A giant magneto resistive (GMR) eddy current sensor for use as a zero width coordinate measuring machine probe

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Summary

This abstract presents the working principle and some early results of using a GMR eddy current sensor as a CMM probe for detecting interfaces and edges. Two sets of factors effect accuracy and precision of this technique, these being the geometry and operational parameters of the probe and the assembly being measured. The influences of these variable parameters on the measurement are briefly discussed. As an example, it is shown that the location of the contact interface between two aluminum plates can be measured from the magnitude and/or phase response of the probe as it traverses over the surface. Analytic methods for interface location are also discussed.

Introduction

Preliminary results using a giant magneto resistance (GMR) based eddy current sensor for the directional detection of edges and discontinuities in solid surfaces are presented in this brief paper. An example of such a surface might be the surface that is created after the shrink fitting of a shaft in a hole, the wringing together of gage blocks or clamping of multiple components into an assembly. Clearly in this case it is not possible to use a conventional coordinate measuring machine (CMM) probe which relies on mechanical contact of a sphere of finite radius. The eddy current probe presented herein consists of a pancake-type excitation coil that creates circular eddy currents confined in a region near the surface of the specimen under test, figure 1. Dimensions of the excitation coils used in experiments range from mean radii of 1 to 8 mm. The sensing element consists of either a unipolar GMR or bipolar spin dependent tunneling (SDT) GMR sensor both in a Wheatstone bridge configuration. This represents a very directional device, detecting only the field vector along its sensitive axis. The GMR sensor is placed at the end of the coil on its symmetry axis, while the sensor's sensing axis is coplanar with the surface of the specimen. In this way, the sensor is insensitive to the excitation field that is oriented perpendicular to the specimen surface. Moreover, when the probe is placed above a defect-free specimen, because of the circular symmetry of the induced eddy currents, the magnetic fields at the sensor's location

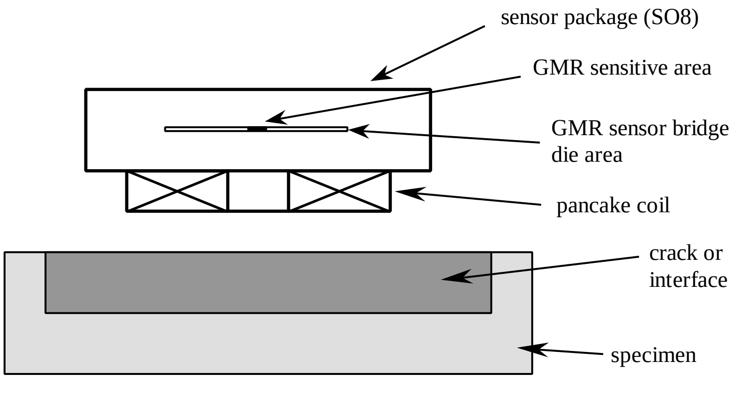

Figure 1: Schematic diagram indicating probe configuration

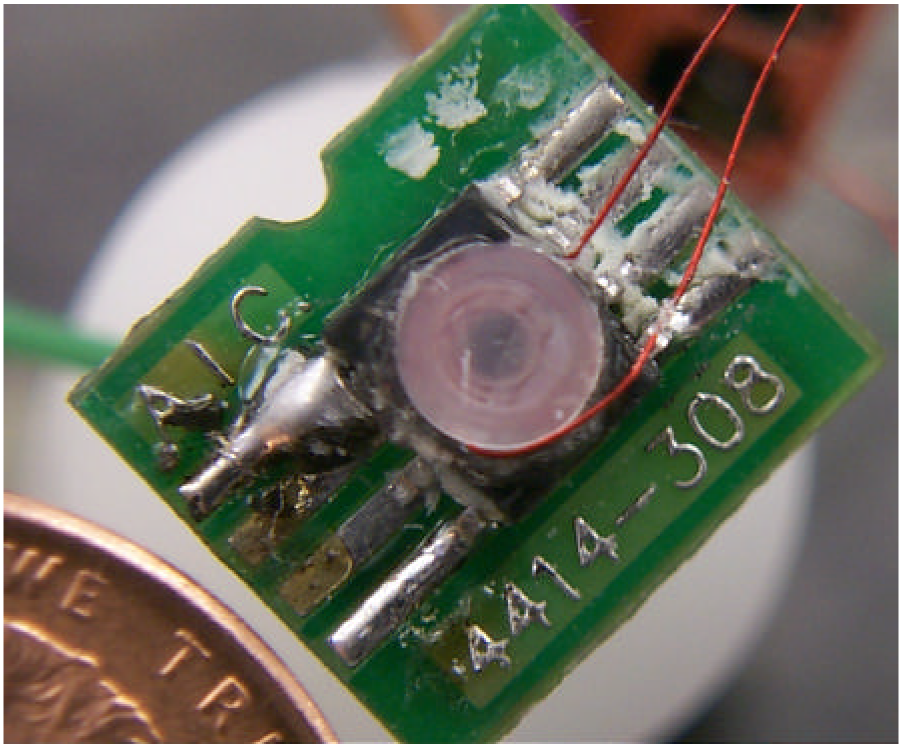

Figure 2: Digital image of GMR sensor with pancake coil attached to the lower face. A US penny (1 cent coin) is shown in the lower left corner for scale.

cancel. As a consequence, the sensor's output is zero in the case of a defect-free specimen. Figure 2 shows a digital image of a typical eddy current probe.

In general, induced eddy currents will form loops confined to the surface by the skin effect and concentrated mainly in a path corresponding to the mean coil diameter[1]. As the probe is traversed towards an edge, a crack or any other electrical discontinuity, the circular eddy current field will be perturbed thereby producing a signal at the sensor proportional to the asymmetry of the eddy current loops. Because of the change in impedance across contacting surfaces, a mechanical interface can be modeled as a thin crack. Consequently, there will be two current loops confined either side of the interface with the currents following the mean circumference of the coil and also along the interface. Because the eddy current loops will circulate in the same direction, the two currents flowing either side of the interface will be in opposite directions or 180 degrees phase shifted. During measurement, the sensor is oriented to be sensitive to fields produced by the currents flowing along the interface, its output will be proportional to the net field at the sensor. As the small sensor traverses over the crack, the single eddy current loop will be split to form a chordal "D" shaped loop on one side and a circular loop on the other that is cut by the interface. As the sensor approaches the interface, the current following the 'crack' on the side nearest to the sensor will produce the largest field. When the axis of the coil is located directly above the crack, there will be equal and opposite current loops, each a perfectly semi-circular "D", either side. Because the currents are of equal magnitude and opposite phase, the magnetic field in the plane of the sensor will be zero. Continuing across the interface the currents on the opposite side will begin to dominate thereby producing a steadily increasing signal that tends towards 180 phase shift relative to that produced on the opposite side.

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[1] Dogaru T. and Smith S.T., 2000, A GMR based, eddy-current sensor, *IEEE Trans. On Magnetics*, submitted

Results

To illustrate the operation of such a probe, a pair of aluminum plates of similar thickness and with ground edges were placed in intimate contact on the bed of a Bridgeport milling machine. An SDT eddy current probe similar to that shown in figure 2 was then mounted in the spindle with the lower face of the pancake coil about 0.1 mm above the surface. The sensor was then rotated to maximize sensitivity to the interface (rotating the sensor by a further 90 degrees would effectively make the crack invisible). Future probes will incorporate bi-directional sensing elements to determine the vector of the field in the plane of the sensor. The specimen was then traversed under the probe at increments of 0.0254 mm and the amplitude and phase was measured at excitation frequencies of 20, 30 and 40 kHz using an SRS 850 lock-in amplifier.

Figure 3 shows the magnitude and phase of the output from the probe as it traverses over the surface of the two plates across the interface between them. A minima and a rapid phase change tending to 180 degrees can be seen as the probe passes the interface located at a position approximately 5.3 mm from the start of the scan. The asymmetry in the magnitude and phase responses is caused by misalignments between the sensor, coil and specimen.

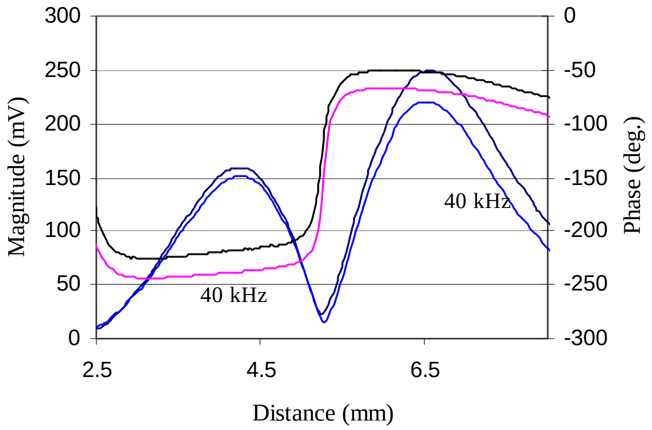

Figure 3: Magnitude and phase response of the eddy current probe at excitation frequencies of 30 and 40 kHz as it is traversed over a interface between two aluminum plates

A number of analytical methods may be used to determine the position of the interface. Tracking the minima, which, for a perfect probe, should tend to zero, is a simple method that may be used to determine the location of the edge. By location, it is inferred that this would be a point that would traditionally be considered the trigger event of a conventional CMM probe.

However, there are analytic methods that might provide a more precise location of the interface. A full representation of magnitude, phase and displacement requires a 3_D plot showing the response as a continua of points in space (i.e. a string). Figure 4 shows the three orthogonal views of such a three dimensional plot for the response measured at an excitation frequency of 40 kHz. The first figure is traditionally called a polar plot and this exhibits a characteristic figure “8”. In this figure the displacement is along an axis perpendicular to the plane of the page. As the sensor moves over the interface the phase shift rapidly changes by 180 degrees and can be seen as the relatively straight line at –45 degrees. The position of the interface can be considered to occur at the point of intersection in the figure “8”. Alternatively, the plot can be viewed along the displacement axis from two directions to yield the real and imaginary parts of the response, figure 4(b). Theoretically, the real and imaginary parts of the response should cross the axis of the graphs when the sensor is located above the interface. In reality, the intersection of the two plots will be shifted by offsets caused by manufacturing tolerances in the probe and specimens (the effects of which are currently under investigation). Closer examination of the data reveals that the crossing occurs at a position 5.295 mm from the start of the scan.

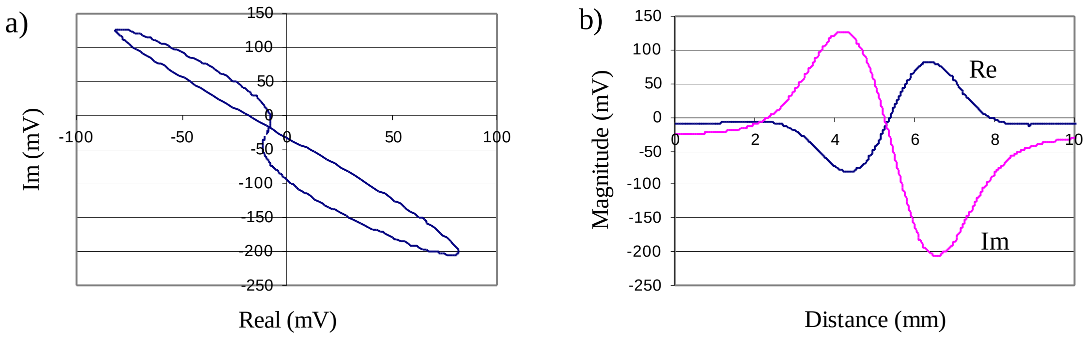

Figure 4: Three orthogonal views of the eddy current probe response, a) polar plot, b) real and imaginary parts of the response. Excitation frequency 40 kHz

Another method can be derived if it is assumed that the most rapid phase change will occur when the probe is traversing directly over it. Hence it may be possible to locate the interface at the peak value of the first derivative of the phase with respect to the scan distance. Additionally, it may be argued that the rate of the phase change is related to the separation of the two opposing eddy currents running along either side of the interface and the relative lift-off of the probe. In general, for a particular material, the eddy currents will be concentrated towards a surface at a depth inversely proportional to the square root of the excitation frequency. In general, the sensitivity of the peak phase slope measurement will be increased with increasing excitation frequency and reduced probe – specimen separation. Figure 5 shows the phase slope as a function of the displacement of the probe. A nonlinear curve fit of a Lorentzian function is also shown for the 40 kHz plot. It is clear that the phase slope is significantly enhanced at the higher frequency. From the non-linear curve fit, the peak is found at a displacement of 5.295 mm a value equal to the location of the intersection of the real and imaginary loci. However, it is also noted that the peak for the phase slope measured with a 30 kHz excitation is slightly shifted. This illustrates that the location of the interface is relative.

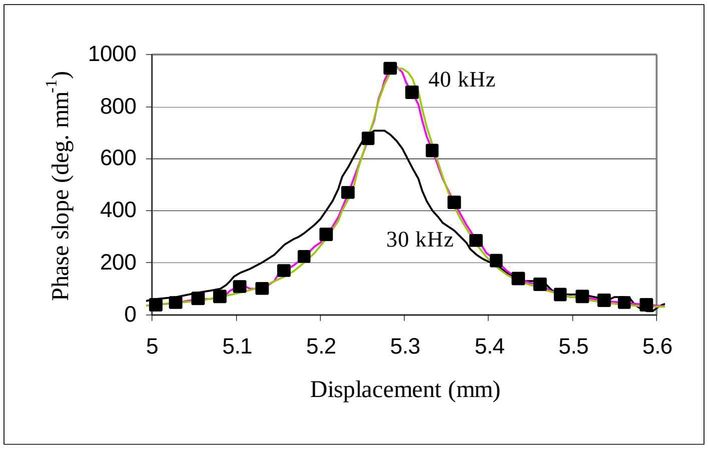

Figure 5: Phase slope as a function of displacement

Although, the principle of operation of an eddy current probe for the location of interfaces has been demonstrated, there clearly remain a number of outstanding issues. In particular, effects of probe and specimen geometry as well as operating parameters such as excitation frequency, coil current and specimen material are to be assessed in future studies.

Acknowledgements

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