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Supply Officer
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Principal Investigator: -
C. G. Gardner, Ph.D.
(512) 684-2000, ext. 506
Project Scientist: -
G. A. Matzkanin, Ph.D.
(512) 684-2000, ext. 787

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Subject: "Development of Nondestructive Testing Techniques for Detecting Stress in Brittle Materials", Second Quarterly Technical Progress Report, SwRI Project No. 15-2474

Dear Sir:

During the second quarter of Phase III of the subject project, effort has been focused primarily on the inductive coil technique for studying the Barkhausen effect. A low noise, battery powered preamplifier was constructed, and after some experimentation with pickup coils, good Barkhausen signals were observed as shown in Figure 1. The specimen used in this case was a three-inch long, one quarter inch diameter rod of polycrystalline Fe-3%Si. The pickup coil was four inches long and 0.705 inch in diameter, comprising 1268 turns of #38 copper wire. Figure 2 is an oscillogram of the Barkhausen signal from this specimen, displayed on an expanded time scale more clearly showing the voltage pulses attributed to the Barkhausen jumps in the specimen. The approach we are currently using is the so-called ballistic technique, where the pickup coil time constant (about 200 msec in our case) is much longer than the duration of the Barkhausen jump. In such a case, the net flux change associated with a Barkhausen jump can be obtained from a measurement of the amplitude of the induced voltage pulse.

8

As was indicated in the previous Quarterly Report (28 September 1970), a 1024 channel pulse height analyzer was recently acquired by SwRI and made available for use on this project. This instrument measures and digitizes the peak value of incoming voltage pulses and records the number of pulses in its memory channels, each channel corresponding to a certain pulse amplitude interval. Thus the data obtained is the number of pulses of a given amplitude versus pulse amplitude. Because of the usefulness of this instrument in the analysis of pulse trains, considerable effort was expended this past quarter in adapting it to our specific experimental situation. Figure 3 is a block diagram of our present arrangement. The voltage pulses induced in the sensing coil by Barkhausen jumps in the specimen are amplified and then analyzed by the pulse height analyzer. Several data readout modes are available as indicated in the block diagram. Figure 4 shows a photograph of the cathode ray oscilloscope (CRO) display of the pulse height analyzer memory contents after recording pulses from a single magnetization reversal of our Fe-3%Si specimen. Each dot displayed on the CRO represents the memory content of one channel. The horizontal position corresponds to channel number (or pulse amplitude); the vertical displacement of the dot is proportional to the logarithm of the number of pulses with the corresponding amplitude.

A voltage discriminator at the input to the pulse height analyzer serves to block out pulses below a certain amplitude, so that it is normally set just above the level of the background noise. However, we have found that during the analysis of Barkhausen signals, counting occurs in channels just below the discriminator level, presumably due to the low signal-to-noise ratio, arbitrary pulse shape, and overlap of pulses, as can be seen in Figure 2. In tests with a pulse generator, we have also found that the proper operation of the discriminator (and the pulse height analyzer, in general) is sensitive to the pulse shape. These observations indicate that suitable pulse shaping of the Barkhausen signals is necessary for the reliable operation of the pulse height analyzer, and we are currently weighing the several approaches available. (This component has already been included in the block diagram of Figure 3, in anticipation of its being obtained in the near future.) In interpreting the data obtained without benefit of pulse shaping, we are currently determining the channel corresponding to the discriminator setting for a particular experiment by using an accurately calibrated pulse generator, and then taking only information in channels above this level as being physically significant. In Figure 4, the discriminator level is set in the neighborhood of the peak of the displayed distribution curve; points to the left of the peak are presumed to be essentially instrumental in origin.

Although the CRO display as shown in Figure 4 affords a convenient means of observing and recording the contents of the pulse height analyzer memory, a more accurate record is obtained by making use of plotter or teletype readout. The teletype provides a printed digital record of the number of counts recorded in each channel of the analyzer memory. (In addition, the teletype terminal can be used as the interface to a computer for automatic manipulation of the data.) In the work done this past quarter, we have made use of the teletype terminal for quantitative readout of the analyzer information and expect next quarter to develop some programs needed for computer analysis of the data.

After putting the pulse height analyzer system into operation and examining some of the details of the technique in relation to Barkhausen studies, preliminary stress dependence experiments were run on polycrystalline Fe-3%Si. The amplitude distribution of voltage pulses induced by the Barkhausen effect was determined with the pulse height analyzer at various values of applied stress. Figure 5 shows the stress-strain curve for the specimen during the performance of the experiment. Data were taken within the elastic region for both tension and compression; the specimen was then plastically deformed (0.2%) in tension. Figure 6 is a graph of the pulse height distributions before and after plastic deformation showing the effects of the cold working and residual stresses. The relationship between the measured pulse amplitude and the Barkhausen jump (i.e., the magnitude of the net change in magnetic moment of the specimen) causing it was determined by a calibration procedure. A 200-turn calibrating coil of size similar to that of the specimen was inserted into the search coil in place of the specimen; current increments of known magnitude were sent through it by a pulse generator. The change in magnetic moment of the calibration coil was calculated to obtain a relation between the amplitude of voltage pulses induced in the pickup coil (and the corresponding pulse height analyzer channel number) and the magnetic moment change inducing the pulse. This calibration procedure is subject to criticism since it assumes the flux change accompanying a Barkhausen jump in the specimen is the same as the flux change of the calibration coil, which is not precisely correct. This, however, is the best way at present to relate the measured voltage pulses to Barkhausen jump size, until reliable calculations for the flux change accompanying a Barkhausen jump become available. Attempts to interpret the data in terms of magnetoelastic interactions are being withheld until the quantitative reliability of the data is assured by using a pulse shaper.

Although most of the effort this past quarter was devoted to the inductive coil method, the magnetooptic work was not entirely neglected. Preliminary work was done on making use of the pulse height analyzer in the magnetooptical photometric detection of Barkhausen jumps. Results using a Permalloy thin film specimen are encouraging, although it is clear that pulse shaping is also required here. Work was also done on the dual-beam magnetooptical experiment (the concept for which was discussed in the Phase II Final Report). The basic optical arrangement was set up and after some experimentation, it was found expedient to split the incident beam prior to, rather than after, reflection from the specimen. Thus two complete polarizer-analyzer sets are used, giving individual control of the polarization (and the domain image contrast) in the two branches of the beam. This approach appears quite promising and it is hoped that additional time can be spent this next quarter to refine and use it.

The high speed cinematographic study of domain dynamics is nearing realization with the acquisition of a new laser (provided by SwRI at no direct cost to the contract). This laser is a pulsed argon laser with the capability of providing a short burst of high-power, fast repetition rate pulses. The specifications call for 25 μsec pulses with a peak power of 9 watts at a repetition rate of 6,000 pulses per second during a burst duration of 8 seconds. A high speed camera (capable of taking pictures at 5,000 pictures per second) which will be used for the domain dynamics studies has been modified to provide external trigger pulses to the laser to synchronize the shutter opening with the laser pulses. Delivery of the laser is expected shortly after 1 January 1971 so that the first high speed domain dynamic studies should be underway during this next quarter.

An additional highlight of the past quarter was the selection of the work being done in this project to be one of several presentations made to the SwRI Board of Directors and Trustees during their annual meeting on November 23, 1970. A brief formal presentation was made covering both the inductive coil and magnetooptic work.

The Technical Monitor of this project was visited on December 15, 1970 and brought up to date on the progress of the work.

Work planned for the next quarter will involve collecting data with the inductive coil apparatus and putting the high speed cinematographic system into operation. There appears to be no major obstacle at this time standing in the way of the inductive coil work. Although the pulse shaping problem needs to be resolved to provide reliable quantitative data, it appears that adequate instrumentation to do this is commercially available. The problem is that most pulse instrumentation of this type is intended for nuclear spectroscopy work, whereas our application is different and somewhat unique. In the meantime, the acquisition of more quantitative data (as presented earlier in this report) will continue. Besides Fe-3%Si, specimens are also available of type AISI 4140 and 4340 steel which have been subjected to various heat treatment operations. The effects of stress (tensile and compressive) on the Barkhausen effect will be examined in these materials and the metallurgical and physical implications analyzed.

With respect to the magnetooptic work, work will focus on putting the high speed cinematographic system into operation. The laser and camera will be thoroughly checked out individually and then the synchronous operation will be examined. It is anticipated that the high power level of this laser will necessitate some changes in the optical system of the magnetooptic experiment, but these are expected to be minor. The only major problem we foresee at this time is the operation of the diffusing wheel used to eliminate the interference patterns due to the coherent light. Modifications of this component will probably be necessary because of the short pulse width and high repetition rate of this laser.

We will be happy to provide further details on any of the work discussed here.

Very truly yours,

John R. Barton

John R. Barton, Director
Instrumentation Research

Prepared by:

C. G. Gardner, Project Manager
G. A. Matzkanin, Sr. Research Physicist

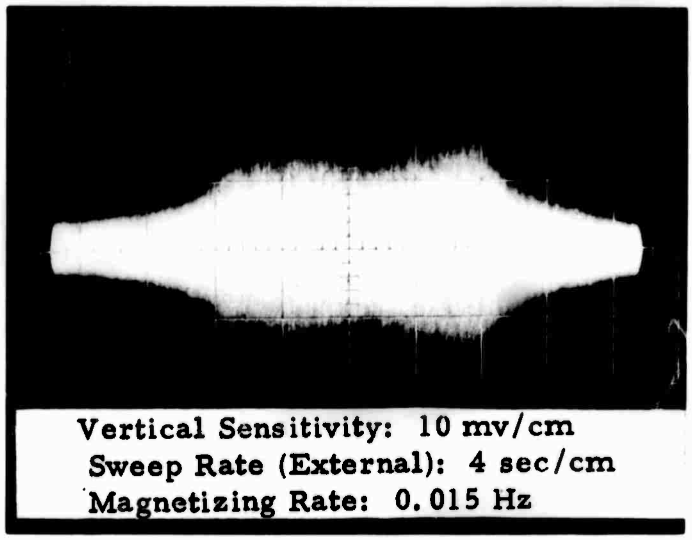

Figure 1. Barkhausen signal from a 1/4-in.-diam rod of polycrystalline Fe-3%Si for one complete magnetization reversal.

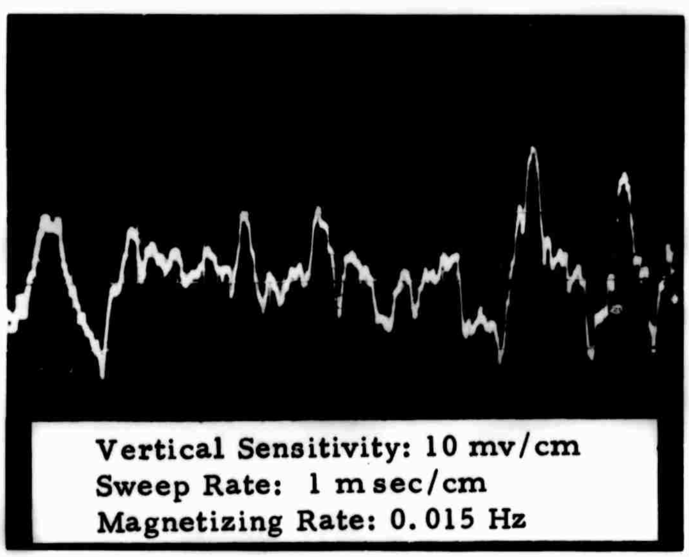

Figure 2. Resolved Barkhausen voltage pulses from a 1/4-in.-diam rod of polycrystalline Fe-3%Si for one complete magnetization reversal.

2142

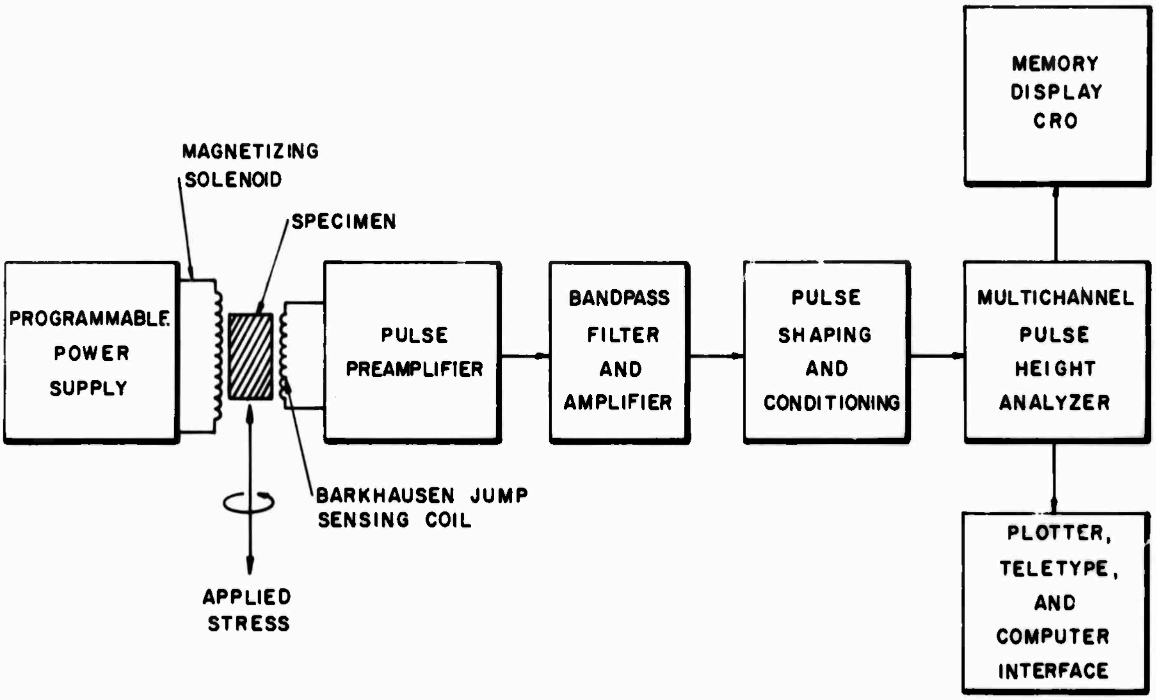

Figure 3. Block diagram of the inductive coil and pulse height analysis arrangement for studying the influence of stress on the Barkhausen effect.

2143

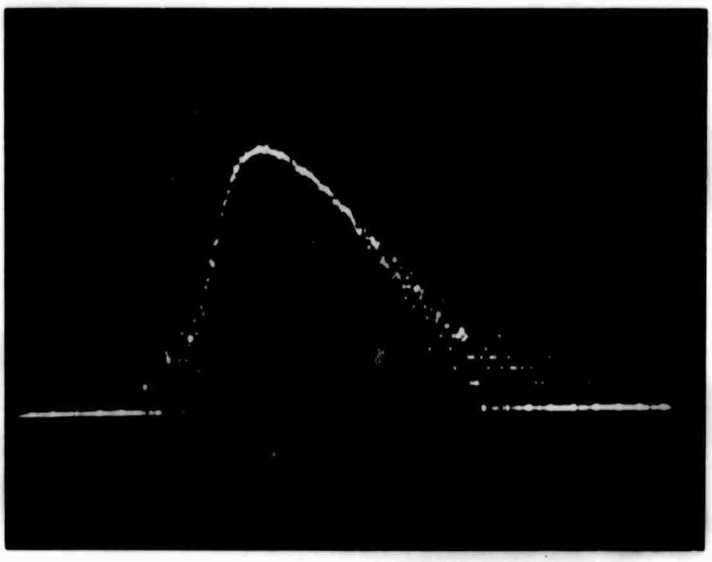

Figure 4. Oscilloscope display of the pulse height analyzer memory contents showing the amplitude distribution of voltage pulses induced by the Barkhausen effect in polycrystalline Fe-3%Si (the vertical scale is proportional to the logarithm of the number of pulses and the horizontal scale is proportional to the pulse amplitude).

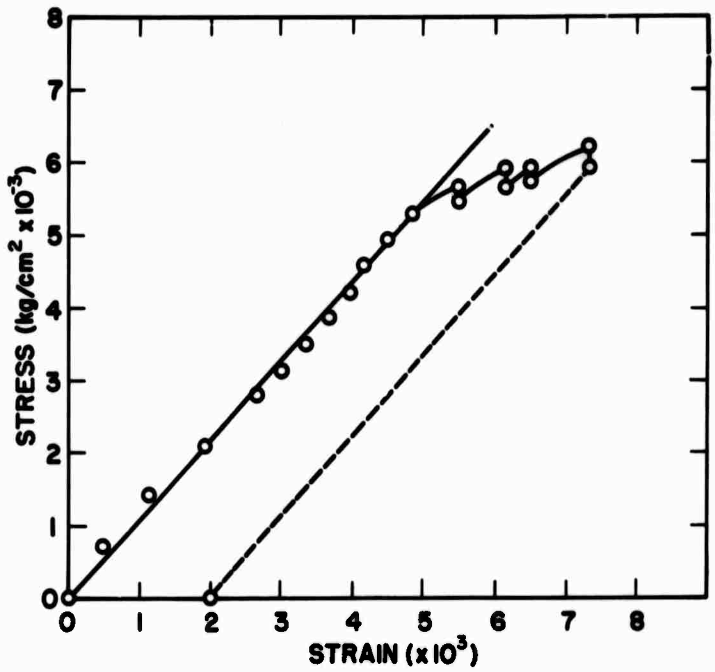

Figure 5. Stress-strain curve for cylindrical polycrystalline Fe-3%Si specimen (1/4 in. diam, 3 in. long) during Barkhausen effect studies (tensile stress).

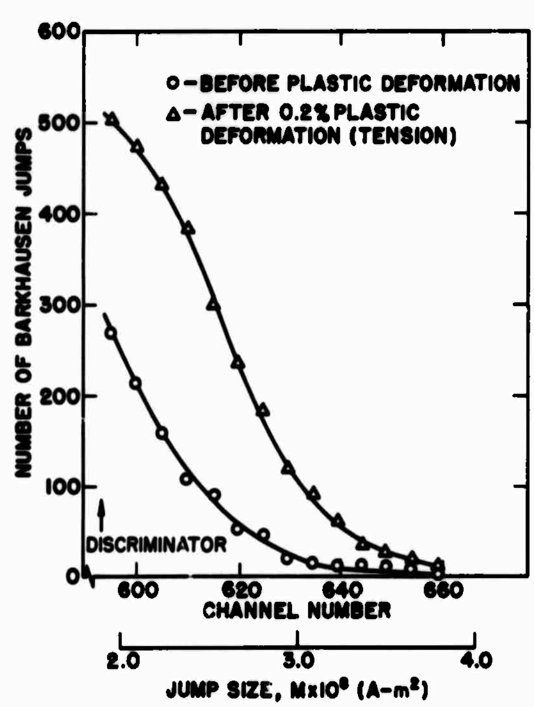

Figure 6. Effect of plastic deformation on the Barkhausen jump size distribution in polycrystalline Fe-3%Si for a single magnetization reversal.