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Universal digital CAMAC spectrometer for investigation of the emission and absorption spectra*

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In this paper the instrumental set-up designed for high accuracy and high resolution automatic recording of emission or absorption spectra is outlined. Resolution of this spectrometer is limited only by resolution power monochromator applied in the spectrometer. Digital detection of the light signal and CAMAC standard modules are used in data acquisition and control electronics. Experimental data are recorded automatically on the printer and/or paper tape punch. The described system enables a continuous on-line calibration of the dispersion scale and the compensation of the intensity fluctuations of the light source.

1. Introduction

Recently developed instrumentation for high accuracy investigation of the absorption spectra is increasingly based on powerful methods of the laser spectroscopy [1–3]. This technique has, however, obvious limitations in the ultraviolet range and in some visible spectral ranges, where appropriate dyes and pump lasers are not available yet. Therefore it is important to investigate other experimental techniques enabling to achieve:

1 High sensitivity together with optimal signal-to-noise ratio.
2. High stability of the wavelength scanning.
3. Automatic operation with output data in a computer readable form.
4. Flexibility of operation for emission and absorption spectra.

The purpose of this paper is the description of an instrumental set-up designed for high accuracy and high resolution studies of the emission and absorption spectra. Special emphasis is put here on the application of this instrument in investigations of the profiles and shifts of atomic spectral lines. The

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instrumental set-up described in the present paper is of a universal type and therefore it can be combined with any monochromator.

In described here system we use grating spectrograph, type ZEISS PGS–2, as a monochromator with a photomultiplier. Scanning of the investigated spectral region has been achieved by precisely controlled rotation of the dispersion element using stepping motor with a specially designed mechanical gearbox and control electronics. To improve the sensitivity and signal-to-noise ratio we use a dry ice-cooled photomultiplier working in the photon counting mode. Output data together with identification parameters are automatically recorded on the printer, as well as on the paper punch tape in the computer readable form. Output data may be recorded independently in the analog form on the strip chart recorder, which has proved to be very convenient for initial adjustments and for fast checks during experimental run.

Data recording and optical system control electronics have been designed according to principles set by CAMAC standards [4], using to a large extent commercially available modules. Due to a full standardization any modifications of the electronic system, including on-line computer data reduction, can be implemented in short time. An important built-in feature of our design is a continuous calibration of the wavelength scale, achieved by essentially simulatneous recording of known, and stable reference of emission or absorption spectra. Another important feature characterizing our design is the possibility of instantaneous recording of the investigated light source intensity in an additional channel. This allows successful measurements of line profiles, even for inherently unstable sources.

2. Optical system

General layout of the optical system is shown in Fig. 1. There are three light sources in which the investigated spectra are formed:

— absorption lamp L_A,

— excitation lamp or laser L_F to excite the fluorescence in the cell C,

— reference lamp L_W with stable linear spectrum for continuous control of the dispersion scale.

The optical system operates with parallel light beams (paths 1 and 2). Light beams from these lamps can be switched on or blocked using optical shutters Z_1–Z_4 with the attached mirrors, controlled by control electronics. Photomultiplier Pm_2 monitors the light beams intensity either of the lamp L_A, reflected by the plate Q, or that of the excitation lamp L_F reflected by the plate Q_P – see Fig. 1.

In order to select a spectral region of a radiation emitted by the lamp L_A a monochromator MCH_2 is used. A light beam from the lamp L_F passes through monochromator MCH_1 and excites a substance in the cell C.

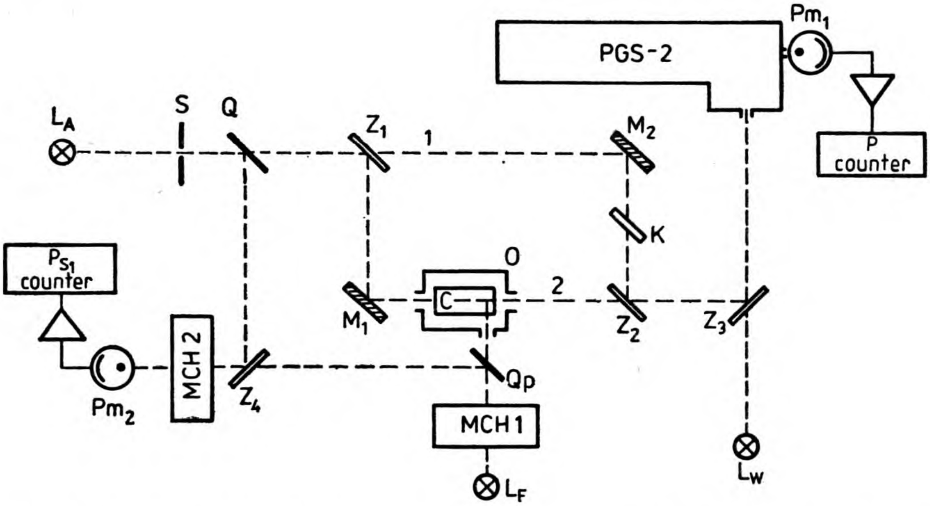

Fig. 1. Block diagram of optical system of the spectrometer. $Z_1 \dots Z_4$ – shutters with mirrors, Q, Q_p – quartz plates, M_1, M_2 – mirrors, S – slit, MCH_1, MCH_2 – monochromators, L_A – absorption lamp, L_W – reference spectrum lamp, L_F – fluorescence excitation' lamp, K – compensation plate, O – oven, C – absorption or fluorescence cell, PGS-2 – grating spectrograph, Pm_1, Pm_2 – photomultipliers

3. Data recording and control electronics

General layout of the electronic circuit for data acquisition and optical system control is shown in Fig. 2. It has been designed to be fully compatible with the CAMAC standards, taking advantage of readily available commercial CAMAC hardware, as well as providing the necessary flexibility for future upgradings and modifications. Logical structure of the control electronic- has been conceived as a coordinated time sequence of the elementary opers ations performed by individual hardware blocks without any significant on-line processing of the measured data. As soon as the optimal measuring sequence or several such sequences are firmly established, they can be memorized in the control electronics and executed automatically afterwards whenever wanted. For extra flexibility the programmed measuring sequences can be branched or executed stepwise using manually operated switches on the control panel.

All the essential components of the control electronics have been assembled in a single standard CAMAC crate with an autonomous power supply. For communication between individual modules standard Camac Dataway and full CAMAC instruction protocol coordinated by autonomous controller have been used. In order to keep overall sophistication and price of the system reasonably low we found it practical to use self-made SEQUENTIAL CAMAC CONTROLLER instead of commercial CAMAC processor. For the same reasons it was also advantageous to design and build specialized CAMAC modules integrating in the single module several hardware operations uneasily implemented using commercial blocks or performing the same function without

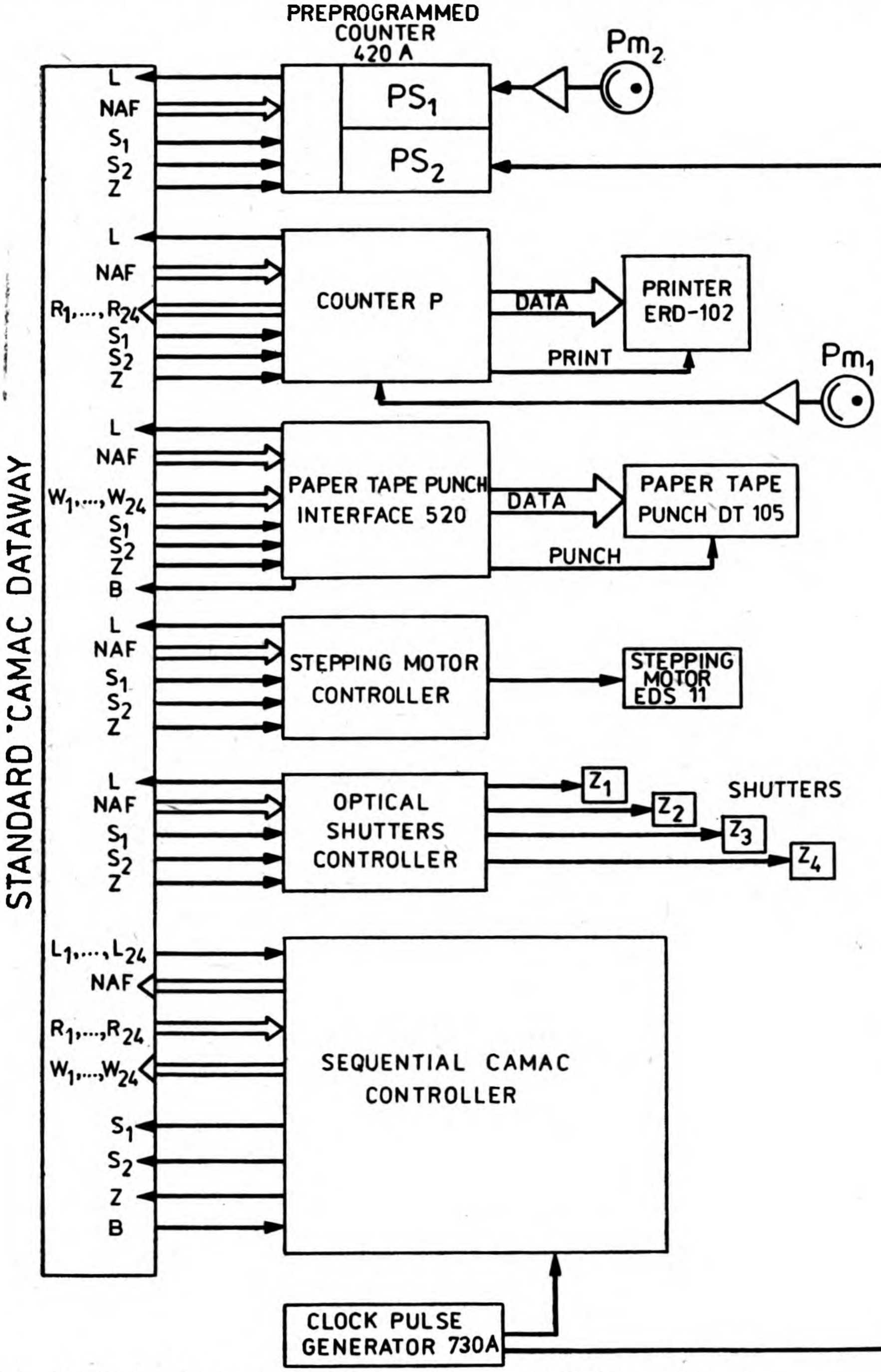

Fig. 2. Block scheme of the electronic system of the spectrometer

unnecessary sophistication and costs. In Appendix we describe those modules going somewhat deeper into details.

4. Principle of operation

4.1. Measurements of the shape and shift of absorption spectral lines

The absorption coefficient $\varkappa(\nu)$ can be derived directly by measuring the intensities of the two light beams $I(\nu)$ and $I_0(\nu)$ on the input and output of the absorption cell C, according to the Lambert-Beer law

$$\varkappa(\nu) = \frac{1}{l}\ln\frac{I_0}{I}$$

where ν is wave number and l – optical path length in the absorption cell.

Absorption line profiles are derived using two-beam spectrometer principle, namely measuring intensity ratio of the light beam going through the absorption cell (beam path 2 in Fig. 1) and the beam passing the reference path 1 with no absorption. To account for the intensity losses due to reflection on the absorption cell windows, appropriate compensating reflection surfaces K have been introduced into the reference path adjusted for unity intensity ratio without absorbing medium. Optical paths 1 and 2 can be switched on using shutters Z_1 and Z_2. Shutter Z_4 with an attached mirror is adjusted to reflect light beam from the lamp L_A and to block light reflected by the surface Q_P.

For line shift determination it is indispensable to calibrate continuously dispersion scale, measuring for each discrete spectral point the light beam intensity from the reference lamp L_W. Therefore each elementary measuring cycle actually consists of the consecutive measurements of three quantities:

- light beam intensity $I_0(\nu)$,
- light beam intensity $I(\nu)$ absorbed in the cell C,
- light beam intensity from the reference spectrum lamp L_W.

After completion of these measurements the content of appropriate counters is printed and/or punched, together with channel identification number and sequential number of the consecutive spectral point. Dispersion element of the spectrograph is then rotated by the stepping motor according to preprogrammed number of steps and the measurement of the next spectral point is automatically started. The stepping motor with specially designed gearbox assures rotation of the dispersion-element drive axis by 5/190 degrees per step with negligible hysteresis and blacklash.

4.1.1. Measurement of the reference light beam intensity $I_0(\nu)$

In this step light beam from the lamp L_A is reflected by the mirror M_2 and by two movable mirrors attached to the shutters Z_1 and Z_3, it enters input slit of the spectrograph and is recorded by photomultiplier Pm_1 in the counter P (see Fig. 2). At the same time part of the light beam from the lamp L_A, reflected by the plate Q and passing through monochromator MCH_2, is recorded by the photomultiplier Pm_2 in the counter PS_1. Counting in both counters proceeds until the counter PS_1 accumulates preprogrammed number of pulses. Therefore any spurious effects due to internal instabilities of the absorption lamp L_A during measurement run are reduced to insignificant level.

4.1.2. Measurement of the absorbed light beam intensity $I(\nu)$

In this step light beam from the absorption lamp L_A is reflected by the mirror attached to the shutter Z_1 and the mirror M_1 and passes through the absorption cell C, shutter Z_2 being in open position. After another reflection by the mirror attached to the shutter Z_3 light beam enters input slit of the spectrograph and is recorded in the same way, as described in the previous section.

4.1.3. Measurement of the reference spectrum

In this system both emission and absorption spectra can be used as a reference spectrum. In the case of the emission reference spectrum the lamp L_W has to be applied. Then in this measuring step light beam from the reference spectrum lamp L_W enters through the open shutter Z_3 into input slit of the spectrograph. Due to the excellent time stability of the reference lamp L_W it is possible to use constant integration time as determined by preprogrammed number of pulses from the external quartz generator type CAMAC 730 A accumulated in the counter PS_2. As mentioned before the measurement of the reference spectrum made in exactly the same instrumental set-up immediately after measurement of the investigated spectrum is indispensable for an unambiguous determining line shifts.

In the case of the absorption reference spectrum a reference beam (optical path 1) passes through an absorption cell containing a substance having well-known absorption spectrum. For instance in the visible region it can be a cell with the iodide (I_2) vapour, the absorption spectrum of which is frequently used as a reference spectrum (e.g., [5]).

The measuring cycle consists then of two elementary measurements, and not three as in case of the emission reference spectrum.

4.2. Measurements of the shape and shift of the emission lines

Measuring procedure for emission spectra is basically the same as the described above procedure for absorption spectra. However, due to the inherent weakness of emission spectra, especially in the wings of the line profiles, it is very important to determine precisely the dark count level of photomultiplier Pm_1. The investigated atoms are excited by the light beam from the lamp L_F of spectral range selected using the monochromator MCH_1. In this mode of operation shutter Z_4 remains open and part of the radiation from the exciting lamp L_F after reflection by plate Q_P is recorded in the photomultiplier Pm_2. Elementary measuring sequence in this mode consists of three steps:

- measuring the dark count level of the photomultiplier Pm_1,
- measuring emission spectrum light beam intensity I,
- measuring reference spectrum light beam I_{ref}.

After such an elementary step the content of the appropriate counter is transferred to the printer and/or paper punch tape. At the end of each cycle dispersion element of the spectrophotometer is rotated by a constant angle and a new measuring cycle is repeated for the next spectral point.

4.2.1. Determination of the dark count level

During this step shutter Z_2 remains closed blocking completely the light entering the photomultiplier Pm_1. Dark current pulses are accumulated in the counter P until the counter Ps_1 integrating pulses from the photomultiplier Pm_2 reaches predefined level.

4.2.2. Measurement of the emission spectrum light beam intensity ($J\nu$)

In the consecutive measuring step shutter Z_2 is open and light beam, emitted by atoms contained in the cell C, reflected by movable mirror attached to the shutter Z_3, enters input slit of the spectrograph and is recorded by the photomultiplier Pm_1. As in previous step of dark count level determination, pulses from the photomultiplier Pm_2 are accumulated until the counter PS_1 reaches the same number of counts. Thus any instabilities of the excitation lamp in the course of experiment do not influence directly the measured emission line profile.

5. Performance tests

To test overall performance of the described system we have recorded a number of emission and absorption spectra. Emission spectra were produced in the low pressure electrodeless radiofrequency discharge in the mercury vapours. Some examples of those records are reproduced in Figs. 3–5. Figure 3 shows emission lines (313.15 nm and 313.18 nm) recorded in the first order diffraction. Figures 4 and 5 show 404.66 nm line recorded in the second and third order, respectively. Partially resolved hyperfine structure of these mercury lines is clearly discernible being in excellent agreement with the data published by Rank et al. [6]. Performance of the system in case of absorption spectra is illustrated in Fig. 6, showing the absorption line and the emission reference line of thallium ($\lambda = 377.57$ nm).

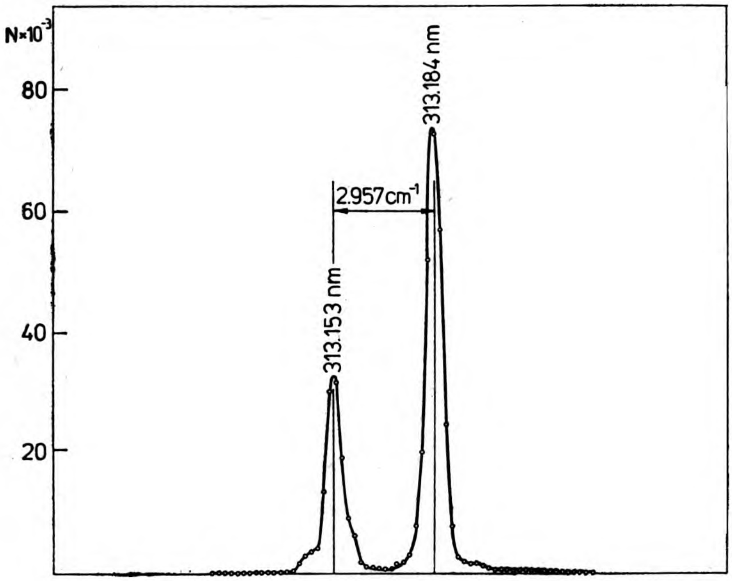

Fig. 3. Record of the 313.15 nm and 313.18 nm mercury lines obtained from low pressue mercury vapour r.f. discharge in the first diffraction order. N – number of counts, o – expeimental points

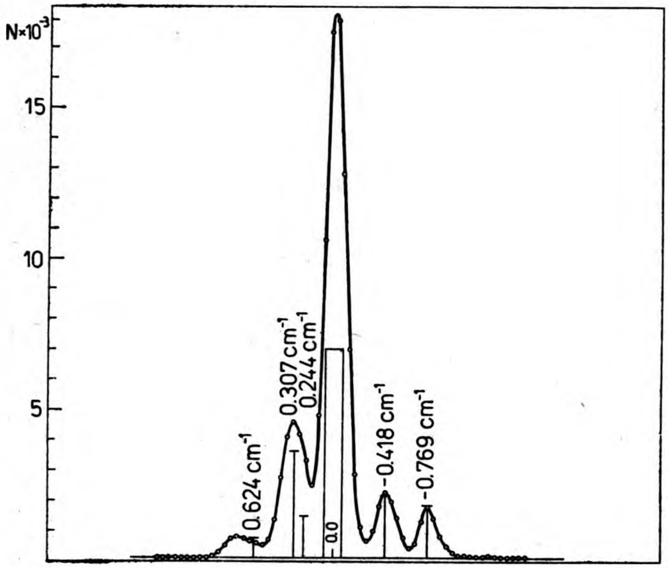

Fig. 4. Record of 404.66 nm mercury line in the second diffraction order. N – measured number of counts, o – experimental points. Vertical lines show positions and theoretical intensities of the line components. Rectangles show positions and intensities of all the even isotopes

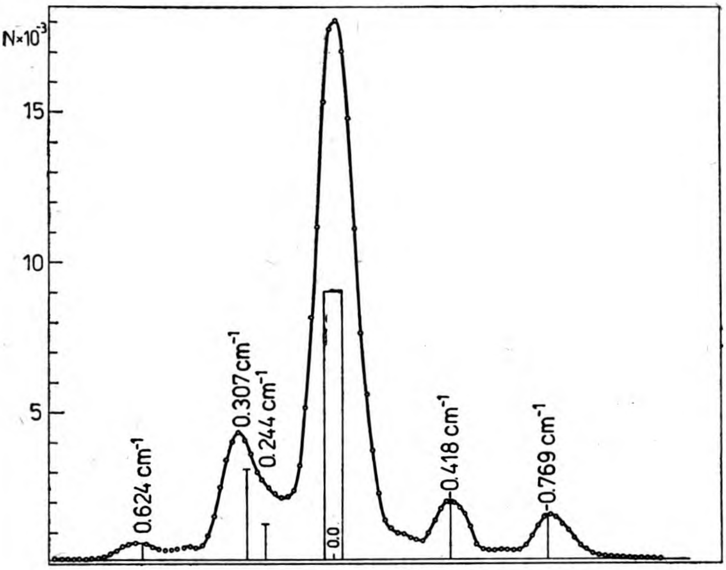

Fig. 5. Record of 404.46 nm mercury line in the third diffraction order. For explanation see Fig. 4.

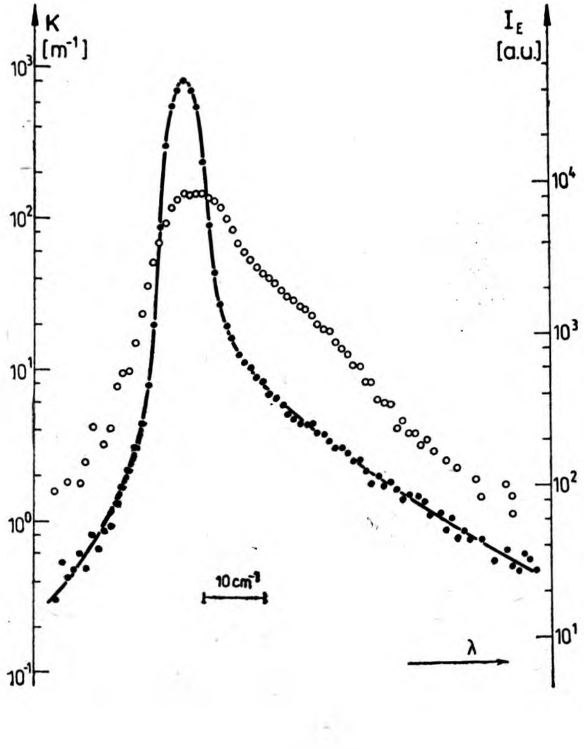

Fig. 6. Profile of the 377.68 nm line of thallium, perturbed by argon: ○ ○ ○ ○ absorption line recorded at the temperature of 903 K (in m^{-1} unites), argon density – $N_{Ar} = 1.10 \times 10^{25}$ at/m^2, –●–●–●–●– emission line from r.f. lamp (in arbitrary units), argon density – $N_{Ar} = 4.91 \times 10^{22}$ at/m^3

Appendix

1. Sequential autonomous CAMAC controller

This module coordinates the operations of the data-reading unit and the optical-system central unit (see Fig. 7). It has been built from commercial type 222 Read Only Memory preprogrammed using diode matrix. Memory contains a sequence of not more than 32 CAMAC instructions programmed by the soldered diodes into the appropriate points in the matrix. When activated by a general reset signal, Sequential Controller reads and sends via CAMAC Dataway the consecutive instructions to the selected CAMAC modules which respond with Q and X signals. A strobe circuit provides a proper timing using standard CAMAC synchronization pulses S_1 and S_2. Not earlier than after successful

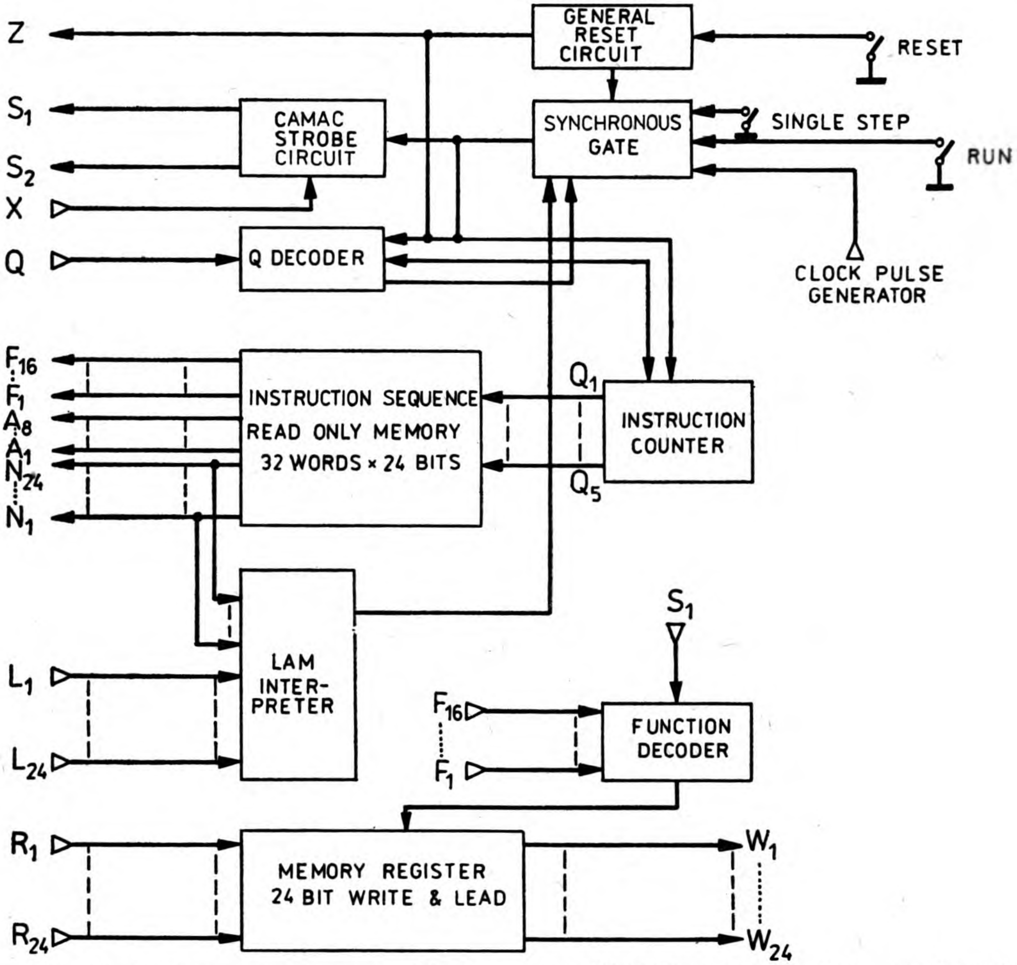

Fig. 7. Block scheme of the sequential autonomous CAMAC controller of the spectrometer

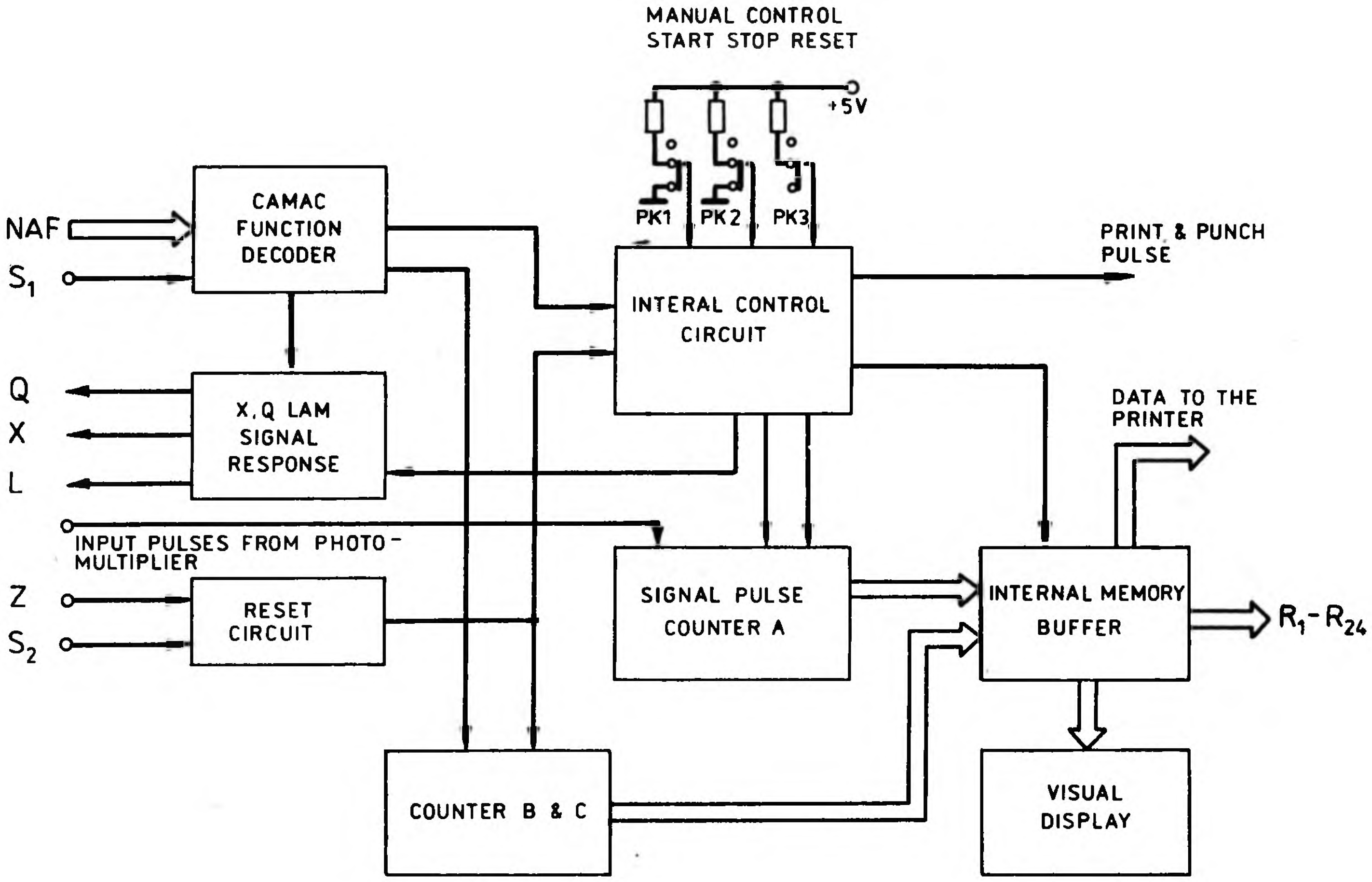

Fig. 8. Block scheme of the counter

completion of each elementary operation, as signalized by an appropriate LAM interrupt signal, Sequential Controller advances to the next instruction in the cycle. Data transfer between the counters and data recording hardware involve a single read and write 24-bit-memory register which stores intermediate data from the counters sampled from the R_1–R_{24} lines, and sends them into W_1–W_{24} lines during output data punching or instruction printing. Operation of the Sequential Controller can be synchronized with external clock generation. It can be also operated manually, instruction after instruction, e.g., during initial setting up or testing procedure.

Basic technical data

1. Instruction memory – up to 32 standard CAMAC instructions.
2. Data memory buffer – 1×24 bits.
3. Instruction cycle control – manual or from external clock generator.
4. Dimensions: 4 standard CAMAC modules.
5. Power supply 6 V, 2 A.

2. Counter

This specialized hardware block integrates in the double width CAMAC modul three elementary operations (Fig. 8):

— counting of signal pulses from the photomultiplier Pm_1 (Counter A),

— counting of elementary measuring cycles, corresponding to consecutive spectral data points (Counter B),

— identification of elementary operations within each measuring cycle (Counter C).

Actual contents of all counters are transferred via internal memory buffer to the R_1–R_{24} read lines during output data read operation initialized by Sequential Controller.

References

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Универсальный численный спектрометр CAMAC для измерения абсорбционных и эмиссионных спектров

Описан спектрометр высокой разрешающей силы и большой точности, предназначенный для измерений абсорбционных и эмиссионных спектров. Разрешаемость этого спектрометра ограничена лишь разрешающей силой использованного монохроматора (спектрографа). Для управления и контроля измерений применена система CAMAC с разработанным нами командо-контроллером кассеты. Детектирование светового сигнала проведено методом счисления фотонов. Экспериментальные данные записывались автоматически в результате использования печатающего устройства и/или перфоратора. Описанная система дает возможность непосредственного калибрования длины световой волны, а также компенсирования флуктуации мощности источника света.