

1-1979

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Recommended Citation

Deeds, W. E., "A Comparison of Multiple Frequency and Pulsed Eddy Current Techniques" (1979). *Proceedings of the ARPA/AFML Review of Progress in Quantitative NDE, July 1977–June 1978*. 23.

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A Comparison of Multiple Frequency and Pulsed Eddy Current Techniques

Abstract

In principle, the same information should be obtainable from either pulsed or multiple frequency eddy current techniques, provided they utilize comparable frequency ranges. In practice, there are important differences and advantages for each method. Pulse instrumentation is generally cheaper, simpler, and less sophisticated. On the other hand, there has been greater development of theory and instrumentation using sinusoidal eddy currents, so that the equipment is generally more quantitative at present. The basic problem of determining certain parameters when others may also be varying can be solved by measuring enough quantities to eliminate the unwanted variables, for example, by measuring the pulse response at various time delays or the sinusoidal response at various frequencies. In practice, the number of useful frequencies is strictly limited. Little additional information is obtainable from frequencies for which the skin depth is much greater or much less than the thickness of the sample. Since the frequencies must be spaced to permit separation by filters, this puts a practical limit of about four on the number of frequencies useful for a given problem. This is not a serious limitation, since one can measure two quantities for each frequency and the total number of pertinent parameters rarely exceeds six. Pulse equipment can more readily handle a wide range of frequencies, but the instrumentation tends to become more elaborate, especially if high frequencies are needed for a particular application, and the repetition rate becomes low if low frequencies are necessary. The reproducibility of pulses is a problem which can be circumvented by the use of bridge techniques, differential coils and other standard techniques. New computer programs and microprocessor equipment have been developed which now make it possible to set up tests and measure parameters directly and precisely without the lengthy optimization calculations once necessary, though the latter will continue to be useful for the design of optimized coils and experiments.

Keywords

Nondestructive Evaluation, Physics

Disciplines

Materials Science and Engineering | Physics

A COMPARISON OF MULTIPLE FREQUENCY AND PULSED EDDY CURRENT TECHNIQUES

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ABSTRACT

In principle, the same information should be obtainable from either pulsed or multiple frequency eddy current techniques, provided they utilize comparable frequency ranges. In practice, there are important differences and advantages for each method. Pulse instrumentation is generally cheaper, simpler, and less sophisticated. On the other hand, there has been greater development of theory and instrumentation using sinusoidal eddy currents, so that the equipment is generally more quantitative at present.

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New computer programs and microprocessor equipment have been developed which now make it possible to set up tests and measure parameters directly and precisely without the lengthy optimization calculations once necessary, though the latter will continue to be useful for the design of optimized coils and experiments.

Actually, most of my experience has been with sinusoidal eddy currents, and until recently I have considered pulse methods to be relatively inaccurate. But recent advances in integrated circuits, microprocessors and memory chips have made it possible to acquire, store and process digital data in ways which may make pulsed eddy currents preferable for many applications.

Computers have revolutionized eddy current testing in two stages. First, large scale computers have made it possible to make accurate calculations of boundary value problems and optimize the testing conditions. New microcomputers have made feasible much more sophisticated equipment and data processing for either multifrequency or pulsed eddy currents.

According to the Fourier theorem, data taken in either the time or the frequency domain should be equivalent, though many bits of data might be needed to make a good transformation from one to the other. Sinusoidal eddy currents (a δ -function in the frequency domain) correspond to an infinitely broad "pulse" in the time domain, whereas a δ -function pulse in the time domain corresponds to a white spectrum in the frequency domain. Though theoretically equivalent, there are a number of practical differences between the two methods.

Sinusoidal excitation is easier to treat theoretically, whereas pulses generally lead to integral transforms. Therefore, the theory of sinusoidal eddy currents is more highly developed. However, the number of fixed frequencies that can provide useful information is limited to about four. The reasons for this are that little additional information can be obtained from frequencies for which the skin depth is much greater or much less than the thickness of the sample and the useful frequencies must be fairly widely spaced because sharp-cutting filters introduce problems of maintaining phase and amplitude information. The result is that multiple frequencies cannot usually provide more than about eight useful bits of information in a given test (for example, the magnitude and phase at each of the four frequencies). Fortunately there are seldom this many parameters to be determined or eliminated in a given test, so the limitation is not serious.

Pulse equipment can be simpler and, with a few exceptions, has been less highly developed than multifrequency equipment. However, a sharp pulse contains a wide range of frequencies and can easily provide multifrequency information. In the past, the reproducibility of pulses has been more of a problem than with steady-state devices, but it can be handled by the use of bridge techniques, differential coils and improved integrated circuits.

Inspection speed is somewhat more limited with pulses, since the pulse must be essentially complete before the probe moves to the next inspection region.

There are several ways to use pulsed eddy currents. The earliest was the pulse-echo technique. This does not work well because eddy currents obey essentially a diffusion equation, not a wave equation. Hence, the wave form is not preserved, and one does not get sharp, distinct "echoes." Rather, there are simple variations in the build-up or decay of the signal. A good analogy would be to try to measure subterranean properties by measuring the surface temperature of the earth when it is struck with a pulse of solar radiation. The corresponding sinusoidal analogy would be to measure the phase and amplitude of the surface temperature relative to the (assumed sinusoidal) excitation. Mathematically, the solutions to a diffusion equation are real exponentials, not the oscillatory solutions of a wave equation.

Disregarding the pulse-echo technique then, should one work in the time or the frequency domain? Using frequency information from pulses generally involved analyzing the pulse into Fourier

components, probably using Walsh filters, to obtain the same sort of data as in the multifrequency method, except that a very wide frequency range can be covered with one pulse without the necessity of special tuning for a particular application. Working in the time domain is somewhat simpler, since fast analog-to-digital converts and sophisticated pattern recognition techniques have been developed. Also, modern microcomputers have made polynomial curve fitting practical and extremely accurate.

At Oak Ridge National Laboratory C. V. Dodd and I have developed a number of new computer programs to optimize multifrequency eddy current tests, take data, perform least squares fitting of data to properties with a minicomputer and then calculate the properties of unknown samples on a real-time basis using an eddy current instrument with an on-board microcomputer. We are also developing pulsed instrumentation using similar techniques.

DISCUSSION

- William Lord, Chairman (Colorado State University): At this time the floor is open for questions of any of the three speakers. I would like to remind you to give your name and affiliation if you have a question.
- Wolfgang Sachse (Cornell University): The previous speaker mentioned that pulse eddy current measurements were not reproducible. I am not an expert--in fact, I don't know very much about eddy currents at all--but the question I have is, "Why is that so? What is the cause of this irreproducibility?"
- W.E. Deeds (University of Tennessee): Well, as I said, I am not an expert on pulses or experimental things either, but it is my impression that you get heating of the sample and of the coil. If you look on an oscilloscope, you will see jitter. It is just electronic noise as far as I am concerned, but it is associated with heating effects and things like that.
- Robert E. Green, Jr. (Johns Hopkins): I don't know much about eddy current either, but I have had trouble using eddy currents with heating effects. Could you, or anyone, comment on how you may eliminate heating effects?
- W.E. Deeds: We have spent a lot of time on that. In the computer programs for designing coils it is possible to design the circuit components in such a way as to eliminate drift. You're quite right, differential coils, differential amplifiers, etc., mounted on the same heat sink can help. There are a lot of ways of doing it, but in general, you have to design the circuit to either compensate or eliminate drift.
- Don Thompson (Science Center): Could any one of you give an overall assessment of what quantitative capability has been successfully demonstrated with eddy current techniques, whether they be pulsed or multifrequency?
- W.E. Deeds: Well, let's see. I think just before I came here I was supposed to be getting a statistical sample of our three frequency measurements on tubing, but the only thing I recall were two frequency measurements on aluminum sheet and it seems to me that we separated the errors into three different categories. One was how reproducible the calculations were; another was how well they fit the actual data and what was the other one? There was a third one which I don't recall. I would say generally that thickness determination in the range of 70 or so mils would be better than a mil. I would say generally dimensional determinations would be of the order of a percent.
- Don Thompson: I meant the question from a slightly different point of view. What is the capability of deducing, as we have been trying in the ultrasonic areas, to determine the quantitative characteristics of a flaw?
- W.E. Deeds: The two-frequency apparatus is the only one that we have really made flaw measurements on so far, but as I recall, the flaw measurements were good to about 10 percent and the depths were good to roughly about 10 percent too. I hope we can do better than that, but at least we were happy to even do it.