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AN APPARATUS FOR OBTAINING HIGH SPEEDS OF ROTATION

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The need for an apparatus, by which it is possible to obtain high rotational speeds, often arises both in the course of original investigations and in ordinary laboratory or lecture demonstrations. In most of these cases the value of the experiment or the success of the demonstration is definitely limited by the maximum rotational speed that can be attained. In the case where the rotor is mounted in metal bearings it is usually not possible to obtain speeds of rotation much in excess of 1000 RPS and then only by the most skillful workmanship. However, this difficulty has been overcome to a considerable extent, at least for some purposes, by the recent work of Henriot and Huguenard.[1] The method which they developed consisted essentially in both driving and supporting the rotor by means of a whirling film of air. In a series of experiments requiring the use of a mirror which rotated from 2000 to 3000 RPS the writer has successfully employed the above method and found it simple to use and the parts easy to construct. During the progress of the experiments the original design of Henriot and Huguenard was modified somewhat and a greater stability and flexibility obtained.

The apparatus as modified is shown in the picture and the essential parts are schematically sketched in Fig. 1. A six inch steel tube E ten inches in length was threaded to take two caps B and B'. (Regular iron pipe sizes and fittings were used.) The caps were then machined so that the stator could be mounted as shown in the figure. A detailed cross-sectional drawing of the stator is shown in Fig. 2 (B) while Fig. 2 (C) is a top view. LL are holes drilled in the brass stator making an angle Q with the intersection of the horizontal plane MN and a vertical plane through LL'. The angle P (usually 90° in these experiments) is the angle made by the projection of LL' on the plane of the paper (which passes through L and the axis CC'). CC' is carefully throated at C, which allows air to enter the stator from the tube II'. The amount of air passing C can be regulated by the valves V_2 and V_3. R and R' are rubber washers which not only serve to make the con-

[1] Henriot and Huguenard, Comptes Rendus *180*, 1389; 1925. J. de Phys. et Rad. *8*, 443; 1927.

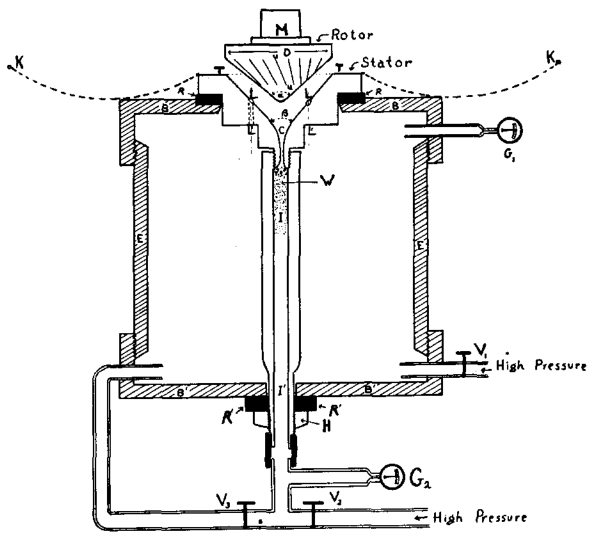
M
Rotor
Stator
K
K
D
R
B
L
C
W
I
E
G1
V1
High Pressure
I'
B'
R'
H
G2
V3
V2
High Pressure

FIG. 1.

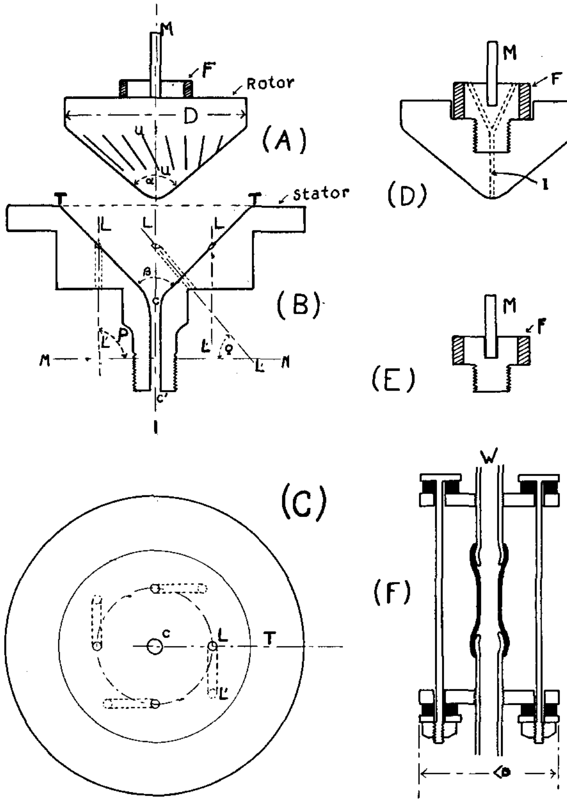
M
F
Rotor
D
(A)
Stator
L
(B)
P
M
N
(C)
C
L
T
L'
(D)
I
(E)
W
(F)

FIG. 2.

nections around the stator air-tight but also hinder the communication of vibrations from the container to the stator. The amount of air passing LL' is regulated by the valve V_1 and the pressure in E determined by the gauge G_1.

The rotor is usually made of phosphor bronze, at least for the lower speeds of rotation. It carries a stellite mirror polished on one face and blackened on the other. The mirror is clamped in a slot between metal disc-shaped segments by means of a steel ring F, which was forced on. For the higher speeds of rotation the segments are machined on the rotor itself, Fig. 2 (A), but up to 3000 RPS the mirror may be mounted as shown in Fig. 2 (E) and screwed into the rotor. The angle δ gives the angle, along the surface of the cone, between the straight fluttings *uu* sawed into the rotor on a milling machine and the generatrix of the cone.

The air pressure is admitted through the valve V_1 until the desired pressure as read on G_1 is obtained. Either V_2 or V_3 is then opened until G_2 registers the correct pressure which has previously been determined by trial. The rotor is then placed in the stator and steadied for a few seconds by a light touch on its rim by a cloth. When the cloth is removed the rotor quickly comes to full speed and seeks a position of equilibrium a fraction of a millimeter from the surface of the stator where it continues to rotate at approximately the same speed until the pressure on the air jets is changed.

The dotted line KK shows the position of a cloth to catch the rotor if it should fly out of the stator. It is made by cutting a circular hole the same diameter as the stator out of a circular piece of woolen material and is supported from a metal ring one foot in diameter. The cloth is allowed to sag about 1.25 inches. One of the principal troubles with the above apparatus arose from air vibrations in the tube II' but it was found that these could be almost completely eliminated by loose steel wool (shown at W) filling the pipe II'. Metal plugs having holes drilled with a No. 73 drill or smaller were also effective. Vibrations in the metal tube itself seemed not to be so important, although these can be easily eliminated by splicing the metal tube with rubber pressure tubing as shown in Fig. 2 (F).

In most of the work the air was furnished by a compressor instead of a large pressure tank and hence it was necessary to pass the air through an auxiliary tank before entering the apparatus in order to damp out the pulsations of the compressor. One of the advantages of the apparatus shown in Fig. 1 is that the pressure can change over a rather wide range without the rotor "grabbing" and becoming unstable. Especially is this true in cases where it is possible completely to close the valve V_2 and let the air into CC' through V_3.

The arrangement as described above is subject to rather wide variations but it is found that each different set of dimensions of the holes, their angles P and Q, size and angles of the stator, diameter and weight of the rotor, etc., worked best over a definite range of pressures which was determined by trial. For example, with a stellite mirror 13 mm $\times$13 mm$\times$1.5 mm (obtained from Bausch and Lomb from stock) mounted on a phosphor bronze rotor with $D=29$ mm, $\alpha=103°$, $\delta=10°$ and a stator with $P=90°$, $Q=48.5°$, $CL=9.5$ mm, $\beta=91.5°$, and the 8 holes LL' drilled with No. 73 drills the rotor reached 2300 R.P.S. when G_1 read 80 lbs./in^2. The valve V_2 was adjusted until the rotor ran smoothly. With this arrangement the rotor would run from 30 lbs./in^2 to 120 lbs./in^2, the number of R.P.S. increasing with the pressure but not as a simple function. When the linear dimensions of the stator and rotor were reduced by one-half, the angles remaining the same and the number of holes LL' reduced to four, without the mirror the rotor turned 7000 R.P.S. with a pressure of about 80 lbs/in^2.

If a large capacity compressor delivering air at a lower pressure is used, some rough experiments indicate that it is advisable to use larger diameter holes LL' and at the same time make $(\alpha-\beta)$ greater. If rotational speeds not exceeding 3000 R.P.S. are desired and a non-pulsating source of air supply is available the long tube II' can be dispensed with and a rod substituted in its place. Either a small hole (92 or 93 drill) may be drilled at C connecting the pressure inside E with the apex of the stator, or this may be made solid and a hole (No. 40 drill) drilled through the rotor as shown in Fig. 2 (D). The pressure range is here somewhat restricted but when once found the rotor is very stable. For about 2000 R.P.S. the following dimensions are very satisfactory. The dimensions of M were 13 mm$\times$13 mm$\times$1.5 mm, $D=28$ mm, $\alpha=101.5°$, $\delta=10°$, $\beta=91.5°$, $Q=41.5°$, $CL=9.4$ mm, 8 holes LL' were drilled with No. 72 drills. The pressure was from 40 lbs./in^2 to 60 lbs./in^2. Unless care is taken the surfaces of the rotor and stator become worn by the stopping process and as a result the air pressure must be changed to keep the rotor stable. If the stator is damaged too much it is best to replace it with a new one.

The speed of rotation was measured by several different methods. The first method[2] tried was to place a magnetized needle inside the

[2] Lawrence Beams, and Garman, Phys. Rev. *31*, A 1112; 1928.

rotor with its center on the axis of rotation and its length making a right angle with it. This whirling magnet induced an alternating current in a nearby coil which after amplification produced a note in a pair of earphones. The frequency of the note was determined by finding the number of beats made with a known-frequency audio oscillator. The oscillator (kindly loaned by Professor J. S. Miller of the Department of Electrical Engineering) was of the vacuum tube type and could be varied from a few oscillations to 35000 per second, and was calibrated with a precision of about 0.1 percent. The second method consisted in reflecting the light of an incandescent lamp from the rotating mirror into a photoelectric cell. The pulsating photo-cell current was then amplified and the frequency determined by beating it with the audio oscillator mentioned above. It was soon found by these methods that the loudest natural note given out by the rotor (about the only one that can be distinguished after the rotor reaches full speed) was equal to the frequency of the rotor. It was therefore possible to dispense with the magnet, or lamp and photo-cell, and beat the frequency of the note given out by the top directly against the note of the audio oscillator.

The constancy of the speed of rotation is indeed striking when the pressure remains constant. Even with the mirror mounted upon the rotor the speed of rotation can be made as constant as the audio oscillator. The nutation and precession of the rotor can also be made remarkably small. For example, in either of the cases mentioned above, when the light from a horizontal slit passes through a lens, is reflected from the rotating mirror, and comes to focus on a screen a meter distant from the mirror, the resultant streak of light did not shift up or down by as much as one millimeter in one minute.

The writer is very much indebted to Mr. A. J. Weed, instrument maker, for his careful construction and valuable help in the design of the apparatus.