Apparatus for friction tests of support elements in fusion devices

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Abstract. Spacers and supports belong to the critical elements in the structure of a nuclear fusion device, particularly, when they are installed in the vacuum or superconducting magnet system of the reactor. These supports have to sustain high loads while allowing a certain amount of tangential movement with low friction and without any stick-slip motion. Vacuum and cryogenic environments are extremely hostile for smooth sliding systems, because conventional liquid lubricants cannot be employed, and only a very limited number of materials for dry sliding systems under these conditions are available. In order to test the friction behaviour of support elements in the field coils of the fusion experiment WENDELSTEIN 7-X, a test rig was build which allows testing in liquid helium environment at 4.2 K, with a normal force up to 150 kN, and a sliding velocity of 0.1 mm/s in oscillating motion. First tests have shown that the apparatus is appropriate for simulating the sliding behaviour of support elements. As an example, a result of an earlier model test of an MoS₂-coating is shown.

1. Introduction
Spacers and supports belong to the critical elements in the structure of a nuclear fusion device, particularly, when they are installed in the vacuum or superconducting magnet system of the reactor. Some of these supports have to sustain high loads while allowing a certain amount of tangential movement with low friction and without any stick-slip motion. Such movement is caused by mechanical and thermal strain during baking out of the vacuum vessel, cooling down, or energizing the superconducting magnets. Vacuum and cryogenic environments are extremely hostile for smooth sliding systems, because conventional liquid lubricants cannot be employed, and only a very limited number of materials for dry sliding systems under these conditions are available.

One nuclear fusion project which is presently under construction is the WENDELSTEIN 7-X experiment at the Max-Planck-Institut für Plasmaphysik (IPP) in Greifswald, Germany [1]. Its design follows the stellarator principle which enables steady-state operation of the reactor. The plasma vessel is a helical shaped vacuum chamber, surrounded by a magnet system consisting of 50 superconducting non-planar coils and 20 planar coils. The supporting elements between adjacent casings of the superconducting coils belong to the critical components of the machine [2]. One Narrow Support Element (NSE) consists of a central pad (diameter 60 mm or 73 mm, 18 mm thick) made from Al-bronze which can slide against the stainless-steel counter-face of the adjacent coil casing. When the coils are energised the pad is compressed against the counter-face with forces up to 1.0 MN. The maximum force is reached when the magnetic field on the plasma axis is 3 T.
Static friction peaks and stick-slip events during sliding of a pad against its counter-face cause disturbances to the magnet system and must be avoided. However, in the case of pure metallic contact, due to the high load, high static friction at the onset of sliding is accompanied by a loud noise and a shock running through the test equipment. In earlier model tests the sliding behaviour of composite materials, MoS$_2$-, and carbon coatings were investigated where MoS$_2$-coatings have proven their suitability for WENDELSTEIN 7-X [3].

2. Operation of the tribometer

In order to test the friction behaviour of Narrow Support Elements (NSE) in the field coils of WENDELSTEIN 7-X a test rig was build at the Federal Institute for Materials Research and Testing (BAM), Berlin. The tribometer is designed for simulating the sliding conditions at the NSE in liquid helium at 4.2 K with a maximum normal force of 150 kN. Compared to the original components, this is a reduction by a factor of 10. Size and shape of the samples are also scaled down to keep the contact pressure comparable to the original components. The Al-bronze pad has a diameter of 23 mm, a radius of curvature of 350 mm, and a fine machined surface. The counterbody is a flat stainless steel cylinder with a diameter of also 23 mm and a similar surface finish. Other test parameters are given in table 1.

The tribometer is designed as an insert for a liquid helium cryostat as shown in the schematic drawing of the test rig in figure 1. Figure 2 is a photograph of the disassembled apparatus during mounting of new samples. To ensure low coolant consumption, the loading and driving actions are transferred by long stainless steel rods and tubes with cross sections as small as possible. Figure 3 shows a sectional view of the tribometer unit. It can be seen that two friction samples are mounted symmetrically on both sides of a plunger which is moving in vertical direction. This configuration allows symmetrical loading of both samples which reduces the resulting horizontal forces on the loading and driving systems to a minimum. During the test the vertical displacement, the normal and the individual friction forces are measured by strain gauges.

![Figure 1. Test-cryostat with insert for friction tests in liquid helium.](image1)

![Figure 2. Assembly of the tribometer insert.](image2)
Table 1. Test parameters (scale down factor: 10)

| environment    | temperature (K) | max. normal force (kN) | sliding velocity (mm/s) | stroke (mm) |
|----------------|-----------------|------------------------|-------------------------|-------------|
| liquid nitrogen| 77              |                        |                         |              |
| liquid helium  | 4.2             | 150                    | 0.1                     | 1.8         |

2.1. Loading System
The load is applied by means of a wedge-roller assembly. When the wedges are pulled towards each other, the rollers move in the direction of the thicker parts of the wedges, shifting the movable pressure plate in the direction of the plunger. The load frame which encloses the complete assembly is shifted in the opposite direction. Thus, an increasing force is applied symmetrically on both samples.

2.2. Driving System
The motion is generated by a linear drive on top of the cryostat and transmitted via a tube-rod assembly. The rod is connected to a plunger which moves two samples oscillating relative to their counterparts which are held in position by two arms of a fork.

Figure 3. Tribometer unit: Loading and driving system.

Figure 4. Samples: Al-bronze pads with MoS$_2$-coating

3. Results
The operation of the tribometer was successfully tested with dummy samples at room temperature and in liquid nitrogen. In both cases all required parameters could be adjusted. Test in liquid helium are planned for the near future. Because the apparatus is still in the test phase, no measurements with original samples have been performed so far. However, in earlier model tests the sliding behaviour of composite materials, MoS$_2$- and carbon coatings were investigated in view of their suitability for WENDELSTEIN 7-X [3]. One result of a test in liquid helium is shown in figure 5. Samples were spherical Al-bronze pins with a diameter of 5 mm against coated stainless steel surfaces. The diagram shows the first five cycles of a test with MoS$_2$-coating on pins with different surface roughness. It can be seen that in both cases it doesn't take more than about four half cycles for the friction force to become essentially constant. During the next few cycles the friction stabilises and varies only very little for the rest of the test. Similar to other tests in vacuum environment, very stable friction behaviour without static friction peaks and without stick-slip behaviour was observed. In all tests only a very short running-in period and no coating failure was observed. Variations of the surface roughness in the order of a few microns had no significant influence on the friction behaviour.
Figure 5. Result of an earlier test [3]: Friction coefficient of sputtered MoS$_2$ against Al-bronze; two samples with different roughness, first friction cycles ($T = 4.2$ K; $F_N = 250$ N; $v = 0.2$ mm/s; negative values indicate the reciprocating motion).

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5. References
[1] Gasparotto et. al. 2005 The WENDELSTEIN 7-X mechanical structure support elements: Design and tests Fusion Engineering and Design 74 161-165
[2] Heinemann B. et. al. 2005 Design of Narrow Support Elements for Non Planar Coils of Wendelstein 7-X 21st IEEE/NPSS Symposium on Fusion Engineering, 26-29 September 2005, Knoxville, Tennessee, USA.
[3] Gradt Th and Assmus K 2006 Tribological Behaviour Of Solid Lubricants At Low Temperatures Proc. 21st International Cryogenic Engineering Conference (ICEC 21) Prague, Czech. Rep., 17-21 July 2006, ICARIS Publishing House, Prague, Czech Rep., 173-176