

compression curve. Copper samples with a mean radius of 1 mm and a wall thickness of 0.1 and 0.2 mm, respectively, have been assumed. The induced current, which is proportional to $(H_a - H_i)$, heats the sample up to the boiling point. The temperature ϑ of the sample depends mainly on the magnetic field. The influence of the field rise and of the wall thickness on the temperature is small. The sample is also subjected to magnetic pressure. This will vary within the sample, according to the current distribution. The peak pressure $\frac{1}{2}\mu_0(H_a^2 - H_i^2)$ is reached at the inner surface, where the sample must be supported by a rigid nonconducting material.

Temperature and pressure are shown in Fig. 2. In the calculation, the well known $\rho(\vartheta)$ curve for copper has been used, and the variation of the specific heat with temperature has been taken into account. Some preliminary diffusion experiments have been carried out. The results are consistent with the calculated curves within the limits of experimental error of the field measurement, which is of the order of 10%. It follows that the present methods for the measurement of megagauss fields are not precise enough to detect smaller deviations from the known $\rho(\vartheta)$ law in megagauss field environments. To obtain meaningful results from differential measurements of this kind, the precision would have to be improved by one or two orders of magnitude.

The influence of pressure on the resistivity is expected to be small in the 100 kilobar pressure range. From an extrapolation of Bridgman's results,⁶ we find for copper at room temperature $\Delta\rho/\rho = 0.15$ at 100 kilobar and $\Delta\rho/\rho = 0.56$ at 1 megabar. If the magnetoresistance follows Kohler's rule⁷

$$\Delta\rho/\rho = f(H/\rho) \quad (3)$$

also in the megagauss range, then there should be no detectable magnetoresistance effect in this experimental ar-

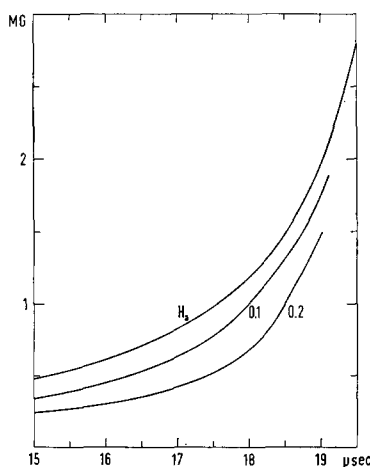


FIG. 1. Diffused field in cylindrical copper samples of 1 mm radius with 0.1 and 0.2 mm wall thickness. H_a is the applied field outside the samples. Initial condition at $t = 0$ μ sec: $H_i = H_a = 65.5$ kG.

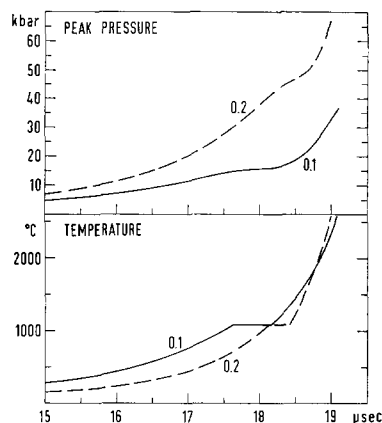


FIG. 2. Temperature of the samples and peak pressure at the inside of the samples. The time scale is the same as in Fig. 1. The parameter of the curves is the wall thickness in millimeters.

angement, because of the high temperature of the sample. From the experimental data of Lüthi⁸ it follows that the magnetoresistance effect will be smaller than $\Delta\rho/\rho = 10^{-2}$ in the two examples calculated here.

This experimental arrangement would be mainly of interest for studying the behaviour of materials which are used as liners in flux compression experiments. In these experiments the liner material is also subjected simultaneously to high pressures, temperatures, magnetic fields and current densities.

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¹ C. M. Fowler, R. S. Caird, and W. B. Garn, *J. Appl. Phys.* **31**, 588 (1960).

² *Proceedings of the Conference on Megagauss Magnetic Field Generation by Explosives and Related Experiments, Frascati, Sept. 21-23, 1965* (EURATOM EUR 2705.e, Brussels, 1966).

³ E. C. Cnare, *J. Appl. Phys.* **37**, 3812 (1966).

⁴ J. W. Shearer, in *Proceedings of the Conference on les champs magnétiques intenses, Grenoble, Sept. 12-14, 1966* (CNRS, Paris, 1967), p. 355.

⁵ D. W. Forster and J. C. Martin, in *Proceedings of the Conference on les champs magnétiques intenses, Grenoble, Sept. 12-14, 1966* (CNRS, Paris, 1967), p. 361.

⁶ P. W. Bridgman, *The Physics of High Pressure* (G. Bell and Sons, London, 1949).

⁷ J. L. Olsen, *Electron Transport in Metals* (Interscience Publishers, London, 1962).

⁸ B. Lüthi, *Helv. Phys. Acta* **33**, 161 (1960).

Air Bearing for Viscometers

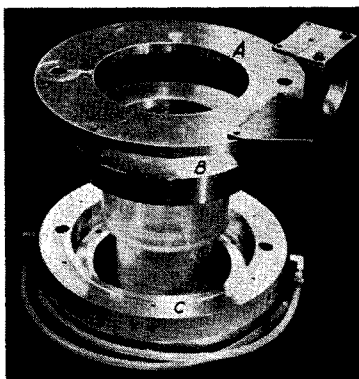
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AN air bearing was constructed to facilitate the measurement of torque induced on the stationary outer cylinder in a circular Couette flow experiment. This annular flow, or ones similar to it, and the associated torque are used in measurements of fluid viscosity and in other studies of fluid physics. The air bearing permitted a seg-

FIG. 1. Exploded view of air bearing showing thrust plate (A), journal (B), and radial-thrust bearing assembly (C).



ment of the outer cylinder to be supported in a virtually frictionless way so that small changes in torque could be observed. Nevertheless there was sufficient constraint to preserve the desired alignment of the parts. The bearing is described in the following paragraphs to provide others who are concerned with measuring small torques with a design that can be used as a reference, or a point of departure. Previous authors¹ have incorporated an air bearing into a viscometer but specific design information on the subject is generally limited.

The bearing is illustrated in Fig 1 in exploded view. The upper thrust plate is labeled A. Part C is a two-piece assembly containing a radial bearing surface and the lower thrust plate which is a mirror image of plate A. The journal is designated as B. This is connected to a segment of the outer cylinder on which torque is to be measured. In making viscosity measurements the inner cylinder is normally stationary and the outer one rotates. The bearing that is described could be easily modified to suit this operating condition.

The appendage at the right of plate A in Fig. 1 is part of the vernier used to measure the rotation of a torsion wire. The figure also shows the pneumatic connections which supplied the air at 1.36 atm to the bearing. A simple filter was added to the air supply just upstream of the bearing to prevent moisture and oil from depositing on the bearing surfaces.

Figure 2 shows the bearing features in greater detail. The numbers associated with each hole are the same for corresponding holes in pieces A and C. Air is introduced into the bearing through 5c, and the hole diametrically opposite. These two holes also are used by the half-round shafts which attach the bearing to the rest of the test apparatus. The air passes along the groove and enters 2c, 2a and similar holes that connect with the groove. Hole 2a supplies 1a by means of a radial passage that has been drilled and plugged. The set-screws that were used to seal this passage are shown clearly in Fig. 1. In the same way air passes along a second groove, not visible in the illustration, to supply 1c. The journal receives axial support in two directions in this way. The air can leave the bearing by

TABLE I. Pertinent dimensions of air bearing in centimeters.^a

o.d. of bearing assembly	22.225
o.d. of journal	16.5353
Length of journal	2.5198
i.d. of radial bearing	16.5481
Length of radial bearing	2.5502
Average radial clearance	0.0064
Average end clearance	0.0152
i.d. of thrust bearing	12.70
Thickness of thrust bearing plate	0.9525
Width and depth of air supply grooves	0.8255×0.1524
Diameter of holes 1a, 2a, 2c, 3c, 4c	0.4978, 0.1168, 0.3175, ^b 0.1575, 0.3175
Width and depth of recess for 1c	1.2065×0.0102
Width and depth of recess for 4c	0.7925×0.0076
Approximate included angle of recesses	50°

^a Tolerances are not given because a development program was not undertaken to determine acceptable limits. However, the authors believe that dimensions within 0.0005 cm of those given in the table should be satisfactory.

^b Conversion to inches would give dimensions corresponding to fractional and number-drill sizes.

flowing across the inside edge of the thrust plates or via holes such as 3c or 3a. The outlet of holes like 3a can be seen in Fig. 1.

The air that enters 2c also escapes through a hole such as 4c and provides for radial support of the journal. It should be noted that holes like 1c and 4c have been beveled to reduce the severity of the change in passage geometry.

The six holes in each thrust plate that correspond to 1c are in a slight recess. The grooves were milled 0.0102 cm deep and were done with the aid of a dividing head. The recess associated with 4c gently merges with the circular wall of the bearing. This occurs naturally when using a circular milling cutter. The pertinent dimensions of the pieces, grooves and holes are given in Table I.

The upper bearing plate (A in Fig. 1) is assembled to the remainder of the bearing by hole 6a and the tapped hole 6c. No gaskets are used in assembling the bearing. The material thickness was more than that needed to provide space for the passages; a minimum of part deflection during operation and assembly was the prime consideration. Aluminum was used to avoid the problem of corrosion.

The loading capacity of the bearing was not ascertained;

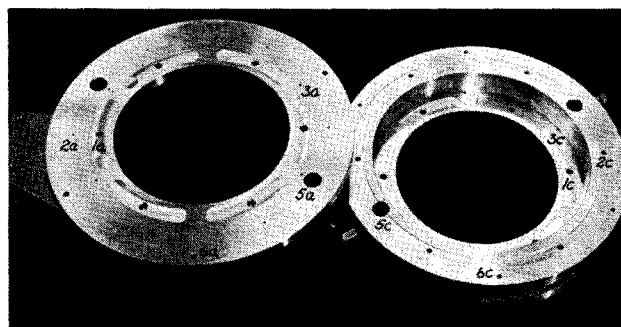


FIG. 2. View of bearing assembly showing the location of holes cited in text.

however, moderate forces applied by hand did not cause the bearing surfaces to touch. Electrical conductivity between A and B in Fig. 1 could be used to sense overloading. Improper design and machining of holes and passages can result in the journal being propelled by the air flow. In the reference cited previously a variable jet was added to the bearing to eliminate this autorotation. The outer edges of the journal were slightly beveled to minimize any contact between the journal and dirt particles which could accumulate in the corner formed by the radial and the thrust bearing surfaces.

¹P. J. Gillinson, Jr., C. R. Dauwalter, and E. W. Merrill, "A Rotational Viscometer Using an A. C. Torque to Balance Loop and Air Bearing," *Trans. Soc. Rheol.* VII, 319 (1963).

Simple Electronic Linear Sweep Circuit for Current-Regulated Magnet Power Supplies*

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NOWADAYS it is the fashion for laboratory electro-magnet power supplies to be field-regulated, usually by means of a Hall-effect probe placed in the magnet gap. On most supplies of this type the circuitry for generating a linear field sweep is built in. This is not the case with older current-regulated supplies, for which a linear sweep voltage must be provided by the user from some external source. In our laboratories this sweep voltage was, for many years, obtained from mercury batteries across a

15-turn linear potentiometer, motor driven through a variable gear train. This scheme suffered from many of the defects inherent in any mechanical system, the most serious being the eventual degeneration of the potentiometer through wear. Recently, when the potentiometer became excessively noisy, this system was abandoned in favor of an electronic linear voltage sweep using solid-state circuitry. This circuit is described here in the hope that it may prove useful to others with current-regulated supplies who would like to add electronic sweep at moderate cost. It was designed specifically for use with a Varian VA2100 power supply, but may readily be adapted to any other similar supply. Its usefulness is, of course, not limited to the sweeping of magnet power supplies.

Unlike some more elaborate circuits,¹ it does not generate repetitive sweeps. For much work in magnetic resonance, automatic repetitive sweeps are less useful than single ones initiated manually.² Considerable simplification results from restricting the circuitry to the generation of single sweeps.

Central to the circuit, shown schematically in Fig. 1, is a commercial solid-state operational amplifier, operated in three different modes. The operation is best described by considering each mode in turn. Schematic diagrams for each mode are shown in Fig. 2.

In the ZERO mode, the amplifier is operated as an inverting amplifier of gain 10, with grounded input. It provides a rapidly-selected zero output while leaving other settings of the circuit undisturbed. It is also used for adjusting the input offset voltage to give exactly zero output by means of the potentiometer built into the operational amplifier. The precision of this adjustment is increased by making the amplifier gain greater than unity. Once made,

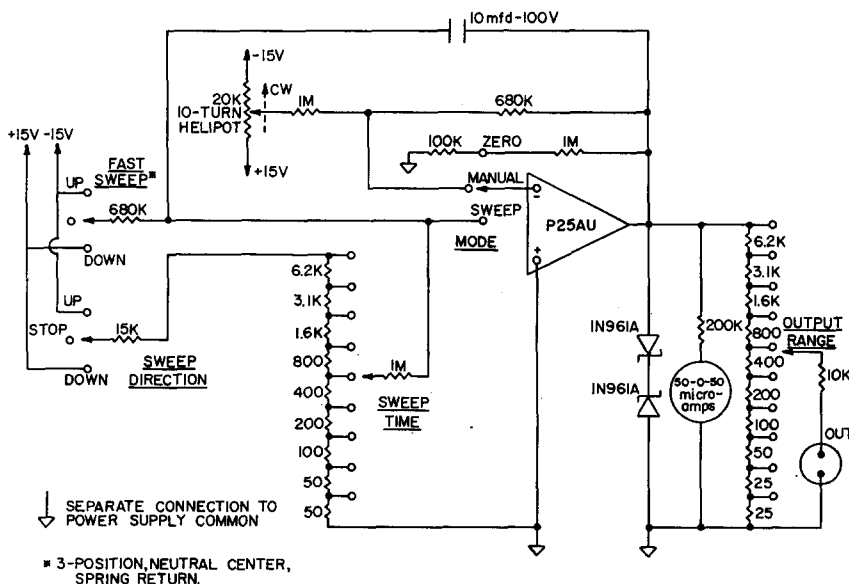


FIG. 1. Sweep circuit schematic.