APPLICATION OF A FLIGHT-LINE DISK CRACK DETECTOR TO A SMALL ENGINE

John P. Barranger
NASA Lewis Research Center, Cleveland, Ohio

A disk crack detector has been developed which is intended to operate while in flight or at the flight line (ref.) The detector is being applied to a small military engine for use as a flight-line turbine crack monitor. The system consists of an eddy current type sensor and its cables within the engine, external connecting cables, and a remotely located electrical capacitance-conductance bridge and signal analyzer. As the turbine spins, the rotor is monitored by the sensor for radial surface cracks emanating from the interblade region of the rotor.

The sensor is a coil of insulated wire wound on a ceramic bobbin mounted in the nozzle. It is located approximately 2 1/2 millimeters (3/32 inch) away from the face of the downstream side of the first stage turbine wheel where experience has shown cracks are likely to occur. The coil has 100 turns of silver palladium ceramic coated wire with a coil inside diameter of 3.18 millimeters (0.125 inch), an outside diameter of 12.7 millimeters (0.50 inch), and a length of 1.59 millimeters (0.062 inch). The coil leads pass through cored nozzle vanes and are brazed to the sensor cables. The coil and coil leads are cooled by air through the core passage in the vanes.

A commercial bridge is used in the monitoring system and is designed to measure capacitance and conductance. By adding designed to measure capacitance and conductance. By adding capacitance in series with the sensor coil, the combined reactance is made capacitive. The bridge cable length is limited to 3 3/4 meters (12 feet) because of the decreased bridge sensitivity resulting from the combination of high carrier frequency (1 MHz) and excessive cable capacitance. The capacitance-conductance bridge is self-balancing, automatically adjusting to changes in average coil inductance and resistance caused by temperature effects and variations in disk-to-sensor spacing.

A test cell at Lewis is being prepared to evaluate the monitor system under full scale engine conditions. Disks that have been removed from service because of time expiration will be installed in the test engine. Bench tests indicate that the system is able to detect a crack 3 millimeters (1/8 inch) long in these disks. This length is considerably shorter than the critical crack length.

Reference: Barranger, John P.: Flight Monitor for Jet Engine Disk Cracks and the Use of Critical Length Criterion of Fracture Mechanics, NASA TN D-7483, November 1973

DISCUSSION

H. Garten, GE-Lynn

How big a crack do you think you can detect? Also must it be on the surface?

J. Barranger, NASA-Lewis

The crack must be a minimum of 1/8-inch long for this system. The crack must be on the surface because this is a high frequency eddy current type detector.

I have a comment stemming from a number of inquiries. Everyone's trying to find that elusive crack that's always under the bolt head. This system cannot detect the disk crack until it propagates out beyond the boundaries of the bolt edge.

B.L. Koff, GE-Cincinnati

Is your plan to keep working until you can detect the crack that is under the bolt hole? What's your plan?

J. Barranger, NASA-Lewis

The present plan is to finish this program and turn the results over to the military. We do not plan to go any further beyond this program.

B.L. Koff, GE-Cincinnati

Do you plan to run this detector full time in the engine? Also, what kind of aerodynamics losses do you have with the step that you put in the flow path?

J. Barranger, NASA-Lewis

I'll answer the second question first. If we talk only about cross-sectional area, it's very small. For the total passage area, that step produced only a small change in the area. Concerning other aerodynamic situations, we really have not looked at it very hard. The detector may be monitored full time or may be monitored periodically. With regard to the testing program since we're putting a disk with a crack in it, which is verboten in most test programs, a high level of control will be exercised with continuous monitoring.

Unknown Questioner

Why was this engine used for this crack detector study?

J. Barranger, NASA-Lewis

We are looking at this particular engine because of the average disk life aspects of it. The disks have been taken out of service because someone says, after so many hours this disk comes out, regardless, cracked or uncracked -- this is the standard procedure. We looked at the disks that were taken out and found that there are cracks in some of the disks at the "end of life".

These are not critical cracks: that is, they are at least four times smaller than critical and, according to the manufacturer, are in a low stress region. What will be done with it in the future is again a matter of decision for the people who are the users, that is, the military. If they want to extend the program to its ultimate, one of these detectors would be installed on the engines that they have in existence. The electronics equipment would be ground based: it would be plugged in the side of the aircraft at the end of a flight or every month or whenever the testing interval might be. Then the decision would be made either to take a disk out earlier than its "end of life" because a crack shows up, or as an alternative, to continue to run the disk after the "end of life" (which is more risky) until a crack did show up. However, whether the average life would be less or greater than what it is now is hard to say. But that part of the program is uncertain at this particular time.

G.J. Mangano, NAPTC

Was that detector developed specifically for that application, or was it a general program, and you're using this particular engine as a test vehicle?

J. Barranger, NASA-Lewis

It was primarily a study program. The particular engine being used just happens to fit the test program needs.

S. Weiss, NASA-Lewis

This has been a concept study which is being further investigated by the Army.

W. Springer, Allison-GMC

The top of the disk is exposed to the gas flow pattern and a severe thermal stress concentration exists. After rapid crack propagation, that crack may become benign. Its growth rate drop off tremendously once the crack tip gets below the high stress field.

For the future do you think that you will ever get this device working for smaller cracks than an eighth of an inch and have it farther away from the disk than ninety mils?

J. Barranger, NASA-Lewis

The signal that I showed was a raw data signal, so without any further processing, it was pretty clear the crack was there. I've not tried to increase the sensitivity. I found that the blade root provides an undesirable signal, and a crack very often looks like an extension of one of the blade signals. To distinguish one from the other might be very difficult. In answer to the first part of your question, I do not think that we can get a substantial improvement in the small crack sensitivity unless the sensor is positioned very close to the disk. For the second part, the farther away you get, the less sensitive it is. More sensitivity with distance implies making the coil larger. However, as it becomes larger, a smaller fraction of the sensor area is exposed to the crack region so it becomes less sensitive to the crack. Thus, it is a balance between those two situations. I do not think that we will do a whole lot better than this. But, I have not looked at the problem hard enough to determine what the answer to that question really is.

J. Doherty, P&W

Just a general comment. It would seem from an operational point of view, that you've chosen a very convenient problem: you know where the crack will be before you start looking. If you don't know where the crack is beforehand, you must have the engine full of sensors -- in every conceivable location. Many of us who have engines in the field know that when we have cracks in components, we must get those cracked parts out as fast as we can; we really don't have a lot of time to go around and find out where the next crack might be.

J. Barranger, NASA-Lewis

Yes, you're right. In this particular example, the cracks are chronic, which means that it is amenable to this sort of solution. If they're random, that's a much more difficult situation.

J. Morelli, TWA

I am going to summarize some comments tomorrow morning to put the meeting in perspective from an airline point of view. Quite honestly I would tend to agree with the gentleman who just spoke here this morning from Pratt & Whitney, that flying that kind of equipment is not the right way to go. But the thing that is important to us, I would like to point out tomorrow, is the ability of detecting cracks of any size installed in an engine. Because we quite honestly fall heir to problems that occur overnight and we're faced with a large fleet of engines and are faced with the problem of trying to segregate from those engines which are the ones we should worry about and which are all right. So I'm very happy to see that work is being done in this area, because I feel it's extremely important. But, perhaps, the flight application is not the one that we would choose as an airline, but instead something that could be done with the engine installed on the airplane (and again to help isolate, because we have had extremely good success in some applications), and I'd like to point that out as we talk tomorrow.

S. Weiss, NASA-Lewis

When we first got into the rotor burst protection problem, we set up a three-prong effort. The first thing that occurred to us was that you build a better wheel, but if you succeed, the designers concerned with increased performance will load it to its maximum and negate any safety benefits. Another concept was also pursued. That was to divert rotor fragments away from any vital parts of the airplane. Yet a third concept was to develop a system that would warn the operator that he has a wheel that is going to fail, before it actually does fail. This is the crack detector and it is not being developed as an NDE device for inspection. We had hoped to lay the groundwork for development of a sensor system that could be flight certified for installation on an engine.

Dr. Barringer suggested the idea of trying to modify eddy current devices for installation in flight engines which would detect a crack of some reasonable size. On the basis of fracture mechanics inspection, a critical crack length criterion might be established. Continuous monitoring of the growth of a detected crack, with such a device, would permit removal of the wheel before the crack length grew to a danger threshold.

B.L. Koff, GE-Cinc.

In industry, we need to have fundamentally sound ideas in order to obtain funding and I doubt that such a program could gain support. We learn by doing but the scheme must be (a) practical in the end result and (b) one that will be accepted.