EMBEDDED SENSORS TO ASSIST PROPER INSTALLATION OF WIRE HARNESS CLAMPS AND TO MONITOR DEGRADATION OF WIRES

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Introduction

Connectors and clamps are an integral part of electrical wiring system in aircrafts. The wires carry electrical power and communication signals for efficient and smooth operation of the aircraft. The connectors are used to route and branch the electrical power, to supply to different parts of the aircraft. The bundles of wires bound together (wire harness) are firmly attached the body of the aircraft using clamps. While connectors help in optimizing the routing of the electrical signals, the wire harness clamps help to organize the wiring and avoid the clutter of the electrical wires. The electrical wiring system without connectors and clamps would be a mess and servicing would be a nightmare.

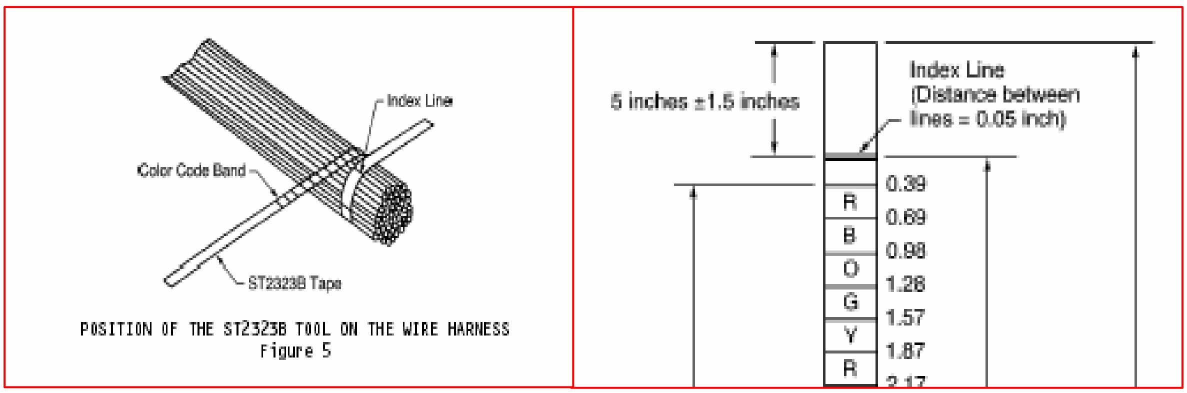
There are large numbers of electrical connectors and a huge number of wire harness clamps in an aircraft. In general, clamps are installed every six to eight inches along the length the wire harness. The most often used clamp on an aircraft, has a rubber cushion with a metallic backing. The rubber cushion avoids direct contact between the signal carrying wire and the metallic backing. In some situations, plastic clamps and wire wraps are also used along with clamps. The entire electrical wiring system installation is hidden behind the structure and is expected to function without failure for a long time. This philosophy has been quite successful and the electrical wiring system has lived up to this expectation quite well. Hence, there wasn't significant research thrust in the area of long term reliability of the electrical wiring system. Recent unfortunate accidents, of commercial aircrafts, and their accident reconstruction, have traced the origin of the problems to failure of electrical wiring system components. This has led to increased awareness and provided impetus to the investigation of the reliability and integrity of the electrical wiring system. Minor accidents as well as mishaps are seriously investigated and the electrical wiring problems are recorded. As in every complex structure, the problems in electrical wiring systems may not appear soon after installation, but they appear gradually over years due to degradation of the components. Many factors like temperature, humidity, dust, chemicals as well as improper installation are expected to contribute to the problems in electrical wiring system.

Especially in the rubber cushioned clamps, when the rubber comes into contact with chemicals, hydraulic fluids, snow removing chemicals, it will either become too spongy or brittle. The rubber will collapse or crumple and the electrical wire will come into contact with the metallic portion of the clamp. Eventually, this condition is expected to lead to fire hazards due to electrical shorts and sparks. Although some problems are due to aging and degradation, many are also related to compromises made at the time of installation. The aircraft manufacturers and Federal Aviation Administration have developed a manual for installation of the clamps [1]. It provides a detailed step by step description of how to install a wire harness clamp. Though the installation of clamp appears to be a simple task, in many situations the installer has limited access and has to perform installation while stationed in uncomfortable posture. Our own investigation of a small cut out portion (3'x 3') of a retired aircraft showed that more than 50% of the clamps didn't conform to the manual. This examination revealed that many of the problems may be related to installation. These observations indicate that there is a need to develop tools to assist proper installation of the wire harness clamps as well as techniques to monitor them.

This paper presents an investigation of the details of wire harness clamp installation and development of sensors to assist proper installation. The paper is organized to present first the details of correct installation procedure and establish criteria to monitor correct installation. This is followed by description of the problems encountered due to departures from correct installation. Based on the established criteria for correct installation, sensor development to assist and monitor installation process is described with preliminary results.

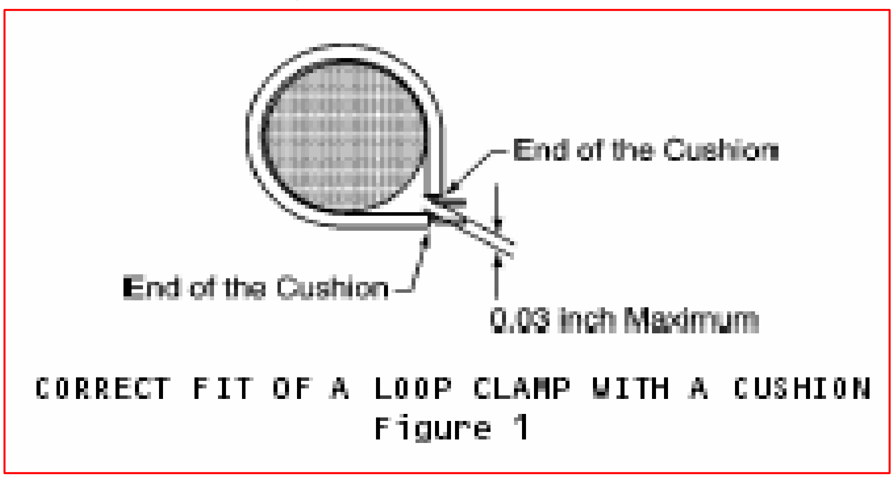
Criteria for correct installation of clamps

The manual describes the correct procedure to install wire harness clamps based on choosing correct size, proximity of the clamp ends, optimized pressure on the wire bundle and angle between the clamp and the harness. Figure 1 describes the process of choosing correct size of the clamp. A tape with different colors 'sizing tool' is placed on the wire bundle and the appropriate color is read. Based on the color and a look up table the appropriate size clamp is chosen for installation.



(Source: Boeing Clamp Installation Manual)

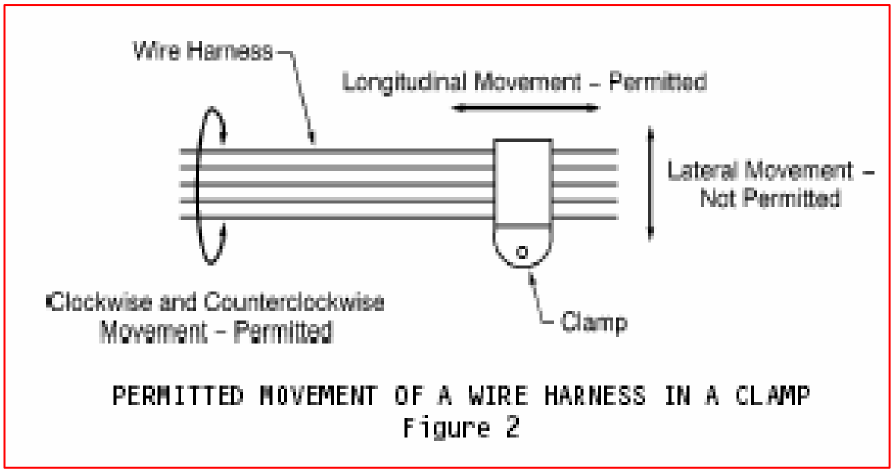
Fig 1: Selection of Correct size



(Source: Boeing Clamp Installation Manual)

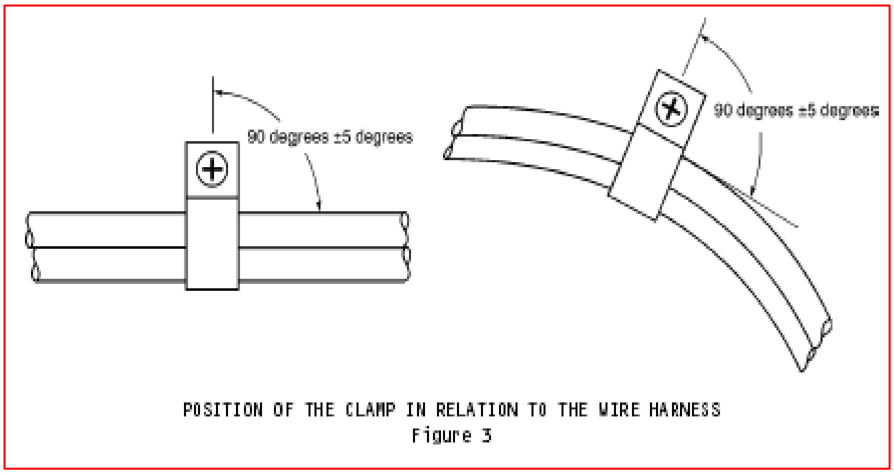
Fig 2: Proximity of Clamp ends

Figure 2 shows the situation when the clamp is laid on the bundle. The rubber cushion should loop around the bundle and the metallic ends should be less than 0.03 inch apart. Figure 3 describes procedure to determine the appropriate pressure on the wire bundle. The pressure attained during the tightening the clamp screw, should provide clockwise, anti-clockwise and the longitudinal movement of the bundle (as indicated in the figure 3). The pressure on the bundle should not allow lateral movement of the wire harness.



(Source: Boeing Clamp Installation Manual)

Fig 3: Pressure on Harness and permitted movement



(Source: Boeing Clamp Installation Manual)

Fig 4: Orientation of Clamp and Harness

Figure 4 shows the correct angle between the wire harness and the clamp. The angle between the clamp and the wire harness should be (90 +/- 5) degrees. All of the steps should be strictly followed for correct installation of the clamp.

The criteria for correct installation is a) choosing exact size, b) the distance between the clamp ends when installed should be less than 0.03 inches, c) the angle between the harness and the clamp should be close to 90 degrees and d) the pressure on the wire harness should allow longitudinal and rotational motion but no lateral motion of the wire harness.

Problems due to improper installation

In this section we examine the effect on the wire harness and the individual wires when the installation procedure is compromised. For this purpose we show a sketch indicating the defective installation and photographs of defective clamps in an actual aircraft wire harness. Figure 5 shows an undersized clamp used for installation. In this case, the ends of the rubber cushion that are supposed to come into contact and provide a loop around the wire bundle are open. Over a period of time due to vibration one of the wires may get loose and come into contact with the metallic portion of the clamp. This situation is shown in the adjacent photograph of a clamp. Figure 6 shows further the effect of choosing an undersized clamp. Whenever a clamp smaller than the required size is used, extra force is needed to bring the metallic ends of the clamp closer to hold the wire harness in place. This will lead to enhanced pressure on the wire harness causing crimping of the wires. The adjoining photograph shows crimping of the wire in a clamp. In spite of closing of the clamp with tightening of the screw, a gap between the lips of the rubber cushion can be observed in the photograph. This is a clear indication of choosing a smaller clamp than required. Further, the effect of choosing a smaller size clamp is depicted in figure 7. A wire escaping from the gap between the cushion lips ends up between the two metallic ends of the clamp. The wire is being ‘pinched” between the two metallic strips. The photograph shows a pinched wire in an aircraft wire harness.

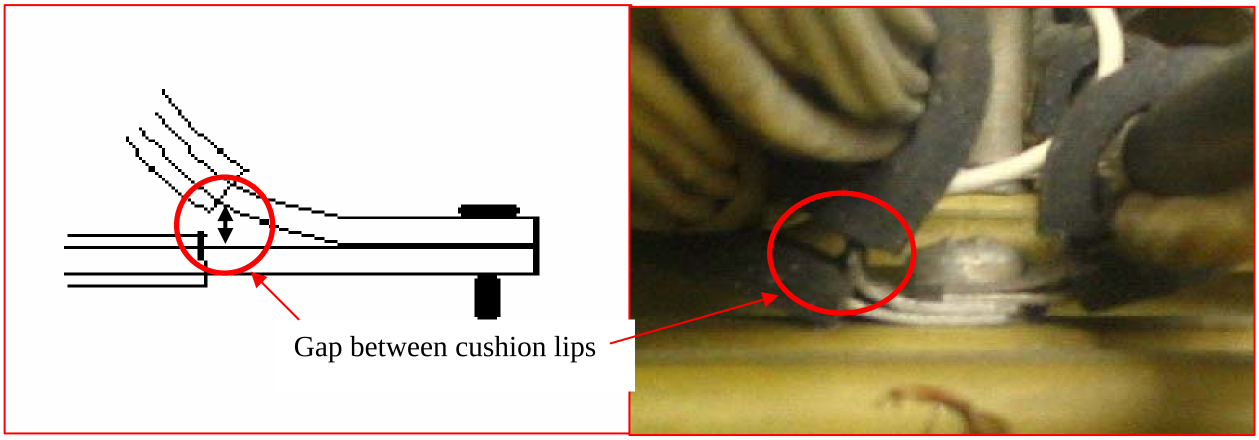


Fig 5: Smaller Clamp selection

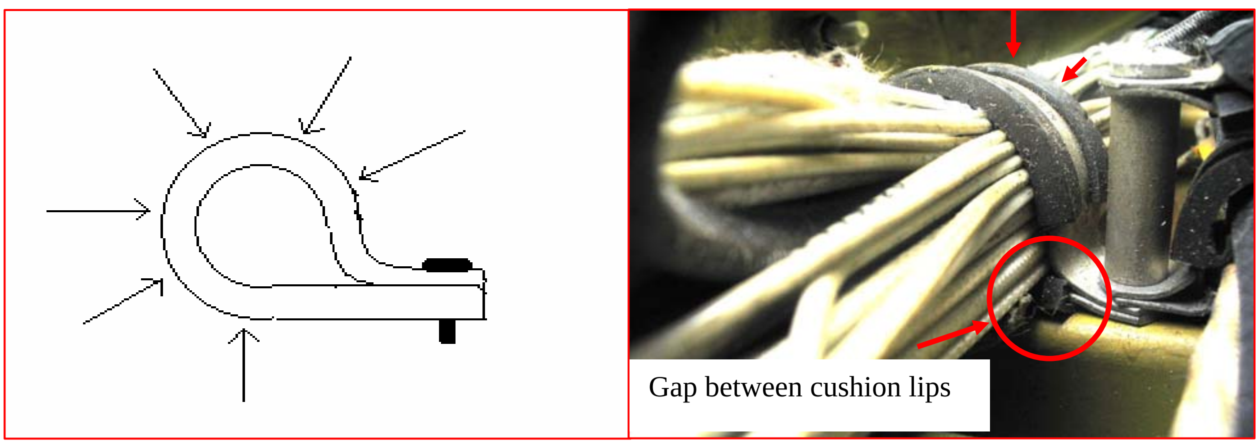


Fig 6: Crimping of wire harness

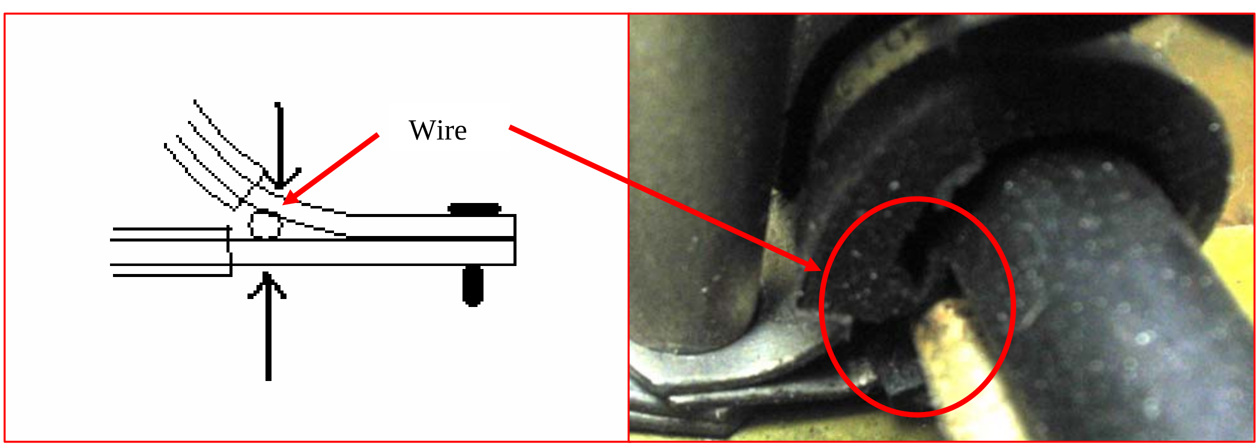


Fig 7: Pinching of wire between clamp ends

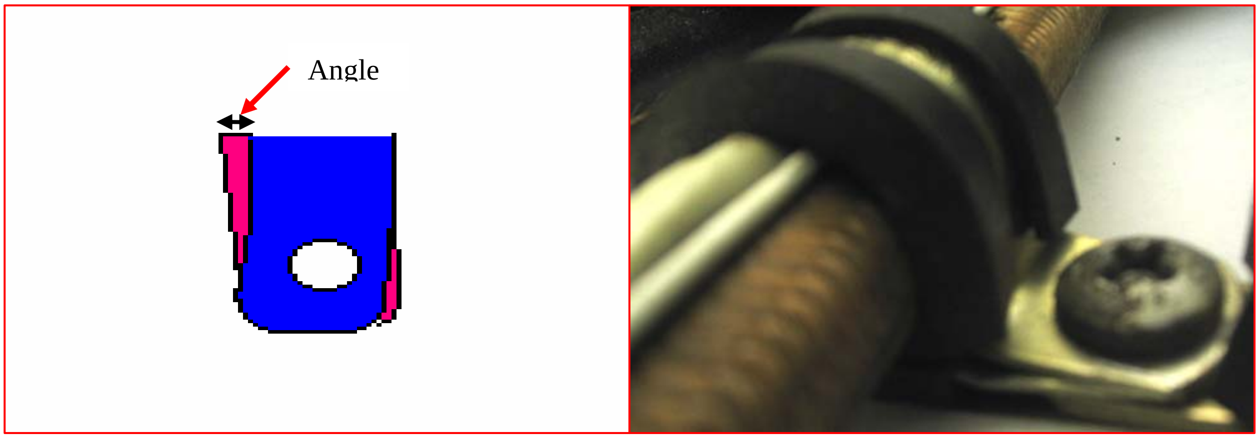


Fig 8: Twisted Clamp ends

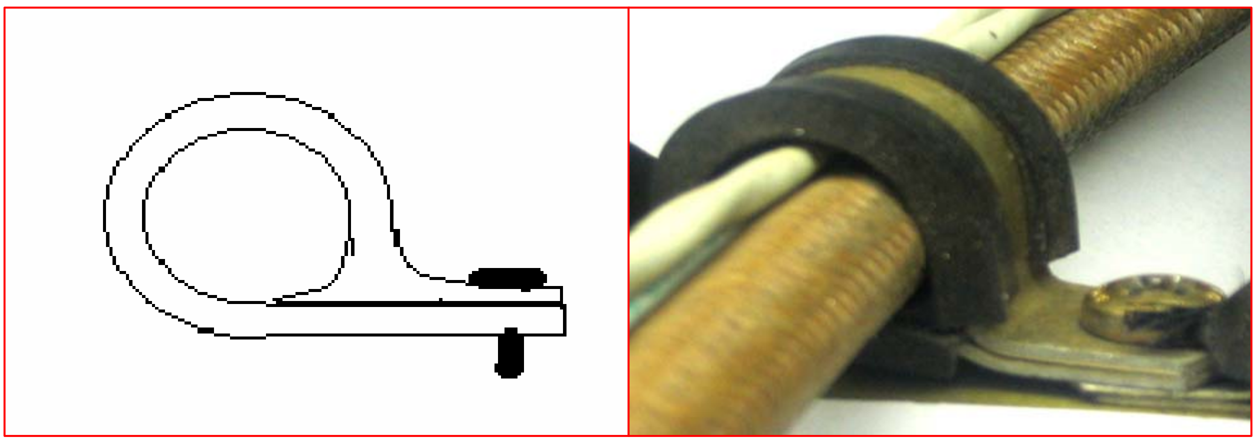


Fig 9: Correct Clamp installation

Figure 8 shows a situation where the two ends of the clamp are twisted instead of being parallel. This situation indicates possible over pressure in the clamps. The photograph depicting the situation in an actual aircraft wiring system is shown where the clamp ends are oriented to each other. Figure 9 shows a photograph of a correctly installed clamp in an aircraft.

Major problems could develop over time due to incorrect clamp installation. Over pressured clamps, could cause crimping of the wires near the clamp edges. The extra pressure causes the rubber cushion to compress more near the edges and reduce the distance between the wire and the metallic body. Over a period time the pressure gradually brings the wire into contact with metal. When the pressure on the clamp is not optimized, the vibrations of the aircraft during operation could cause small relative displacement between the clamp and the wire harness. Over a period of time, this causes 'chaffing', a gradual removal of the insulating material of the wire. This has been found to be a serious problem in electrical wiring system. In general, combination of incorrect installation and the environment around the electrical wiring could cause potential hazard to the functioning of the aircraft.

Detailed examination of the clamp installation manual and investigation of installed clamps in aged real aircraft wire harness shows that there is a necessity to develop tools to assist and monitor proper installation of the clamps. Our observation shows that for a proper installation, correct size clamp should be selected; during installation the distance between the rubber cushion ends should be monitored. A complete closing of the gap could avoid crimping and related problems. Monitoring of the gap distance between the metallic ends of the clamp could help in avoiding trapping and pinching of the wire between the metallic strips. Monitoring the orientation angle between the two metallic ends of the clamp could avoid over pressure in the clamp. A quantitative measurement of the pressure between the wire harness and the clamp could decrease the chances of crimping of multiple wires and development of chaffing.

Sensors to monitor clamp installation

To monitor proper installation of the clamp it is necessary to determine the proximity of the rubber cushion lips, distance and angle between the metallic ends of the clamp, and the pressure between the wire harness and the clamp. The distance between the cushion lips and the metallic ends can be measured using several different types of proximity sensors. To monitor the installation procedure the sensors should be significantly small so that they can be embedded into the clamp or integrated into the tool. For this purpose we chose Giant-Magneto-Resistive (GMR) sensor [2], because of its size, low cost and stability. GMR sensors detect static as well as dynamic magnetic field. The small dimension, low cost and high sensitivity in magnetic field detection has made them important sensors in computer read write heads. GMR sensors consist of a stack of alternating, very thin magnetic and non magnetic layers. The resistivity of the GMR decreases in presence of a magnetic field and the output voltage across it increases.

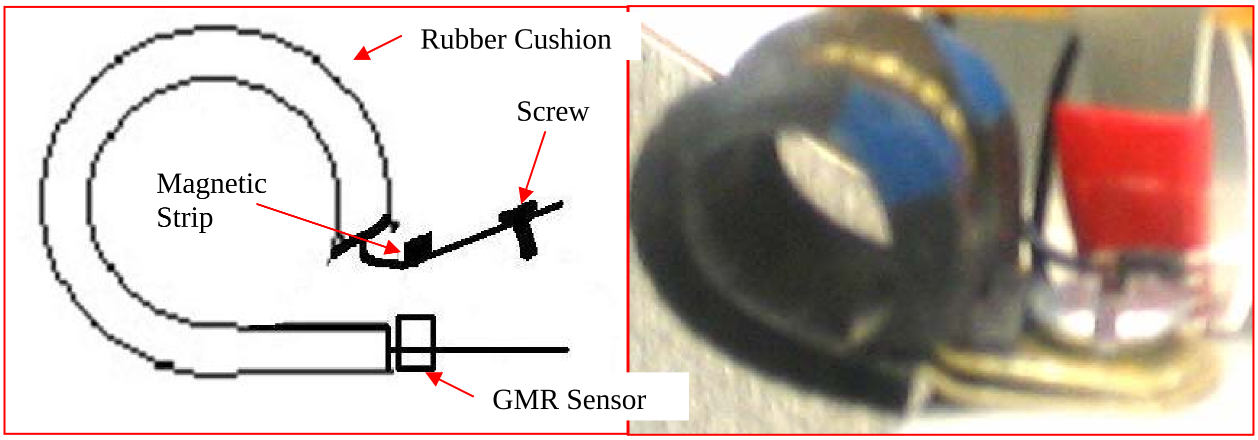


Fig 10: GMR sensor and magnetic strip

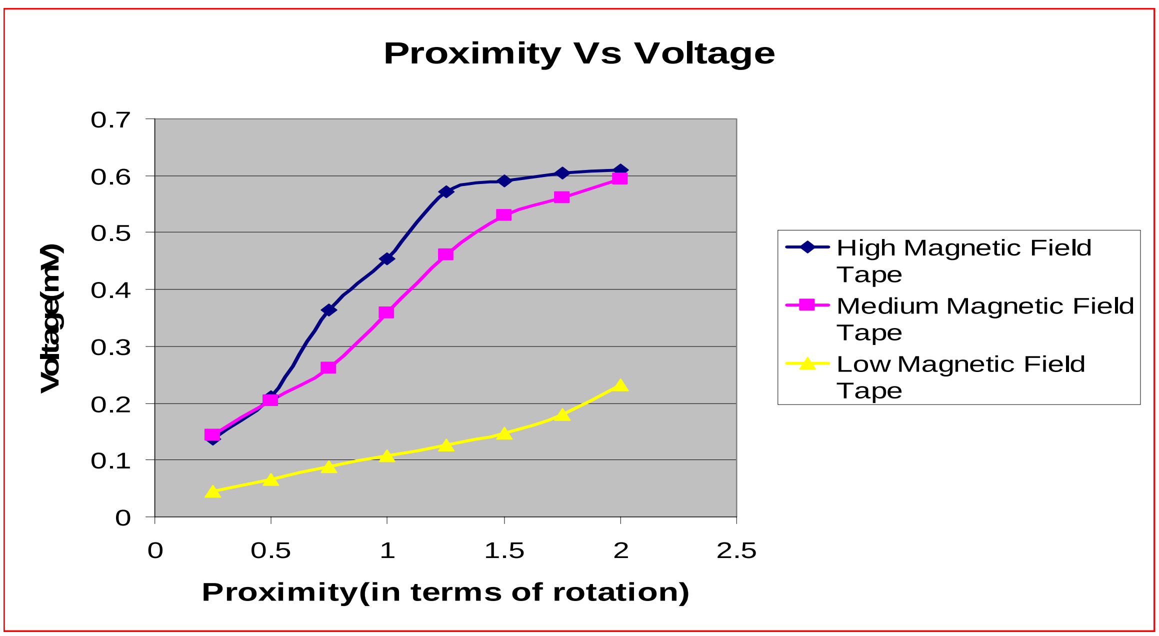


Fig 11: Proximity Vs Voltage graph

In order to use a GMR sensor to detect and measure the proximity in a wire harness clamp, the sensor and a tiny piece of magnet are placed in appropriate locations. As the ends of the clamp are brought closer, the magnetic field increases, causing decrease in the resistivity of the GMR. The output voltage increases dramatically providing a very high sensitivity to measure the distance. Figure 11 shows the relation between output voltage and the distance between clamp ends for different magnetic field strengths. The distance between the metallic ends or the distance between the cushion lips can be measured by placing the magnet and GMR sensor in appropriate locations. In order to measure the clamp pressure on the wire harness we have attempted to use several different types of sensors. Most of the sensors measure pressure only when they are placed between wire harness and the clamp. Thus every clamp requires a sensor to measure pressure. We feel this is may not be cost effective and hence we are continuing to investigate alternative methods to determine the clamp pressure.

Embedded sensors for wiring degradation: Smart Clamps

The sensors used for monitoring, the installation of wire harness clamps, can also be extended to monitor electrical wiring degradation by embedding them in the rubber cushion part of the clamps. The output of the sensor can be radio transmitted using MOTE [3], a low power low cost system that ca transmit over a distance of 500 ft to a computer for periodic monitoring. To test the feasibility of this approach, we embedded GMR sensors inside the rubber cushion and installed it on a wire harness. When an electrical signal propagates through the wire, the GMR sensor detects the magnetic filed around the wire (current sensor). Generally, the current is affected by the quality of the conductor, open and shorts as well as damage to the insulation like chaffing. The output of the GMR sensor was connected to a MOTE and the data was transmitted to a computer. Figure 12 shows the output of the current sensor as a function of current through the wire. The same GMR sensor can also be used to detect the vibration of the wire harness. Figure 13 shows the response with and without vibration.

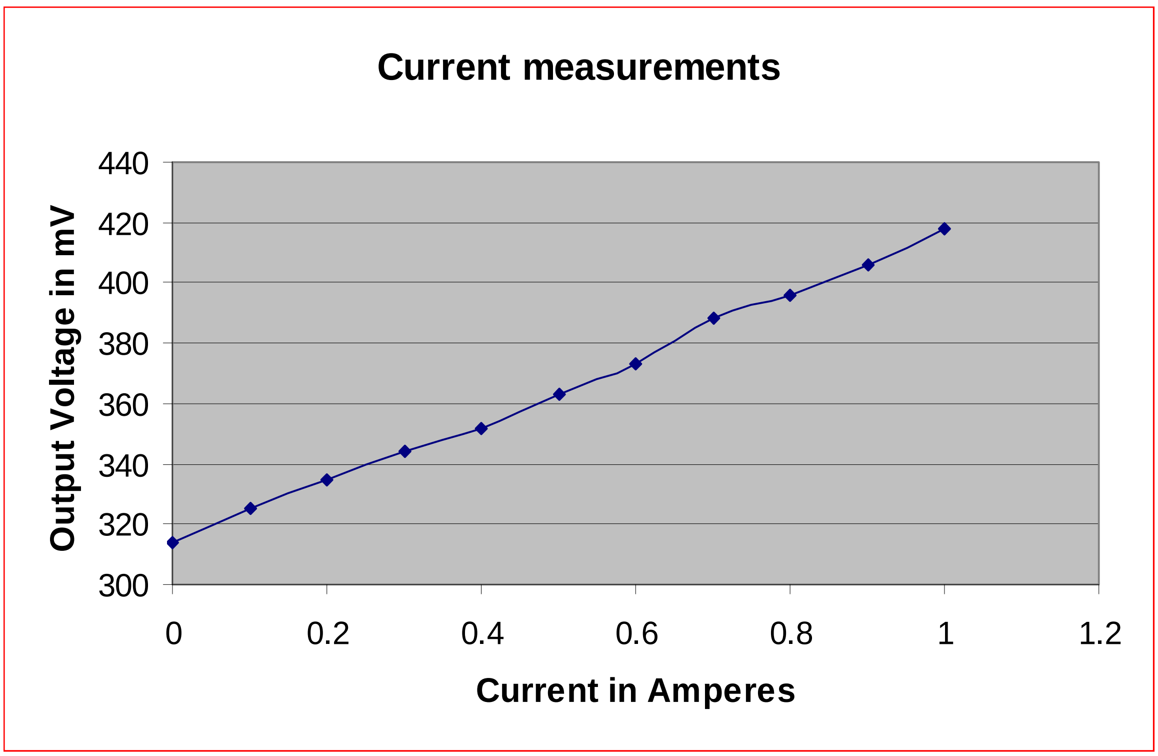


Fig 12: Output of current sensor

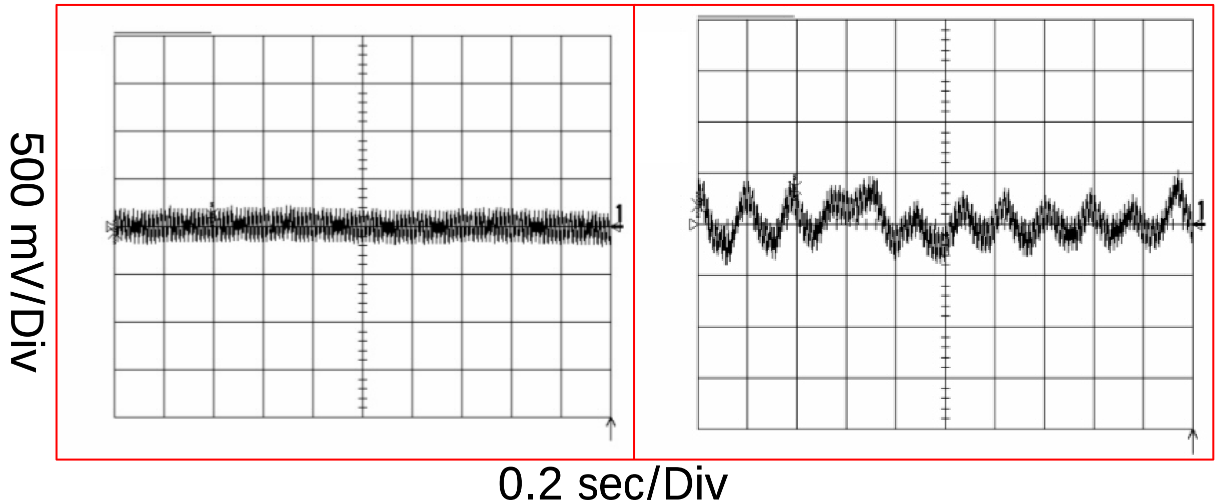


Fig 13: Response of GMR with and without vibrations

Although we have shown preliminary results, the methodology has potential, to remotely monitor the degradation of electrical wiring system by installing 'Smart Clamps' in selected critical locations in aircrafts and aerospace vehicles.

Acknowledgement
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References
[1] Boeing Standard Wiring Practices Manual.
[2] www.nve.com
[3] www.xbow.com