of $1^1/_4$ in. diam can be made to reach approximately 120,000 rpm with 100 psi air pressure.

4 The chief advantages of this type of spinner are simplicity and economy of construction, versatility, relative insensitiveness to static unbalance, quietness, no heating problem, no bearing wear, and a minimum of maintenance.

Discussion

O. C. Brewster.[8] This paper describes an interesting application of the Beams spinning top. It is believed that many operations could take advantage of the possibility of very high rotative speed with the virtual absence of friction as exemplified by the Beams rotor or by using air (or other gas) as the lubricant in more or less conventional journal bearings. Kingsbury pointed this out before the turn of the century but his work has largely been forgotten and the writer knows of few practical applications of this type of lubrication. There is a fertile field of exploration here that is nearly untouched.

The writer recently has done a considerable amount of experimental work with air bearings. The minute one gets into the realm of really high speeds with air lubrication of plain cylindrical journal bearings, the phenomenon of "bearing whip" assumes great importance and under many conditions may block effectively the attainment of desired speeds.

Whip is particularly pronounced with gas lubrication because of the great fluidity of the lubricant and also because of its compressibility. It manifests itself as a vibration which increases in intensity rapidly as the speed increases and finally reaches such severity that higher speed becomes impossible.

A simple and effective method for eliminating bearing whip has been found.[9] By applying air pressure to one side of the bearing, thereby forcing the journal into an eccentric position in the bearing, whip is eliminated entirely. The amount of side air pressure required is a direct function of rotor speed and there appears to be no limit on the rotational speed obtainable other than that set by the limit of available air pressure, the strength of the rotor material, or the capabilities of the driving means.

As an illustration, a rotor was required for an optical device, the rotor to spin at 240,000 rpm (4000 rps). The exposed end of the rotor was to carry a mirror slanting slightly from the plane of rotation. Many attempts to use a Beams-type rotor were made but all were unsuccessful owing to instability. The problem was solved by the small air motor shown in Fig. 6 of this discussion. The steel rotor is $^1/_2$ in. diam $\times$ $2^3/_{16}$ in. long, running with 0.001-in. diametral clearance in two journal bearings $^1/_2$ in. long, spaced axially $^1/_2$ in. apart. An air turbine is provided, consisting of flutes milled into the rotor near one end, impelled by the jets from three small nozzles. Side air pressure is applied at the middle of each bearing through 0.025-in-diam holes.

With no side air pressure applied the rotor speed could not be forced higher than about 50,000 rpm, regardless of air supply to the turbine. At that speed the vibration was violent and would be destructive if allowed for any appreciable time; also, the speed fluctuated violently. With side air pressure applied this rotor attained speeds well over 240,000 rpm with no vibration. At this speed a minimum of 75-psig side air pressure was required to eliminate whip. A slight reduction in the pressure results in a sharply defined hum which increases with further reduction in pressure and is accompanied by a slowing down of the rotor owing to energy losses. Application of side air pressure higher than that required for the suppression of whip has no effect other than a very slight increase in friction due to reducing the thickness of the air film on the load-carrying side. A very high side air pressure would, of course, load the supporting film above its carrying capacity and the bearing would seize. The minimum side-air-pressure requirements of this particular rotor are shown in Table 1 of this discussion.

TABLE 1 MINIMUM SIDE AIR PRESSURES

Rpm	Minimum side air press, psig	Turbine air press, psig
60000	15	7
120000	22	15
180000	30	25
240000	75	54

The largest rotor of this type with which the writer has any experience is one of 1 in. diam in the form of a small laboratory centrifuge spinning at 75,000 rpm but there appears to be no inherent size limitation, and there is every reason to believe that this method should be effective over a large range of sizes.

Rotors of the Beams type are employed advantageously when the geometry of the rotor is such that the moment of inertia in the plane of rotation is large as is pointed out by the authors of this paper. However, when this is inconvenient or perhaps impossible and when the other advantages of a constrained journal running in fixed bearings are important considerations, then the design described herewith is called for.

While it may appear that possible applications for this type of bearing operation are limited, a number of cases which should bear investigation come readily to mind. Most small very high-speed devices are obviously in this category, such as small spray nozzles, high-speed grinding wheels for small internal grinding, very small drills, gyroscopes and microtomes, to name a few in addition to the centrifuge and optical use already mentioned.

[8] Consulting Engineer, Litchfield, Conn. Mem. ASME.
[9] U. S. Patent No. 2,603,539.

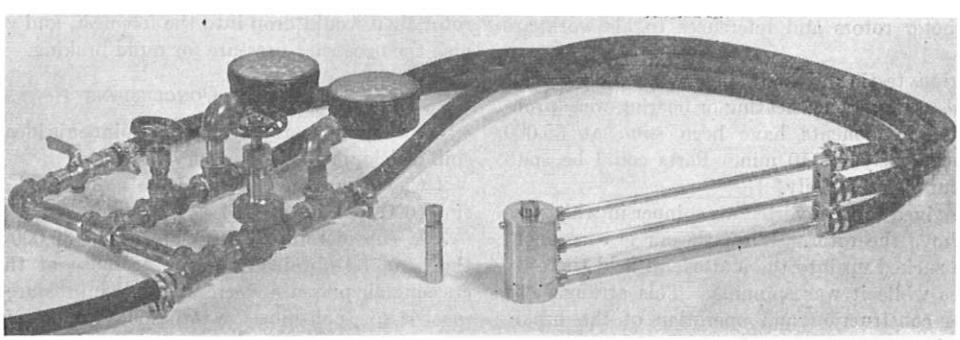

Fig. 6 240,000 Rpm Air Motor

In addition to these more obvious applications the writer is foolhardy enough to believe that someday we may find it entirely feasible to apply the principles of gas-film lubrication to such things as steam turbines, gas turbines, or other large units where the load is steady and rubbing speed is high. The use of gas lubrication in situations where the bearing is too hot for ordinary lubricants is immediately suggested. There should be some concern in this country with the imagination and courage to explore this nearly virgin field.

J. A. Frost.[10] The writer has used a spinner of the type described in the paper with great success.

Because of the high speed required in testing a particular device, it was necessary to make certain modifications over the one described. These included a smaller stator and rotor and elimination of the extra apparatus not pertinent to the problem at hand.

Using a $2^1/_2$-in-diam rotor and 100 psi air pressure, 66,000 rpm was obtained. The device to be tested was mounted in a cavity in the center of the rotor. Operation of the device was observed through the use of a strobotac and speed was checked, using a photoelectric cell of the type described.

The writer agrees with the authors' conclusion and highly recommends the air spinner for laboratory use.

H. E. Ruehlemann.[11] The writer has designed and operated air spinners for the past 10 years, and a spinner similar to the one described in the paper has been used by the Ammunition Division of the Naval Ordnance Laboratory for the past 2 years. This type of spinner, with minor modifications to meet our special needs, has performed satisfactorily in all respects. The spinner is dependable, has no maintenance problem, and is ideally suited for laboratory testing of components, and multiple-purpose developmental apparatus, at various spin rates. The ability of the spinner to operate properly with reasonable unbalance is truly a desirable characteristic in laboratory testing.

It is felt that the claims made for the spinner when operated under the conditions specified are truly indicative of the versatility of this device.

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[11] Project Engineer, Ammunition Division, U. S. Naval Ordnance Laboratory, White Oak, Md.

Authors' Closure

The comments of Mr. Brewster, Mr. Frost, and Mr. Ruehlemann are greatly appreciated.

It is hoped that this paper has helped to make a little more widely known the characteristics of air-supported and air-driven spinners. We feel that such a spinner is a most important tool in a development laboratory concerned with high-speed rotation of small devices.

Since this paper was written, some consideration has been given to a redesign to make the air spinner suitable for production-line testing of small timing mechanisms. At present, testing is time-consuming and not particularly well suited to mass-production testing. About one minute is needed for installation of the device to be tested, three minutes to accelerate to 36,000 rpm, and one-half minute to bring the spinner to a stop after the test is completed. In an attempt to speed up this process, the following possibilities are being considered.

1 Faster installation, of the device to be tested, by use of snap-action locking detents rather than the present two hold-down screws.

2 A hand or foot-lever action for bringing the auxiliary-equipment assembly down over the rotor and stator. This action would also initiate the air drive supply.

3 A feedback system to hold automatically the proper speed when reached and initiate the monitoring operation.

4 An air brake consisting of reverse jets and actuated by completion of test operation.

5 Use of a bank of such spinners side by side—enough to keep an operator continually busy. The operator's complete job would be inserting the test device, initiating the operating sequence, removing the test device, and recording the test results.