Development of Magnetostriction Based Ultrasonic Transducer For In-situ High Temperature Inspection

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Abstract

Ultrasonic transducers that can work under in-situ high temperature are of much interest to the nuclear industry, in view of the possibility of on-line inspection without plant shut down. This paper describes a novel solution to address this problem, based on ultrasound generation through the magnetostriction phenomenon. Previous research by the authors led to the development of a novel material that supports significant magnetostriction even at elevated temperatures. Here, this material is incorporated into a waveguide sensor/actuator pair that forms the core of the proposed transducer, which is then tested under high temperature furnace conditions. Results show that the proposed concept can be used for high temperature defect characterization at 1 MHz. Advantages and challenges to practical realization of the technique are discussed.

Keywords: magnetostriction, high temperature, in-situ, ultrasonic transducer

1. BACKGROUNDAND INTRODUCTION

Nuclear industry is interested in ultrasonic transducers capable of operation at high-temperatures for non-destructive evaluation (NDE) of various critical components to obtain the internal state of the structures [1]. On-line inspection and monitoring is very important, as safety can be improved and life-cycle cost can be reduced [2,3].High-temperature ultrasonic transducers based on piezoelectric active-elements are widely reported in the literature[4].

This paper reports on our efforts to develop high-temperature bulk ultrasonic transducers based on the principle of magnetostriction. Ultrasonic transducers based on magnetostriction are typically used in the context of ultrasonic guided-wave inspection of plates and pipes [5]. They are cost-effective and can be suited for long-range applications [6, 7] but operate typically in the low-frequency regime.

The paper is organized as follows. The problem under study is first addressed, followed by a description of design approach and testing procedure. Results are presented and discussed, after which the paper concludes with an outlook for future work.

2. PROBLEM STUDIED

The broad goals of the research reported here is to provide a solution to the problem of in-situ high-temperature bulk ultrasonic inspection and monitoring. In view of the focus of bulk ultrasonic waves, high frequencies of operation in the 1 - 5 MHz range are of interest. The designed transducer needs to meet the following criteria:
(i) capable of ultrasonic NDE
(ii) be able to withstand and operate at elevated temperatures in the range of 300-600°C
(iii) be able to operate continuously for long durations

3. METHODOLOGY

3.1 DESIGN

The developed transducer is based on principles of magnetostriction and its inverse effect. The basic design is adopted from literature[5]. The challenge is to extend the design to sustain high temperature during longer duration of operation.

In the transducer design proposed here, there are two separate coils, transmitter coil (T) and receiver coil (R) which facilitate generation and reception of ultrasonic waves. To make the design simple, at the current stage, the transmitter coil and the receiver coil are placed away from each other to avoid any induction which may occur. The design uses a magnetostrictive core which must sustain the long hours of operation at high temperature. A suitable magnetostrictive core, Metglas® is chosen for stable properties at high temperature [8]. MWS mutlifilar wires are used in coils [9].

T and R coils along with the magnetostrictive core are wound on a rod (MS Φ 5 mm). This acts as the sensor/ actuator pair of the developed transducer. The rod is welded on a test block of known dimensions. T and R coils are connected to a pulser-receiver [10] which provides alternating voltage. T coil generates ultrasonic waves as a result of the alternating magnetic fields generated when this voltage passes through the coils wound over the magnetostrictive core. Axisymemtric longitudinal guided wave modesare generated in the rod at 1 MHz by the T coil and received by R coil after reflection from the free surface of the test block.

3.2 EXPERIMENTAL STUDIES

The experimental setup consists of a pulser-receiver [10], a high-resolution scope [11] and a furnace [12] to simulate the high temperature environment. The experimental setup is shown in Figure 1.

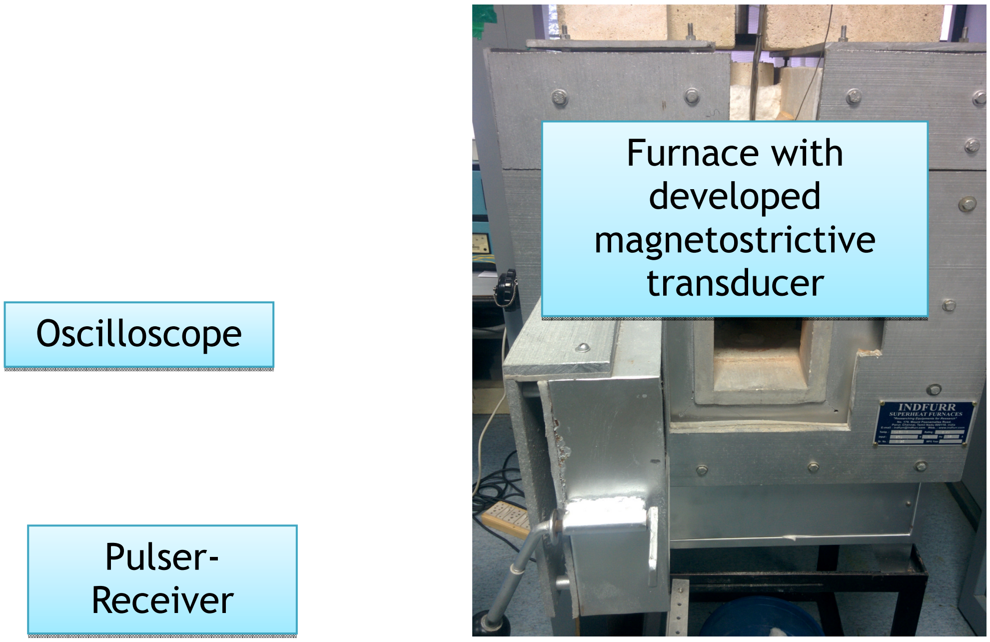

Figure 1: Photograph of developed high-temperature magnetostrictive ultrasonic transducer

Two experimental procedures are followed to demonstrate continuous high-temperature operation. The first experiment is to determine if the transducer is able to generate and receive the ultrasonic waves and withstand the temperature. The temperature range is slowly increased in steps. The second experiment is to study the variation of the amplitude of signals (in V) received by transducer as a function of time (in hours). The results of these two experiments will be discussed in the following section.

4. RESULTS AND DISCUSSION

4.1 Demonstration of high-temperature (350°C) operation

The transmitter coil generates ultrasonic wave when alternating voltage passes through the winding, as a result of the principle of magnetostriction. An input frequency of 1 MHz is used to excite the same. L(0,2) is generated at 4488 m/s in the rod medium. The A-scan is shown in Figure 2. Different regions of the plot are highlighted. They are detailed, as follows. When the ultrasonic wave reaches the Receiver coil, through the principle of inverse magnetostriction, voltage is induced into the winding and the same is recorded by the oscilloscope. This is described as *First arrival from T coil.* Following which, the wave encounters the weld joining the rod and the test block. Another reflection is observed as a result of impedance mismatch. This is described as *Reflection from the welded joint.* The final reflection is seen as the wave is reflected from the free surface of the test block. It is approximately 71 µs. This is described in the plot as *Reflection from the test block.*

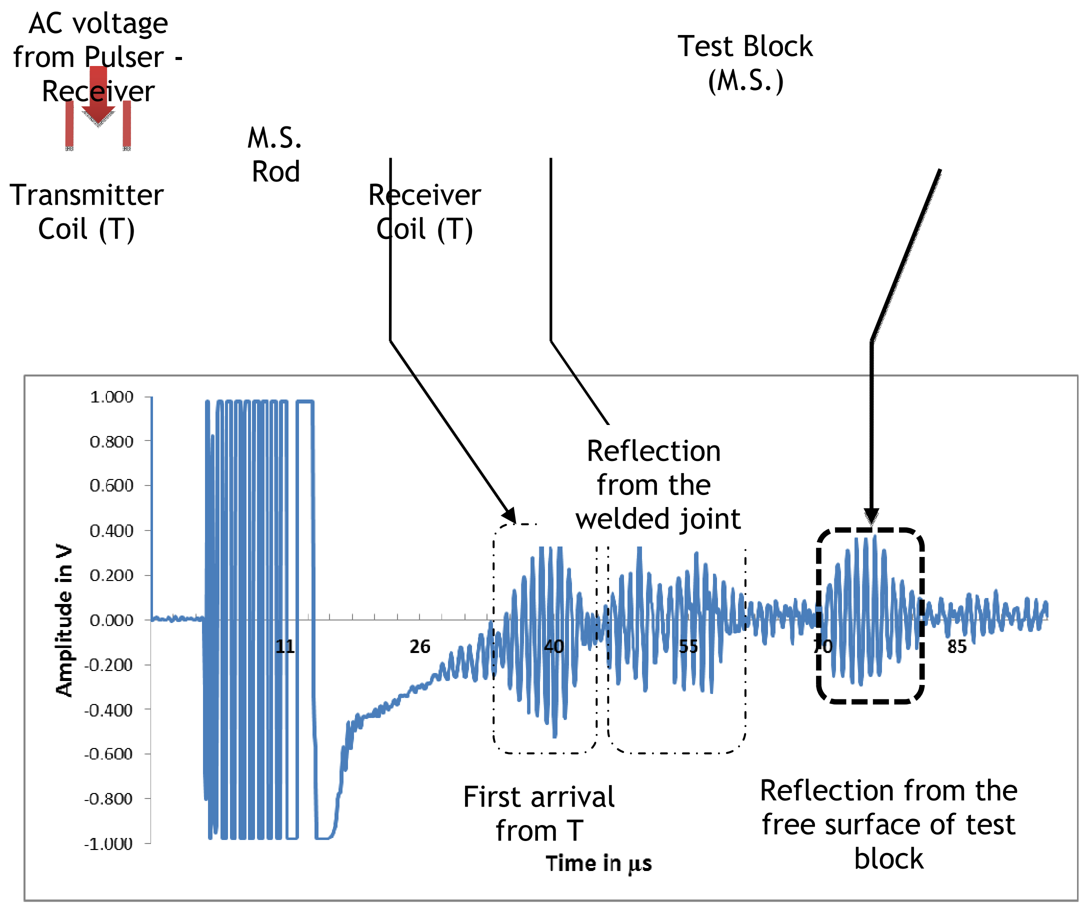

Figure 2: A-scan demonstrating operation of developed magnetostrictive transducer at high temperature (350°C)

4.2 Demonstration of in-situ high-temperature operation for 10 hours

The variation in the amplitude of reflection from the free surface of the test block is studied as a function of operation time. The developed transducer is left to run in the furnace for 10 hours continuously. The A-scans are recorded at regular intervals. Peak amplitude of target signal is plotted against the observation time, as shownin Figure 3 below: this demonstrates continuous operation of the prototype design for 10 hours. The reasons for initial increase of amplitude and other fluctuations are currently being investigated.

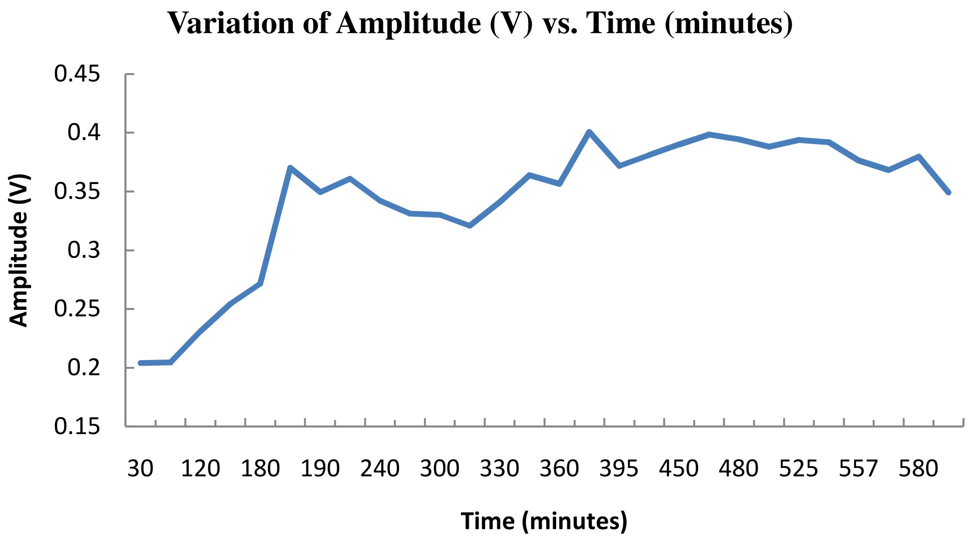

Figure 3: Plot demonstrating operation of developed magnetostrictive transducer at high temperature (350°C) for 10 hours continuously

5. SUMMARY AND FUTURE WORK

This paper describes the development ofin-situ high temperature magnetostrictive ultrasonic transducer at 350°C for 10 hours. The amplitudes of output are 200 to 400 mV, which are much high compared to most piezoelectric-based transducers. Future work involves extending the operating temperature range and make it suitable to sustain immersion conditions.

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