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50. Internationales Wissenschaftliches Kolloquium
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T. Tiankov / D. Chakarov / Muhammed Al Wahab / K. Kostadinov

Design of Mechatronic System for Measurement of Electrochemical Impedance

ABSTRACT

THE SUBJECT OF THIS PAPER IS A MODELLING OF A SCANNING system for investigation the surface quality in micro or nano range by using electrochemical impedance technique. Because of the necessity of high dynamic scanning modulus, linear piezo ceramic elements with high resolution and high dynamics are used, allowing application of the scanning system for investigation of granular structures. A virtual modulus is developed on Solid Dynamics 2004+ and a suitable scanning motion of the measured electrode is simulated. Finally the graphs of effective forces and the motion trajectories of piezo elements and end effector are obtained.

INTRODUCTION

THE INVESTIGATION OF THE SURFACE QUALITY BY MEASURING THE by measuring the electrochemical impedance is widely used in domain of corosion, battery testing, biological and photoelectric effects [1-3]. It is possible to measure effects such as corrosion rate, or battery life, by direct analytical methods, for example weight loss measurements or solution analysis by spectroscopy; but, because the processes are slow, these methods are time consuming and inefficient.

The used approach is electrochemical and the analysis is made using electrical methods. The advantages of this approach are a relatively short measuring time, high accuracy and the possibility of monitoring the process continuously. Naturally there are also disadvantages, the major of these being that the system under investigation has to be perturbed from its normal state by an external signal, which inevitably changes the properties of the system. The perturbation itself can be due to an AC or DC signal. AC methods are finding increasing applications in electrochemical research, because only small perturbation signals (which do not disturb the electrode properties) need to be used and low conductivity media can be investigated.

Known electrochemical impedance-scanning systems are presented by Princton Applied Research – USA. The developed scanning device LEIS270 [4] is composed of three step motors with 1000 step per rotation, scanning range in X, Y, Z axes is 70x70x20 mm, resolution - 1µm, frequency range - 10 µHz – 50 kHz. The system positions the electrode on the investigated surface and measures the resulting current. A scanning reference electrode approach is used that enables the measurement of the local current near corrosion surfaces in seewater.

Other achievement in domain of EIS is SVP100 SRET scanning system [5]. A technique with vibrating scanning electrode is used that measures electric field generated above the surface of an electrochemically active sample. A piezo-ceramic displacement device allowing vibration amplitudes from 1-60 µm controls the probe vibration (perpendicular to the sample surface). It is an AC technique; thus, high system sensitivity can be achieved via a differential electrometer in conjunction with a lock-in amplifier.

The aim of this paper is a development of a scanning mechatronic modulus for investigation of granular surfaces. The obtained virtual modulus is simulated into an interactif environment and the forces and motions of used piezoelements are presented graphically. The simulation results are necessary for creation of final physical prototype.

PROBLEM STATEMENT

The known electrochemical scanning approaches don't allow surface scanning in submicron range because the measurement is made at static mode and the resolution of the scanning systems is very high.

The approach, discussed at this paper, allows local scanning motion of the measured electrode on the investigated surface in micro and nano range. Inconvenience at this approach is the calibration of the scanning system because of the maximal range of the piezo elements (8µm).

The other problem is the high dynamics of the chemical reactions that prevents the achievement of the system stability for a long time [4].

The linearization of the hysteresis of the used piezo elements also is a problem that has to be resolved.

MECHATRONIC SYSTEM FOR LOCAL SURFACE SCANNING

The investigations are made into an electrochemical cell that is composed of three electrodes, immersed in electrolyte. Between two of the static electrodes is created an electric field while a small sinusoidal voltage perturbation is applied from a PC. The investigated surface is placed on the one of the static electrodes. The used scanning electrode is from wolfram. It's connected to a potentiostat that control the voltage between the static electrodes and measures the local current that flows into the electrolyte. A convenient mechatronic system is developed (fig. 1) that enables scanning motion of the Wolfram electrode. This system is composed from three degrees of freedom necessary for one translation in Z direction for fine probe positioning and two scanning motions among the X, Y directions of the surface of measurement.

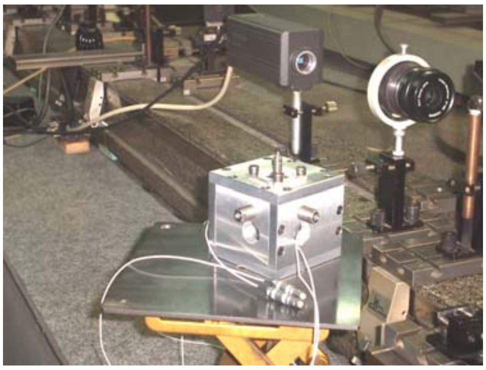

Fig. 1. Photo of the developed local scanning system for investigation of surfaces by measurement of electrochemical impedance

Kinematic scheme is shown on figure 2. The stick with wolfram electrode is mounted on Z-axis and piezo actuators are respectively on axes X, Y, Z. The sick is connected with joint p_3 (type Point-line) that has one translation on Z and two rotations on X, Y. Each piezo actuator is modelled with one prismatic joint p_5. Piezo actuators are connected to the based stick with spherical joints p_3 and to the fixed base with spherical joints p_4. The stress mechanism exists at the opposite part of the X, Y axes. It's composed of a lever with disk springs parallel situated to him. Each lever is fixed to the based stick with spherical joint P3 and to the base with joint p_3 (type Point-line). The stress mechanisms reduce backlash in nanometer range.

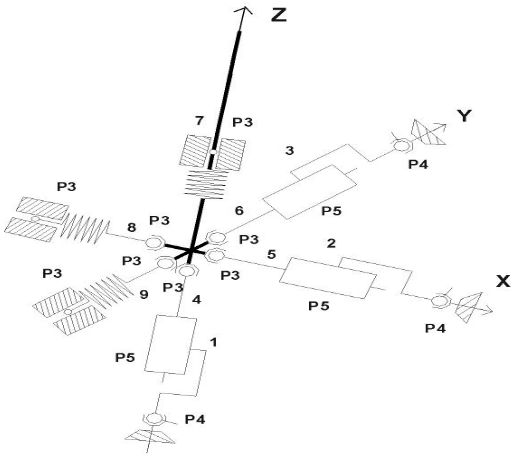

Fig. 2. Kinematic scheme of system for local electrochemical impedance scanning of surfaces

The degrees of freedom (DOF) of the system are presented by the following equation:

$$(h = 6 \times n - 5 \times p_5 - 4 \times p_4 - 3 \times p_3)$$

Where n – number of mobile links and p_3, p_4, p_5 – number of different joints
The system presented on the figure 2 with n=9; p_3=8; p_4=3; p_5=3 has h=3 DOF. The joint p_3 in the link 7 between a stick and fixed base is an elastic plate (Fig. 3). It realizes joint motions and stress of the piezo actuator on Z-axes. The stiffness of the plate is defined with simulation software Ansys that measures axial stress of the plate versus displacement and presents graphically the obtained results. Figure 4 shows the thickness (1mm) and the stiffness (110.558N/mm) of the plate.

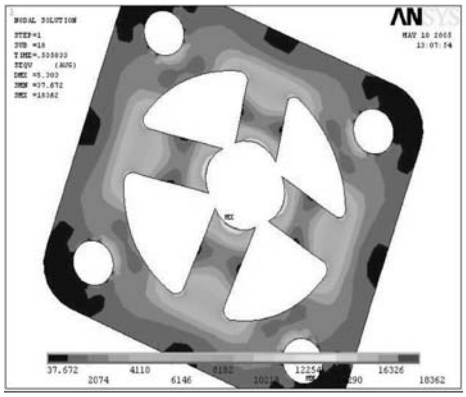

Fig.3. Type of the elastic plate and corresponding axial measurements

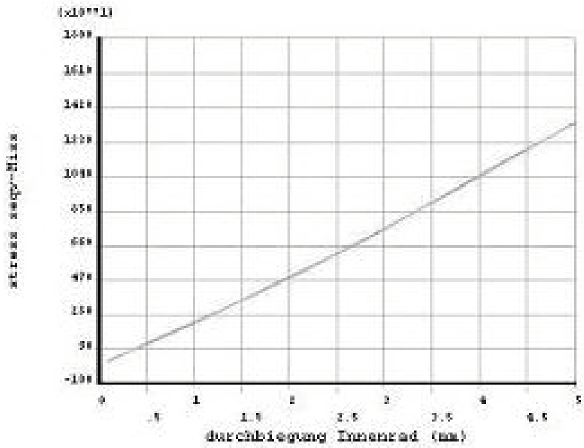

Fig. 4. Presentation of the measured stress forces versus displacement of the plate, obtained with ANSYS software

The piezo ceramic elements (series 8/12) [7] from the company Piezojena – Germany are the modulus realizing the scanning motion of the developed system. They are with maximal range 8µm and resolution open loop 0.01 nm. These features allow local scanning of surfaces in nano range. The PA series of actuators are internally pre-loaded by a mechanical spring, making them ideal for dynamic applications. The ability to generate a large force and be subjected to High Mass loading make them particularly useful for machine tools and dynamic scanning systems. The motion of actuators is made with a three-channel high voltage card (NV C1 PC –10V till 150V) from Piezosystem Jena – Germany. In its dimensions this is a normal PC-card with full length. It needs an 8-bit slot of an IBM compatible computer. Three channels can be directed by software program. With an output noise of 3mV it is excellent suited for positioning in the sub-micron and nanometer range. A high stability of the output voltage makes the PC-card NV C1 ideally suited for positioning problems with highest precision. The resolution of 14 bit makes it possible to operate in the nm-range. A microscope Zeiss Jena and connected digital camera Hitachi F110 are used for reading the position and orientation of the scanning element. Joystick and keyboard is used for development of a telemanipulated system. The joystick is connected to PC into the game port. The relation between all system modulus is made by suitable software developed on C++ Builder. On this way the mechatronic system is more comfortable and easier to use from humans.

MODELLING ANS SIMULATION WITH SOLID DYNAMICS 2004+

Solid Dynamics 2004+ combines the physical motion simulation technology and 3D modelling, visualization and data translation capabilities available in one product. The work with speed, acceleration and reliability in Solid Dynamics are comfortable and comprehensive to use. With Solid Dynamics 2004+, designers and engineers can use the comprehensive 3D modelling capabilities to design their mechanical assemblies or easily import geometry files from other CAD packages. Kinematic and Dynamic Simulations can then be performed to optimize the mechanical motion of the assembly in a virtual environment before. Solid Dynamics 2004+ will help you design better products faster and at lower cost. Solid Dynamics 2004+ has the following features: 3D full body contact, input graphics, comprehensive joint library, relative kinematical functions, interactive physical motion. Full 3D animations of the motion are displayed with the option of adding trajectory traces and vector representation of the imposed and resulting forces, torques, moments, velocities and accelerations. The display also updates interactively as variables are adjusted (making it straightforward to define initial conditions), and also as results are analysed. A scanning modulus is developed (Fig. 5) that is composed of basic, motion and adjustment circuits.

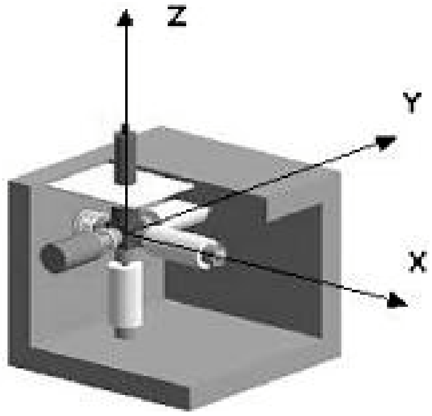

Fig. 5. Structural scheme of mechatronic system for local surface scanning

The basic circuit (fig. 6) is composed of a leading element (1) and stick (4) with a length of 10cm. At the end of the stick is mounted a wolfram measured electrode. The modelling with Solid Dynamics is made using simple figures like cube, sphere, cylinder, pyramid, cone, spline trajectories and references. The elements are oriented about the base frame reference using Euler coordinates or Denavit-Hartenberg coordinates. The connection between the leading element and the corps of the system is made with an elastic plate that is modeled by Point – Line (PL1) joint with 4 DOF (three rotations and one translation on Z direction). The frame reference XYZ is a base and the frame reference X1Y1Z1 is relative. The rotation around axe Z1 of the joint PL1 is locked because this motion isn't available in reality. The translation along axe Z allows introduction of stress coefficient (2mm) and elastic stiffness (110.558N/mm).

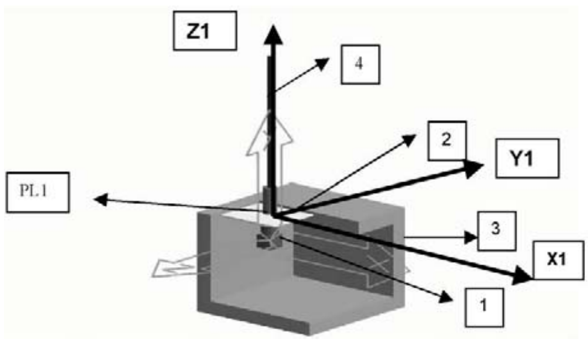

Fig. 6. Base circuit modelled in Solid Dynamics

The motion circuit is composed ot three piezoelements on X, Y, Z axes. Figure 7 presents a part of this circuit (on axe X), that is composed of one piezo element (1). The connection of this piezo modulus with the based circuit and the main body is made using spherical joints S2 and S3. The rotations around axes Z2 ≡ Z4 are locked. The translation of the piezo element 1 is modelled using prizmatic motion (p^1) with a frame reference X3Y3Z3. An appropriate motion low and stiffness (120N/μm) are set. The same operation is made for the other piezo components.

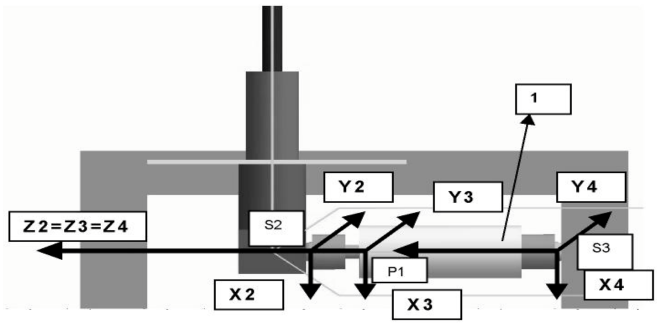

Fig. 7. Motion circuit modelled in Solid Dynamics

The regulated circuit is composed of two disk springs and a leading element. Figure 8 presents a part of the regulated circuit, that contains one disk spring (1), stressed until 3mm and with stiffness 22N/mm. The connection between

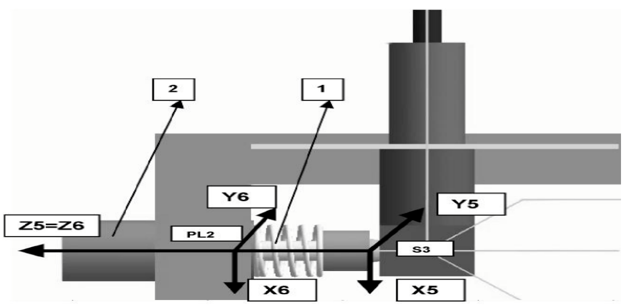

Fig. 8. Regulated circuit modelled in Solid Dynamics

the leading element and the main body is made using a spherical joint (S3) and Point-Line joint (PL2) that translation of the disk sping along Z axe and rotation around X, Y, Z axes. The same manipulation is made for the other spring. The regulated circuit is used for reduction of the scanning system backlashes. After the modelling of all subcircuits they are connected each other in exact order and finally they form a closed loop. Figure 9 presents a part of the cloosed loop containing the system body, based, motion and regular circuits. The closed loop scanning system is simulated setting desired motion laws of piezo actuators, stress coeficients and suitable stiffnesses. The motion trajectory of the scanning electrode, defined from the appropriate laws is shown on the Figure 10.

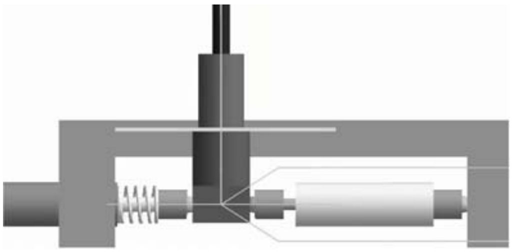

Fig. 9. Part of Closed loop modelled in Solid Dynamics.

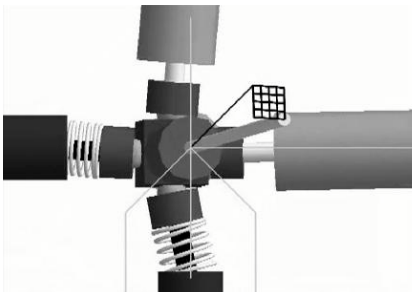

Fig. 10. Motion trajectory of the measuring electrode

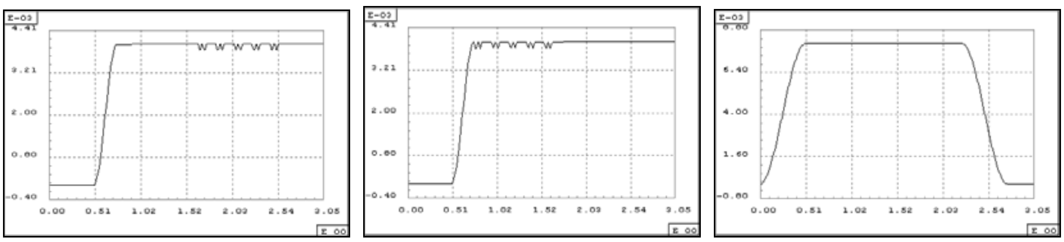

Fig. 11. Prismatic motion of piezoactuators on X, Y, Z axes

It presents a grille with dimensions 9x9nm and a step between each scanning line equal to 3nm. On this way it's possible to realize local scanning in nano range. Figure 11 presents the motion lows of the prismatic joints versus time. The piezo actuators on X, Y-axes make five contiguous couples of sinusoidal oscillations with amplitude 9nm and appropriate frequency. On Fig. 12 is presented graphically the trajectory of endeffector on X, Y, Z axes. A reference is modelled that is placed on the top of the endeffector for investigation of the motion of the wolfram electrode. The graphs show that the motion on Z axis saves its value of 8 μm but the motion on X, Y axes arises until 20μm and wave oscillations are 45nm. This change is a result of the stick length. The stress of the disk springs with 3mm, the elastic plate with 2mm, setting its stiffness equal to 22N/mm and 110N/mm change the forces of piezoactuators (fig. 13). At the the resulting forces reduce on X, Y axes. Then the force on X, Y axes became 60N/mm because piezo actuators move with 4μm amplitude. The forces remain almost constants during the scanning motion and finally they arise its values because of the return of the piezoelement on Z-axis at home position. The force on Z axis becomes 220N/mm.

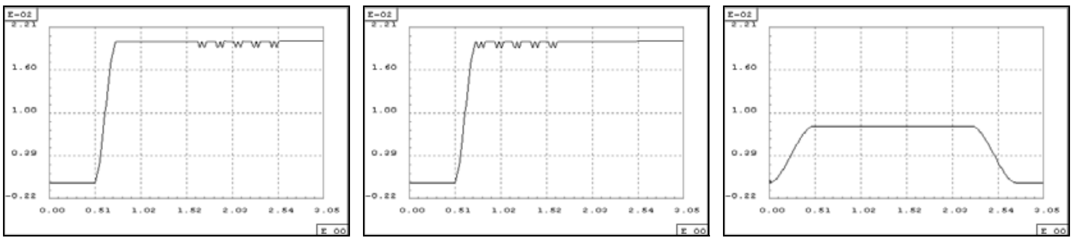

Fig. 12. Resulting motion of endeffector on Z, X, Y axes

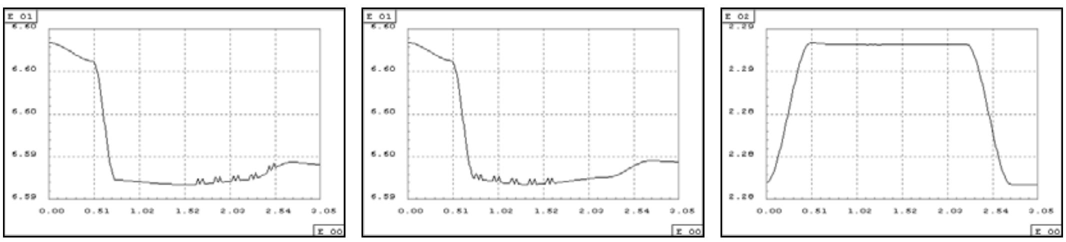

Fig. 13. Resulting forces on Z, X, Y axes

CONCLUSION

System for local electrochemical surface scanning is modelled in Solid Dynamics 2004+. The use of linear piezo elements with high dynamics allows scanning motion in micro nano range. The realization of preliminary system simulations allows more rapid and exact creation of the scanning modulus and makes comparative evaluation between the simulation and real measurements. The motion trajectory of the measured electrode is visualised that allows the application of the system for investigation of granular structures

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Authors:

PhD student Tihomir Tiankov
Assoc. Prof Dr.-Eng Dimitar Chakarov
Dr.Eng. Muhammed Al Wahab
Assoc. Prof. Dr.Eng. K. Kostadinov
Institute of Mechanics – Bulgarian Academy of Sciences
Acad. G. Bonchev STR,
BG-1113, Sofia
Phone: +35928706264
Fax: +35928707498
E-mail: tihomir@imbm.bas.bg