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Evaluation of the Davey Crack Detection System

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Background

The failure of many engineering structures has been attributed to premature crack initiation and propagation. This has led to the development of a large number of crack detection systems. These can be broadly categorised as optical, mechanical and electrical. The Davey crack detection system considered herein falls into the mechanical category, and is one of many such systems that offers the potential to provide accurate, reliable detection of fatigue cracks.

On New Years Eve 1968, Vickers Viscount VH-RMQ crashed on descent into Port Hedland Western Australia. Catastrophic failure of the starboard wing due to fatigue cracking was identified as the cause of the crash. An 85% through crack in the lower spar boom was reported. First Officer Ken Davey (the inventor of the system) was on the aircraft the day before the crash.

Development of a monitoring system began 10 years later when the inventor noticed the rapid rate at which vacuum was lost in a cathode ray tube through a minuscule crack. Initial attempts to elongate sensor manifolds on the surface of a structure were slow and insensitive.

Sensitivity was achieved by isolating the manifold sensor cavity from the vacuum storage by means of a long length of fine bore tubing. This isolation meant that the manifold sensor cavity could be very small and hence very sensitive to change in pressure.

Measurement of the pressure drop across the long length of fine tubing, together with the provision of a constant vacuum source completed the fundamental concept and led to the development of the sensors to be evaluated by BAe.

- Ken Davey 06/10/98

Summary

Ken Davey of SMS Ltd. has developed a crack detection system based on the principle that a vacuum maintained within a small volume is extremely sensitive to leakage. Sensor pads are attached to the structure in question and evacuated, a differential pressure monitor compares vacuum conditions on either side of a calibrated flow impedance. When a crack initiates or propagates beneath a sensor pad, a leak path is formed, thus creating a change in differential pressure and an indication of a crack on the differential pressure monitor.

BAe Airbus undertook a short program of testing to evaluate the Davey crack detection system for possible use during materials or structural testing, or as an in-service detection technique.

Three test specimens were utilised during this investigation; each one designed to evaluate a different feature of the system. Pressure pad sensors and separate wire sensors were attached to opposite sides of each specimen to allow a comparison between traditional crack detection methods and the Davey system. The specimens were then tested under fatigue loading.

The pressure pad sensors consistently out-performed conventional wire sensors and appeared to give accurate, repeatable results. A further programme of work is proposed to learn more about this system and gain confidence in the system.

1 Introduction

Today's civil aircraft are designed to meet the airworthiness requirements of Fatigue and Damage Tolerance (JAR/FAR 25.571). This requires that the structure should be capable of sustaining the applied loads encountered in service even in the presence of possible damage arising from fatigue, corrosion or accidental damage. The detection of such structural damage through inspection programmes, and the repair and / or replacement of damage, as part of a structural maintenance programme, are an integral part of the continuing airworthiness of the structure. The SMS crack detection system offers the potential to provide accurate and reliable monitoring of structures identified as at risk from fatigue cracking.

Ken Davey of Structural Monitoring Systems Ltd. (SMS), Australia, has developed a novel technique to complement contemporary mechanical crack detection systems. The Davey system offers the ability to detect crack initiation over a wide area, in inaccessible locations, on a wide range of structural components. The system alleviates the requirement for expensive NDT equipment and possible human error or inconvenient structural disassemblies.

The system has a number of potential applications, from on-line monitoring of specific aircraft structures to material testing. It is possible that such a system may offer cost and time savings over existing mechanical crack detection techniques such as wire sensors or clip gauges.

Following communication with SMS it was decided that the Davey system had sufficient potential to warrant an evaluation program to assess its performance under controlled conditions. The aim of the work was to establish the feasibility in terms of process, equipment and application of the Davey system. In particular, the work was undèrtaken to establish the accuracy of this technique and any limitations that may prevent the use of this system in practice. The technique attracted considerable interest across BAe with the business units of Airbus, Military Aircraft and Aerostructures (MA&A) and BAe Australia.

1.1 Basic Principles

The basic principle behind the Davey system is that a steady state vacuum, maintained within a small volume is extremely sensitive to any change in pressure. The sensor pads may contain channels alternating between atmospheric and vacuum pressure. Cracks are detected as they form a 'bridge' between adjacent channels, leading to an air ingression into the evacuated section, which may be detected as a change in pressure.

The Davey system comprises four main elements:

(1) A vacuum source

(2) Self adhesive sensor pads, attached to the surface to be monitored

(3) A calibrated flow impedance in the connecting line between the vacuum source and sensor pads

(4) Differential pressure monitor

2 Test Programme

To enable a thorough assessment of the performance of the Davey system a number of tests have been carried out. To enable a direct correlation between the Davey system and existing crack monitoring techniques, wire sensors and pressure pad sensors were used simultaneously.

Various combinations of test specimen and sensors were used during the evaluation programme and for clarity the information relating to the tests is presented as a test matrix in Table 1.

Once machined, the specimens had the various crack detection systems attached. Wire sensors were mounted on one side and were connected to the test rig to allow the test to stop automatically upon detection of a crack. The sensors were wired in such a way that enabled individual sensors to be disabled once they had detected a crack.

Ken Davey (SMS) mounted the self adhesive pressure sensor pads to the opposite surface of the specimens and attached silicone tubing which, once sealed using silastic, was connected to the vacuum source and the Structural Integrity Monitors (SIMs), an operational SIM may be seen in figure 1. The SIMs contain a highly restrictive duct and a pressure transducer to provide differential pressure readings. A schematic of the system is shown in figure 2. Problems with interference causing variation in steady state readings off SIMs during initial systems checks led Ken to use a 'clean' power supply from batteries.

Pressure sensor pads may be manufactured in a variety of configurations, each one optimised for a particular situation. During this programme of work, two pad types were utilised. The first consisted of single channel pad connected to the vacuum source and SIM via a tube positioned under the end of the pad. Figure 3 shows four single channel pressure sensor pads in position prior to testing.

The second type of pressure pad sensor utilised had multiple channels alternating between vacuum and atmospheric pressure. The design of such a pad may be seen in a schematic diagram in figure 4. The system was set up so that the first channel (closest to the crack tip) in each pad was at vacuum pressure and therefore active. In the event that a crack was detected and indicated by the Structural Integrity Monitor, the connections were to be reversed so that the second channel in the pad was at vacuum pressure. This was then the active channel and if the crack reached this second channel the structural integrity monitor should again indicate the presence of a growing crack.

To ease data recording, the various sensors were numbered. The numbering system was consistent throughout the test program. Wire sensors were numbered as shown in figure 5. Note that sensor numbers are the same on both sides of the specimen i.e. wire sensor 1 is opposite pressure sensor pad 1. In the situation where multi-channel pressure sensor pads were utilised, pressure pad sensor 1 was mounted opposite wire sensors 1 and 2, with pressure pad sensor 2 opposite wire sensors 3 and 4.

The sensor position in table 2 relates to the distance from the edge of the machined notch to the edge of the 1st channel on the relevant pressure pad sensor.

The specimens were mounted in a Schenck 160 kN S56 rig, which was used throughout the testing, with loading applied as detailed in the test matrix shown previously.

Data from the tests was obtained by connecting a maximum of 2 SIMs to a chart recorder. Data from the other SIM was, where necessary, captured either manually or on video. The testing was monitored with video equipment (videotape reference B24/SF/2039 & B24/SF/2040).

3 Experiment

The results from the three tests are presented in a matrix for clarity [see table 2]. Specific points relating to each test may be found later in the report.

Note that the crack lengths in table 2 are based on the findings made in the event of a crack indication by either the wire break or Davey system pad. In each case, the test was stopped and a constant load equal to P_{max} was applied to the specimen. The crack was then visually measured with a microscope on the side of the wire break sensors.

3.1 Specimen 1

The specimen was set up as described in table 1, with sensors mounted approximately 1 mm from the notch edge and 4 mm from the notch edge. A photograph of the specimen with wire break sensors fitted may be seen in figure 6.

Testing started with the loading detailed in the test matrix [table 1]. Results are presented in Table 2.

Once the audible alarm on the SIMs sounded to indicate a crack the output from the chart recorder was studied and revealed a small but discernible indication of a crack. This took the form of a step change in indicated pressure and an example may be seen in figure 7. Indications of this form were similar throughout the testing.

During isolation of wire sensor 2 following indication of a crack, it was found that wire break sensor 1 had short-circuited. This was isolated before the testing continued.

The testing continued up to 27635 cycles, at which point the test was stopped. Further examination of wire sensor 4 revealed that the 7.758 mm long crack had passed under the sensor without breaking the wire.

At one point during the test the sensitivity and the output speed of the chart recorder were increased. The resultant output demonstrated how sensitive the Davey system is, with individual load cycles becoming visible as can be seen in figure 8.

3.2 Specimen 2

A second test using an identical test specimen, but different pressure pad sensors was undertaken. Sensor positions are detailed in table 2.

Test 2 started with a loading regime designed to create a ΔK of 8, this level was increased after 5046 cycles due to a low crack propagation rate.

Once a crack had been indicated under the pressure sensor pads, the vacuum and atmospheric pressure channels were reversed in the pad by swapping the connections over to ensure that the second channel became active.

The test was stopped at 20580 cycles after letting the test run to obtain data relating to the readings from the pressure sensor pads during crack propagation.

3.3 Specimen 3

The third and final test was designed to investigate how the sensor pads could cope with rough, shot peened surfaces and whether the reported strain gauging capability of the Davey system could detect crack 'tunnelling' in shot peened material. Existing mechanical crack detection techniques struggle to detect cracks in shot peened material due to crack closure effects caused by residual stresses at the surface. This caused a potential problem with regards as to how to monitor the crack growth via an independent system to allow some comparison of the Davey system with existing crack monitoring techniques. For these reasons it was decided that the best course of action would be to machine a shot peened specimen so that one face was free of residual stress and would therefore be suitable for visual monitoring, while the Davey system pads would be mounted on the shot peened face.

Visual monitoring of the crack was undertaken on the rear, machined face of the specimen through a microscope as the test progressed.

A number of leaks caused by delamination of sensor pad 2 from the rough, heavily shot peened surface were overcome following application of pressure to the pad. However, following repeated pad detachment from the specimen, it was decided to disconnect this sensor and continue the testing. This operation was performed at 17500 cycles.

Although the crack could clearly be seen propagating along the machined face of the specimen, there was no sign of cracking on the shot peened surface due to crack tip closure caused by residual compressive stresses in the surface of the specimen.

Davey system pad 1 indicated a crack at 29844 cycles when the crack on the rear, machined surface of the specimen had reached a length of 13 mm. Later examination of the shot peened surface of the unloaded specimen revealed that the crack was approximately 1.0 mm long, and had just reached the first channel under the pad.

4 Discussion

The pads seem to be very straightforward to fit to the component in question and Ken Davey demonstrated how easy it is to produce pads for areas requiring specific pad geometries. Staff from the laboratories observed Ken fitting some sensor pads and reported that the pressure sensor pads can be fitted with minimal training. The amount of time taken to apply the pressure sensor pads is currently high compared with conventional techniques such as wire sensors, although this is expected to improve as experience is gained and the system is optimised.

As mentioned earlier in this report, the SIMs experienced fluctuation from a steady state value, which Ken unsuccessfully attempted to overcome through the use of a battery powered d.c. supply. The level of fluctuation was very small and in no way affected the ability of the system to detect small cracks. It is thought that the scatter originated from environmental disturbance in the laboratory, although further work is required to confirm this.

Some of the wire sensors detected cracks only when the crack tip was some way past the wire. One occurrence of a sensor missing the passing of a crack tip was sketched during test 1 at wire sensor 4 and may be seen in figure 9.

The problem appeared to stem from the delamination of the wire sensor in the local area around the crack. To enable the sensors to be placed in close proximity during the testing, the mounting paper was trimmed. It is possible that this operation may have led to reduced adhesion of the wire sensor and the local delamination observed. It may also be possible that the adhesive selected (M Bond 200) was the cause of the problem. In contrast, the pressure sensor pads appeared to give reliable and repeatable results during the entire evaluation test program. Although it should be noted that experience has shown that wire sensors perform very consistently and usually provide reliable results.

Test 2 continued after the Davey system pads had identified cracking in order to obtain information relating to the data output from a multi-channel pad as a crack propagated beneath it. The indicated pressure slowly increased as the crack grew. Therefore, it may be possible to use this technique to monitor crack growth. Again, further work is required to confirm this and to develop a suitable method.

During test 3, sensor pad 2 had adhesion problems on the rough shot peened surface. Each time the pad delaminated the data logging equipment recorded a huge step change in pressure, many times greater than the indication of a crack. It is therefore interesting to note that if the pads were used on a real structure, due to the inherent fail-safe characteristics of the system, it would be instantly recognisable that the pad had come unstuck. It should also be borne in mind that the system is very much in development at present and it is very likely that the adhesive could be improved in the future to allow use on rough shot peened surfaces such as the one used during test 3. Previous testing by SMS on shot peened surfaces has not presented an insurmountable challenge.

Analysis of the relative positions of the various sensors compared with measured crack length show that the Davey system pads consistently detected cracks before the wire break gauges. In some cases, the Davey system pads detected a crack at a stage when the visible portion of the crack had not reached the sensor, confirming that the Davey system has the potential to detect very sharp cracks.

During the final test when a shot peened specimen was used the pressure pad sensor detected a very fine crack. The crack was closed so tightly that it was difficult to measure using optical techniques. This suggests that the Davey system could prove to be very useful when monitoring structures under loading with a negative R ratio or residual compressive stresses present at the surface.

5 Conclusion / Further Work

SMS Ltd. provided BAe Airbus with the operating instructions of the system. In order for the test program to be feasible in terms of cost it was suggested that Ken Davey train someone from BAe Airbus to enable them to design, manufacture and fit pressure sensor pads for evaluation purposes.

Following this evaluation programme, initial impressions of the Davey crack detection system are favourable. Results were better than expected, with the system proving to be very reliable and accurate. There is no doubt that this system has great potential.

However, the extent of the testing at this time was limited and if the pressure sensor pads are to be used to detect cracks during materials and structural tests or even to monitor aircraft structures, confidence in the technique must be improved. It is suggested that this should involve further, more rigorous, testing.

At this point, BAe has only compared pressure pad sensors with wire sensors and it would be of great interest to see how the system compares with other crack detection. Again, this could only be accomplished with further testing.