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Citation: Review of Scientific Instruments **42**, 637 (1971); doi: 10.1063/1.1685190
View online: https://doi.org/10.1063/1.1685190
View Table of Contents: http://aip.scitation.org/toc/rsi/42/5
Published by the American Institute of Physics

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THE REVIEW OF SCIENTIFIC INSTRUMENTS VOLUME 42, NUMBER 5 MAY 1971

# Improved Method of Spinning Rotors to High Speeds at Low Temperature*

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(Received 21 December 1970)

A technique is described for spinning rotors of almost any size up to rotational speeds limited only by their strength, at liquid helium temperatures. The rotor is spun on the lower end of a long vertical stainless steel hypodermic needle tube shaft which connects to an air turbine drive above the apparatus. Electrical leads from the rotor are brought out through the hollow shaft and liquid mercury contacts. A convenient low noise system of liquid mercury electrical connections is described.

ROTORS have been spun at low speeds at low temperatures by many different workers. Also magnetically suspended rotors have been spun to high speed in a vacuum at liquid nitrogen and liquid helium temperatures and used for the study of the tensile strength and adhesion of metals.[1] However, in several other experiments it is important to be able to add and withdraw gas or liquid from the spinning rotor and/or to pass comparatively low resistance electrical leads out of the rotor for temperature and other measurements, while it is at rest or spinning at any speed. In addition, it is often essential to be able to vary or maintain the electrical potential of the rotor at any desired value and also to vary the direction and magnitude of the magnetic field in the rotor from zero to comparatively large values, while the rotor is spinning. This was not possible with magnetically (freely) suspended rotors used previously. The purpose of this paper is to describe a method which meets the above requirements and with which the rotor speed is limited only by the strength of the rotor.

The method consists in spinning the rotor on the end of a vertical long flexible stainless steel tubular shaft inside a long stainless steel vacuum tight cooled chamber by an air turbine located above the chamber. Figure 1 is a schematic diagram of the apparatus. The air turbine drive is similar to those previously used,[2] so that it will only briefly be described. The Duraluminum turbine T has an outer diameter of 2 cm and a height of 0.9 cm. It is driven by air jets produced by air under pressure entering at $I_1$. The turbine and other rotating parts are supported on an air cushion produced by air entering at $I_2$. The turbine is fastened to the shaft with a small split collet. The Babbitt lined oil gland bearing $G_1$ mounted in neoprene O-rings as shown serves both as a journal bearing and as a vacuum tight seal to the vacuum chamber V. The vapor pressure of the oil entering at $O_1$ is about $10^{-8}$ Torr and the oil leakage from the bearing into V is practically negligible if the bearing clearance is small. $G_2$ is similar to $G_1$. The shaft S is a stainless steel hypodermic needle tube gauge No. 19, 0.12 cm outer diameter and 0.018 cm wall thickness. Its length varied from 50 to 120 cm, although longer and shorter shafts may be used when desired. Such a long small flexible vertical shaft is ideal for spinning rotors to high speed because it allows the rotor to find its own axis of rotation. However, during the acceleration and deceleration of the rotor, standing waves occur in the shaft at certain critical rotor speeds. Unless the amplitudes of these vibrations are controlled or damped, the shaft rapidly becomes fatigued and breaks. For this reason, it is advisable to operate the rotor at speeds above or below the critical speeds of the shaft–rotor combination. In this work a method has been devised by which the shaft is damped and constrained at all rotor speeds, without the expenditure of appreciable amounts

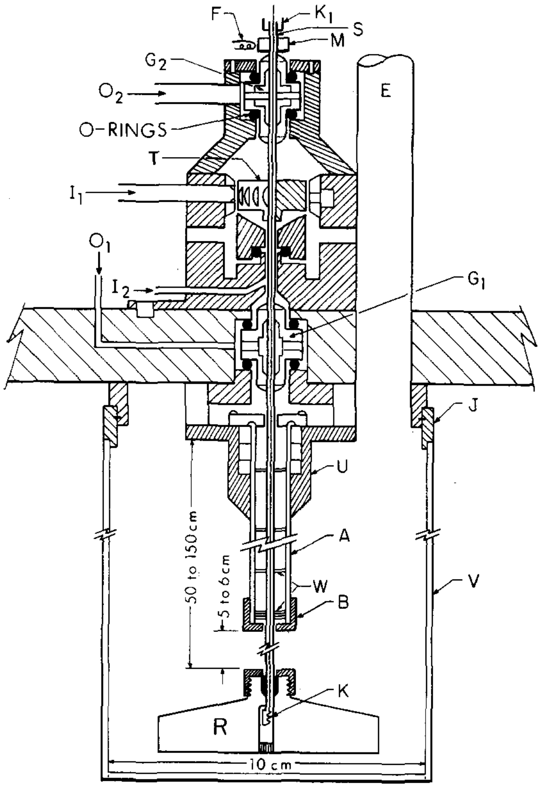

FIG. 1. Schematic diagram of the low temperature centrifuge.

of energy and without appreciably heating the shaft due to friction. It consists in surrounding the long shaft with a coaxial stainless steel tube A (1.3 cm o.d.) with a wall thickness of 0.025 cm which is filled with flake graphite. A series of cylindrical felt washers W about 0.3 cm thick and with small clearance around the shaft S is spaced at intervals along the length of the tube A. Closing the lower end of the tube A is a tight fitting Teflon cap B with at least 50 $\mu$ clearance around the shaft. Just inside the cap B are five close fitting felt washers which serve both to prevent the flake graphite from falling out of the tube and for damping. The upper end of the tube is mounted in a tight fitting reinforced Bakelite support U and secured at the top with a Lucite cover (at least 50 $\mu$ clearance around S) fastened to the Bakelite as indicated in Fig. 1. The gas tight chamber V is a thin walled 10 cm diam stainless steel tube, closed at the bottom and fastened at the top with a bayonet joint J which is sealed with a vacuum sealing compound. It is evacuated through E by high speed pumps. Surrounding the vacuum chamber V is a glass Dewar containing liquid helium and finally a glass Dewar filled with liquid nitrogen. (These are not shown in the figure.) The 7.5 cm diam (Duraluminum, 7075-T6) rotor is attached to the tubular shaft with a split collet arrangement. A lead or soft copper washer seals the hollow shaft S from the surrounding chamber. A carbon resistance thermometer K is mounted in the rotor on the axis. One of the leads to the thermometer is connected either to the rotor or to the shaft S and the other is connected to a fine electrically insulated wire which passes up through the hollow shaft. The lower 15 cm of this wire is a poor heat conducting nickel alloy wire and the remainder a fine copper wire. A dimension of importance is the length of the shaft S between the Teflon cap B and the rotor. In a high vacuum this constitutes a major heat leak to the spinning rotor and consequently should be made as long as possible. At the same time this distance must not be long enough to allow appreciable amplitude of the standing waves to develop. A distance of 5–6 cm was found to be satisfactory with the shaft–rotor combination shown in Fig. 1. The calculated heat leak up the shaft is about $10^{-5}$ W/K between R and B. The temperature of the 200 g rotor spinning at 800 rps in helium gas ($\sim 10^{-4}$ Torr) increased on the order of magnitude of 1 K/min. This is adequate for some experiments. To hold the temperature of R constant, the lower end of A should be in good thermal contact with a vacuum tight jacket containing liquid helium and the pressure in V should be less than $5 \times 10^{-7}$ Torr. Also the resistance type of thermometer probably should not be used. Mounted in the top of V is a 2 cm layer of plastic covered on the lower surface with a shiny aluminum foil in order to shield the oil gland $G_1$ from the cold chambers below. A small permanent magnet M is fastened near the top of the shaft. This produces an ac signal in the pickup coil F which is used to measure the rotor speed.

In the past, a major problem has been to get noise-free electrical lead connections out of the spinning rotor. Devices such as slip rings and brushes not only are very noisy but they get hot and rapidly wear out. When the shaft can be brought out below the rotor, a single mercury contact is satisfactory if oil can be kept out of the mercury. Unfortunately, this arrangement cannot be used in most low temperature experiments because the rotating leads usually must come out of the top of the appratus. This problem has now been solved in a manner shown in Fig. 2. A small flexible tube (steel or stainless steel hypodermic tube) $S_1$ is attached to the upper end of the shaft S at

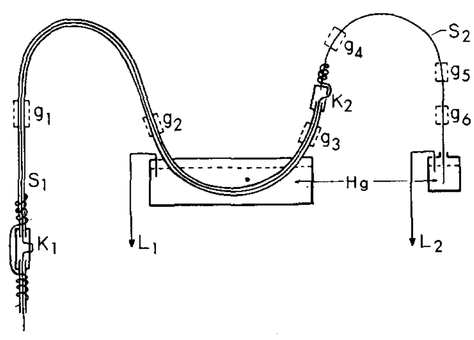

FIG. 2. Schematic diagram of the liquid mercury connections.

$K_1$ by a small diameter nylon connector. S and $S_1$ are cemented to the nylon connector with a nonconducting cement. An electrical connection is made from S to $S_1$ with a small tightly wound copper wire. The connections of the latter to $S_1$ and $S_2$ are secured by a conducting silver paint. The small insulated lead wire also is connected to a similar insulated wire lead inside $S_1$. $S_1$ then passes through the lubricated Teflon guides $g_1$, $g_2$, and $g_3$ which bend it into a gentle sinusoidal curve. The clearance of the guides is several diameters of $S_1$. A Lucite rectangular trough containing liquid mercury is located so that $S_1$ passes well below the surface of the mercury and makes good electrical contact with it. At the second nylon connector $K_2$ the insulated wire inside $S_1$ is electrically connected to $S_2$ which either may be a small (steel or stainless steel) tube or wire. $S_2$ dips into a mercury filled cup to which the lead $L_2$ is connected. If the curves into which $S_1$ and $S_2$ are bent are gentle enough so that there is only comparatively low elastic strains produced which are well below where plastic flow takes place, then $S_1$ and $S_2$ may be rotated almost indefinitely without harmful fatigue. The mercury contacts when clean (free of oil contamination especially) are practically free of noise and make it possible to measure accurately the temperature or other signals in the rotor with comparatively low resistance leads. It is clear that the gentleness of the curve (Fig. 2) depends upon the diameter and flexibility of $S_1$ and $S_2$. A stainless steel tube gauge 24 (0.055 cm o.d., wall thickness 0.012 cm, and approximately 1 m long) $S_1$, and a 0.035 cm steel wire (guitar string) $S_2$ approximately 0.5 m long have been used in experiments for a year without replacement. Rotor speeds up to 2000 rps have been used but most of the time the rotor speed was below 1000 rps. During the acceleration and deceleration of the rotor, $S_1$ and $S_2$ may develop standing waves at their critical flexure frequencies. The operating speed is usually somewhat removed from these critical frequencies and they produce no problem. It has been found that small diameter lubricated plastic tubes (spaghetti) surrounding $S_1$ and $S_2$ and placed between $g_1$ and $g_6$ will effectively eliminate the standing waves during acceleration and deceleration, but are not required when the acceleration is rapid. It is clear that more than two leads can be brought out of the rotor by using tubes for $S_1$, $S_2$, etc., and more than one mercury trough for contacts. It should be noted that the O-rings in $G_1$ and $G_2$ electrically insulate the shaft S from the stationary parts and also that the tube A is supported in insulated mounts which adds flexibility to the electrical connections to the rotor. It also should be mentioned that in addition to the direct leads described above, both electrostatic and electromagnetic pickoffs have been used to get measured quantities out of the rotor while it is spinning. Also, information has been broadcast out of spinning rotors. The fact that the rotor can be grounded or its electrical potential regulated makes it easier to bring information out of the rotor by all the above methods.

In some of the experiments an additional small gas tight chamber (not shown in Fig. 1) was mounted above the gas tight oil gland $G_2$. A second gland similar to $G_2$ was mounted in the top of the small chamber. This allowed the rotor to be evacuated or filled with gas (in some cases argon and helium was condensed in the rotor) through a small radial hole in the tubular shaft S just above $G_2$.

The procedure of cooling the rotor consisted in first filling the chamber V with helium gas at atmospheric pressure which served as a thermal connection between the rotor and walls of V. The two coaxial Dewars surrounding V were then filled with liquid nitrogen. When the rotor reached liquid nitrogen temperature, the nitrogen in the inner Dewar which surrounds V was removed and replaced by liquid helium. When the rotor temperature reached that of liquid helium or the desired value, the helium in the chamber V was pumped out and the rotor rapidly accelerated to operating speed. With an air pressure of 4 atm at $I_1$ (Fig. 1) the operating speed was reached in about 30 sec. It should be pointed out that a high speed grinding electrical motor can be used in place of the air turbine drive. It was not used in this work in order to avoid possible electromagnetic effects produced by the electrical motor. Furthermore, it is clear that rotors and rotor shafts varying over a wide range of sizes may be used by roughly scaling the essential dimensions of the apparatus given above.

The author is greatly indebted to W. Frewer and W. B. Walton for the skillful construction of the apparatus.

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* Supported by Office of Naval Research.

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