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Automatic system for ionization chamber current measurements

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Abstract

The present work describes an automatic system developed for current integration measurements at the Laboratório de Metrologia Nuclear of Instituto de Pesquisas Energéticas e Nucleares. This system includes software (graphic user interface and control) and a module connected to a microcomputer, by means of a commercial data acquisition card. Measurements were performed in order to check the performance and for validating the proposed design.

1. Introduction

Ionization chambers in current mode operation are usually applied in nuclear metrology for the determination of radionuclide activity. A liquid radioactive sample can be easily and quickly standardized by means of an ionization chamber in 4π–γ geometry. The same measurement may take several days to be performed in a $4\pi\beta$–γ coincidence system. Ionization chambers for activity measurements are only suitable as secondary standards and the calibration factor for the chamber, in a specific geometry, must be determined using a standard calibrated with a primary technique.

Once the ionization chamber is calibrated and if the uncertainty due to measurement repeatability and reproducibility for the ionization is very small compared to the uncertainty of the primary calibration, the uncertainties reached by both systems are nearly the same (Woods et al., 1996, 1998). Therefore, ionization chambers are good for routine measurements.

In this application, measurements of very low currents (10^{-8}–10^{-14} A) are required. Usually, electrometers perform the current integration and are commanded by signals from an automatic system. The integration time between two accurately determined voltages are registered by means of an automated system (Simoen and Ostrowsky, 1979). This procedure is normally used for reducing systematic errors in the measurements.

The Laboratório de Metrologia Nuclear (LMN) from the Instituto de Pesquisas Energéticas e Nucleares (IPEN, São Paulo, Brazil) has, among their measurement systems, two ionization chambers for activity determination (one at atmospheric pressure and another filled with argon at 2.0 MPa). These systems are used for standardizations in the range from several kBq up to GBq. The present work describes a new automated system developed for these chambers, which includes accurate voltage measurement, timing determination and a user friendly software interface.

2. Measuring and automation system

The schematic diagram of the complete system is shown in Fig. 1. The ionization chamber (IC) Model IG12/A20 by 20th Century Electronics is connected to an electrometer (E) Model Keithley 616 which in turn is coupled to the automation system hardware. This hardware (called *ActMASTER H01*) was developed at

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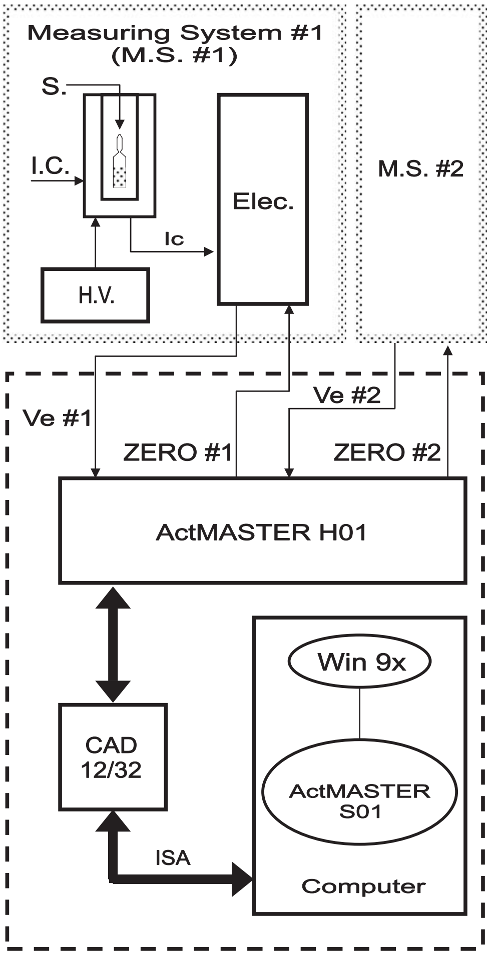

Fig. 1. Block diagram of complete measurement system. The components inside the dashed lines correspond to the automated system.

the LMN and is fully computer-controlled by means of specially designed software (*ActMASTER S01*), also developed at the LMN. Data acquisition is performed by means of a commercial multi I/O card (CAD12/32 manufactured by LYNX Tecnologia Eletrônica Ltda).

The computer minimum requirements are: 166 MHz CPU, 16 MB (RAM), running under Windows 95. The automated system can be connected to up to two ionization chambers simultaneously (selectable by software). The electrical signals in Fig. 1 can be described as follows: I_c is the ionization current; $V_e\#n$ is the integration voltage output from the selected electrometer and *ZERO#n* is the *NULL* command for electrometer #n (#1, #2 or #Test).

2.1. Software

The *ActMASTER S01* software allows inclusion of a sample description, desired number of readings, electrometer selection; test mode scale selection (from 10 to 500 s acquisition time), system voltage monitoring (electrometer analog output, references, supply voltages), file commands (open, save, print), acquisition commands (start, interrupt, restart, cancel) and activity calculation. A virtual analog dial follows the electrometer voltage variation allowing current integration online monitoring.

2.2. Hardware

The *ActMASTER H01* hardware module has been designed to connect one or two electrometers, selectable by the *S01* software. The simplified electric diagram of *H01* module is shown in Fig. 2. The Reference Source provides two very stable voltage values, $V_1 = 2.0\,\mathrm{V}$ and $V_2 = 8.0\,\mathrm{V}$, corresponding to the current integration extremes (start and stop). Amplifiers with voltage gain of 10 provide the 0–10 V signal (from 0 to 1 V electrometer output) to the discriminator (D) stage.

Three independent voltage comparator pairs constitute the discriminator stage, which is responsible for generating the start and stop signals. D#1 and D#2 are the comparator pairs for measuring systems #1 and #2, respectively; D#T is the comparator pair for the internal voltage slope generator (test stage). Only one comparator pair is operational at a time. The logic stage generates the GATE signal, which starts the timer

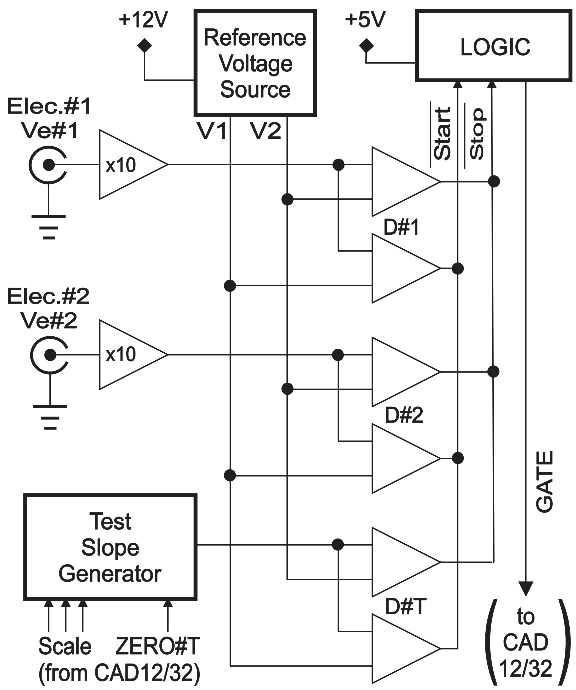

Fig. 2. Simplified diagram of H01 electronic module.

counter in the CAD12/32. This card has a 2 MHz quartz oscillator, used as a clock reference for the time counter (Intel 8253).

The *H01* operation is shown in Fig. 3. The ionization current integration cycle is started when the ZERO signal is disabled by software command (when enabled, this signal forces the electrometer to have the NULL output). The selected electrometer begins the current integration. When the amplified electrometer output reaches the start voltage ($V_1 = 2.0$ V), the corresponding comparator pair generates the start signal leading the LOGIC stage GATE signal to its active state. When the comparator pair input reaches the stop voltage ($V_2 = 8.0$ V), the stop signal is produced, leading the GATE signal to its inactive state. At the end of the cycle, the integration time can be read from the time counter.

A test stage (voltage Test Slope Generator) was designed to produce voltage slopes in the 0–10 V range. The slope value can be selected providing four integration time scales. These slopes simulate the electrometers integration outputs, in order to perform testing, without any measuring device (Chamber/Electrometer) coupled to the system.

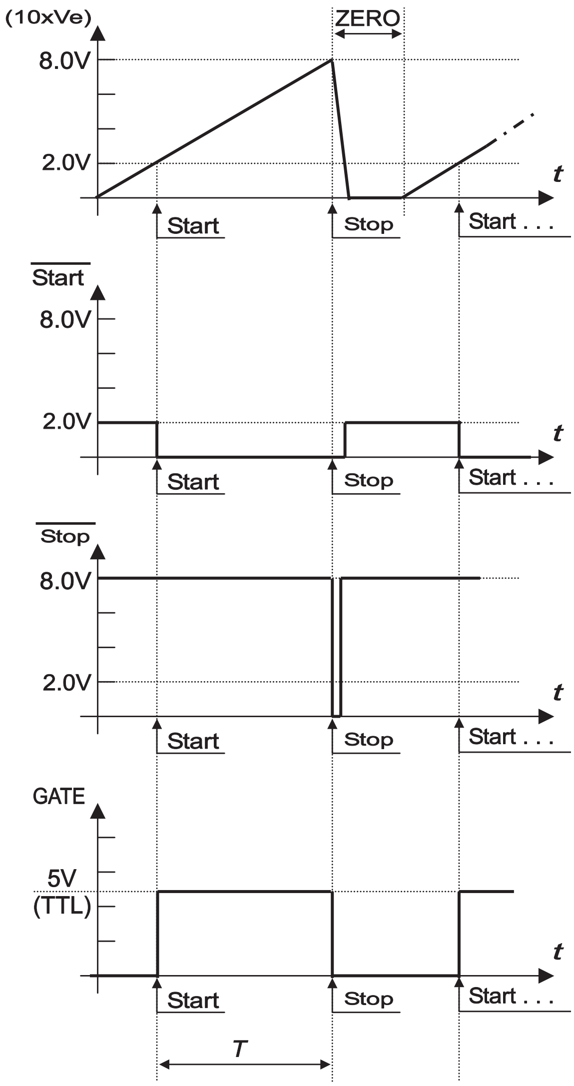

Fig. 3. H01 module timing diagram.

3. Performance

3.1. Linearity

The linearity of the ionization current measuring system was checked by following the decay of ^{153}Sm. A linear least-squares fit of current vs. time in log-linear scale has been performed yielding the experimental half-life estimate for this radionuclide. Fig. 4 shows the residuals between the experimental points and the fitted values. The standard deviation of residuals indicates the degree of linearity of the system (Schrader, 1997). The fitting parameters are shown in Table 1 and indicates a linearity around 0.03% which was considered satisfactory. The experimental half-life (46.329 ± 0.050) hours agrees to within 0.1% of the value taken from the literature (46.285 ± 0.004) h (Bowles et al., 1998).

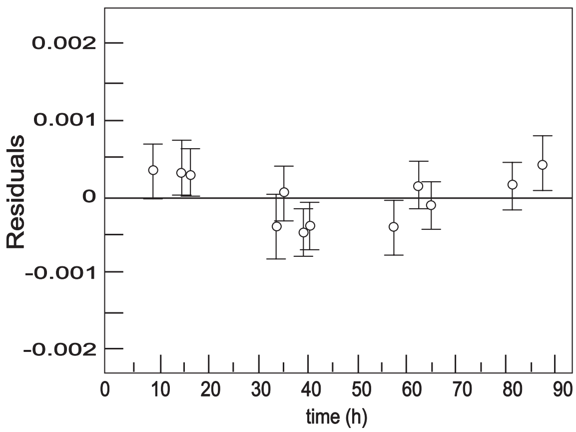

Fig. 4. Residuals of ^{153}Sm decay current as a function of time.

Table 1
Least-squares fitting parameters from ^{153}Sm decay. Parameter ***A*** is the intercept and ***B*** the slope

Parameter	Valves	Uncertainty
A_1	-9.0877×10^{-1}	2.1×10^{-4}
B_1	-1.49613×10^{-2}	4.0×10^{-6}
Reduced chi-square	0.999974	

Table 2
Percent current standard deviation as a function of inverse square root of integration time (t^{-05})

Integration time (t) (s)	$t^{-0.5}$ ($s^{-0.5}$)	Percent standard deviation	Uncertainty
496.693	0.04487	0.12	0.02
131.452	0.08722	0.28	0.07
49.274	0.14246	0.57	0.16
4.966	0.44873	1.2	0.3
1.313	0.87264	3.0	0.5
0.492	1.42595	4.2	1.5

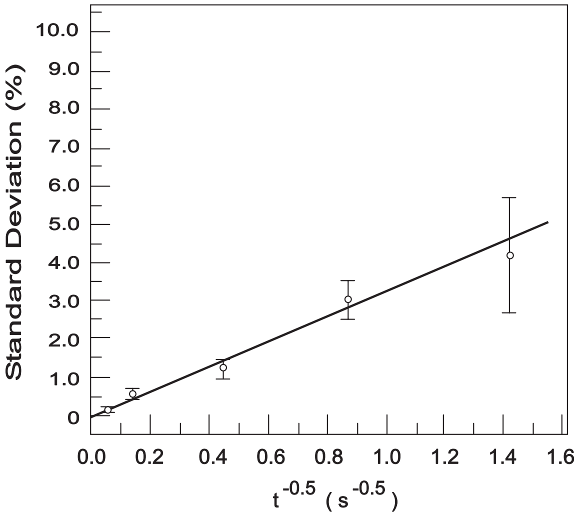

Fig. 5. Percent current standard deviation as a function of inverse square root of integration time (t^{-05}).

3.2. Intrinsic uncertainty

The determination of the intrinsic uncertainty for the proposed system was performed by measuring currents with a long-lived radionuclide (^{137}Cs) for different integration times. From the Poisson distribution, the expected relative standard deviation in the measured ionization current is proportional to the square root of the inverse integration time (Schrader, 1997; Knoll, 1989). For very long integration times, $t^{-0.5}$ will go down to zero and the extrapolated standard deviation will approach the system intrinsic uncertainty.

The results are presented in Table 2 and Fig. 5. The solid line in this figure corresponds to the linear fitting of experimental data and the system intrinsic uncertainty was estimated to be $(-0.0185 \pm 0.0180)\%$, indicating that no significant systematic error is introduced by the automated system.

For typical integration times around 100 s, the measurement uncertainty is close to 0.3% per integration. If better accuracy is needed, larger integration time is recommended (~0.1% per integration, for 500 s integration time).

4. Conclusion

The proposed automated system showed excellent performance, with linearity better than 0.04% and intrinsic uncertainty as low as 0.02%. Therefore, radioactive source activities, half-lives and calibration factors can be determined quickly and with good accuracy.

Acknowledgements

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