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Friction and Wear of Radiation Resistant Composites, Coatings and Ceramics in Vacuum and Low Temperature Environment

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FRICTION AND WEAR OF RADIATION RESISTANT COMPOSITES, COATINGS AND CERAMICS IN VACUUM AND LOW TEMPERATURE ENVIRONMENT

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ABSTRACT

Superconducting magnets used in accelerators such as the Superconducting Super Collider (SSC) are exposed to fast neutron and gamma irradiation. Some of the components used in the SSC cryostat are fabricated from organic materials with low radiation resistance. The slide bearing material presently supporting the magnet assembly contains Teflon and must be replaced with a material of improved radiation resistance. A group of sliding materials, most of which have suitable radiation resistance, were tested under conditions of pressure, temperature, velocity, and vacuum typically encountered in normal cryostat operation. As this was a preliminary screening test, the samples were only cooled to liquid nitrogen temperature. The group of materials tested consists of composites, coated base metals, and ceramics. The criteria was to maintain a low coefficient of friction throughout the experiment in spite of changes in temperature and vacuum. Subsequent tests will expose finalist materials to fast neutron irradiation at liquid helium temperatures. This paper describes the experimental setup and presents data of the friction coefficient measurements taken for the various samples.

INTRODUCTION

The effect of radiation on materials has been of great concern to the designers of high-energy accelerators. The subject of high-energy radiation damage to polymers used in accelerators has been the subject of several studies and publications. It has been pointed out[1] that the Teflon(trade name used by DuPont) resin, used in the present cold mass slide material, could be affected by the high levels of radiation found in the SSC dipole magnets.

The cold mass assembly is supported and laterally restrained by cradle assemblies at five locations along its length. Aside from the center cradle which is fixed, the other four cradles allow for thermal expansion or contraction of the cold mass along its axis, as shown in figure 1. The cold mass assembly slides on four bearing pads mounted in the sliding cradle as illustrated in figure 2. The present bearing pads are DU (trade name used by Garlock Bearing) bearings which contain Teflon (PTFE), impregnated in the porous bronze as well as in the form of an overlay.

This paper describes the work performed to select one or more materials with comparably low coefficients of friction, yet better radiation resistance properties, with which to replace the DU bearing material.

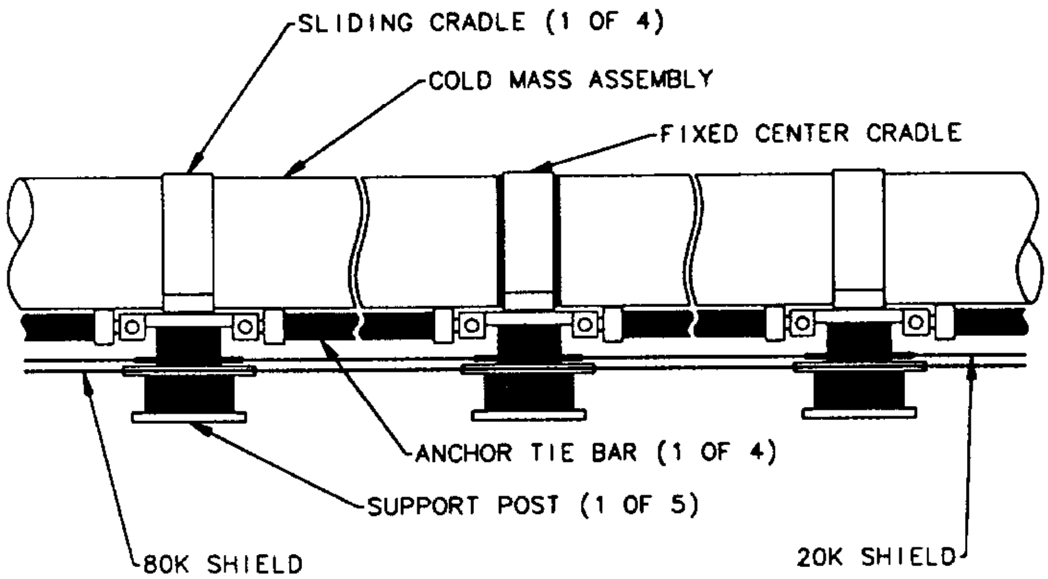

Fig. 1. SSC 50mm Dipole Cryostat Suspension System

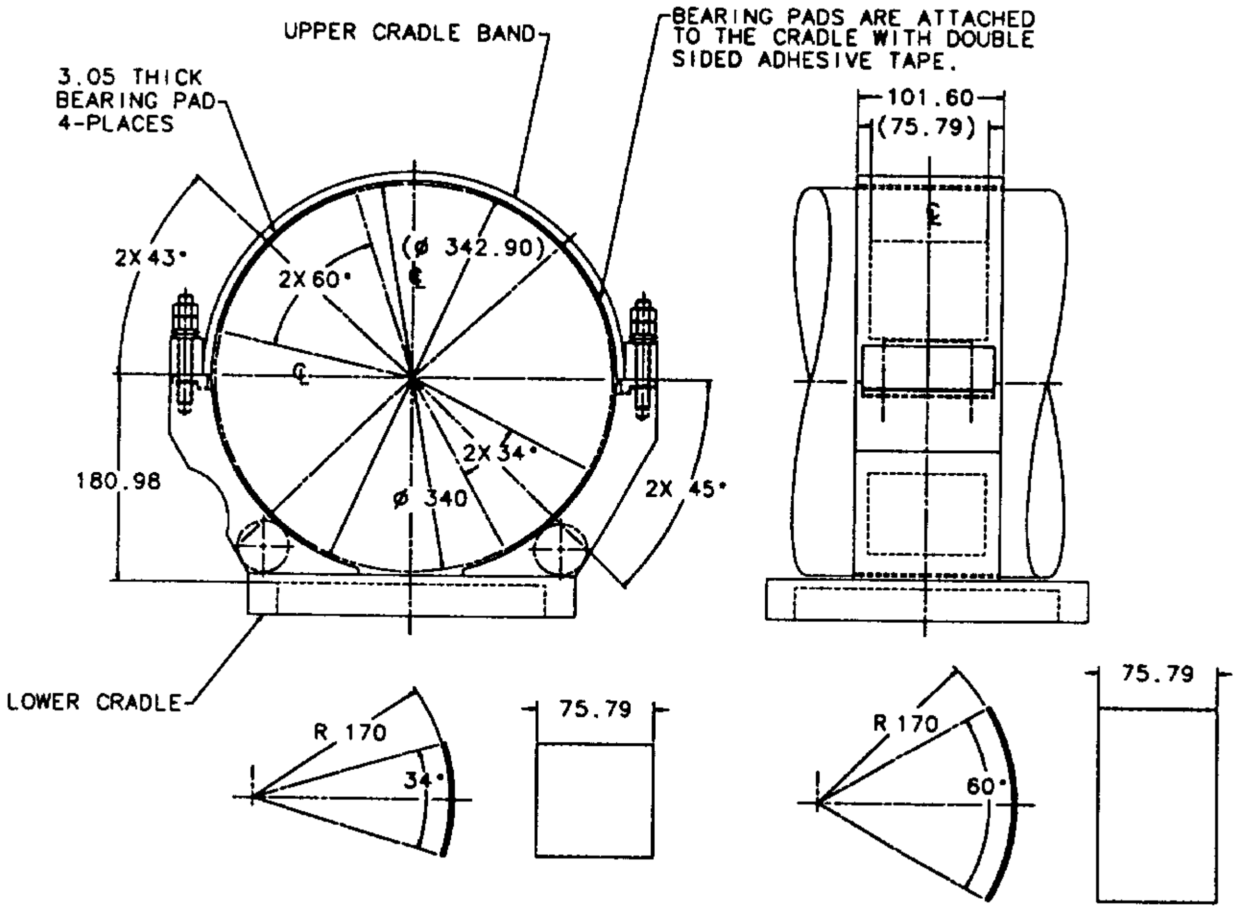

Fig. 2. Cradle Assembly and Bearing Pad Detail

MATERIAL SELECTION

The primary requirements for selecting the slide material were:

- Maintain friction coefficient of 0.20 to 0.22 at operating conditions.
- Maintain performance capabilities in radiation levels exceeding 3×10^3 gray over a 20 year period.

In addition the following operating conditions will have to be met:

- Temperature: Operating temperature of approximately 4 K; storage temperature of approximately 340 K
- Vacuum: 10^{-7} Torr at the operating temperature
- Pressure: 4.14 MPa - dynamic at the operating temperature.
  8.28 MPa - static at 320 K
- Humidity: 0% at the operating temperature.

Other performance criteria which have been taken into consideration are aging and wear.

The slide samples are tested for approximately 900 cycles of duty. A cycle denotes expansion and contraction of a magnet (±2.5 cm). Over a 24 hour period the magnet will contract 2.5 cm when cooled from room to operating temperatures. It is also assumed that the slide material will be exposed to air after being irradiated several times during the course of its lifetime.

The selected materials can be divided into three groups: coatings (of metals), composites and ceramics, as shown in Table 1.

EXPERIMENTAL SETUP

The test setup was made to simulate the actual conditions of the slides in the magnet. However, since this is a preliminary test, several variations from the actual situation were adopted. (See material selection)

- The low temperature is approximately 80 K and the vacuum is 10^{-5} Torr.
- The support posts are made of solid stainless steel to minimize post deflection
- The loading pressure is the equivalent to that of a dynamic loading during operating conditions. (See material selection)

Table 1. Sliding Test Samples

Coating/Metal	Composite	Ceramic
$CoNiInMoS_2$/Inconel 718	Vespel SP-1	$AlPO_4+Al_2O_3$ (SiC - continuous fiber)
Graphite (embedded) / bronze - copper	Vespel SP-3	Glass bonded Mica
	APC-2/AS4 (PEEK) (0° fiber orientation)	
Everlube 860/316 SS		
Ti-TiN/316 SS	Torlon 4301	
WS_2/316 SS	PEEK/carbon (short fiber)	

The samples were secured on the stationary portion of the sliding apparatus. All samples were tested sliding against 316 stainless steel plates with a surface finish of 0.50 μm to simulate the cold mass skin. Each set of samples was fitted with a new set of stainless steel plates. The stainless steel plates were mounted on to the moving portion of the sliding apparatus. The complete sliding apparatus was placed inside a vacuum vessel as shown in figure 3.

In order to maintain close simulation between the test and the actual magnet performance the following system requirements were imposed:

- Stroke = $\pm$ 2.54 cm
- Stroke velocity = .0025 m/sec
- Total contact area = 12.9 cm^2
- Dead load weight = 485 kg

The friction force was measured by a load cell in line with the actuation system. The load cell readings and corresponding temperature readings were recorded by a computerized data acquisition system. The coefficient of friction (COF) was calculated by dividing the friction force by the normal force (dead weight).

The actuation system included a closed loop controller which produced a constant speed reciprocating motion, thus eliminating inertia from affecting the load cell measurements.

Data for dynamic COF is obtained from 900 cycles as shown in Table 2. The force data for the dynamic COF (coefficient of friction) was generated by taking an average of six readings per cycle. In addition, measurements of static coefficient of friction (force to slip) as well are taken at six separate instances as described in Table 2. The static COF was measured for a single cycle over a length of 1.5mm traveling at a velocity of .025mm/sec.

RESULTS AND DISCUSSION

As can be seen from Table 3 as well as from figures 4 and 5, three coatings sucessfully completed the test. However the COF of the graphite (embedded) / bronze-copper was the lowest within the required range. Its COF never exceeded 0.20 throughout the test. The embedded solid lubricant bearing is composed of a solid lubricant bearing (in a plug form) and base metal. The sliding medium consists of a pattern of embedment and a surface lubrication which is used for startup.(See figure 8) The other two coatings which met the test requirements were the Everlube 860 / 316 SS and the $CuNiInMoS_2$ / Inconel 718. Over all, the test results show that the COF of the coating group is lower than that of the composite group. The APC-2 / AS4 (0°

Table 2. Sliding Test Sequence

Cycle #	Pressure (Torr)	Temperature (K)
Dynamic COF		
1 - 300	10^{-5}	80
300 - 600	10^{-5}-10^{-3}	warm-up (80 - 285)
600 - 900	10^{-3}	285
Static COF		
1	760	285
2	10^{-3}	285
3	10^{-5}	80
300	10^{-5}	80
600	10^{-3}	285
900	10^{-3}	285
900	10^{-3}	285

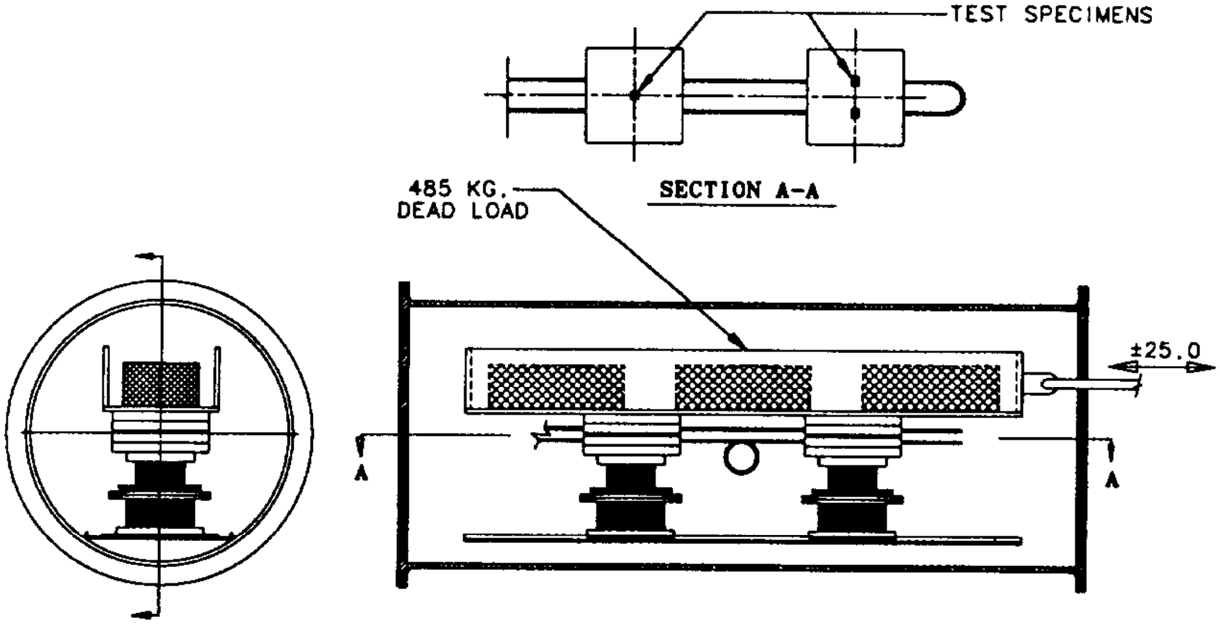

Fig. 3. Sliding Test Apparatus

fiber orientation) had the lowest COF among the composites group. As evident in the comparison plots (figures 6 and 7) the COF increased when temperatures increased from 80K to room temperature for all samples. However there is no uniform pattern evidenced in the behavior of the various materials at room temperatures. While the COF for composites changed erratically over a wide range of values, that of the coated metals maintained a more settled nature with respect to temperature changes and number of cycles.

The materials in the tests which were terminated failed by exceeding the upper limit of COF. (upper limit was set at 1890 N) In the composite group, the materials which failed exhibit stick - slip behavior and the high COF seems to result predominantly due to adhesive frictional interaction between the stainless steel and the composite material.

Graphite (embedded)/bronze-copper is the only sample of which the COF continued to increase during the last portion of the test. In comparison the COF of all other samples dropped or stabilized.

Table 3. Summary of Test Results

Material Tested	**Friction Coefficient**			**Remarks**
	0-300 cycles	300-600 cycles	600-900 cycles	
DU (Bronze + Teflon)	.16	.18	.12	
<u>Composites</u>				
Vespel SP-1	.37	-	-	Test terminated after 50 cycles @ 80K
Vespel SP-3	.18	.18 - .40	-	Test terminated after 400 cycles @ 200K
APC-2/AS4 (0°fiber orientation))	.13	.33	.14	
Torlon 4301	.34	.36	.23	
PEEK/carbon	.28	.37	.38	
<u>Coatings</u>				
$CuN_iI_nM_oS_2$ / Inconnel 718	.09	.22	.16	
Graphite (embedded) /Bronze-copper	.08	.15	.19	
Everlube 860 / 316 SS	.08	.21	.21	
T_i-T_iN / 316 SS	.42	-	-	Test terminated after 25 cycles @ 80K
WS_2 / 316 SS	.40	-	-	Test terminated after 25 cycles @ 80K

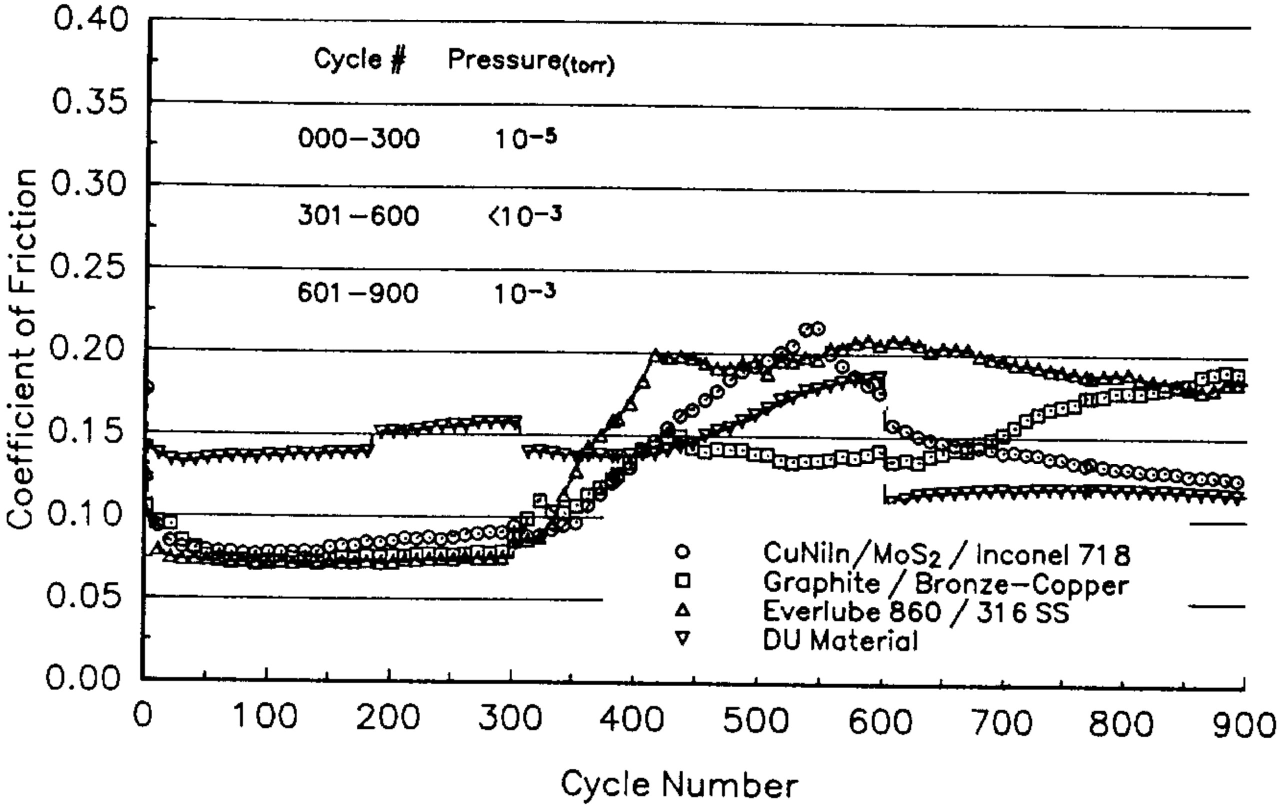

Fig. 6. Comparison Plots of COF for Coated Metals

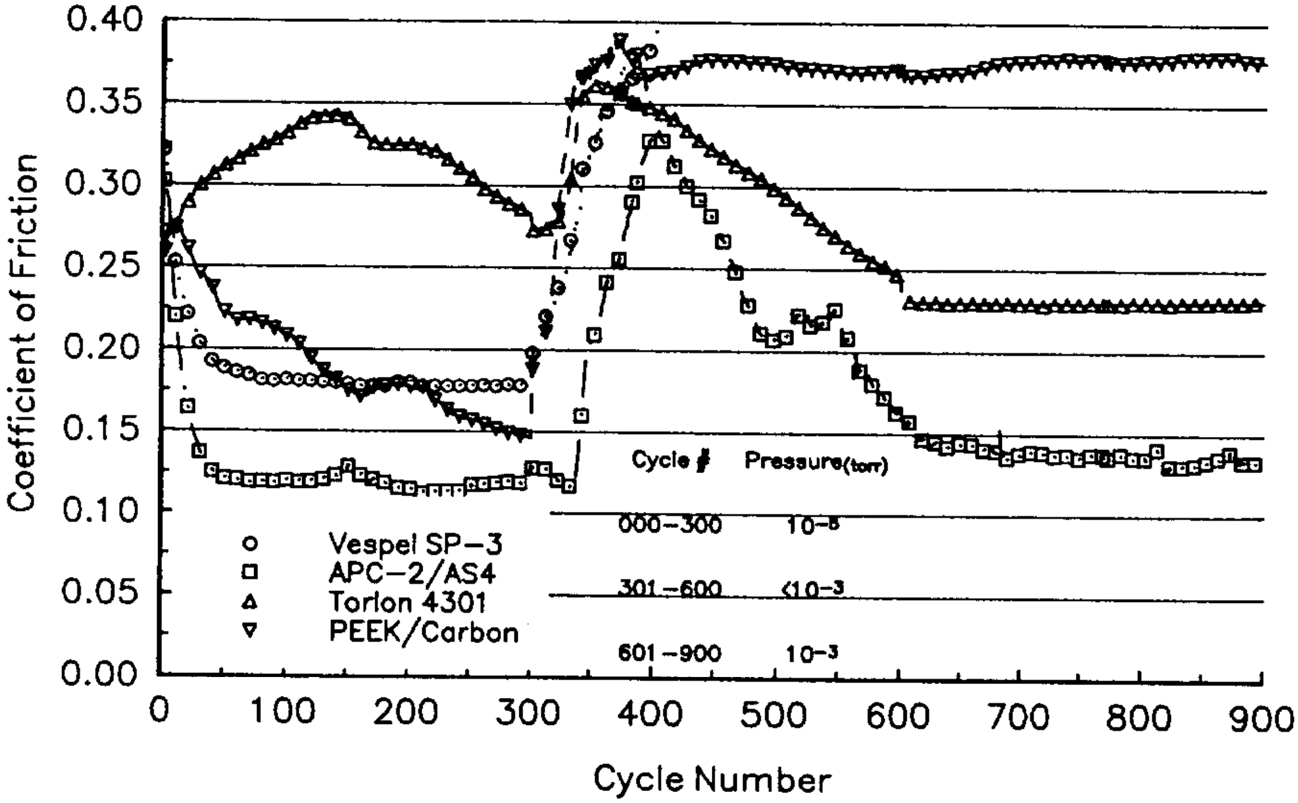

Fig. 7. Comparison Plots of COF for Composites

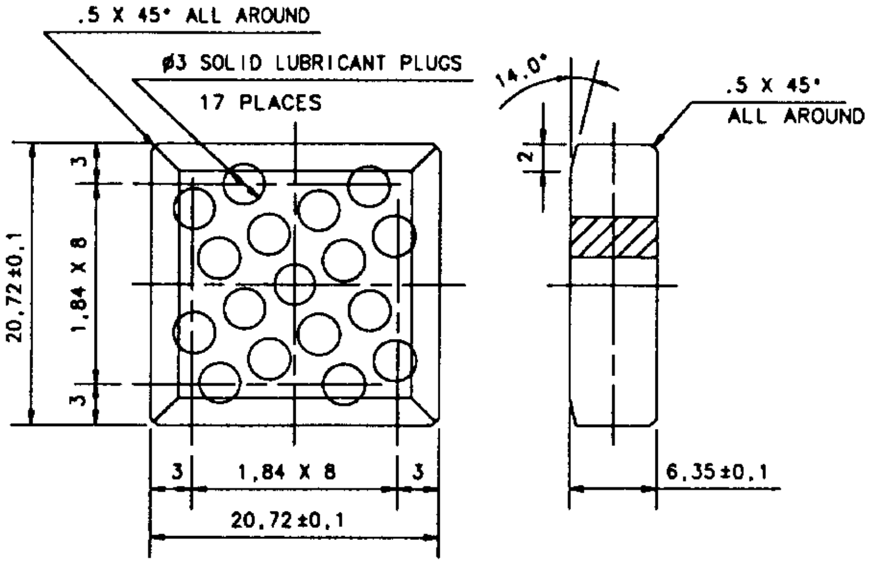

Fig. 8. Graphite (embedded)/Bronze-Copper (Courtesy - Oiles America Corp.)

CONCLUSION

This work concentrated on the selection of materials which have known good resistance to radiation yet unknown COF at vacuum and low temperatures. The test attempted to simulate the actual conditions occurring inside a dipole cryostat during cool down and warm up. Over all it was found that coatings of metals performed better than bearings made of solid composites. The dynamic COF increased in direct proportion to the rise in temperature and then either decreased or stabilized (in most cases) during the last portion of the test at room temperature. In most of the cases the number of cycles did not seem to have an adverse effect on the COF. The COF of the coatings appear to be more uniform than that of the various composite materials. Although three materials met the required COF of 0.20 - 0.22, the investigation for a replacement material for the DU bearings is far from complete. The materials which took part in this test so far represent only a fraction of a more comprehensive list of coatings and composites which need to be evaluated. Ceramic materials have the potential to be good candidates, thus further evaluation and testing are recommended.

In addition, further testing and evaluation is required with finalist material such as graphite (embedded)/bronze-copper or the Everlube 860/316 SS. Prior to selecting a replacement material for the DU the following subjects should be investigated.

- Long term effects of high vacuum (10^{-7} Torr) on the material and its compatibility in the cryostat environment.
- Bearing ability to perform adequately after being irradiated as well as exposed to air.
- Wear mechanism.
- Behavior under multiple thermal cycles.

ACKNOWLEDGEMENTS

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REFERENCES

1. DuPont, "Radiation Tolerance of Teflon Resins," January - February 1969 issue of The Journal of Teflon.