Mössbauer spectrometer with very high channel resolution utilizing real-time industrial computer

Pavel Kohout[1,2], Lukáš Kouřil[2], Antonín Opíchal[1,2], Alena Kohoutová[1,2] and Jiří Pechoušek[2]
[1] Joint Institute for Nuclear Research, Joliot-Curie 6, 141980 Dubna Moscow region, Russia
[2] Department of Experimental Physics, Faculty of Science, Palacký University in Olomouc, 17. listopadu 1192/12, 771 46 Olomouc, Czech Republic

Introduction

This paper reports the development of a new Mössbauer spectrometer based on modular industrial computer and virtual instrumentation technique. Virtual instrumentation is new technology, which is used for development of measurement and test systems. It allows replacing complex analog circuits with computers and software. Thanks to this technology, it is now possible to easily create complex automatic control systems, that allows to implement processes with e.g. self-diagnosis or self-setup, and which do not need the immediate presence of an operator because their management may be possible via the Internet or those system can be completely autonomous. Another technology that is becoming increasingly important are FPGA (Field Programmable Gate Arrays). Because of their configurability, determinism and speed they have found wide use in many areas where there is need for great computing power - even in nuclear physics. This talk will deal with combining those two new technologies for creating Mössbauer spectrometer. Mössbauer spectrometry is spectrometric method, which uses Mössbauer effect - recoilless emission and absorption of gamma rays by certain nuclei

Methods

Developed Mössbauer spectrometer is based on modular industrial computer CompactRIO by National Instruments™ and programmed in LabVIEW™ graphical programming environment. This device has integrated FPGA, which is used for most critical functions, as scintillation detector signal acquisition, spectra processing and driving of transducer movement. The first part of the study deals with the development of spectrometric application on a CompactRIO, that performs velocity reference signal generation, velocity transducer PID regulation, detector signal acquisition and spectrum registration. The second part deals with PID parameters autotuning using evolution algorithms and additional spectra linearization methods implemented in developed Mössbauer spectrometer.

Hardware and Software

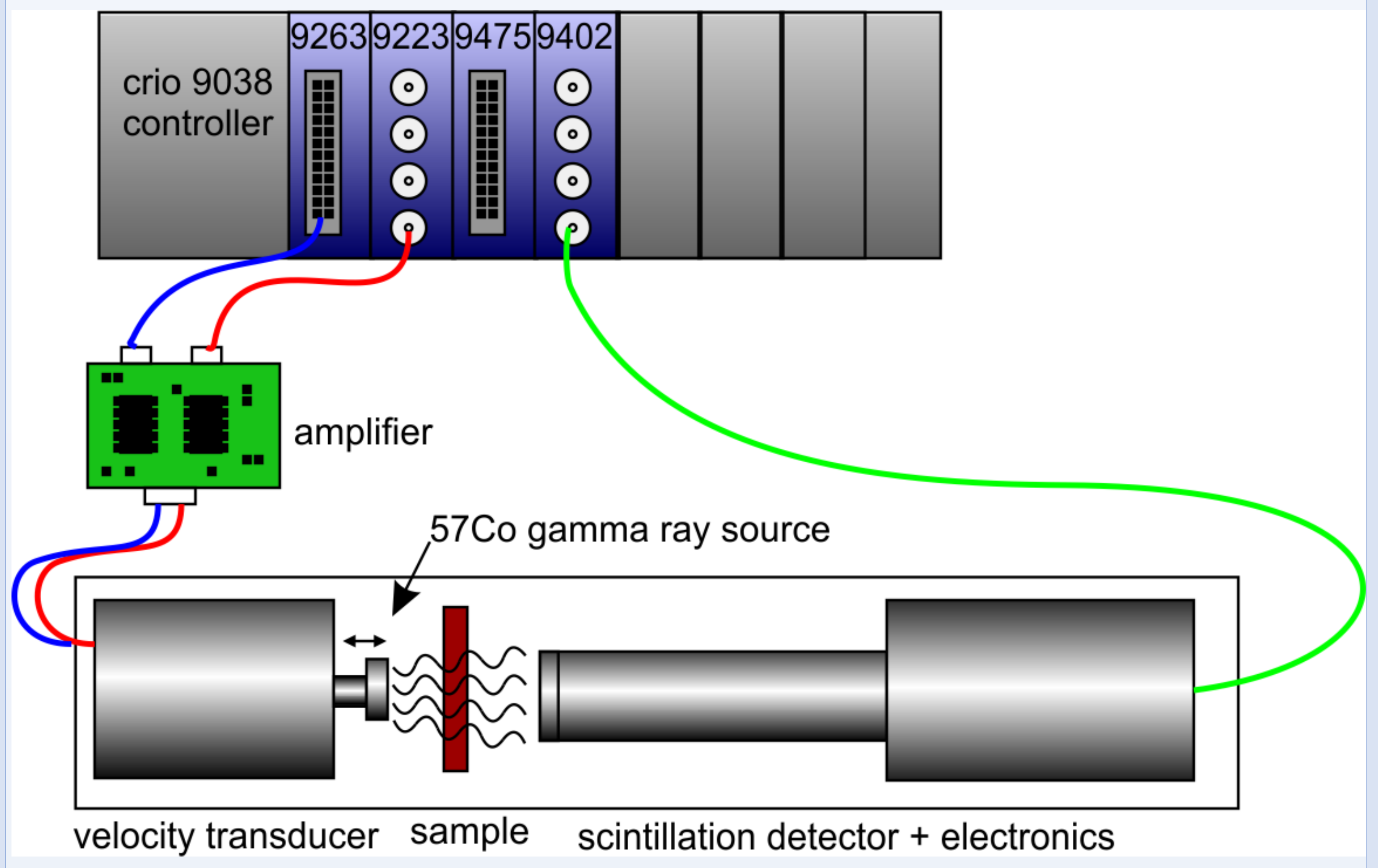


Fig. 1. Wiring scheme of developed spectrometer

Wiring diagram of individual spectrometer parts is shown on Fig 1. The used CompactRIO setup is on the top. It consists of NI cRIO 9038 controller, NI 9263 Analog output card, NI 9223 analog input card and NI 9402 fast digital inputs and outputs card. From the NI9263 analog output card leads the coaxial cable to the amplifier board. Amplifier board uses Texas Instruments OPA547T operating amplifier for amplification of pickup coil signal and Texas Instruments LF356N operating amplifier for amplification of drive coil signal. The amplified signal leads to the velocity transducer, which is placed in a spectrometric bench based on the [1]. Velocity transducer (based on [2]) modulates the gamma rays by its movement via Doppler effect. Movement induces electrical current in the pick-up coil, which is then routed via the coaxial cable to the amplifier and then to the NI9223 analog inputs card. A sample holder is placed opposite to the velocity transducer and scintillating detector is behind it. The detector has integrated high voltage source, signal amplifier and amplitude discriminator [3]. The amplitude-discriminated signal is then fed into the NI 9402 fast digital inputs and outputs card.

There are two places, where the programmed software is deployed – the real-time part and the FPGA. The FPGA part offers higher computing power, but the program code is limited by the number of the gates. There is also the host computer, which is connected remotely via ethernet. This host computer is used for programming the CopmactRIO and when the development is done, it is used also for control. Control can be done also with other computer with corresponding application or even with smartphone or tablet.

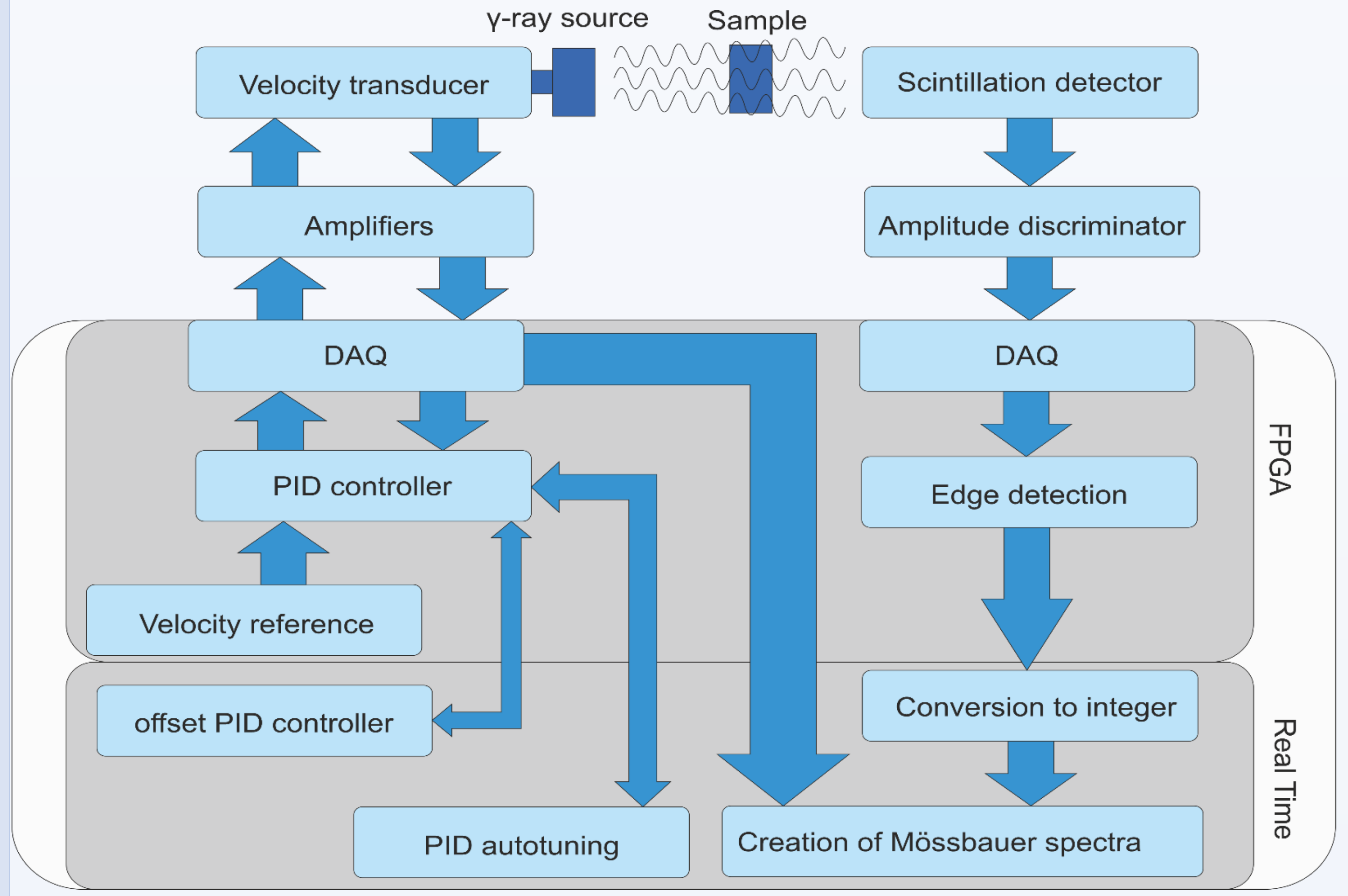

γ-ray source
Sample
Velocity transducer
Scintillation detector
Amplifiers
Amplitude discriminator
DAQ
DAQ
PID controller
Edge detection
Velocity reference
offset PID controller
Conversion to integer
PID autotuning
Creation of Mössbauer spectra
FPGA
CompactRIO
Real Time

Fig. 2. Block diagram of program code of developed Mössbauer spectrometer.

Fig. 2 shows a block diagram of spectrometric application of the developed spectrometer. This program consists of two parts. First part is dedicated to velocity driving and second performs the data acquisition of signal from the scintillation detector

Velocity driving system

The velocity driving system consists of virtual velocity reference signal generator, which uses look-up table with ideal velocity waveform and PID regulator, which drives the transducer movement. On the real-time part of CompactRIO, there is located the genetic algorithm for autotuning of PID controller parameters similar to [4], which minimalizes the error signal amplitude. Second PID regulator which regulates the DC value of velocity signal is located also on the real-time part CompactRIO.

DAQ and Mössbauer spectra creation

Detection of signal from scintillation detector is performed using an integrated single-channel analyzer [3]. The single-channel analyzer is used with a LabVIEW™ program, which scans channels step by step and performs multi-channel analysis. After finding suitable channel, that corresponds to required energy of gamma photons, single-channel analyzer is set to this channel. At the output of a single-channel analyzer, pulses about 300 ns long with amplitude of 5 V are obtained. Original pulse from detector is displayed on Fig. 3 (a) and the same pulse after amplitude discrimination is displayed on Fig. 3 (b). The signal from the detector (now only logic pulses) is then read by digital input on the measuring card NI 9402. Sampling period of digital inputs is 33,3 ns, so it is more than enough to fulfill the sampling theorem for detection of 300 ns long pulses. This card uses LVTTL (low voltage transistor-transistor-logic) logic and is tolerant to 5 V. A signal between 0.0 V and 0.8 V is considered a logical “0” and signal are between 2.2 V and 5.5 V is considered a logical “1”. After digitalization, this signal is represented only with array of Boolean values saved at the FPGA (see Fig. 3 (c)). This solution was chosen to save the capacity of the FPGA - storing data in the FPGA is very demanding on the number of logic gates used. In the next step, the edge detection is performed. Only first bits of sequence will remain, every following bit is changed to “0” (see Fig. 3 (d)). Also sequences shorter than 8 bits are changed to 0. This is done for filtering the noise, because valid pulse should be approximately 300 ns long, which corresponds approximately to 9 bits. Now a positive bit indicates detection of valid pulse which corresponds to the detection of a gamma photon in a selected energy interval. A zero bit indicates that there was no valid detection.

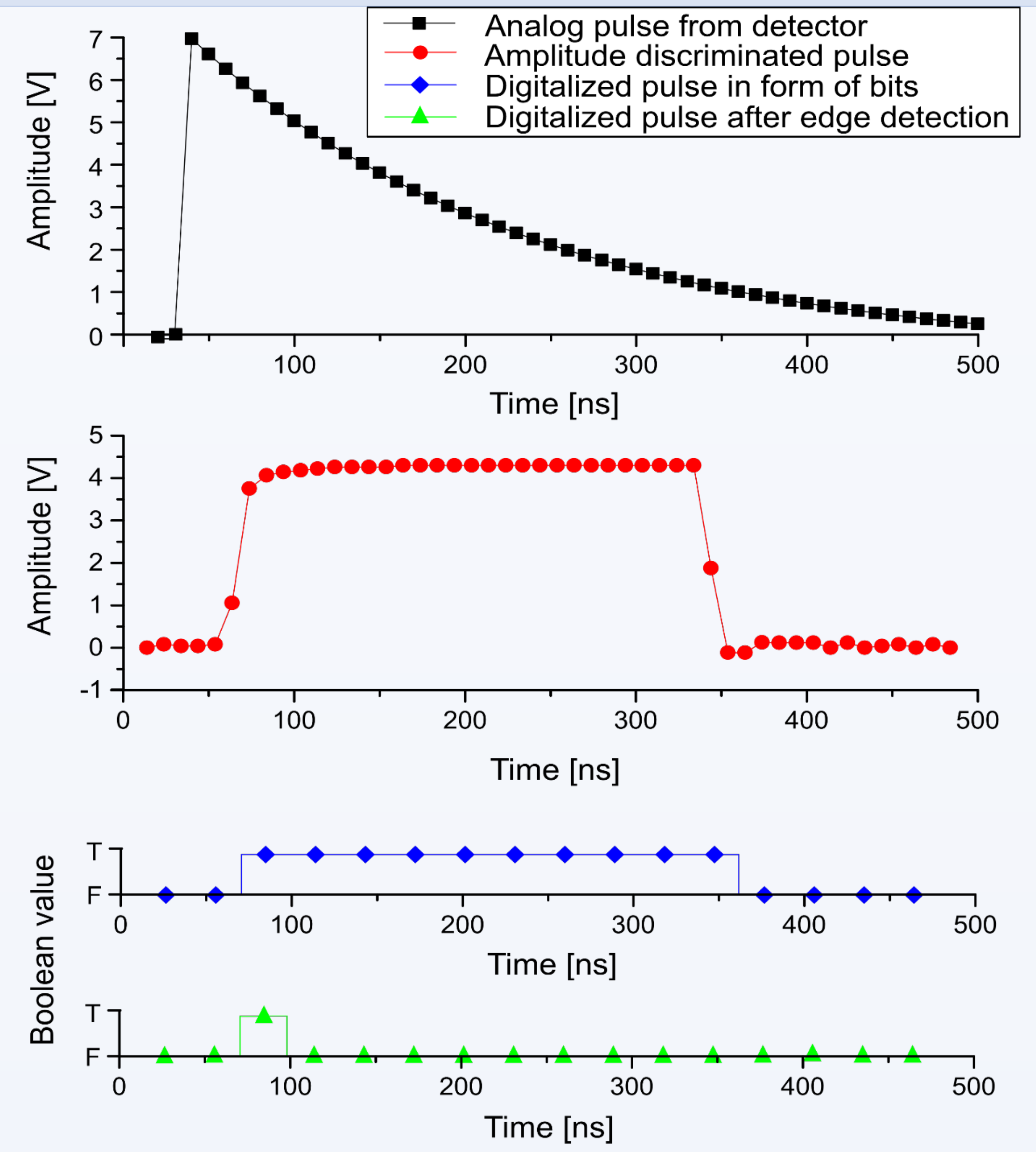
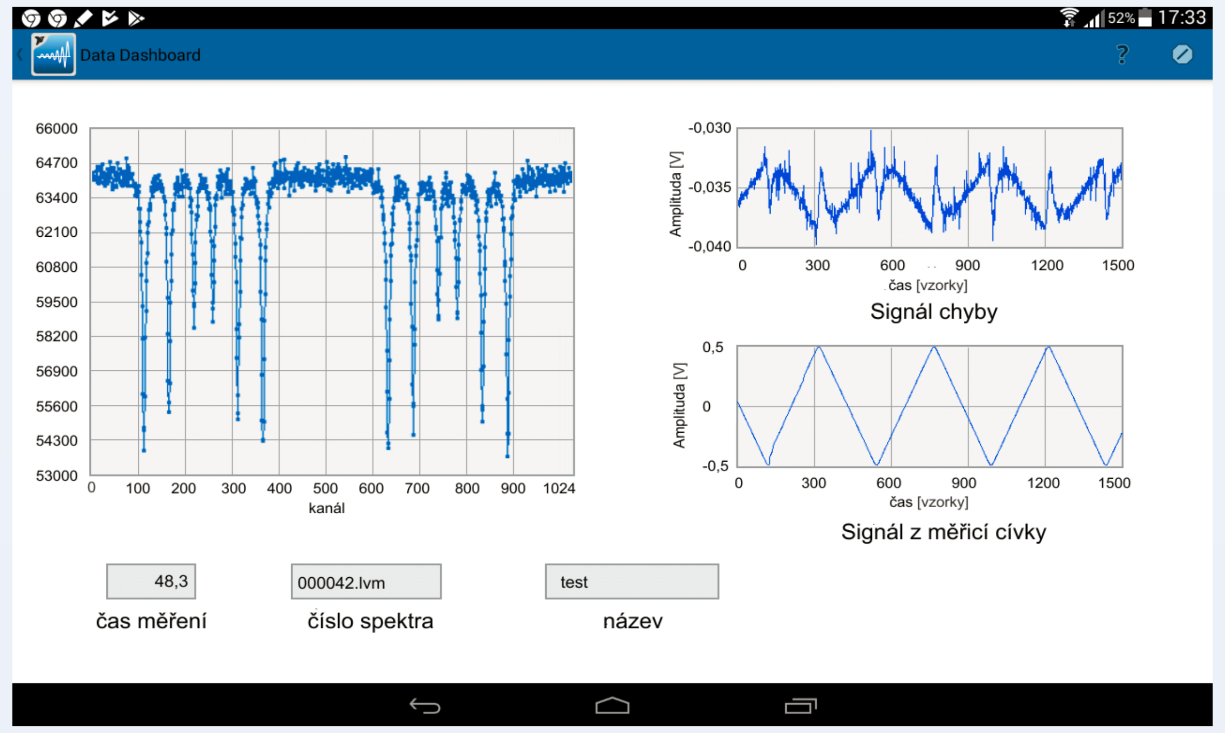


Fig. 3. Processing of signal from scintillation detector. Original signal from scintillation detector (a), signal after amplitude discrimination (b), Boolean representation of signal as an array in FPGA of CompactRIO (c), Boolean representation of valid detections of gamma rays after edge detection (d).

Array with valid detection bits is transferred to the real-time part of the CompactRIO system, where it is converted to array with integer 0 and 1 and summed with arrays from all periods. Sum of arrays from all the periods then represents the Mössbauer spectrum. Timing of FPGA provides synchronization between velocity driving system and detection system, so every array element corresponds to precise velocity interval and thus precise energy interval thanks to the Doppler effect. This Mössbauer spectrum has very high number of channels. If the frequency of Doppler modulator is 30 Hz and sampling time of digital input is 33,3 ns, the Mössbauer spectrum has 1 million of channels. This high number of channels is usable for further spectra processing [5], [6]. After processing it is summed to form 1024 channels spectrum (unfolded) as it is common in Mössbauer spectroscopy. Front panel of developed spectrometer with example Mössbauer spectrum is displayed on Fig. 4.



48,3
čas měření

000042.lvm
číslo spektra

test
název

Fig. 4. Front panel of developed spectrometer, displayed in LabVIEW Data Dashboard for Android. On the left there is Mössbauer spectrum, On the right the error signal and velocity signal.

Results and conclusion

Spectral lines positions, nonlinearities and FWHMs obtained from α-Fe calibration sample are shown on Table 1. Nonlinearity of velocity axis is 0,01% or lower for each spectral line. Developed spectrometer shows comparable or better calibration spectra parameters than previous spectrometer models (compare with [7]). The additional linearization methods allow to increase the spectra linearity in a wider frequency and amplitude range of a drive signal (up to 100 Hz and ±120 mm/s [5], [6] with the mini transducer, which was designed to measure at maximal velocity range ±70 mm/s [2]). Error signal amplitude is below 10 mV [5], [6].

Table 1: Spectral lines positions x(i), nonlinearities non(i) and FWHMs obtained from α-Fe calibration sample.

i	1	2	3	4	5	6
x(i) [mm/s]	-5,3122	-3,0776	-0,8396	0,8395	3,0757	5,3145
non(i) [%]	0,0105	0,0102	0,0050	0,0036	0,0085	0,0103
FWHM [mm/s]	0,3354	0,3281	0,3126	0,3104	0,3314	0,3369

Conclusion

Due to its simple configurability, the developed spectrometer offers many improvements, such as easy implementation of advanced procedures for further improvement linearity of the velocity axis. Those advanced procedures allow achieve better spectra linearity in a wider frequency and amplitude range of a drive signal. Also, it simplifies operation by automatic tuning of PID parameters or remote control and monitoring via internet even with smartphone. Moreover, there is a possibility of developing “real-time” time-mode Mössbauer spectrometer.

Acknowledgment

This work was supported in part by the internal IGA grant of Palacký University (IGA_PrF_2020_011).

References

[1] J. Pechoušek, D. Jančík, J. Frydrych, J. Navařík, and P. Novák, “Setup of Mössbauer spectrometers at RCPTM,” *AIP Conf. Proc.*, vol. 1489, no. 1, pp. 186–193, 2012.
[2] V. A. Evdokimov, M. Mashlan, D. Zak, A. A. Fyodorov, A. L. Kholmetskii, and O. V. Misevich, “Mini and micro transducers for Mössbauer spectroscopy,” *Nucl. Instruments Methods Phys. Res. Sect. B Beam Interact. with Mater. Atoms*, vol. 95, no. 2, pp. 278–280, 1995.
[3] J. Navařík, P. Novák, J. Pechoušek, L. Machala, D. Jančík, and M. Maslan, “Precise compact system for ionizing radiation detection and signal processing with advanced components integration and electronic control,” *J. Electr. Eng.*, vol. 66, no. 4, pp. 220–225, 2015.
[4] A. J. A. Nazir, Gautham, R. Surajan, and L. . Binu., “A simplified Genetic Algorithm for online tuning of PID controller in LabView,” in *2009 World Congress on Nature & Biologically Inspired Computing (NaBIC)*, 2009, pp. 1516–1519.
[5] P. Kohout, J. Pechoušek, and L. Kouřil, “Evaluation of Mössbauer spectra linearization methods,” *Hyperfine Interact.*, vol. 240, no. 1, Dec. 2019.
[6] P. Kohout, T. Frank, J. Pechousek, and L. Kouril, “Mössbauer spectra linearity improvement by sine velocity waveform followed by linearization process,” *Meas. Sci. Technol.*, vol. 29, no. 5, p. 057001, May 2018.
[7] J. Pechousek, R. Prochazka, M. Mashlan, D. Jancik, and J. Frydrych, “Digital proportional-integral-derivative velocity controller of a Mössbauer spectrometer,” *Meas. Sci. Technol.,* vol. 20, no. 1, p. 017001, Jan. 2009