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Methods of Spinning Rotors at High Speeds and Low Temperatures[†]

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Abstract: Two methods of spinning rotors up to their bursting speed at liquid helium temperatures are described. In the first, the rotor is magnetically suspended by a method used previously at room and elevated temperatures. The rotors are driven in a manner similar to that of a synchronous or induction motor. In the second method, the rotor is supported and driven on the lower end of a long, small-diameter, stainless steel shaft. Vibrations in the shaft are prevented by teflon guides; the shaft is driven by an air turbine. In both methods the rotors spin in chambers which may be evacuated if required. These chambers are surrounded by concentric dewars, the inner one containing liquid helium and the outer liquid nitrogen. A number of applications of this new technique are discussed.

HIGH speed rotors have been used in a wide variety of important problems in several different fields of science[1]. Most of these investigations have been carried out within a temperature range extending from about 25C above to about 25C below room temperature. However, in a number of problems it is of importance to extend this temperature range to much wider limits. For example, high speed rotors are useful in determining the mechanical strength of materials (especially thin films of material), and these measurements clearly should be carried out over as wide a temperature range as possible. Also, where the rotor is used as a centrifuge, the equilibrium separation of a substance above its freezing point is greatly increased as the temperature is lowered, etc. The purpose of this paper is to describe two methods of spinning rotors at high speeds and low temperatures. With minor modifications, the two methods also may be used for spinning rotors at high temperatures.

In order to maintain a high speed rotor at liquid helium temperature, it is necessary to effectively insulate the rotor thermally and to reduce the generation of heat in the rotor to an extremely small value. This is accomplished in the first method by freely suspending the rotor magnetically in a vacuum surrounded by a concentric dewar flask arrangement and driving it by a rotating magnetic field having a frequency approximately that of the rotor. In the second method, the rotor is supported and spun in a vacuum inside of a concentric dewar flask arrangement by means of a long, small-diameter shaft made of material possessing a very small heat conductivity.

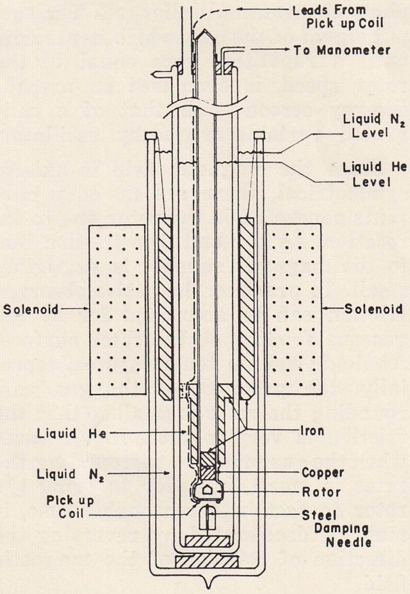

Fig. 1. Magnetic Suspension Arrangement

Magnetic Suspension Method

Fig. 1 is a diagram of the magnetic suspension method. The ferromagnetic rotor is suspended inside a long evacuated glass tube by the solenoid situated outside and concentric with the dewar flask containing the liquid nitrogen. In order to reduce the necessary current through the solenoid, steel cores are placed, as shown, inside of the dewar flasks containing the liquid nitrogen and liquid helium. Permanent magnets or soft iron may be used for these cores if desired, but ordinary cold rolled steel was used in these experiments. Such a freely suspended rotor in the axial magnetic field of a solenoid carrying a fixed current is, of course, unstable with respect to vertical motion; so it is necessary to regulate the current through the solenoid. This is accomplished by placing a small *pickup* or sensing coil just below the vacuum chamber surrounded by liquid helium. The *pickup* coil is in the grid circuit of a roughly 5 megacycle tuned-grid-tuned-plate oscillator which regulates the current through the solenoid in such a way that, when the rotor rises, the current is decreased and vice versa. In order to prevent vertical oscillations of the rotor, the control or servo circuit (Fig. 2) contains derivatives, or electrical damping. When operating properly, no vertical oscillations can be observed by a microscope focused upon scratches on the rotor. Since the magnetic field is strongest on the axis, the ferromagnetic rotor always moves toward the axis and is, therefore, horizontally stable. However, the damping of horizontal oscillations about the axis is very small, so in these experiments two damping devices have been added. The first consists of a short cylinder of pure copper which is placed between the lower end of the steel core and the rotor in such a way that the magnetic flux to the rotor passes through it. Clearly, when the rotor oscillates horizontally, induced currents which damp the oscillations are set up in the copper. An additional damping mechanism consists of a small steel or permalloy wire needle surrounded by a plastic-foam cylinder. The needle is anchored below by a very small copper wire or a thread which is adjusted so that the needle follows any horizontal motion of the rotor and has no appreciable restoring torque to bring it back to the axis. Since the needle and plastic foam cylinder are in liquid helium, which has a small viscosity, the rotor oscillations are further

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[1] Superior numbers refer to similarly numbered references in the Bibliography at end of paper.

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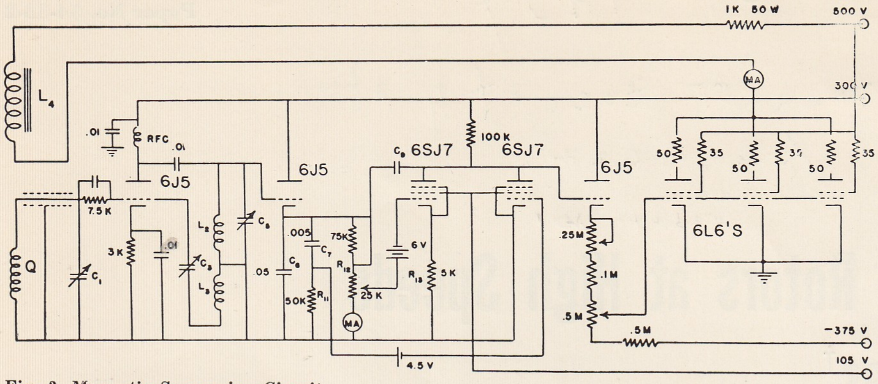

Fig. 2. Magnetic Suspension Circuit

damped. The exact size of the cylinder and needle are found by trial and error, but for the rotor shown in Fig. 1 they are about to scale. A small plastic shield (not shown) is placed below the cylinder to keep bubbles in the liquid helium from disturbing the damper. The size of the rotor may be varied over a very wide range; i.e., from the order of 0.001 inch diameter to as large as the dewar flasks which surround them can be made. Rotors weighing from 10^{-5} to over 3×10^4 grams have been freely supported by this method at room temperature. The solenoid contains 25,000 turns of well insulated A.W.G. No. 24 copper wire, and the pickup coil contains 15 turns of No. 34 copper wire, bunch-wound. To prevent heat leaks, the leads to the pickup coil are made of fine manganin wire, at the points where they pass out of the liquid helium bath. The current in the pickup coil is kept as small as possible.

The control circuit for the support is shown in Fig. 2. This type of circuit has been described before, so only a brief indication of its action will be given[2,3]. It will be observed that a change in the vertical position of the rotor with respect to the pickup coil changes the *Q* of the oscillator circuit and, hence, the amplitude of the oscillations. The d-c voltage appearing across the cathode resistor is proportional to the amplitude of the oscillations, and, hence, is an electrical measure of the rotor height above the pickup coil. This *error* signal and its derivative are separately amplified, mixed, and then applied to the grids of the 6L6's which, in turn, control the current through the solenoid. Since the magnitudes of the error and its derivative signals are separately adjustable, it is a simple matter to find the proper relative absolute values to give stable support of the rotor.

The rotor is spun in a manner similar to that of the armature of an induction or of a synchronous motor. The former may be used at liquid nitrogen or higher temperatures, but the latter is much preferable at liquid helium temperatures. The rotor drive consists of two pairs of drive coils with their axes at 90 degrees. They are actuated by a power oscillator in such a way as to produce a rotating magnetic field of the desired frequency at the axis of the rotor. When the rotor is accelerated by the induction motor method, the power oscillator has a fixed frequency well above the maximum rotor speed. This method, of course, generates eddy currents which produce considerable heat in the rotor unless the power input to the coils is small and the resultant acceleration is small. On the other hand, the rotor may be accelerated as a synchronous motor, without appreciable heating, if the frequency of the driving oscillator is maintained approximately the same as that of the rotor and is slowly increased. Space is not available here to describe these oscillators, but they are of standard design. The rotor speed is measured by reflecting light off the rotor into a photo-electron multiplier cell. The output signal of the cell, which is periodic with a repetition rate equal to the rotor speed, is compared on a cathode-ray screen with that of a calibrated variable frequency oscillator.

Since the magnetic field is axially symmetrical, there are no eddy currents generated in the rotor due to its rotation. As a result, the friction due to the magnetic support is negligibly small. In practice, the entire observed friction can be accounted for by the gaseous friction on the rotor surface. At liquid helium temperatures, especially, the pressure of the gas surrounding the rotor is small so that the friction is very minute. In all cases when the gas pressure surrounding the rotor is small, in order to bring the rotor to rest in a reasonable time, it must be decelerated by reversing the direction of rotation of the magnetic field.

This method of spinning rotors is being used for determining the tensile strengths of materials at temperatures down to that of liquid helium. It has been found especially useful in determining the tensile strengths of thin metallic films as a function of their thickness. Also, it has been used to determine the adhesion of one substance to another. In general, it may be used for any experiment which may be carried out in the presence of a relatively weak magnetic field and where connections do not have to be made to the rotor.

Flexible Shaft Rotor Drive

Although, in the magnetic suspension method, the rotor has almost perfect thermal isolation, in many experiments it is necessary to make direct connections to the rotor; i.e., measurements of vapor pressure, resistance, temperature, etc., usually require wires or tubes connecting with the rotor. In the second method, this is accomplished with a minimum of direct thermal connection between the rotor and the regions at higher temperatures. Fig. 3 shows a schematic diagram of the second method. The rotor (R) is fastened to the lower end of a long 0.025 in. stainless steel hypodermic needle tube by means of a gas tight clutch arrangement. This hypodermic needle shaft (S) is supported by the air-supported, air-driven turbine (T) and ends at the top in a gas-tight chamber. The shaft (S) passes into the two gas-tight chambers through the vacuum-tight oil glands G_1 and G_2. In order to prevent the long shaft from being destroyed by vibrations during the periods of rotor acceleration and deceleration, the shaft (S) is surrounded by teflon guides (TE) mounted in a long, pyrex glass tube (QT). The teflon guides are short 0.25 in. OD cylinders with cylindrical holes bored along their axes about 0.045 in. in diameter, so that there is a clearance around the shaft of about 0.01 in. at room temperature. They are held in vertical position by the coil spring, SP. Teflon is used for guides because of its low coefficient of friction. A flywheel (FW) may or may not be mounted on the shaft. The glass tube (QT) is mounted at the top in B, but the lower end is free. As the rotor speeds up, the amplitudes of the critical vibrations of the shaft are prevented from building up by the teflon guides. This, of course, communicates vibrations to the glass tube (QT) which must be damped. For this reason at least three dampers (D) are fastened to QT. They consist of a thin disc of metal, rigidly clamped to the glass tube, upon which rests a cylindrical ring of another metal. As the tube vibrates, the ring tends to stand still, while the disc vibrates; the resulting friction is sufficient to damp the oscillation. At running speed no vibrations are detectable. The discs are made of steel or stainless steel with OD of 1.5 in.; the rings are of brass with ID of 0.75 in., OD of 1.5 in., and height of 0.75 in. The rotor and flywheel are surrounded by a gas-tight glass cylindrical chamber GT which in turn is surrounded by the dewar flask V_2 containing liquid helium. Flask V_2 is surrounded by a second dewar flask containing liquid nitrogen. Both GT and V_2 are sealed at the top with special tape and may be evacuated or filled through the tubes shown at the top. The corks C provide support for V_2 and GT.

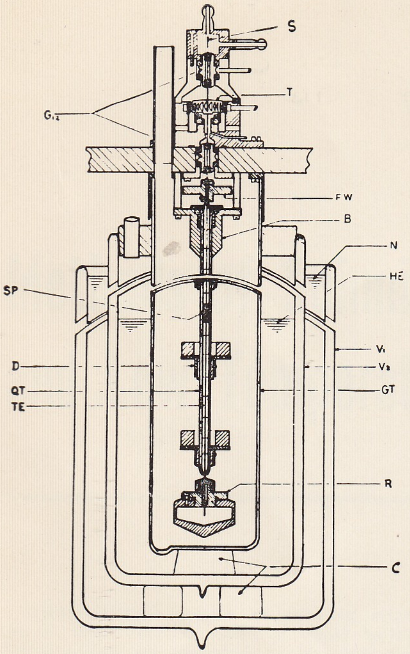

Fig. 3. Air Turbine Drive and Suspension

Several sizes of rotors have been used. The one shown in Figs. 3 and 4 is made of stainless steel and has an ID of 1.60 in. and an OD of 1.75 in. It is used for studying the creeping film of liquid helium II in a centrifugal field. In addition to the 0.025 in. OD, 0.014 in. ID, 22.5 in.-long stainless steel hypodermic needle shaft, a 0.032 in. OD, 0.018 in. ID shaft of the same length and material has been used successfully. Both of these shafts are commercially available. The distance from the lower end of the teflon guides to the top of the rotor is about ½ inch. The flywheel was made of stainless steel and has an OD of 1.25 in. and a height of 0.32 in. The turbine was made of duralumin, with an OD of 0.75 in. and a height of 0.32 in. The OD of the glass tube QT was 0.34 in., and the ID was 0.25 in.

The air-driven, air-supported turbine drive together with the vacuum-tight glands has been described in detail previously[1]. The dimensions of the parts given above are not critical and may be varied over wide ranges. Electrical leads to the rotor are made by one or more long, insulated, fine wires inside the hypodermic needle shaft. The *slip ring* electrical connections are made to these, above the turbine. As mentioned above, the apparatus shown in Figs. 3 and 4 is being used for studying the properties of liquid helium II in a centrifugal field. The method also may be used for studying the tensile strength of materials, etc.

In both of the above methods of spinning rotors at high speeds and low temperatures, the only limitation on the maximum speed obtainable is the mechanical strength of the rotating parts. Also, in both methods, the rotor sizes may be varied over very wide ranges. When properly adjusted, the rotors spin with great stability and are free of vibrations.

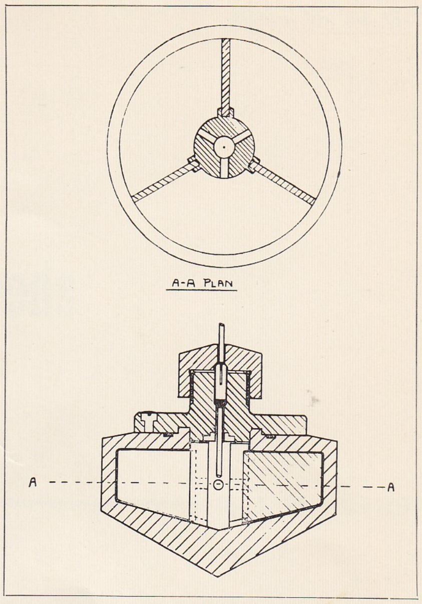

Fig. 4. Rotor for Liquid Helium

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Bibliography

1. J. W. Beams, Reviews of Modern Physics *10*, 245 (1938); **Journal of Washington Academy of Science** *37* (1947), p. 221.
2. J. W. Beams, James Young III, and J. W. Moore, **Journal of Applied Physics**, Vol. 17 (1946), p. 886.
3. J. W. Beams, E. C. Smith, and J. M. Watkins, **Journal of Society of Motion Picture and Television Engineers**, Vol. 58 (1952), p. 159.