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Comparative Vacuum Monitoring (CVM)

Monitoring of fatigue cracking in aircraft structures

By

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Abstract

In order to ensure the integrity of aircraft structures, the detection, monitoring and analysis of fatigue cracks still plays an important role today, and will do so in the foreseeable future. Methods which involve the inspection of structures for cracks or flaws, without long term monitoring, are generally termed NDT techniques. At the same time, techniques exist which differ from NDT, and which monitor structures for cracks or flaws over a long period of time. One of these is called CVM, or Comparative Vacuum Monitoring. This technique provides a novel and exciting method for crack initiation detection, and long term monitoring of fatigue cracks in aircraft structures.

CVM has the ability to monitor external surfaces of materials for crack initiation, propagation and corrosion. In addition, CVM sensors can also be embedded between components (e.g. lap joints) or within material compounds such as composite fibre. In this way, problems related to cracking, fatigue and corrosion can be detected when and where they are initiated. This technique offers a quick and easy way to monitor "Hot Spot" areas and thus improve the operational efficiency of the aircraft.

This presentation will briefly explain the principle of CVM technology and its current ability for crack detection on material surfaces and within lap joints. Furthermore, a few of the large array of standard CVM sensors will be shown, together with examples of laboratory tests, component tests and the first applications on a full scale fatigue test.

The CVM technology can also be utilized for aircraft maintenance purposes. For this application a portable system has been developed which provides the technician with an instant status report of the monitored structure without wasting time for dismantling and reassembly of items restricting access to the area of inspection.

1. Introduction

CVM is one of the key technology required when implementing Structural Health Monitoring (SHM).

At this stage Airbus is using CVM technology both for laboratory and structural tests. It is used on a regular basis to monitor and control fatigue test programs, due to its proven reliability and built-in fail-safe properties. Airbus, together with Structural Monitoring Systems, the CVM supplier, have developed sensors for early detection of fatigue cracks within riveted lap and butt joints. This is achieved by placing the sensor between the lap/butt joint components.

In the future, Airbus will also be concentrating on condition monitoring of in-service aircraft which takes place during pre-flight inspections. This monitoring requires only a matter of minutes, thus resulting in aircraft operating cost reductions

2. Sensors

The CVM sensors can be used for monitoring hot spot areas e.g. specific, predetermined locations on the fuselage, wings, door edges, landing gear and stabilizers [1]. For monitoring specific and multiple locations within the fuselage, inspection points may be interconnected, and several SSI's carry out more than one inspection task. For this task, a variety of sensor types are available. These include self-adhesive sensors for the measurement of surface crack initiation and/or propagation and sensors embedded within the structure (lap and butt joints). There is also the ability for corrosion detection and management of structures.

In the area of composites, CVM technology has exhibited the ability to detect delamination and impact damage. This in its own right has exciting prospects.

The sensors are produced from a variety of materials to suit the environmental conditions which allows the sensors to conform to the surface contours, including preened surfaces and complex curves. Sensors may either comprise self-adhesive polymer or Teflon sensors, or may form part of the component to be monitored. The surface preparation is similar to a strain gauge application. It is possible to use several kinds of adhesives depending on the type of surface coating and application. The geometric size and shape of a sensor pad, plus the size and configuration of the galleries will depend on the shape of the object to be monitored, its location, and the material it is made from. The sensitivity of the sensor is determined by the gallery spacing, which determines the shortest crack that may be detected. The sensors are inert and may be left in-situ on the structure for real time or periodic monitoring. Further, the sensors do not suffer the restriction of wire crack gauges and the like, which have a significant probability of failure if a bending moment is repeatedly applied to the sensor.

3. Comparative Vacuum Monitoring (CVM) Principles

Comparative Vacuum Monitoring (CVM) offers an effective method for in-situ, real time monitoring of crack initiation and/or propagation. CVM is a measure of the differential pressure between fine galleries containing a low vacuum, alternating with galleries at atmosphere in a simple manifold. If no flaw is present, the vacuum will remain at a stable level. However, if a flaw (crack or corrosion) develops, air will flow through the passage created from the atmosphere to the vacuum galleries. A transducer measures the air flow between the galleries; the sensitivity is governed by the gallery spacing and the rate of flow is an indication of flaw size [2]. No medium e.g. adhesive layer exists between the CVM sensor and the test object. Therefore the CVM technique permits the direct measurement of the surface flaw.

The principles of the sensor with the atmosphere and vacuum galleries are shown respectively in Figure 1.

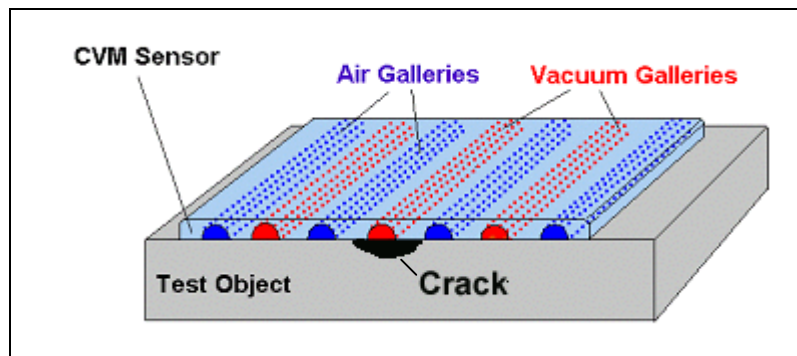


Figure 1. Measuring principle of the CVM Technology

4. Crack Initiation Measurements

Test programs were conducted by Airbus to determine the ability of the CVM technique to measure crack initiation on curved surfaces and within lap/butt joints. It was the aim to detect surface flaws of less than 1 mm with surface sensors and to detect initial cracks of less than 2 mm with embedded sensors.

4.1 Measurements with Surface Sensors

Seven coupons were prepared for the tests. The surface sensors were attached at the radius of the test coupons. Figure 2 contains the coupon design as well as the location and orientation of the sensor galleries. The gallery wall thickness was 0.250 mm. That means that surface flaws with more than 0.250 mm can be detected [3]. For the tests coupons with three different radii (20/10 and 5 mm) was used. The fatigue tests were carried out with a constant R-value of 0.1 and a frequency of 10 Hz. The upper loads used are shown in Table 1.

Figure 3 shows an example of the CVM output versus the load cycles. The first crack detection occurred after 70200 cycles. At this stage the test was stopped

and the specimen was fractured with a second loading (R-value 0.8) so that the crack length on the broken surface could be measured and verified by microscope.

Table 1 shows the measured crack lengths and the cycles. The results demonstrated the ability for the CVM system to detect cracks less than 1 mm. This capability of the CVM technique can thus be utilised by test equipment to control all of the testing programs without the presence of a technician, as the system can be programmed to shut down when this crack is detected. It is also imaginable that in this manner the CVM technique can give an alarm for an aircraft structure before a catastrophic failure occurs.

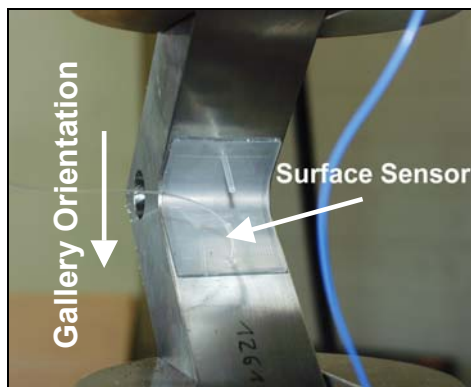


Figure 2. Test coupon with surface sensor

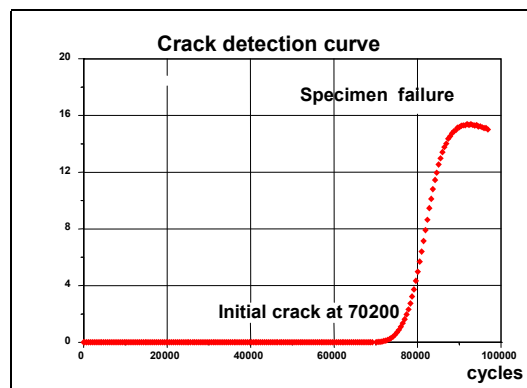


Figure 3. Example plot of CVM output versus load cycles

TABLE 1. EXPERIMENTAL DATA

No.	Radius [mm]	Upper Load [N]	Cycles to Initial crack	Crack length [mm]
R5-1	5	35000	37207	0.26 0.49
R5-2	5	35000	41811	0.28 0.87
R10-1	10	48650	54511	0.85
R10-2	10	48650	33760	1.40
R10-3	10	48650	71043	0.78 0.52
R20-1	20	62240	70200	0.71
R20-2	20	62240	103629	0.83

4.2 Measurements with embedded sensors

Of the many CVM applications, the monitoring of aircraft riveted lap and butt joints is one of the most exciting. The fatigue cracks in these joints normally commence at the hole edges within the joints. Initial cracks in the range of less than 1.8 mm are not detectable with standard NDT methods, or by disassembling of the joints with proximate visual inspection, because the cracks will be closed. That was the reason for the development of embedded sensors for detecting hidden cracks. The sensors have been developed to be located within a lap or butt joint, replacing the sealing material, but without the requirement for milling the plate surface to create space for the sensor. Tests have shown that this sensor is very effective in the detection of cracks. Figure 4 shows a lap joint coupon with 5 embedded sensors.

After assembly, this coupon was fatigue loaded with 5 Hz, $R = 0.1$ and upper stress = 120 MPa. The first crack alarm occurred after 58000 load cycles. Figure 5 shows the plot from the CVM sensor. After disassembly, a surface crack of less than 2 mm was found on the affected sheet. (Figure 6).

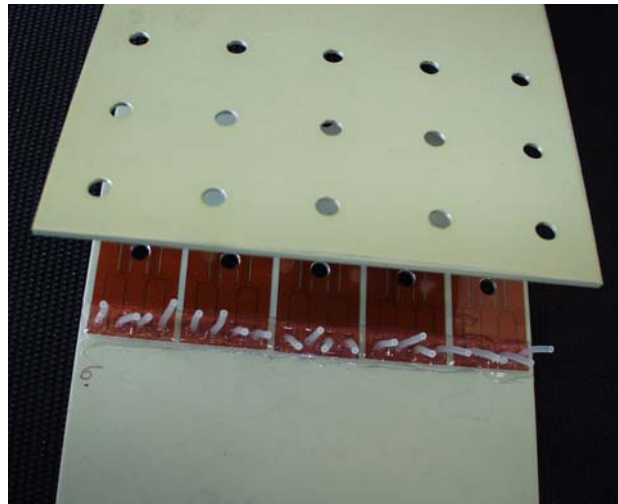


Figure 4. Lap Joint with 5 embedded CVM Sensors

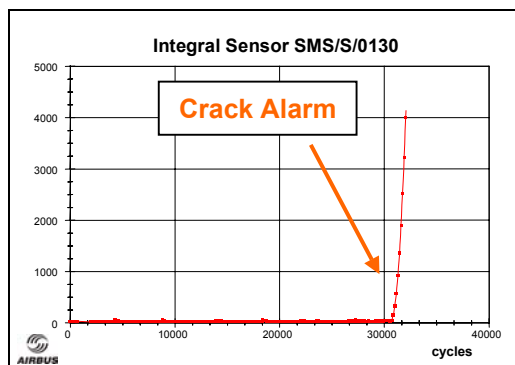


Figure 5. Plot from the CVM sensors

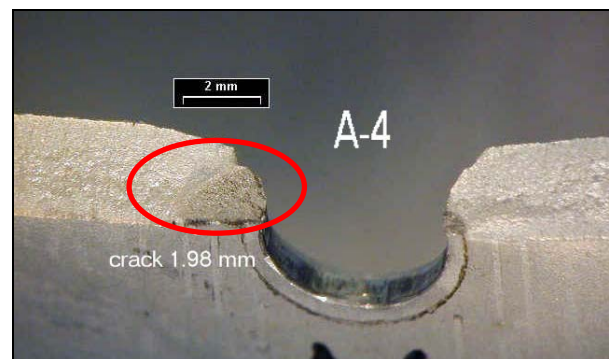


Figure 6. Fatigue crack within lap joint

5. Portable Monitoring System

A fully self contained and portable CVM unit (PM-4) is available to allow periodic monitoring and data control of critical aircraft structures. The CVM monitor is connected periodically to the sensor system, as part of a regular inspection program for the integrity of the structure [4]. Figure 7 shows how the periodic monitoring system operates. The sensors are installed on the structure with the vacuum lines conducted to a convenient connection point. The operator connects the portable monitor and applies vacuum. The data logger records all of the information and displays it. The whole operation will only take a few minutes.

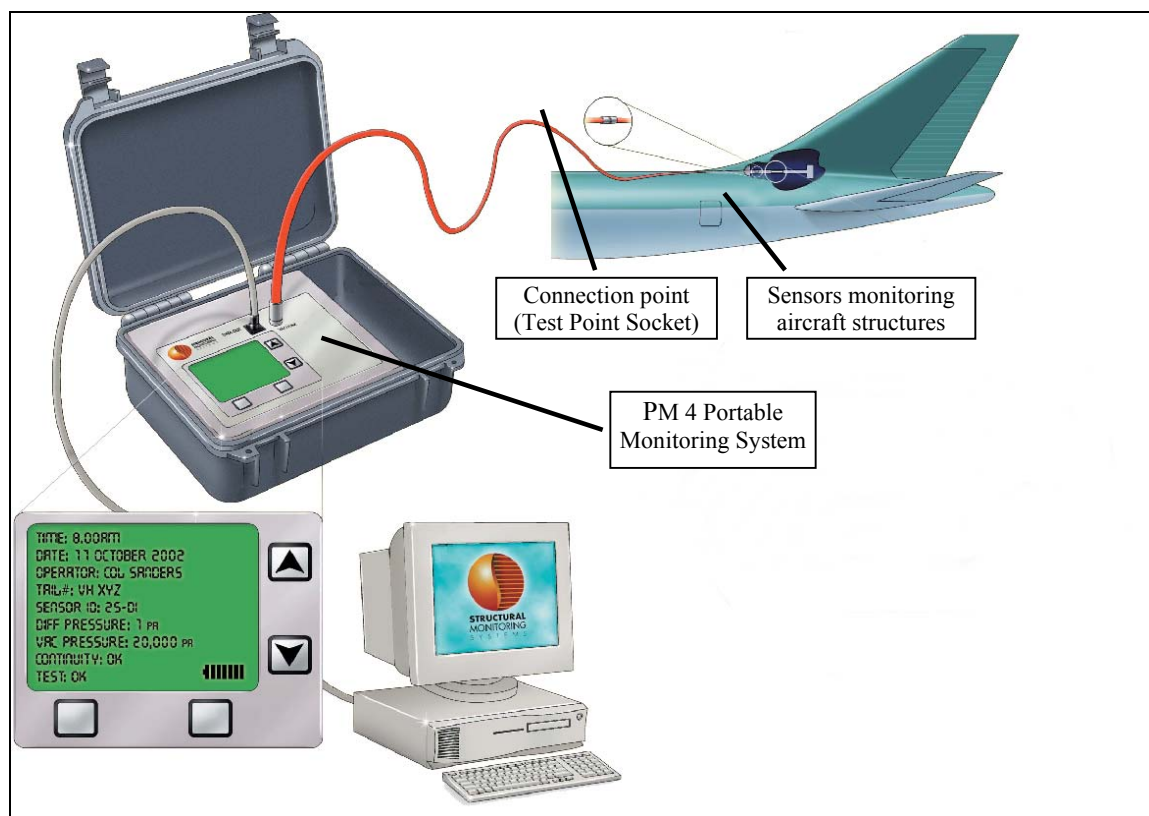


Figure 7. PM 4 operating principle

6. Application on Full Scale fatigue test

The CVM technique can also be applied to the periodic monitoring of Full Scale Fatigue tests. Airbus is using this technique during the testing of a pressurized fuselage (Figure 8) within the TANGO program. The aim is to measure flaws within the lap joints and on the surface of a laser beam weld. The measurements of cracks inside lap joints are an exciting method to find cracks of less than 1.8 mm (Figure 9). In the case of welded joints, flaws of less than 0.3 mm can be detected (Figure 10).



Figure 8. Tango barrel test facility

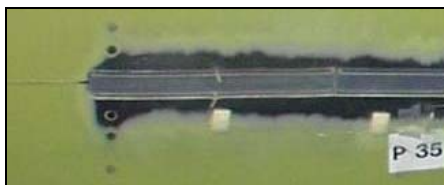


Figure 9. Surface sensors monitoring LBW-weld

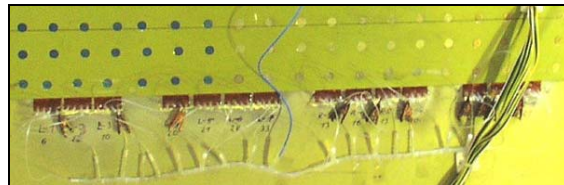


Figure 10. Integral sensors monitoring longitudinal lap joint

7. Conclusion

Airbus has identified the importance and value of Structural Health Monitoring. Increased aircraft operational efficiency, both through optimisation of airframe structures, and thus weight, plus maintenance management, can thus be facilitated. For any new design and maintenance concept considerations to be realised, appropriate tools and technology is a prerequisite. CVM forms an integral part of SHM, together with other technologies that may be required to cover the whole spectrum of SHM requirements.

References

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