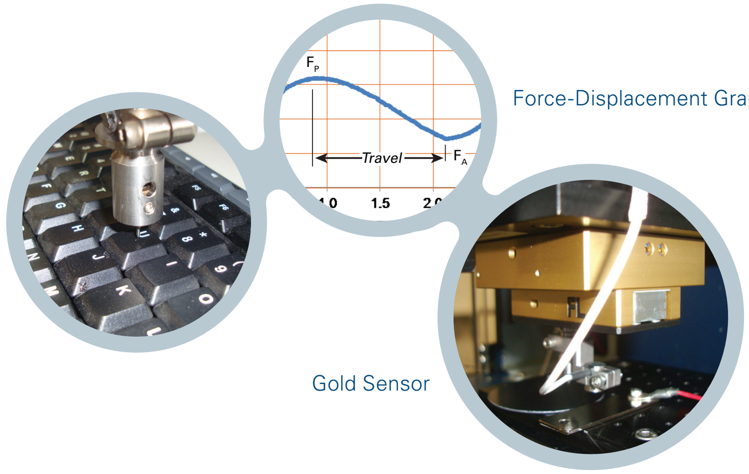

Application Note #1008

Precision Force-Displacement Measurements on MEMS and Computing Input Devices

Force-displacement characteristics of structures on microelectromechanical systems (MEMS) or micro-measuring devices are extremely important to validate the overall design and fitness for use in a wide range of applications, including robotics, micro-manipulation, bio-systems, and micro-assembly. Bruker's UMT TriboLab™ test system is capable of performing such precision measurements reliably and accurately across wide force (mN to kN) and displacement (µm to mm) ranges. Such exceptional ability to adapt to a wide range of force and displacement measurement scenarios sets the TriboLab system apart from other available measurement instruments. This application note discusses these characteristics in action on a MEMS lever arm and a computing keyboard.

Introduction

Force and displacement data are extremely important to verify the design of any micro and macro component, such as MEMS, keyboards, micro-switches etc. Each of these devices is designed with certain stiffness and other structural considerations in mind to enable specific functions. A force-displacement plot can be used to obtain structural stiffness, which is an important factor in design of an elastic body.[1, 2] A quick force-displacement measurement can help evaluate such components for quality and intended functionality. It can also be used to understand the instability of structures due to buckling,[2, 3] especially for key and switch input devices for computing and musical instruments. Depending upon the scope of the components, the force range for such measurements can vary from a few mN to the order of kN, and the displacement can range from µm to mm. Bruker's UMT TriboLab is capable of performing very precise tests across a wide range of force and displacements. The TriboLab system is equipped with precision Gold-series force and displacement sensors that include strain-gauge, capacitance, and LVDT technologies that give it an advantageous position for such applications over other measuring devices currently available in the market. This and other features make the TriboLab an invaluable tool for force-displacement measurements for the manufacturers of MEMS, robots, computing accessories, micro-manipulators, precision and scientific instruments, sensors, and actuators.

The UMT TriboLab Test System

UMT TriboLab is built on the industry-leading Universal Mechanical Test (UMT) platform, which has a long history of providing precision control of load, speed, and position. The new model's modular design ensures the flexibility to cover test capabilities across wide force and displacement ranges. The tester has three major drive systems for motion in X, Y, and Z directions. Integrated intelligent hardware and software interfaces make the system an extremely user-friendly, versatile, and productive testing tool. TriboScript™offers an enhanced and secured scripting interface for easy compilation of force-displacement test sequences from blocks that are already built in, and TriboID™ not only automatically detects the various components attached to the system that are necessary for its proper functioning, but it also configures them. The system's automatic positioning device, which is based on optical microscopy techniques, allows users to look over a test specimen and select a location for testing. The system then positions the specimen under the test probe to perform measurements at that specified location. This is undoubtedly an indispensable accessory for handling tiny specimens and performing tests on smaller sub-structures within them. The system is also equipped with real-time control and data analysis software to ensure high accuracy and repeatability. A series of Gold series force sensors (FVL: 1 to 100 mN; FL: 5 to 500 mN; DFM series: 0.05 to 20 N; DFH series: 0.5 to 2 kN) are available for tests. Capacitance and LVDT sensors are used for accurate displacement measurements in micron and millimeter ranges, respectively.

Test Results

Example results of Force-displacements tests that were performed on Bruker's UMT-TriboLab on MEMS lever arms and keyboards in different ranges are presented below.

Force-Displacement Measurements at Low Range on a MEMS Lever Arm

Force-displacement measurements in the mN and micron ranges were performed on a MEMS lever arm with a UMT TriboLab using a Gold series FL sensor and a capacitance sensor, respectively. A 1-mm diameter tungsten carbide ball probe tip was used for the measurement. Figure 1 presents a force-displacement plot of a lever arm specimen within 0 to 5 mN force and 0 to 1 µm displacement ranges, respectively. Although the force range measured was about 1% of the full-scale of the force sensor, the data scatter was minimal. The scatter could be further decreased by using an anti-vibration table and an acoustic enclosure for measurements in such low force range. The force-displacement of the lever arm, as shown in Figure 1, indicates a linear-elastic behavior.

The lever was tested further for its force-displacement characteristics at increased load levels. Figures 2 and 3 depict force-displacements plots up to 50 mN and 400 mN, respectively. Figure 2 suggests a linear-elastic behavior up to 50 mN. Figure 3, however, exhibited an initiation of a non-linear force-displacement behavior after about 250 mN. The stiffness of the specimen was found to be increased beyond 250 mN. The maximum displacement after 400 mN of load was about 82 µm. The results trend presented in Figures 1 to 3 confirms that the TriboLab is capable of performing measurements at low ranges of force and displacements very precisely.

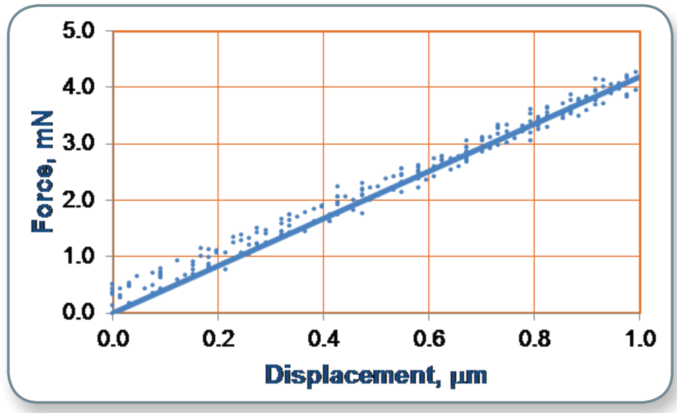

Figure 1. Force-displacement plots up to 5 mN using a Gold series FL sensor and Cap sensor.

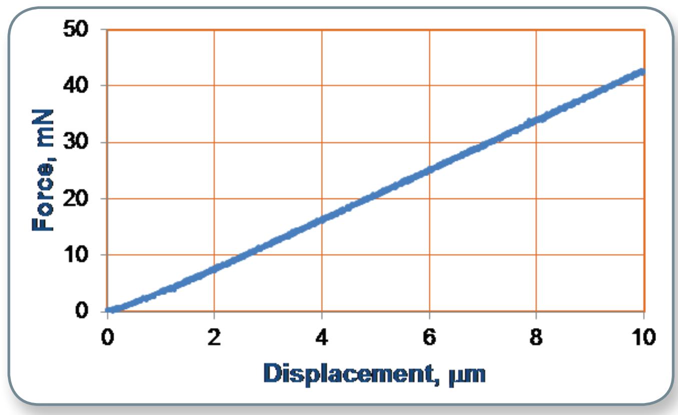

Figure 2. Force-displacement plots up to 50 mN using a Gold series FL sensor and Cap sensor.

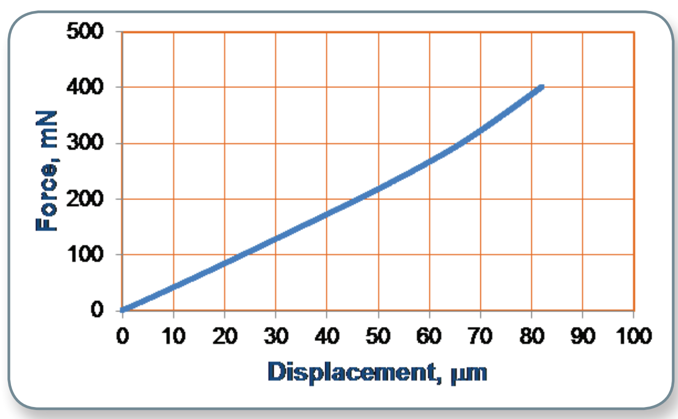

Figure 3. Force-displacement plots up to 400 mN using a Gold series FL sensor and Cap sensor.

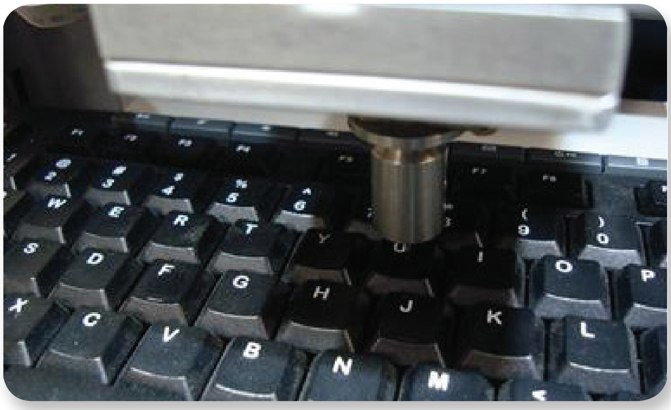

Figure 4. Close-up view of the test setup for force-displacement measurements on a keyboard.

Force-Displacement Measurements on Keyboard Keys

A computer keyboard was installed on the Y-stage of the TriboLab, and a key was pushed progressively down by using the flat surface of a cylindrical probe that was mounted under the force sensor. Force and displacement values were measured using a DFM-0.5 force sensor and an LVDT sensor mounted on the carriage of the TriboLab, respectively. The normally observed displacement range of keyboard keys could also be measured using the Z-encoder data of the TriboLab. A portion of the test setup is shown in Figure 4.

Figure 5 presents a force-displacement plot on a computer keyboard key showing three regions. Initially, the force increased with displacement and attained a maxima, the corresponding force is denoted in Figure 5 as the peak force (F_P). By pressing the key beyond the peak force, the value of force decreased until it hit the minima, although the displacement continued increasing during that period. After attaining the minima, the force started rising again. Such force-displacement characteristics confirmed a buckling of the underlying structure in the key. The force corresponding to the minima in Figure 5 is designated as actuation force (F_A). The slope of the force-displacement curve is very useful[1] in assessing the tactile response of such a keyboard component. F_P and F_A parameters are useful to manufacturers and users since they represent comfort, quality, and durability.

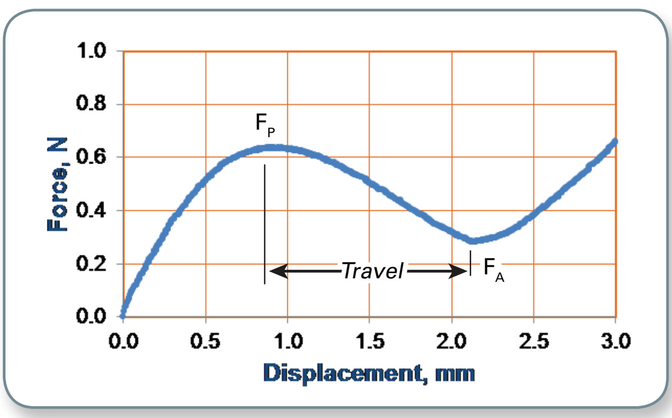

Figure 5. Force-displacement of a keyboard obtained using DFM-0.5 and a LVDT sensor.

Table 1

Variable	Mean	SD	COV,%
Peak force (F_P), N	0.635	0.002	0.36
Actuation force (F_A), N	0.279	0.001	0.48
Travel, mm	1.216	0.015	1.21

Table 1. Repeatability of peak force, actuation force, and travel data for a computer keyboard key.

The distance between the peak force and actuation force in Figure 5 is denoted as the travel. The test was repeated 25 times by using an automated test script on the same keyboard to elicit data repeatability of the F_P, F_A, and travel by obtaining their mean, standard deviation (SD), and the coefficient of variance (COV), as presented in Table I. COV values of F_P, F_A, and travel were really small, confirming that the TriboLab produces repeatable results on the force displacement measurements. F_P, F_A, and travel are considered important design parameters for the proper functioning of the keys with minimal discomfort to a user typing at sufficient speed.

Conclusions

Bruker's TriboLab is an invaluable tool for force-displacement measurements across a wide range of forces and displacements for the manufacturers of MEMS, robots, computing accessories, micro-manipulators, precision and scientific instruments, sensors, and actuators. TriboLab's integrated automated positioning system enables a user to perform test on microscopic substructures of any specimen. It also offers automation for repeatable tests for quality assurance activities.

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Author

Suresh Kuiry, Ph.D., Senior Applications Scientist,
Bruker Nano Surfaces Division (suresh.kuiry@bruker.com)

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Bruker Nano Surfaces Division
San Jose, CA · USA
+1.408.376.4040
productinfo@bruker.com

www.bruker.com/tribology