Development of a microprocessor system for monitoring the accelerations of moving elements of technological machines

E Yu Orlova¹, F Yu Shmelev¹, I Sh Gertsenshteyn¹, O V Trapeznikova², Yu N Panin², Minhee Lee³

¹Moscow Polytechnic University, 38, B. Semenovskya str., Moscow, 107023, Russia
²Omsk State Technical University, 11, Mira av., Omsk, 644050, Russia
³Joongbu University, 201 Daehak-ro, Chubu-myeon, Geumsan-gun, Chungnam 32713, Korea

E-mail: orrlova@bk.ru

Abstract. During the operation of machines and aggregates, processes, that are difficult to describe in theoretical ways, occur. When studying the mechanism in detail, it is still better to resort to experimental measurements in order to gain a greater understanding of the transients that occur during its operation, movement, and shut down. Such detailed data can be used to improve the properties of the mechanism, the principles of its design, as well as to reduce its dimensions and energy consumption. An acceleration sensor was developed, which will allow to investigate the causes of problems with mechanism precision, occurrence of noise, as well as identify a poor assembly and adjust machine mechanisms.

Key words: accelerometer, static acceleration, mechanism clearances, technological equipment, acceleration sensors.

1. Introduction
Mechanism clearances that occur due to wear or some poor-quality assembly and adjustment, errors in connecting the laws of movement when profiling cams in batch-operated mechanisms can lead to a violation of the accuracy of technological operations, prevent an increase in operation speed, and are accompanied by an increase in noise. The cause of these defects can be identified by the nature of moving links accelerations. These accelerations can be detected using accelerometers - acceleration sensors [1-4]. These sensors can be conveniently divided into two groups. Active piezoelectric accelerometers [5-6] are the most common, having number of advantages, but their frequency response begins with a few hertz, which does not allow them to be used for the study of relatively low-speed machines and mechanisms [7]. In these cases, accelerometers are needed that can measure even static accelerations, such as the gravitational acceleration [8-9].

2. Problem statement
This study is aimed to evaluate the possibility of using electronic accelerometers of the second type for monitoring defects in the operation of technological equipment by checking the compliance of experimental and calculated accelerations.
3. Problem solution

For the experiments, the ADXL78 sensor of Analog Devices was chosen - a low-power, full-featured, uniaxial accelerometer with an analog output signal in the form of voltage and analog signal conversion circuits, implemented on a single monolithic integrated circuit [10].

ADXL78 provides a fully differential sensor structure and a circuit that provides resistance to electromagnetic interference. In this latest generation, electrical reaction-coupled feedback with zero effort to improve accuracy and stability is used. The resonant sensor frequency is significantly higher than the signal bandwidth set by a built-in filter, which allows avoiding signal analysis problems caused by resonant peaks near the signal bandwidth (see Figure 1-3.)

Figure 1 shows a simplified sensor structure, which is a simplified view of one of the differential sensor elements. Each sensor includes several elementary cells of a differential capacitor. Each cell consists of fixed plates attached to the substrate and movable plates attached to the frame. Displacement of the frame changes the differential capacity, which is measured by the circuit on a chip [11].

Figure 1. Sensor structure. 1, 4 - frame mounting points; 2 - movable frame; 3 - movable cell element; 5 - fixed plates; 6 - movable plate

Figure 2. Flowchart of the accelerometer connection
Figure 3. Sensor function chart

Additional square waves of 400 kHz energize the fixed plates. The electrical feedback adjusts the square wave amplitudes so that the AC signal on the moving plates is 0. The feedback signal is linearly proportional to the applied acceleration. This unique feedback method ensures that no total electrostatic force is applied to the sensor. The differential feedback control signal is also fed to the filter input, where it is filtered and converted to an asymmetrical signal.

A printed circuit board (PCB) is produced to accommodate the sensor itself and the elements (see Figure 4). To reduce the influence of high-frequency interference on the sensor operation, ceramic capacitors with a nominal value of 0.1 nF are used, and a light-emitting diode with a current damping resistor is installed to indicate the power supply to the IC. Figure 5 shows the circuit diagram of the sensor connection.

Figure 4. PCB for placement of accelerometer elements

To obtain data from the acceleration sensor, the NI Compact DAQ-9178 hardware system was used (see Figure 6). This system allows receiving both digital and analog signals, which makes it possible to work simultaneously with several sensors with different interfaces. The NI programming environment is integrated top-level software tools, which greatly simplifies the development, debugging, and deployment of such a technical system. Using these software tools and ready-made language functions, a flowchart for reading and processing signals from the sensor has been developed. Using the DAQ-9178 chassis, it's easy to digitize the signals received from the analog
input of one of its input modules. To process the received data, the NI LabVIEW software product was used (see Figure 7), equipped with a high-speed USB 2.0 interface built using the NI signal streaming technology. This greatly facilitates receiving and measurement of an analog signal from the accelerometer [12]. To smooth the received signals from the sensors, the chart was provided with a programmed anti-aliasing filter with a rectangular window with a half-width of five dimensions. The sensor report rate was 100 Hz.

Figure 6. NI Compact DAQ-9178 hardware system. 1 - LEDs for the POWER, READY, and ACTIVE statuses; 2 - USB connector; 3 - BNC connectors for connecting triggers; 4 - connector for connecting to the power supply unit; 5 - module slots; 6 - installed modules; 7 - ground connection

Figure 8 shows rolls that are being operated in print works and have already passed 25 mln impression prints. Surface resistance is within the range of 0.05 mm per diameter so far. This material proved to be rather reliable, wear-resistant, and prospective in application.

Figure 9 shows the lower part of the finished housing, performed by means of 3D print with in-built measurement device boards for monitoring the check mark on the impression print in the process of printing. The experience of this product manufacture demonstrated that additive technologies allow personalizing the plant needs and solving issues of controlling the quality of the printed goods in the equipment operation point, with regard to features of installation, arrangement, and fixation of measurement devices on printing machines.

\[ +g = +u = 2.735 \text{ V}; \]
\[ -g = -u = 2.325 \text{ V}. \]

\[ \Delta U = (+u) - (-u) = 2.735 - 2.325 = 0.41 \text{ V}; \]

\[ K = \frac{2 \cdot g \cdot \Delta U}{m} = \frac{2 \cdot 9.8 \cdot 0.41}{m} = 48.8 \text{ m/s}^2. \]

As a result, it was assumed that one volt at the sensor output corresponds to 48.8 m/s².
Figure 7. The NI LabVIEW program interface with a flowchart for reading and processing sensor signals. 1 – AD converter (data collection unit); 2 – anti-aliasing filter for a signal; 3 - monitor showing a curve of the rod strain values; 4 - monitor showing a curve of the crosshead acceleration values; 5 - signal selection device; 6 - unit showing the numeric value of the rod strain at the moment; 7 - unit that shows a numerical value for the acceleration of the crosshead at the moment; 8 – on/off button for recording sensors readings; 9 – signal recorder; 10 – “Stop” button

4. Results and Discussion
Mounted sensor is shown in Figure 8. This board has the inputs for connecting the stabilized power supply, protected from incorrect connection, the ST self-test input, and the sensor signal output. The elements are mounted on a double-sided foiled fiber-glass plastic using the surface-mounted technology (SMT). To simplify the design, there is no AD converter or operational amplifier on the sensor board [11]. That board was connected to the hardware data acquisition unit by a short shielded cord.

Figure 8. Board with the acceleration sensor
To automate processes or to read data, it is advisable to use an autonomous complex consisting of sensors and a microcontroller, and, for example, in combination with programmable logic controllers, it can be possible to get a convenient and flexible tool for managing complex processes [9]. As a similar complex, it is possible to use microcontrollers, for example, the AtmegaXX family of AVR company, which have several ADCs and other hardware peripherals and special functions, which in turn will allow quickly performing AD conversion of the data received from the accelerometer or other sensors with an analog or digital interface, save the received data for their subsequent processing, or control other devices according to a certain algorithm, for example, using pulse width modulation (PWM) or proportional integral differentiation (PID), as well as control devices via industrial networks with the Modbus protocol for data transmission via widely used communication lines RS-232, RS-485, RS-422 and using networks with the TCP/IP protocol [13, 14]. A similar system is shown in Figure 5 [15].

**Figure 9.** Diagram of an autonomous system for reading and processing data on a microcontroller.

1, 2,…,N - sensors

5. Conclusions
The developed sensor was calibrated and tested on technological equipment (in the laboratory/in production). The sensor is used to obtain data from various moving elements and mechanisms of the equipment. The flowchart is obtained that will allow measuring, processing, and storing various physical quantities, for example, acceleration (m/s²), angular velocity (s⁻¹), angular acceleration (s⁻²), etc. of real objects and physical phenomena occurring in them, such as strain. It is intended to use such a sensor on such equipment as: a three-knife trimmer, a gold blocking press for embossing, an automatic book sewer, a book casing-in machine, various printing machines and others. The use of such a system will allow visualizing the transient processes occurring in the assemblies and mechanisms of technological equipment, as well as use the data obtained for scientific and other purposes.
References

[1] Cheynet E 2021 Operational Modal Analysis with Single Sensor. Zenodo DOI: 10.5281/ZENODO.4487060

[2] Polizzi J P, Fain B and Maspero F 2020 Handbook of Sil. Bas. MEMS Mater. and Techn. Chapter 45—Accelerometer (Third Edition) Elsevier 879-898 URL: https://doi.org/10.1016/B978-0-12-817786-0.00045-1

[3] Youssef A Al-Subaie N El-Sheimy N and Elhabiby M 2021 Accelerometer-Based Wheel Odometer for Kinematics Determination Sensors 21 1327

[4] Mostovoy N V and Pahomov D G 2013 The Use of Accelerometers in Industry Young Russia: advanced technologies - to industry 2 061–063

[5] Lutsenko V and Kosarev O 2009 A highly sensitive precision piezoelectric accelerometer with a built-in mechanical filter Jour. of Mach. Manufact.and Reliab. 38 91–93

[6] Boroznet S A, Garaev D Yu, Proskurin A V and Tausenev V V 2019 Determination of the lower eigenfrequency of vibrations of a piezoelectric accelerometer Instruments and Experimental Techniques 62(5) 718–722

[7] Büttgenbach S, Constantinou I, Dietzel A and Leester-Schädel M 2020 Surface Micromachined Acceleration Sensors. Case Studies in Micromechatronics 87–144

[8] Saprudin S, Prihatmanto A L, Agus S, Sparisoma V, Heni S, Yulina I and Chaerul R 2020 Gamified experimental data on physics experiment to measuring the acceleration due to gravity. Journ. of Phys.: Conf. Series 1567 032079.

[9] Morris C and Peterson S 2020 A Component Analysis of an Electronic Data Collection Package. Journ. of Org. Beh. Manag. 40 1–23

[10] Analog Devices Accelerometers. Structure, Application, and Continuous Update. URL: https://www.kit-e.ru/assets/files/pdf/2007_05_46.pdf.

[11] CTSD ADC – Part 1: How to Improve Your Precision ADC Signal Chain Designs. URL: https://www.analog.com/en/analog-dialogue/articles/ctsd-adcs-part-1.html.

[12] Hrbacek J, Hrbacek R and Lesinsky J 2019 Automatic Mechatronic Test Stand Development for Embedded Electronics Using NI LabVIEW International Conference Mechatronics 2019: Recent Advances Towards Industry 4.0 113–118

[13] Jiang D, Shen Z, Li Q, Chen J and Liu Z 2021 Advanced Pulse-Width-Modulation: With Freedom to Optimize Power Electronics Converters Springer Singapore 380p DOI: 10.1007/978-981-33-4385-6

[14] Firdaus F, Chadri R and Nasrullah N 2020 Rancang Bangun Generator PWM Berbasis Mikrokontroler AVR ATMega Elektron : Jurn. Ilmiah 12 61–66

[15] Qosimov F, Jiang R, Zhang D, Ismailov M 2020 Development of a control device and algorithm for autonomous-moving systems Chemical Technology, Control and Management 2020(2) Article 10 6–15 DOI: https://doi.org/10.34920/2020.2.62-69