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BEAM DIAGNOSTICS DEVICES AT THE JINR PHASOTRON

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The JINR phasotron is a pulse-operating cyclic proton accelerator of the final energy 680 MeV and the mean beam current up to 10 μA [1]. The phasotron beam diagnostics system allows a continuous monitoring of the following parameters of the accelerated beam:

1) radius of losses in the 50-270 cm range,
2) vertical position on radii of transducers' installation from 107 cm to 262 cm,
3) azimuthal charge density,
4) average energy gain per turn,

and

5) radial beam distribution, its vertical position in the extraction channel and behind it.

Fig. 1 shows the lay-out of the diagnostics system: 3,4,5,6 are the secondary emission (SE) transducers, 7 are the induction transducers (pick-up-electrodes), 9 is the γ-detectors for the radius of beam losses. Transducers 7 are completely transparent for the beam, transducers 3-6 produce no noticeable effect on it.

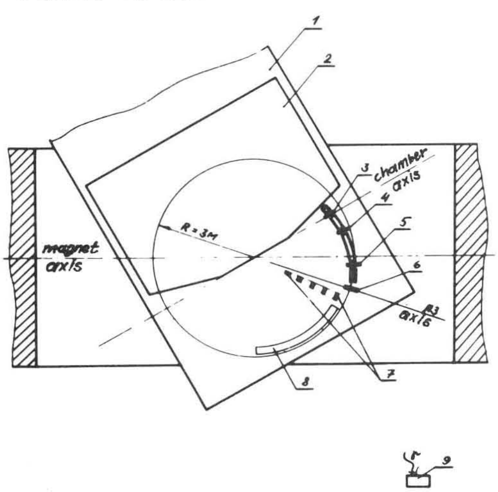

Fig. 1. Lay-out of the diagnostics system: 1 - accelerating chamber, 2 - dee, 3 - SE-transducer of the exciter, 4 - SE-transducer of the 2nd section, 5 - SE-transducer of the focusing device, 6 - SE-transducer of the probe P3, 7 - induction transducers, 8 - C-electrode.

The main element of the device for determination of the loss radius is a crystal NaJ scintillation detector for γ-quanta from interaction between the proton beam and the accelerator elements. The detector is placed outside the chamber at a distance of ~10 m. In Fig. 2 one can see oscillograms of an acceleration cycle. Pulses from the γ-de-

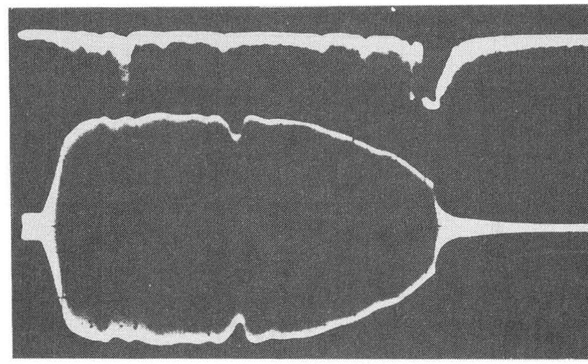

Fig. 2. Oscillograms of an acceleration cycle. Up: a signal from the γ-detector output. Down: accelerating voltage.

tectors synchronised with the beginning of the acceleration cycle give a position of losses in time. The radial beam position corresponding to the moment of losses can be determined by the probe. The measurement accuracy for the radius of losses depends on the measurement accuracy for the probe position, it is sufficient for carrying out the experiment. The device is simple in operation and provides visual information on beam motion at acceleration, starting from the 50 cm radius and up to its extraction, which is suitable for adjustment work.

Five pairs of induction transducers (Fig. 3) are mounted on two cantilevers symmetrically to the geometric mean plane of the accelerator in the 107-262 cm range of radii with an equal step. Their azimuthal dimension is 5°, radial dimensions vary from 15 cm for the first transducer to 4 cm for the last one,

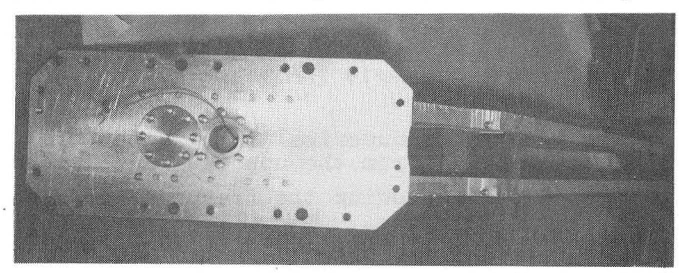

Fig. 3. Induction transducers.

the aperture is 10 cm. The load is a cabel of the coordinated measurement section with a wave resistance 50 Ω. Consequently, they are transducers of differential type, sensitive to the rate of variation of the flux of the electric shift vector through its sensitive surface. The current through the surface of a transducer

$$i = \frac{\partial \Psi}{\partial t} = \frac{\partial}{\partial t} \int_S \vec{D} \cdot d\vec{S} \qquad (1)$$

and voltage at its output

$$u = i \cdot \rho \qquad (2)$$

are determined by the beam total charge and its angular position, i.e.

$$u = u(\varphi) = \int K(\varphi, \varepsilon) \cdot \sigma(\varepsilon) \cdot d\varepsilon \,, \qquad (3)$$

$K(\varphi,\varepsilon)$ is the instrumental function of the transducer, ε is the angular position of the charge in the beam, $\sigma(\varepsilon)$ is the azimuthal density of the charge. Fig. 4 shows the transducer signal $u(\varphi)$ obtained via stroboscopic

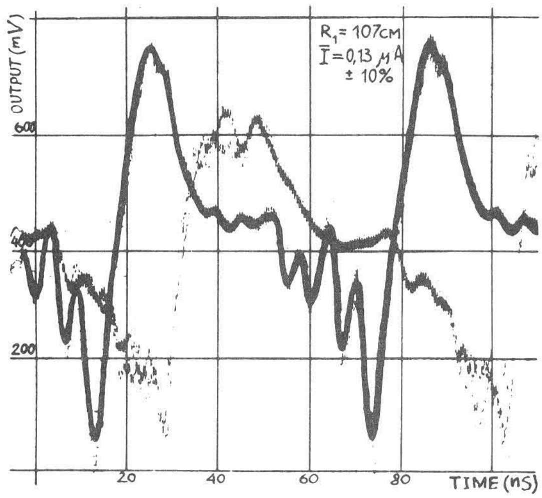

Fig. 4. Fast signal from an induction transducer (a curve from C7-8 oscillograph output to the recorder). $\bar{I}$ = 0.13 μA, F = 20 sec^{-1}.

transformation. Solution of Eq. (3) for our case is found in Ref.[2] with the following relation for the charge density:

$$\sigma(\varepsilon_k) = \frac{2\pi}{k \cdot 2b \cdot \rho \cdot \omega \cdot 2\alpha_0} \cdot \frac{a^2 - z_p^2}{2a} \cdot S(\varphi_k) \,, \qquad (4)$$

2b, $2\alpha_0$ are the radial and angular dimension of the transducer respectively, $2a$ is the aperture, ω is the angular frequency of the beam circulation, k is the gain of the measurement section, Z_p is the beam vertical position,

$$S(\varphi_k) = k \cdot \int_0^{\varphi_k} [u_u(\varphi) + u_l(\varphi)] \cdot d\varphi \qquad (5)$$

is the results of numerical integration of the total signal from the upper U_u and lower U_l transducers. Knowing the frequency of acceleration cycles F, one can easily obtain the mean current of the beam

$$\bar{I} = F \cdot \int_0^{2\pi} \sigma(\varepsilon) \cdot d\varepsilon \qquad (6)$$

The total error, including the technique error and instrumental errors, in measurement of the accelerated beam density is $\leqslant$ 10% in our case[2].

It is shown in Ref.[3] that the vertical position of the beam on the radius of installation of a transducer like this is determined by the expression

$$z_p = a \cdot \frac{u_u - u_l}{u_u + u_l} \qquad (7)$$

While the beam position is being determined, signals from the upper and lower transducers are cleared from the first harmonic of the accelerating voltage which is the largest part of inducing. The measurement error in the range of vertical beam shifts $Z_p = \pm 25$ mm, with allowance for its vertical dimention $\Delta Z_p \leqslant \pm 1.5$ mm.

The mean energy gain per turn in the range of radii between neighbouring transducers can be obtained from the relation

$$\Delta E_K = 2e \cdot \overline{V_{mD}} \cdot \overline{\cos\varphi_s} \cdot \Delta t_K \cdot \overline{f_{hf}} \,. \qquad (8)$$

Hence we have for the mean energy gain per turn

$$2e \cdot \overline{V_{mD}} \cdot \overline{\cos\varphi_s} = \frac{\Delta E_K}{\Delta t_K \cdot \overline{f_{hf}}} \,, \qquad (9)$$

ΔE_K is the energy gain at the radial movement between neighbouring transducers, Δt_K is the time of movement, $\overline{V_{mD}}$, $\overline{f_{hf}}$ are the mean amplitude and frequency of the accelerating voltage. The time of beam movement between neighbouring transducers can be easily determined, as is seen from Fig. 5. The block diagram of electronic system that allows automatic processing of signals from induction transducers is shown in Fig. 6. The measuring and controlling blocks 11,12,13 are made in the CAMAC standard. All instruments are in the control hall, except input commutators.

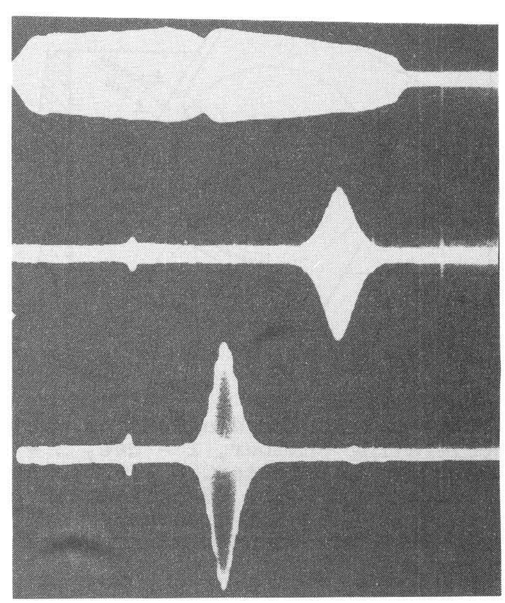

Fig. 5. Oscillograms of an acceleration cycle. Up: accelerating voltage; middle: a signal from the 4th transducer (R=222.5 cm); down: a signal from the 5th transducer (R=262 cm). $\bar{I}$=0.13 μA, F=20 sec^{-1}, sweep is 500 μsec/div. vertical shift is 100 mV/div.

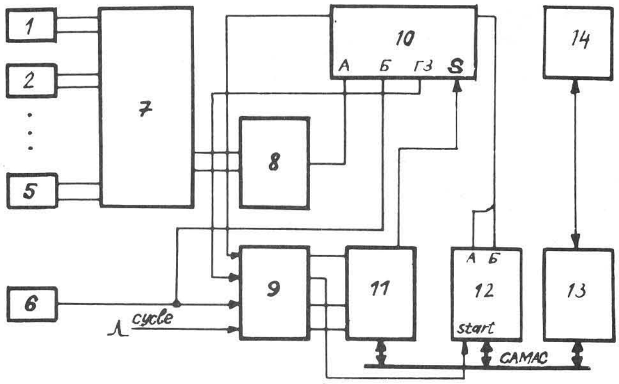

Fig. 6. Block diagram of the electronic equipment in the system of induction transducers. 1-5 - beam transducers, 6 - accelerating voltage transducer, 7 - output commutator, 8 - summer, 9 - adaptor, 10 - strobe oscillograph C7-8, 11 - ADC, 12 - synchronisation block, 13 - crate controller, 14 - mini-computer MERA-6055.

SE-transducers of two types are used in the output region: multibar transducers (Fig. 7) and differential ΔR-transducers (Fig. 8) which help to fine-adjust the curvature of the deflecting channel and to measure the value of beam overshoot and position with respect to the mean plane. In a multibar transducer aluminium foil 50 mg/cm^2 thick is placed on the way of the beam at an angle 74° to the vertical. Electrons, knocked by the beam out of the foil, move along magnetic lines of force and reach bars of the radial dimension 4 mm, evenly distributed over the radius and placed below the mean plane. Multibar transducers 3,4,5 (Fig. 1) are between elements of the output system. The transducer 6 can be placed in the extracted beam by the probe P3; a histogram of currents from bars of this transducer is shown in Fig. 9. Foil of this transducer covers the whole cross section of the beam; being calibrated, the transducer may be used to measure the average beam current.

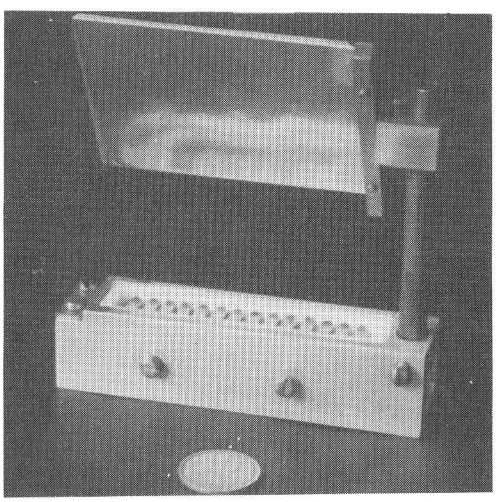

Fig. 7. Multibar SE-transducer.

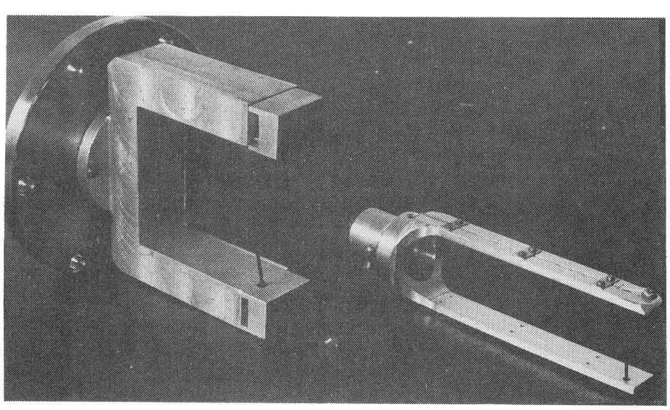

Fig. 8. Differential ΔR-transducer.

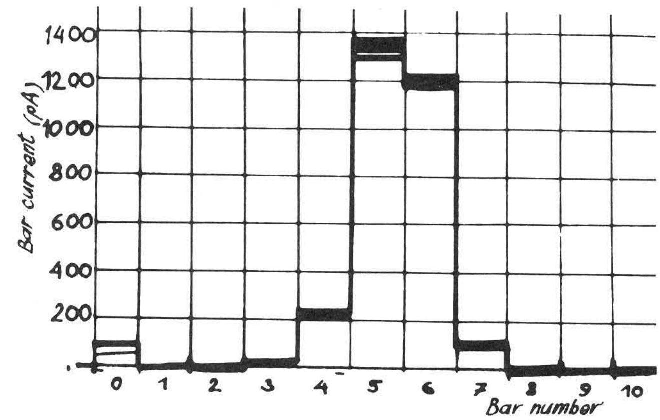

Fig. 9. Histogram of currents from the multibar SE-transducer of the extracted beam. I = 0.6 μA.

In a differential ΔR-transducer two molybdenum plates are placed on the way of the beam symmetrically to the mean plane at some angle to the vertical; they are shifted along the azimuth. A ΔR-transducer is mounted on the movable probe P3 or on the probe of the output system which allows beam scanning in order to obtain its radial distribution and vertical shift. Secondary emission currents from SE-transducers are measured with electronic apparatus (see block diagram in Fig. 10). Note that the electrometric amplifier has the input resistance 1GΩ, input sensitivity 1 mV/pA, input-reduced drift about 20pA for 8 hours in the +(15 ÷ 40)$^\circ$C temperature range. The whole apparatus is in the basement of

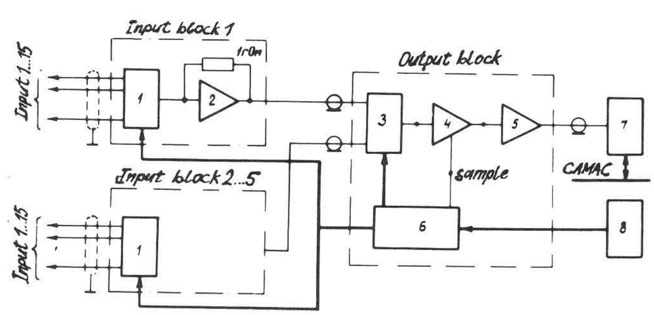

Fig. 10. Block diagram of the electronic equipment in the system of secondary emission transducers. 1 - bar commutator, 2 - electrometric amplifier, 3 - commutator of input blocks, 4 - selection-storage amplifier, 5 - terminal amplifier, 6 - logic system, 7 - recorder or ADC, 8 - control block.

the acceleration hall, except the detecting device 7 and the control block 8. The measurement time of a multibar transducer is 30 sec.

The diagnostics system employs computers of the automatic control system of the phasotron. This allows automated processing of measured signals. The system is operated during experiments and adjustment.

References

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