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

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I. 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 spectrometery is spectrometric method, which uses Mössbauer effect - recoilless emission and absorbtion of gamma rays by certain nuclei.

II. 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.

A. Hardware and software

Wiring diagram of individual spectrometer parts is shown on Figure 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. Analog inputs and outputs are connected using 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.

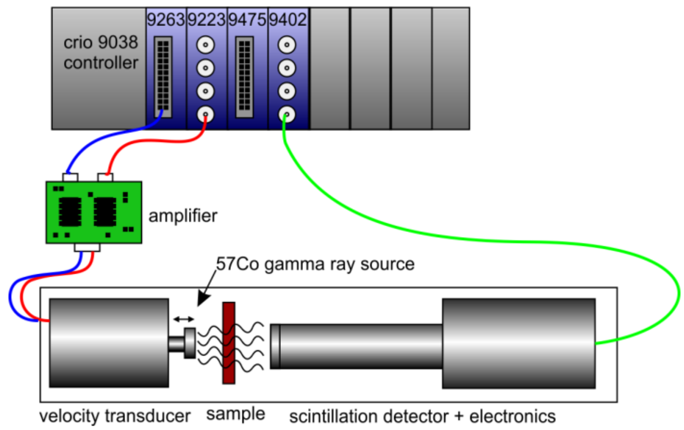

Fig. 1. Wiring scheme of developed spectrometer

Fig. 2 shows architecture of CompactRIO. There 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 with smartphone or tablet.

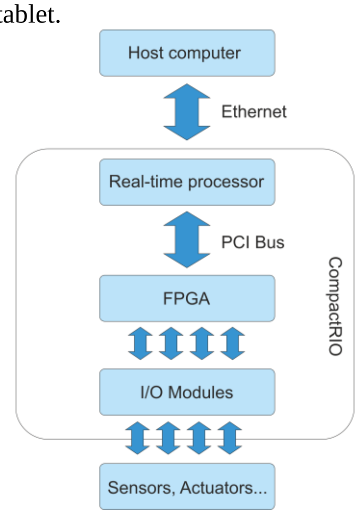

Fig. 2. CompactRIO architecture.

Fig. 3 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.

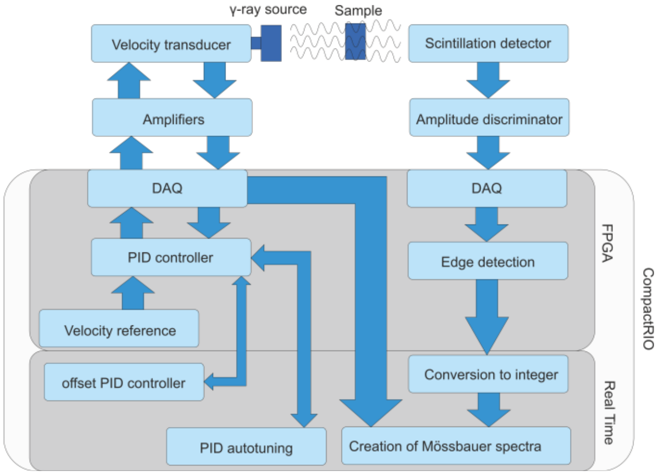

Fig. 3. Block diagram of program code of developed Mössbauer spectrometer.

B. *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.

C. *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. 4 (a) and the same pulse after amplitude discrimination is displayed on Fig. 4 (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. 4 (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. 4 (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.

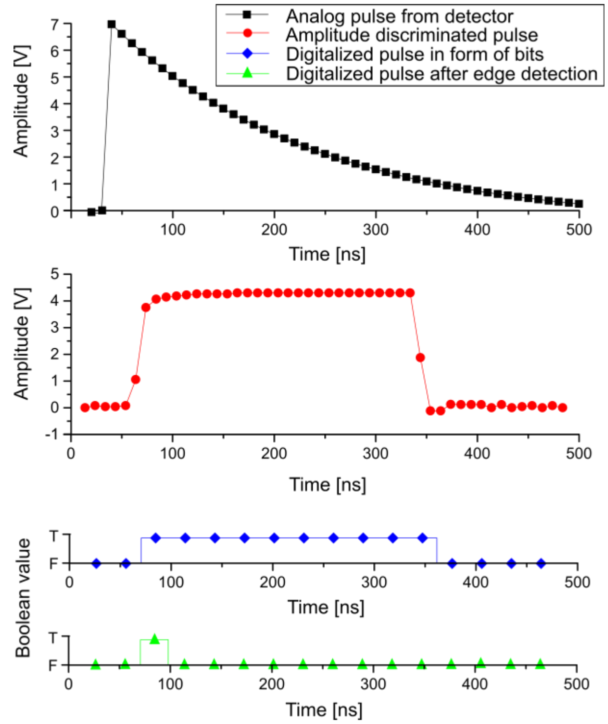

Fig. 4. Processing of signal from scintillation detector. Original signal from scintillation detector (a), signal after amplitude discrimination (b), Boolean representation of signal as an array in FPGA of CompactRIO (c), Boolean representation of valid detections of gamma rays after edge detection (d).

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 of 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.

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