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Development of coating thickness gauge for magnetic coatings

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Abstract – A gauge to measure the coating thickness of magnetic coatings on non-magnetic base material has been developed by directly measuring the magnetic flux density between the coating and the permanant magnet. Magnetic induction method was found to be inadequate for measuring magnetic coating thickness which is greater than 0.4mm. Magentic flux density was measured by Hall effect sensor and calibration curve was constructed by using the data acquired from 10 standard reference samples. The developed gauge can be used to measure non-magnetic coatings over magnetic substrate as well. The relative standard error was found to be 2.1% for nickle coatings on copper substrate.

I. Introduction

A number of coating thickness gauges are now available commercially for various coating and substrate combinations[1]. For non-magnetic coatings coated on magnetic base materials, electromagnetic induction method is commonly employed as a measuring technique and give a high accurracy for a broad range of coating thicknesses[2]. However, for magnetic coatings on non-magnetic substrate, this method can only be applicable for very thin coatings. As a consequence, there is no portable instrument is availble commercially to measure this kind of coatings untill now.

In this paper, direct magnetic field strength was utilized to measure the coating thickness of magnetic coatings over non-magnetic substrate. Neodymium(Nd) permanent magnet was used to magnetize the coatings and Hall sensor was used to measure the magnetic flux density between the coating and the magnet.

The gauge, whose operational principle is based on this technique, could be succefully applied to measure the coating thickness for nickle(Ni) coatings on copper(Cu) substrates. This type of coatings is usually applied to the a mold plate in order to improve the wear resistnace during the continous casting process in steel making industry.

II. Principle of the measurement

Several commercially available magnetic induction probes have been tested with diffrent excitation current to measure this magnetic coatings on non-magnetic materails. The measuring principle is illustrated in Figure 1.

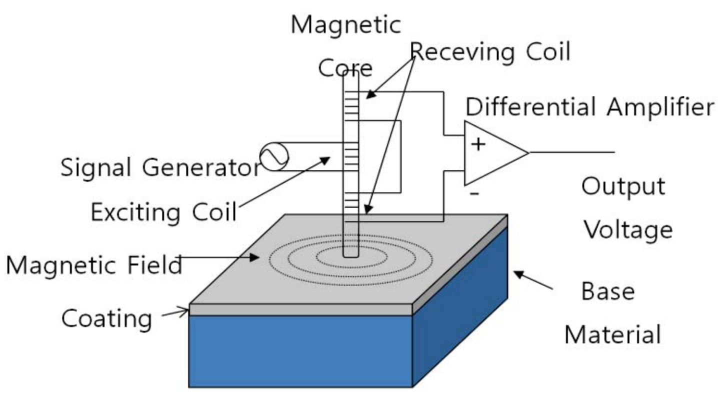

Figure 1. Principle of magnetic induction method to measure magnetic coatings on non-magnetic material.

Low frequency AC magnetic field is applied to the magnetic core and the AC voltage is induced in a receving coil. The induced AC voltage have a good correlation with the coating thickness if one of the coating or the substrate is magnetic material.

Output voltages as a function of coating thicknesses are shown in Figure 2. Even though the types of probes, such as coil diameters and sensor dimensions, are different, the output voltage is saturated when the coating thickness reached to 0.4mm. The saturation voltage is nearly same regardless of types of magnetic probe sensor. If we increase the excitation current to 100mA, which is practically maximum current because of the limit of sensor temperature, the output voltage increases, whereas, the induced voltage is still saturated when the coating thickness is greater than 0.4mm. From the test results, we concluded that magnetic induction sensor can not be applied to measure the magnetic coating thickness which is greater than 0.4mm.

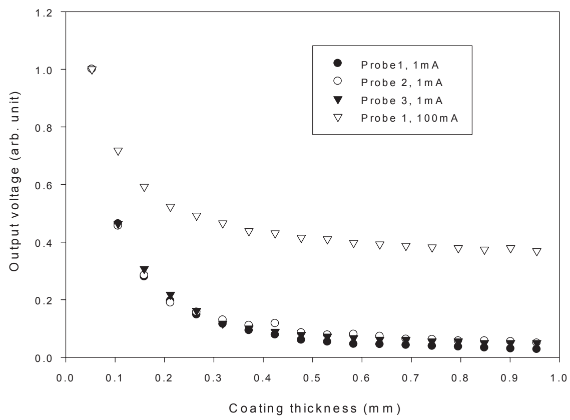

Figure 2. Output voltage of magnetic induction sonsor for different types of probe and excitation current.

Direct magnetic field was utilized to measure the coating thickness of magnetic coatings on non-magnetic substrate. Figure 3 shows the configuration of the coating thickness gauge head. Yoke type electrical steel and Nd permanent magnet was used to generate and apply DC magnetic field to the coatings. The Nd magnet could be rotated to detach the head easily from the sample. Between the electrical steel and the coatings, Hall effect sensor was placed in plane to the coating surface. DC 3~ 5V power was supplied to the Hall sensor and the Hall sensor output voltage were measured as a function of coating thicknesses.

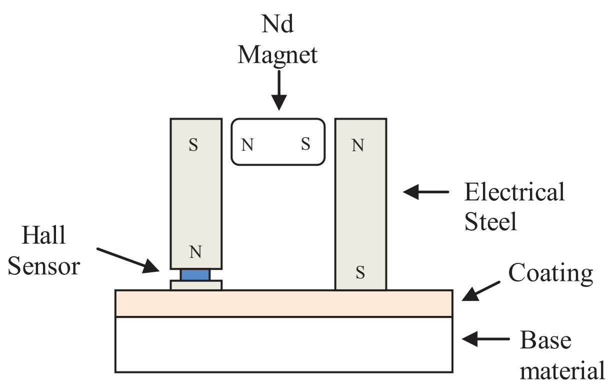

Figure 3. Configuration of coating thickness gauge head.

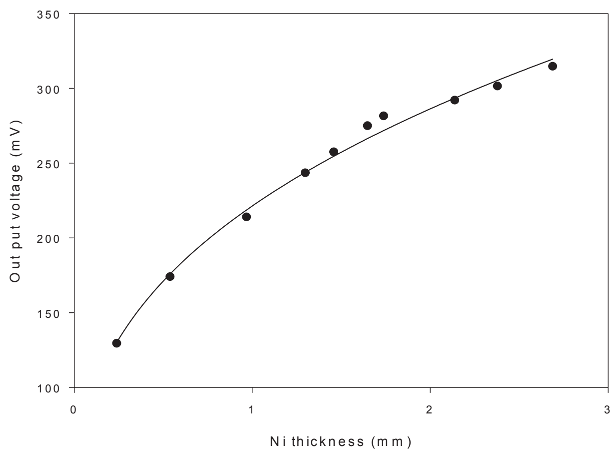

Figure 4. Hall sensor output voltage as a function of Ni coating thickness coated on Cu substrate.

Figure 4 shows ths Hall sensor output voltage as a function of Ni coating thickness for 10 standard reference samples. The output voltages were increased until the coating thicknesses reached to 3mm. The best fit calibration curve could be represented by the following equation (1) with apprepriate fitting parameters.

$$V = aX^{b} \qquad (1)$$

(where, V : Hall voltage, X : coating thickness, a, b : fitting parameters)

III. Results

In order to check the accurracy of the developed gauge, standard reference samples were prepared by end-milling process of electroplated Ni coatings. The nominal coating thickness was determined by substracting the base metal(Cu) thickness from the coated sample thickness with digital micrometer.

Table 1 shows the results of coating thickness measurement for standard reference samples. Two coating thickness samples(0.24mm and 2.14mm) were used to determine the fitting parameter in equation (1). After eliminating minimum and maximum values from 5 measured data, final coating thickness were determined by averaging the 3 remained data. It was found that the average relative standard error between the nominal value and the measured value was 2.1%, where the relative standard error was defined by (nominal value-measured value)/(norminal value)*100.

Figure 5 shows the linearlity between nominal and measured coating thicknesses. The correlation coefficient is found to be 99.76%

Nominal coating thickness (mm)	Measured coating thickness 1 (mm)	Measured coating thickness 2 (mm)	Measured coating thickness 3 (mm)	Measured coating thickness 4 (mm)	Measured coating thickness 5 (mm)	Processed coating thickness (mm)
0.24	0.23	0.26	0.22	0.24	0.24	0.24
0.97	0.96	1.04	0.98	1.04	0.97	1.00
1.3	1.49	1.27	1.39	1.31	1.3	1.33
1.46	1.39	1.48	1.56	1.52	1.46	1.49
1.74	2.05	1.79	1.82	1.83	1.74	1.81
2.14	1.91	2.04	1.97	2.05	2.14	2.02

Table 1. Measured coating thicknesses for 6 standard reference samples. Last column represents average of 3 data, after elemination of maximum and minimum values from 5 measured data.

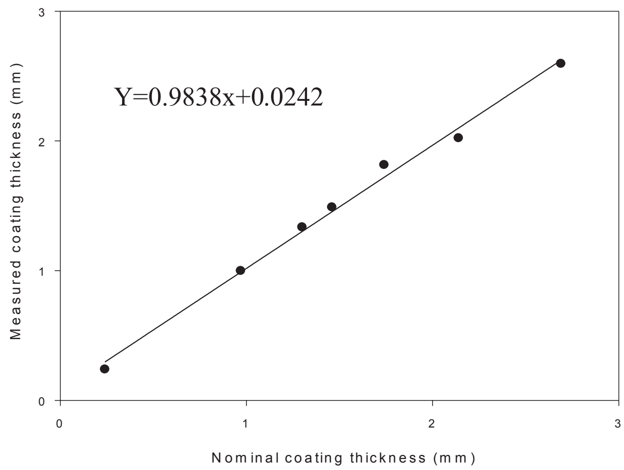

Figure 5. Linearlity between nominal and measured coating thicknesses.

Figure 6 shows the photo of gauge controller and head on standard samples. From the controller, power is generated to apply voltage to the sensor and Hall voltage is calibrated to coating thickness from the data taken by standard reference samples. Measured coating thickness is displayes at LCD display

Figure 6. Gauge head and controller.

IV. Conclusions

New type of coating thickness gauge was developed for magnetic coatings on non-magnetic substrate to measure broad range of coating thicknesses. This type of gauge can be also applied to non-magnetic coatings on magnetic base materials. The relative standard error was found to be 2.1% for the coating thickness range from 0 mm to 3 mm. The developed gauge can be applied successfully to measure the coating thickness for Ni coatings on Cu substrates for a continous casting mold plate.

References

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