Presented at: ***1999 Cryogenic Engineering Conference***, Montréal, Canada, July12-16, 1999

FRICTION MEASUREMENTS FOR SC CAVITY SLIDING FIXTURES IN LONG CRYOSTATS

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ABSTRACT

Filling factor and static cryogenic losses considerations suggest the use of long multi-cavity cryomodules for high energy superconducting linacs. In the case of TTF/TESLA a further gain has been obtained including the Helium Gas Return Pipe (HeGRP) in the cryostat vacuum vessel and using it as the reference supporting beam for the active elements. One limit of this solution has been the need of developing expensive flexible couplers to feed RF power in the cavities. For cost and reliability considerations in view of TESLA, a new spring loaded sliding fixture, to connect the cavities to the HeGRP, has been developed and qualified at the different operating conditions, from room to cryogenic temperature. Static and quasi-static friction has been measured in a dedicated apparatus for different material coupling and surface finishing. The icing effect in case of a vacuum break has also been studied. The results of this analysis are presented in this paper.

INTRODUCTION

The third cryomodule generation[1] designed for the TESLA Test Facility (TTF)[2] Super Conducting accelerator opens the possibility to use semi-rigid power coupler and superstructures[3]. This result has been obtained by designing a new fixture scheme that decouples the longitudinal position of the cavity string from the structural supporting beam, that is the Helium Gas Return Pipe (HeGRP). During the cooldown, the thermal contractions of the cavity string and of the HeGRP are independent, but the cavity alignment guaranteed by the HeGRP is preserved. Each cavity is now connected to the HeGRP by four low friction sliding fixtures. The qualification tests of this new fixture design are presented in this paper.

SLIDING SUPPORT

As in the previous generation cryostats, in the present design the SC cavities and the quadrupole package are anchored, through the Helium vessels, to the HeGRP which acts as a structural beam for the cold mass and preserves its alignment from room temperature to cryogenic operation.

To appear on: *Advances in Cryogenic Engineering*, Vol. 45
Plenum Press, New York

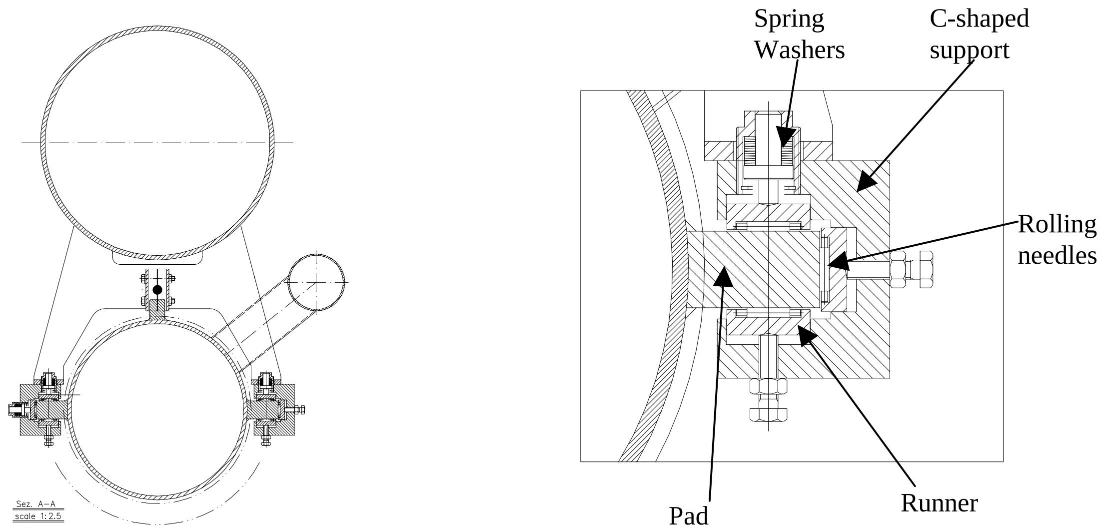

Figure 1. The cavity support scheme. Each cavity is attached to the HeGRP by means of four fixtures. Each fixture includes rollers, runners and reference screws to define the vertical and lateral position. Spring washers are used to give e constant 80 kg_f load. Rolling needles keep the cavity longitudinal position free.

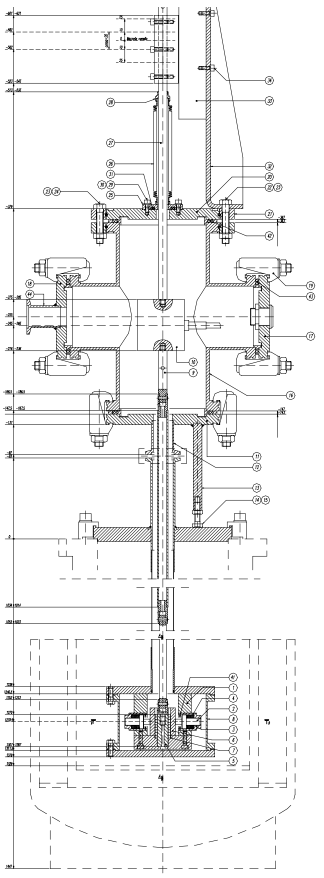

Figure 2. Schematic drawing of the system developed for the sliding fixture measurements.

In the third generation of TTF Cryomodules, new fixture design has been developed in order to adjust and keep fixed the transverse position of the active elements, while leaving the cavity longitudinal position independent from the HeGRP displacements due to the thermal contraction/elongation during cooldown/warmup cycles. This freedom is obtained through a set of low friction rolling needles. The drawing of a cavity anchored by the sliding fixtures is presented in Fig. 1. Each cavity is connected to the HeGRP with four sliding fixtures, each clamping a titanium pad welded on the cavity helium vessel. Each pad fixture consists of a C-shaped stainless steel element that defines the transverse position (with respect to the beam axis) through the sequence of rolling needles, runners and reference screws. In each direction one screw is used for adjustment, while the other is transferring a 80 kg_f force via spring washers. But for the low friction, the longitudinal displacement is independent from that of the HeGRP. The cavity longitudinal position, that could be determined by the use of a rigid coupler solution, is presently fixed via a connection to an independent Invar rod that runs over the cavities and has a fix point at the cryomodule center. This produces a total longitudinal motion of less than 3 mm, which should be compatible with a semi-rigid coupler design.

MEASUREMENT APPARATUS

To qualify the new fixtures a moke-up has been built and a measuring apparatus has been set up. The scheme of the system is shown in Fig. 2. The sliding fixture prototype is assembled in a vacuum chamber that is part of a properly designed insert for a test cryostat. A motorized computer-controlled linear actuator moves the sliding element with a bellow and a “load cell”. The system is designed to test the fixture either under vacuum or at atmospheric pressure. The test temperature, measured by an adequate thermometer system, can range from room temperature to that of liquid Helium. Measurements at 2 K can be taken pumping on the He bath.

The sliding fixture prototype consists of a remotely actuated titanium pad (a copy of that welded on the cavity helium vessel) moving between two rolling needles arrays. Both stainless steel and titanium runners have been tested, the load being controlled through a spring washer set. Measurements have been performed with different surface roughness and the results compared and discussed.

The test apparatus is assembled in a stainless steel vacuum chamber which is part of the insert of a vertical cryostat that can be filled by liquid nitrogen or liquid helium. The vacuum system is designed to allow a controlled venting of the vacuum test chamber with different gasses and pressures. Ice effect on the sliding surfaces has been produced and its influence on the system performance has been measured.

To read the applied force, a commercial low cost load cell (from Philips) has been chosen and its measured characteristic curve is presented in Fig. 3. Its linear range reaches more than 10 kg_f, with a few gram accuracy and an elastic constant of 72.5 kg_f/mm. In our friction measuring system we chose a working point close to the center of the load curve, by means of applying an external weight to the actuation rod.

The motorized linear actuator uses a slide guide and is controlled by a programmable PID. The position is read with micrometric precision, while the velocity and acceleration are set via computer. In order to compensate pre-load effect on the reading of the load cell, a calibration has been performed on the basis of the data from a set of four different movement patterns and kinetic parameters. The settings used are summarized in Table 1. The movement shape can be easily deduced also from the time domains plot as shown in Fig. 4.

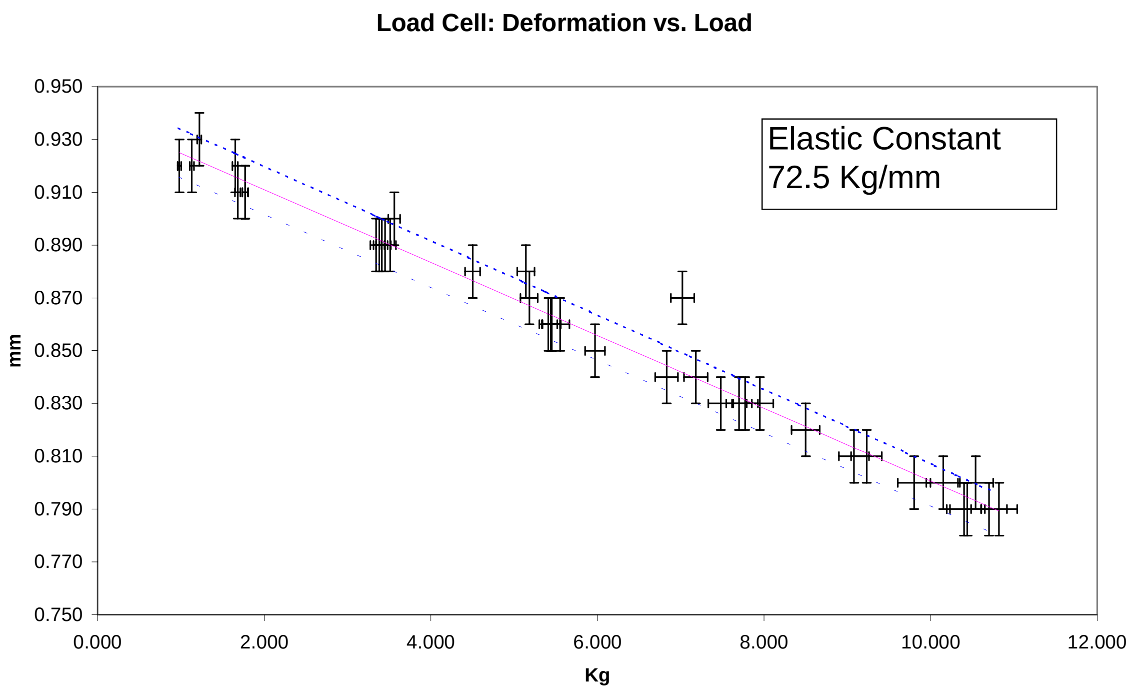

Figure 3. Displacement vs. force characterization of the load cell. The device shows a good linearity and reproducibility, with an elastic constant of 72.5 kg_f/mm.

Table 1. Actuator settings for the four different movement patterns used for calibration. They are obtained combining two velocity and acceleration sets with two motion types: I) 5 mm up, wait, 5 mm down; II) 2.5 mm up, wait, 2.5 mm up, wait, 5 mm down.

Pattern type	Velocity [mm/s]	Acceleration [mm/s^2]	Wait time [s]	Movement Pattern
1	0.25	0.25	5	I: Up 5 mm Wait Down 5 mm
2	0.25	0.25	2	II: Up 2.5 mm Wait Up 2.5 Wait Down 5
3	0.5	0.5	10	I: Up 5 mm Wait Down 5 mm
4	0.5	0.5	10	II: Up 2.5 mm Wait Up 2.5 Wait Down 5

DATA ANALYSIS AND INTERPRETATION

The system composed by the sliding pad, the runner, the rolling needles and the load cell is driven by the laws of static and dynamic friction. To describe and simulate this system we have developed a dynamic non linear numerical simulation. By exploring the parameter ranges of the model we have tested different movements setting, and chosen the movement patterns and parameters listed in Table 1, in order to allow a good sensibility to the static and dynamic friction effects. Fig. 4 summarizes some simulation results showing the difference in movement patterns of type I and II. This analysis predicts that the maximum extension of the signal from the load cell is equal two times the static friction, while the oscillation amplitude is equal to two times the difference between the static and dynamic friction. Unfortunately experimental results are not as clear as the simplified model used for the simulations, because surfaces roughness, the acquisition system and the instrumentation introduce noise that needs to be filtered by repeating several times the measurements. To discriminate the amplitude of the oscillations, that depends from the value of static and dynamic friction, we had to fit result including a proper error estimate.

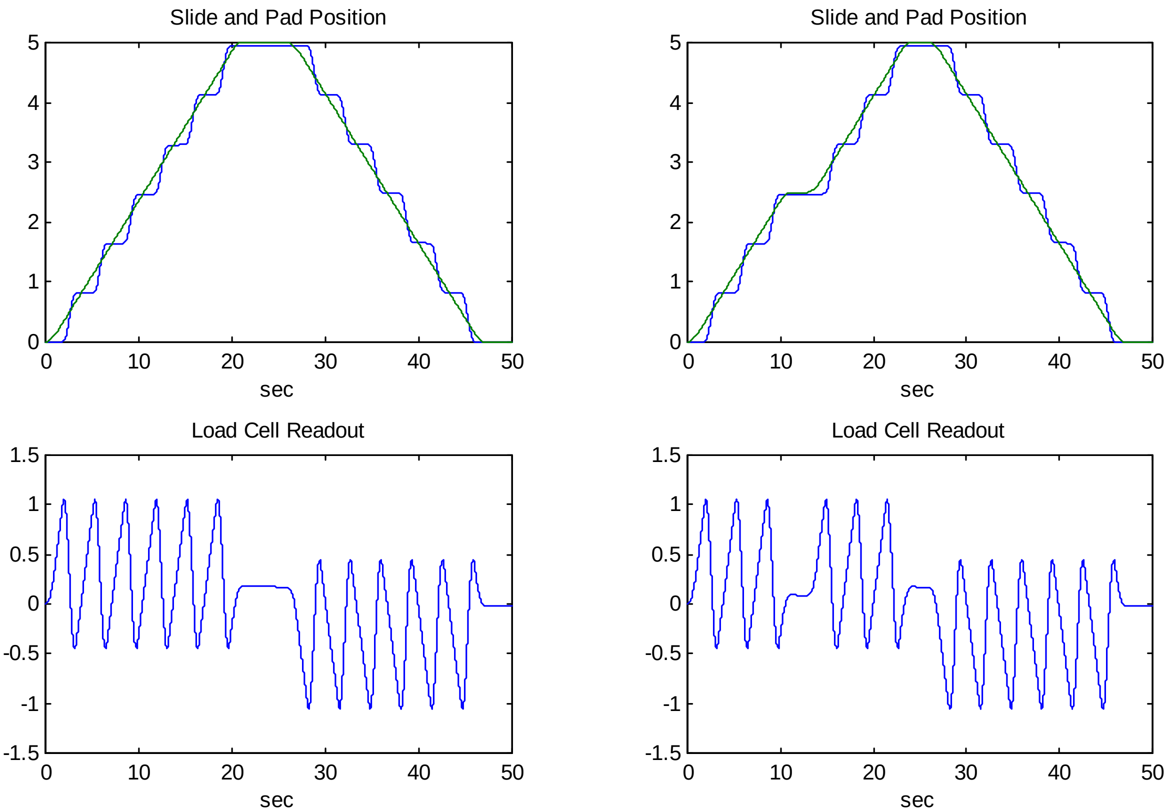

Figure 4. Simulated behavior of the readout system for movement patterns of type I (left) and type II (right).

MEASUREMENTS RESULTS

In order to qualify the cavity support system, stainless steel and titanium slides have been built and tested. The slides have been worked to a range of surface roughnesses, from very good to extremely rubbed, in order to test the starting life, end life and the case of extremely damaged components. Tests have been performed under different conditions of environment pressure, vacuum, and temperature. A failure in the vacuum system and the consequent surface icing has been also simulated. Each situation has been measured with the four movement patterns, each pattern has been repeat five to ten times, in the same slide position, with a very good repeatability to filter quantization noise. The same pattern has been then tested at different slide positions. An automatic LabView[4] procedure operated the movements and the data acquisition, while a Matlab[4] routine analyzed data and compute the measured static and dynamic friction, producing a report of the measured run (Fig 5 and Fig 6). All the four movement patterns (two sets for each pattern) are reported and plotted with the calculated friction value, and a summary comparing the eight measurements is generated. Using the eight results (of friction values and corresponding errors) a mean static and dynamic friction value is computed. The previous procedure has been repeated for the whole samples in the condition previously listed. Table 1 summarize the results acquired by the test system. The stainless steel slides have been used and tested also with a double force load (corresponding to about 80 kg_f), in order to check for the linear dependence of the measured friction values. The average friction force results in about 0.1 kg_f for stainless steel and about 0.8 kg_f for the titanium slide. The behavior of the

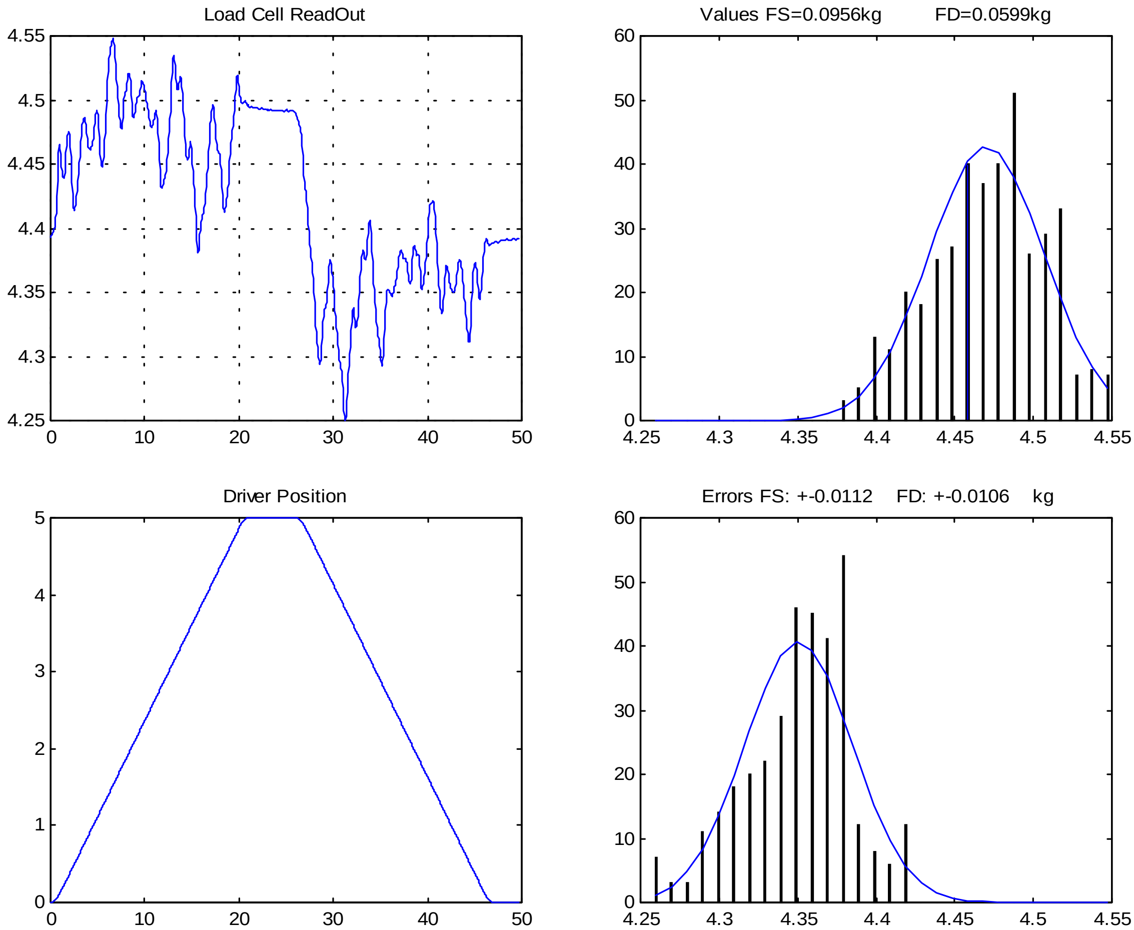

Figure 5. Data as output by the "Data Analysis Tool" developed to analyze the friction system results, for the case of the movement pattern of type I (Slow motion and single step). Studying the Load Cell tracks and checking them with the driving motor data the oscillations predicted by friction theory are reconstructed, and static and dynamic friction are evaluated, with their errors.

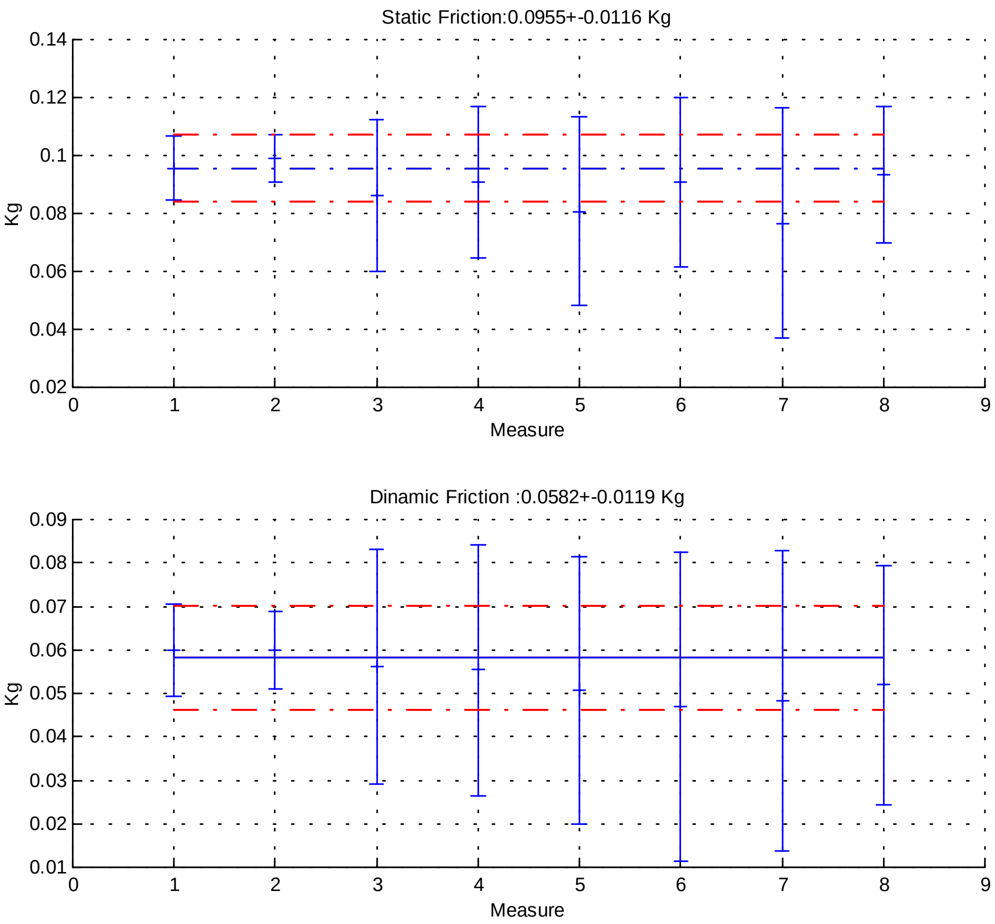

Figure 6. Results summary prepared by the “Data Analysis Tool”. Results from the eight measures (four movement patterns, two run for each trip) are compared to achieve a final result value (and error) for dynamic and static friction.

slide does not depend strongly on the cryogenic temperature and no differences have been seen from the measurements. Icing effects have been "simulated" manually producing a vacuum break in the chamber at the liquid nitrogen temperature, raising the pressure to about 0.5 bar for 10 minutes (enough to condense water and other gases), but the rolling system performance was not impaired. The extremely damaged slides are characterized by an average friction value of about 0.8 kg_f, but some samples reached values up to 1.2 kg_f. This value is however compatible with the actual design of the cavities fixing feature[3] and should not be able to produce neither deformation in the cavity string nor damage in the supporting structure.

CONCLUSIONS

In this work the sliding support for SC cavities in long cryostats, proposed for the third generation of the TTF cryomodule have been qualified in its working condition. A test system has been built and used to simulate the cryogenic operation conditions of the support. Accurate data analysis has been necessary for the interpretation of the measurement results and to obtain static and dynamic friction in stainless steel and titanium sliding supports. A mechanical and vacuum failure has been simulated using severely damaged slides and icing the support during the test. Static friction measurements results in 0.1 kg_f reaction force with about 80 kg_f applied.

Table 2. Summary of the measurement results.

Sample[1]	Condition	Static Friction [kg_f]	Error [kg_f]	Dynamic Friction [kg_f]	Error [kg_f]
SS18	Liq. Nitrogen	0.0942	0.0266	0.0491	0.0203
SS18	Atm	0.0643	0.0078	0.0385	0.0061
SS18	Vacuum	0.0569	0.0135	0.0346	0.0118
SS36	Liq. Nitrogen	0.0901	0.0121	0.0449	0.0108
SS36	Ice	0.0715	0.0314	0.0362	0.0279
SS36	Atm	0.0979	0.0036	0.0564	0.0037
SS36	Vacuum	0.0955	0.0116	0.0582	0.0119
SS36Dam[2]	Liq. Nitrogen	0.5631	0.0761	0.2807	0.0751
SS36Dam[2]	Ice	1.0259	0.0381	0.6943	0.0460
SS36Dam[2]	Atm	0.4302	0.0387	0.2501	0.0375
SS36Dam[2]	Vacuum	0.4527	0.0330	0.2568	0.0346
Ti18	Liq. Nitrogen	0.1738	0.0433	0.0892	0.0352
Ti18	Atm	0.0756	0.0206	0.0458	0.0200
Ti18	Vacuum	0.0835	0.0210	0.0537	0.0189
SS18	Helium	0.0427	0.0153	0.0315	0.0214

[1] The "sample" notation is 'SS' for stainless steel and 'Ti' for titanium. The number is the spring load over the rolling needles, where 36 correspond to about 80 kg_f.

[2] The samples with the 'Dam' suffix have been heavily damaged before the tests.

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4. LABVIEW and MATLAB are trademarks.