Fabrication of Fabry-Perot Interferometer Sensors and Characterization of their Performances for Aircraft Inspection

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Abstract

This work provides the information for fabricating Fabry-Perot Interferometer sensors and their performances. The Fabry-Perot Interferometer sensors developed here will be used for the detection of flaws in aircraft structures. The sequel also contains discussion of the experimental setups for the Ultrasonic technique and the Fabry-Perot Interferometer.

Introduction

In order to make the type of fiber optic sensor in this work, a single mode fiber and capillary tube were used. A fiber is a glass filament with a core having a slightly higher index of refraction than the surrounding cladding and a buffer layer which surrounds the cladding layer. A fiber is also used as input and output signals. The capillary tube is a hollow core optical fiber tube where the fiber is inserted.

The purpose of this study is to fabricate fiber optic sensors in a cost effective way to be able to detect damage such as corrosion and disbond in the walls of aircraft. In choosing a specific fiber optic sensor the format in which the final output is available is an important concept to consider. In this experiment, an extrinsic Fabry-Perot fiber optic sensor was designed to develop a Fabry-Perot Interferometer Sensor. The performance of the Fabry-Perot sensor was characterized using a multimeter, and an optical microscope. The 1300nm laser light source was used to observe the performance of the Fabry-Perot Interferometer by showing the amplitude changes, due to temperature variation as a function of time.

This work provides additional information for fabricating and characterizing the performance of Fabry-Perot sensors. Many research groups and individuals are either working on or have worked on this same type of project, but in more detail or different aspects. The fiber and electro-optics Research Center in correlation with the Materials Response Group of Virginia Tech have done an analysis of macro-model composites with Fabry-Perot optic sensors [1]. This particular experiment shows how useful macro-model composites, with Fabry-Perot fiber optic sensors, are in measuring strain concentrations introduced by damage events. The department of mechanical engineering at the University of Maryland did research on the phase-strain temperature model for structurally embedded interferometric optical fiber strain sensors with applications [2]. The fiber and electro-optics research center and Bradley department of electrical engineering at Virginia Tech did research on the Fabry-Perot fiber optic sensors in full scale fatigue testing on an F-15 aircraft [3]. This experiment deals with strain and temperature being applied to a interferometric optical fiber sensor and the optical phase changes that occur.

Even though there are many groups and individuals working with fiber optic sensors, in support of this particular work the sources mentioned above were used along with help from my mentor and individuals in the fiber optics group at NASA.

Experimental Procedure

The simplest configuration of the extrinsic Fabry-Perot Interferometer consists of two plane, parallel, highly reflecting surfaces separated by some distance(air gap), see figure 1 [4]. In the construction of the Fabry-Perot fiber optic sensor a single mode fiber (λ_o=1300nm) was used as the input/output fiber and as a reflector to form an air gap. The buffer layer , of two pieces of single mode fiber, was removed using a razor and a radio solvent(a solvent used to remove and loosen cemented cones). The buffer layer was removed because the diameter of the fiber was too large to fit into the capillary tube. After the fiber was taken out of the solvent and wiped off, the ends of the fiber were cleaved with a cleaver. The cleaving had to be parallel in order for the energy reading to be more accurate. The portable fiber splicer(model pfs 330) was used to confirm if the fiber ends were cleaved correctly.

One end of each piece of fiber was put into the capillary tube. Since the capillary tube has a 155μm inner diameter and the fiber optic core and cladding has a 125μm diameter, each piece of fiber must be 15μm away from both edges of the tube. The other two ends of the fiber were put into the splicemates. This setup is shown in figure 2. In this setup the light coming from the laser through the fiber goes into the photodetector and the output(energy reading) is obtained from the multimeter. When an acceptable energy reading was obtained epoxy was applied to both ends of the capillary tube. After the epoxy cured the sensor was characterized using the optical microscope. The optical microscope captured images of the sensors on the computer, making sure an air gap was present, see figures 3-5. The reflection and transmission methods were used to test the quality or performance of the sensor. In the reflection method the coupler was used to help the signal go back to the photodetector. In the transmission method a coupler was not used. Test were ran on the Fabry-Perot sensors in effort to obtain changes in amplitude due to temperature variations as a function of time. These results are shown in figures 6-10. These test were run using the experimenter application. Two sources of temperature were used to determine the change in temperature, which led to the change in amplitude as shown on the graphs, shown in figures 6-10. When there was a small fluctuation and then a change in temperature occurred and the fluctuation became large, the variation of temperature versus time was acceptable. If the quality of the Fabry-Perot sensor was good, the flaws in the aircraft structures were able to be measured using the ultrasonic technique and the Fabry-Perot Interferometer sensor. The aluminum is held together by epoxy and if any detachment takes place or loosens the sensor or transducer can detect the damage. In the ultrasonic technique two transducers were used to find the waveform propagated ultrasonically through the aluminum, see figure 11. In the Fabry-Perot Interferometer sensor setup, the sensor, placed between two transducers, was used to find the amplitude changes within the aluminum, see figure 2.

Experimental Setup and Results

The experimental setup for this project consisted of a 1300nm laser used as a light source, a photodetector used as a detector, a coupler used to help measure transmitted optical power and reflection, and a Norland Products, Inc. splicemate used to connect the sensor to the coupler(all of these devices are shown in figure 2) [5]. A Reicher Austria Nr. 362257 Optical Microscope was used to capture images of the fiber optic sensor revealing the air gap, these images are shown in figures 1, 3,4, &5. A Hewlett Packard 3478A multimeter was used to show the output amplitude reading obtained from the sensor(readings are shown in figures 6-10). A solder iron was used as a source of temperature, a CT-03 Cleaver was used to form parallel cut fibers, and a Portable Fiber Splicer model PFS 330 was used to confirm the parallelism of the cleaved fiber.

Experiments were performed using Fabry-Perot sensors. The Fabry-Perot fiber optic sensors shown in figures 1 and 3 were used to obtain experimental results. If an energy reading less than -.5volts occurred, the performance of a sensor was not acceptable. Sensor number three contained a low energy reading of -.046millivolts. This could have been caused by the size of the air gap. In an air gap the light is dissipated by the air, which means the larger the air gap the smaller the intensity, and the smaller the air gap the more light can pass through the two fibers. Another cause of low energy readings could have been because of a misalignment between the two pieces of fiber in the capillary tube. The problem occurred in sensor number three because of a large air gap, shown in figure 1. Tests were run on sensor number three, despite the low energy reading, to further justify the malfunction in performance of the sensor. Figures 6 and 7 show the amplitude changes due to temperature as a function of time for sensor number three. As mentioned in the procedure, when a small fluctuation occurs and then there is a change in temperature and the fluctuation becomes large, the variation of temperature versus time is acceptable. Shown in figure 6 there is really no type of amplitude change to make this test run acceptable, and in figure 7 the amplitude decreases at a temperature change instead of increasing. Sensor number four contained an initial energy reading of -1.28volts and a final reading of -1.69volts. This sensor, shown in figure 3, was of good quality and therefore could be further tested. In figures 8-10, amplitude changes due to temperature variation as a function of time are shown for sensor number four. In figure 8, when a temperature change occurred, the amplitude increased. In figure 9, the temperature did not have any type of effect on the sensor, which caused a great amount of fluctuation. And lastly in figure 10, a solder iron was used as a source of temperature to indicate amplitude changes. The Fabry-Perot sensors shown in figures 4 and 5 are just two of the first sensors fabricated during this project. Figure 4 shows a misalignment and figure 5 is a good quality sensor but it was broken so it was not used for testing.

Acknowledgments

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Discussion

The testing of damage such as corrosion and disbond that occurs in aircraft structures can not be accomplished without first fabricating and characterizing the performance of the Fabry-Perot Interferometer sensor. This particular project indicated the experimental procedure used to complete fabrication and characterization of the Fabry-Perot Interferometer sensor. The actual testing of damage in aluminum or aircraft structures was not performed, but the setups for the ultrasonic technique and the Fabry-Perot Interferometer sensor were completed. Figure 11 shows the setup for the ultrasonic technique. If a waveform is not shown on the Lecroy 9400A Dual Digital Oscilloscope, there is indication that a crack or disbond has formed in the aluminum. Figure 2 shows the setup for the Fabry-Perot Interferometer sensor. If the voltage reading from the multimeter changed or approached zero, there is indication of a crack or disbond in the aluminum. The readings from the multimeter and the oscilloscope relate because when there is a waveform on the oscilloscope there is a voltage reading on the multimeter and when there is not a waveform, the reading on the multimeter is zero or very close to zero.

References

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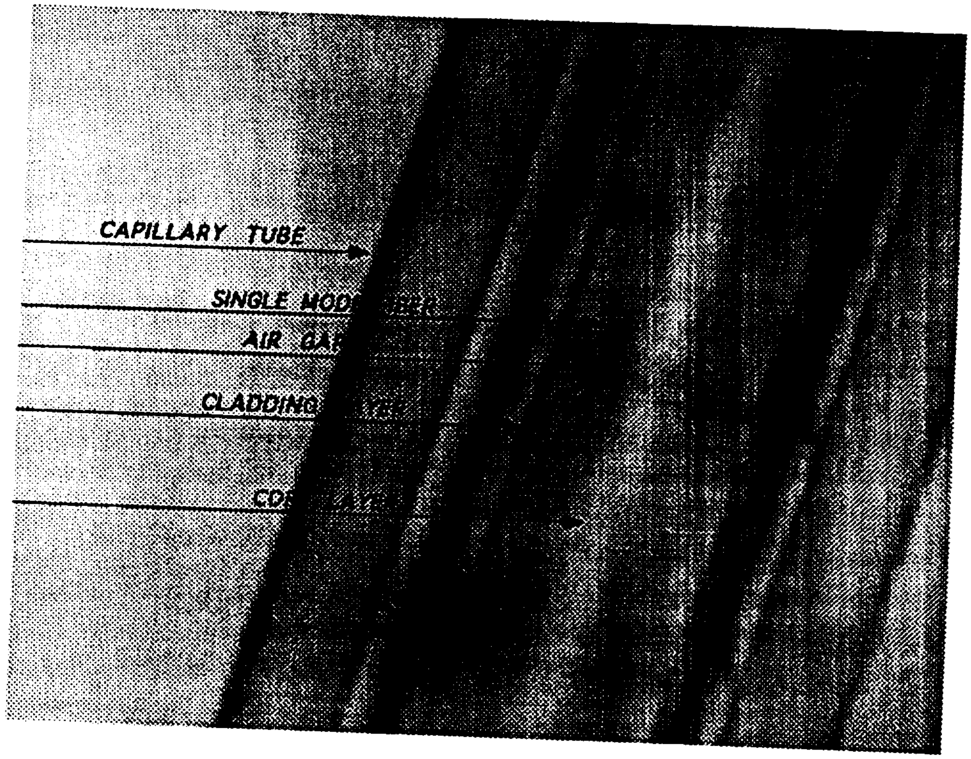

Figure 1. The Fabry-Perot Interferometer Sensor(sensor number three) characterized using the optical microscope.

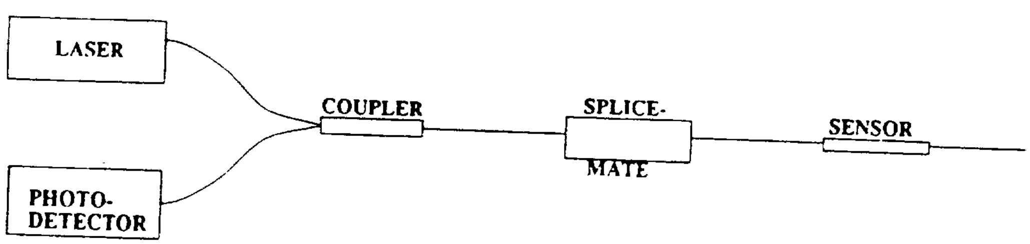

FIGURE 2. EXPERIMENTAL SETUP FOR FABRY-PEROT INTERFEROMETER INSPECTION

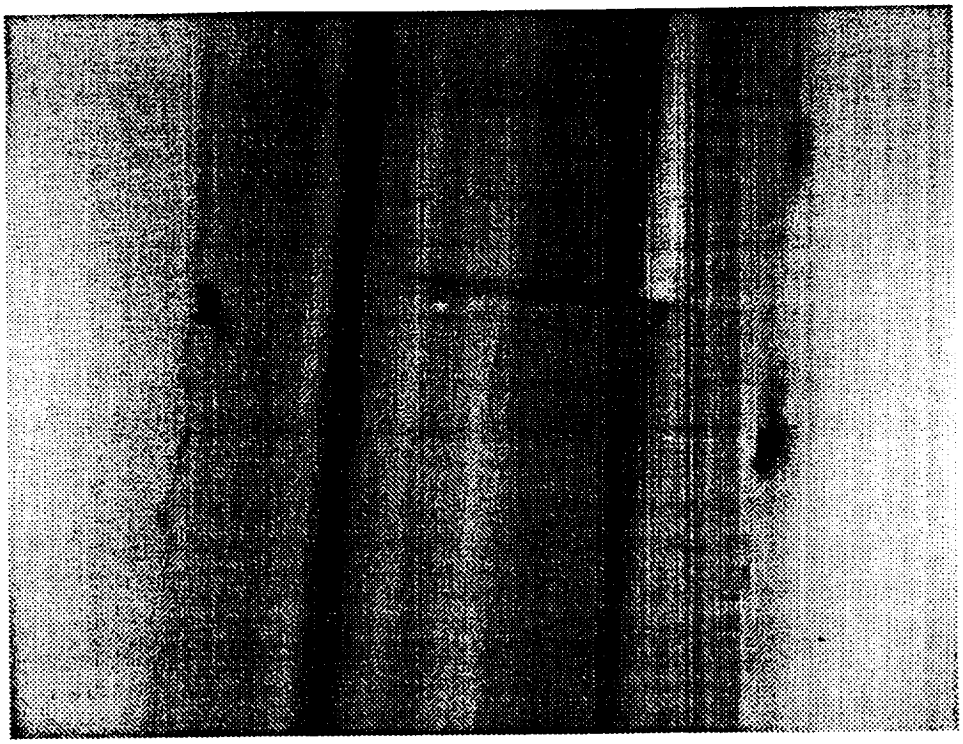

Figure 3. Characterization of the Fabry-Perot Interferometer Sensor(sensor number four) using the optical microscope.

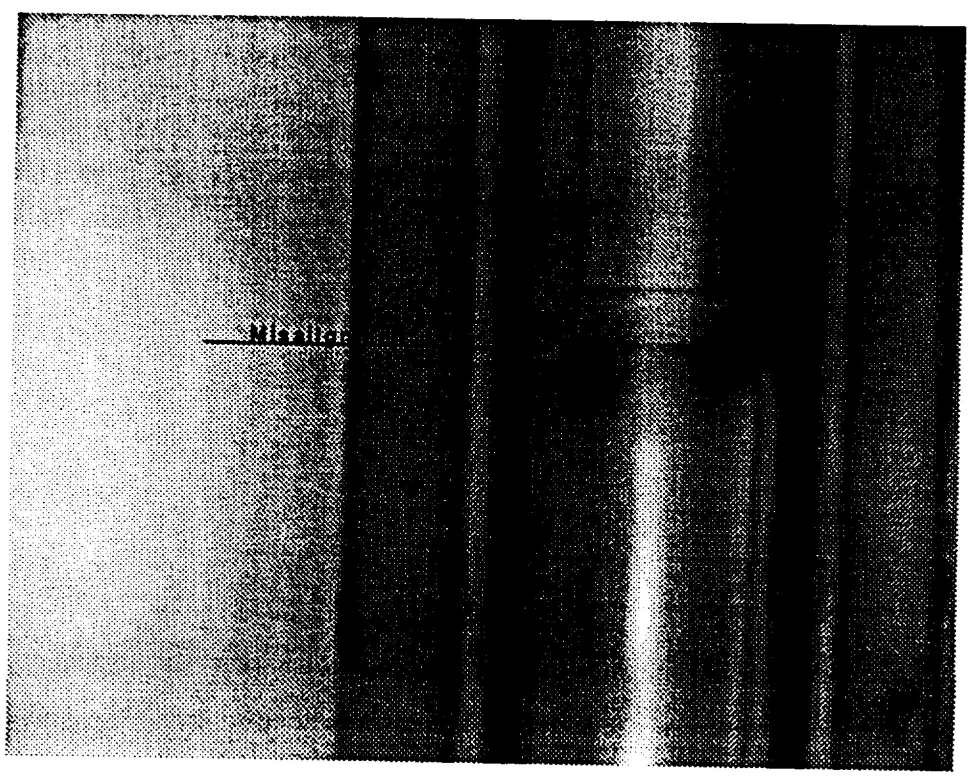

Figure 4. Characterization of the Fabry-Perot Interferometer Sensor(sensor number one) using the optical micrscope.

Figure 5. Characterization of the Fabry-Perot Interferometer Sensor(sensor number two) using the optical microscope.

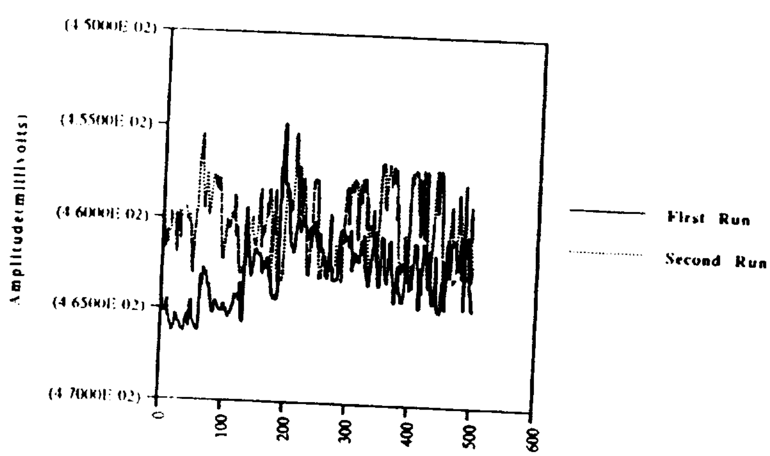

Figure 6. Amplitude changes due to temperature variation as a function of time(Reflection method using sensor number three).

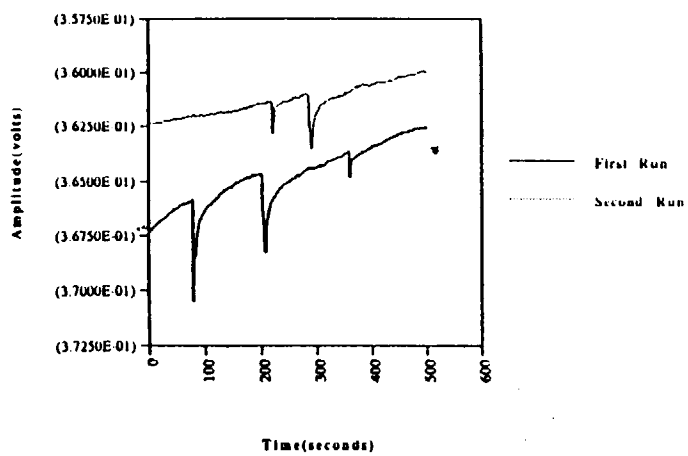

Figure 7. Amplitude changes due to temperature variation as a function of time(Transmission method using sensor number three).

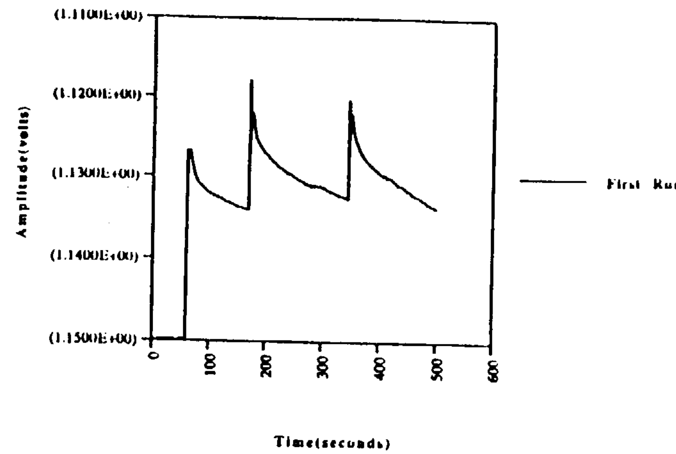

Figure 8. Amplitude changes due to temperature variation as a function of time(Transmission method using sensor number four).

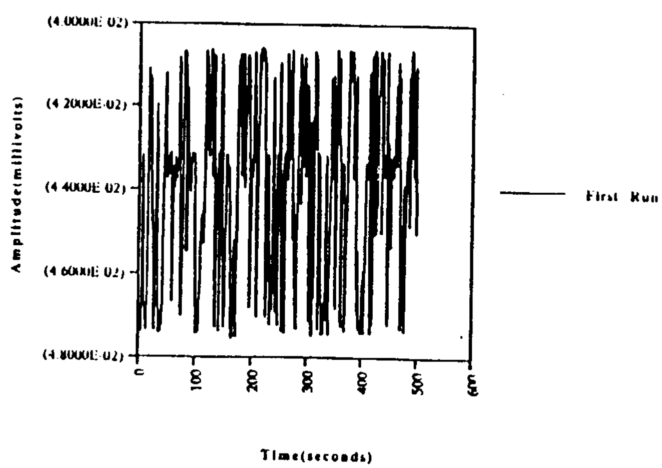

Figure 9. Amplitude changes due to temperature variation as a function of time(Reflection method using sensor number four).

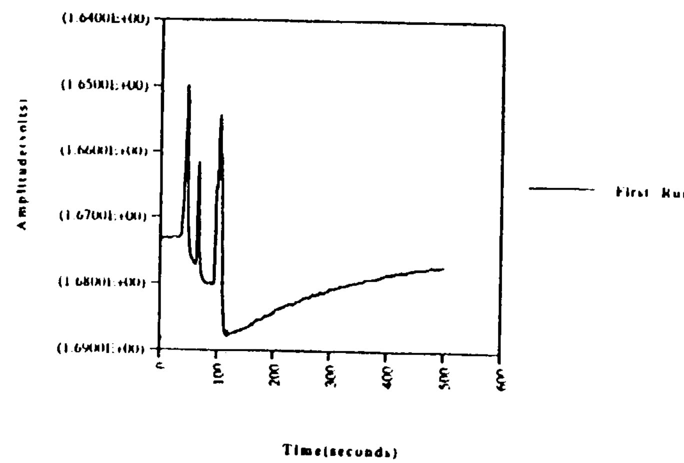

Figure 10. Amplitude changes due to temperature variation as a function of time(a solder iron was used on sensor number four).

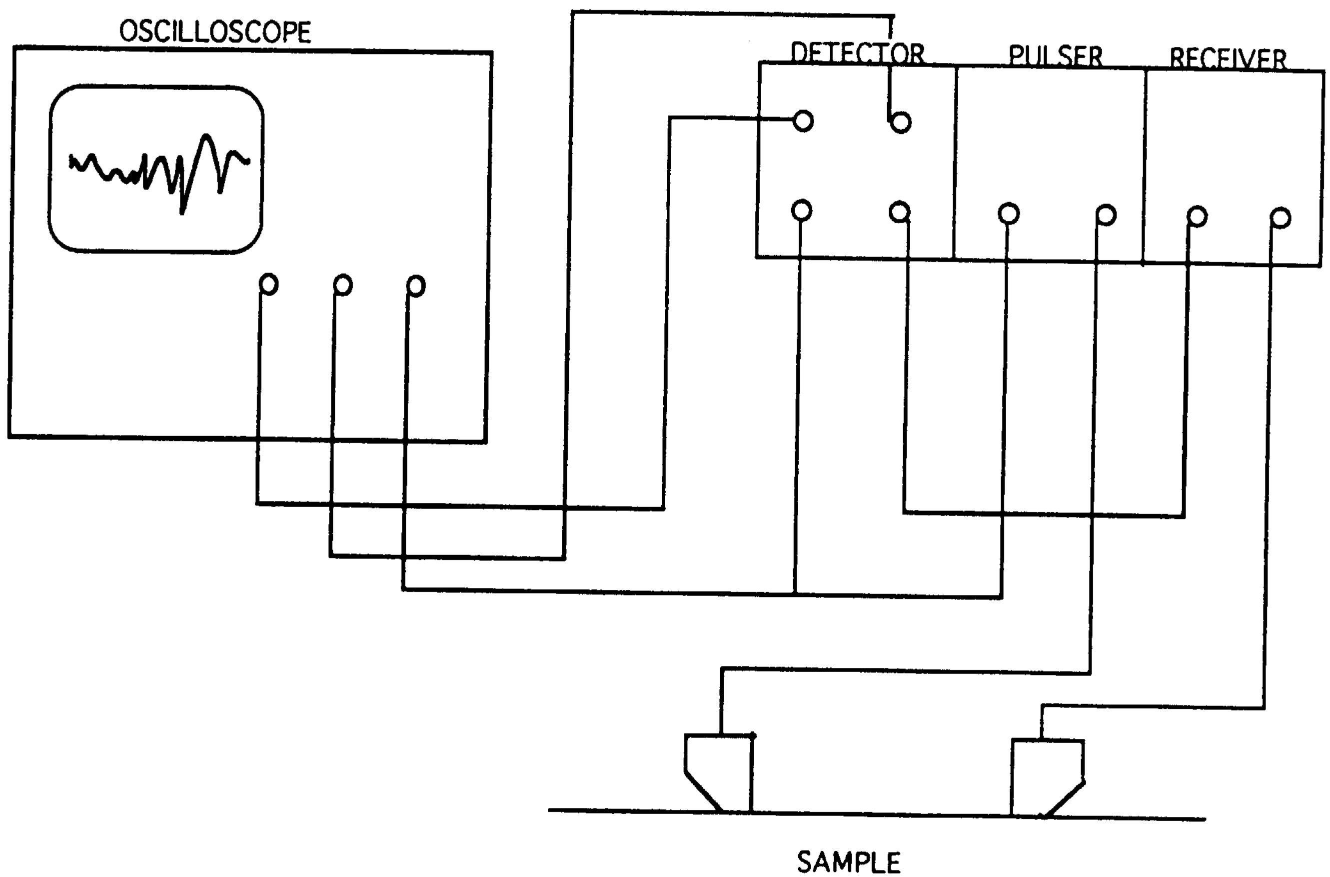

Figure 11. EXPERIMENTAL SETUP FOR ULTRASONIC INSPECTION