 2' x 6' and weighs up to 1000 pounds depending on the shielding required. In addition, Positron Systems offers small systems that are in some cases slower or in some cases less accurate, but can be used to develop high-low fatigue estimates for some material types.

Q. What is the cost?

A. Pricing depends upon specific applications and modifications necessary to meet the customer's needs. Products and services include: a Lab Based Test and Analysis Center, which provides testing and analysis for customers primarily concerned with research and development; mobile systems, which can be transported to remote locations and access hard to reach areas on fixed structures; and on-site systems, which are specifically designed to meet the needs of customers who have a high demand for testing at fixed research and development, manufacturing, or maintenance facilities. Training and ongoing support and maintenance packages are available.

n the winter issue of The Shot Peener, we will publish a case study from Positron titled "Subsurface Residual Stress Nondestructively Quantified for Alloys: PIPA measures shot peening effects at the atomic level".

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