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VALUE OF DEFORMATION ENERGY DEPENDING ON DEFORMATION OF FLEXIBLE PNEUMATIC ELEMENT

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Keywords: flexible coupling, elastic element, rubber, deformation energy
Abstract: The article describes a flexible element used in flexible pneumatic couplings. These elements are manufactured by various manufacturers and are mostly made of rubber. Each element, depending on the number of bellows and diameter, has permissible stroke values. It is necessary to expend a certain amount of energy to compress and expand them. The article examines the amount of deformation energy required to compress and expand this elastic element.

1 Introduction

Shaft couplings are among the most important elements in various mechanical systems for torque transmission. Very often used couplings are flexible shaft couplings. They have greater advantages than conventional fixed shaft couplings. At our workplace, we deal with the issue of flexible pneumatic couplings and torque transmission. In our department, we have already developed several types of these flexible couplings with flexible pneumatic elements, as well as various test equipment for determining the static and dynamic properties of flexible pneumatic shaft couplings [1-5].

These flexible pneumatic shaft couplings contain flexible pneumatic elements that carry the entire load. These make it possible to tune the torsionally oscillating system, and to adjust its stiffness, damping or mass parameters according to the operating characteristics so that during the operating mode of the system there is no dangerous resonant state and damage to the whole equipment or injury to the operator. At present, attention is being paid to the development and research of pneumatic flexible members, which are formed from a rubber-cord casing filled with a gaseous medium. These elastic elements are dynamically stressed. However, it should be noted that the load is not transmitted by the rubber but by the gaseous medium with which the pneumatic coupling is filled [3,6-8].

For the correct operation of the coupling, it is important to know the properties of the elastic element such as compressibility, volume and the amount of deformation energy required to compress this element [9,10].

The aim of the article is to find out how large values of deformation energy are needed to compress the elastic element that we use in pneumatic shaft couplings developed at our workplace [11].

2 Flexible elements

The There are various manufacturers of flexible elements in the world. Different sizes and different numbers of bellows are also produced. Most single-wave, double-wave and triple-wave elements are produced Figure 1.

Figure 1 Types of flexible pneumatic elements

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These flexible elements are friction-free and require maintenance and lubrication. They are designed for low strokes and high pressures. The height of the pneumatic element depends on the diameter of the cylinder and the number of bellows. The higher the height of the element, the larger the dimensions of the pneumatic shaft coupling in which this element is mounted. The construction provides insulation against shocks and manufacturers also offer various types of anchoring flanges, which ensures easy assembly of the element. The working pressure is limited by the maximum working pressure which is 800kPa. Normal operating temperature is in the range of -40 °C to 70 °C. For special operations, the manufacturer can provide another material that has a working temperature in the range of -20 °C to 115 °C.

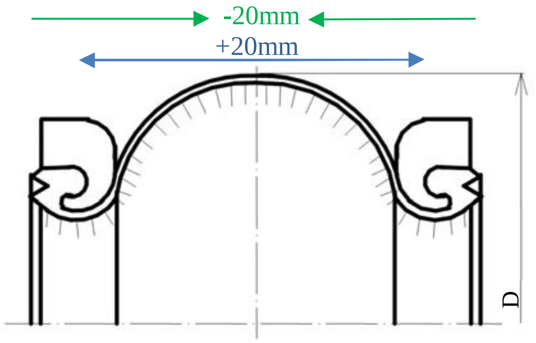

Figure 2 Investigated flexible pneumatic element PE 130/1

For our research, we used a flexible pneumatic element PE 130/1. The marking itself defines the diameter of the cylinder D = 130mm and the number of bellows (Figure 2).

3 Results of experimental measurements

To numerically solve the problem, it was necessary to find out some parameters.

Dependence of the volume of the pneumatic elastic element PE-130/1 on the deformation. This is shown in the following Figure 3. The values obtained were measured in the laboratories of our department. Using experimentally obtained values of the volume of the pneumatic-elastic element at different values of its deformation. Table of values 1. The maximum stroke of our flexible element is in the range of + 20mm and -20mm. (Figure 2) [12-19].

3.1 Volume of the elastic element

We obtained the volume values experimentally. Based on the measured values, we were able to write a numerical formula to describe the volume depending on the stroke. The corresponding dependence is:

$$V(x) = 468{,}6 + 5{,}436 \cdot x - 0{,}0651 \cdot x^2 + 0{,}00162 \cdot x^3. \qquad (1)$$

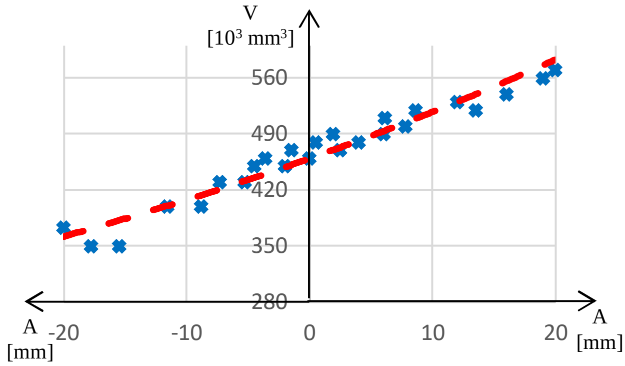

Figure 3 Dependence of volume V on deformation A

Table of experimentally obtained values of volume of pneumatic-elastic element *V* depending on its deformation A (Table 1).

Table 1 Element volume values

	A [mm]	*V* [10^3mm^3]
1	-20	373
2	-17,8	350
3	-15,5	350
4	-11,6	400
5	-8,8	400
6	-7,3	430
7	-5,3	430
8	-4,5	450
9	-3,6	460
10	-2	450
11	-1,5	470
12	0	460
13	0,5	480
14	1,9	490
15	2,5	470
16	4	480
17	6	490
18	6,1	510
19	7,8	500
20	8,6	520
21	12	530
22	13,5	520
23	16	540
24	19	560
25	20	570

3.2 Bellows deformation

We obtained the volume values experimentally. Based in Table 2 we show the experimentally obtained values of the forces F acting in the axis of the pneumatic-elastic element with the corresponding magnitudes of deformations A. These values are subsequently plotted in the graph in Figure 4.

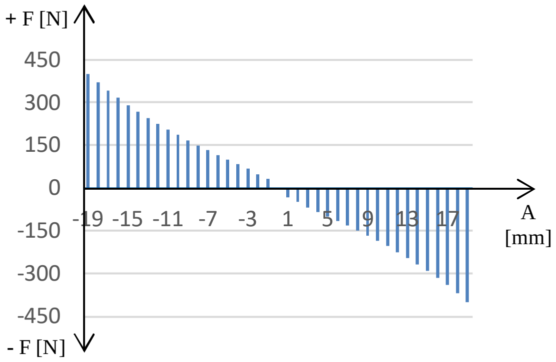

Figure 4 Dependence of force F on deformation A

Table 2 Bellows deformation

A [mm]	*F* [N]	*A* [mm]	*F* [N]
-19	400	1	-32
-18	370	2	-48
-17	341	3	-68
-16	316	4	-84
-15	290	5	-100
-14	268	6	-116
-13	246	7	-132
-12	225	8	-149
-11	204	9	-167
-10	186	10	-186
-9	167	11	-204
-8	149	12	-225
-7	132	13	-246
-6	116	14	-268
-5	100	15	-290
-4	84	16	-316
-3	68	17	-341
-2	48	18	-370
-1	32	19	-400
0	0	20	-430

The translated dependence is described by a function where the value of the stroke *x* is in millimetres

$$F(x) = -18{,}153 \cdot x - 0{,}00686 \cdot x^3. \qquad (2)$$

3.3 Deformation energy

The measured parameters are used to calculate the amount of deformation energy E_D stored in the pneumatic-elastic element at different sizes of its deformation (3).

$$E_D(x) = -\int_0^x F(x')\,\mathrm{d}x'. \qquad (3)$$

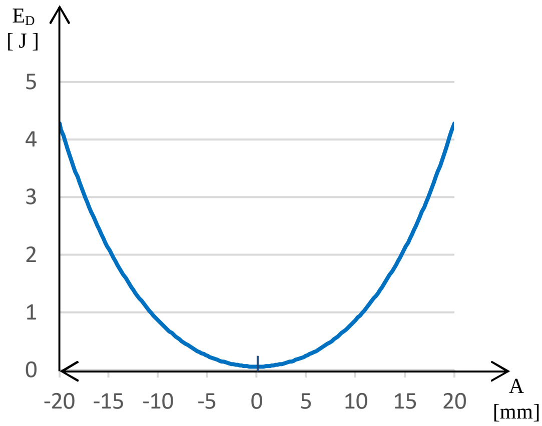

Figure 5 Dependence of deformation energy E_D on deformation A

In Figure 5 we can see that with increasing stroke, the amount of deformation energy also increases up to the value of 4.3J. When the elastic element is compressed up to a maximum value of 20 mm, the amount of deformation energy also acquires the value of 4.3J. The course of deformation energy when compressing or expanding a pneumatic element is not linear but exponential.

When the elastic element is compressed and expanded, the elastic elements heat up and heat is generated. Finding the amount of deformation energy is necessary for the numerical solution of the heat conduction equation.

This heat heats the rubber from which the elastic element is made evenly in volume and thus contributes to increasing its temperature.

It should also be emphasized that the stated values refer to an unpressurized open flexible rubber element. Thus, they really only capture the force and energy needed to deform the rubber.

4 Conclusions

The article describes a flexible element used in flexible pneumatic couplings. These elements are important for the proper operation of the clutch. The article focuses on the flexible element PE130 / 1, which describes in more detail. Experimental measurements were performed on a given elastic element and the course of the volume depending on the compression and expansion of the element was recorded. The volume of this element varied from 373x10^3 mm^3 at maximum compression to 570x10^3 mm^3 at maximum compression. We listed all measured values in the table and also showed the course graphically. By further measurement, we determined the force required to compress or expand the unpressurized elastic element. It changed from 400N at maximum compression to 430 N at maximum expansion of the elastic element. We also displayed the given values graphically and in a table. Based on these measured values, we were able to calculate the value of deformation energy required for compression and expansion of the elastic element. The maximum value of the deformation work was 4.3J and the magnitude changed exponentially with increasing deformation of the elastic element. Finding the magnitude of the deformation energy is necessary for the numerical solution of the heat conduction equation, which we want to address in further research.

Acknowledgement
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References

[1] KRAJŇÁK, J., GREGA, R.: *Analysis of external temperature in flexible element at various speed levels*, Projektowanie, badania i eksploatacja Tom 1, Bielsko-Biała: Akademia Techniczno-Humanistyczna w Bielsku-Białej, pp. 191-198, 2018.
[2] HOMIŠIN, J.: *Nové typy pružných hriadeľových spojok: vývoj, výskum, aplikácia*, TU, SjF, Košice 2002. (Original in Slovak)
[3] ŽUĽOVÁ, L. GREGA, R. KRAJŇÁK, J., FEDORKO, G., MOLNÁR, V.: Optimization of noisiness of mechanical system by using a pneumatic tuner during a failure of piston machine, *Engineering Failure Analysis*, Vol. 2017, No. 79, pp. 845-851, 2017.
[4] KAŠŠAY, P.: Effect of torsional vibration on woodchip size distribution, *Scientific Journal of Silesian University of Technology, Series Transport*, Vol. 99, pp. 95-104, 2018.
[5] URBANSKÝ, M.: Comparison of piston and tangential pneumatic flexible shaft couplings in terms of high flexibility, *Scientific Journal of Silesian University of Technology, Series Transport*, Vol. 99, pp. 193-203, 2018.
[6] KOSTKA, J., FRANKOVSKÝ, P., ČARÁK, P., NEUMANN, V.: Evaluation of residual stresses using optical methods, *Acta Mechatronica*, Vol. 4, No. 4, pp. 29-34, 2019.
[7] CZECH, P., MADEJ, H.: Application of cepstrum and spectrum histograms of vibration engine body for setting up the clearance model of the piston-cylinder assembly for RBF neural classifier, *Maintenance and Reliability*, Vol. 4 , pp. 15-20. 2011.
[8] CZECH, P., TUROŃ, K., BARCIK, J.: Autonomous vehicles: basic issues, *Scientific Journal of Silesian University of Technology. Series Transport*, Vol. 100, pp. 15-22, 2018.
[9] MALÁKOVÁ, S., HARACHOVÁ, D.: Konštrukčná optimalizácia prevodovky pre odstránenie prevádzkovej poruchovosti, *Technológ. Žilina*, Vol. 11, No. 3, pp. 43-48, 2019. (Original in Slovak)
[10] FEDORKO, G., LIPTAI, P., MOLNÁR, V.: Proposal of the methodology for noise sources identification and analysis of continuous transport systems using an acoustic camera, *Engineering Failure Analysis*, Vol. 83, pp. 30-46, 2018.
[11] MORAVEC, M., LIPTAI, P.: Smart city concept system for the municipal waste disposal, *International Journal of interdisciplinarity in theory and practice*, Vol. 2017, No. 12, pp. 53-56, 2017.
[12] JAKUBOVIČOVÁ L., SÁGA M., KOPAS P., HANDRIK, M., VAŠKO M.: Some Notes on Analysis of Bending and Torsion Combined Loading, *Machine Dynamics Research*, Vol. 34, No. 3, pp. 97-105, 2010.
[13] PUŠKÁR, M., FABIAN, M., KÁDÁROVÁ, J. BLIŠŤAN, P., KOPAS, M.: Autonomous vehicle with internal combustion drive based on the homogeneous charge compression ignition technology, *International Journal of Advanced Robotic Systems*, Vol. 14, No. 5, pp. 1-8, 2017.
[14] SAPIETOVÁ, A., SÁGA, M., NOVÁK, P.: Multi-software platform for solving of multibody systems synthesis, *Communications*, Vol. 14, No. 3, pp. 43-48, 2012.
[15] SAGA, M., VASKO M.: Stress Sensitivity Analysis of the Beam and Shell Finite Elements, *Communications – Scientific Letters ofthe University Zilina*, Vol. 11, No. 2, pp. 5-12. 2009.
[16] MORAVEC, M., IŽARÍKOVÁ, G., LIPTAI, P., BADIDA, M., BADIDOVÁ, A.: Development of psychoacoustic model based on the correlation of the subjective and objective sound quality assessment of automatic washing machines, *Applied Acoustics*, Vol. 140, pp. 178-182, 2018.
[17] LACIAK, M., KOSTÚR, K., DURDÁN, M., KAČUR, J., FLEGNER, P.: The analysis of the underground coal gasification in experimental equipment, *Energy*, Vol. 114, pp. 332-343, 2016.
[18] KOSTÚR, K., LACIAK, M., DURDÁN, M.: Some influences of underground coal gasification on the environment, *Sustainability*, Vol. 10, No. 5, pp. 1-31, 2018.
[19] FABIAN, M., PUŠKÁR, M., BOSLAI, R., KOPAS, M., KENDER, Š., HUŇADY, R.: Design of experimental vehicle specified for competition Shell Eco-marathon 2017 according to principles of car body digitisation based on views in 2D using the intuitive tool Imagine and Shape CATIA V5, *Advances in Engineering Software*, Vol. 115, pp. 413-428, 2018.

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EMBEDDED SYSTEMS – CONTROL OF POWER SUBSYSTEMS

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Keywords: embedded systems, controlling, power systems, signal

Abstract: The main role of embedded system is to control the product behaviour or control of outside world. Microcontroller as embedded system obtains information through the sensors and makes adequate impact to outside world after sensor data processing. The microcontroller impact is realized through the actuators which convert the electrical energy (or different type of energy) to mechanical work. These processes are executed because of fulfil customer requirements. Microcontrollers as signal controllers work only with low power signals. This paper discusses the possibilities and application of controlling the power subsystems via using the embedded systems.

1 Introduction

An embedded system is a computer system with a dedicated function within a larger mechanical or electrical system, often with real-time computing constraints [1,2]. It is embedded as part of a complete device often including hardware and mechanical parts. Embedded systems control many devices in common use today [3]. Ninety-eight percent of all microprocessors are manufactured as components of embedded systems. Embedded systems range from portable devices such as digital watches and MP3 players, to large stationary installations like traffic lights, factory controllers, and largely complex systems like hybrid vehicles, MRI, and avionics (Figure 1).

Because an embedded system is engineered to perform certain tasks only, design engineers may optimize size, cost, power consumption, reliability and performance. Embedded systems are typically produced on broad scales and share functionalities across a variety of environments and applications.

Embedded systems are managed by single or multiple processing cores in the form of microcontrollers or digital signal processors (DSP), field-programmable gate arrays (FPGA), application-specific integrated circuits (ASIC) and gate arrays. These processing components are integrated with components dedicated to handling electric and/or mechanical interfacing.

Figure 1 Embedded systems application examples

An embedded system's key feature is dedication to specific functions that typically require strong general-purpose processors. For example, router and switch systems are embedded systems, whereas a general-purpose computer uses a proper OS for routing functionality. However, embedded routers function more efficiently than OS-based computers for routing functionalities [1,2].

Embedded systems sense quantities from surround and make the actions via using actuators by the following own algorithm (Figure 2).

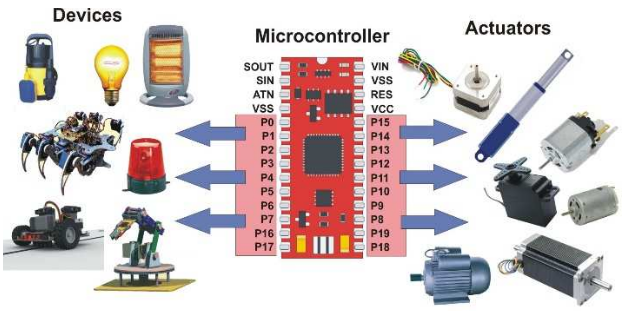

Figure 2 Microcontroller with sensors and actuators

Vane anemometer (Figure 3) is also suitable for wind speed measurement. It uses the propeller on horizontal axis in wind direction.

2 Controlling of power systems

Embedded system realized through the microcontroller includes signal processor. It means that it operates with low voltage and low currents, which are safely for the controller. The maximum current is limited to several milliampers. Direct connection most of actuators to pin of microcontroller causes the immediately damaging of pin al overall microcontroller.

This problem can be solved via using of high power part as transistor, thyristor, triac, relay etc. Inductive loads (DC and AC motors etc.) require big attention in selecting of power parts and circuits. Protection diode is very often used for this purpose (fig. 3).

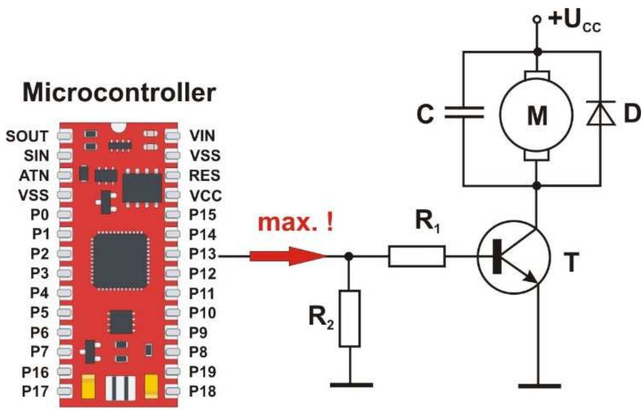

Figure 3 Microcontroller with power transistor and protection diode for inductive load

Simple circuit (Figure 3) is useful for actuator activation (simple switch on of DC motor, relay coil etc.). If it is necessary to control of DC speed rotation, it is possible to make it via using the pulse-width modulation (PWM). PWM is forming of the signal through the duty cycle of the signal (Figure 4). Its main use is to allow the control of the power supplied to electrical devices, especially to inertial loads such as motors. The average value of voltage (and current) fed to the load is controlled by turning the switch between supply and load on and off at a fast rate. The longer the switch is on compared to the off periods, the higher the total power supplied to the load.

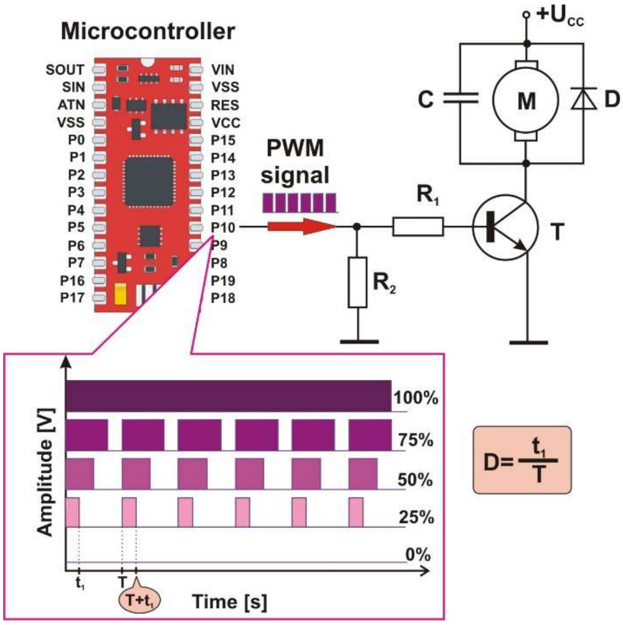

Figure 4 Pulse width modulation principle for controlling of the DC motor speed

Switching frequencies varies from several times per minute in an electric stove; 120 Hz in a lamp dimmer; between a few kilohertz (kHz), to tens of kHz for a motor drive; and well into the tens or hundreds of kHz in audio amplifiers and computer power supplies.

The term duty cycle describes the proportion of 'on' time to the regular interval or 'period' of time; a low duty cycle corresponds to low power, because the power is off for most of the time. Duty cycle is expressed in percent, 100% being fully on. The main advantage of PWM is that power loss in the switching devices is very low. When a switch is off there is practically no current, and when it is on and power is being transferred to the load, there is almost no voltage drop across the switch. Power loss, being the product of voltage and current, is thus in both cases close to zero. PWM also works well with digital controls, which, because of their on/off nature, can easily set the needed duty cycle. PWM has also been used in certain communication systems where its duty cycle has been used to convey information over a communications channel [3].

Many microcontrollers include on-chip PWM controllers. Advantage of PWM is that the signal remains digital all the way from the processor to the controlled system; no digital-to-analog conversion is necessary. By keeping the signal digital, noise effects are minimized.

Increased noise immunity is yet another benefit of choosing PWM over analogue control and is the principal reason PWM is sometimes used for communication. Switching from an analogue signal to PWM can increase the length of a communications channel dramatically. At the receiving end, a suitable RC (resistor-capacitor) or LC (inductor-capacitor) network can remove the modulating high frequency square wave and return the signal to analogue form [4,5].

The circuit on figure 3 allows only one direction of rotational speed of DC motor. This problem can be solved via using the H-bridge composed from four transistor switches (Figure 5).

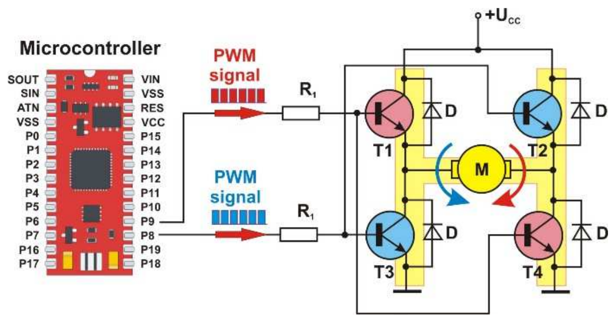

Figure 5 Principle of H-bridge for DC motor control

Connecting of PWM signal to base of transistor T2 and T3 causes that DC motor rotates in one direction and vice-versa connecting of the PWM signal to base of transistor T1 and T4 reverses the direction of DC rotation. PWM signal must be connected only to one output (Figure 4) of controller. Short circuit occurs in case of simultaneously activating of both pairs of transistors.

Inductive load as DC motor can cause the problems because inductive load devices (DC motor, relay, solenoid etc.) produce electrical spikes that damage the outputs of microcontroller or also it can be totally damaged. For the higher safety and reliability, it is useful to use electric isolation protection that isolates the signal part of controller from power part of DC motor (Figure 6).

Optocouplers and opto-isolators can be used on their own, or to switch a range of other larger electronic devices such as transistors and triacs providing the required electrical isolation between a lower voltage control signal and the higher voltage or current output signal. Common applications for optocouplers include microprocessor input/output switching, DC and AC power control, PC communications, signal isolation and power supply regulation which suffer from current ground loops, etc. The electrical signal being transmitted can be either analogue (linear) or digital (pulses) [6].

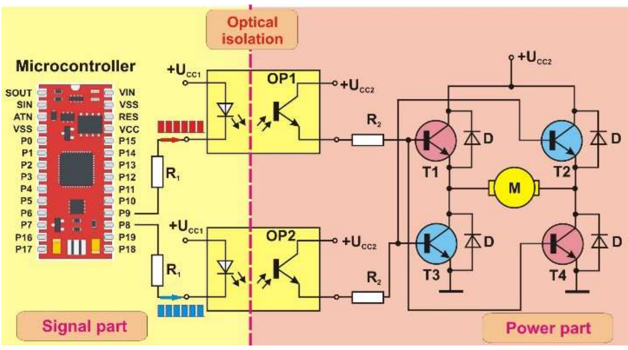

Figure 6 DC motor controlling with H-bridge with electric isolation protection

3 Controlling of RC servo

RC servo is positional servomechanism, which consists of DC motor, positional sensor and control electronic. There are rotational and also linear servos (Figure 7).

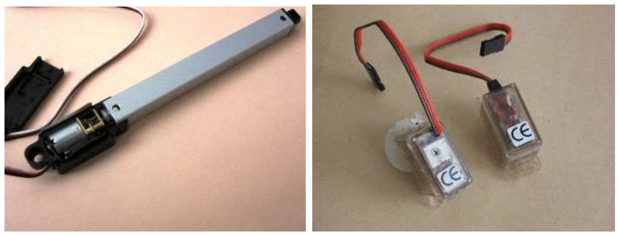
Figure 7 Rotational and linear RC servo

Controlling of these servos is with conventional RC signal. It is pulse-width modulation signal and width of pulse constitutes the value of desired position of angular horn or linear shaft. Pulse width is in range from 1ms to 2 ms and delay between the pulses is in range from 10ms to 20ms (Figure 8).

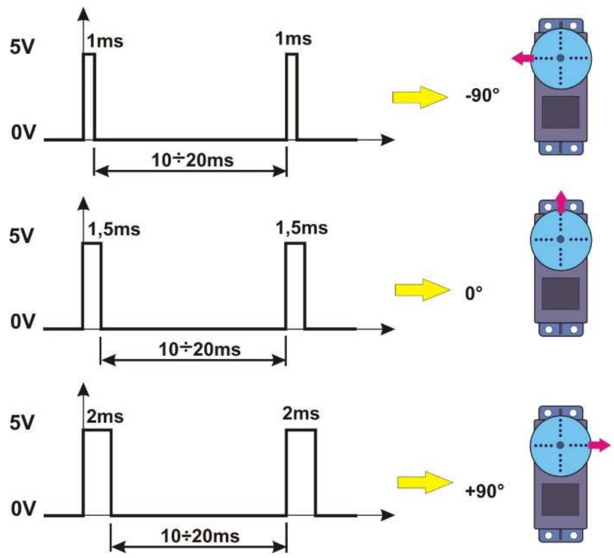

Figure 8 Principle of rotational RC servo controlling

Pulse with width of 1ms means that rotation servo horn rotates to position -90° and pulse with width of 2ms means horn rotation to position +90° (Figure 8). Linear servo shaft is moving out to end position for pulse width of 1 ms and pulse with width of 2 ms causes the forward shifting of the linear servo shaft (Figure 9).

Experiences shows that above mentioned convention (Figure 8 and Figure 9) may varies and every producer has different servo characteristic and also every piece from the same producer can has the different behaviour. It is good to make calibration of the servo before using of RC servo in your application. Also loaded servo may has different characteristic.

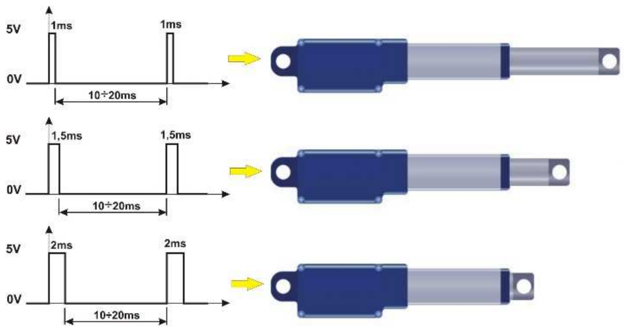

Figure 9 Principle of linear RC servo controlling

Every microcontroller is able to generate the pulses with specified width. Some of them can also generate pulses on background of the main process. Connection of the RC servo to microcontroller is simple. In every case it is more safely insert the resistor for limiting of the current of output signal (Figure 10).

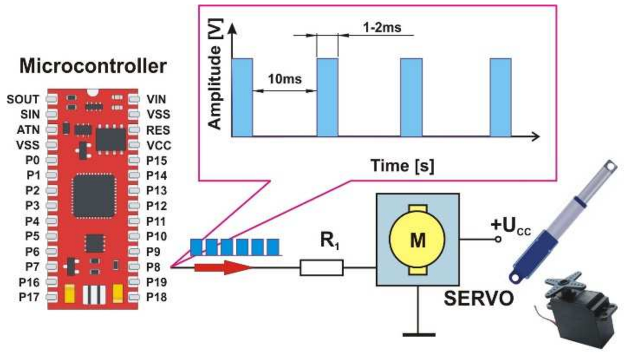

Figure 10 Connection of RC servo to microcontroller

4 Stepper motor controlling

Stepping motor is a brushless DC electric motor that divides a full rotation into a number of equal steps. The motor's position can then be commanded to move and hold at one of these steps without any feedback sensor (an open-loop controller), as long as the motor is carefully sized to the application in respect to torque and speed.

The stepper motor is known by its property to convert a train of input pulses (typically square wave pulses) into a precisely defined increment in the shaft position. Each pulse moves the shaft through a fixed angle.

There are two basic winding arrangements for the electromagnetic coils in a two-phase stepper motor: bipolar and unipolar.

A unipolar stepper motor has one winding with center tap per phase. Each section (A, B, C, D) of windings is switched on for each direction of magnetic field. Since in this arrangement a magnetic pole can be reversed without switching the direction of current, the commutation circuit can be made very simple (e.g., a single transistor) for each winding (Figure 11).

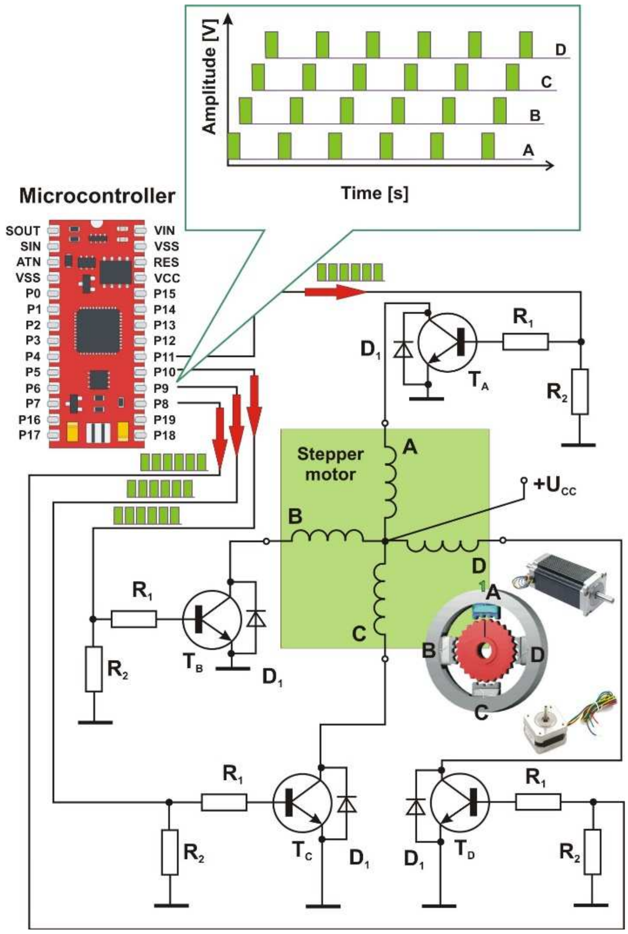

Figure 11 Controlling of the unipolar stepper motor

Bipolar motors have a single winding per phase. The current in a winding needs to be reversed in order to reverse a magnetic pole, so the driving circuit must be more complicated, typically with an H-bridge arrangement (however there are several off-the-shelf driver chips available to make this a simple affair). There are two leads per phase, none are common [7,8].

Measured data are relatively stable and it is close to the reference value. Blower has been adjusted to ten different values and it brought the ten various values of airflow velocity. From this data the averages have been done for comparing the results with reference value. It is shown on figure 8.

5 Applications

Controlling applications of embedded systems is almost unlimited. The biggest advantage is the small dimensions of the microcontroller which enables to include the microcontroller into controlled machine (Figure 12).

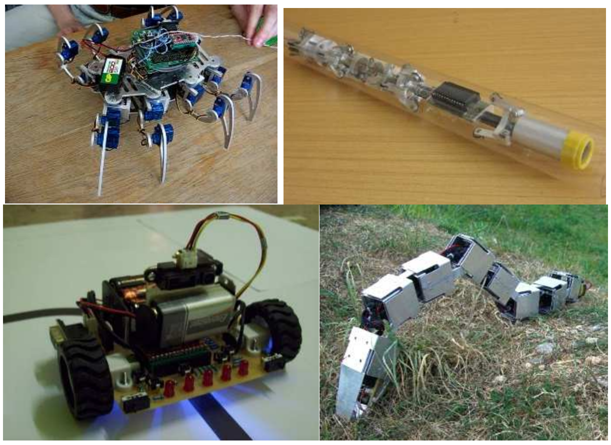

Figure 12 Embedded system applications

6 Conclusion

Embedded system is equipment which enables to make mechatronic system. It gives intelligence to products and also many new functions. Also new type of products can be developed thanks to embedded systems as CD players, Segway, drones, airbags, ABS, ESP and other automotive systems in cars, military systems, service robots, ATM machine, planetary rovers etc [9-24].

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References

[1] Embedded system, From Wikipedia, the free encyclopedia, [Online], Available: https://en.wikipedia.org/wiki/Embedded_system [24 Mar 2020], 2016.

[2] Embedded System. Techopedia Inc, [Online], Available: https://www.techopedia.com/definition/3636/embedded-system [24 Mar 2020], 2016.

[3] HUANG, J., PADMANABHAN, K., COLLINS, O. M.: The sampling theorem with constant amplitude variable width pulses, *IEEE transactions on Circuits and Systems*, Vol. 58, pp. 1178-1190, 2011.

[4] BARR, M.: Pulse Width Modulation, *Embedded Systems Programming*, Vol. 2001, No. 10, pp. 103-104, 2001.

[5] BARR, M.: *Introduction to Pulse Width Modulation (PWM)*, Barr Group, [Online], Available: http://www.barrgroup.com/Embedded-Systems/How-To/PWM-Pulse-Width-Modulation [24 Mar 2020], 2001.

[6] *Optocoupler Tutorial*. Electronic tutorials by AspenCore, Inc. [Online], Available: http://www.electronics-tutorials.ws/blog/optocoupler.html [24 Mar 2020], 2019.

[7] LIPTAK, B. G.: *Instrument Engineers' Handbook*: Process Control and Optimization. CRC Press, 2005.

[8] JONES, D. W.: *Friction and the Dead Zone*, http://www.divms.uiowa.edu/~jones/step/physics.html#friction

[9] KONIAR, D., HARGAŠ, L., HRIANKA, M.: *Application of standard DICOM in LabVIEW*, Proc. of 7th conf. Trends in Biomedical Engineering, Kladno 11.-13. 9. 2007, 2007.

[10] VITKO, A., JURIŠICA, L., KĽÚČIK, M., MURÁR, R., DUCHOŇ, F.: Embedding Intelligence into a Mobile Robot, *AT&P Journal Plus*, No. 1, pp. 42-44, 2008.

[11] BOŽEK, P.: Robot path optimization for spot welding applications in automotive industry, *Tehnicki vjesnik - Technical Gazette*, Vol. 20, No. 5, pp. 913-917, 2013.

[12] DUCHOŇ, F., BABINEC, A., KAJAN, M., BEŇO, P., FLOREK, M., FICO, T., JURIŠICA, L.: Path planning with modified A star algorithm for a mobile robot, *Procedia Engineering*, Vol. 96, pp. 59-69, 2014.

[13] PÁSZTÓ, P., HUBINSKÝ, P.: Mobile robot navigation based on circle recognition, *Journal of Electrical Engineering*, Vol. 64, No. 2, pp. 84-91, 2013.

[14] ABRAMOV, I. V., NIKITIN, Y. R., ABRAMOV, A. I., SOSNOVICH, E. V., BOŽEK, P.: Control and Diagnostic Model of Brushless DC Motor, *Journal of Electrical Engineering*, Vol. 65, No. 5, pp. 277-282, 2014.

[15] KONIAR, D., HARGAŠ, L., ŠTOFAN, S.: Segmentation of Motion Regions for Biomechanical Systems, *Procedia Engineering*, Vol. 48, pp. 304-311, 2012.

[16] AL-DHAHER, A.H.G: Integrating hardware and software for the development of microcontroller-based systems, *Microprocessors and Microsystems*, Vol. 25, No. 7, pp. 317-328, 2001.

[17] FISHER, D. K., KEBEDE, H., A low-cost microcontroller-based system to monitor crop temperature and water status, *Computers and Electronics in Agriculture*, Vol. 74, No. 1, pp. 168-173, 2010.

[18] QIN, Y., YU, B.: Heuristic Education of Microcontroller Unit Principle and Applications, *Procedia Engineering*, Vol. 24, pp. 708-712, 2011.

[19] KARAVAEV, Y. L., KILIN, A. A.: Nonholonomic dynamics and control of a spherical robot with an internal omniwheel platform: Theory and experiments, *Proceedings of the Steklov Institute of Mathematics*, Vol. 295, No. 1, pp. 158-167, 2016.

[20] VIRGALA, I., MIKOVÁ, Ľ., KELEMEN, M., HRONCOVÁ, D.: Snake-like robots, *Acta Mechatronica*, Vol. 3, No. 4, pp. 7-10, 2018.
[21] MIKOVÁ, Ľ., VIRGALA, I., KELEMEN, M.: Embedded systems, *Acta Mechatronica*, Vol. 3, No. 2, pp. 1-5, 2018.
[22] KELEMENOVÁ, T., FRANKOVSKÝ, P., VIRGALA, I., MIKOVÁ, Ľ., KELEMEN, M., DOMINIK, L.: Educational models for mechatronic courses, *Acta Mechatronica*, Vol. 1, No. 4, pp. 1-6, 2016.
[23] LIPTÁK, T., KELEMEN, M., GMITERKO, A., VIRGALA, I., HRONCOVÁ, D.: THE CONTROL OF HOLONOMIC SYSTEM, *Acta Mechatronica*, Vol. 1, No. 2, pp. 15-20, 2016.
[24] KURYŁO, P., PIVARČIOVÁ, E., CYGANIUK, J., FRANKOVSKÝ, P.: Machine vision system measuring the trajectory of upper limb motion applying the Matlab software, *Measurement Science Review*, Journal of Institute of Measurement Science of Slovak Academy of Sciences. Bratislava. Vol. 19, No. 1, pp. 1-8, 2019.

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SIGNAL NOISE REDUCTION AND FILTERING

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Keywords: measurement, noise, filter
Abstract: The paper deals with noise reduction in signal. Normally measured signal very frequently includes noise and data processing includes the activities for its reduction. The best choice is to reduce the source of noise, but often it is not possible to reduce noise source. Filtering is another activity, which helps us to reduce noise in measured signal. Data processing can be executed only with filtered signal.

1 Introduction

Measurement is a set of actions to determine the value of a measurand, which can be performed manually or automatically.

A measuring instrument is a device intended for the conversion of a measured quantity into a quantity holder signal bearing information about its value (data) with possible displaying of the measured value on the indicating device. In most cases, the measuring device is understood to be a ready-to-use compact device. The equivalent term measurement instrument is also often used.

A measuring device is a set of technical means and measuring instruments designed to carry out the measurement of a selected quantity, including all measuring instruments and other auxiliary measuring devices necessary for the application of the given measuring method. The measuring device need not be in a compact state but can be tailored to the application.

The measuring instrument and measuring device are as chains of blocks - a measuring chain in which the measured quantity (input) is transformed into an output quantity i. e. measuring instrument data. A single measuring string may take the form of serially connected blocks (Figure 1).

A signal is a physical quantity that carries added modulated information about the measured quantity with which it is functionally coupled.

The sensor (sensor) transforms a physical quantity into another quantity, so-called quantity holder of information. The sensor transforms information from the physical area of the measured quantity into another physical area, for example a signal to a unified signal, most often to an electrical unified signal.

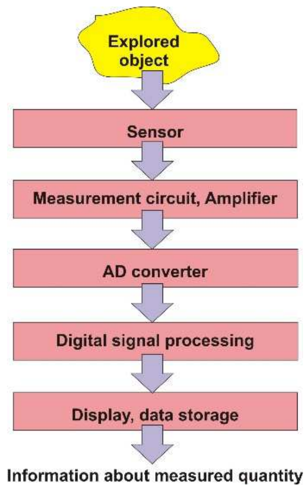

Figure 1 Structure of measurement instrument

Unified signal - moves within a predefined range of the quantity holder variable. eg.:

- 0 to 20 mA or 4 to 20 mA current signal
- 0 to 10 V or -10 to +10 V voltage signal
- pneumatic signal 20 to 100 kPa.

There are two types of signals: according to the nature of information transformation:

- analogue signals (arbitrary value),
- discrete signals, digital signals (finite number of values).

The measurement process can also be controlled by a microprocessor. The microprocessor may perform some activities in a block diagram. However, it is most often used for signal processing and compensation of disturbances. Advantages of microprocessor-controlled measuring instruments:

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- the possibility of configuring device features according to user requirements
- possibility to connect several types of sensors
- possibility to modify static characteristic (zero-point shift, change of directive)
- suppression of interferences affecting the measured quantity
- limit state signalization
- the possibility of communicating with the computer
- blocking against unwanted interference
- processing of measured data (average, MAX, MIN, Modus, Median, ...)
- possibility of archiving measured data
- self-diagnosis
- self-calibration
- remote control and data acquisition (GSM, WiFi, ...)

Signal processing is area, which focuses to analysis, to modify and to synthetize the signal captured as sound, image or measurement set. Al activities is used because of a better transferring and storage of the signal.

Mainly analogue signal is damaged with noise. For this purpose are used many additional devices as passive or active filters, mixers, integrators, amplifiers, oscillators etc.

2 Signal noise

Noise reduction is an activity for rejection of noise from signal from measurement and also from sound or image source. Algorithm of reduction depends on character of signal and noise. Noise is characterized as unwanted part of the signal. This unwanted part is as random disturbance (Figure 2).

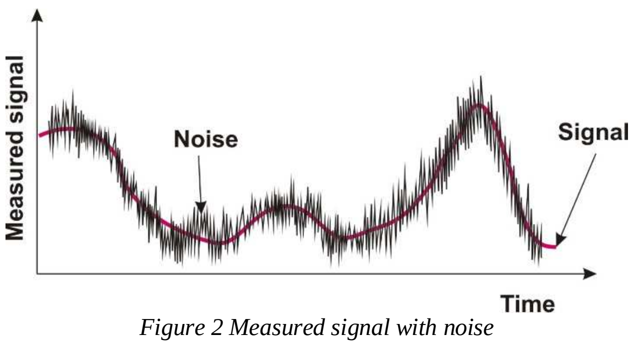

Figure 2 Measured signal with noise

There are several types of noise:

- Short impulse (spikes) and harmonic noise (high-frequency and low-frequency noise)
- White noise
- Impulse, non-stationary noise

Practically, for noise is used colour classification obtained from analogy of sound and light wave spectrum frequencies. White noise (Figure 3) is coming from analogy to white light, which has flat frequency wave spectrum.

Figure 3 White noise

Pink noise (Figure 4) has linearly proportionally wide frequency spectrum in logarithmic scale. Spectral density of pink noise decreases by constant decrement 3 dB per octave.

Brown noise or also called as Brownian noise (Figure 5) has power density which is decreased by 6dB per octave with increasing frequency shown in logarithmic scale.

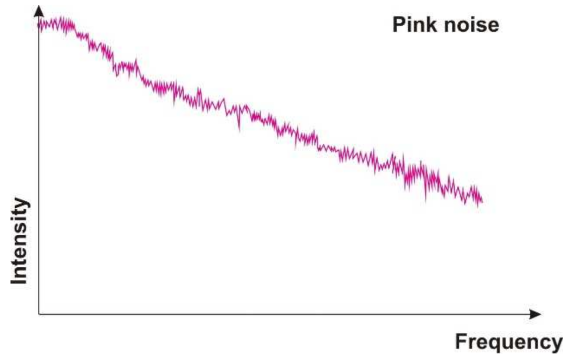

Figure 4 Pink noise

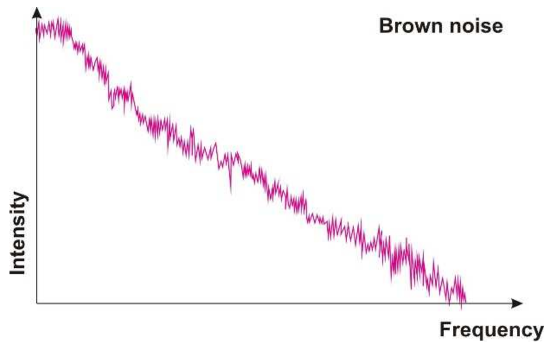

Figure 5 Brown noise

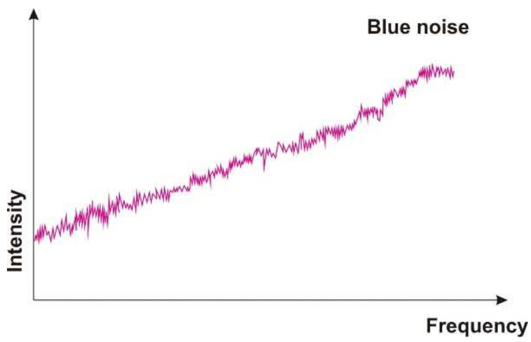

Figure 6 Blue noise

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Blue noise (Figure 6) has power density which is increased by 3dB per octave with increasing frequency shown in logarithmic scale.

3 Noise reduction

There are several ways of noise reduction:

- Faraday cage - is a fully enclosed cage made of an electrically conductive material (e.g. wire mesh). The interior of the cage is protected against the effects of external electric, electrostatic and electromagnetic fields and waves. The principle lies in the characteristic of the electric charge, which concentrates only on the surface of the driver, but not in its volume. The cage as a whole acts as a driver, so there is no charge in its inner volume. Electromagnetic radiation is absorbed by the surface of the cage.
- Shielding cables – electric cable composed from one or more insulated wires in common isolation and covered by conductive layer from foil or braided strands made from aluminium or cooper. Shield should be connected to ground and it works like faraday cage.
- Filtering – electronic circuits, which enable to pass of certain frequencies and to block unwanted frequencies through the filter.

Filters can be divided into two main groups as passive and active filters. Passive filters are composed from combination of passive electric components as resistors, capacitors and inductors. Inductors have ability to block high frequency part of signal and allow to flow low frequency part of signals. Capacitors block low frequency part of signals and allows flow of high frequency part of signals. Resistor has no direct impact to transmitted frequency, but it has influence to value of time constant of filter circuit.

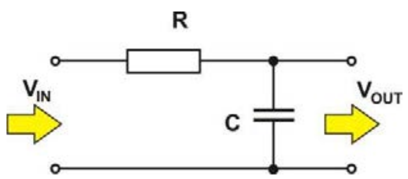

Figure 7 Low-pass frequency passive filter

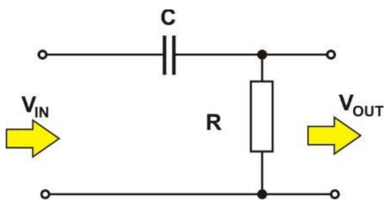

Figure 8 High-pass frequency passive filter

These passive components can be used for building of simple passive low-pass frequency filter (Figure 7), high-pass frequency filter (Figure 8).

Low pass filter is used for removing of high frequency noise. But high pass filter is used for removing of low frequency noise. Beside the mentioned passive filters, there are also Band-pass filter and Band-stop filter. Band-pass filter allows to pass only wanted band of frequencies, but Band-stop filter blocks only frequencies belong to specified bans (Figure 9). Frequency response shown on figure 9 is only ideal case. Real frequency responses of filters have different characteristic. Rising edge and falling edge are not rectangular but there is any slope angle on these responses (Figure 10).

Low-pass filter shown on figure 7 is also called as "first order filter", because it includes only one reactive components (capacitor). For low-pass filters (Figure 7), it is possible derive the equation for cut-off frequency (also called as "break-point"). For low-pass filter it specifies the frequency when input signal amplitude is reduced by value -3dB. For low-pass filter it is defined as:

$$f_{cutoff} = \frac{1}{2\pi \cdot R \cdot C} \quad (1)$$

The same equation for cut-off frequency is valid also for high-pass filter.

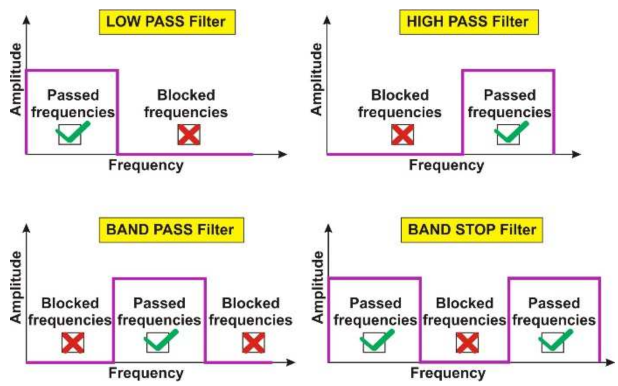

Figure 9 Ideal frequency response of basic types of passive filters

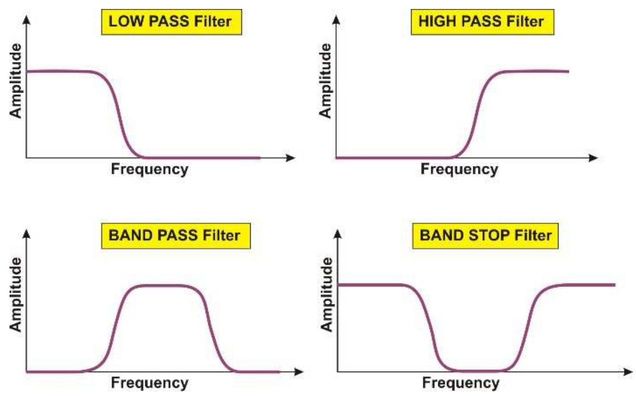

Figure 10 Frequency response of basic types of passive filters

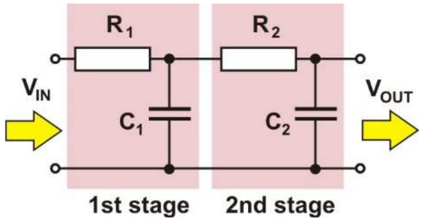

Figure 11 Second order low-pass passive filter

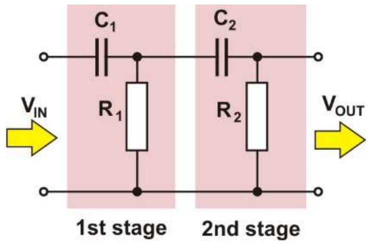

Figure 12 Second order high-pass passive filter

Cutt-off frequency for both second order filters (low-pass and high-pass) is defined as follow:

$$f_{cutoff} = \frac{1}{2\pi \cdot \sqrt{R_1 \cdot R_2 \cdot C_1 \cdot C_2}} \quad (2)$$

Active filters include also active electronic parts for amplifying of signal intensity. Normally, transistor or operational amplifiers are used for this purpose. For example, non-inverting amplifier can be used as it shown on figure 13 for low-pass active filter and high-pass active filter shown on figure 14. These filters are based on Sallen-Key topology.

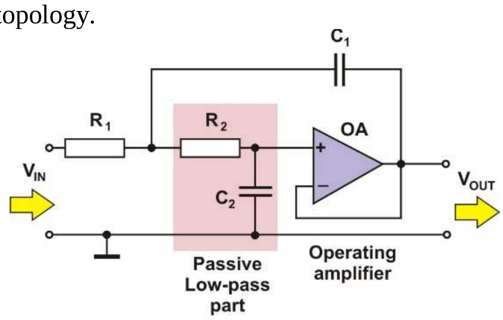

Figure 13 First order low-pass active filter

Natural undamped frequency f_0 is defined:

$$f_0 = \frac{1}{2\pi \cdot \sqrt{R_1 \cdot R_2 \cdot C_1 \cdot C_2}} \quad (3)$$

Attenuation is defined as:

$$A_T = \frac{1}{2 \cdot C_1} \cdot \frac{R_1 + R_2}{R_1 \cdot R_2} \quad (4)$$

Analogically, it is possible to build high-pass active filter (Figure 14). Natural frequency is defined with the same equation as before, but attenuanion is defined as:

$$A_T = \frac{1}{2 \cdot R_2} \cdot \frac{C_1 + C_2}{C_1 \cdot C_2} \quad (5)$$

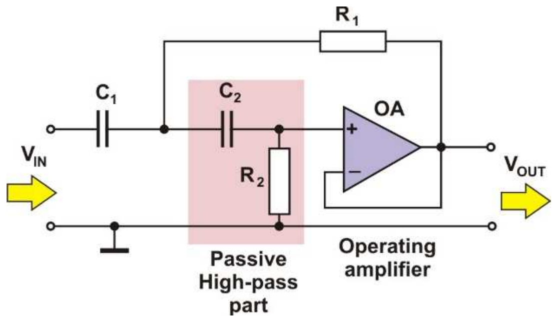

Figure 14 First order high-pass active filter

4 Filtering

Activity of displacement actuator has been measured via using the measurement data acquisition card into PC. Measured signal (Figure 15) is damaged by noise and this signal cannot be used for analysis and for this reason it is necessary to repair it. Noise source was not identified. Therefore, the only possible way is to filter the measured signal. The measured signal was recorded in a file (Figure 15) and its offline processing is thus possible additionally.

Offline data processing can be realized via using of simulation model (Figure 16) with data recorded from real process.

The course of the measured signal (Figure 15) is wavy, and this indicates the presence of higher frequencies in the signal. For this purpose, a frequency analysis was performed (Figure 16), according to which the individual frequencies of the signals present in the measured course were identified (Figure 17).

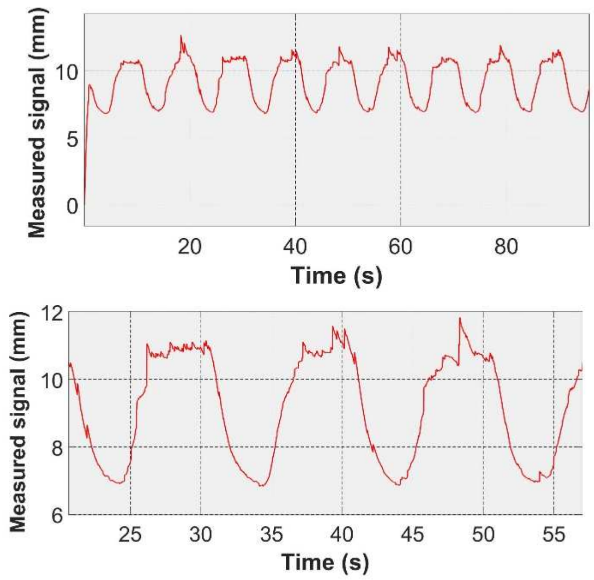

Figure 15 Measured signal and selected detail of noised signal

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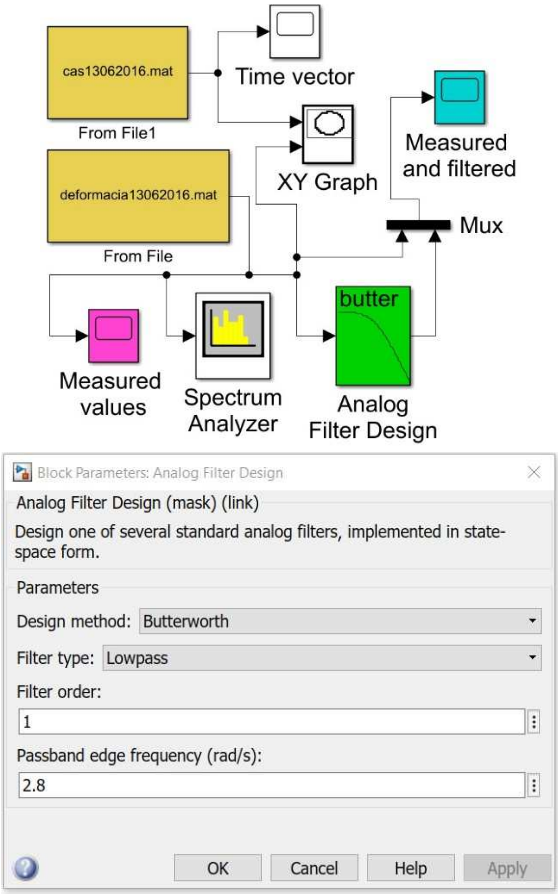

Figure 16 Simulink model for data filtering and setup of filter parameters

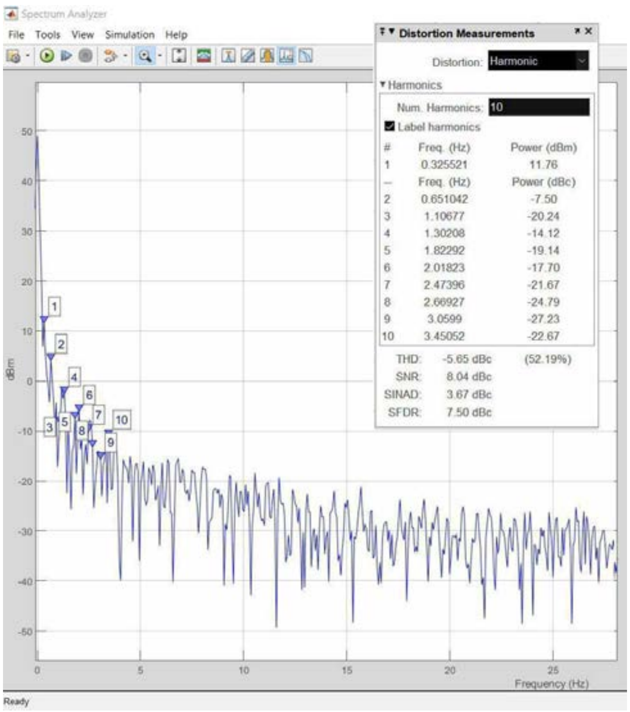

Figure 17 Spectrum analysis in Matlab/Simulink

Result from Spectrum analyser (Figure 17) shows amplitudes of all frequencies. We know that excitation frequency of actuator was 0.3Hz and this signal is the main signal. Other higher frequencies are undesirable, and we would like to reject them from measured signal.

Low pass filter has been proposed into simulation structure (Figure 16) for suppressing of higher frequencies. Result if filtering is visible on Figure 18.

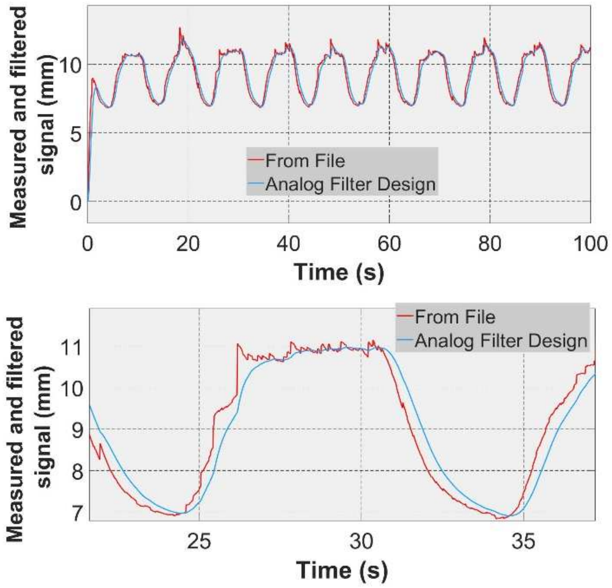

Figure 18 Filtered signal and detail of signal

The filtered signal (Figure 18) is smoothed, and it is possible to make any analysis of actuator dynamic characteristic. As it is visible the filtered signal has also phase shifting as small-time delay of signal.

5 Conclusion

Almost all measurement systems have problems with data processing, because of noise, which is mixed into measured signal. Very frequently measured quantity is lost inside the noise and filtering is inseparable activity during the measuring process [1-23].

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References

[1] MILIC, L.: *Multirate Filtering for Digital Signal Processing: Matlab Applications*, Information Science Reference, Hershey – NewYork, 2009.

[2] LUTOVAC, M. D., TOŠIĆ, D.V., EVANS, B. L.: *Filter Design for Signal Processing Using MATLAB and Mathematica.*, 2001.

[3] SALIVAHANAN, S., Vallavaraj, A.: *Digital Signal Processing*, McGraw-Hill Education, NewYork, 2001.

[4] LACANETTE, K.: *A Basic Introduction toFilters–Active, Passive,and Switched-Capacitor*, National Semiconductor Application Note 779, National Semiconductor Corporation, April 1991, 22 pages.

[5] WINDER, S.: *Analog and Digital Filter Design*, 2nd ed., Newnes. Elsevier Science (USA), 2002.

[6] INGLEJOHN, V. K., PROAKIS, G.: *Digital Signal Processing Using MATLAB*, 3rd ed., Northeastern University, Cengage Learning, 2012.

[7] EA-4/02 M:2013 *Evaluation of the Uncertainty of Measurement In Calibration*, Publication Reference, European Accreditation Laboratory Committee, September 2013 rev 01. cited August 8th, 2019, Available online: https://european-accreditation.org/wp-content/uploads/2018/10/ea-4-02-m-rev01-september-2013.pdf.

[8] JCGM 200: 2012, *International vocabulary of metrology – Basic and general concepts and associated terms (VIM)*, 3rd ed., (BIPM, 2012).

[9] JCGM 100 – *Evaluation of measurement data – Guide to the expression of uncertainty in measurement (ISO/IEC Guide 98-3)*, 2008, Available online: http://www.iso.org/sites/JCGM/GUM-JCGM100.htm; http://www.bipm.org/en/ publications/ guides/gum_print.html.

[10] MSA-L/11 *Guidelines on the expressions of uncertainty in quantitative testing* (EA - 4/16: 2003). Guidelines on the expression of uncertainty in quantitative testing. Slovak national accreditation service, SNAS BRATISLAVA, August 2009. (Original in Slovak)

[11] MSA–L/12 *Expression of the uncertainty of measurement in calibration* (EA-4/02) - Expression of the uncertainty of measurement in calibration, Slovak National Accreditation Service, SNAS BRATISLAVA, November 2010. (Original in Slovak)

[12] PALENCAR, R., SOPKULIAK, P., PALENCAR, J., ĎURIŠ, S., SUROVIAK, E., HALAJ, M.: Application of Monte Carlo method for evaluation of uncertainties of ITS-90 by standard platinum resistance thermometer, *Measurement Science Review*, Vol. 17, No. 3, pp. 108-116, 2017.

[13] WIMMER, G., PALENČÁR, R., WITKOVSKÝ, V.: *Stochastic models of measurement*, Graphic studio Ing. Peter Juriga, Ľ. Fullu 13, 841 05 Bratislava, 2001. (Original in Slovak)

[14] BOŽEK, P., CHMELÍKOVÁ, G.: *Virtual Technology Utilization in Teaching*, Conference ICL2011, September 21-23, 2011, Piešťany, Slovakia, pp. 409-413. 2011.

[15] TURYGIN, Y., BOŽEK, P.: Mechatronic systems maintenance and repair management system, *Transfer of innovations*, Vol. 26, pp. 3-5. 2013.

[16] HARGAŠ, L, HRIANKA, M, KONIAR, D, IZÁK, P.: Quality Assessment SMT Technology by Virtual Instrumentation. *Applied Electronics* 2007, 2007.

[17] SPANIKOVA, G., SPANIK, P., FRIVALDSKY, M., PAVELEK, M., BASSETTO, F., VIDIGNI, V.: Electric model of liver tissue for investigation of electrosurgical impacts, *Electrical Engineering*, Vol. 99, No. 4, pp. 1185-1194, 2017.

[18] KARAVAEV, Y. L., KILIN, A. A.: Nonholonomic dynamics and control of a spherical robot with an internal omniwheel platform: Theory and experiments, *Proceedings of the Steklov Institute of Mathematics*, Vol. 295, No. 1, pp. 158-167, 2016.

[19] VIRGALA, I., MIKOVÁ, Ľ., KELEMEN, M., HRONCOVÁ, D.: Snake-like robots, *Acta Mechatronica*, Vol. 3, No. 4, pp. 7-10, 2018.

[20] MIKOVÁ, Ľ., VIRGALA, I., KELEMEN, M.: Embedded systems, *Acta Mechatronica*, Vol. 3, No. 2, pp. 1-5, 2018.

[21] KELEMENOVÁ, T., FRANKOVSKÝ, P., VIRGALA, I., MIKOVÁ, Ľ., KELEMEN, M., DOMINIK, L.: Educational models for mechatronic courses, *Acta Mechatronica*, Vol. 1, No. 4, pp. 1-6, 2016.

[22] LIPTÁK, T., KELEMEN, M., GMITERKO, A., VIRGALA, I., HRONCOVÁ, D.: THE CONTROL OF HOLONOMIC SYSTEM, *Acta Mechatronica*, Vol. 1, No. 2, pp. 15-20, 2016.

[23] PIRNÍK, R., HRUBOŠ, M., NEMEC, D., BOŽEK, P.: Navigation of the autonomous ground vehicle utilizing low-cost inertial navigation, *Acta Mechatronica*, Vol. 1, No. 1, pp. 19-23, 2016.

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