THE DIAGNOSTICS OF THE BEAM PHASE CHARACTERISTICS OF THE 240-cm ISOCHRONOUS CYCLOTRON

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Abstract

Measuring and stabilizing equipment for beam phase characteristics of the 240-cm isochronous cyclotron are briefly described. A recording system determines the pulse shape of an accelerated ion bunch and measures the pulse duration with an error of no more than 1° for average beam currents up to 1μA in the cyclotron chamber as well as in the beam tube.

The achieved accuracy of the stabilizing system for optimum phase position of the bunch at extraction radius was no worse than 2°.

The use of the stabilizing system made it possible to simplify cyclotron adjustments and to enhance the extracted beam intensity and stability. Results obtained with the diagnostic equipment for proton beams up to 53 MeV are given.

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Pulse duration of the ion bunch is measured and its shape is registered by an apparatus including beam probes, stroboscopic signal conversion devices, and summing and compensating amplifiers [1]. The measuring device incorporates a stationary capacitive phase probe installed at the final acceleration radius, a moveable capacitive phase probe covering the radial range from $0{,}3 \cdot R_{ext}$ to $1{,}1 \cdot R_{ext}$, and an inductive beam probe located in the beam tube. To measure signals from all these probes similar apparatus is used. The measurement error is determined by that of the stroboscopic signal conversion method and does not exceed 1° in the given case.

Use of "shaded" probes with compensating amplifiers of the noise signals [1] and the diagram of the useful signal time selection permits one to measure the shape and phase duration of the ion bunch at a noise/signal ratio up to 1db and a mean beam current up to 1μA.

Since the accelerated particle beam should be highly monoenergetic, rigid tolerances are kept relative to the phase shift of particle flight through the acceleration slits compared with the optimum value.

The reasons for the phase shifts have been analyzed; it is shown that the main reason for this phenomenon is time instability of the magnetic field. With this in mind, the phase shifts in the cyclotron U-240 are corrected by magnetic field control depending on the value of the bunch phase shift from the optimum one. To provide the operating conditions of the monoenergetic beam cyclotron, the stabilization system of the mean phase at the final acceleration radius has been designed and put into operation; a small power stabilizing coil has been used. To decrease phase shift due to the non-isochronous magnetic field, a system of spatial phase shift correction in the radius region $0.85\ R_{ext} \leq R \leq R_{ext}$ is provided later on.

The functional diagram of the phase stabilization loop is presented in fig.1. The accelerated particle beam is a control object in the loop, the bunch phase is a controlled value (the bunch temporal position relative the reference pulse), changing of the magnetic field ΔH is a controlling action, changing of the external magnetic field ΔH is a perturbing action. The reference pulse is that of the phase probe, the time position of which relative to the accelerating voltage phase corresponds to the maximum value of the extracted beam intensity.

The phase stabilization system is a pulsed one since the phase bunch position data are obtained with the frequency determined by the macropulse repetition rate (in pulsed cyclotron mode) or with 100 Hz frequency (in continuous mode). The transfer function of the closed loop using Z-conversions of the grid functions has a form:

$$\phi(Z) = \frac{K(Z\alpha - \beta)}{Z^2 a - Z\{a[1 + \exp(-aT) - Kd\} + a\exp(-aT) - K\beta}$$

where K = a static control factor

$\alpha = aT - 1 + \exp(-aT)$

$\beta = aT\exp(-aT) - 1 - \exp(-aT)$

$a = 1/\tau$

T = macropulse repetition rate;

τ = time constant of the stabilizing coil.

At the selected parameters of the control loop, the system is stable, the transient process is of an oscillating nature, and stabilization time does not exceed 0.4 s.

The influence of the phase stabilization system upon changing of the phase bunch position relative to the optimum value is shown in fig. 2(a). Measurements have been carried out with the phase probe at the radius R = 103 cm. The long-term phase bunch stability under operating conditions has been studied: slow phase excursions do not exceed 1.5°; at the same time phase excursions up to 23° are observed with the system turned off. Pulsation and sharp phase overshoots, caused by the envelope amplitude instability of the accelerating voltage and considerable current pulsation of one of the concentric coils are presented in the diagram. The experiments were carried out in the pulsed cyclotron mode and with 53 MeV energy for the extracted protons.

The phase stabilization system increases considerably the stability of the extracted beam current. Time behaviour characteristics of the beam intensity measured by the probe after the deflector are shown in fig. 2 (b). The positive system influence on the intensity stability is explained by the fact that the 240-cm cyclotron is designed as a "resonance" tuning accelerator, i.e. to obtain high beam parameters, the optimum tuning of all cyclotron systems is required: r.f. power supply, magnetic field, collimator system etc. Thus, to obtain maximum beam intensity, the optimum tuning of the magnetic field is of great importance.

The experimental curve I(ΔH) for the beam in the beam tube (fig.3) shows a sharp maximum for this dependence. The resonance curve maximum conforms to isoch-

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ronous particle acceleration, and the "plateau" at the curve agrees with non-isochronous acceleration mode, as a result of which the beam quality decreases noticeably and the extraction efficiency becomes less sensitive to the magnetic field tuning. To provide 10% stability of maximum intensity, magnetic field instability not worse than $\pm 1 \cdot 10^{-4}$ H_0 is permitted. If better stability of the extracted beam current is required, still more rigid tolerance for the magnetic field oscillation should be set. Such fine control of magnetic field and maximum beam intensity without a stabilization system of this type is practically impossible.

Literature

1) A.K.Vaganov et al., Proc.7th Int. Conf. on Cyclotrons and their Applications, p.368-370 (1975).

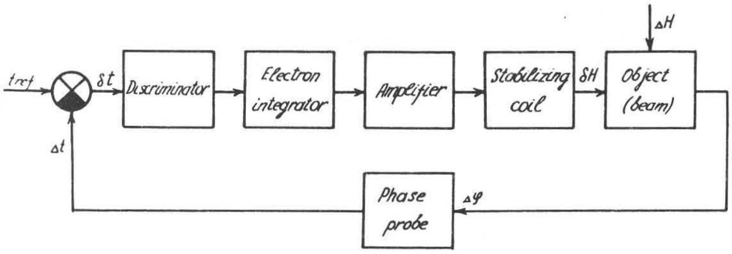

Fig. 1. The functional diagram of the automatic phase tuning loop.

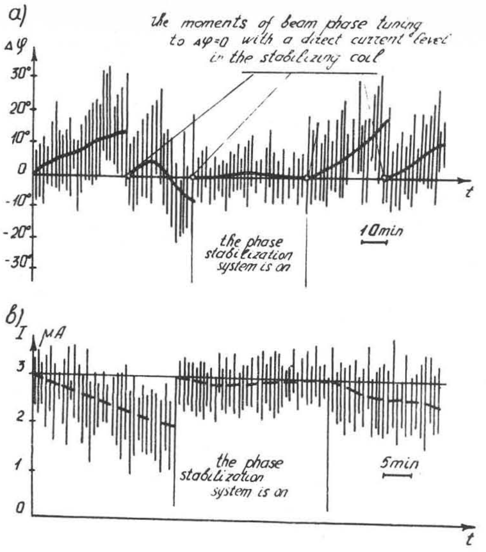

Fig. 2. Time changes of the phase bunch position
(a) relative to the optimum value
(b) the beam intensity behind the deflector.

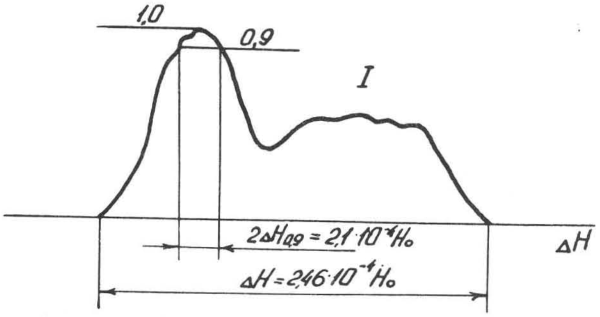

Fig 3. Resonance curve I (ΔH) for the beam current in the ion tube.