EXPERIMENTAL SETUP FOR STATIC CHARACTERIZATION OF STACK-TYPE PIEZOELECTRIC ACTUATORS

Emil-Ionut Nita[1], Edgar Moraru[1], Coanda Philip[1], Mircea Udrea[2]*
[1]*University Politehnica of Bucharest, Department of Mechatronics and Precision Mechanics, Bucharest, Romania*
[2]*Apel Laser S.R.L, Bucharest, Romania*
*Email: *nitaemilionut@yahoo.com*

Abstract – The paper presents the hysteresis problem of high precision piezoelectric actuators used in an open loop control system. In order to observe the actuators behavior when a well-defined input signal is applied, but also the negative influence of the appearance hysteresis in the form of minor loops and major loops, it was proposed to develop an automatic test and characterization setup. Acquisition systems and software packages from National Instruments as well as laboratory instrumentation were used. Finally, the paper deals with the results obtained from the tests from the perspective of the user interface but also the measured physical phenomenon.

Keywords: Piezoelectric, Actuators, Hysteresis, Testing.

1. Introduction

Theoretically, any material capable of converting one type of signal into another type of signal, of the same or different physical nature, can be considered an active material, usable as an actuating or sensory material. Any material whose properties vary in relation to an external parameter can also be used as sensory material. In current applications there are many examples of materials that can be considered sensory or actuating materials [1-4]. In the realization of active composite materials, the optimum is represented using materials that can have both a sensory and an actuating role [5]. The current trend is to obtain active composites based on piezoelectric [6] or electrostrictive materials [7], magnetostrictive [8], shape memory alloys [9], chemically controlled polymer gels [10], electroreological liquids [11], optical fibers [12] and other intelligent materials. Among these mentioned materials, the most widespread at present are composite materials based on the piezoelectric phenomenon. The widespread use of piezoelectric ceramic materials, which are difficult to manufacture and process, has required a multilayer structure [13]. For lightweight structures, the current trend is to use polymers with a piezoelectric effect, the current example being materials called PVDF (polyvinylidene fluoride) [14]. These intelligent materials are based on the phenomenon of generating electric dipoles in certain anisotropic crystals when subjected to mechanical stress. In the same materials there is also a reverse piezoelectric effect which consists in the appearance of dimensional changes associated with mechanical stresses under the influence of an electric field [15]. Over time, the study of these piezoelectric actuators has aroused great interest among researchers, because there are many applications of these materials in various important fields. Mohith et al [16] presents the use of these actuators in applications where high precision is required, but also analyses the perspectives for further development of actuators based on piezoelectric effect. Wang et al [17] discuss piezoelectric actuators that are used in applications that require large working strokes and characterize five main modes of use of piezoelectric materials in terms of operating principle: monolayer, multilayer or stack type, amplified actuating devices, stepping and ultrasonically actuated. Sabarianand et al [18] investigated various solutions to compensate for some important problems (hysteresis, creep), which may occur in the operation of piezoelectric actuators and thus may significantly affect the efficiency and characteristics of the systems in which they are used. The study of the characteristics and finding the solutions for the improvement of piezoelectric actuators is very important, because these actuating devices are used in applications of great importance. Among the main emerging uses in recent years are piezoelectric pumps with applications in medicine and engineering [19], nano positioning systems [20], MEMS and MOEMS systems [21, 22], applications with harsh operation conditions [23] or regenerative medicine [24].

Given the above, in this paper the authors will develop an experimental stand for raising the characteristics of multilayer piezoelectric actuators. The paper studies the behavior of a piezoelectric stack type actuator when applying an electrical voltage. The presence of hysteresis curves over time and the presentation of the resulting major and minor loops will be monitored. The specifications of the experimental stand and its constituent elements, as well as the main characteristics of the piezoelectric actuator used is detailed in Chapter 2.

2. Materials and Methods

Figure 1 shows the operating principle of the stand developed for the experimental research for this paper. It consists of the following main elements: PC, multifunction I/O device, piezoelectric actuator and piezoelectric driver-amplifier, inductive displacement transducer and universal measuring instrument with digital display.

Multifunction I/O device NI-USB 6218 was used for data acquisition. This device can process high performance multifunctional data (DAQ) for USB and is optimized for superior accuracy at fast sampling frequencies. It features a structured or fast-designed NI-PGIA 2 amplifier with designed or fast stabilization times at high scan frequencies, ensuring 16-bit accuracy even when measuring all available channels at full speed. All these devices have at least 16 analog inputs, 24 digital I/O lines, seven programmable input intervals, analog and digital trigger, and two counters / timers [25].

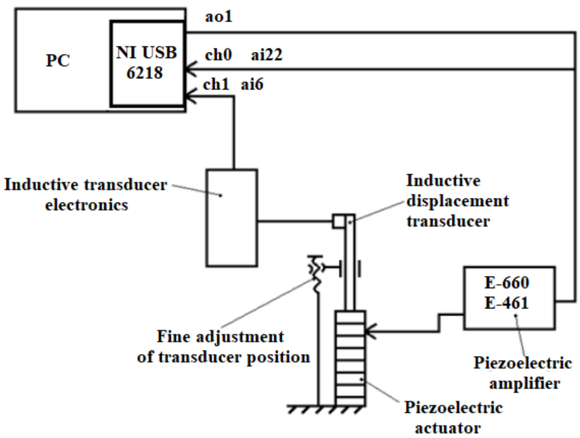


Figure 1: Schematics of the experimental stand for testing piezoelectric actuators

The P842.20 piezoelectric actuator (Figure 2) was used for testing purposes. These types of actuators find applications in the field of nanotechnology, accurate positioning (static and dynamic) or laser adjustments. The major advantage of these devices is that they have protection against moisture and damage associated with increased leakage current due to ceramic insulation, resulting in a lifespan of more than 10 times than the classic polymer insulated actuators.

The main technical features of the piezoelectric actuator used in experiments [26]:

- Displacement range at 0 to 100 V: 30 μm with a tolerance in range of ±20%
- Resolution: 0,3 nm (only amplifier noise and measurement method can affect this parameter)
- Operation temperature: from -40°C to 80°C
- Push/pull force: max. 800N/300N
- Length: 55 mm
- Mass: 42 g
- Electrical capacitance: 3 μF with a tolerance of ± 20%
- Unloaded resonant frequency: 14 kHz with a tolerance of ±20%

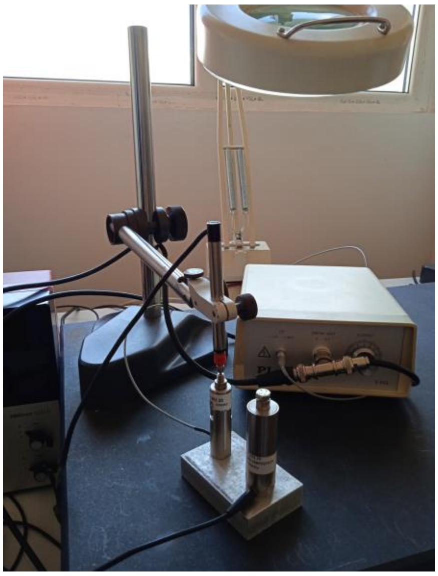


Figure 2: Testing of piezoelectric actuator

The E-660 piezo driver with the following features was used for amplification [26]: input voltage – 0-11 V, output voltage – 5-110 V, max output power – 2 W, average output power – 1 W, average current – 20 mA, voltage gain 10±0,1, input impedance – 100 kΩ, operating temperature – 5-50°C. The Mahr P200M inductive model was used as the displacement transducer [27].

3. Simulation Program

The LabVIEW program was used as a simulation software [25]. The DAQmx Create Virtual Channel block allows the selection of two analog input channels (ai6, ai22), which can receive values between -10 and 10V.

The DAQmx Timing block configures the number of samples, and the number of samples and the frequency of acquisition can be selected in the control panel. These blocks are part of the initialization part, shown in Figure 3.

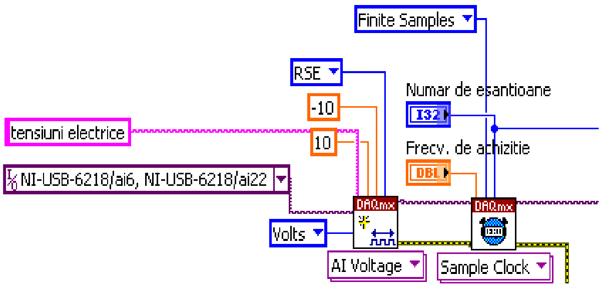
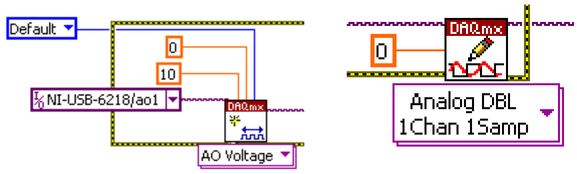


Figure 3: Initialization part of the program

The next step is to use a DAQmx Virtual Channel block to select an analog output channel (ao1) with values between 0 and 10V. This step is the configuration part and is shown in Figure 4a.



a **b**

Figure 4: a – Configuration part of the program; b – Signal generation

To generate a 0V signal applied to the actuator, the DAQmx Write block is used, which does this at the start of the application, only once, shown in figure 4b.

The inductive transducer cannot always be manually set to position 0, so when starting the application, a reading of the already existing signal on the two input channels is performed and each reading is mediated separately, obtaining a reference value (Figure 5), which will be used in the WHILE loop.

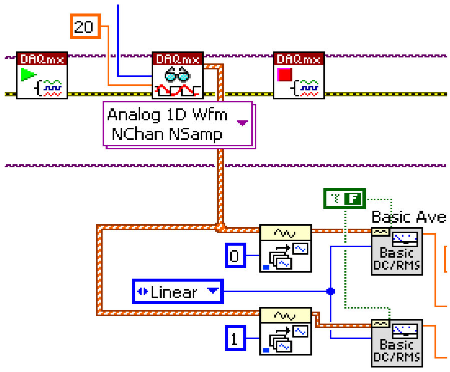


Figure 5: Obtaining a reference value

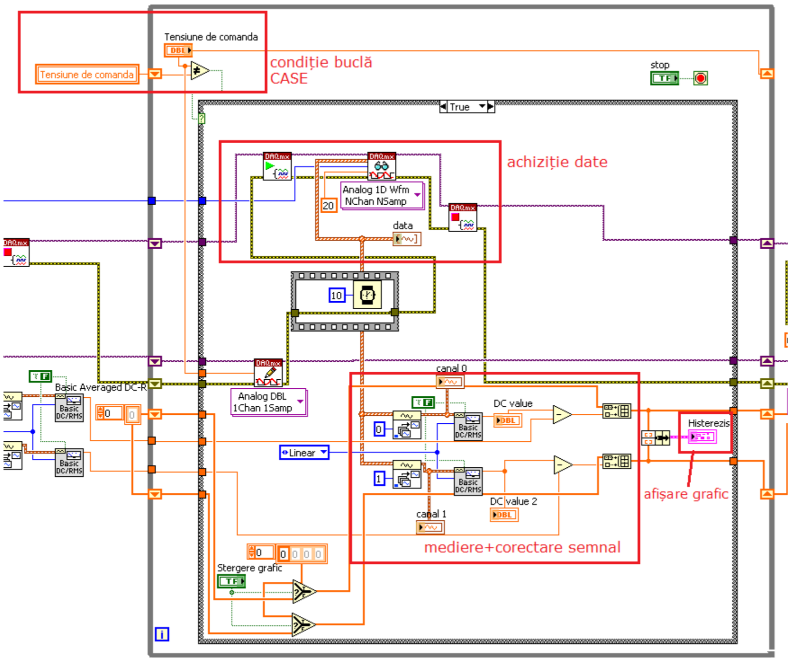


Figure 6: WHILE and CASE loops

If the STOP button is not pressed, the WHILE loop runs. Within this loop there is a CASE type structure, which, if the current control voltage is the same as the previous one, does not generate or read any signal. If the current control voltage differs from the previous one, the voltage value will be written to the output channel, then wait 10ms. After 10ms the data is acquired from the two input channels, each signal is mediated, and the value of the reference voltage is subtracted from the value obtained (Figure 6).

This dataset is displayed on an XY chart.

To resume measurements, the program allows the values to be reset. When the STOP button is pressed, the WHILE loop closes, a voltage signal 0 is sent to the actuator, and then the acquisition and generation channels are closed, respectively.

After that, a .csv file is created in which the acquisitioned data is saved and processed in a spreadsheet program (Figure 7).

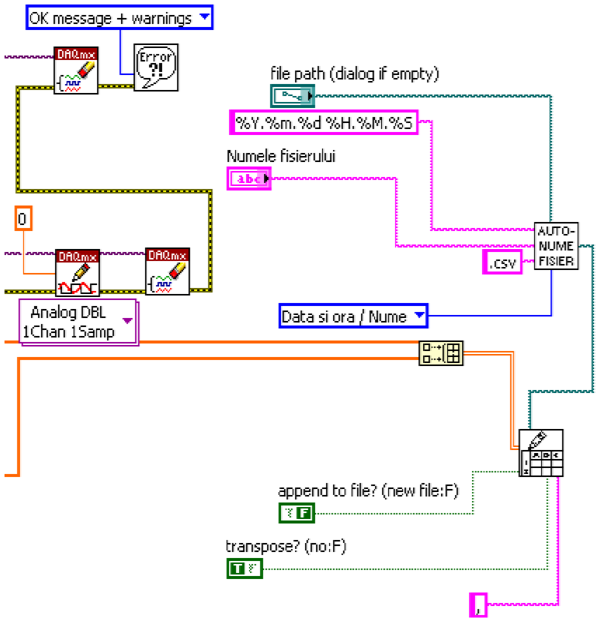


Figure 7: Closing channels and saving data

Another application is used to automatically test the behavior of piezoelectric actuators. In the second application, only the major loops of the hysteresis effect of the piezoelectric actuators are highlighted, as well as the stabilization of the loop after several loading/unloading cycles.

Regarding the programming, the modification takes place on the definition of the process parameters (number of cycles and the maximum applied voltage) but also of the center loop, where it will be used repetitive for-type structure, with a number of steps (complete loading-unloading cycle) imposed by the user.

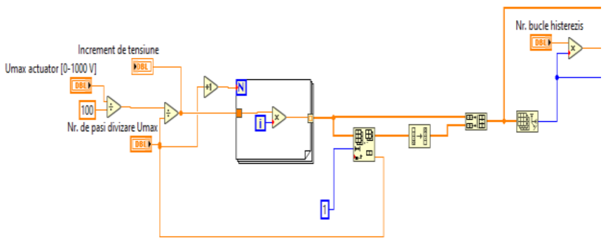


Figure 8: Generating the number of cycles for actuator testing

The FOR loop shown in Figure 9 runs a certain number of times, set at the test beginning.

Using this program, it is possible to determine the global characteristic of the actuator, respectively the behavior under the action of a ramp-type voltage signal when charging and discharging completely under voltage.

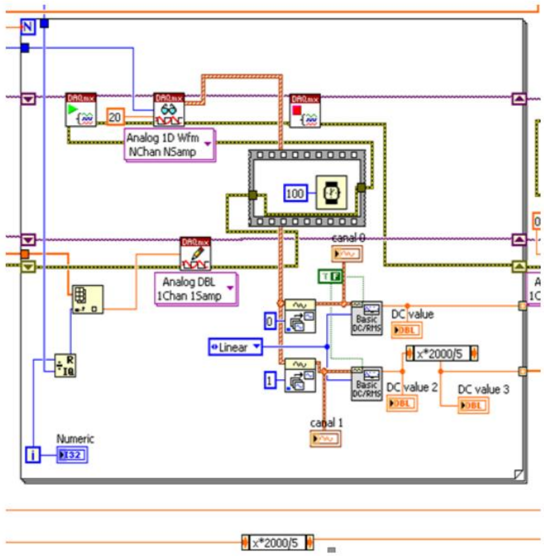


Figure 9: FOR loop for testing piezoelectric actuator

Together with the help of the differential transducer, the graphs presented below are made.

4. Conclusions

The interface of the first application for determining the minor and major loops is shown in the following figure. On the left side of the interface are the declaration of the acquisition parameters, the declaration of the access path and the file name for saving the data, the buttons for stopping and deleting the graph and the measured parameters.

The use of the program allows to highlight the hysteresis and the major loops (which appear during the continuous run, without oscillations of values) of a cycle between the minimum and maximum electrical voltages) but also the minor loops that appear when there is a change in the direction of travel, respectively a change in the direction of the voltage ramp. It is observed how the minor loops disappear and the information about them is "forgotten" when the voltage returns to the value corresponding to the beginning of a minor loop.

Therefore, the system returns and operates on the main hysteresis loop from which it came out in the minor loop. These results confirmed the applicability of the Preisach model for this type of actuator and generated the data needed to create a software model associated with the actuator. This software model is the basis of an open loop control of the actuator by the feed-forward technique, to eliminate the effect of hysteresis and nonlinearities and implicitly to improve the positioning accuracy.

The second application allowed to highlight the change of hysteresis over time, by repeatedly going through the major loops.

The application interface for raising the overall hysteresis characteristic is shown in Figure 11. On the left side of the interface are found the acquisition parameters, the declaration of the access path and the file name for saving the data and the current values for testing parameters (applied voltage, actual displacement, the increment, and the actual number of cycle).

The additional ordering of the crystalline structure of the material, which appears under the effect of the external tension, leads to a modification of the hysteresis curves at the first passages of the major loops. This preliminary "ordering" is lost in time if the actuator is not used and involves cycles of "reordering" before use.

It is essential that these cycles have a short duration so that many loading-unloading cycles are not required. In this case the actuator stabilized at the limit of an error of 5% after a number of 10 cycles.

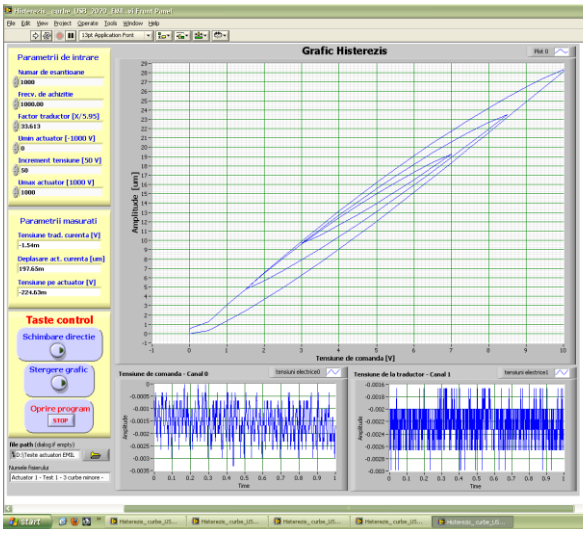


Figure 10: Minor and major hysteresis loops

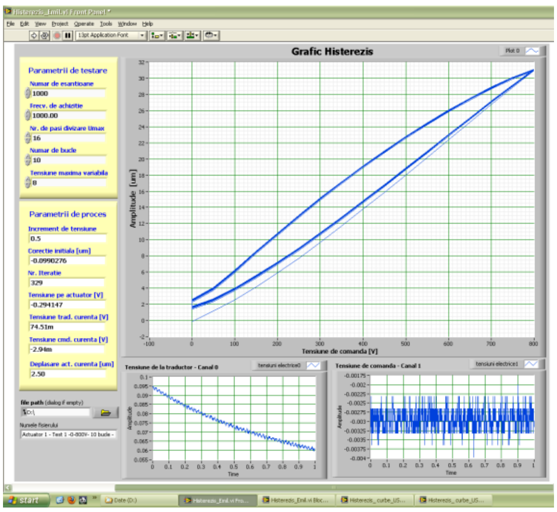


Figure 11: Global hysteresis loops

Acknowledgements

This work was supported by a grant of the Romanian Ministry of Education and Research, CCCDI-UEFISCDI, project number PN-III-P2-2.1-PTE-2019-0253, within PNCDI III.

References

[1] Selvakumar, B., Kathiravan, A. (2021). Sensory materials for microfluidic paper based analytical devices - A review. Talanta, Volume 235, 122733.

[2] Ruiz, J.A.R., Sanjuan, A.M., Vallejos, S., Garcia, F.C.&Garcia, J.M (2018). Smart Polymers in Micro and Nano Sensory Devices. Chemosensors, Volume 6, Issue 2, pp.12.

[3] Oshchepkov, A.S., Oshchepkov, M.S., Oshchepkova, M.V., Al-Hamry, A., Kanoun, O.& Kataev, E.A (2022). Naphthalimide-Based Fluorescent Polymers for Molecular Detection. Advanced Optical Materials. Volume 9, Issue 6, 2001913.

[4] Li, X., Shang, J.&Wang, Z. (2017). Intelligent materials: a review of applications in 4D printing. Assembly Automation, Volume 37, Issue 2, pp.170-185.

[5] Anderson, E.H.&Hagood, N.W. (1994). Simultaneous Piezoelectric Sensing/Actuation: Analysis And Application To Controlled Structures. Journal of Sound and Vibration, Volume 174, Issue 5, pp.617-639.

[6] Chen, Y., Zhang, D., Peng, Z., Yuan, M.&Ji, X. (2021). Review of Research on the Rare-Earth Doped Piezoelectric Materials. Froniters in Materials. Volume 8, Article 679167.

[7] Liu, Y., Ren, K.L., Hofmann, H.F.&Zhang, Q. (2005). Investigation of electrostrictive polymers for energy harvesting. IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control, Volume 52, Issue 12, pp.2411-2417.

[8] Olabi, A.G.&Grunwald, A. (2008). Design and application of magnetostrictive materials. Materials & Design, Volume 29, Issue 2, pp. 469-483.

[9] Dahake, S., Awate, N., Shelke, R.&Khalatkar, A. (2022). Shape Memory Alloy as a Smart Material: A Review. In: Kolhe, M.L., Jaju, S.B., Diagavane, P.M. (eds) Smart Technologies for Energy, Environment and Sustainable Development, Vol 2. Springer Proceedings in Energy. Springer, Singapore. https://doi.org/10.1007/978-981-16-6879-1_38

[10] Hu, Z., Chen, Y., Wang, C., Zheng, Y.&Li, Y. (1998). Polymer gels with engineered

environmentally responsive surface patterns. Nature, Volume 393, pp.149-152.

[11] Wang, Y., Yuan, J., Zhao, X.&Yin, J. (2022). Electrorheological Fluids of GO/Graphene-Based Nanoplates. Materials, Volume 15, Issue 1, pp.311.

[12] Theodosiou, A.&Kalli, K. (2020). Recent trends and advances of fibre Bragg grating sensors in CYTOP polymer optical fibres. Optical Fiber Technology, Volume 54, Article 102079.

[13] Shivashankar, P.& Gopalakrishnan, S. (2020). Design, modeling and testing of d_{33}-mode surface-bondable multilayer piezoelectric actuator. Smart Materials and Structures, Volume 29, Issue 4, Article 045016.

[14] Xie, L., Wang, G., Jiang, C., Yu, F.&Zhao, X. (2021). Properties and Applications of Flexible Poly(Vinylidene Fluoride)-Based Piezoelectric Materials. Crystals, Volume 11, Issue 6, pp.644.

[15] Katzir, S. (2006). The discovery of the piezoelectric effect. In: Katzir, S. (eds) The beginnings of piezoelectricity. Boston studies in philosophy of science, Volume 246. Springer, dordrecht. https://doi.org/10.1007/978-1-4020-4670-4_2

[16] Mohith, S., Upadhya, A.R., Navin, K.R., Kulkarni, S.M&Rao M. (2021). Recent trends in piezoelectric actuators for precision motion and their applications: a review. Smart Materials and Structures, Volume 30, Issue 1, Article 013002.

[17] Wang, S., Rong, W., Wang, L., Xie, H., Sun, L.&Mills, J. (2019). A survey of piezoelectric actuators with long working stroke in recent years: Classifications, principles, connections and distinctions. Mechanical Systems and Signal Processing, Volume 123, pp. 591-605.

[18] Sabarianand, D.V., Karthikeyan, P.& Muthuramalingam, T. (2020). A review on control strategies for compensation of hysteresis and creep on piezoelectric actuators based micro systems. Mechanical Systems and Signal Processing, Volume 140, Article 106634.

[19] Asadi Dereshgi, H., Dal, H. & Yildiz, M.Z. (2021). Piezoelectric micropumps: state of the art review. Microsystem Technologies, Volume 27, pp. 4127–4155.

[20] Yang, C.&Youcef-Toumi, K. (2022). Principle, implementation, and applications of charge control for piezo-actuated nanopositioners: A comprehensive review. Mechanical Systems and Signal Processing, Volume 171, Article 108885.

[21] Wang, Y., Li, G., Zhou, Q., Almeida, S., Lee, S.W., Ho, D.&Wang, Y. (2022). Piezoelectric MEMS mirror optimized by particle swarm optimization algorithm. Proc. SPIE 12013, MOEMS and Miniaturized Systems XXI, 1201309.

[22] Boni, N., Carminati, R., Mendicino, G., Merli, M., Terzi, D., Lazarova, B.&Fusi, M. (2022). Piezoelectric MEMS mirrors for the next generation of small form factor AR glasses. Proc. SPIE 12013, MOEMS and Miniaturized Systems XXI, 1201305.

[23] Peddigari, M., Kwak, M.S., Kim, H.S., Min, Y., Choi, J.J., Yoon, W.H.& Jang, J. (2022). Characterization of single-crystal macro-fiber composite-based piezoelectric energy harvesters in various temperature and humidity environments. Ceramics International, Volume 48, Issue 8, pp. 10821-10826

[24] More, N., Ranglani, D., Hiray, A.R.&Kapusetti, G. (2022). Chapter 14 - Piezoelectric ceramics as stimulatory modulators for regenerative medicine. Editor(s): Shiv Singh, Pradip Kumar, D.P. Mondal, In Elsevier Series in Advanced Ceramic Materials, Advanced Ceramics for Versatile Interdisciplinary Applications, Elsevier, pp. 313-338

[25] National Instruments, https://www.ni.com/

[26] Physik Instrumente (PI), https://www.physikinstrumente.com/

[27] Mahr, https://metrology.mahr.com/de/produkte/artikel/5323010-induktiver-messtaster-millimar-p2004-m