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ON-BOARD MONITORING OF CRACK AND CORROSION USING WIRELESS NETWORK

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Abstract-Structural health monitoring is an important safety factor in aviation that might benefit from advanced smart systems for damage sensing. This paper presents a new concept for a wireless crack and corrosion detection system for on-board health monitoring of aircraft. The sensor which is use to identify the structural damage and material loss on the surface of the aircraft by Ferrous Fluid under magnetic field. The Ferro fluid shall be applied as an emulsion on the test substrate. When a crack occurs, due to the crack there will a flux leakage. By constantly monitoring the flux on the surface of the substrate, whenever there is a flux leakage we can correlate it to a crack. The Ferro fluid shall be a ferromagnetic material and the particles should be in sub micron or nanometer region. These particles shall be mixed in suitable surfactants to get a uniformly monodispersed emulsion. This emulsion is to be applied on the test substrate and then the flux generated due to the emulsion shall be first measured. This measured flux density shall be taken as the baseline. Any deviation from the baseline shall be considered as flux leakage. It is possible to differentiate between the signals received from a crack and corrosion. One of the advantages of the present set up using Ferrous Fluid Sensor (FFS) for the generation and detection of signals can be easily processed by wireless application. The signal sensed by the FFS is transmitted to the cockpit through the wireless sensor network for monitoring of crack and corrosion on the surface of the aircraft.

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1. INTRODUCTION

Structural health is directly related to structural performance and in this respect it is a governing parameter with regard to safety of operation. This aspect of structural health is particularly relevant to transportation systems including their infrastructural elements and in this connection structural health monitoring is a **safety issue**. At the same time a change in structural health may affect structural performance to a degree that remedial actions become necessary. Structural repairs increase the cost of transportation in at least two ways. First, the design and implementation of repairs implies *direct costs*. Second, the execution of repairs generally requires the transportation system to be temporarily taken out of service and this induces *indirect costs* due to the loss of production volume or as a result of leasing a substitute system. To reduce repair and maintenance cost one might attempt to repair at a very early stage of damage development to limit direct costs. Alternatively, it might be decided to postpone repair until the transportation system has to be taken out of service for scheduled major overhauls to reduce indirect costs. In this connection structural health monitoring becomes a **cost issue**.

Modern physical systems such as those used in aircrafts are becoming more and more complex. This increase in system complexity has led to an increased desire for automated prognostic and health monitoring systems. To provide such capabilities, however sensors may mounted on the surface of aircraft to sense physical parameters such as crack and corrosion. Using a network of sensors these physical parameters can be transmitted to a central processing unit using wiring and multiple wiring harnesses for future prognostic analysis. These wiring and wiring harnesses can increase overall system weight and can reduce overall system reliability. Therefore, there is a need for a system and a method of providing sensors to sense physical parameters without using wiring and multiple harnesses. Safety, costs and performance issues of the structural health and usage monitoring are particularly important in the aircraft industry.

2. SYSTEM INTEGRATION

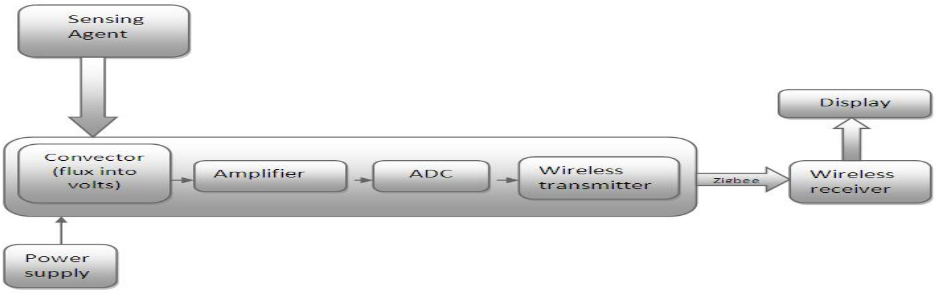

Fig: 1 Functional block diagram of On-Board Monitoring of crack and corrosion using wireless network.

2.1 SENSOR AND DATA COLLECTION

FERROUS FLUID SENSOR which is used to locate surface-breaking defects in all non-porous materials (metals, plastics, or ceramics). The penetrant may be applied to all non-ferrous materials and ferrous materials, but for inspection of ferrous components magnetic-particle inspection is also preferred for its subsurface detection capability. The experiments presented above in full generality are a formidable task [4]. The impact of the magnetic field on the ferrofluids drop is described by the magnetic stress

$$\sigma_{ik}^{m} = \frac{1}{4\pi}\left(H_i B_k - \frac{1}{2}H^2\delta_{ik}\right) + \frac{1}{2}(M_i H_k - M_k H_i) \quad (1)$$

Where ***B***, ***H*** and ***M*** denote the magnetic induction, the magnetic field and the magnetization respectively. A complete analysis would require one to simultaneously solve the *free-boundary* value problem for the hydrodynamics of both fluids and the magneto-static Maxwell equations for the magnetic fields ***B*** and ***H***. This is, even numerically, highly demanding and we therefore propose several approximations which on the one hand describe the experimental situation to sufficient accuracy and on the other hand render the theoretical problem tractable.

Our basic assumptions are as follows:

- The shape of the drop is approximated by a three-axis ellipsoid. This assumption describes the experimental situation rather well except for the intermediate values of the magnetic field for which large peaks develop at the periphery of the drop. Within this approximation the shape of the drop is uniquely described by the values of the three semi-axes $a \geq b \geq c$. In fact, because of volume conservation, two parameters are sufficient which we choose to be the semi-axes *ratios* $b = a/b$ and $c = a/c$. The theoretical analysis simplifies considerably since the magneto-static problem of a Magnetizable ellipsoid in a homogeneous external field can be solved analytically and both the internal field ***H*** and the magnetization ***M*** are known to be homogeneous.

- The shape is assumed to be determined solely from the balance between surface energy and Magnetic energy. This assumption can be justified by estimating the different stresses relevant to the problem. The capillary stress can be estimated by $pc \sim 2\alpha/R$, with $\alpha \cong$_ 2.5 dyn cm−1 and $R \cong$_ 0.25 cm we hence get $pc \cong$_ 20 dyn cm−2. The magnetic normal stress is given by $pm \sim 2\pi M2n$, where Mn is the normal component of the fluid magnetization. For a spherical drop we have $M = 3\chi/(3 + 4\pi\chi)G$ and using $\chi \cong$_ 1.3, $G \cong 20$ Oe as well as $Mn \cong$_ $M/2$ we end up with pm _$\cong$ 13 dyn cm−2. The viscous stresses can be estimated as $pv \sim \eta\ (e)$ _. With the experimental values $\eta\ (e) \cong$_ 1 P and $\cong$ _ _ 1 s−1 we get $pv \cong 1$ dyn cm−2. The viscous stress is at least one order of magnitude smaller. For the determination of the shape of the drop the viscous stress is therefore negligible. Nevertheless the viscous stresses will be crucial in the analysis of the *motion* of the drop.

- The hydrodynamic flow problem can be treated within the Stokes approximation. This assumption is reasonable since the Reynolds number can be estimated as $Re\ \rho\quad R2/\eta\ (e)$ and with ρ 1.8 g cm−3 we find Re 0.9. We are hence allowed to neglect the inertial term in the Navier–Stokes equation which makes the hydrodynamic equations *Linear*. In our solution of the flow problem we will take advantage of this linearity by exploiting a superposition ansatz.

- The flow inside the drop in the co-rotating coordinate system is horizontal and of uniform Vorticity. This final assumption builds on the last one, i.e. the dominance of the viscous terms in the flow problem. The stationary internal flow field ***v*** *(i)* can then be well approximated by the two-dimensional elliptical form matching the shape of the drop. The parameter ζ characterizing the vorticity of the flow remains to be determined. Note that this ansatz is hence more general than just describing a solid body rotation of the drop given by the special case $\zeta = 0$.

2.2 CONVERTER

A magnetic field induces a voltage proportional to the change in flux seen by the coil. Similarly, a varying field induces a voltage on a stationary coil. These principles have been understood and exploited since the 19th century to precisely measure, for example, the earth's magnetic field. Flux meters also continue to play an important role in the measurement of the hysteresis of magnetic materials and in magnet design[6], for example to determine the losses in a magnetic circuit. Since the voltage induced on the coil is proportional to the flux change, we need to integrate the voltage to obtain the change in flux:

$$V = -\frac{d\Phi}{dt} \Rightarrow \Delta\Phi = -\int_{t_{start}}^{t_{end}} V\,dt \quad (2)$$

There are two commonly used approaches to building an integrator:

- A standard analogue integrator circuit, using a high-gain amplifier with a capacitive feedback. The low-end bandwidth is limited by the size of the capacitor, and there are numerous analogue noise sources, such as leakage currents and temperature dependence.In addition, we usually wandigital result, so we have to digitize the output anyway.
- Digitize the voltage at periodic intervals and perform a numerical integration. This method has to limit the high-end bandwidth to satisfy the Nyquist criterion; it depends critically upon the linearity of the ADC, and can suffer from quantification noise.

2.3 POWER SUPPLY

Power to the device was achieved with an X-band microwave rectenna designed for converting microwave energy into DC power [3]. The rectenna developed is shown in Fig. 2. The Antenna elements are narrowband, linearly polarized patches for 10 GHz on a 0.25-mm thick Rogers Duroid substrate with a permittivity of 2.2. The gain of the patch calculated from its physical area is 1.39 (1.45dB). In each element, a rectifying diode is connected directly to the patch so that DC output is obtained with incident microwaves. The thin substrate allows the rectenna array to be flexible and conformal to the moderate curvature of an airframe while the desirable microwave properties are maintained. A single rectenna element at a 10mW/cm2 incident RF power density has an output power of 5 mW with an estimated efficiency of 50%. The combination of 25 antenna elements in series achieves the total power of more than 100mW at an estimated efficiency of 40%.

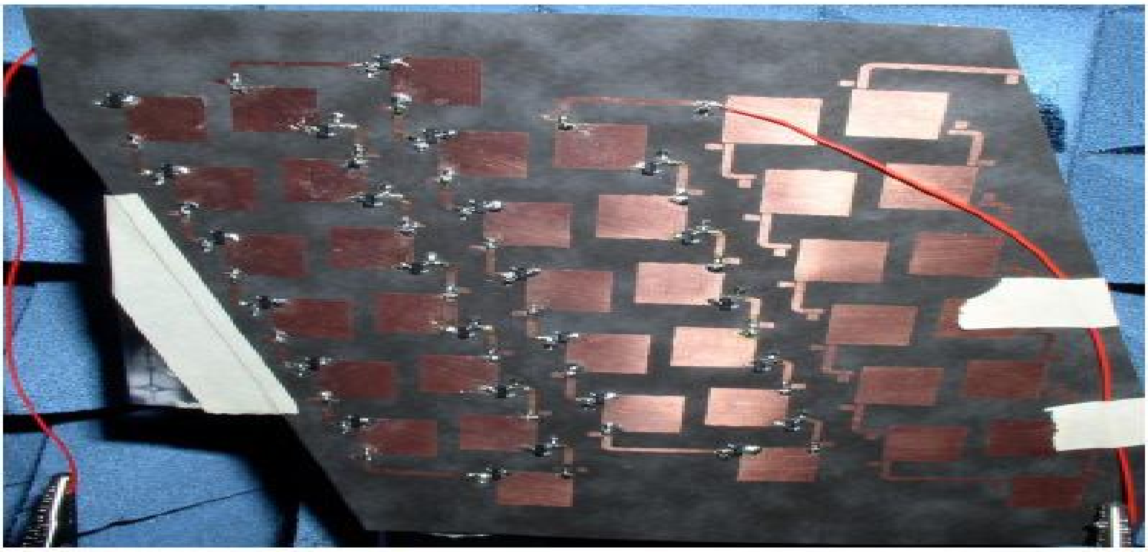

Fig 2. X-band microwave rectenna for wireless powering the on-board electronics

2.4 WIRELESS TRANSMISSION

The IEEE 802.15.4 standard is a simple packet data protocol for lightweight wireless networks and specifies the Physical (PHY) and Medium Access Control (MAC) layers for Multiple Radio Frequency (RF) bands, including 868 MHz, 915 MHz, and 2.4 GHz. The IEEE 802.15.4 standard is designed to provide reliable data transmission of modest amounts of data up to 100 meters or more while consuming very little power. These features are enabled by the following characteristics

- 2.4GHz and 868/915 MHz dual PHY modes.
- This represents three license-free bands: 2.4-2.4835 GHz, 868-870 MHz and 902-928 MHz .The numbers of channels allotted to each frequency band is fixed at 16 channels in the 2.45 GHz band, 10 channels in the 915 MHz band, and 1 channel in the 868 MHz band.
- Maximum data rates allowed for each of these frequency bands are fixed as 250 kbps @2.4 GHz, 40 kbps @ 915 MHz, and 20 kbps @868 MHz
- Allocated 16 bit short or 64 bit extended addresses.
- Allocation of guaranteed time slots (GTSs).
- Carrier sense multiple access with collision avoidance (CSMA-CA) channel access Yields high throughput and low latency for low duty cycle devices like sensors and controls.
- Fully “hand-shake” acknowledged protocol for transfer reliability.

- Low power consumption with battery life ranging from months to years.
- Energy detection (ED).
- Link quality indication (LQI).
- Multiple topologies: star, peer-to-peer, mesh topologies.

3. RESULTS AND DISCUSSION

The test setup for an aluminum alloy plate of aircraft's surface is by applying Ferrofluids on the plate which is under the magnetic field which was connected to the embedded SHM device that can generate signals and collect sensor data. With a LINX RF module and receiver device, the collected data was successfully received from the on-board SHM device. A near real-time data collection and display was achieved with a range about 5~10 meters in an office environment. Figure 3 shows example waveforms collected.

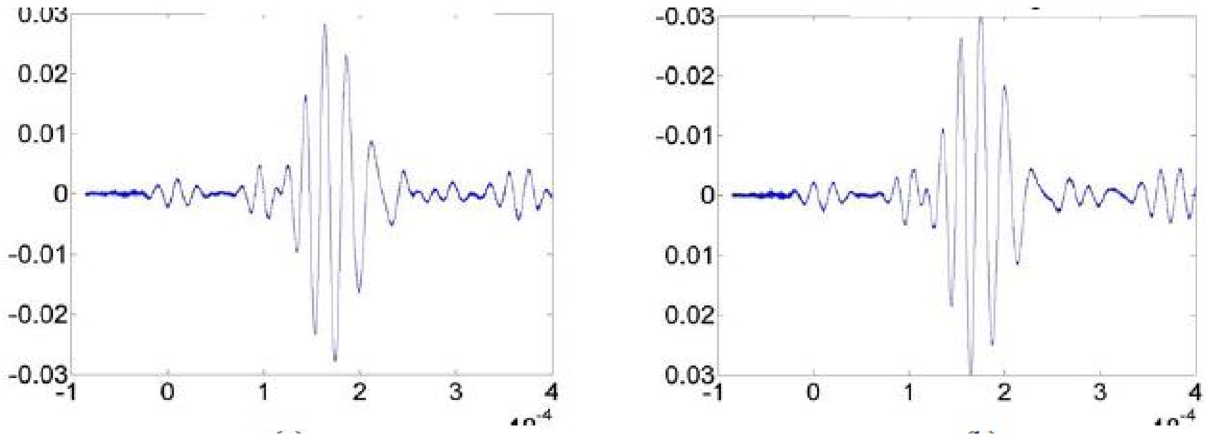

Fig 3.Wireless waveform of Al plate with crack and without crack respectively

The data collected were transferred wirelessly to a laptop PC and processed with RAPID algorithm developed previously [7]. The estimation result after applying a proper threshold to the probability density map. The estimated defect location agrees very well with the true location. This test proves the peasibility of using ferrofluids and diagnosis device for in- suit structural integrity monitoring of aircraft of aircraft structure.

4. CONCLUSIONS

The approach of using ferrofluids sensing agent in magnetic field and wireless structural monitoring device for aircraft structural inspection has been studied. Flux leakage signal can be collected on-board over the aircraft surface and sent out wirelessly. The signal quality is good and can be used for defect detection and localization. The use of Zigbee radio saves energy and can tolerate noise interferences. Power supply for the electronics and sensor can be achieved with an energy harvesting device such as microwave rectenna. Experimental test were carried out over the surface of the aircraft. Defect detection and location estimation are successfully demonstrated. In future, we plan to continue our studies in order to actually quantify damage based upon the measurement of these effects for different corrosion measurement of these effects for different corrosion depth and intensity.

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