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Optimized hardness testing: Precise force application and measurement at low forces

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Summary:

In hardness testing, an indenter is pressed into the workpiece with a defined force to determine its hardness. It is important that the force builds up without shocks or vibrations and without overshoots. The ideal test sequence comprises four phases: approach without force contact, continuous application of force, holding the test force and finally withdrawal. The precise implementation of the test force is particularly demanding with small forces and requires sensitive force measuring cells and controls. The time of contact is critical, as too fast approaches can distort the measurement. With small forces, the approach speed must therefore be reduced. Distance sensors are used for optimization. Improvements include sensitive Si strain gauges and a two-stage spring for the indenter.

During hardness testing, an indenter is pressed into the workpiece to be tested with a defined force, the hardness of which is to be determined. The force applied during the penetration process should be free of shocks and vibrations and without overshoot. The idealized force curve during a test can essentially be divided into four phases (see Figure 1).

- Approach: the indenter approaches the test object; there is no force contact
- Application of force: after the force contact, the force is continuously increased so that the specified test force is reached after a specified time
- Stationary holding of the test force: the test force acts for a specified period of time
- Retraction of the indenter: the test force is reduced until there is no longer any force contact and the indenter is removed from the sample

The realization of the test forces, especially in the small and smallest force range, places high demands on the hardness test. There are various options here, using weights that are placed on in a controlled manner, hydraulically or by electric motor. The electric motor implementation of the test forces is widespread nowadays, as it allows very high precision with great flexibility and a wide range of test forces used - an almost mandatory requirement for testing machines. The force is applied in a closed control loop, which requires a force measuring cell to feed back the effective force. The smaller the test forces to be applied, the more delicate the force measuring cell must be, which increases its sensitivity to environmental influences. The aim is to create very rigid and very sensitive measuring cells.

Limits are set by the required penetration tools, which are attached directly to the force transducer. The most critical moment in the application of force is the time at which the indenter tip hits the DUT. If the approach speed is too high, the starting point on the surface of the test object immediately leads to a rapid increase in force, which would impair the entire measurement or render it unusable and for this reason must be checked as quickly as possible. However, the distance between the indenter tip and the test object surface is usually not known with sufficient accuracy in currently available systems, which is why the approach of the indenter must be slower the smaller the desired test force is. Currently available systems usually scan the surface using a tactile system to measure hardness and then detect the distance from the sample surface to the indenter tip using depth or length measurements on the test object. The approach takes a very long time when small test forces between 1 gf and 20 gf are implemented (approach speed in the last 100 µm above the test object approx. 1 µm/s).

In order to achieve a reliable assessment of the expected force contact and the associated increase in force, the approach process must be examined using suitable distance sensors and included in the measurement so that the remaining distance between the indenter and the DUT, where the measurement is particularly slow, can be shortened from 100 µm to around 10 µm and the entire measurement can be accelerated. This not only increases the measurement and movement accuracy, but the distance detection between the indenter and the workpiece surface also optimizes the autofocus.

Some adjustments are made to optimize the process. Highly sensitive Si strain gauges with low temperature sensitivity of the measuring range. A two-stage spring for the indenter and a displacement measuring system for detecting the workpiece surface.

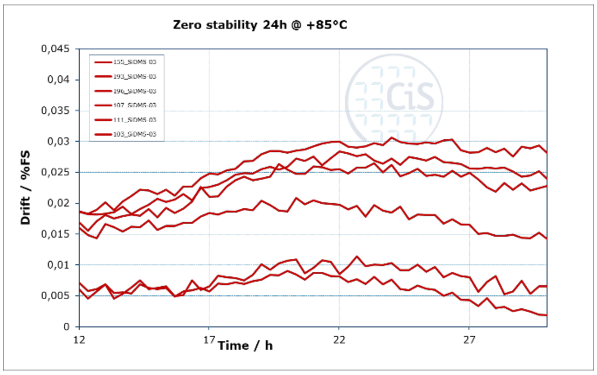

Fig. 1. Zero point stability, drift, at 85°C and 24h in % Full Scale Output (FS)

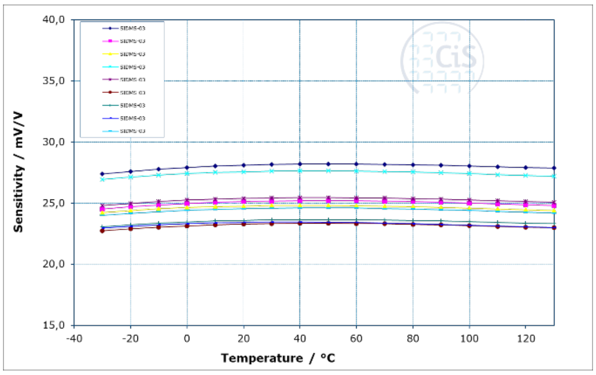

Fig. 2. Temperature dependence of the measuring range or sensitivity

The basis is a two-stage force sensor. This consists of two pairs of parallel springs, which are rotated by 180°, so that the unwanted movement on the side is compensated. In the first section, up to approx. 50 N, or 0.12 mm, only the outer springs work. After this, the inner, stiffer springs are connected in parallel. For this purpose, a drive pin is integrated into the spring. Fig. 1 and 2 show the characteristics of the system, the zero-point stability, 24 hours at 85°C and the temperature dependence of the measuring range.

Due to the very low temperature dependence of the measuring range, compensation of the temperature in the working area is not necessary. Fig. 3 shows the two-stage spring with attached Si-Strain Gauge without PCB. The characteristic curve of the spring is shown in Fig. 4. The distance sensors will be described later.


a)

b) c)

*Fig. 3. a) Assembled Si-Strain Gauge with glass frit, b) Two-stage spring body, 60 mm*30 mm*10 mm, stainless steel 1.4542 c) Focus on the inner parallel spring and the driving pin.*

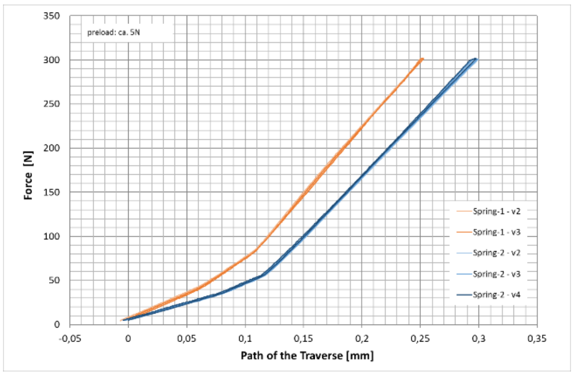

Fig. 4. Characteristic curve of the two-stage spring, blue line: softer inner spring

Literatur

[1] Thomas Frank, Stefan Hermann, André Grün, Danny Hanig, Manuel Kermann, Michael Hintz, Andrea Cyriax, Ralf Röder, Uwe Krieger, "Verwendung von Siliziumdehnungssensoren für makroskopische Prüfkörper", 10. MikroSystemTechnik Kongress 2023, Dresden, 23.-25.10.2023