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Experimental Set-Up for Complex Investigation of Stack Piezo-Actuators

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Abstract: *In this article the design of an experimental set-up for investigation of the static force and displacement characteristics of piezo-actuators are described, as the maximal provided force, the dependence of the hysteresis effect and transfer function on the applied preload force, capability of holding a position under dynamic force action and other functional parameters. With the realized set-up the creep effect and temperature dependence of different types of stack piezo-actuators can also be investigated.*

Due to the specific purpose, the experimental set-up is designed for investigation of stack piezo-actuators only. The introduction gives an overview of piezo-actuators application, their advantages and disadvantages. In the experimental part the graphical diagrams of creep and hysteresis effect dependence on the applied preload force are shown.

Keywords: *piezo-electrical actuators, preloaded actuators, staked actuators, creep.*

I. Introduction

Nowadays in new high-tech industrial branch as micro-manufacturing and microelectronics and even in the field of microbiology, microsurgery and genetic engineering, most of the technological processes are automated by robot systems for micro-nano manipulation [1]. For each task of the production process or manipulation of micro products and objects, there are requirements for extremely high accuracy of positioning. With such work conditions, it is obvious that these requirements become mandatory also for robotized systems for micro-nano manipulation. They have to ensure high positioning accuracy, of the order of few nanometers. Because of this reason, the design of micro-nano manipulators has a special focus on system actuation. The most applicable elements for actuation in these systems are piezo-electrical actuators. This is due to their multiple advantages, especially, high dynamics, high accuracy, high stiffness and fast response. On the other hand, their bigger driving force, lack of internal friction on displacement, independence on magnetic or electrical fields, also lack of generation of such, make them unique in the actuation of micro and nano manipulators. On the background of all their advantages, they have three significant disadvantages – large temperature dependence, presence of creep and hysteresis effect. The last one is most unwanted and causes very complicated behavior of their transfer function and a lot of problems in positioning control [2]

Micro-nano manipulators are unique custom ordered systems, with specific requirements for each one, but in spite of this, they inevitably use parts that are in serial production and one of them are the piezo-actuators. As it was mentioned above, the requirements for positioning are extremely high, so the task for selection of a proper piezo-actuator, according to specific customer's limitations, is one of the most important design phases. In the process of selection it is necessary to take into consideration a lot of parameters and characteristics of the piezo-actuators with sufficient precision, to satisfy a specific functional task [3]. As far as piezo-actuators are serial products, in some cases when provided by a manufacturing company, the technical parameters are not well defined or they are presented as a range – a min and max value, and the designers of micro-nano manipulators have to perform their own experiments and measurements in order to check the real parameter value, to select actuators with completely identical parameters, test its behavior under dynamic force action, determine the influence of hysteresis phenomena, creep, temperature dependency and many others not provided by the company producer measurements.

The main purpose of this paper is to present the development of an automated experimental set-up for complex investigation of the force and displacement characteristics of stacked piezo-actuators, which will support the designers in these additional experiments and will automate most of them. Three different types of piezo-actuators are known – bimorph, stacked and piezostructured [4]. The experimental set-up presented here is designed for for one of them – stacked piezo-actuators.

Another implementation of the experimental set-up, as a stand for calibration and test of the proper functionality of stacked piezo-actuators, after a long period of exploitation as actuation elements in existing micro-nano manipulators, is also described.

II. Specific functional tasks and reqirements towards the experimental set-up for piezo-actuators investigation

II.1. Specific requirements towards the mechanical part of the experimental set-up

First, it is necessary to clarify that the design will be constrained only for static parameters investigation. The general static parameters of the stack piezo-actuators are: max displacement, resolution, blocking force, stiffness and applied preload force – relevant to the mechanical part of the set-up and max-min operating voltage, over voltage, resonant frequency and capacitance – relevant to the electronic part [5]. Undoubtedly each one of these parameters is important for accuracy of positioning and there is also a large variety of functional dependence between each of them, in some cases even with a third parameter. From this point of view the basic requirement for set-up is to be able to measure each one of the general static parameters of piezo-actuators. So the mechanical part of the set-up must possess sensors for measurement of force and displacement, of course with as higher as possible resolution. On Fig. 1 the mechanical construction of the experimental set-up is shown. It consists of a solid metal fundament – 6, where a piezo-actuator – 1, and sensors are mounted. For displacement measurement a capacitive sensor is chosen – 2, due to its simplicity of signal processing, linearity and fast response. The resolution of the sensor is 0.2 nm [14]. Position 7 is the target plate for capacitive measurement, which is mounted on the piezo-zctuator. For initial alignment of the sensor and target plate a mechanical micro meter is used – 5. The force sensor is a T-shaped console – 3 with an integrated metal-layered tenso-resistor – 4, calibrated for measurement of forces up to 1000 N, with resolution of 0.1 N. Another requirement towards the mechanical construction is to cancel the influence from vibrational disturbances. For this purpose the capacitive sensor and piezo-actuator are mounted as close as possible one to another.

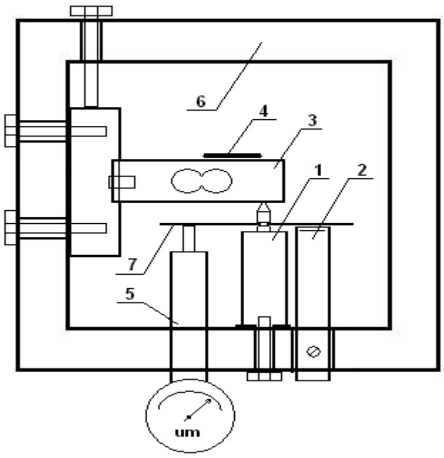

Fig. 1. Mechanical construction of the experimental set-up

II.2. Specific requirements towards the electrical part and the user interface of the experimental set-up

A basic requirement for the electrical part of a set-up is to measure and process signals from different types of sensors and to generate control voltage for the piezo-actuator, with a sufficiently small and tunable by the user step. As far as the capacitive sensors are provided calibrated and with an electronic block for signal conditioning, the tenzo-resistor has to be temperature compensated, integrated in a measurement bridge and the signal has to be amplified and formed by an instrumental amplifier, for disturbance protection. An additional requirement is the proper and convenient display of the obtained experimental results, and the user friendly interface for work in a set-up, allowing an easy and simple way for tuning, reconfiguring and automating the process of measurement.

With already defined functionality, the sensor types for measurement of the actuator parameters, accuracy and requirements for user interface, it is possible to proceed to synthesis of the set-up block structure. Fig. 2 shows a completed block diagram of the experimental set-up for investigation of the static force characteristics of the stacked piezo-actuators.

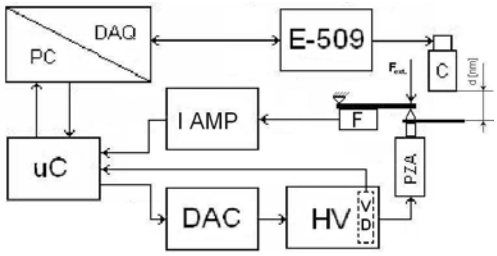

Fig. 2. A block diagram of experimental set-up

III. Experimental set-up for complex piezo-actuators investigation – functional working

The realization of a set-up (Fig. 2) consists of generating high voltage, up to 1500 V supplied by the High Voltage module (HV), through which the PieZo-Actuator (PZA) is driven. The high voltage is adjustable via a variable step, set by the user, in accordance with the required accuracy. It is important for the HV module to have strictly linear output characteristics in order to prevent the multiplication of a nonlinearity error in the output experimental data. A HV module from “Matsusada Precision” company is selected, type S3-1.5PL, its scheme and output characteristics been shown on Fig. 3 [13]. The displacement of the PZA is detected by a Capacitive sensor (C), the signal from which is processed by the module E-509, a specialized module of “Physik Instrumente” for signal processing of capacitive sensors [14]. The generated force, also applied to the actuator, is measured by a strain gauge sensor (F), a metal-layer tenso-resistor, mounted on a T-shaped console.

The signal from the sensor is amplified and formed by an instrumental amplifier – module IAMP made by ”Texas Instruments”– integral circuit IA 928 [12].

The linearity of the metal tenso-resistor, in difference from the semiconductor ones, ensures proportionality between its output signal and the measured force. The amplified and formed by IAMP signal respectively is also proportional to the applied force. The guaranteed proportionality of the measured force and the output signal ensure easy calibrating and achieving resolution of the order of 0.01 N. The measuring of the realized displacement and generated/applied force from the PZA, allows the designers to obtain a variety of the functional relation of the actuator displacement and generated force, with different input parameters [6].

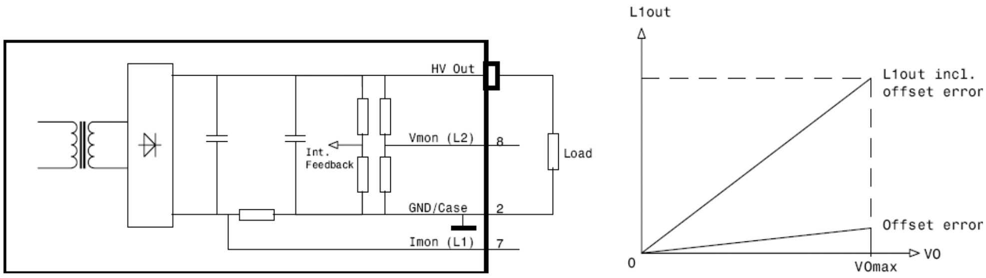

Fig. 3. Schematic diagram of the HV module S3-1.5PL

The high volt module is driven by analog input voltage in the range from 0 V up to 2.5 V provided by the Digital to Analog Converter (DAC). For the purpose it is preferable to take a product of MAXIM company – 12 bit, temperature compensated DAC unit, based on MAX 5581 integral circuit [15]. With a 12 bit DAC, 4096 steps of output voltage can be obtained, or a minimal step of 0.25 V, which is completely sufficient for realizing of enough small displacement, ten times above the highest requirements of micro-nano manipulators.

The microcontroller module – µC, is a basic component of the electrical part of the set-up. The usage of an external microcontroller is required for in order to prevent the influence of “Windows” operating system and to ensure real time work of the set-up. The module is responsible for the control of DAC, by SPI protocol, as a result of which control voltage is applied to PZA with different waveform and parameters, defined by the user. By two10 bits analog to digital converters – ADC is measured the analog voltage from the instrumental amplifier IAMP and also the output high voltage, by a precise Voltage Divider (VD), integrated in HV module. The microcontroller used is Atmega 128 [10], its block structure is shown on Fig. 4. The module is designed with additional functions, in order to be able to cover the future requirements for extension functionality of the set-up that are: a pattern generator, work with a LCD display and communication by I^2C, W2TAB and CAN/LIN interfaces. For flexibility of the connection with a PC, it has USB, RS232 and Bluetooth interfaces.

In the design of the set-up special attention is paid to displaying and processing of the experimental results and to the user interface. With the purpose to cover requirements for flexibility, easy reconfiguring and automated process of data collecting, a standard personal computer will be used – module PC/DAQ, with installed LabVIEW – a specialized software platform for graphical programming [9].

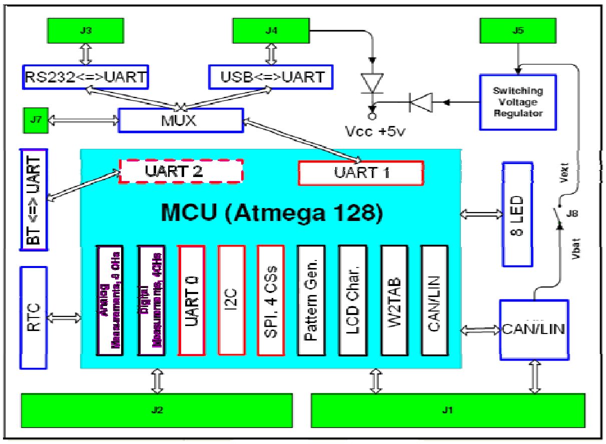

Fig. 4. The block diagram of a µC module

The module collects data from the µC and E-509 modules, by DAQ (Digital AcQuisition), processing and visualizing it. Fig. 5 shows the main control panel of the set-up with indicators for voltage control and applied external force.

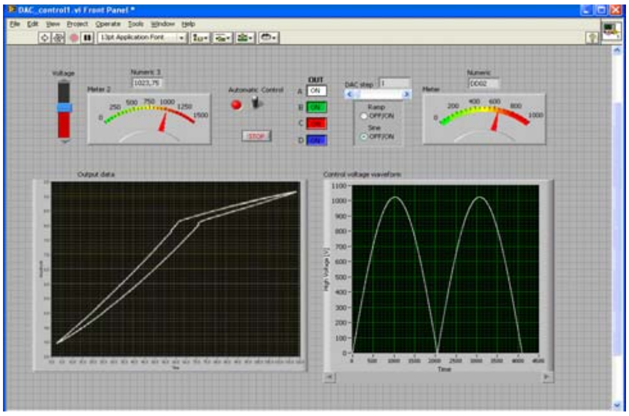

Fig. 5. Graphical user Interface

There is also graphical visualization of the control voltage waveform and output results. The change of parameters, reconfiguring, automated execution of previously defined consequences of actions, can be easy done by change of the graphically represented software code of LabVIEW application, even from non SW engineers.

IV. Experimental rezults obtained by the set-up

In the process of work with a realized set-up, a stack piezo-actuator type P-150-00, product of “Piezosysteme Jena”, from PA series, is investigated [11]. On Fig. 6 the creep effect and the main hysteresis cycle obtained by the developed experimental set-up are shown.

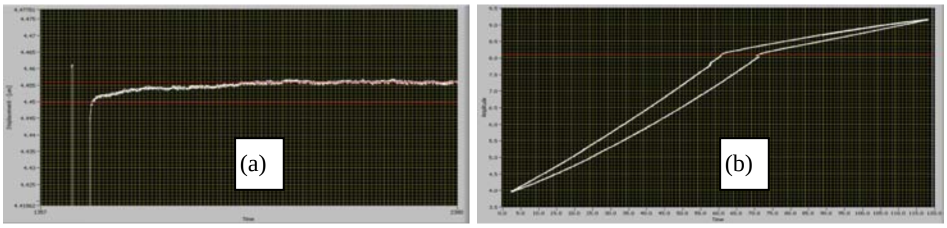

Fig. 6. Creep – (a) and main hystresis cycle – (b)

The achieved resolution is 0.5 nm and it can be seen that the displacement cost of the creep effect is 6 nm for a time interval of 15 min (Fig. 6a). The investigation of the displacement and the hysteresis effect influence from the applied external force is shown on Fig. 6b. From the visual graphic the changing of the coefficient of piezo-electricity can be traced and evaluated when external force of 10 N is applied, at position of 8.1 µm and build its functional dependence on the applied force [7].

From the data in Fig. 6b, other important parameters for positioning control can be calculated – the percent of nonlinearity, the cost of hysteresis, for all ranges of displacement. The collected data allows to evaluate the reducing of this nonlinearity by increasing of the applied preload force and in this way to make proper engineering compromise between them, according to the specific project requirements [8].

On the picture shown on Fig. 7 the process of work with a set-up is shown. On the left side the electrical part is indicated – the HV module, uC and power supply. On the right side – the mechanical part with PZA and sensors and module E-509, for capacitive sensor signal processing.

Because of the sufficiently small distance between the PZA and the capacitive sensor, and the solid metal plate on which they are mounted, the influence of the vibrational disturbances is reduced to 0.2 nm – resolution of the sensor. The bigger disturbances are canceled due to their synchronous rise in the PZA and capacitive sensor, so usage of vibroisolated platform is not necessary.

Fig. 7. View of the experimental set-up in the process of work

V. Conclusions and future work

The paper describes the design and functionality of an experimental set-up for investigation of the force and displacement characteristics of stack piezo-actuators. The aim of the set-up realized is to support the designers of manipulation systems for micro-nano operations in the process of selection of the proper actuation element. Another additional implementation of the set-up is as a stand for calibration and test of the proper functionality of stacked piezo-actuators after a long period of exploitation as actuation elements in existing micro-nano manipulating systems. With the experimental set-up the efficiently of the algorithms for motion and trace control of stacked piezo-actuators can be tested and evaluated.

In future the aims defined are to investigate the new tendencies for design of force self sensing actuators, which use the dependence between the applied force and the current through the piezo-actuator and between the capacitance and the applied force.

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Экспериментальная установка для комплексного исследования стека пьезо-актуаторов

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(Р е з ю м е)

В работе обсуждается проектирование экспериментальной установки для исследования статической силы и характеристик перемещения пьезо-актуаторов, как например максимальной силы, зависимости эффекта гистерезиса и передаточной функции от силы преднагрузки, способность удерживать заданное положение при воздействий динамических сил, а тоже и других функциональных параметров. При помощи полученной установки можно тоже исследовать и крип-эффект, а также и температурную зависимость разных видов пьезо-актуаторов.

Ввиду специфической цели, экспериментальная установка создана только для стека пьезо-актуаторов. Во введении обсуждается применение пьезо-актуаторов, их преимущества и недостатки. В описании эксперимента показаны граффические диаграммы крипа и эффекта гистерезиса, а также и зависимость гистерезиса от силы преднагрузки.