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Evaluation of FeCo Magnetostrictive Sensors for SHM of Components Operating in Harsh Environmental Conditions

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ABSTRACT

One effective way to inspect or monitor large components such as pipes or plates is to use guided wave testing (GWT) systems. A number of commercially available GWT systems suitable for inspection of various components at ambient and elevated temperatures have been developed by different groups [1-3]. Development of GWT systems for monitoring at high temperatures is very challenging, because the sensor is exposed to a harsh environment for long periods. Some experimental work and findings related to SHM of pipes operating at temperatures up to 200°C have been reported [4-5]. In the nuclear and petrochemical industries, however, there is a need for monitoring of components operating at temperatures up to 650°C.

Magnetostriction is promising transduction mechanism for high temperature applications because generation of elastic waves in materials does not require soldered joints, which a limiting factor in other transducer designs. The work presented here demonstrates significant progress in the generation of guided waves at elevated temperatures utilizing a ferromagnetic strip with a high magnetostriction coefficient, attached to the component under test. The strip material evaluated during this effort was a special alloy of Iron Cobalt (FeCo). The transduction efficiency as a function of temperature and strip magnetization were studied. It was shown that the necessary transduction can be supported at a satisfactory level in a temperature range up to 800°C, with variations in signal amplitude in the order of 6 dB. The most suitable temperature range was found to be below the recrystallization temperature of 700°C for this material. The results of the test can be used to improve magnetostrictive sensor designs for SHM of pipes operating at 500 °C [6].

Keywords: Guided waves, SHM, magnetostrictive sensors, structural health monitoring, high temperature, Wiedemann effect

NOMENCLATURE

SHM	Structural health monitoring
GWT	Guided wave testing
FeCo	Iron Cobalt alloy
MsS	Magnetostrictive sensor

1. INTRODUCTION

Of the many magnetostrictive materials suitable for transducer design, the FeCo alloy Hiperco 50HS has the highest Curie temperature (approximately 938° C). This alloy has a relatively large magnetostrictive coefficient (60 versus 30 microstrains for nickel). It is mechanically strong (yield strength 276 to 414 MPa versus less than 138 MPa for nickel, for example). These material characteristics make it suitable for use in sensors intended for operation in harsh environmental conditions.

The magnetic properties of this alloy in static fields as a function of annealing regime and rolling process have been extensively studied, as summarized by Bozorth [7]. On the other hand, the performance of the Hiperco 50 HS alloy in superposed 5 – 200 kHz magnetic fields (specifically for generation of transverse vibrations) and at elevated temperatures has not been so widely reported on in the literature. The most relevant investigations for high temperature applications were related to space power systems; these covered frequencies up to a few kilohertz (kHz) [8]. The purpose of this study was to evaluate the performance of this alloy for generation and reception of guided waves for GWT applications at high temperatures.

2. MATERIALS AND METHODS

To evaluate the performance of Hiperco 50 HS at elevated temperatures, two rectangular 25.4 mm x 25.4 mm x 0.15 mm (1 inch x 1 inch x 0.006 inch) patches of Hiperco 50 HS alloy were spot welded to a stainless steel strip waveguide and loaded in a furnace, as shown in Figure 1A. One patch was located in the furnace in the 'hot' region, while the second was located outside the furnace in the 'cold' region. For each sensor, two excitation coils were wound around the patch to create mutually orthogonal static and time-varying magnetic fields. This arrangement utilizes Wiedemann effect for transduction [9]. The bias magnetic field was provided by a short duration (10 millisecond) pulse of DC current. The alternating current (AC) pulse was generated by a magnetostrictive GWT instrument (MsSR3030R); data acquisition was initiated with a DC signal synchronized with the magnetic bias pulse.

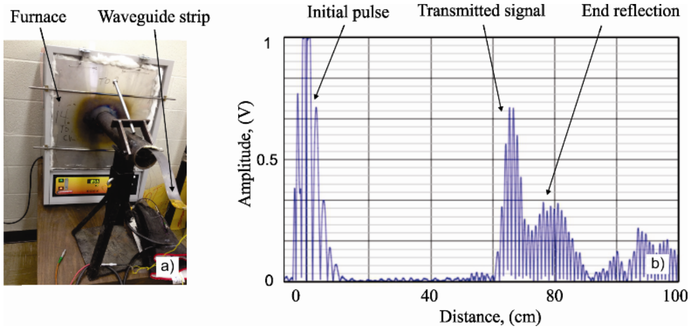

FIGURE 1: A) EXPERIMENTAL SETUP, B) ACQUIRED SIGNALS

The transduction efficiency of the strip samples were assessed at 50 kHz in a pitch-catch mode by generating a guided wave using a magnetostrictive strip located in the hot area and receiving the transmitted signal using a receiver located in the cold area. Reception efficiency was assessed at 50 kHz in pitch-catch mode by reversing the transmitter and receiver locations. The signal amplitudes were recorded in the temperature range 70 – 940°C, with the current in the exciting coils maintained at a constant level over this temperature range. A fundamental shear horizontal (SH0) mode guided wave was excited in the FeCo strip sample. Only the amplitude of the pulse traveling in the forward direction (towards the receiver placed near the far end) was measured. The interference of the wave with the near end of the waveguide was effectively eliminated by placing the patch at a 200 mm (~ 8'') distance from the near end. The received signal amplitude at the beginning of the test is shown on Figure 1B.

3. RESULTS AND DISCUSSION

Figure 2 shows a plot of the amplitude readings obtained during this experiment from the strip sample exposed to the heat in the furnace. Two nearly identical heating cycles and one cooling cycle were used to measure the amplitude produced by the strip sample acting as a transmitter and as a receiver. Temperature readings were averaged between the built-in furnace temperature sensor and a thermocouple attached to the waveguide near the end of it. The rate of heating/cooling was approximately 300°C/hour.

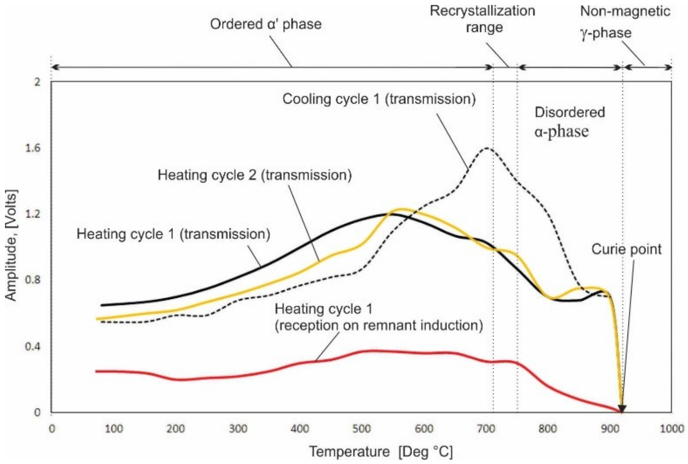

FIGURE 2: AMPLITUDE READINGS OBTAINED FROM THE SAMPLE OF FECO MATERIAL IN THE TEMPERATURE RANGE OF 70 – 920°C FOR ONE HEATING CYCLE FOLLOWED BY A COOLING CYCLE FOLLOWED BY ANOTHER HEATING CYCLE

The strip sample produces a steady increase in the transmitted signal amplitude from 0.6 to 1.2 volts up to 550° C. This could be explained by the fact that the coercive force of the material tends to decrease with the temperature. Following amplitude reduction to 0.6 volts at 800°C most likely resulted from reversible changes in the magnetic properties of the material, because ordered α' phase converts to disordered α phase. In the temperature range 800 – 900°C, the amplitude stayed at 0.6 volts. After the temperature reached 900°C, the amplitude started to decline and dropped to zero at 930°C. This is likely the result of a transition from ferromagnetic α phase to paramagnetic γ phase; this transition determines the Curie temperature for the alloy.

The same sample was run through the heating cycle twice and produced a substantially similar pattern of signal amplitudes both times. This confirms that an appropriate experimental setup was selected. It was also noticed that during cooling cycle, a local peak in the signal amplitude was observed (1.6 volts) in the temperature range of 720 to 740°C (recrystallization range). The reason for this effect needs to be better understood. The received signal amplitude using only remnant induction fluctuated in the range of 0.3-0.4 volts until the temperature reached about 800°C and then started to decline. After exposure to the heat, the strip sample was covered by an oxide layer (known as an effective corrosion resistant coating).

The results of this test indicated that with 6 hours of overall exposure to temperatures up to 900°C, the strip sample produced either similar or higher transmitted signal amplitudes compared to the measurements taken with the original strip material conditions. Also, it was concluded that remnant induction of the sample should allow it to function as a receiver up to approximately 750 - 800°C.

4. CONCLUSION

Performance of the Hiperco 50 HS alloy strip as a magnetostrictive actuator was investigated at temperatures up to 920°C. The alloy exhibited high potential to work as a magnetostrictive transduction sensor at up to 800°C. Approximately 6 -10 dB variations in signal amplitudes were observed as a function of temperature; this behavior needs to be taken into account when configuring systems used for SHM.

Longer term testing is needed to evaluate the impact of aging at higher temperatures on the alloy's magnetic properties.

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