



Technical Note #1008

The Advantages of the 6D Force-Torque Sensor with Multiple-Axes Measurement

High-precision evaluation of tribological properties, such as friction forces, friction coefficients, and torques for arbitrary material pairs, is critical for many research and industrial applications. The only practical method available to produce a quantitative assessment of tribological properties is through laboratory experimentation and testing. Despite the availability of multiple options, ranging from commercial tribometers to self-developed systems, the effort to obtain accurate and repeatable tribological property measurements remains a challenge. This results from the interdependency of the material, surface, environment, and the measuring equipment itself. Bruker's UMT TriboLab™ utilizes the latest developments in sensor technology, and features the new 6D Force-Torque Sensor. This advanced sensor provides simultaneous measurement of up to six components of a tensor (three forces and three torques in the x, y, and z axes, respectively). The six-axis load sensor contributes to high measurement sensitivity and isotropy, while maintaining low interference between measurement axes over a wide force range (up to 1160 N in normal direction and a maximum torque of 20 N.m.). Simultaneous measurements of these additional variables, along with changes in lateral forces, enable a deeper understanding of the dynamics being explored. This tech note covers the specific features and measurement advantages of TriboLab's 6D Force-Torque Sensor.

High-Performance Sensor Design

The architecture of the force-torque sensor is based on the principle of mechanical deformation of the structure via silicon strain gauges. The strain gauges are placed on a compliant structure that produces six channels of strain gauge voltage output, which are digitized and converted to forces and torques through matrix calculations. The sensing elements are conveniently located on a highly stressed area of the spokes, allowing an almost constant strain distribution on the surface of the spoke. The constant strain distribution offsets the negative effects caused by strain gauge positioning errors, thus increasing the accuracy of the sensor in the evaluation of the standard six force and torque components (F_x , F_y , F_z , T_x , T_y , T_z).

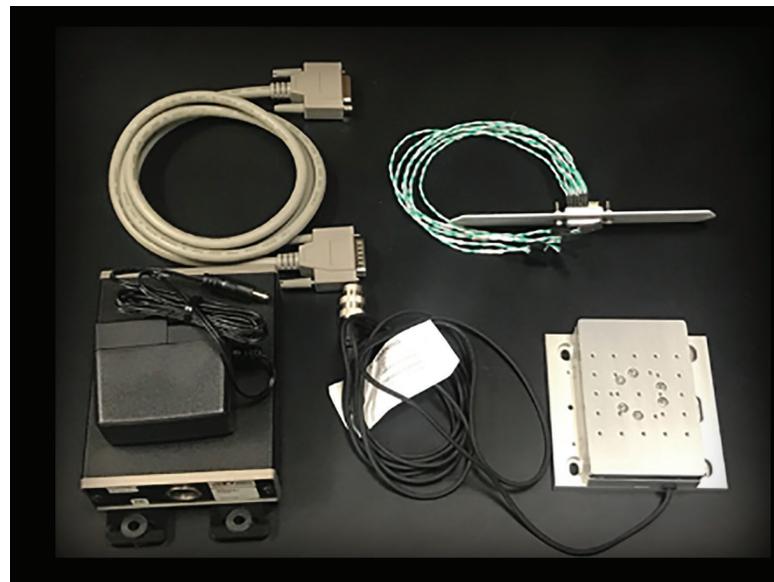


FIGURE 1.
UMT TriboLab 6D
Force-Torque Load Cell Kit.

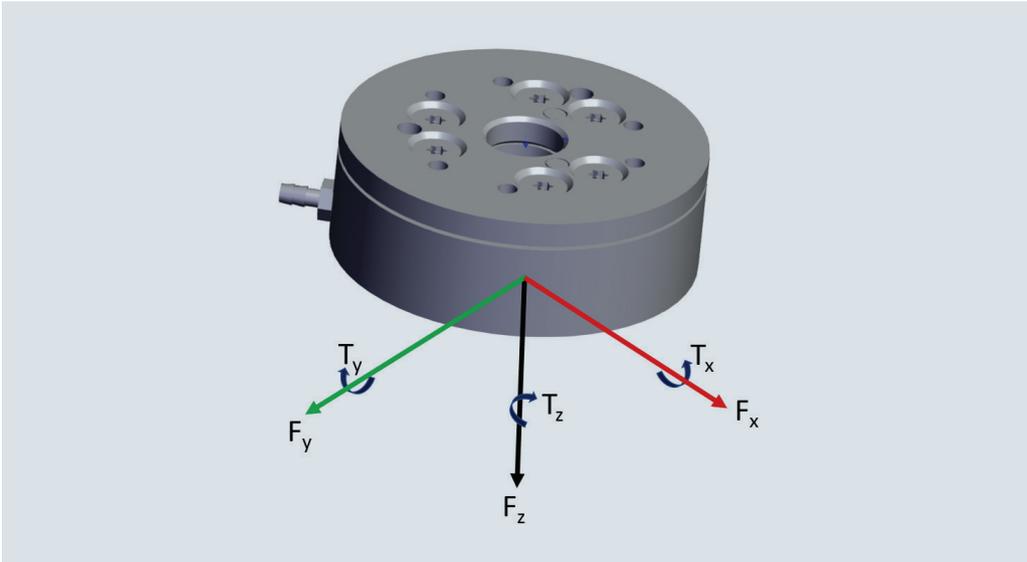


FIGURE 2.
Structure of force-torque sensor and its position indicator.

Widest Range of Measurement Benefits

Integrated load sensor for multiple measurements

The 6D Force-Torque Sensor integrates the strain gauge transducer in its unique design to offer ideal simultaneous force-torque measurement over a wide range of forces and torques. The feasibility of providing simultaneous measurements of forces and torques in the x, y and z axes is extremely useful for calculating macroscopic friction coefficients to monitor the distribution of friction forces along an interface, and to measure external torques important for local stress evaluations of the interface. The 6D Force-Torque Sensor comes in three different specifications for various types of applications (see Table 1).

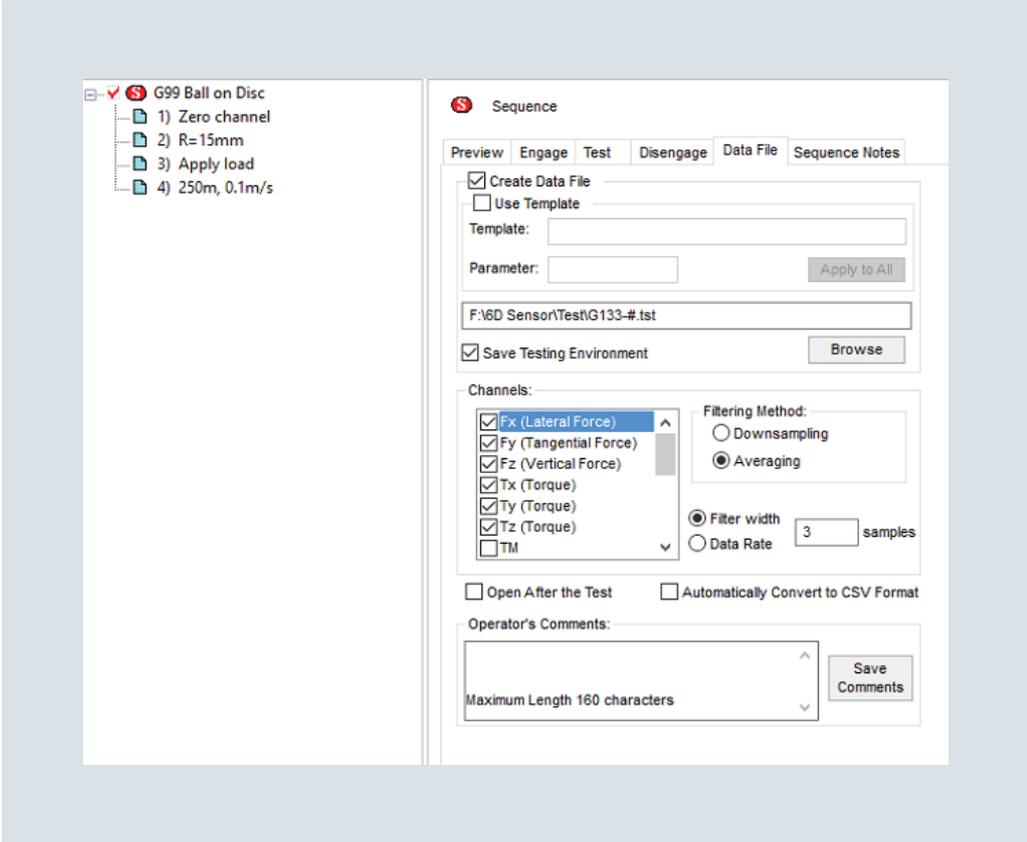


FIGURE 3.
Structure of force-torque sensor and its position indicator.

Models/Specs	6D-Low	6D-Mid	6D-High
Friction/Lateral Force (Fx, Fy)			
Range	0 – 145 N	0 – 290 N	0 – 580 N
Resolution	62.5 mN	125 mN	0.25 N
Load (Fz)			
Range	0 – 290 N	0 – 580 N	0 – 1160 N
Resolution	62.5 mN	125 mN	0.25 N
Torque (Tx, Ty)			
Range	5 Nm	10 Nm	10 Nm
Resolution	1 Nm	2.6 Nm	5.3 Nm
Torque (Tz)			
Range	5 Nm	10 Nm	10 Nm
Resolution	0.06 Nm	1.3 Nm	2.6 Nm

TABLE 1.

Technical specifications of UMT TriboLab 6D Force-Torque Sensors.

Superior accuracy and sensitivity

Prime quality of raw output signals is critical to reduce any uncertainty of friction and torque coefficient measurements. A recent study reported to have improved measurement accuracy by placing the force sensors as close as possible to the contact surface.¹ The configuration of UMT TriboLab and the 6D Force-Torque Sensor synergizes the forces produced on the contact surface, reducing the torques experienced by the sensors and minimizing measurement uncertainties. Table 2 shows that the average full-scale error was less than 2% measured on the 6D Force-Torque Sensors. These measurement values represent the maximum amount of error expressed as a percentage of the full-scale load for each axis. In addition to the negligible precision uncertainty measurement, the 6D Force-Torque Sensor experiences high stability over extended periods of time (see stable vertical load in Figure 4), as well as along thermally controlled experiments, (see Figure 5). These attributes are mandatory to finely calibrate sensor targeting for accurate tribological data.

Models/Specs	Fx	Fy	Fz	Tx	Ty	Tz
6D-Low	1.25%	1.00%	0.75%	1.25%	1.50%	1.25%
6D-Medium	1.00%	0.75%	0.75%	1.00%	1.25%	1.25%
6D-High	1.75%	1.25%	1.00%	1.25%	1.75%	1.00%

TABLE 2.

Precision measurement (95% confidence level, percent of full-scale load) for the 6D-Low, 6D-Medium and 6D-High Force-Torque Load Cells tested at ambient condition.

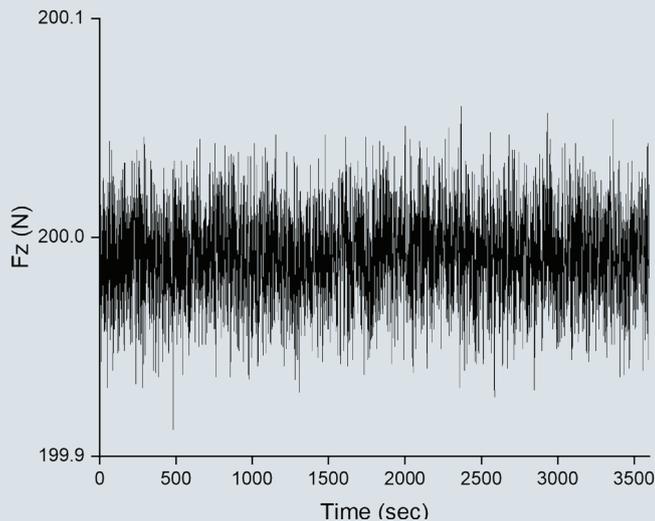


FIGURE 4.

A force of 200 N was applied on a steel specimen for 1 hour. The recorded noise level of the 6D Force-Torque Sensor was less than 0.05% of full-scale values.

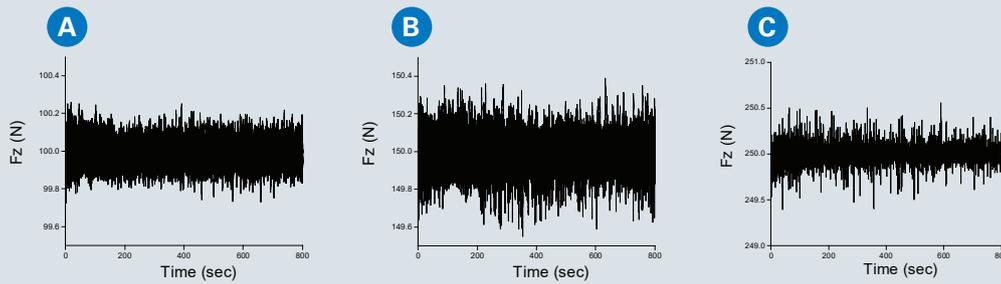


FIGURE 5.

The 6D Force-Torque Sensor experiences minimum thermal drift effect with applied force of (a) 100 N, (b) 150 N, and (c) 250 N, at 200°C, respectively.

Eliminating artifacts with high-precision measurements

The contributions of the kinetic friction ratio of the normal (F_z) and tangential (F_x , F_y) forces, as well as its torque (T_x , T_y and T_z) constraints comprise fundamental investigations in the field of tribology. However, a misalignment issue often occurs when force and torque sensors are assembled separately to perform these measurements, triggering crosstalk between the different signal channels and impairing accuracy of tribological data. With its single-cell design, Bruker's 6D Force-Torque Sensor provides minimum crosstalk of less than 1.5%, providing researchers relevant and accurate data for each tribology experiment (see Figure 6). Furthermore, the UMT software allows users to compensate and offset noise bias during tests.

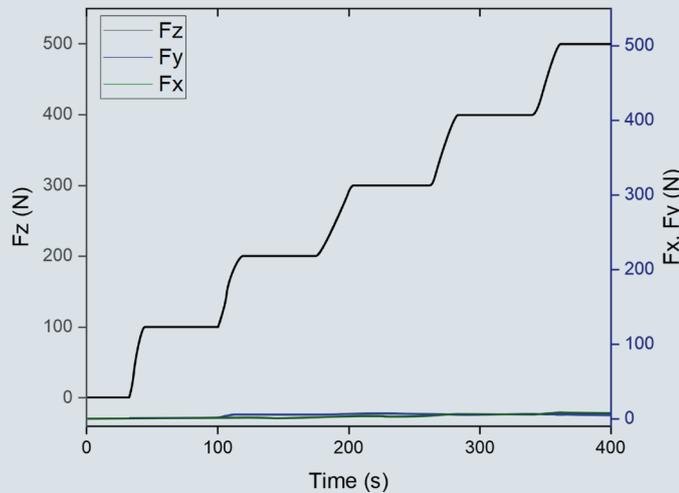


FIGURE 6

Minimal crosstalk between normal load F_z and lateral force sensing F_x/F_y .

Product compatibility with reduced footprint

The 6D Force-Torque Sensor is fully compatible with the existing UMT TriboLab configuration, making its integration into existing experiences seamless. The sensor is a plug-and-play peripheral that is used together with the fast exchange kit (AM30C413), fast exchange plate (M30C784), and 2-inch or 4-inch extension blocks (M30C366-1, M30C366-2). Different types of upper specimens can be used with this configuration, to fit a wide range of test conditions and applications.

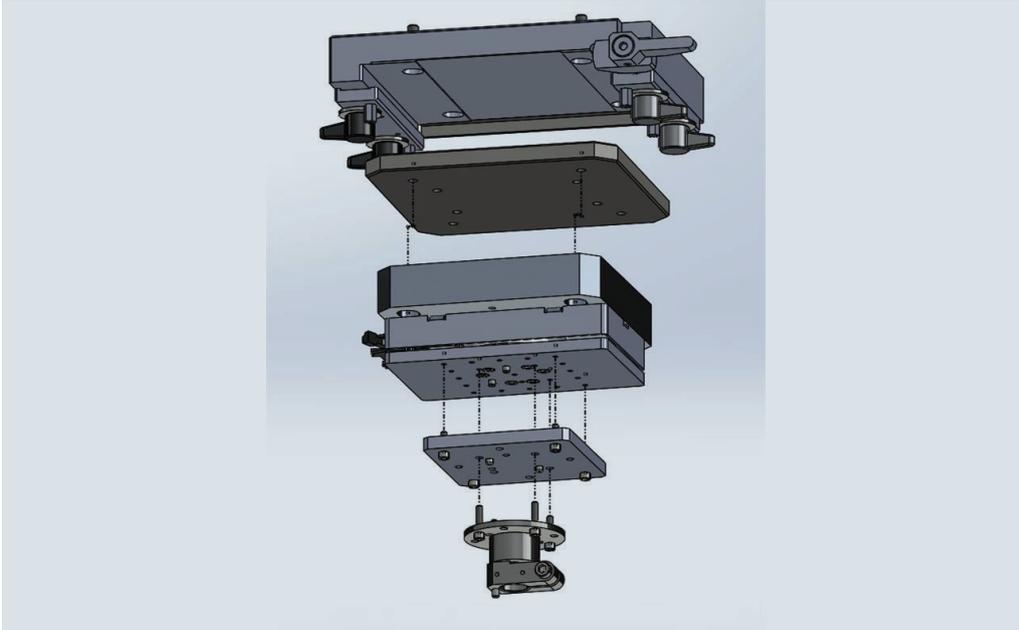


FIGURE 7.

Assembly diagram of the 6D Force-Torque Sensor.

Experimental Applications

Bruker's UMT TriboLab is a unique modular platform with a single high-torque motor integrated into the base system to accommodate a wide range of speed and torque tests. Together with the advanced 6D Force-Torque Sensor, TriboLab provides complex motion and high-precision measurements around multiple axes, which is the essence of tribology research and industrial applications.

Rotary test

Rotary test is one of the most common friction and wear testing methods for laboratory and industrial applications. In this test, a ball or pin is installed under the 6D Force-Torque Sensor, and a standard disk is installed as the lower specimen (see Figure 8a/b). During the test, forces and torques in multiple axes are measured to obtain the friction coefficient and torque coefficient. The multiple axes measurements are exceptionally useful to understand the friction and wear behavior of a tribosystem. The in-situ coefficient of the friction measurement takes into account the contributions of both F_x and F_y , following the mathematical equation $COF = \sqrt{(F_x^2 + F_y^2)} / F_z$. During high-speed rotational tribotests, any undesired movement of the contact partners due to loose assembly or a breakage event would critically affect the tests. The 6D Force-Torque Sensor allows such occurrences to be easily identified through real-time monitoring of the torque output along the x and y axes (see Figure 8c), so that the potential failures can be immediately addressed.

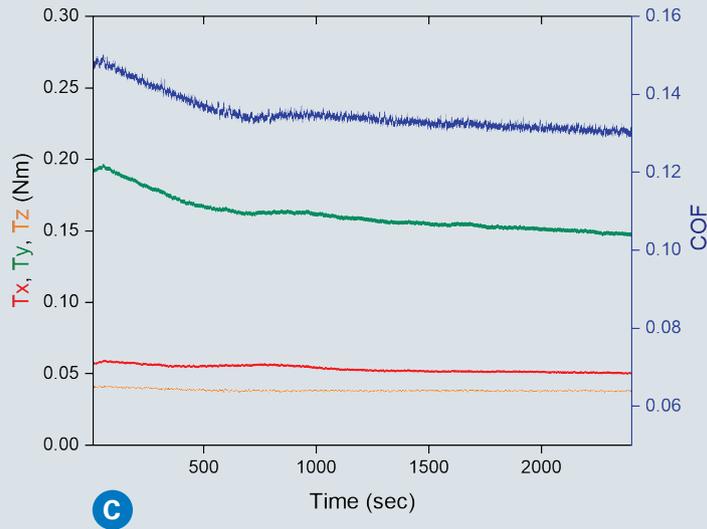


FIGURE 8

UMT Tribolab rotary test module with 6D Force-Torque Sensor; (a) ball-on-disc, (b) pin-on-disc tests, and (c) graph of dynamic friction coefficient and torques against time.

Brake and clutch materials screening

The Brake and Clutch Material Screening Tester for UMT Tribolab is specifically designed to be a cost-effective and rapid way to screen and rank materials before proceeding to component-level evaluation. These techniques allow characterization of the tribological performance of small friction material samples in a precise and timely manner. This occurs while monitoring key parameters, such as friction, sliding speed, temperature, and wear. The scaled-down method is typically employed to simulate vehicle brake systems while consistently matching the critical physical parameters used by dynamometers for protocols, such as SAE J2522. The 6D Force-Torque Sensor contributes to screening tests by allowing for simultaneous multiple axes measurements to better understand the dynamic behavior of the tribosystem. Figure 9a depicts a typical setup on Tribolab for brake material screening with the integrated 6D Force-Torque Sensor. The torque output (T_x , T_y and T_z), shown in Figure 9b, is among the new output features available with the sensor. It allows for better assessment of the mechanism of brake fade from thermal deterioration of the brake lining material.

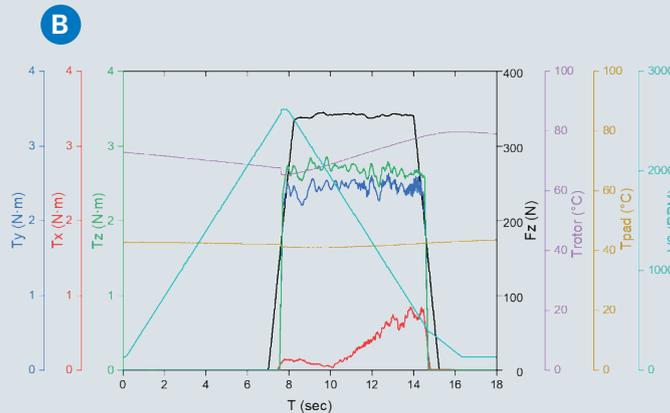
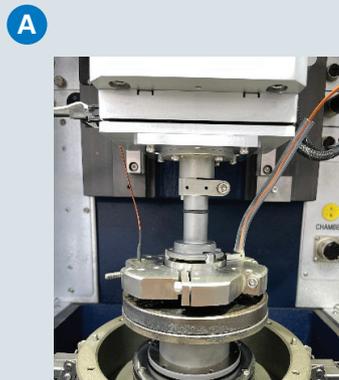


FIGURE 9.

(a) UMT Tribolab Brake Material Screening Tester with 6D Force-Torque Sensor, and (b) simulation of snub performed by varying the speed from 2620 to 131 rpm (100 to 5 km/h vehicle speed) in 8 seconds, and under an applied force of 354 N (2 MPa contact pressure).

Table 3 illustrates other applications that can benefit from having six components of forces and torques, including the four-ball test, the twist compression test, and the sliding-to-rolling ratio tests.

ASTM#	Description	Advantages
D4172-20 & D2266-01	Wear Preventive Characteristics of Lubricating Fluid & Greases (Four-Ball Method)	Multidirectional torque output signals enable quick identification of balls rolling and slipping in the four-ball cup holder.
D5183-21	Determination of the Coefficient of Friction of Lubricants (Four-Ball Method)	
D2596-20 & D2783-19	Measurement of Extreme-Pressure Properties of Lubricating Fluid & Greases (Four-Ball Method)	
G99-17	Wear Testing with a Pin-on-Disk Apparatus	Stability of applied forces with minimum effects of thermal drift is suitable for extended period testing.
G132-96(2018)	Pin Abrasion Testing	
D3702-94(2019)	Wear Rate and Coefficient of Friction of Materials in Self-Lubricated Rubbing Contact Using a Thrust Washer Testing Machine	Sensitivity of the load sensor improves self-levelling of the upper sample in a thrust washer test.
D5619-00 & D8288-19	Comparing Metal Removal Fluids	Cross-threading during tapping can be easily identified and prevented.

TABLE 3.

The advantages of using a 6D Force-Torque Sensor to perform ASTM standard tests.

Summary

Bruker’s UMT TriboLab is an invaluable tribometer for force-torque measurements across a wide range of forces and torques in research and industrial applications. These applications include precision for scientific instruments, sensors, actuators, automotives, micro-manipulators, robotics and lubrications. With the latest 6D Force-Torque Sensor, TriboLab delivers:

- Solutions to independent simultaneous force and torque measurements,
- High-precision measurements that resolve interference between measurement axes in multiple directions,
- Linear responses with high natural frequency, and
- Overload protection.

Lastly, TriboLab can perform a wide range of friction, wear and lubrication testing in compliance with various internationally recognized standards, such as the ASTM, ISO, DIN, SAE, and many others.

References

1. Grégoire, C., Laulagnet, B., Perret-Liaudet, J., Durand, T., Collet, M., and Scheibert, J., Design and characterization of an instrumented slider aimed at measuring local micro-impact forces between dry rough solids. *Sensors and Actuators A: Physical*, 317, 112478, (2021).
2. Ballo, F., Gobbi, M., Mastinu, G., and Previati, G., Advances in force and moments measurements by an innovative six-axis load cell. *Experimental Mechanics*, 54(4), 571-592, (2014).
3. Heglund, N.C., A simple design for a force-plate to measure ground reaction forces. *J. exp. Biol.*, 93, (1981).
4. SAE J2522, Dynamometer Global Brake Effectiveness, SAE International (2013).
5. ASTM G09-05 (Reapproved 2010), Standard Test Method for Wear Testing with a Pin-on-Disk Apparatus, ASTM International, West Conshohocken, PA, (2010).

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