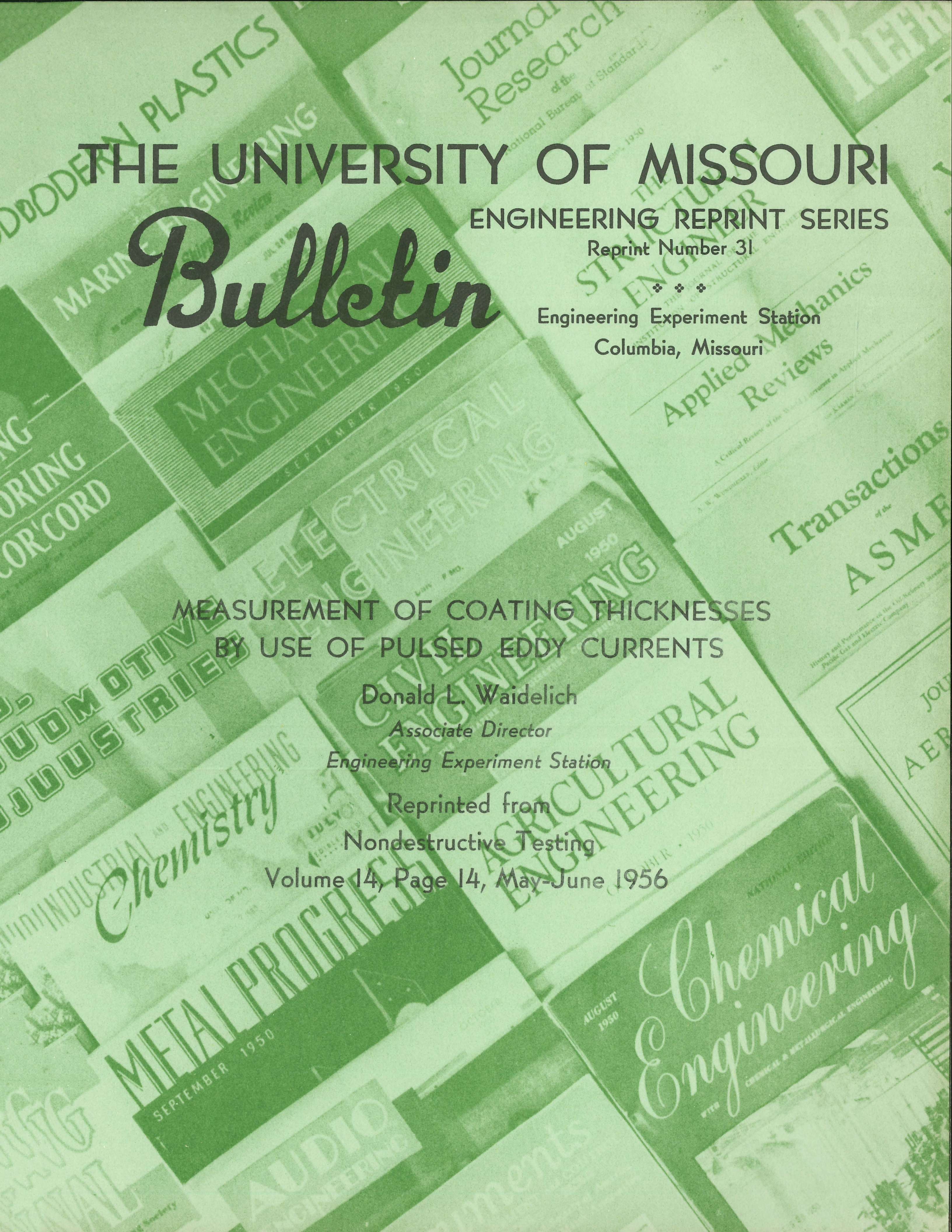

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Engineering Experiment Station
Columbia, Missouri

MEASUREMENT OF COATING THICKNESSES BY USE OF PULSED EDDY CURRENTS

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Measurement Of Coating Thicknesses By Use Of Pulsed Eddy Currents*

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The application of pulsed eddy currents to determine the thickness of a metal clad on another is described. The theoretical bases of the method are presented, and the equipment used is described in detail.

INTRODUCTION

One of the problems that seems to arise in many applications at the present time is that of measuring in a nondestructive manner the thickness of one metal coated or clad upon a base metal. If one of the metals is ferromagnetic, the problem is relatively simple(1,2). For two nonmagnetic metals, the problem is more difficult, but a number of methods might be used, such as ultrasonic, back-scattering of beta or gamma rays, and eddy currents. The eddy-current method seemed to offer certain advantages, and it was decided to investigate this method. Sinusoidal eddy currents of a single frequency have been employed by a number of investigators(3,7), but this method of using sinusoidal eddy currents seems to present difficulties, such as low sensitivity and high harmonic content. Therefore, it was decided to try the use of pulsed eddy currents in the manner of echo sounding. This paper presents some of the theoretical considerations and a brief summary of the experimental work.

THEORETICAL CONSIDERATIONS

Some work had been done already on pulsed high-frequency currents in conductors(8,9). In the present application, an intense localized electromagnetic field is applied to the surface of the clad metal and echoes are received from the metallic layers. These echoes result when the electrical properties of the metals have a sudden discontinuity, such as that caused by a metal-to-metal interface.

A small single-layer probe coil with its axis perpendicular to the surface of the metal is used to set up the electromagnetic field and to receive the echoes. This allows investigation of a small area and facilitates point-by-point depth measurements. Since the exact solution of the field of such a coil is difficult, it was decided to simplify the problem by assuming that a plane wave with its front parallel to the metal surface was set up. This would indicate the kind of echo that might result, but would ignore the spreading of the waves from the source, which is almost a point source. Another approximation used was that of assuming the input pulse to be square and of duration T seconds, when actually it is shaped more like a sinusoidal half-period wave.

The clad metal is assumed to have a thickness d, as shown in Figure 1. A theoretical analysis revealed that the reflection from the metal is composed of a series of waves. The paths of these waves are shown in Figure 2. The first wave in the series represents the reflection from the surface of the clad metal and consists of a sharp rise at the head of the wave and a tail that is quite long compared with the reflection time of the wave. This reflection time, T_1, is of the order of 10^{-18} sec for most air-to-metal boundaries. The characteristics of this first wave depend upon the permeability, μ_1, and the conductivity, σ_1, of the clad metal, and hence the length or amplitude of the tail would be useful in determining these electrical constants of the clad metal. If, on the other hand, the primary object is to measure the thickness of the cladding, then the first reflected wave will not be useful and should be balanced out by means of a bridge circuit.

The second reflected wave contains information about the depth, d, of the clad metal, and it should be used for this purpose, because it will be the strongest of all the remaining waves. The more electrical difference there is between the clad and the base metals, the larger is the metal-to-metal reflection factor, R_{12}, and the easier it is to determine the clad depth. The basic constant having to do with the depth of the clad metal is the time, $T_2 = d^2\mu_1\sigma_1$, representative values of which are given in Table 1. The output pulse for a step input magnetic field is shown in Figure 3. This pulse has a large positive peak, followed by a very small negative peak. If a rectangular input pulse were used, the output would be a large positive pulse followed by a large negative pulse. Any characteristic, such as the amplitude or length of this output pulse, would be sufficient to determine the depth, d, but the crossing point between the positive and negative pulses was found to be the most useful one. This crossing point depends directly on T_2, which, in turn, depends upon d. The crossing point also depends upon μ_1 and σ_1, and hence, for good measurements of d, the electrical constants of the cladding should remain nearly constant. Since third and higher order reflected waves will be present to a smaller extent, the electrical properties of the base metal should also remain fairly constant. From Figure 3, it is clear that, for greatest sensitivity, the input pulse, if rectangular, should have a length of about $T = 2T_2$. For input pulses with less abrupt rises, such as half-sinusoidal-loop and triangular pulses, probably T should be more of the order of $5T_2$ or $6T_2$. According to Table 1, this would necessitate an extreme range of pulse lengths, and hence it is better to select the pulse length or lengths to fit the most difficult case. This case in Table 1 would be that of zirconium on uranium, and thus a pulse length of approximately 3 μsec was decided upon. This means a decreased sensi-

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*The work reported in this paper was done while the author was either a resident research associate or consultant to Argonne National Laboratory.

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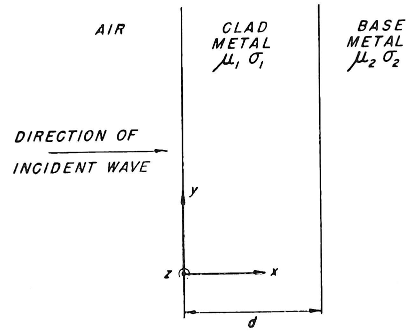

Figure 1 — Schematic Representation of a Clad Metal

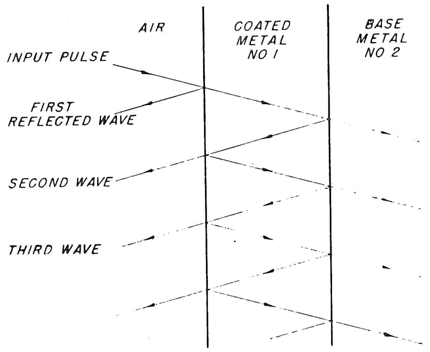

Figure 2—Reflections From a Clad Metal

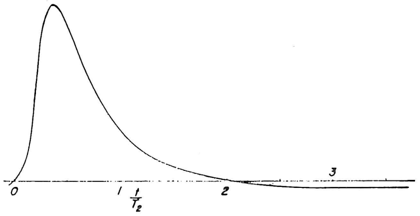

Figure 3—Output Pulse for a Step Input Magnetic Field

Table 1. Value of Time for Various Materials

Material	Values of Time (T_2), μ sec, at Distance(d), mils		
	5	15	25
Aluminum	0.7520	6.770	18.830
Zirconium	0.0449	0.404	1.123
347 stainless steel	28.1000	252.000	702.000

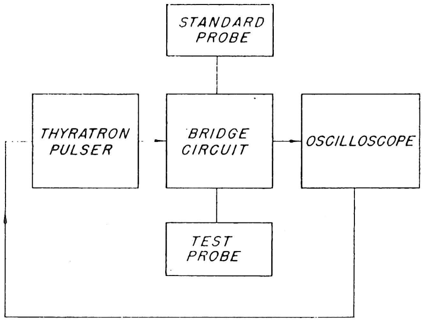

Figure 4—Block Diagram of Experimental Setup

tivity in the other cases. The repetition rate seemed to have no influence except for the duty cycle's becoming too long or the oscilloscope image's becoming too dim.

EXPERIMENTAL WORK

The basic block diagram of the experimental setup is shown in Figure 4. The rate generator of the oscilloscope is used to trigger a thyratron which sends identical pulses through the standard and the test probes. The responses of these probes are balanced against each other and the difference voltage is amplified and reproduced by the oscilloscope. Proper interpretation of the oscilloscope trace will yield the depth of the coating thickness.

A simplified schematic diagram of the thyratron pulser and bridge circuit is shown in Figure 5. Capacitor C_1 is charged through Resistor R_1 and then discharged through the primary of the air-core transformer, T. Since the secondary of the transformer is rather loosely coupled to the primary, the duration and shape of the pulses are determined primarily by the shunt circuit composed of Capacitor C, Resistor R, and primary Inductance L, along with Capacitor C_1. The shape of the pulses is modified further by the action of the transformer and the bridge circuit containing the probes. Auxiliary variable resistors and capacitors are inserted in the bridge circuit to make the balance as nearly perfect as possible. The secondary winding of the transformer is isolated and shielded sufficiently from the primary winding that both ends of the secondary are nearly symmetrical with respect to ground potential. Various other bridge circuits were tried, some with a fair amount of success. The circuit of Figure 5, however, appeared to have the most promise and was adopted.

Two probes are used and are made as nearly identical as possible. A simplified cross section through the axis of one type of cylindrical probe is shown in Figure 6. The cross-hatched material is one of the ferromagnetic ceramic materials, and the single-layer coil is wound on the axial rod. This rod has two separate parts mounted within an insulating tube with an air gap between the two parts. The left-hand part of the axial rod is movable, so that a better balance is obtainable between the standard and the test probes. These probes were about 1/2 in. in diameter. If sufficient sensitivity were available, the outer shell of the probe could be dispensed with, and only the inner axial rod used. This would reduce the effective area of the probe materially.

The oscilloscope amplifier should have sufficient band width that the

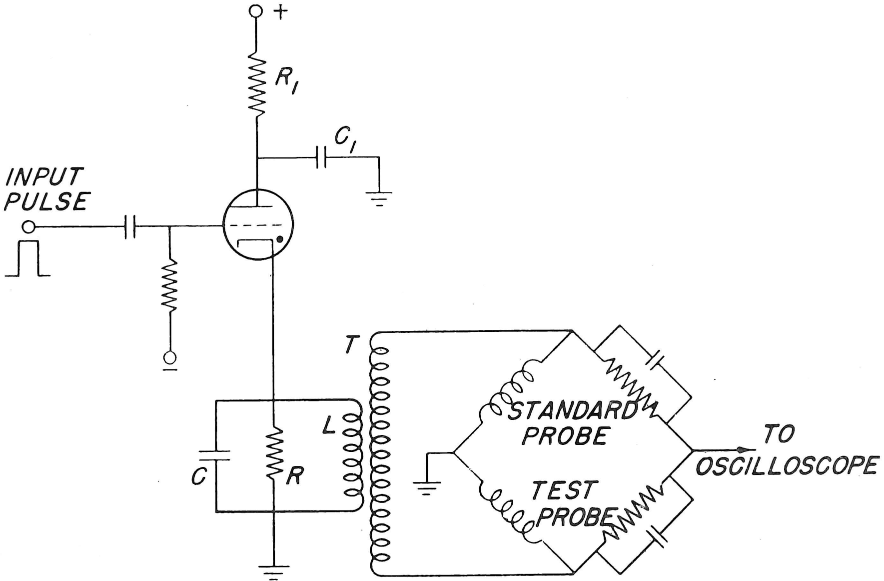

Figure 5—Simplified Schematic Diagram of Thyratron Pulser and Bridge Circuit

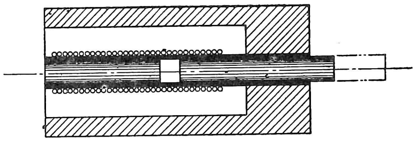

Figure 6—Cross Section of Cylindrical Probe

details of the pulse are reproduced faithfully. Enough gain is needed to bring the pulse response up to a readable level, and auxiliary wide-band amplifiers are useful in this regard. It is convenient, but not necessary, to have the rate generator contained within the oscilloscope itself. A variable delay is needed, so that portions of the pulse response may be selected and examined.

The standard sample of metal is placed on the standard probe and another sample of metal is put on the test probe. The various balancing adjustments, such as those of the bridge and that on the probe, are made then, so the pulse output is as nearly zero as possible. Then a slight unbalance is added by changing the test-probe adjustment a small amount. The crossing point of the resulting pulse is singled out and the time axis about this point is expanded. As the thickness of the cladding of the sample changes, the position of the crossing point on the zero axis also changes, and thus the position of the crossing point may be calibrated in terms of cladding thickness.

One of the early difficulties with this method was that the crossing point would change position with the probe spacing, i.e., the distance between the probe and the metal plate. It was found experimentally that the slope of the oscilloscope trace varied with this probe spacing also. If the distance between the probe and the plate were varied until the slope of the trace had some fixed value, then the probe spacing would always be the same and the crossing point would be a measurement of the clad thickness. This method was followed with good results. The appearance of the oscilloscope trace is shown as A in Figure 7. The position A, for example, might correspond to a clad thickness of 25 mils, that of B to 15 mils, and C to 5 mils. Sloping lines ruled on the bezel of the oscilloscope aid in maintaining the slopes of the traces of Figure 7 constant.

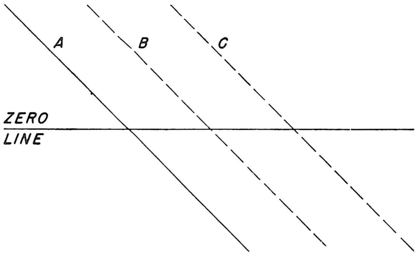

Figure 7—Oscilloscope Trace

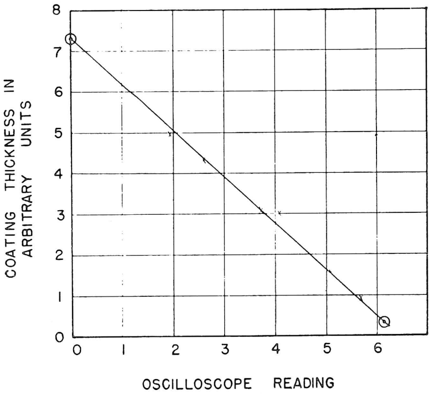

Figure 8—Coating Thickness Versus Oscilloscope Reading

As an example of the use of the instrument, a metal coated with another metal was tested to determine the depth of the coating. The piece was then sectioned and polished, and the depth of the coating was measured by optical methods. The resulting variation of coating thickness versus the oscilloscope reading is shown as crosses in Figure 8. The straight line drawn between the two calibrating points encircled in Figure 8 could be used as the calibrating curve for the instrument.

ACKNOWLEDGMENTS

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