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# Mössbauer spectrometer MsAa-3

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**Abstract.** The paper is aimed at the description of the newly developed Mössbauer spectrometer MsAa-3. The spectrometer MsAa-3 consists of a high quality $\gamma$-ray spectrometer including either a proportional gas detector head or a scintillation detector head, a transducer driving system including the transducer, data storage system, and data communication system based on the TCP/IP protocol. Additionally, the Michelson-Morley interferometer is provided for precise calibration of the transducer velocity. The spectrometer is equipped with an integrated simple temperature controller. All the essential functions are remotely controlled over the TCP/IP link allowing for the spectrometer set-up as the stand-alone unit in the computer network, e.g. on the Internet. External $\gamma$-ray detectors or external complete nuclear blocks could be used as well. The spectrometer is equipped with software allowing for setting all the functions, to perform on-line control, and retrieve data. The Mössbauer data processing software MOSGRAF is enclosed as well. The latter software allows for the calculation of the variety of velocity reference functions.

**Key words:** Mössbauer spectrometer • layout • performance tests • laser calibration

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## Introduction

The spectrometer MsAa-3 is a typical Mössbauer spectrometer [1, 3–5, 8, 11, 13, 14], though of very high precision and with a modern design of electronics and general layout. Special features include TCP/IP communication and fully remote control, integrated temperature controller, and flexible down loaded velocity reference functions. This contribution is aimed at the description of the basic features of this spectrometer. The following section describes the relevant functions, which are ordered as subsequent blocks performing particular tasks. The last section is devoted to the summary of highlights and drawbacks.

## Spectrometer layout

Each of the typical Mössbauer spectrometers consists of a nuclear block (NB) responsible for the collection of desired $\gamma$-quanta, a transducer driving system including a transducer (TR), and a control and data storage unit equipped with some communication port (CP). Additional blocks are required frequently as well. A short description of the basic blocks for the MsAa-3 spectrometer follows below.

### Nuclear block

The nuclear block is a complete multichannel $\gamma$-ray spectrometer. It contains a detector head equipped with the detector, preamplifier and high voltage (HV) power supply for the detector. Two heads have been developed. One can use either a head with the proportional gas filled detector, or a scintillation detector head based on the NaI(Tl) crystal. External detectors with own preamplifiers and HV supplies could be attached instead. A special input is provided for this purpose. Data collection could be interrupted by the reset pulses coming from the optically coupled FET based preamplifiers used in conjunction with high resolution Si-detectors. The incoming pulses are processed by a pulse-shaping amplifier, and fed to the equivalent of a single channel analyser (SCA), the latter allowing for selection of the proper energy range. The same pulses are processed by the 12-bit analogue to digital converter (ADC) in order to obtain γ-ray spectrum. Data are stored in the coincidence and anticoincidence mode with the SCA pulses. The sum of these two data arrays gives a complete γ-ray spectrum. Both data banks have 4096 channels each of 32-bit capacity. The ADC uses 256 last channels to perform averaging, and hence 3840 channels are available for the spectrum. In fact, this number is slightly reduced, as one has to set lower and upper limits of the ADC in order to discriminate against background. However, about 3600 channels are available. The nuclear block could be operated during the Mössbauer spectrum accumulation assuring very good definition of the background under the resonant line. The SCA pulses could be fed internally into the remainder of the Mössbauer spectrometer. One can replace the SCA pulses by the pulses from the external nuclear blocks. There are two multi-scaler data banks with 4096 channels per bank each of 32-bit capacity. Critical points of the NB are accessible for the inspection by an external oscilloscope, and are software selectable to the single BNC output.

## Transducer and the driving system

A rigid and robust transducer is used having a hollow central tube of 8 mm diameter clear bore. The transducer is equipped with a shielding collimator and a special ring to safely mount the heavy collimator. The source holder is equipped with the M4 male thread. The transducer can be mounted in a vacuum tank as well, provided the collimator and the safety ring are detached. The transducer could be used either in horizontal or vertical geometry. It is equipped with the position sensor, and one can adjust the average working position applying additional constant current to the driving coil. This feature is particularly useful under heavy load in the vertical geometry. A compensation current is of bipolar type. A repetition frequency is adjustable in fine steps in the range starting from less than 1 Hz and ending above 60 Hz. The velocity range is adjustable in fine steps as well. A reference function is down loaded to the spectrometer memory allowing for very flexible operation. The reference memory consists of 8192 channels per cycle with 16-bit capacity each. Currently, 12 bits are used by the digital to analogue converter (DAC) mounted on board. Position, velocity and error signal, the latter amplified 200 times are available for the inspection by the external oscilloscope by means of the BNC outputs. For typical round-corner triangular reference function folded Mössbauer spectra may have up to 2048 channels (2047 channels for the standard transmission integral approach).

## Control and data storage unit

The data storage unit is used to store the coincidence and anticoincidence γ-ray spectra, and the multi-scaler data collected in two banks. The second bank is usually reserved to store the laser calibration data. An additional bank is used to store the reference function. All settings are kept in the memory and are attached to the data file transferred from the spectrometer to the external devices (except for the reference function and PZC settings of the respective inputs from preamplifiers). Hence, one can reload all the settings in order to reproduce previous conditions. A temperature controller could be used to control data acquisition in the first multi-scaler bank. A single bit sensor could be attached as well to perform similar functions. Communication with the external devices is provided by means of the Tx-100 TCP/IP port. One can set the MAC address, IP4 address and the range of IP ports to be used. Hence, the spectrometer could be located behind the firewall and still could be accessible from the whole world. A hardware lock switch is provided to avoid unauthorised change of the settings.

## Additional blocks

Currently, a universal thermometer is provided with a simple temperature controller. It can operate with the majority of thermocouples attached either to the internal or to the external cold junction. Provision is made to check for the thermocouple integrity. Alternatively, one can use some resistance thermometers, as this block is equipped with a finely adjustable and very stable current source. The actual current flowing through the sensor is measured continuously in order to improve the accuracy. Diode temperature sensors are acceptable as well. The output from the simple temperature controller is fed to the opto-isolated effector unit having several choices for the resulting output signal. One can mount several temperature controllers on the main bin, but only one can be used to control the vital functions of the spectrometer. This unit is protected from the unauthorised access for setting as well. Auxiliary blocks for various non-standard user-defined functions could be inserted as well. The temperature controller could be used as the stand-alone unit on the Internet as well, as it could be powered either by on-board separate power supply or via an effector socket.

## Velocity calibration

The Michelson-Morley interferometer containing a high quality He-Ne laser could be attached directly to the back-end of the transducer. Alternatively, one can attach this unit to the vacuum tank with the transducer, provided a proper optical window is mounted on the back of the tank. The movable corner prism could be mounted just behind the source (absorber) due to the presence of the hollow central tube within the transducer [7, 9, 10]. Such design allows for measurement of the true velocity of the sample. Velocity is measured in each channel of the multi-scaler spectrum. The laser calibration unit is equipped with a laser power supply. The raw signal is available for inspection. The interferometer is equipped with a beam expander to assure stability, and the geometry is designed in such a way as to avoid multiple scattering (spatially separated beams are used). The phase locking is removed using a triple mode laser with random switching between modes. The velocity calibration unit covers velocities falling in the ranges from ±0.1 mm/s to ±1000 mm/s.

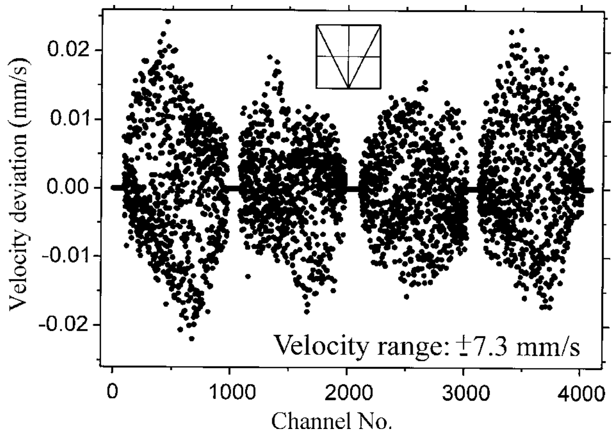


**Fig. 1.** Deviations of the velocity from linearity for the round-corner triangular reference function shown schematically in the inset. Four distinct and relevant ranges of the complete cycle are shown. Data were processed by MOSGRAF.

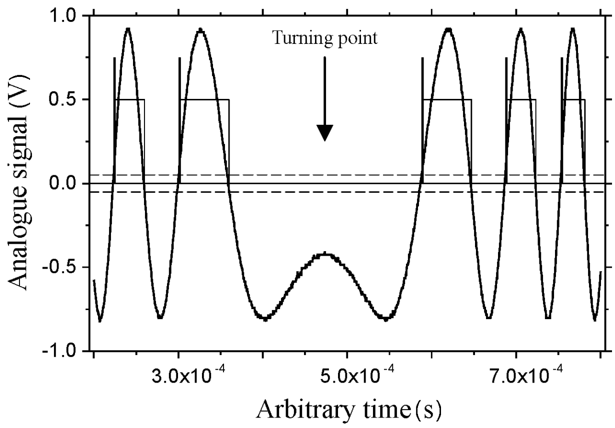


**Fig. 2.** Analogue raw signal from the photo-sensor of the laser calibration unit is plotted vs. arbitrary time around the turning point of the transducer. Rectangles show schematically pulses beyond the comparator with the relevant time marks shown as vertical bars. Dotted horizontal lines show in a schematic way the hysteresis applied to the comparator.

## Power supply

The spectrometer is operated using a high capacity rechargeable battery as a buffer. Hence, several hours of uninterrupted operation are assured since the power failure.

## Software

There are two kinds of the software, however both of the above layers are strongly dependent one on another. The first set of programs consists of the programs used to set the spectrometer, operate it and retrieve data. The second layer (MOSGRAF [12]) is used to prepare reference functions and to process data. Both of them could be implemented for any computer running the Microsoft Windows-*xx*® operational system with *xx* being 95 (32-bit) or higher. Some time consuming programs are available in the form acceptable by Linux in order to implement on the multiprocessor computers. Currently, a single computer can be connected to a given spectrometer and/or temperature controller at a given time. However, multiple computers running appropriate software can make a connection to the given spectrometer and/or controller at various times. The software is designed in such a way that the computer can be connected simultaneously to many spectrometers and/or to many controllers.

## Discussion of some performance data

The most important part of any Mössbauer spectrometer is the transducer and the associated driving system, as the quality of the spectrometer critically depends upon linearity and stability of this part. Figure 1 shows deviations of the velocity from linearity for a typical triangular round-corner reference function with 3% of the rounded part in four relevant regions of the velocity vs. relative time (Channel No.) of the spectrometer cycle. The reference function was adapted to have constant DAC steps in the linear regions. The data were obtained by means of the laser calibration system. One can see that except noise and remnants of the Moiré patterns no global structure remained. Hence, one has to resort to the less accurate although much more sensitive methods to look upon global deviations. The analogue raw signal from the laser calibration unit photodiode is shown in Fig. 2 upon having removed the constant component.

Typical raw data obtained from the laser calibration unit are shown in Fig. 3. One can see reproduction of the round-corner part and the transducer behaviour around the turning points. The latter are slightly delayed by approximately the same time interval, and some deviation from linearity could be seen around the turning points. This deviation is almost the same for both the turning points.

The velocity signal from the pick-up coil is a good measure, while compared with the reference velocity signal, i.e., upon having made the error signal. Figure 4 shows such signals registered by the digital oscilloscope

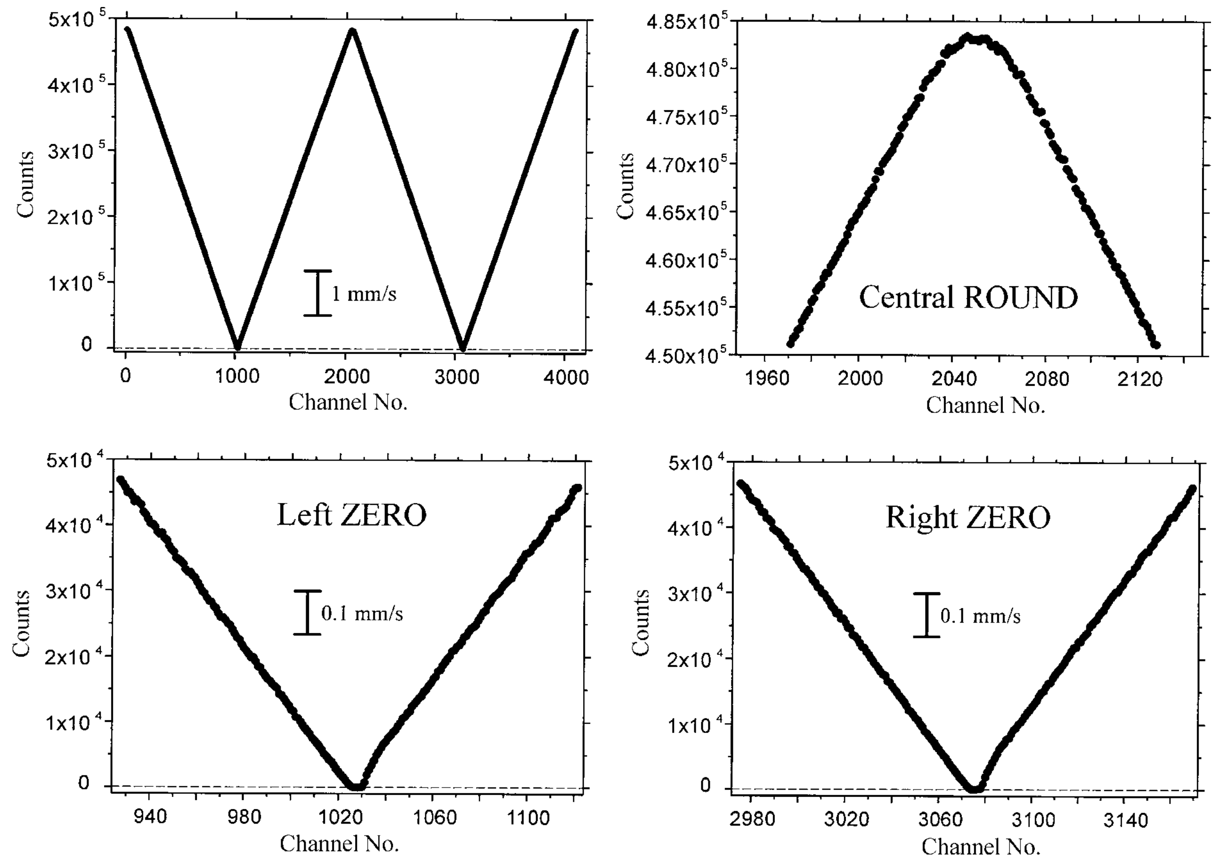


**Fig. 3.** Typical raw data obtained from the laser calibration unit.

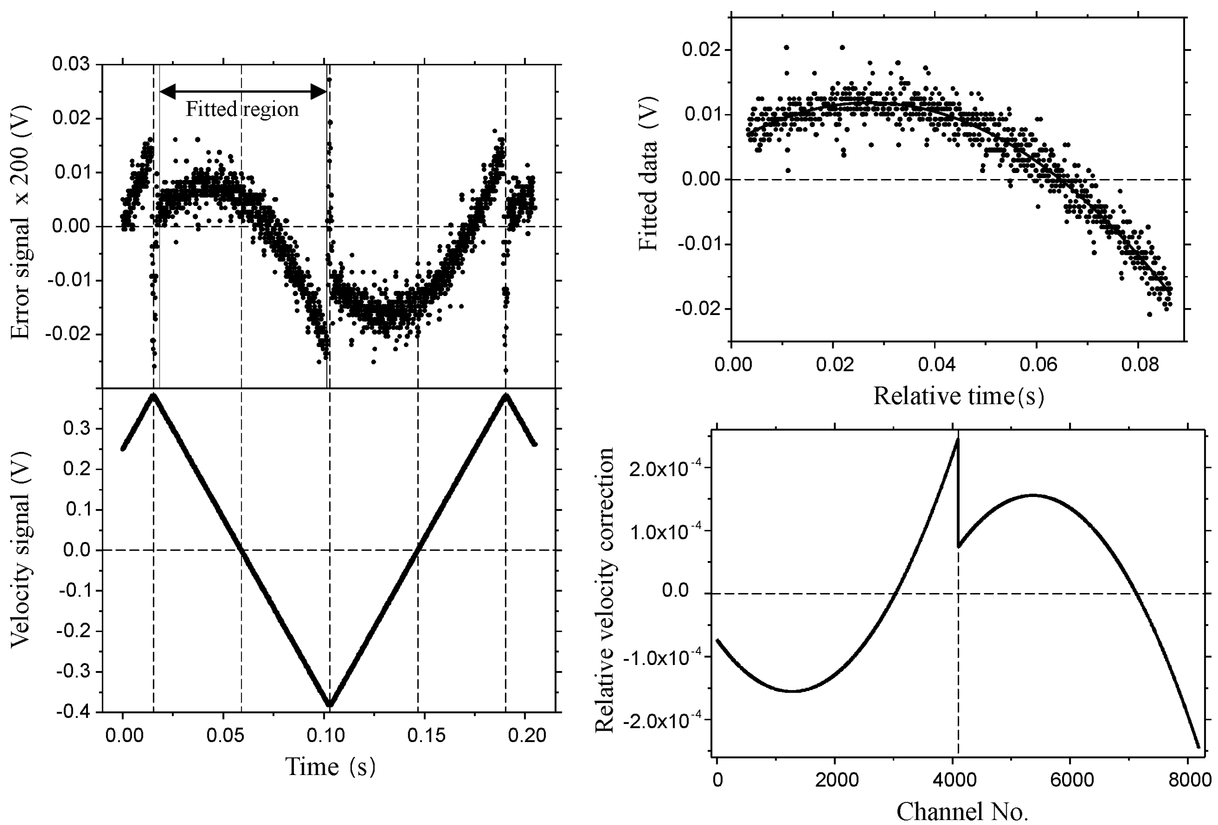


**Fig. 4.** Error and velocity signals are shown vs. time upon averaging over 512 spectrometer cycles for the round-corner triangular velocity reference function. Relative time starts at the beginning of cycle, while part of the error signal marked by arrows was fitted to the parabola and used to derive smoothed correction to the velocity reference function over the cycle. Data were processed by MOSGRAF.

and averaged over 512 spectrometer cycles. It appears that the average deviation from the linearity is quite small. Actually, the relative mean squared deviation for the data shown in Fig. 4 amounts to $1.24 \times 10^{-4}$. Hence, the laser calibration data are insensitive to such small deviation. Actually estimated corrections could be used to improve linearity by adding to the reference function. However, DAC with 12 bits has insufficient accuracy in order to be effective for such small deviations.

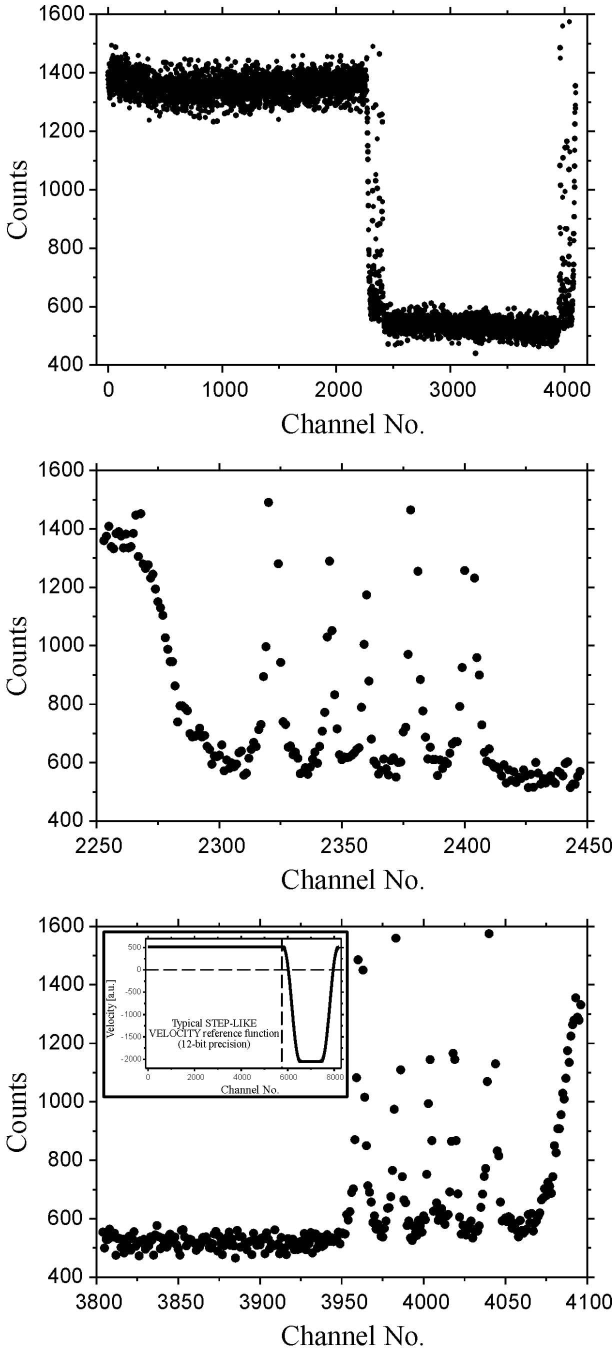


**Fig. 5.** The CEMS spectrum of the room temperature enriched α-$^{57}$Fe obtained with the help of the $^{57}$Co(Rh) source kept at room temperature, too. A constant velocity set to the highest inner slope of the rightmost line of iron has been applied. A velocity reference function is shown in the inset in a schematic way. Note a reproduction of the hyperfine patterns during transitions to and from the compensation region.

Some effectiveness could be expected upon having applied DAC with 16 bits. The constant component calculated over the cycle had been removed from the error signal prior to fitting parabola. One can see that every 256th channel of the reference function has some kink of very short duration due to the DAC imperfection. However, those kinks have no effect on the motion of the transducer, as they are very short. It is interesting to note that the deviations around the turning points, seen by the laser calibration system, are invisible in the signal of the pick-up coil. Such behaviour is understandable, as the pick-up coil generates no signal in the vicinity of the turning point. Deviations around the turning points have a local character, and therefore they cannot be corrected in a simple way.

The spectrometer could be used at constant velocity for such applications as selective excitation of the desired hyperfine line or for the Mössbauer holography [6]. Figure 5 shows the CEMS spectrum of the enriched α-$^{57}$Fe obtained with the help of a $^{57}$Co(Rh) source. A target and the source were kept at room temperature. A constant velocity set to the highest inner slope of the rightmost line of iron has been applied. One has to note a very good stability of the velocity in the above region, as this part of the spectrum appears quite flat. Transitions to and from the compensation region produce quite recognisable hyperfine patterns due to the large number of channels used.

A hollow central tube of the transducer makes this transducer particularly useful for the applications involving synchrotron-generated beams. Typical applications of the resonant synchrotron beams do not require any Doppler motion, but some transducers are required for more advanced applications like resonant γ-ray interferometry [2].

The ability to collect simultaneously γ-ray spectra is quite useful while working with some rather exotic short-lived precursors. In such cases, the background under the resonant line varies quite significantly during the single Mössbauer spectrum accumulation period. Provision for the additional auxiliary blocks allows for relatively easy set-up of the variety of non-standard configurations required for some more exotic experiments.

A digital control of all the vital functions, and the ability to store the settings together with the archived data allows for the reproducibility of the experiments unavailable by other methods. A TCP/IP link to the external world is the simplest method assuring flexibility and universality of the data transfer from and to the spectrometer.

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