IMPULSE ANALYSIS OF ULTRASONIC INDICIA

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What I would like to talk about today is essentially a portion of a program that has been sponsored by the AFOSR. The primary objectives of the program are to try and analyze defects associated with fastener holes. These include straight-shank fastener holes, tapered shank fastener holes, and cold-worked holes. The total scope of the program is to try and understand the factors that affect the detection capabilities associated with the fastener hole, both with the fastener in place and with the fastener out (including metallurgical, geometric, and local stresses), and to see if there is some way of characterizing the size, the shape and the orientation of the hole in the hope of differentiating between what might be considered a benign defect versus a critical defect. A benign defect, for example, could be some scratches on the inside of the hole that might not be expected to grow. I say, "would not be expected to grow," because you don't know if they are or not.

The two things that we decided to concentrate on were ultrasonics and eddy current. What I am going to talk about primarily is the ultrasonic work that we have done.

We took a very simplistic approach in the sense that we did not want to develop a very complex instrumental configuration because the idea was essentially to solve an Air Force problem, namely, to provide a means for inspection in the field, i.e., ease of setup was required. The problem of a crack associated with a fastener hole or with a fastener system is that the fastener holes, even though they may be the same size and they may have the same amount of cold work initially, will have widely differing ultrasonic interactions and widely differing stress states from place to place, depending upon the particular amount of stress and the particular degree of tightening up of the hole or the amount of the sealant.

So, one thing was to try and get some self-standardizing system rather than to develop a technique where you standardized against some reference off in the laboratory. We wanted it reliable, which everyone does. We wanted it sensitive enough, which everyone does, and we wanted a piece of information that was easily interpretable. Those are the problems. They are rather close to being insurmountable, but they are not. They are at least approachable.

Several solutions that have been proposed among quite a number of people include such things as multiple heads, unique types of scans, modes conversion (such as delta-scan techniques), frequency analysis techniques, and the last one is (to use this word that we are coining) indiciam analysis.

As I say, what we tried to do was to make it as simple as possible, and what we have is nothing more than something that is pretty close to being used right now by the user's command, which consists of a shear wave ultrasonic unit which sends a scan that interacts in some way, including mode conversion and everything else like this with the interface that is associated with the fastener hole. You can either get a single bounce off the bottom surface and then another reflection, or if you get close, you can get the single reflection off of the interface, if you can get a reflection off the interface. What we do is we scan across the part with the transducer emitting a shear wave. When the transducer sends a shear wave to the centerline of the hole, there is no signal. There is no reflected signal associated with a particular distance, some function of the acoustic distance in the particular vicinity of this hole. In other words, there is no signal in certain regions, nothing is returned.

On the other hand, as you scan across you start to get some reflections associated with a particular crack interface, so within a particular volume we get some kind of a signal from the hole or from the hole plus the defect, or just some kind of signal that comes back from everything.

The signal includes all of the parameters that have been discussed here because of the fact that all we are doing is we are using the same transmitter and the same receiver, so that the pulse and the lobes and the mode conversion and everything else are all tossed into the pot. We don't know what is coming out of it. All we do know is that we are getting some kind of a signal back.

Now, the idea is very simply to take this signal out, rectify it, and plot it as a function of the position of the transducer. This technique was initially developed by the Soviets and it is called an indicatrix or an indicia. The plot of this gated, reflected signal as a function of the position of the transducer is a measure of the totality of all of the reflections associated with this particular type of defect as the ultrasonic probe goes across. So that, essentially, is the concept of an indiciam. We would like to go on from here. We would like to automate the system through the computer. Unfortunately, this costs a beaucoup amount of money, and while large laboratories can afford this, we have to rely on brute force. So, instead of running it through a five-thousand-dollar computer, we run it through three undergraduate students. We automatically digitize it by hand through a hot wire digitizer system and send it through and do our impulse analysis.

In looking at the results of the measurements, we find that we get a normal curve that is associated with the hole itself. Crack information shows up as a perturbation upon this normal function. Even though the crack is not truly reflecting at the interface, it perturbs the totality of the reflected signal in some way. Which way, I don't know, but it affects the indiciam by giving some kind of a perturbation in the indicia. The difficulty comes in the sense that when you start applying it to a real type signal, you don't know whether or not some of the perturbation is associated with the natural defect, the actual interference of the interface or worse. We are trying techniques, for example, some Chebyshev smoothing techniques, which appear to be able to resolve these questions. The problem is that the smoothing functions are not constant across the interface because of the fact that the interference fastener may be in good contact at one place and not at another.

The difficulty comes in when the cracks are very, very small. In this case, the magnitude of the perturbation becomes very small with respect to the total signal, and you have to use some kind of a signal analysis technique. What we chose to use was essentially what we call an impulse analysis technique. Now, this is developed primarily from chemical engineers or from systems analysis people. I will give you the analogous problem. If I have a production line, for example, that consists of a fluid flowing down a long pipe and I want to change one of the parameters and I want to know the properties of the system down at the other end, the mixing properties, what I do is I apply a Laplace transform and do a Laplace transform analysis and get what is called the transfer function and the characteristic frequency of the mixing. Analogously, I can take an input function as a direct pulse. Then, you make the transfer function the absolute magnitudes of the two interfaces and you plot the absolute magnitude of the transfer function versus the dummy frequency, and this produces what is called the Bode plot.

Now, we could have used a whole series of input functions, but this impulse (which is the direct function) has the simplistic property that the Laplace transform is unity. Thus, we can work with it very easily, and we end up with a series of Bode diagrams. The characteric of some of these pulses is some kind of a decay function at some particular characteristic frequency. Thus, if the output function is just a smooth curve, the source function is the hole itself. If, on the other hand, there are some little bumps associated with it, i.e., some perturbations, the Bode plot shows some deviations which can be associated with the presence of some kind of defects around with the hole.

At the present time, we can pretty regularly detect cracks within a hemisphere of a straight-shank fastener, independent of the position of the focused transducer. In other words, you can be defocused by as much as half the diameter of the hole and still produce a perturbation and, therefore, still end up with the second order term within the Bode plot. These results indicate that pretty reliably we can come up with some indication of crack growth out of the fastener holes.

DISCUSSION

DR. BRUCE THOMPSON (Science Center, Rockwell International): Why do you take the Laplace transform rather than, say, the Fourier transform? That is not immediately apparent to me.

PROF. PACKMAN: That is not to me either, but I have got a good computer mathematician that says to do it by the Laplace transform. To treat it as an impulse rather than as a fast Fourier transform seems to give you a more sensitive indication.

DR. DAVID LEE (Air Force Aerospace Research Lab., Wright-Patterson AFB): Let me speak to that point. The idea of making some integral transform or another of a pattern from which you would like to extract certain features is, of course, the standard problem in pattern recognition. As you suggest, there are types of transform representations with expensive operating systems and representations of loss functions, even zero and one. I think it would be most interesting to see how different features set that pattern recognition types.

PROF. PACKMAN: We are trying to go further. We are going to try the Fourier transform of this and some other, say, the Henkle transform. We started off with the Laplace, and it seems to be coming out very nicely, and I am not going to blow a good thing. It is as simple as that.

DR. JOHN R. BARTON (Southwest Research Institute): Are the flaws that you have been using fatigue cracks or notches or what?

PROF. PACKMAN: They are fatigue cracks.

DR. BARTON: Have you had any way to assess how much crack opening you have?

PROF. PACKMAN: That's a ball of wax. We grow these cracks at an R value of close to unity. The maximum-minimum of a fatigue stress are very close to each other, so we get the crack as tight as we could imagine that it would be. This is difficult, because it takes a long time to grow the crack. Then what happens is we grow the crack and a part-through crack, a thumbnail shaped crack in a certain size, and we locate the position for the hole, and then drill the hole through and ream it out to a final size. The problem is that while we might make tentative guesses as to what the crack tightness might be in the part-through crack, you have no idea what it might be after you drill the hole and ream it.

DR. DENNIS CORBLY (Air Force Materials Laboratory, Wright-Patterson AFB): One very quick question or comment. On the basis of our crack-under-fastener work which Paul alluded to, we have found that service-induced fatigue cracks grown at low load levels seem to be relatively open and virtually unaffected by applied stress states as compared to lab cracks grown at the higher stress level.

PROF. PACKMAN: Right.

DR. CORBLY: You get a worst case analysis from the lab.

DR. OTTO GERICKE (U.S. Army Materials & Mechanics Research Center): I wonder if you have considered producing an electrical signal? This may depend on your scanning speeds.

PROF. PACKMAN: That's the way we would like to go.

DR. GERICKE: In which case I would assume that just differentiating your signal or passing it through a high-pass filter, which is the same thing, would enhance your crack indications.

PROF. PACKMAN: Right. The trouble, very honestly, is that the fixed asset dollar value to do that is large. It is much easier to use graduate students or undergraduate students to do that.