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INTELLIGENT MECHATRONIC COMPLEX SYSTEM FOR TOPOGRAPHIC CHARACTERIZATION OF NANOSTRUCTURED SURFACES

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Topographic characterization of materials is important to determine features of different surfaces that are used in many areas. During the time, these surfaces deteriorate and complex deterioration mechanisms appear. There are techniques with complex mechanisms that allow observing all the surface characteristics. In INCDMTM, a mechatronic system made up of an atomic force microscope and a robotic nanomanipulator is used in order to characterize steel, titanium alloys or CoCr alloys surfaces. It is a proper system to study surfaces of different materials from tribological point of view.

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1. Introduction

Materials characterization is important to determine features of different surfaces that are used in many areas. Many phenomena in materials science require measurements of mechanical properties of a material surface or interfaces of thin films deposited on a surface.

Generally, a surface deteriorates due to the pressures produced by mechanical movements of the systems it is part of. The deterioration process varies from one system to another, in some cases with a complex mechanism. For mechanical and biomechanical systems there are different types of wear mechanisms, such as: abrasive wear, adhesive wear, wear with the third body and wear by fatigue [1].

Abrasive wear [2] represents the removal of material from one surface by the other. Local high points called “asperities” on the surface of the harder material will produce into the softer material wear particles.

Adhesive wear is produced where localized bonding of the two surfaces occurs, such that the attachment force is stronger than the yield strength of the material. A small piece of material is removed from one surface and is attached to the other.

In a physiological environment, metallic, ceramic or polymeric wear particles may be trapped between two moving surfaces, causing three-body wear [3].

Fatigue wear can lead to subsurface cracks propagating and flaking off of particles from the surface. High subsurface stresses can also be caused by third bodies between the two articulating surfaces leading to accelerated fatigue wear.

Wear processes occurring inside different systems are an important source of wear particles, but these changes are often impossible to see with the naked eye. A methodology of ascending degrees of resolution was established using macroscopic (resolution millimeters), microscopic (resolution microns) and nanoscale (resolution nanometers) measurements. There are

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also techniques with complex mechanisms that allow to obtain, for example, tribological parameters and to observe all the surface characteristics. Tribological parameters help to this type of characterization, mainly for worn surfaces.

2. Techniques for topographic characterization of materials surfaces

During the years different methods of investigation were used to establish the surface's topography and any evidence of changes to their topography.

Characterization of worn surfaces and determination of its tribological parameters can be achieved by various experimental techniques. Some of these are non-contact surface measurements using atomic force microscope, confocal microscope, scanning interferometer or laser.

Measurement systems for 3-D surface topography may be characterized by the physical principle used in the surface-sensor interaction. Profilometric 3-D instruments may be either contacting or noncontacting. The former, use a stylus to trace the contours of a surface and are limited by the geometry of the stylus. It may be unable to register narrow or deep grooves within surface topography.

The WYKO NT 2000 (WYKO NT 2000 Veeco, Tucson, AZ) interferometer is a noncontacting optical instrument that uses the interference patterns of light reflected by a surface to measure surface topography. The accuracy of this method is limited only by the wavelength of the light used for assessment [5].

3-D Interference Microscopy, another important technique for the measurement of surface topography, provides quantitative information at a nanometer scale, surface mapping and parametric analysis.

X-ray photoelectronspectroscopy analysis is another method used for topographic characterization of coated surfaces. It was employed to analyze the chemical composition and structure of electrochemically passive film formed by a composite.

The composition and microstructure of the nano-SiO_2 particles reinforced Ni-based composite alloying layer were analyzed by using XRD (X-ray diffraction), TEM (Transmission Electron Microscopy) and SEM (Scanning Electron Microscopy). Using TEM, nanoparticles can be observed with difficulty because of insufficient contrast for their size, which has to be smaller than the thickness of the thin section investigated (typically about 60 nm).

Different techniques based on scanning probe microscopy (SPM) were developed to study elastic and inelastic properties of surfaces, interfaces or inhomogeneous materials phases at micrometer and nanometer scales. Scanning acoustic microscopy (SAM) is used to study the materials properties at micrometer scale. To study the local mechanical properties of materials have been recently used methods based on scanning force microscopy (SFM).

Atomic force microscopy is a popular method for these types of studies.

3. Mechatronic systems used for characterization of materials surfaces

In INCDMTM, characterizations and determinations of tribological parameters for different materials surfaces are realized. For example, is determined surfaces roughness of some femoral heads from hip prostheses realized by steel, CoCrMo, steel coated with TiN; polycrystalline diamond compact surfaces COMPAX 1321; steel – component material of different mechanical parts.

Using roughness analysis it is possible to determine some parameters in order to characterize the surface. Besides minimal, maximal and average height of it, is possible to find out some important parameters:

- Ten point height (S_z) that expresses surface roughness by the selected five maximal heights and hollows, nm
- Surface skewness (S_{sk}) characterizes the non-symmetry of distribution. If the asymmetry is different from zero the distribution is non-symmetrical. The asymmetry equals to zero for the symmetrical distribution.

- Coefficient of kurtosis (S_{ka}) characterizes the distribution spread.

For these measurements we are using an atomic force microscope (Microscope Probe NTEGRA) working in the noncontact mode and a roughness tester Talysurf PGI.

Working principle of AFM is to measure the interaction force between tip and sample surface using special measuring heads, made of a cantilever with a pointed end. AFM images are processed using Nova SPM software.

The samples are positioned on the base unit of AFM using a robotic nanomanipulator that has more degrees of freedom including rotation for control of orientation and thus, can be used to manipulate 0D objects (spherically symmetric) to 3D objects in space.

A Hexapod positioning system for Micro-Movement, F-206 is used in this experiment [4]. 6-axis positioning system F-206 consists of an attachment position system and a control unit. A keyboard and a monitor for the control unit (either included or connected as a peripheral device) may be used to control F-206 system directly or, typically, the control unit can be controlled by a PC. System's mechanics uses a parallel - cinematic positioning system. The system provides 6 degrees of freedom and a minimal increase of movement of 0.1 µm. Workspace boundaries are not parallel to the axes, but it cannot overcome a rectangular solid which is given by the limits of movement X, Y and Z. The control unit is equipped with integrated software to define a pivot point anywhere inside or outside workspace of F-206 system. Rotation around this pivot point may be ordered for any combination of the 3 rotation axes. Digital command system processes complex positioning and elements of movement, including scanning procedures and alignments using optical or analogue response signals from more than 2 meters.

All orders for positioning "F-206 platform" are given in orthogonal coordinates and converted by command system in F-206 specific actuator positions and speeds before making the action.

The connection between NTEGRA Atomic Force Microscope and the Hexapod positioning system for Micro-Movement F-206 is done with a gripper that allows nanopositioning of samples used. A scheme of the obtained complex system used to characterize and analyze the studied surfaces is presented in the Fig. 1.

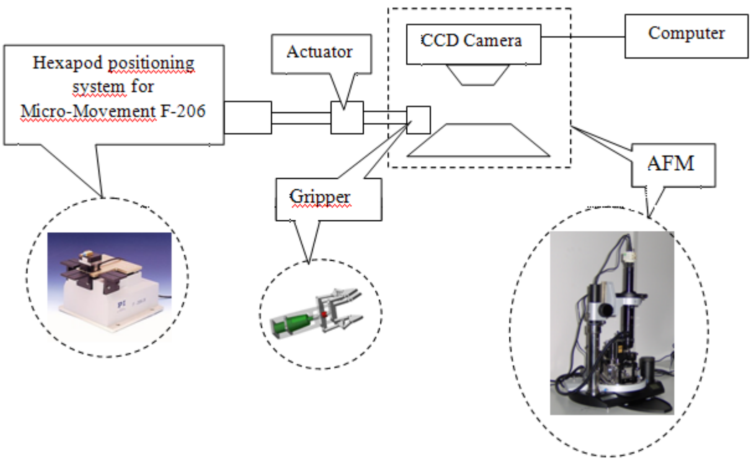
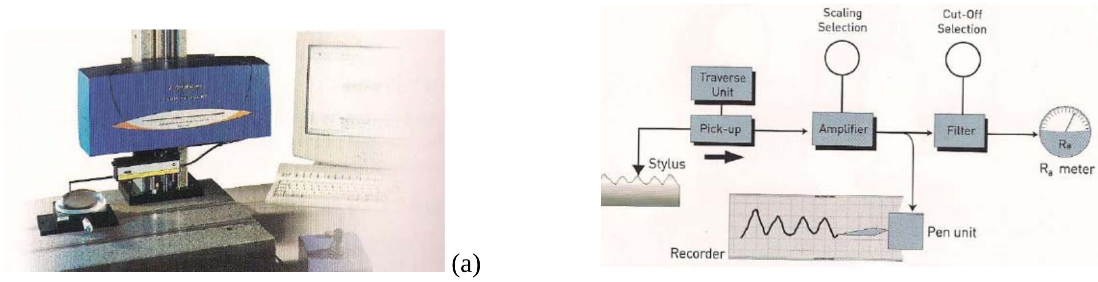


Fig. 1. Complex mechatronic system made up of NTEGRA Atomic Force Microscope and F-206 alignment and positioning system with six axes

In INCDMTM, Talysurf PGI Instrument roughness tester is also used to determine tribological parameters (Fig. 2a). The main components of such a device are shown schematically in Fig. 2b. The stylus is moved on the surface and its transducer converts its vertical movements into an electrical signal which is amplified and used to operate a recorder. From this filtered signal was derived R_a value that is presented on an indicator.

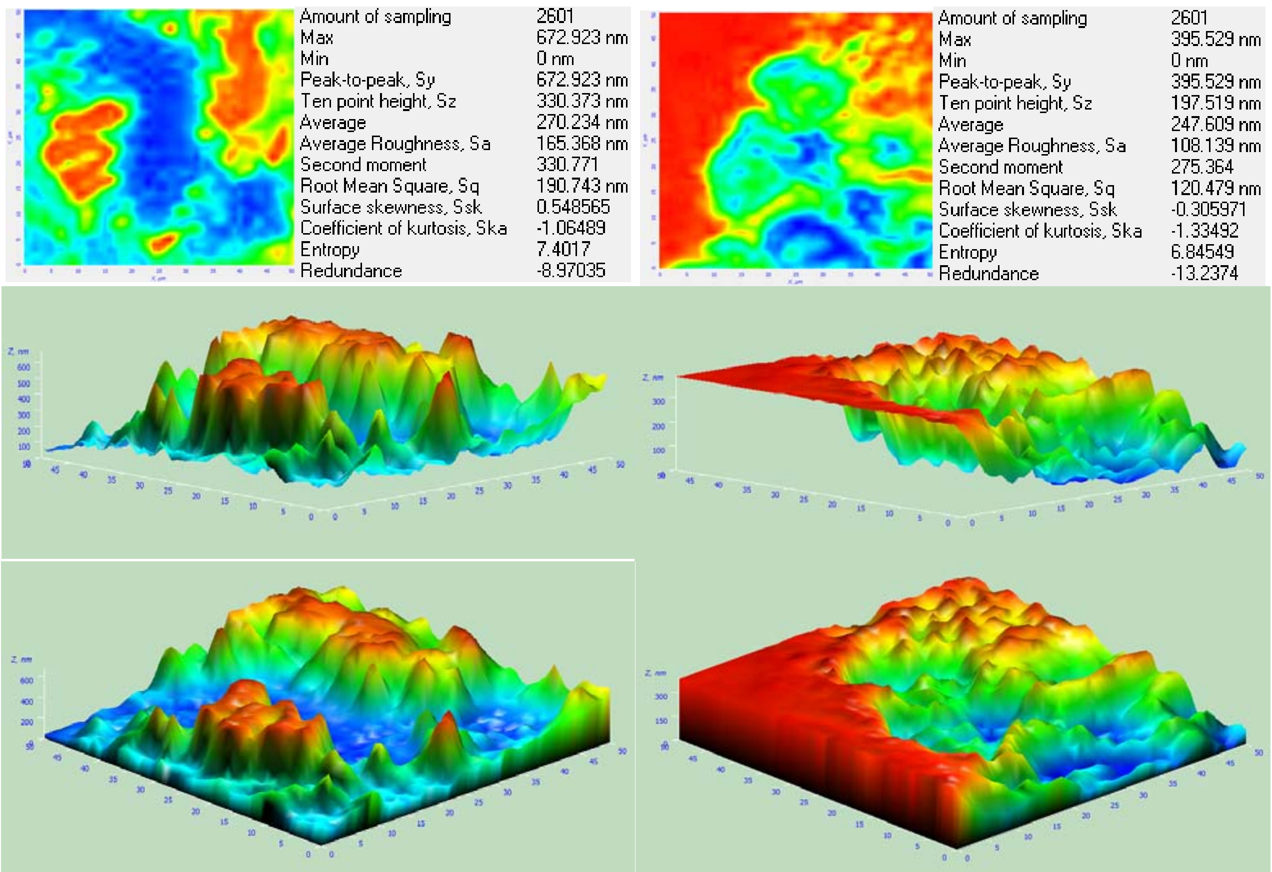


(a) (b)

Fig. 2. Talysurf PGI (a) and components diagram of a measuring system of a surface texture

3. Results obtained using complex mechatronic system for topographic characterization of surfaces

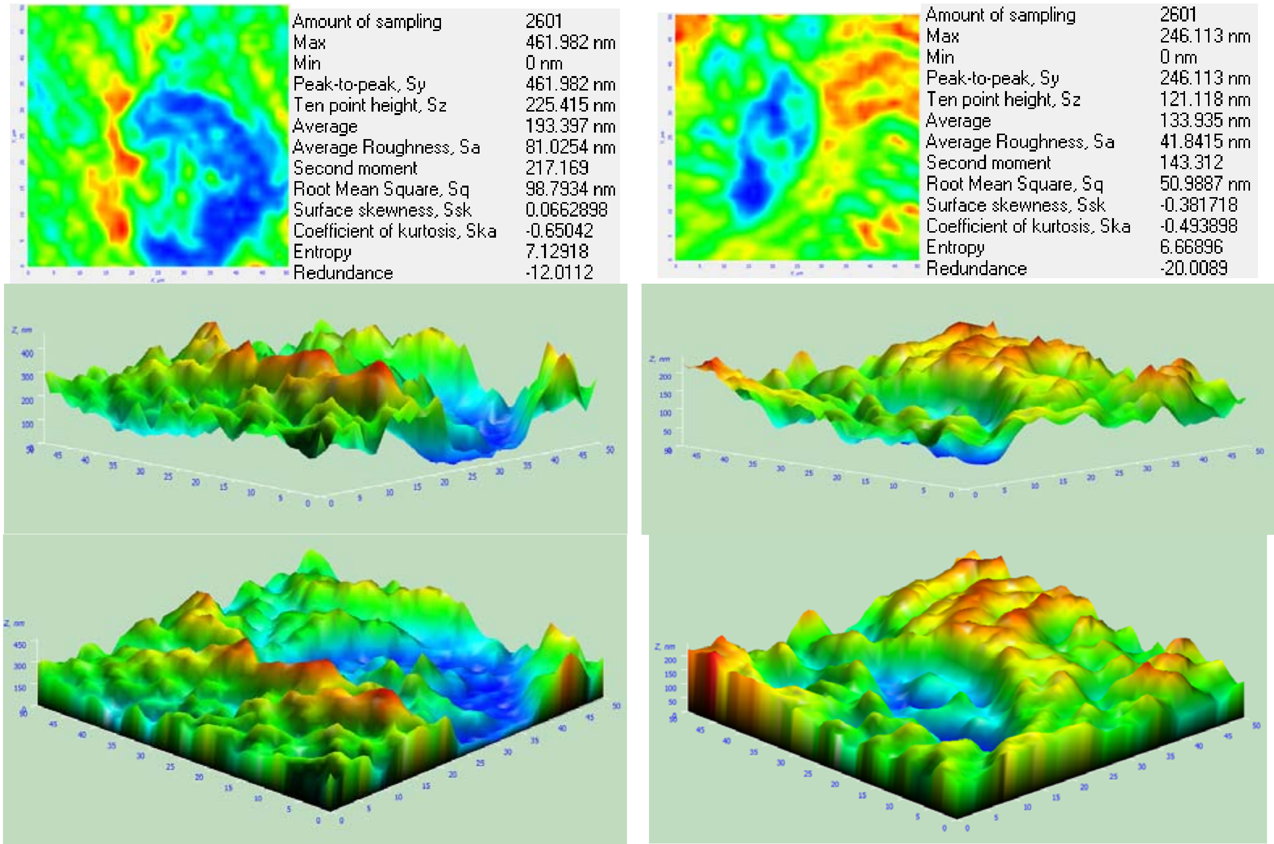
In INCDMTM were carried out characterizations and tribological parameters determinations of surfaces of the femoral heads from hip prostheses made of: CoCrMo (Fig. 3), TiN (Fig. 4), Ti6Al4V (Fig. 5).



a b

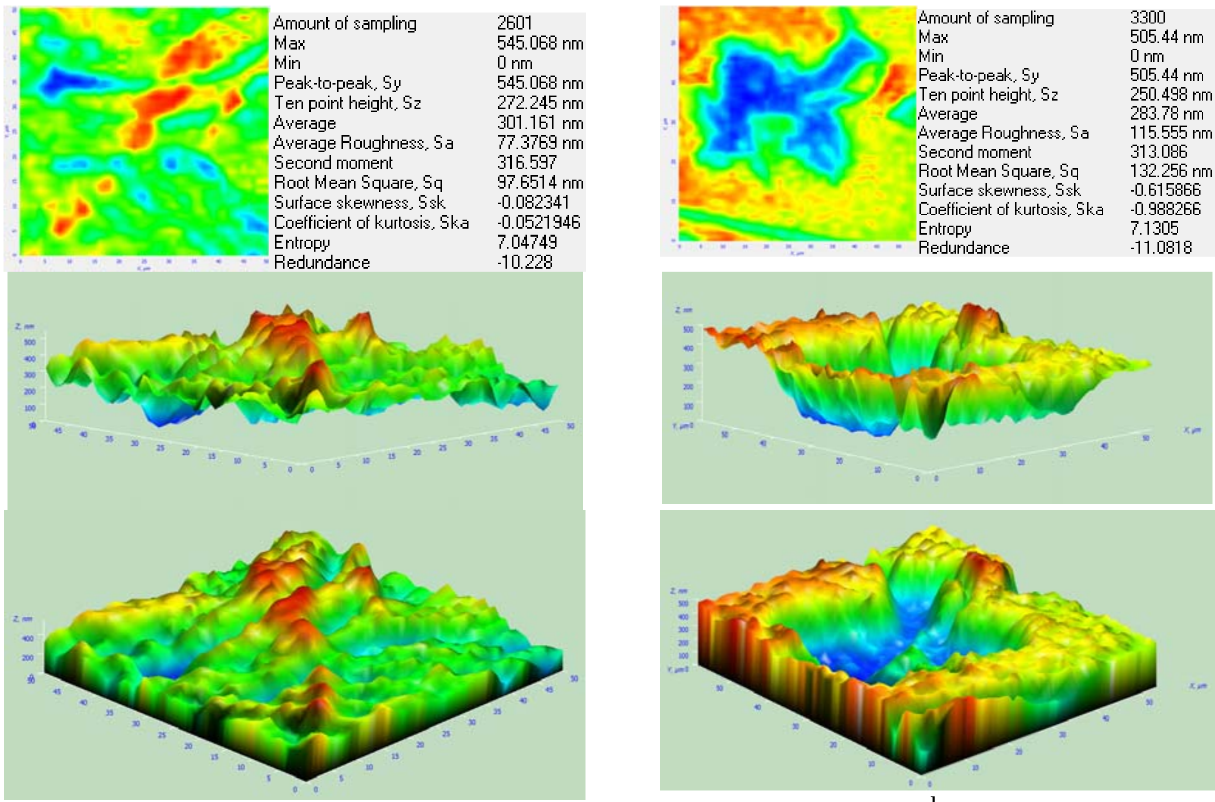
Fig. 3. Characterizations and tribological determinations of CoCrMo surfaces using complex mechatronic system, on NTEGRA atomic force microscope

As it is shown in the examples presented, roughness has different values (in different parts of the same femoral head) depending on the movements of the body that uses the prostheses.



a b

Fig. 4. Characterizations and tribological determinations of TiN surfaces using complex mechatronic system, on NTEGRA atomic force microscope



a b

Fig. 5. Characterizations and tribological determinations of Ti6Al4V surfaces using complex mechatronic system, on NTEGRA atomic force microscope

After a few experimental results it was observed that roughness is lower for TiN. From this observation, an important conclusion is that this material can be used for femoral heads for a longer period of time compared with the other two materials.

Besides the hip prostheses surfaces, were also characterized polycrystalline compact diamond COMPAX 1321 (material that can be used as an active part of a lathe tool for processing metallic/non-metallic materials) surfaces. Tribological parameters obtained can be seen in Fig. 6, together with the 3D image of the worn surfaces.

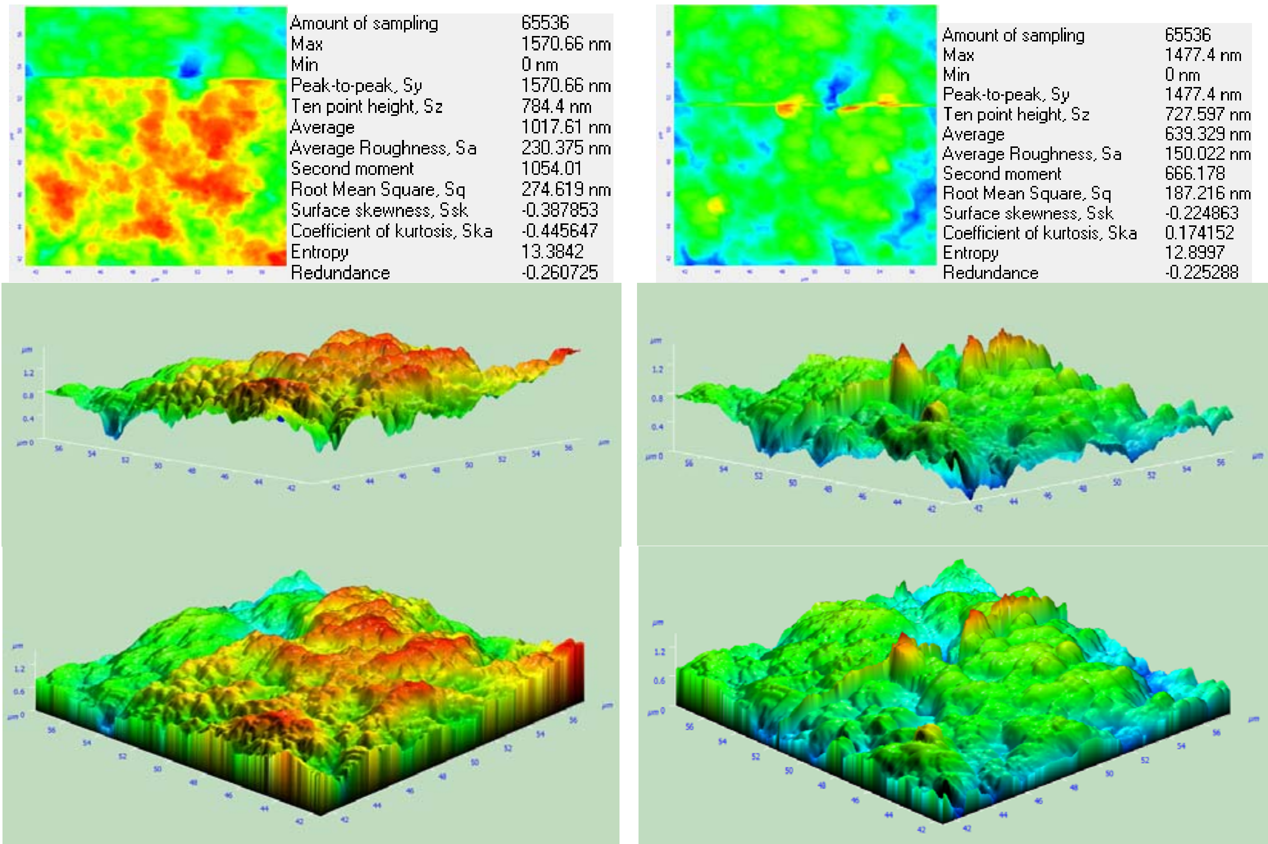


Fig. 6. Characterizations and tribological determinations of polycrystalline compact diamond COMPAX 1321 surfaces using complex mechatronic system, on NTEGRA atomic force microscope

Some results of roughness measurements of steel parts made with the Talysurf PGI roughness tester are shown in Fig. 7.

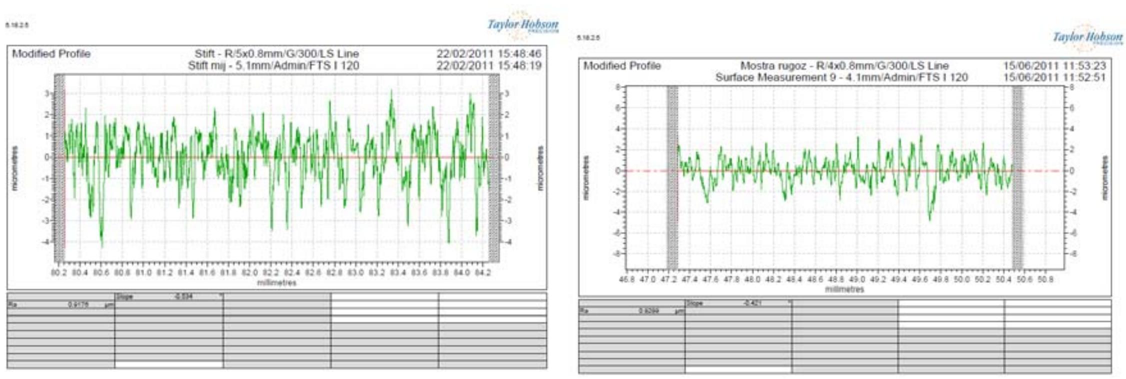


Fig. 7. Surfaces roughness measured by Talysurf PGI roughness tester.

4. Conclusions

In order to obtain a clear micromechanical characterization of realized parts surfaces or the coatings from the femoral head of a hip prostheses the study of its topography and roughness determination are useful. Such a study can be made by different techniques and different systems, but we decided on AFM because its images display high quality and dense nanocrystalline structure of prepared thin films. NTEGRA Probe Atomic Force Microscope has been connected with a Hexapod positioning system for Micro-Movement F-206 in order to obtain a complex positioning of the sample, followed by surface characterization and determination of few tribological parameters. Taylor PGI roughness tester used is an adopted system that can determine the exact roughness values of different materials surfaces (in this case, steel).

Taking into account all these studies we shall continue the research using these systems, which can improve the surfaces topography characterization to obtain implants, prostheses, active parts of the processing tools, etc., with optimal quality and in accordance with international standards.

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