Eddy Current Measurement of Case Hardened Depth of Steel Components

John CUFFE [1], Haiyan SUN [2], Yuri PLOTNIKOV [2], Shridhar NATH [2], Aparna SHEILA-VADDE [3]
[1] GE Inspection Technologies, Lewistown, PA, USA, john.cuffe@ge.com
[2] GE Global Research, Niskayuna, NY, USA, sun@research.ge.com, plotnikov@crd.ge.com, nath@crd.ge.com
[3] GE John F Welch Technology Centre, Bangalore, India, aparna.vadde@ge.com

Abstract

Steel components are often subjected to a hardening process in which the surface gets hardened in order to improve resistance to wear. This introduces a casehardened layer. Various steel components have different requirements for the case depth. It is necessary to develop a nondestructive tool to monitor case depth for quality control. The case hardening process produces changes in the microstructure. As a result, the electrical conductivity and magnetic permeability in the casehardened region are different from those in the substrate. This makes it possible to determine case depth using eddy current method. In this paper, multi-frequency eddy current and pulsed eddy current methods will be investigated to measure case hardened steel components. Results and recommendations will be provided showing comparison between measured and actual case depths.

Keywords: case hardened steel, case depth, multi-frequency eddy current, pulsed eddy current

1. Introduction

Induction hardening of steel components improves the resistance to wear by changing and microstructure of the surface region. The required depth of the casehardened layer varies depending on the purpose for which the component is needed. Monitoring case depth in steel components is critical for quality control of both new and remanufactured products. Usually, case depth is determined by measuring micro hardness profile in randomly selected samples. Sample preparation includes cutting and polishing in the areas of measurements. This method is time consuming and expensive. As a result it can be used on a small fraction of samples. A reliable non-destructive method is desired to improve efficiency of the measurements and monitor all the parts ran through the case hardening process. Different nondestructive methods have been investigated to measure hardness and case depth, such as ultrasonic wave [1], Barkhausen noise measurement [2] and eddy current [3].

The case hardening procedure produces changes in the electrical conductivity and magnetic permeability of the steel in the case hardened region [4]. As the eddy current method is sensitive to these material properties, it is an expected candidate for the case depth estimation. An encircling coil was used to obtain the case depth of induction-hardened cylindrical rods using model-based approach, with case depths varying from 0.5mm – 2mm [2]. In this work, eddy current systems using pencil probe were developed to conduct measurements on induction hardened cylindrical samples with case depth varying from 1mm to 6mm. Localized measurement at different locations of the sample will be shown. Comparison between estimated and actual case depths will be provided.

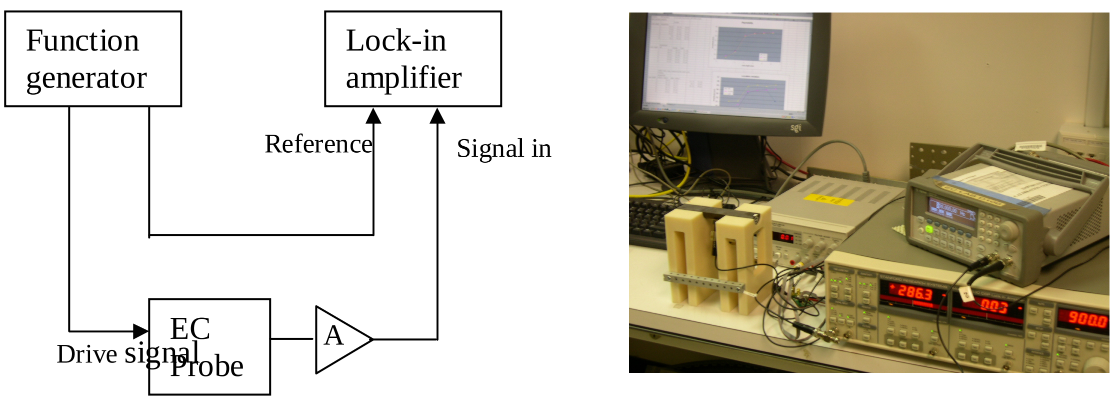
2. Samples and Systems

2.1 Cylindrical induction hardened samples

To investigate applicability of the eddy current technique, a set of samples with different case hardening depths was fabricated. All the samples are cylindrical rods, which are 100 mm long and 30 mm in diameter. There are 3 sets of samples (A, B and C), which are induction hardened with nominal case depth from 1 mm to 6 mm.

2.2 Eddy current systems

A multi-frequency eddy current (MFEC) system and pulsed eddy current (PEC) system were developed for the experimental study. The MFEC system includes a function generator to generate the drive current in the eddy current probe, a lock-in amplifier to measure the probe response and a preamplifier to amplify probe signal. The lock-in amplifier has a frequency range from 1 mHz – 102.4 kHz. The function generator has a maximum output voltage of 10V. Gain of the signal preamplifier is adjustable with a single resistor. Fig.1 shows the diagram and picture for the MFEC system.



(a) (b)

Fig. 1 Multi-frequency eddy current system for case depth measurement (a) diagram (b)

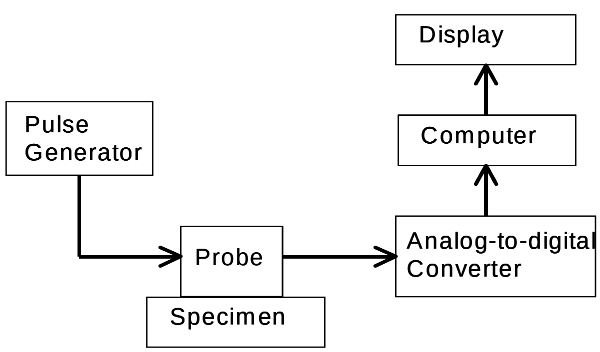


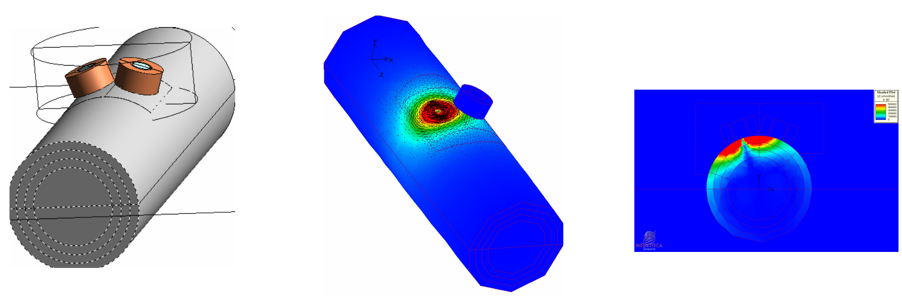
Fig. 2. Block diagram of the PEC system for case depth experimental setup

The PEC includes a pulse generator that can produce drive pulses of variable width and amplitude, a 14-bit resolution analog-to-digital converter with a sampling rate up to 100 MS/s connected to an industrial computer and display (Fig. 2). A special program was developed to control data acquisition and process data in digital form. The pulse generator produces 5 ms long pulses of 40 V in magnitude with a repetition rate of 10 Hz. Transient responses 20 ms in length are received and digitized with a sampling rate of 100 kS/s.

3. Probe Designs

Various eddy current probes were designed and fabricated. Simulations were conducted by FEM software to optimize design and testing parameters. Parameters that were simulated include different probe types, number of turns, ferrite core, probe orientation and excitation frequency. As an example, Fig. 3 (a) below shows the FEM model for a circumferential probe. Fig. 3 (b) and (c) show the simulated eddy current field.

A number of probes were fabricated by GE Inspection Technologies. Different probes were tested and compared. Results to-date shows that a 16mm reflection probe



(a) (b) (c)

Fig. 3. FEM simulation for the circumferential probe. (a) FEM model (b) 3D view of eddy current field. (c) Cross section view of eddy current field in the sample.

and a 20mm circumferential probe provide the best results.

4. Experimental Measurement

A sample holder with curved slots on the top was made to hold the cylindrical samples. The probe was attached to the sample holder and maintained rigidly during the measurement. LabView software routines were developed to allow automatic control of the MFEC or PEC system for data acquisition and analysis. These algorithms were developed and embedded in the LabView program to enable real time display of the case depth. Calibration data were first taken on a set of standard samples. Case depths were then obtained based on calibration data. Results by MFEC and PEC are shown below separately.

4.1 Results obtained by the MFEC system

Different probes were tested by MFEC system and a 16mm reflection probe was found to be the most sensitive to case depths. Multiple excitation frequencies were used and 120Hz was found to be the best. Thus for all the following results by MFEC system,

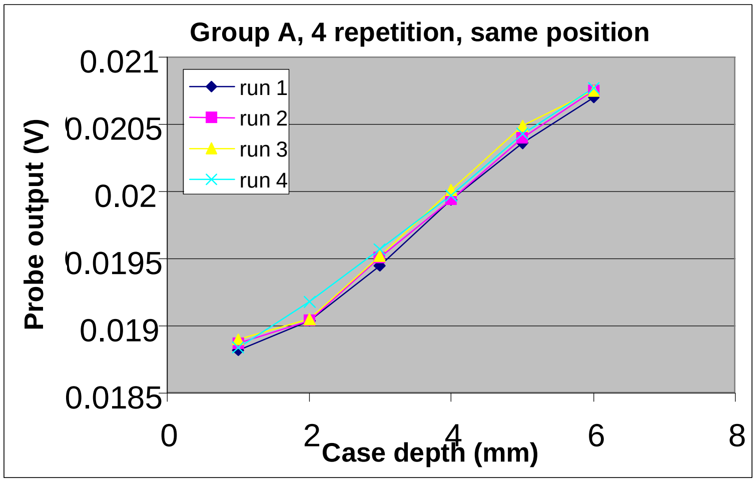


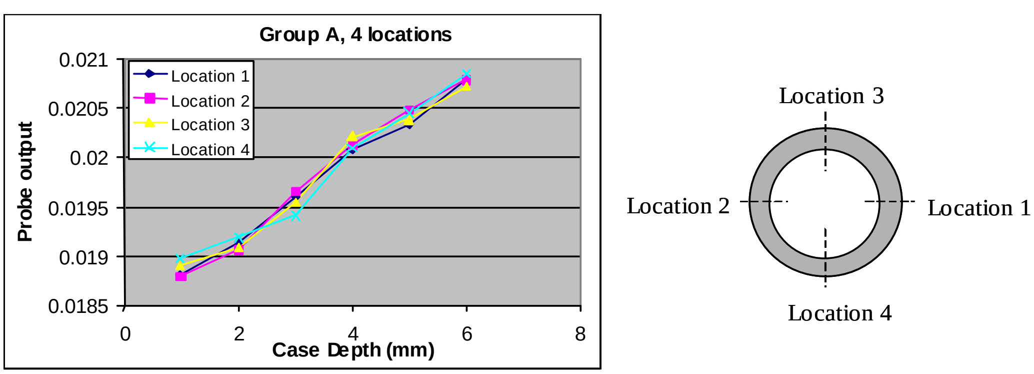
Fig. 4. Repeatability measurements of MFEC system on the same location of sample set A.

the 16mm reflection probe was used at 120Hz.

Fig. 4 shows the repeatability of MEFC system. Data was obtained on the same spot of sample set A1 – A6. Four repeatable measurements were taken and results in Fig. 4 shows that the system is very repeatable. The variation at every case depth is much smaller than the signal generated by different case depth, implying that the system can differentiate all of the samples.

Fig. 5 shows the results on 4 different spots, 90 degree apart along the circumferential direction on sample A1 – A6. More variations are observed in Fig. 5 compared with Fig. 4. Micro hardness testing shows that the effective case depth varies up to 20% within the same sample. The variation shown in the Fig. 5 agrees with the micro hardness test results.

Fig. 6 shows the results by MFEC system on all the 3 sets of samples. Case depths measured by MEFC system are plotted against the nominal case depths. For each sample, four different locations were measured along the circumferential direction, 90 degree apart. Results in Fig. 4 – Fig. 6 show that case depth measured by MFEC system agrees well with the nominal case depths.



(a) (b)

Fig. 5 (a) MFEC results on one set of samples at four locations along circumferential direction (b) illustration of four locations.

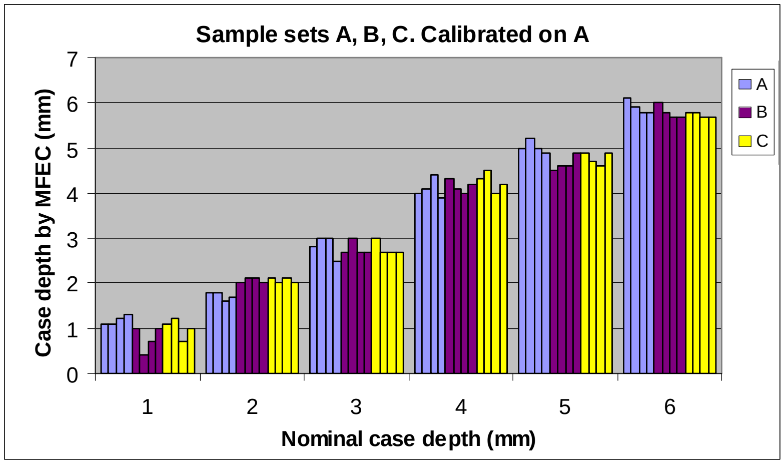


Fig. 6. Case depths measured with MFEC system for all the three sample sets.

4.2 Results obtained by the PEC system

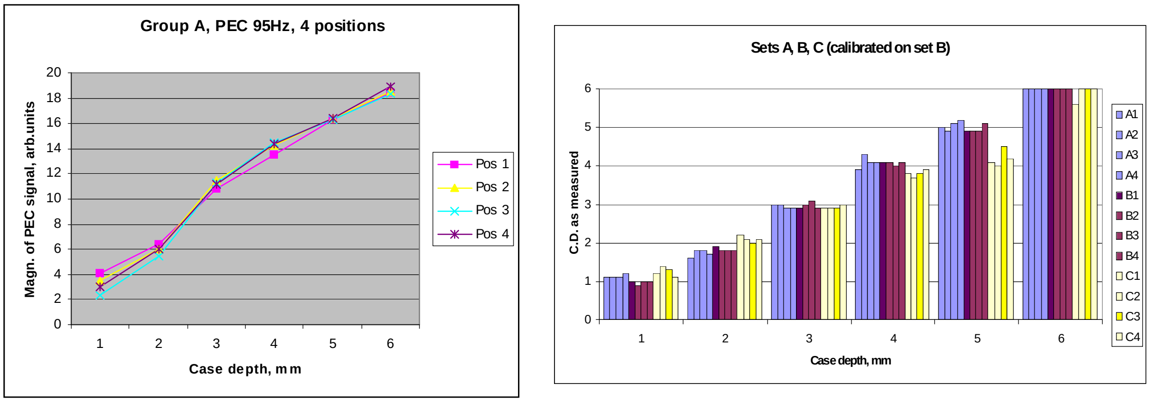
Several different implementations of the PEC technique have been previously reported as applied for measuring the resistivity of metals [5] and the case depth [6]. For the purpose of this work, a recently developed transient processing technique [7] was used to convert the pulsed response into a conventional representation of the eddy current signal on the complex plane. To obtain the real and imaginary components of the transient response for a desired frequency, two orthogonal transforms are applied to the digitized response. The starting point of the transforms coincides with the leading edge of the drive pulse and the length for the transforms is in inverse proportion to the frequency component extracted for the analysis.

It must be pointed out, that the frequency components of the transient response extracted using integral transforms might not be exactly compatible to the harmonic-based eddy current analysis. However, the sensitivity level and reliability of the measurements are similar.

Experimental results obtained with the PEC system from the sample set A1 – A6 and processed for 95 Hz are shown in Fig. 7 (a). Figure 7 (b) contains variations of the pulsed eddy current measurements, which correspond to the results presented in Fig. 5 & Fig. 6 for the MFEC system.

5. Conclusions and Future Work

Eddy current probes and systems were developed to measure case depth of induction hardened steel rods with case depth varying from 1mm to 6mm. Various probes were designed and evaluated. Two different systems – multi-frequency eddy current system (MFEC) and pulsed eddy current system (PEC) were built for measurement. Calibration data were taken on a set of samples with known case depths. A transfer function was generated from the calibration data. Test pieces were then measured and case depth could be obtained in real time. Case depths measured by MFEC & PEC system agree well with nominal case depths. Both system shows good repeatability. A



(a) (b)

Fig. 7. Results obtained with the PEC system from one group of specimens (a) and three groups of specimens (b).

16mm reflection probe was found to be the best for MFEC system while a 20mm circumferentially drive-pick up probe was most suitable for PEC system.

There are a lot of noise parameters that affect the sensitivity of the eddy current measurement. The noise may come from sample surface condition, curvature, alloy difference, residual stress, residual magnetic field, probe lift-off and tilt angle, temperature drift, etc. Future work will focus on controlling these noise factors to allow robust measurement in the production environment.

6. Acknowledgement

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