MULTIPARAMETER METHODS WITH PULSED EDDY CURRENTS

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ABSTRACT

Multiparameter methods have been used for a number of years to distinguish certain material properties from others that may be varying in the same eddy-current inspection. Usually the measured data are the magnitudes and phases of the eddy currents at several fixed frequencies. Alternatively, the necessary data can be obtained from pulsed eddy currents by measuring the pulse heights at various times or the times to reach various pulse heights. Such data can be used to analyze the pulse into various Fourier components, but that is time consuming and unnecessary. The raw data (for example, the pulse heights at various times) can be used as variables in polynomial approximations to the various properties in exactly the same way as has been used with the multifrequency, multiparameter method. This approach has several advantages, including simpler equipment, ability to use higher frequencies, and less modification required for different inspection problems.

INTRODUCTION

The greatest problem in eddy-current nondestructive evaluation is to distinguish particular sample properties from others that may be unimportant but are capable of strongly affecting the eddy-current readings. A popular approach is to use the extra information available from tests at several frequencies to eliminate the unwanted variables. Pulsed eddy currents can also give the additional information necessary to discriminate among various sample properties. An extensive bibliography of early work with pulsed eddy currents has been given by Libby.[1]

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†Operated by Martin Marietta Energy Systems, Inc., for the U.S. Department of Energy under Contract DE-AC05-84OR21400.

EXTRACTION OF THE PULSE INFORMATION

The most common method of obtaining the necessary information from the pulse response has been to pass the coil output signal through a filter that can separate the pulse into various orthogonal function components. Alternatively, the pulse shape can be recorded and then analyzed with a Fast Fourier Transform (FFT) computer routine. The filter or FFT outputs can then be correlated with various sample properties or "mixed" to minimize the effects of unwanted variables.

The purpose of this paper is to show that it is not necessary to filter or FFT the pulse output before correlating it with the sample properties. Indeed, the additional steps involved in the filtering or FFT calculation can introduce additional noise in the data and decrease the accuracy of the correlation. The filtering method may also require extensive and expensive hardware changes for different inspection applications.

ORNL DIGITAL CORRELATION METHOD

A simpler approach is to use the digitized pulse shape directly for input data to the correlation process. For example, the pulse heights can be measured at various preset times, or the times to reach certain pulse heights can be measured. Figure 1 shows a plot of voltages measured at certain preselected times during a pulse, and Fig. 2 shows a block diagram of an instrument to measure the pulse heights at the preset times. The TRACK AND HOLD units are usually called sample and hold (S/H) modules, and each measures the pulse height at the time the correct signal comes from the computer. Figure 3 shows a plot of the times at which the pulse height reaches certain preselected voltages, and Fig. 4 shows a block diagram of an instrument to measure the times to the preselected pulse heights. Each voltage comparator stops a timer when the pulse voltage passes a computer-determined reference voltage.

Present S/H modules become less effective at frequencies above a few megahertz, as do filters in multifrequency equipment. Therefore, time-to-pulse height modules based on voltage comparators are more effective at frequencies higher than a few megahertz. On the other hand, if the lift-off becomes too great, no reading will be obtained from the voltage comparator, whereas the S/H circuit loses resolution only slowly.

Whichever method is used, the digitized data can then be used as the variables in a polynomial approximation to the desired property. The coefficients in the polynomial are determined so as to give the best fit (in a least-squares sense) to the given property. This is exactly the same process as has previously been used in the multifrequency, multiparameter method [2], except that pulse heights (or times-to-pulse heights) are used as measured variables instead of the magnitudes and phases at various fixed frequencies.

The pulse method has a number of advantages: the equipment is much simpler and cheaper, the changes required for different inspection problems can usually be made with simple software commands rather than hardware changes, and it is possible to work at much higher frequencies than those at which present equipment can make accurate phase measurements. This last advantage is particularly important for inspecting very poor conductors or very small specimens. For inspecting ferromagnetic

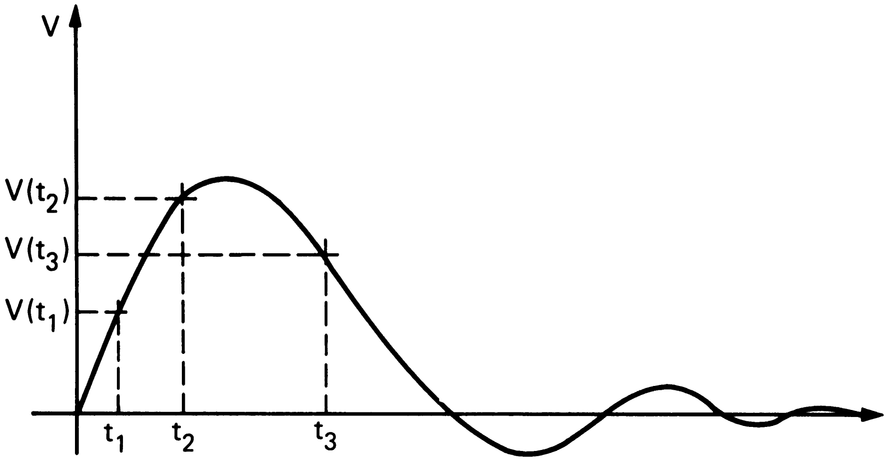

Fig. 1. Voltage at various times in a pulse.

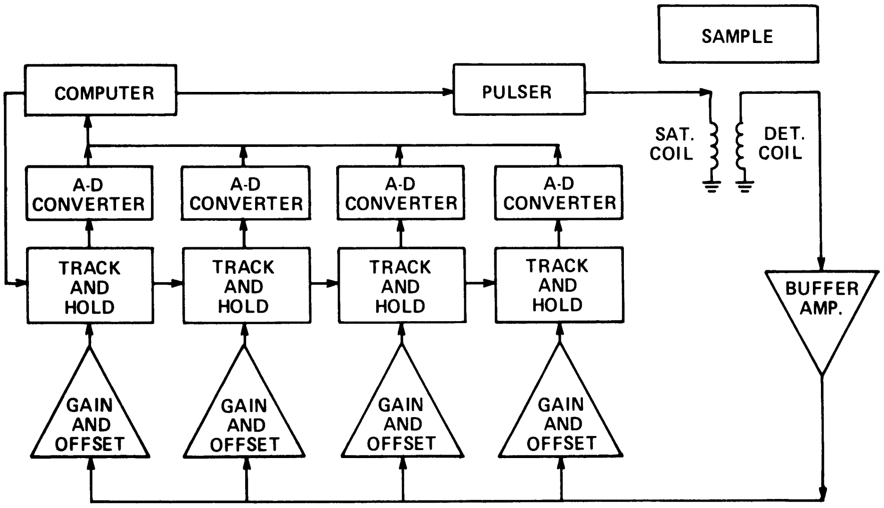

Fig. 2. Pulse amplitude instrument.

materials there is the additional advantage that a large driver pulse can be used to saturate the material as well as generate eddy currents for nondestructive evaluation.

In the past, pulse equipment has not been able to equal the accuracy of the best multifrequency equipment. However, recent electronic modules are capable of producing, measuring, and digitizing pulses with an accuracy, speed, and reproducibility that make the pulse method as accurate as the multifrequency method, while remaining much simpler. To change operating frequencies for different applications of a multifrequency system usually requires extensive changes of hardware, such as oscillators, amplifiers, and filters, whereas any changes that might be needed with a pulsed system, such as times for measuring the pulse height, can usually be made with software instructions. Ordinarily, only the coil design needs to be optimized, and that is normally necessary for any eddy-current inspection.

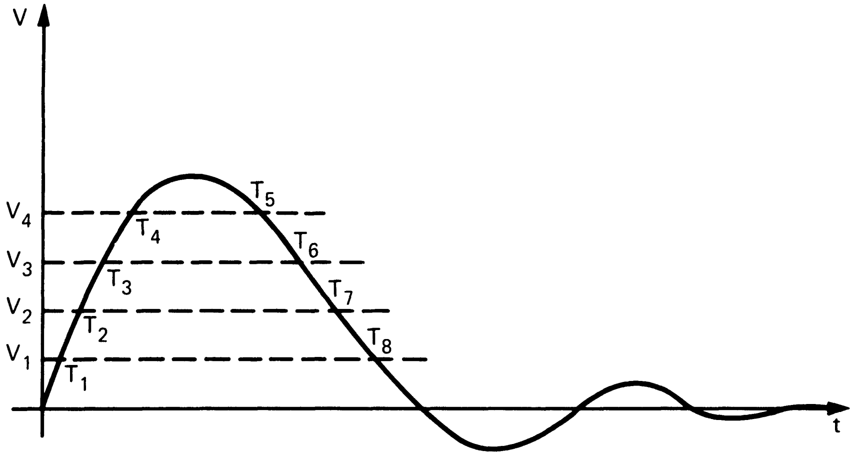

Fig. 3. Times to various voltages in a pulse.

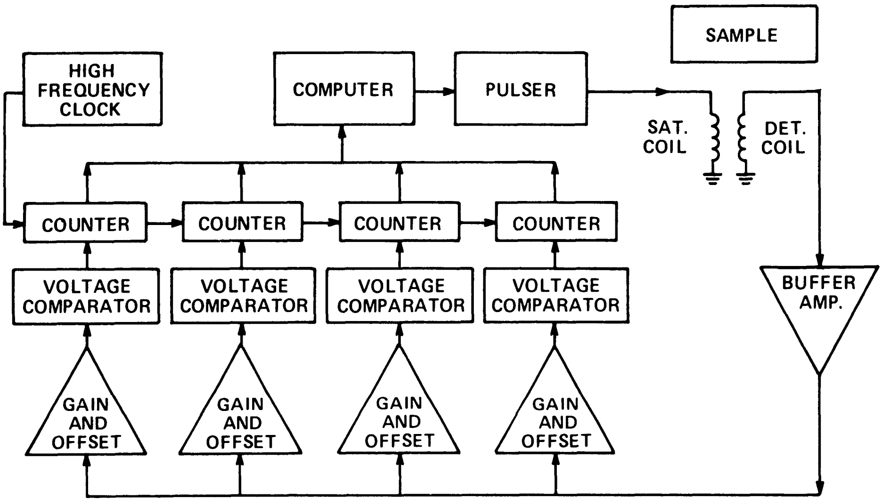

Fig. 4. Pulse time interval instrument.

APPLICATION TO THIN-WALL TUBING

At Oak Ridge National Laboratory we have used a pulsed system to make several inspections that would be difficult with conventional equipment. One inspection was for internal flaws in stainless steel tubing with an outside diameter of 3.56 mm (0.140 in.) and wall thickness of 0.13 mm (0.005 in.).

The optimum operating frequencies for the small, thin tubing were too high for our phase-sensitive detectors to give accurate readings, but a short duration pulse with a very small coil was able to make accurate and reliable measurements of flaws that were less than 10% of the wall thickness and located on the opposite side of the tube wall. Figure 5 shows scans of electrodischarge machined (EDM) notches with depths of 25, 51, 8, 13, and 18 μm (0.001, 0.002, 0.0003, 0.0005, and 0.0007 in.) from left to right; the top trace is for flaws on the inside of the tube, the lower trace for flaws on the outside, where the probe was located. Note that the flaw depths are reliably indicated regardless of the location of the flaw, because the flaw size polynomial can compensate for such extraneous variables. Figure 6 shows flaw readings obtained in a scan across an area of the tube with EDM notch depths of 25, 51, 76, 76, 51, and 25 μm (0.001, 0.002, 0.003, 0.003, 0.002, and 0.001 in.) from left to right, the first three being on the near side and the last three being on the far side of the 127-μm-thick (0.005-in.) stainless steel tube wall.

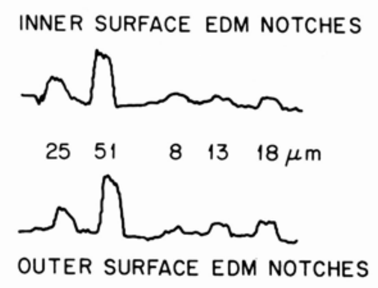

Fig. 5. Scan of machined notches with depths of 25, 51, 8, 13, and 18 μm on the opposite side (upper trace) and near side (lower trace) of a stainless steel wall 0.13 mm thick.

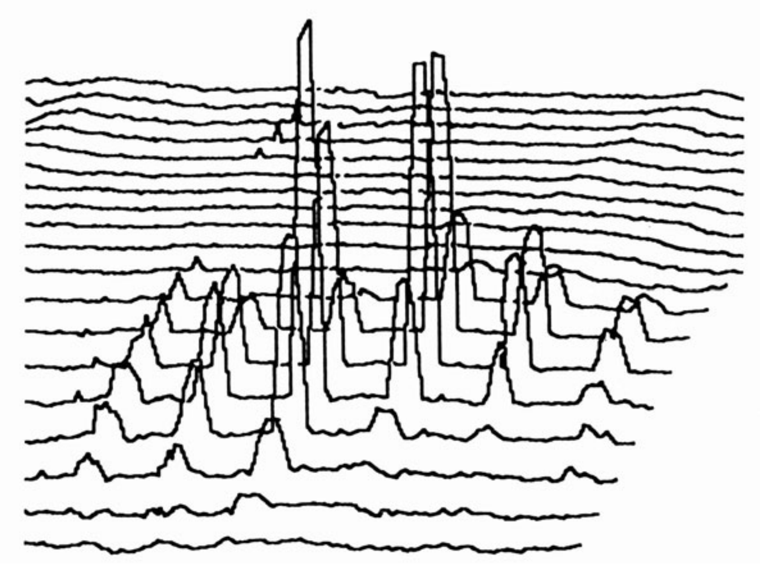

Fig. 6. Flaw depth scan of stainless steel tube with 3.56-mm outside diameter and 0.13-mm wall thickness. From left to right the EDM notches have depths of 0.03, 0.05, and 0.08 mm on the outside and 0.08, 0.05, and 0.03 mm on the boreside of the tube wall.

The conventional reflection-type coil had opposing twin pickup coils with mean radii of 0.25 mm (0.010 in.) inside a driver coil of mean radius 0.50 mm (0.020 in.). The pulse rise and fall times were approximately 10 ns, and the maximum pulse rate was 10 MHz. Eight test readings could be taken per pulse, but it was found that four data points per pulse were sufficient to give very good defect sensitivity and lift-off rejection, if taken at the proper parts of the pulse. In fact, the percentage accuracy was at least as good as that obtainable with conventional multifrequency equipment measuring magnitudes and phases at three frequencies. Of course, the latter equipment could not even operate at frequencies high enough to be effective for such thin, small-diameter tubing.

REFERENCES

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