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INDUSTRIAL APPLICATIONS OF RUS

FRANK WILLIS
DYNAMIC RESONANCE SYSTEMS, INC.

ABSTRACT

Although most attendants of this meeting are concerned with the attribute of RUS that apply to the determination of elastic properties, it should not be forgotten that the major industrial use is part sorting based on mechanical property differences. RUS is rapidly being accepted as an industrial tool for nondestructive testing. Many industrial installations are now in existence, which help define the space for the best applications. The primary uses of the DRS Q9000 is for quick and accurate pass /fail testing. The Q9000 is an effective system to detect defects in ferrous and nonferrous metals, ceramics, and sintered metals. The DRS Q9000 can accurately and economically test parts for cracks, dimensional variations, proper heat treatment and plating thickness. Often a single measurement cycle or scan across a specified frequency range provides sufficient data for multiple tests The Q9000 serves as a stand-alone audit center, providing fast analysis for audit and pre-production verification. By integrating the DRS Q9000 to an assembly or machining center, the Q9000 system can provide 100% in-line testing. Specific examples will be discussed, especially where no other NDT methods were previously successful.

TRANSCRIPT

DR. WILLIS: I am Frank Willis from Dynamic Resonance Systems.

[Transparency 1]

I will start with a little background on the company. It was founded almost two-and-a-half years ago and I have been there for a little over two years myself. We are manufacturing two RUS systems. It is basically identical electronics with small differences in the software. I know a lot of the people here have one of the systems that we call the Modulus 1 for basic research.

We also have another system that we call the Q9000, which we market toward industry. The purpose of that system is as a quality-control aid during manufacturing to separate good parts from parts that contain some sort of defect.

I am going to tell you a little bit about some of the types of defects we look for and some of the existing methods -- quality control has been a topic for several years -- and, finally, how we are using RUS to solve some of these problems.

[Transparency 2]

The primary defects that people are trying to look for include things like cracks in a part that has been manufactured. That may be a chip when a part is pulled out of a mould or from just rough handling. Sometimes dimensional variations are considered a defect; if you want parts to fit together properly they have to be the right size.

We have an application in process right at the moment for the actual composition of the material that can be incorrect. There is an application we are working on now for companies manufacturing brake rotors. From time to time, they get the wrong alloy of steel in. It is not really something that is going to lead to a failure of the brake but it is more of an annoyance. If they get the wrong alloy to make the rotor out of, the brakes may squeal or chatter, which is something the end consumer does not like, anyway.

One of the things we have been asked to look at several times now and really have had a tremendous amount of difficulty with is a defect called microcracking, which is a very fine, almost microscopic, networks of cracks in a material.

One of the last things we do is look at the hardness of alloys, for example, to see if the heat treatment has been performed correctly.

[Transparency 3]

These are some of the existing systems that we run into from time to time. The list is not exhaustive by any means but it seems to be the ones that we bid against quite often.

One of the most common ones seems to be eddy current that, as its name suggests, uses eddy currents induced in a metal to look for cracks, primarily. The limitation there is that it obviously works on only materials that conduct electricity.

One of the other things we run into quite often is dipenetrant, where you simply soak a part in a vat of dye (usually a dye that fluoresces under an ultraviolet light), soak the part and, if there are any cracks, the dye will seep into the crack and you wipe it off or rinse it off and then look at it under an ultraviolet light. It is a very simple idea and it works quite well in a lot of cases.

It does have the one problem that eventually you have to get rid of the dye. If you are rinsing the parts off with water you have a weak concentration of dye in the water. If you are wiping it off with a towel, you have to get rid of the towel or wash the towel. While the dyes are usually fairly nontoxic these days, they still have to be disposed of.

Another technique we run into is called mag particle, which I think is really quite similar to dye penetrant, but it uses the magnetic field to concentrate particles in cracks, and then there is a visual inspection, usually under an ultraviolet light, again, to look for these particles left behind in the crack.

Of course, there are things like x-ray that can be used to look for cracks.

Two of the problems with a lot of these techniques is that they are slow. It may take a minute or so, or even longer, to inspect each individual part. If you are sitting there having a person looking at it, it takes a while.

A related issue to that is it works only as good as the person you have looking at the parts. I imagine the quality can vary a lot from, say, 10 o'clock on a Wednesday morning to 4:30 on a Friday afternoon.

[Transparency 4]

I think resonant ultrasound was first used about five years ago to look at parts by another company and it solved some of the problems of the other methods; it is not perfect by any means itself, but it works in a lot of cases that the others do not.

It works on a lot of different types of materials. We have looked at ceramics, metals, glasses, for example. Really, anything that has a nice acoustic response is a candidate for this technique. Occasionally we get plastic parts that just do not ring at all.

There is really nothing to dispose of. There are no dyes, there are no x-rays floating around that you have to worry about being certified to track. We have even gone to the point of having the system tested for RF exposure and certified that the RF leakage out of the system is within allowed limits.

One of the problems with systems that rely on a visual inspection somewhere along the line is you are going to be able to see defects only on the surface of the parts. The surface may look perfectly fine and you have a gigantic crack right under it that you just do not see, but RUS is sensitive to those types of defects as well.

Finally, it can be completely automated. There are instances where people do what we call a manual pick and place, where a person simply picks up a part and places it on a transducer assembly, hits a button, records the result, and then repeats that process. It can also be fully automated so that a person does not even need to sit around and watch it.

[Transparency 5]

When we are looking at a part with RUS for nondestructive testing, we have to start with some sample of the manufactured parts. At this point we have to have a set of parts that are free from defects or at least defined to be good and a set of parts that contain the defect.

We have been working on some ways to just look at the good parts without having the bad ones and we have made a little bit of progress in that, but it is not entirely usable yet. We look at the resonance spectra between the good parts and the bad parts and try to find something in the spectra that is common to the good parts but different amongst the bad parts, and then we sort the parts based on that pattern.

It is very important to know that even what we call good parts may very well contain defects. Quite often a crack may be acceptable as long as it is below a certain size, where a chip may be acceptable if its size does not exceed some critical value.

[Transparencies 6-7]

When we are looking at these patterns, right at the moment we have 6 tests that we can apply to the patterns. The first one, and it is relatively common to use it, is just a simple position test. The good parts may have one resonance between 100 and 105 kHz and the bad parts do not have a resonance in that region.

I really do not like using just one of these tests. It is not inconceivable to think of a bad part being defective in a certain method, but it just happens to have a peak in that one region where you are not expecting it. When I do use this test, I usually use a combination of two or three of them to try to avoid that little statistical possibility, which happened to me at a customer site one day.

There was a sheet about half the size of an 8 x 11 piece of paper, a ceramic, and they brought one out and there was about a quarter of it missing. I warned them that it was a pretty simple test and, sure enough, it had a peak right in this window where we did not want one.

Another very useful test in these patterns is what we call a doublet test, which is where you have 2 peaks very close together and if you think about the symmetry of parts, for example, if you have something with a square cross- section, you are going to have 2 resonances at the same frequency, but then you never make anything that is an exact square, so 2 resonances will split apart by some small amount and you can use that difference to look for other defects that may break the symmetry.

[Transparency 8]

Just to wrap up the final tests that we use, this first one I have listed here, the linked test, is a way of looking for 2 resonances that we just notice have a mathematical relationship between them. We usually look for a linear relation between 2 peaks. I have never really had any need to use any relationship more complicated than that.

It is useful, because we can often use that to correct for small variations in density or small variations in dimensions. We measure one peak and then, based on its position, we can predict where another peak should appear.

The last 3 tests that we have built into the software really are not used very much, oddly enough. Q is a test on the width of a peak of a specific resonance. It is useful sometimes, in particular when you have a relatively large crack in the part. If you have a large crack, you get a large change in Q, and we can use that.

One of the 2 other tests, that I cannot say we have ever really used, is amplitude. I think most people here can imagine the difficulties in trying to measure the amplitude of a particular resonance. It is very dependent on the exact placement of the transducers on the parts.

Our system does measure both components of the response and, in principle, we could use the phase of the resonance to look for defects, but we have never been successful in doing that, either.

[Transparency 9]

I am going to move on to a couple of actual applications now. This first one was a ceramic gas seal, kind of like a ceramic o-ring. It was about a 14-mm-diameter-o-ring, a little over half an inch. One of the things I eventually found out about this part was the tolerances on some of the dimensions were plus or minus 6/1000 of an inch. In industry you often get a curious mixture of metric and English units. They give you diameter in millimeters and tolerance in thousandths of an inch. (Laughter)

Anyway, this was an interesting part, in that I was actually able to see a correlation between the size of the chip missing out of the part and the separation of a doublet. The bigger the chip was, the farther apart these 2 peaks spread. It is something we do not really look for often, but I just happened to notice it in this.

The reason I noted the dimensions on here, if you took the diameters in thickness of this part and varied the dimensions by 12,000th of an inch, which was the allowable extreme, it worked out to change in volume of about 9 cubic mm, which really surprised me, that it was that large.

The problem with this part was we could find the big chips but we could not find these little tiny chips that they wanted to find. I started to think about it and eventually realized that a change in volume of 9 cubic mm would be about the same as a 2-mm-diameter chip; that is, if you took the chip as a half sphere.

I calculated that just because of variations from part to part maybe about 2 mm would be the smallest we could find, but then in actually looking at the parts I was able to detect chips down to 1 mm in diameter. One of the obvious ways to reconcile the differences there is a change in diameter is probably a symmetric change, while a chip is probably not symmetric.

[Transparency 10]

Here is a picture of the actual part sitting between some transducers. It has flat faces on this side that form an airtight seal.

[Transparency 11]

These are the sorts of data that I ended up using to set up the test. This is a snapshot of the software that we use. The software is set up to stack the resonances on top of each other, so the top 3 resonances are from these rings that were defined to be good, and the bottom 3 resonances are from these rings that obviously had a chip in them.

As you can see, in the 3 good parts we have a very narrow doublet. In one case the doublet is so narrow you do not even see it (you see just a single peak, which happens from time to time). In the bottom 3 scans for the bad parts you can see the doublet actually became separated by some noticeable amount. We were able to look at the separation of that doublet and make a decision as to whether this part was acceptable or not.

DR. ISAAK: Can you quantify by looking at that separation of the bottom spectra how much it was off?

DR. WILLIS: It was not an exact number by any means, but I did notice that -- it is difficult to measure the size of a chip, there are different depths and they are never circular, they are elongated sometimes. It appeared to me that the more volume that was missing out of the part, the wider the separation was. I do not have a number for how many millimeters or how many hertz, but it certainly appeared to be that way.

One of the unfortunate things is that we get these parts in and we get data like this and, in this particular case, the company wanted the parts back. They were building an automated system and they wanted to check it to see if it was working properly. In a lot of cases I have a small amount of data archived and I do not have the luxury of going back to reproduce more of them, but I wanted to try to do that a little more quantitatively, because it is one of the few times I have really seen that.

[Transparency 12]

One of the other applications we have under way right at the moment is machined steel bearing race. The problem here is what the company that manufactures them calls grinding burns. The bearing race is a piece of steel that is ground with a grinding wheel. The people who typically do this sort of work, who run the machines, often get paid by the piece, so they try to cut corners and make a few more per hour to get their paycheck up a little bit by the end of the week, and they get the grinding wheel running too fast and it heats the steel and creates a grinding burn.

It is probably, if anything, a hardness variation over a small area on the part, and it is something that is very difficult to detect by any other method. Visually it looks just the same as the rest of the material, you do not even see it, or at least only with great difficulty.

Things like dipenetrant do not seep into it, so you cannot do that, but since it is a hardness variation, which is basically a change in the elastic constants, RUS is a natural candidate to look for these sorts of defects.

In this particular case -- I mentioned earlier that I do not like using one test, often, I just think there is a statistical chance that a bad part will happen to look like a good part in that case -- I actually used 2 resonances that did not seem to be correlated between themselves and I was able to get a much better sort than using either of the resonances individually.

[Transparency 13]

Here is a picture of this part, a steel race sitting on some transducers.

[Transparency 14]

Here are a few of the data that we took on that. Again, the top 3 scans were from supposedly good bearing races that had a resonance at a slightly lower frequency than the ones we were told had grinding burns in them.

Resonant ultrasound for testing parts is relatively new; it has been around for a few years. I did not want to give you the idea that it is an absolutely perfect system yet; we have a lot of problems that we are working through. One of the big ones is simply pattern recognition.

[Transparency 15]

We get the spectra and there is a tremendous amount of data to look through to look for these differences in the patterns. It would be really nice to have an automated software package to look for these patterns and generate the tests, and we are working on something like that, and I have got at least the prototype of a package like that.

One of the problems in writing a pattern-recognition package is the peaks do not line up even amongst the good parts, for example. If you had 2 perfectly good parts, the peaks would line up, hopefully perfectly, but since there are differences in dimensions and composition you get basically the same pattern, but they will shift, so it may look like these 2 peaks are the same peak, when, really, it is these 2, and that is the first problem you have to overcome.

Again, we have differences in dimensions, which may mean that sometimes you see more peaks than you do in other parts. Parts are often big, which means the resonances are very low frequency. To me, a high frequency may be 100 kHz, which probably sounds low to a lot of you, but we are looking to get down into probably the hundredths-of-hertz region. It is difficult enough finding one test, much less trying to find multiple tests.

[Transparency 16]

There is one type of material in particular that seems to give us more trouble than others, and this is a process called a powdered metal part, where you take a metallic powder and mix it with a resin in a mould to make the part and then bake the part in an oven to cure it. For some reason we have a lot of problems with those.

The patterns, even amongst the good parts, just do not line up. Of course, the good parts have to be more consistent than the defects you are looking for. I do not know if it is a composition problem or a dimensional problem; we just really have not figured that out yet.

For all the parts we look at, one of the problems we often run into is that a customer will send us a box of parts and say these are all good, and you take maybe 10 or 20 good parts and you start looking at the patterns and you will find one of those parts just does not look right, so we go back and start looking at it under the microscope, or we have dye penetrant ourselves that we can look at it with.

Probably, I would say, in one out of three cases, perhaps, we are actually sent parts that have a defect that just got through the process before, so sometimes we do not even get a perfectly good set of good parts to look at.

[Transparency 17]

Some of the things that we are working on right at the moment: We have 2 systems, the Modulus and the Q9000. I am working on systems right now to go to lower frequency. I have a need to go down to at least 500 Hz, and I would like to get down to about 100 Hz some time soon.

We are looking at doing what I call a broad spectrum RUS and, rather than driving a part at one frequency and measuring the response, we will drive it at a lot of frequencies and measure the overall signal onto an FFT to get the spectrum and, of course, pattern-recognition software is in the process of being developed.

[Transparency 18]

Just to finish up here, I think in the future we are going to see tolerances on parts are going to become tighter and tighter, the materials are going to become more consistent -- hopefully, that is the problem with powdered metals (I do not know) -- and even the machines that we use to manufacture parts will be improved.

I think all of these things will make the parts themselves more consistent amongst the good parts, more accurate, and that is going to make RUS easier to use to sort these parts.

Thank you.

DR. MCCALL: For all of the ways that you test parts there must be a rate of bad decision? No matter what you do, there is a certain number of bad parts that get through? When you set up a system for industry, is your rate of bad decisions about the same or better --

DR. WILLIS: About the same as what?

DR. MCCALL: Dipenetrant or whatever other system you might use.

DR. WILLIS: Whenever you ask a manufacturer about these rates that you are talking about, you ask how many of the good parts must I pass and how many of the bad parts must I catch, every one of them will tell you that you have to pass 100% of the good parts and you have to fail 100% of the bad parts, and I tell them to go away and come back and talk to me when they have realistic numbers.

With this bearing race, I think looking at 30 or 40 parts statistically, the distribution of the frequencies and the standard distributions, I think I predicted we would pass about 99.5% of the good ones and we would fail something over 99% of the bad ones.

The related question to that is if you fail 99% of the bad ones, really, how many bad ones per thousand parts get through, then? In this particular case I think it came down to either 8 or 17 bad parts out of every 10,000 parts manufactured would get through.

Thank you.