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Development of Bearings for Nuclear Reactors in Space*

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Atomics International, under an AEC program, has developed bearings to operate in reactor control components in a space environment at pressures from as low as 10^{-12} torr to as high as 10^{-3} torr at temperature ranges from 950 to 1500°F, with a life requirement of 1 to 5 years.

Three development phases included: (1) a 1000-h sliding friction evaluation at design temperature in ultrahigh vacuum, to screen candidate materials; (2) a compatibility test in vacuum, at and above the design temperatures, with candidate materials in static contact; and (3) testing of prototype bearing assemblies under design loads in the design environment. Test results were used to select material combinations for reactor control drum bearings; these combinations are tabulated for the listed SNAP systems. Information obtained was also used in selecting material combinations for such other components as electric actuators, position sensors, limit switches, and ground test scram mechanisms.

I. Introduction

Over the past 9 years, Atomics International has developed bearings for nuclear reactor operations in space and has directed its efforts into areas where stringent conditions are imposed and where few agencies or companies are actively involved. These conditions are long-term operation (1 to 5 years), high temperature (950 to 1500°F), high radiation levels (10^{20} nvt, 10^{11} rad), and high launch shock and vibration loads.

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The bearings used in our SNAP[1] reactor control drum, which is a 15- to 30-lb cylindrical segment, eccentrically mounted between two pivot points (Fig. 1), were the focal point of bearing development. Bearings for other components were designed from the control drum bearing data. The choice of a journal bearing in a self-aligning ball was made early in the program, because of the heavy launch loads, low operating speed, long dwell

[1]*Systems for Nuclear Auxiliary Power*. For more information on the SNAP reactors, see "The Development Philosophy for SNAP Mechanisms," by O. P. Steele III, in these *Proceedings*.

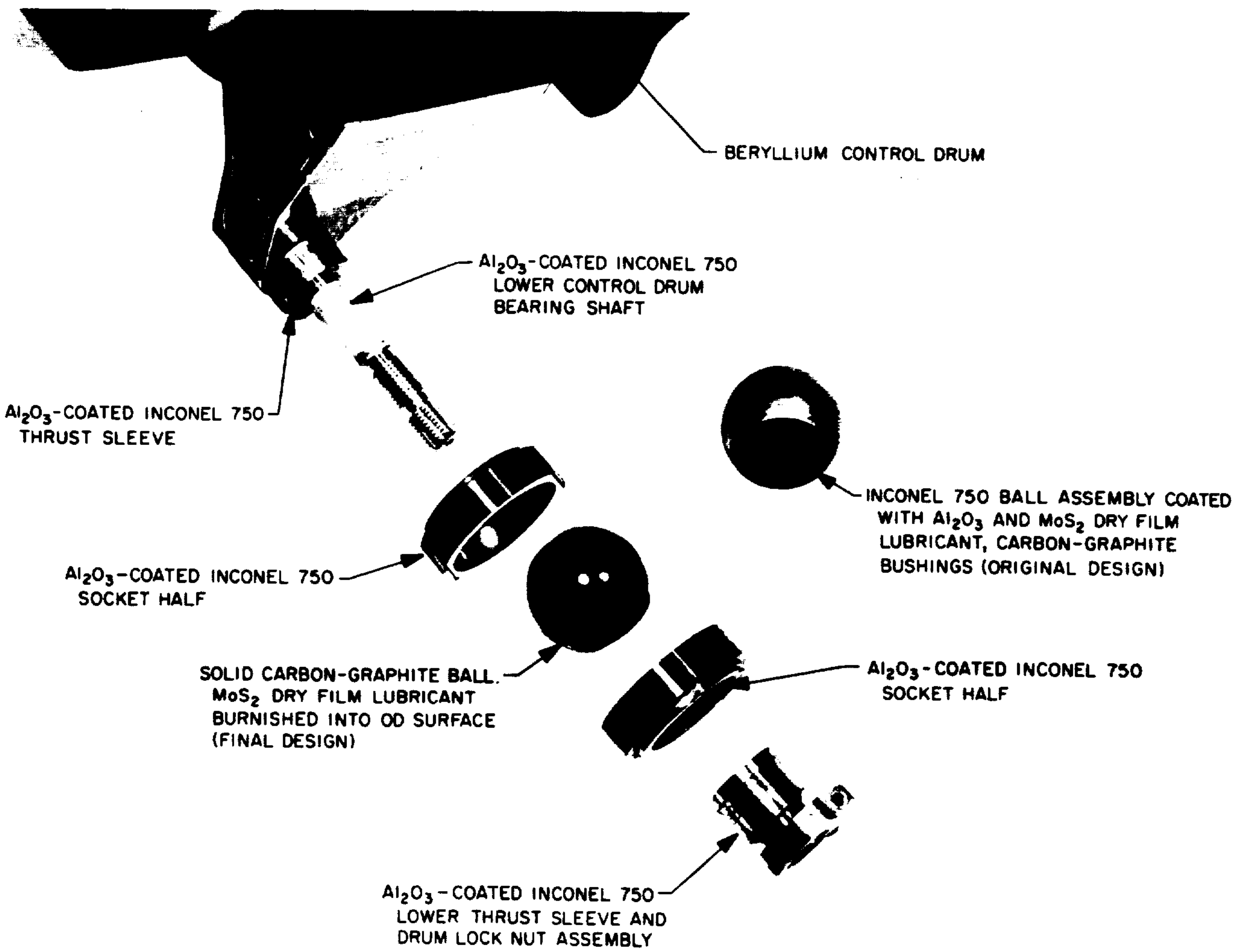

Fig. 1. SNAP 8 control drum thrust bearing assembly

periods, and cost. Table 1 summarizes the results of our bearing program.

II. SNAP 10A and SNAP 2 Reactor Programs

The SNAP 10A, 950°F, 1-year life bearing was our first milestone. Friction tests, to screen material combinations for 1000°F, were conducted in an oil diffusion-pumped, 10^{-5}-torr vacuum chamber (Ref. 1). As the effects of high vacuum on materials and the effects of diffusion pump oil on bearing couples became known, we added self-weld testing and extended our friction testing to ion-pumped, 10^{-8}-torr vacuum chambers (Refs. 2 and 3). Several combinations of materials looked promising, but the material couple used was spray-coated Al_2O_3 against sintered TiC. Table 1 shows the testing and operating history.

From friction tests, carbon graphite against Al_2O_3 had been found to be the material combination having the lowest friction, but designing around its low expansion, brittleness, and tricky machining properties was not developed for SNAP 10A. However, the SNAP 2 design used carbon graphite impregnated with a lithium salt as inserts in the self-aligning ball. The backup choice for SNAP 2 was a solid carbon graphite ball with Al_2O_3-spray-coated shaft and socket. Initially, fretting of the carbon ball during vibration was a problem, but the use of bonded MoS_2 on the socket provided damping to overcome the fretting.

Table 1. SNAP reactor control drum bearings (self-aligning ball-socket type)

Reactor	Design conditions	Material combinations		Status
		Shaft to ball	Ball to socket	
SNAP 10A	950°F 1-year life 10^{-3} to 10^{-12} torr 20-g shock 7.5-g vibration	Al_2O_3 (spray coat)[a] against TiC	TiC against Al_2O_3 (spray coat)[a]	Operated after 43 days on spacecraft at 600°F. Operated after 10,000 h of nuclear ground test at 600°F, 3.6×10^{18} nvt, and 10^{-3} torr. Qualification tested 5000 h at 700°F and 10^{-8} torr.
SNAP 2	1000°F 1-year life 10^{-4} to 10^{-11} torr 20-g shock 7.5-g vibration	Al_2O_3 (spray coat)[a] against carbon graphite impregnated)	TiC against Al_2O_3 (spray coat)[a] and MoS_2	Prototype tested to 1500 h at 850°F and 10^{-7} torr.
SNAP 8	1150°F 12,000-h life 10^{-5} to 10^{-11} torr 35-g shock 19-g vibration	Al_2O_3 (spray coat)[b] against carbon graphite (no impregnant) and MoS_2	Carbon graphite (no impregnant) and MoS_2 against Al_2O_3 (spray coat)[b]	1000-h friction test completed at 1250°F. 5000-h compatibility test completed at 1250 to 1450°F. Design verification tests in progress at 1150 and 1250°F, 10^{-5} and 10^{-9} torr.
Advanced ZrH reactor	1500°F 3- to 5-year life 10^{-6} to 10^{-12} torr 35-g shock 19-g vibration	Al_2O_3 (spray coat)[c] against carbon graphite (no impregnant)	Carbon graphite (no impregnant) against Al_2O_3 (spray coat)[c]	Operational test of prototype in progress at 1500°F and 10^{-8} torr. Friction and compatibility tests to start in Fiscal Year 1969.

[a]Ti–6 Al–4V substrate.
[b]Inconel 750 substrate.
[c]Ta–10 W substrate.

III. SNAP 8 Reactor Program

Next, we started work on the SNAP 8 reactors, with a 12,000-h life and 1150°F bearing temperature. To provide for the higher temperature requirement, the structural material for the bearings was changed from Ti–6 Al–4V to Inconel 750; to accommodate thermal expansion, the TiC ball was discarded in favor of Al_2O_3-sprayed Inconel 750. Otherwise, SNAP 2 material combinations were used.

The testing of prototype bearing assemblies was proceeding satisfactorily, until they were examined after 10,000 h at 1150°F; it was then discovered that the Al_2O_3 was spalling from the shaft. Spalling occurred only when the Al_2O_3 was in contact with the impregnated carbon graphite. Examination of the Al_2O_3 showed a phase change from γ to α, which represents an 8% density increase. Later, it was shown that the impregnant, and not the carbon graphite, had some catalytic effect on this phase change.

With a year to go before the startup of the reactor was scheduled, a selection of other promising couples was made, and a three-phase approach to the development of a stable shaft coating was implemented as follows:

(1) Sliding friction tests (Fig. 2) were conducted for 1000 h in ion chambers. Using our 1000°F fixturing with heaters at 1250°F presented problems. The Kanthal A-1 heater wire oxidized and burned up in 100 h, and a switch to platinum wire was necessary. The stainless steel specimen supports also had to be strengthened.

(2) Concurrently, stacks of candidate material couples were cooked in a vacuum at 1250, 1350, and 1450°F for 500, 1000, 2000, and 5000 h (Fig. 3). This required the design and fabrication of vacuum heaters of tantalum. Temperatures above the design temperature were selected, to accelerate any incompatibilities in order to obtain early results. Couples of Al_2O_3, in contact with both impregnated (the original SNAP 8 combination)

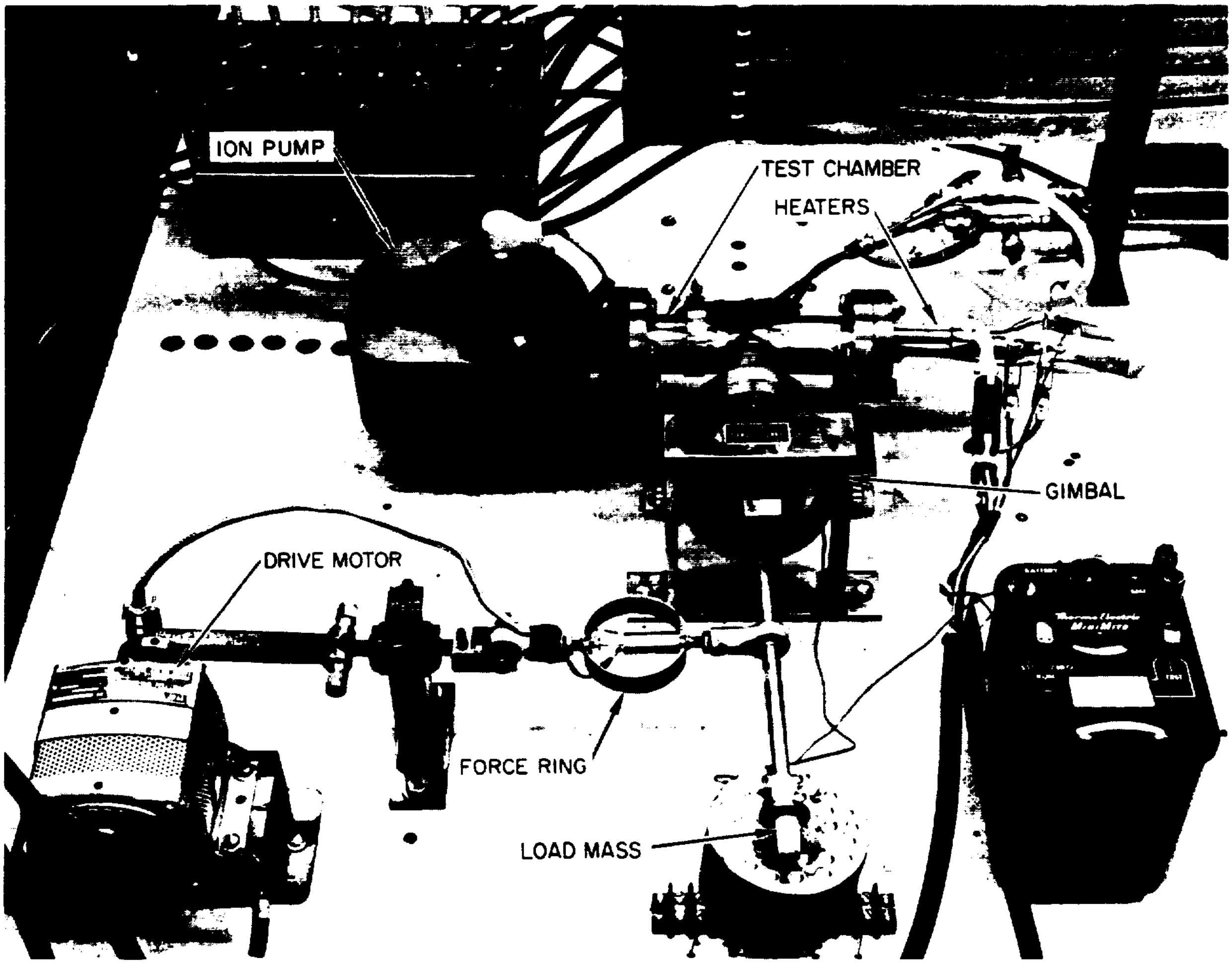

Fig. 2. Sliding friction test facility

and nonimpregnated carbon graphite, were also included.

(3) Journals, coated with several other candidate materials, were also put on test in the impregnated carbon graphite bearings, under design load, cycling, and temperature conditions (Fig. 4).

The results of this three-phase program are summarized in Table 2. The catastrophic failure of Al_2O_3 against P5N was duplicated, and the stability of Al_2O_3 against the nonimpregnated carbon graphite was demonstrated. Both Cr_3C_2 and WC showed considerable transfer of chrome to the P5N. A choice of P5 against Al_2O_3 was made; and the complex Inconel 750 ball, coated with Al_2O_3 and fitted with P5N inserts, was replaced with a solid, nonimpregnated carbon graphite ball. Design verification testing of this choice, to 12,000 h at 1150 to 1250°F and 10^{-5} to 10^{-8} torr, is underway.

IV. Advanced ZrH Reactor Program

We have started the development of a 1500°F bearing for an advanced reactor and are taking the three-phase approach found so effective for the SNAP 8 program. Upgrading test fixtures for this temperature requirement has been as difficult as testing the candidate combinations.

Tantalum alloys are used for basic high-temperature structure, and high-purity alumina is used for insulators. The handling and cleanliness of all parts that go into the vacuum chamber must be given special attention. Material combinations of P5 against K162B, P5 against Al_2O_3 coated on Ta–10 W, solid Al_2O_3 against LT-2 (a cermet of W, Cr, and Al_2O_3), LT-2 against P5, and LT-2 against LT-2 are to be tested for 1600°F compatibility and friction. In addition, P5 against Al_2O_3 on Ta–10 W is on test as a prototype bearing.

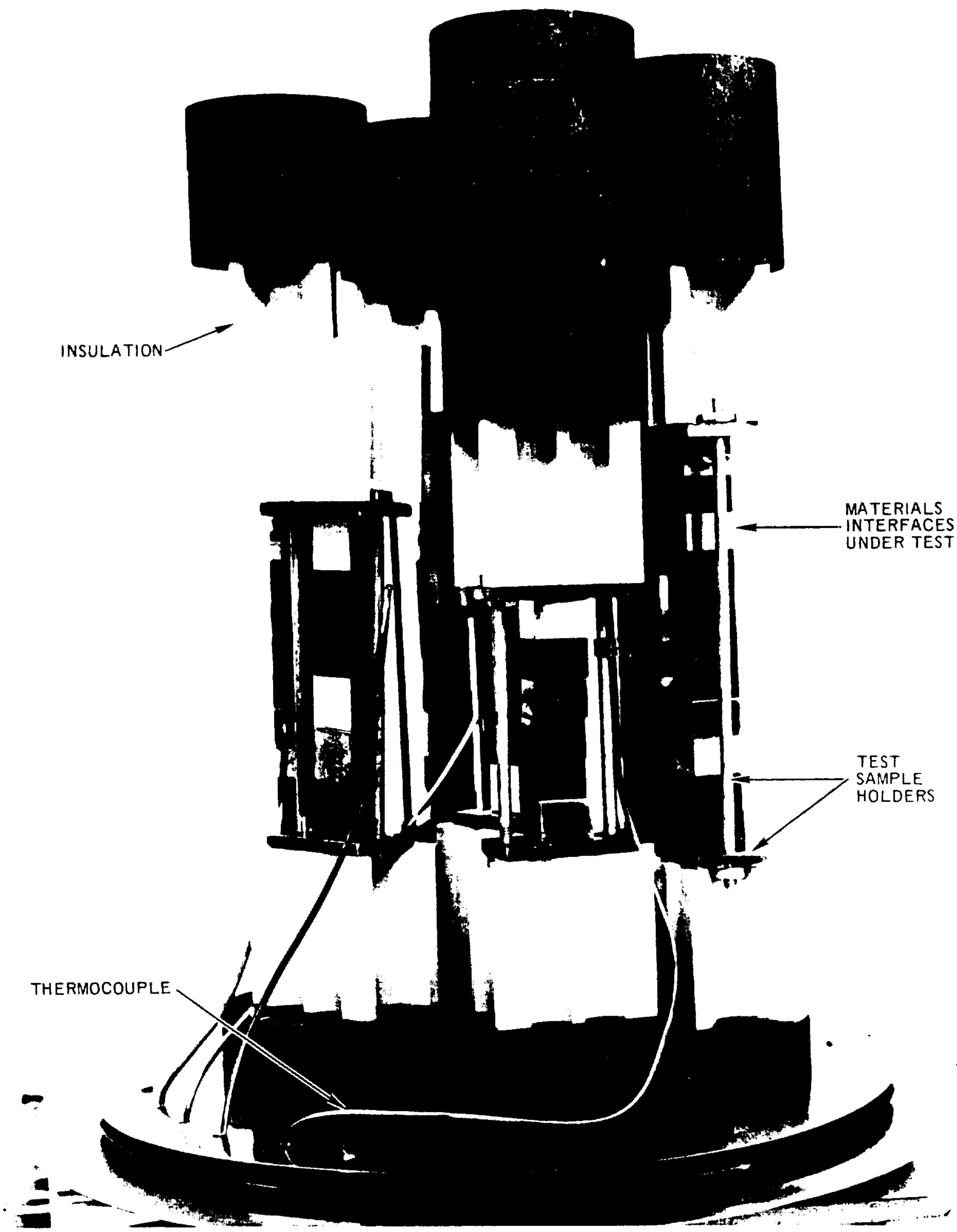

Fig. 3. Compatibility tests of candidate bearing materials

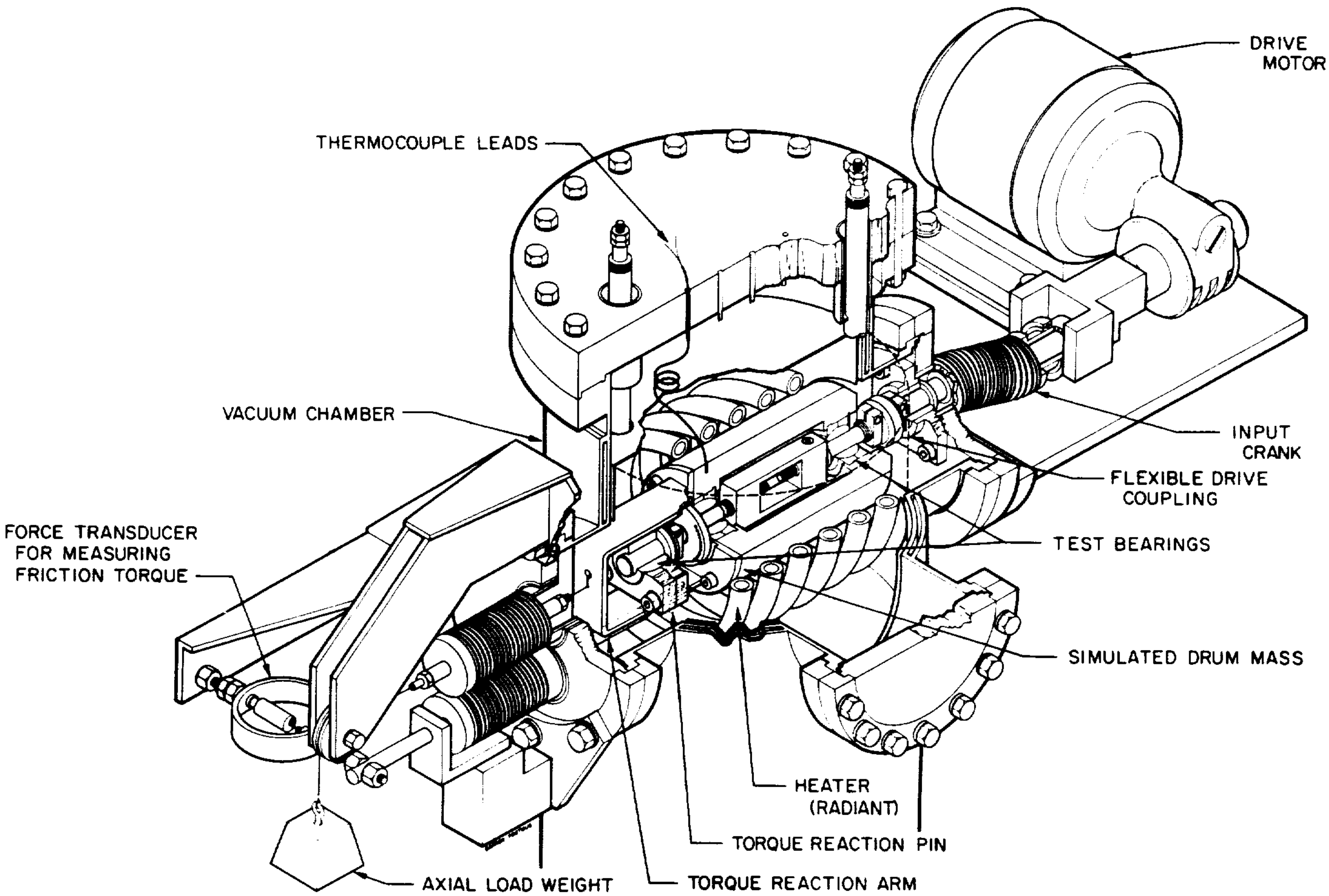

Fig. 4. Bearing development test fixture

Table 2. SNAP 8 bearing redesign program

Bearing couple	Maximum friction coefficient (1000 h, 10^{-7} torr)		Maximum torque, 1250°F shaft tests (700 to 2000 h, 10^{-8} torr), in.-lb	Compatibility tests (1000 h, 10^{-8} torr) (1250, 1350, and 1450°F)
	1250°F	Room temperature		
Al_2O_3 against P5	0.29	0.69	—	Coating showed no significant changes.
Al_2O_3 against P5N	0.28	0.69	2.5	Coating separated from substrate.
TiC against P5N	0.62	0.78	5.7	Generally stable, but showed slight porosity increase.
Cr_3C_2 against P5N	0.85	0.68	4.8	Chrome transfer to the P5N was apparent.
WC against P5N	1.0	2.0	5.5	Chrome transfer to the P5N was apparent.
Cr plate against P5N	0.32	0.64	Heavy chrome transfer to P5N prompted no further testing.	
K162B against P5N	0.35	0.50	Long time for delivery of material precluded use on this program.	

NOTES: P5N and P5 are carbon graphites from Pure Carbon Co., impregnated (Li salts) and unimpregnated, respectively.
Al_2O_3, TiC, Cr_3C_2, and WC were spray-coated on Inconel 750.
K162B is a TiC sintered material from Kennametal Corporation.

V. Concluding Remarks

Information obtained in the testing program was used not only to select material combinations for bearings, but also in selecting such other components as electric actuators, position sensors, limit switches, and ground test scram mechanisms.

Some of the problems encountered during our program should be of interest to other developers of high-temperature components. The materials selected for these extreme conditions tend to be exotic, and suppliers tend to give rather poor delivery, especially on small development quantities. Also, they do not always have adequate specifications for the materials, or proprietary processes may be involved, and they resist giving us the details necessary for us to analyze the materials. The machining of such materials can also require considerable effort, on our part, in locating and working with the fabrication vendors.

Fabricating test fixtures from materials that have not had wide use (e.g., tantalum alloys) has required training in machining practices in our own shop. Heaters for our uses were not available from commercial vendors, and we found ourselves involved in a heater development program. Also, our personnel who were setting up tests had to be trained in clean handling practices.

Where there are long-term design life goals, it pays to devise methods of accelerating the effects, as in our compatibility tests at above-design temperatures. At the same time, the test sequence on prototype assemblies should not be so severe, or have such an excessive margin, that a failure leaves one wondering whether the test might not have been successful with just a modest margin.

References

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