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Contract N7onr-30307 between Carnegie Institute of Technology  
and the U. S. Office of Naval Research.

J. E. Goldman - Chief Investigator

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The objectives of this research contract are to equip a laboratory for magnetic measurements in very intense magnetic fields, to devise a new technique for the measurement of volume magnetostriction using resistance strain gauges, and to make measurements of this quantity on various ferromagnetic metals and alloys. To date, the first two objectives have been essentially completed. The success of the method which we have developed suggests that a great deal of interesting information will be obtained on the nature of the ferromagnetic interaction as soon as further measurements are made on the various alloys under investigation. This phase of the task order has already been initiated and we have preliminary results.

1. The Magnetic Laboratory. In the spring of 1951, a large electromagnet that had been purchased by Carnegie Institute from the Arthur D. Little Company was delivered. The major portion of the year 1951 was spent getting the magnet and laboratory into operation. Control equipment for the magnet was designed and built with funds made available by ONR under this contract. The control equipment is described in some detail in an Appendix attached to this report. Some difficulties have been experienced in the operation of the magnet and the control equipment. The former is a result of faulty design by the manufacturer; the latter, in consequence of the difficulty of providing a unit which would make possible stability at all fields as well as continuous control of the field current. Some minor modifications are contemplated but on the whole the laboratory is in satisfactory operation and

being used a maximum number of hours on the various ONR sponsored programs.

2. Method for Measurement of Volume Magnetostriction. The method which we have devised for the measurement of the volume magnetostriction has been perfected. By use of resistance strain gauges mounted in each of the three principal directions of a rectangular parallelepiped and by connecting the three gauges in series in one arm of an extremely sensitive Wheatstone Bridge, it is possible to simplify considerably the measuring technique and improve the accuracy to an appreciable extent. The principal difficulty has been to maintain the temperature constant during a measurement since a very small change in temperature is equivalent to a volume change larger than that which we seek to measure. The advantages of the method are as follows: (a.) By using a DC amplifier as the detecting element in the bridge, very great sensitivity may be obtained. (b.) The method is electrical so that a continuous record of the changes in resistance of the active gauges can be obtained. In this way, we can be certain of measuring equilibrium properties and minimizing errors due to thermal drift or expansion due to magnetocaloric effect. (c) The high sensitivity of the method makes possible measurements as a function of field and simultaneous elimination of effects due to longitudinal magnetostriction. (d.) Using a special technique which we have devised and which will be described in more thorough detail at a later date, we can make measurements while the sample under consideration is part of a continuous magnetic circuit. This eliminates completely errors due to form effect which arise when there are poles present at the extremities of the sample and which in all other methods of measurement have to be corrected for. At the same time this makes possible a more rapid approach to thermal equilibrium than is possible with a liquid dilatometer.

3. Measurements on Ferromagnetic Metals and Alloys. Accurate measurements have already been made on a sample of pure nickel. We have made

these measurements as a function of field and agreement with the only available data at the one value of field which the early investigators employed is good. Measurements on this sample are continuing in an endeavor to cover a wider range of fields and temperatures. We have taken steps to obtain other metals and alloys on which we hope to make measurements. In addition to the measurements on iron, hexagonal cobalt and face-centered cobalt, we contemplate measurements on a nickel-manganese alloy, Heusler alloy and Gadolinium.

4. Miscellaneous Activities. Measurements have continued on the study of the single crystal magnetostriction constants of iron-cobalt alloys. For the region in composition where no single crystals are available, we have been employing a technique suggested by Bates of obtaining the single crystal data from measurements on polycrystalline materials. Miss Helen M. A. Urquhart has been working on this problem. She has been supported by an Allegheny-Indiana fellowship but has availed herself of the facilities made available by this contract. In connection with her thesis, she has also been investigating dipole-dipole interactions in antiferromagnetic lattices and the possibility of an antiferromagnetostriction. This has necessitated the investigation of the potentialities of strain gauges at low temperatures.

Dr. K. Azumi of Tokyo is now with us for a year as a visiting physicist and will investigate the temperature dependence of the longitudinal and volume magnetostriction in single crystals of copper-nickel alloys in which the Curie temperature has been depressed so that it is close to room temperature.

We have had the benefit of the consultations with several of the distinguished European visitors who came to this country in connection with the ONR sponsored Conference on Magnetism held at the University of Maryland in September. In particular Professors Bates, Stoner and Sucksmith visited the laboratory.

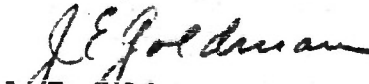
The writer, with support from this contract, contributed to the

organization of the program for this conference, authored a paper presented there, and helped to edit the proceedings for publication.

5. Personnel: The following people have contributed in some measure to the work supported by this contract as full, part-time or summer employees:

Helen M.A. Urquhart (Graduate Assistant, part-time)  
E. Anolik, (Graduate Assistant, full time to August, 1951)  
C. Peters, (Laboratory Assistant)  
H. Lefke (Machinist, part-time)  
W. Bitler (Graduate Assistant, summer)  
Margaret Schaeffer (Secretary, part-time)  
H. Weinshanker (Graduate Assistant)

Respectfully submitted,

  
J. E. Goldman  
Chief Investigator

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### Appendix I

The current control system for the new ADL magnet has been completed and test runs on stability and reproducibility obtained. An additional unit has been added to the starting system to avoid heavy overloads of the motor windings during starting. A brief description of the magnet current regulating system is included in this report, the details will be presented at a later date.

The ADL magnet is powered by a 135 KW, 24 KV Allis Chalmers generator with a separately excited field. Current control is obtained from the closed loop servo system shown in the accompanying block diagram (Fig. I). The heart of the control unit is the signal resistor  $R_s$ , (Leeds and Northrup shunt .001  $\Omega$  .500 amp) which is placed in series with the magnet. The voltage across  $R_s$ , proportional to the total magnet current, is compared with the voltage produced in the field control box. The difference between these two voltages (the error signal) is fed to the remote controls for proper polarity and is then supplied to the DC breaker amplifier. Here the signal is converted to A.C., amplified ( $10^6$ ) and rectified with the proper polarity and phase. The pulsating D.C. output (208~) is fed thru a biasing battery  $B_1$  to the grids of a large bank of 1625 beam power pentodes (96 tubes in parallel). These tubes, operated so that parasitic oscillations are suppressed, furnish the current for the generator excitation field thru the remotely controlled polarity switch which, in turn, causes the generator output current to vary in such a way that the voltage across  $R_s$  is exactly equal to a given preselected value chosen from the field control box. The maximum tube current of 12 amps is sufficient to produce maximum output of the generator. Hunting is prevented by a feedback voltage from the generator via the remote controls (for polarity) to the amplifier.

For protection of these tubes, a safety circuit is included to limit the maximum grid voltage in case of failure of any part of the system. The bias battery  $B_2$  fixes the grid voltage for low power operation when the safety circuit locks out because of an overload. The common for the appropriate circuits is placed at -110V DC, so that the available DC power could be utilized for the 1625 tube bank resulting in considerable economy for plate, screen and filament power supplies. The remote controls and field control are grouped together near a laboratory bench so that the operator may readily control the magnet while making measurements during an experiment.

Test results, obtained by connecting a portable Rubicon potentiometer across a 1200 amp, 100mv shunt in series with the magnet, and using a single feedback system gave the following results for the current variations in the magnet:

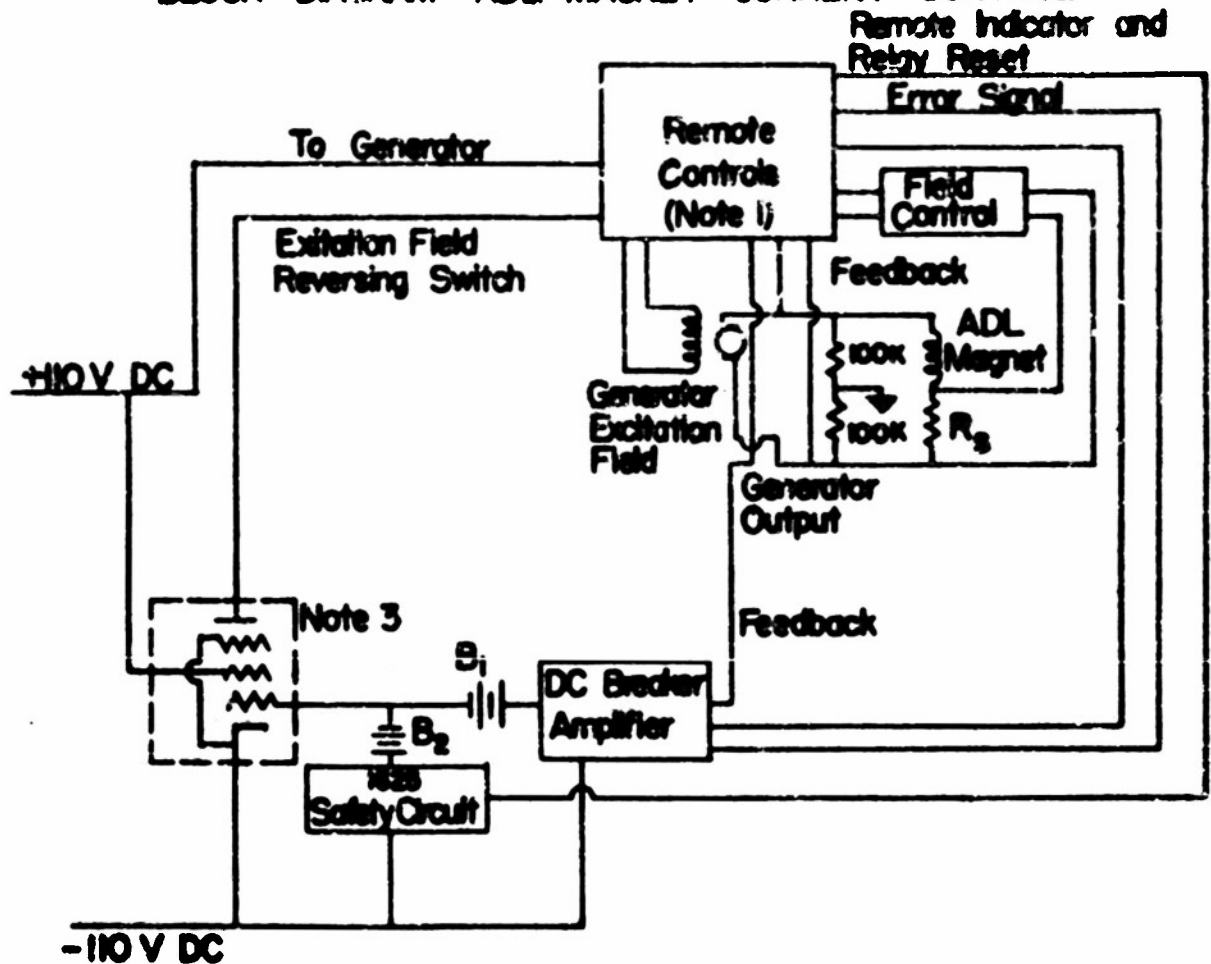
- a) Reproducible currents to 1 part in 2000 or better with higher reproducibility at higher powers.
- b) Maximum variations of current less than 1 part in 2000 over entire range of currents.
- c) Using a Rawson Rotating coil flux meter, measurements were taken of the magnetic field at the various power levels. With proper cycling, the fields were reproducible as closely as

could be read on the meter (three places). Further tests will be run when a proton resonance probe is available.

Note that the above tests were made with currents up to 260 amps corresponding to a power of about 35 KW.

Where higher stability is desired, there are several methods which can be used at a sacrifice of ease of operation and versatility. The shunt,  $R_s$ , may be changed depending on the current required so that a maximum signal voltage is obtained in each range. By this means a factor of about 10 sensitivity can be obtained. Of course, for low powers, a further modification would be to place  $R_s$  in an oil bath at constant temperature. Since the inductance of the magnet varies considerable over the operating range, a number of different feedback networks maximized over a limited power range could be used to decrease the maximum variation of current in the magnet. Finally, several methods of using the magnetic field to furnish a signal for control can be used. This could be applied to the generator or to the special control coils (a set of high resistance, low current coils included in the yoke assembly) by means of appropriate amplifying and feedback systems. The above modifications all have certain advantages when operating over a limited power range or at a fixed field; however, the complexity and lack of flexibility of such systems have limited their use. Sufficient latitude is allowed in the design, that if a special problem arises which has more stringent requirements, all above modifications may be included if desirable. Mr. S. Foner who was supported on another ONR contract, assisted in designing and building the control equipment.

## BLOCK DIAGRAM - ADL MAGNET CURRENT CONTROL



Note 1: Remote controls include

- (a) 3 DPDT Switches ganged to control polarity of generator excitation field, error signal, feedback, and generator voltage output indicator.
- (b) Remote overload indicator.
- (c) Emergency stop switch.

Note 2: Common is 110V DC.

Note 3: Ninety-six 1625 tubes in parallel.

Figure M-1