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Development of a high precision scratcher tester

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Abstract
Scratch test was proposed by Heavens [1] in 1950 as a quantitative method or evaluate the adhesion between thin metallic films and the substrate. The test consists on drawing a spherically tipped diamond indenter across the material surface, considering three strategies: constant normal force with an increase indenter depth until the failure; constant normal force and depth of the indenter; and a constant depth with a floated normal force. The scratch test allows the characterization of surfaces mechanical properties regarding its tribologycal aspects. The friction behavior of a surface with or without thin films or coatings, has a strong dependence on the nature of the mechanical contact. At a sub micrometer level scratch test allows the determination of adhesion, fracture, deformation and friction coefficient of surfaces material or its constituents a. e. hard phases and inclusions. The development of a high precision scratch tester allows the exploration on nature of the mechanical contact on a sub micrometer level. This paper describes the development of a high precision scratch tester, and its positioning and geometrical qualification. The machine consists in a three-axis ring type bridge structure made of natural granite. Aerostatic bearing supports all axis, and the motion were based on ball screws for X and Z-axis, and metallic belt capstan drive for the Y-axis. The positioning accuracy is 1μm for X and Y-axis, and 0.1μm for the Z-axis.

Key words: Scratch tester, motion control, precision position, machine design

1. Introduction

The characterization of surfaces mechanical properties has been growing in importance regarding its tribologycal aspects. Friction behavior and wear resistance of a surface with or without thin films or coatings, has a strong dependence on the nature of the mechanical contact. At a sub micrometer level scratch test allows the determination of the mechanics of adhesion, fracture, deformation and friction of materials or its constituents a. e. hard phases and inclusions. The test consist on generates a controlled scratch with a sharp geometrically defined stylus with a diamond tip on a selected area. Scratch test can be performed using a position controlled or load controlled strategy. The capacity to characterize thin film and coating layers or its substrate make the scratch test a powerful research instrument to investigate a series of tribologycal phenomena's on or in a sub-surface level.

Simplicity and high degree of reproducibility are two of the scratch test characteristics, and one of the reason why it is a well-accepted test. It can be considered as a semi quantitative test since its results can be affected by various extrinsic factors related with the device and intrinsic parameters regarding the material. As factors related to the test device it's possible to list: straightness and geometrical errors during the movements, vibrations, scratch speed and load variation, and structural deformations. For micro and nanoscale scratch tests the sensibility for the relation between load and scratch displacement, and precision of the stylus depth penetration are high concern requirements [2,3,4].

The development of a high precision scratch tester had the objective of allow the investigation of tribologycal phenomena on a nanoscale level.

2. Design process

The design recommendations from Nakazawa [5] were used as a guide line for the project. The design process was also supported by the recommendations from Slocun [6]. The first design consideration was: the point where the load is applied during the scratch is the geometrical point of symmetry for the structure. In order to obtain sub micrometer positioning accuracy one of the main requirements was all the movements must be friction free. Vibrations, noise and thermal sources should be eliminated or minimized in order to reduces the interference on the measurement process. Deformations from fixtures and thermal origins also were eliminated or minimized. Reconfigurability was required in order to allow the device operate as a pin-on-disc and its variation, or a reciprocate tester device. These operations modes cover the main tribologycal tests, with the potential of working in a nanometer level. Figure 1 brings a general view of the device.

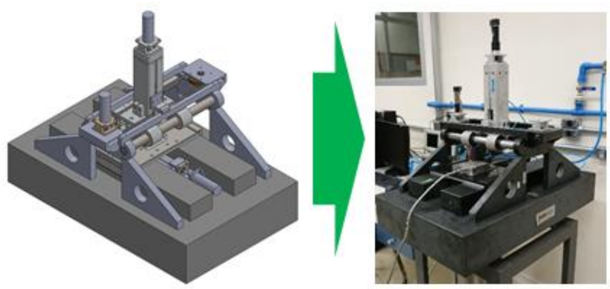


Figure 1. General view of the scratch tester.

The structure was a close loop portal type with of three axes numerically controlled. In order to rationalize the design process, the structure was developed using metrological granite standards. This provides thermal and dynamic stability, and the geometrical and dimensional references necessary for the other systems assembly.

The assembling was done using a 3D coordinate measurement machine to set the dimensional and geometrical references. Precision pins were used as assembly and alignment references, no screws were used. The fixture of the structure was done using high strength adhesive to avoided deformations.

2.1. Motion and control

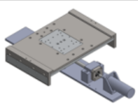
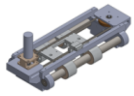
The motion system consists of aerostatic linear guides, DC brushless servomotors, movement transmission/conversion elements, and positioning measurement sensor. The X axis was based on a pair of prismatic aerostatic guides, with aerostatics pads on Z and Y directions. The aerostatic pads in the Y direction were used to restrain the movement. The X axis motion was based on a combination of DC brushless motors / ballscrew.

The Y axis was based on a pair of 30mm cylindrical guides, each one with two aerostatic bearings to support the slide pad. Its motion was provided using a DC brushless motor and metallic belt capstan drive. A Renishaw LM13 linear magnetic encoder system was used for position measurement, and a rotatory optical encoder was used form speed control.

The Z axis structure is assembled at Y pad. The action axis Z is guided by two 30mm cylindrical air bearings, at its end the scratch stylus is assembled. Its motion was done using a CC brushless motor / ballscrew combination. The Z axis control system used a rotatory optical encoder for position and a three axis piezo dynamometer for the force control looping.

The motion control was implemented using an estimation filter for speed and a multi-level controller P-PI [7,8]. The force control uses a Kistler 9256C Multicomponent Dynamometer with maximum load capacity of 250 N. Table 1 presents the main characteristics of motion systems.

Table 1. Characteristics of motion systems.

Axis	X	Y	Z
			
Aerostatic linear guides	Prismatic flat pad, two directions	Cylindrical L/D = 1.5	Cylindrical L/D = 1.5
Flow restrictor type	Inherently compensated	Inherently compensated	Inherently compensated
Load capacity at c/c_0 = 0,8	220N at 5bar, Z direction	150N at 5bar/bearing, 600N total	150N at 5bar/bearing, 300N total
Bearing clearance c_0	20 µm all directions	15 µm (radial)	10µm (radial)
Stiffness	15N/ µm	10 N/µm	20N/µm
Motor	CC brushless motor	CC brushless motor	CC brushless motor
Transmission/conversion	Ball screw	Flat belt capstan drive	Ball screw
Measurement system	Linear magnetic encoder	Linear magnetic encoder	Rotatory encoder
Positioning accuracy	0,5µm	0,5µm	0,05µm
Displacement	250 mm	250 mm	20 mm

3. Qualification and results

The micro scratch tester resembles a machine tool in its constructive form, for this reason the metrological analysis and qualification was based on the directives from ISO 230 [9] series for *Test code for machine tools*. Due to the small displacement Gage Blocks were used as standards for the geometrical qualification, and a Laser interferometer was used for position accuracy and speeds qualifications. Figure 2 show a tray out scratch test done on a polished cast iron blank.

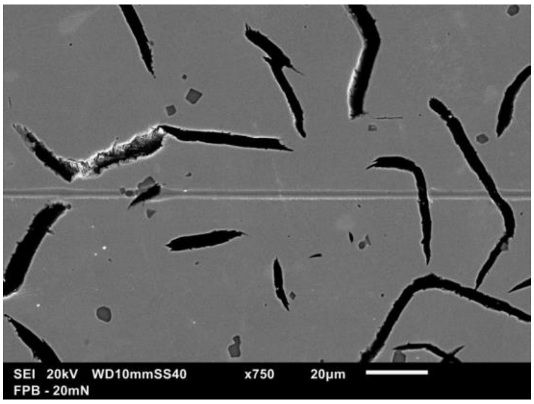


Figure 2. Try-out scratch test on polish cast iron with 20mN of normal force (Fz).

4. Conclusions

The developed high precision scratch tester was able to perform scratch test according to ASTM G171 [10] and ASTM C1624 [11] standards. It can also perform advanced scratch tests with constant and progressive load using X-Y-Z axes simultaneous, and geometrical pattern controlled scratch. It´s can evaluate failure, friction and adhesion of coating and bulk materials. It´s able to perform controlled scratch with deepness up to 0.05µm.

Concerns from ultra-precision machine design allowed the reduction, control or elimination of some of the test device influences over the scratch, generating results with a higher degree of reliability.

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[10] ASTM Standard G171 (03) 2009, Standard Test Method for Scratch Hardness of Materials Using a Diamond Stylus.

[11] ASTM Standard C1624 (05) 2010, Standard Test Method for Adhesion Strength and Mechanical Failure Modes of Ceramic Coatings by Quantitative Single Point Scratch testing