MEASUREMENTS OF ENERGY SPECTRUM AND INSTABILITY OF THE SYNCHRONOUS BEAM ENERGY AT THE OUTPUT OF THE ION LINAC BY MEANS OF TRANSPARENT PICK-UPS DURING OPERATION

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(presented by I. Semenushkin)

Abstract

A method of measuring the energetic spectrum of the beam of charged particles at the ion linac output has been considered. This method is based on a signal of the first harmonic of the Fourier expansion of a periodic sequence of bunches of charged particles, produced at the ion linac output, by means of a transparent pickup and an amplifying system. The method makes possible to obtain some information on an instantaneous value of the energetic spectrum for all the time of the injection [1].

The use of two inductive pick-ups, located along the drift space of the injection system at some distance one from another, allows (after comparison of signal phases) to obtain some information on the instability of the injector synchronous energy during both one injection pulse and several pulses.

The well-known method of measuring the energetic spectrum by means of bending magnets allows to obtain the curve of the energetic spectrum accurate enough in absolute units, but it requires quite a long time and high precision devices [2].

In the latter case, measurements are made by bending the beam from the usual direction, therefore any information on the energetic spectrum in the operating régime is absent.

Behaviour of the Bunch of Charged Particles along the Drift Space of the Injection System.

It is known that the beam, emerging from a linac, consists of discrete proton bunches. The distance in phase between bunch centres is 2π and the linear distance is $L = \beta_{KS}\lambda$ where β_{KS} is the final relative velocity of synchronous particle, λ is the accelerator wave length.

At the linac output a bunch has small linear and phase sizes (in comparison with 2π and L). Such a bunch, because of the energetic spectrum of its particles, expands in phase travelling along the drift space of the injection system. The degree of the bunch phase expansion depends on the energetic spread of its particles.

In order to simplify the analysis, one assumes :

1) The cylindrical shaped bunch has a uniform charge density.

2) All the charges of successive bunches are equal.

3) Inside a bunch the longitudinal components of proton velocities are distributed, with respect to the Z-axis, as a linear function. Particles in the middle of the bunch (Z = 0) have no velocity spread.

These assumptions allow to consider bunches as a succession of periodical functions, the form of which at the distance l_1, l_2, l_3 ($l_3 > l_2 > l_1$) from the linac output is shown in Fig. 1.

The function succession, shown in Fig. 1, can be expanded into the Fourier series [3]. According to the chosen coordinate, this Fourier development is :

$$J_{An} = \frac{J_0}{2} + \sum_{K=1}^{\infty} J_{Kn} \cos Kz \tag{1}$$

$$J_{Kn} = \frac{2}{T}\int_0 J_{An} \cos Kz \, dz = \frac{4}{T}\int_0^{z_n} J_{An} \cos Kz \, dz \tag{2}$$

where K is the harmonic number, n is the harmonic order depending on the function development amplitude or on the site where the bunch is located.

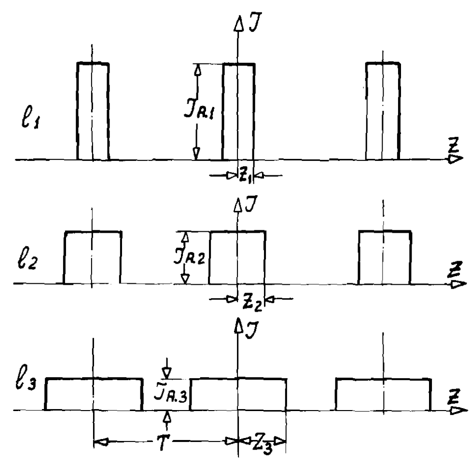

Fig. 1. Functions describing the cylindrical shaped bunches with uniform charge density.

Thus, electromagnetic waves with multiple frequencies and amplitudes, defined by the formula (2), are running along the injection system. The peculiar character of this process is that the harmonic amplitudes are not constant as the bunches move across the drift space.

In fact, measuring the first harmonic amplitude at the distance l_1 from the linac output (bunch succession, given in Fig. 1) and using the formula (2), one can obtain :

$$\mathcal{J}_{1.1} = \frac{4}{T}\int_0^{z_1} \mathcal{J}_{A1}\cos z\,dz = \frac{2}{\pi}\int_0^{z_1}\frac{Q}{z_1}\cdot\cos z\,dz = \frac{2Q}{\pi z_1}\sin z_1 \qquad (3)$$

where $I_{A.1.} = \frac{Q}{z_1}$ is the development amplitude; Q is the bunch charge.

Accordingly, by measuring the first harmonic amplitude at the most remote point (l_2) from the linac output, one can obtain :

$$\mathcal{J}_{1.2} = \frac{4}{T}\int_0^{z_2}\mathcal{J}_{A2}\cos z\,dz = \frac{2Q}{\pi z_2}\sin z_2 \qquad \text{etc.}$$

Similar calculations can be performed for higher harmonics.

Figure 2 shows the results obtained by the formula (2), i.e. the first and the second harmonic amplitude change depending on the half-width $\Delta\phi$ of the phase bunch. The value $\Delta\phi$ is varied from 0 to π.

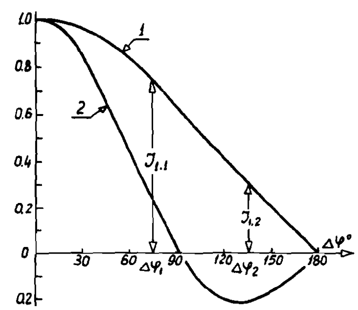

Fig. 2 Normalized curves of the first and second harmonic amplitudes depending on the half-width of the phase bunch.

If at a distance l from the linac output an inductive pick-up e.g. a cylindrical pick-up electrode, is installed, and if the pick-up amplifier is tuned on the frequency of the measured 1st harmonic, the signal at the output of the amplifier will depend on the phase bunch width 2 $\Delta\phi$ at the location of the electrode. The phase bunch width, in the nonrelativistic approach, is linearly dependent on the energetic spread, according to the following relation :

$$2\Delta\varphi = \frac{1}{2}\frac{\Delta W}{W_{KS}}\frac{\ell}{\beta_{KS}\lambda}\cdot 2\pi = A\frac{\Delta W}{W_{KS}}$$

Thus, the pick-up electrode signal is a function depending on the energetic spectrum:

$$\mathcal{J} = f_1(2\Delta\varphi) = f_2\left(\frac{\Delta W}{W_{KS}}\right)$$

This functional dependence is such that the energetic spectrum minimum corresponds to the maximum of the pick-up electrode signal.

The analysis shows that in the case of the real charge density and energetic spread of particles in the bunch the curve plots of Fig. 2 change slightly, but the statement that the maximum signal from the pick-up electrode, located at a definite distance from the linac output, corresponds as before to the minimum of the energetic spectrum of the bunch, remains valid.

The described method does not allow to define the synchronous energy instability ΔW_s during either a single injection interval or several injection intervals.

Figure 3 shows an arrangement with two pick-ups separated by a drift space. The pick-up signals are fed into tuned amplifiers (5), then into a phase bridge (6) which gives a signal proportional to the phase difference between the two inputs.

A change in the energy of the synchronous particle (i.e., the average energy of the bunch) gives rise to a change in the phase shift between the selected harmonic of the two pick-up signals. Hence changes in the synchronous energy are monitored by the phase detector output.

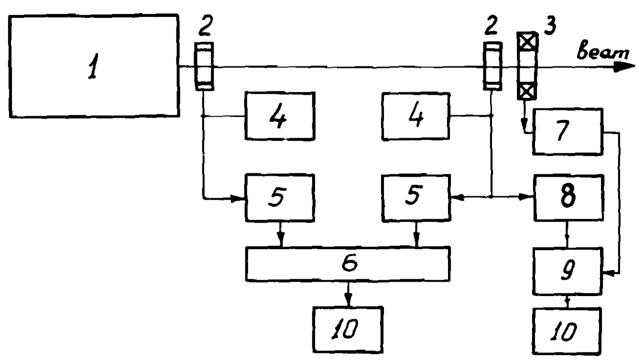

Fig. 3 Block diagram of the device.

1. Linear accelerator of ions. 2. Pick-up electrode. 3. Current transformer. 4. Matching devices. 5. Power resonance amplifier. 6. Phase measuring bridge. 7. Measurer of ion current. 8. Resonance amplifier. 9. Normalizer. 10. Indicator.

Thus, the signal change at the output of the phase measuring device allows to evaluate the qualitative and quantitative change of the synchronous beam energy during both a single injection pulse and several injection pulses.

Device Description

A device, which realizes the described method, has been constructed at the Joint Institute for Nuclear Research for measuring the energetic spread and the instablility of the beam synchronous energy at the linac output used as an injector for the synchrophasotron. The block diagram of the device is presented in Fig. 3. Two pick-up electrodes are installed at a 8 m distance one from another (2). The 10 mV signal of the first harmonic (f=143 MHz) is supplied to the resonance amplifier input (5). The amplifier has a small coefficient of non-linear distortions at the amplitude of an output signal up to 15 V. The phases are compared at the frequency of the first harmonic with an accuracy of 3%. Such an accuracy allows to measure fluctuations of the linac synchronous energy of 9 KeV. Figure 4 presents the oscillograms characterizing the instability of the synchronous energy of the injector operating in two régimes : without an energy modulator (curve 1) and with an energy modulator (curve 2). The modolator is placed between the pick-ups (2).

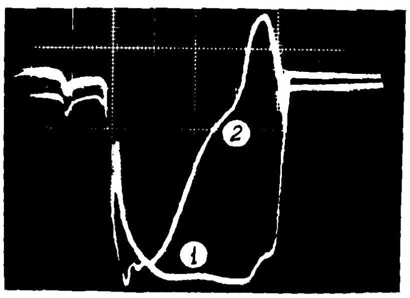

Fig. 4 Oscillogram of signals from the measurer of the instability of the synchronous energy. 1. Changes of the linac energy. 2. Changes of the injector energy with the operating energy modulator. Scale : horizontal 1 cm - 100 s, vertical 1 cm - 20 KeV.

In order to measure the energetic spectrum, one of the pick-ups, located furthest from the linac, is used. For normalizing the spectrum signal, the system of measuring ion current by means of a current transformer is applied.

The results of measuring the energetic spectrum versus accelerating field levels of the linac cavity are presented in the oscillograms (Fig. 5).

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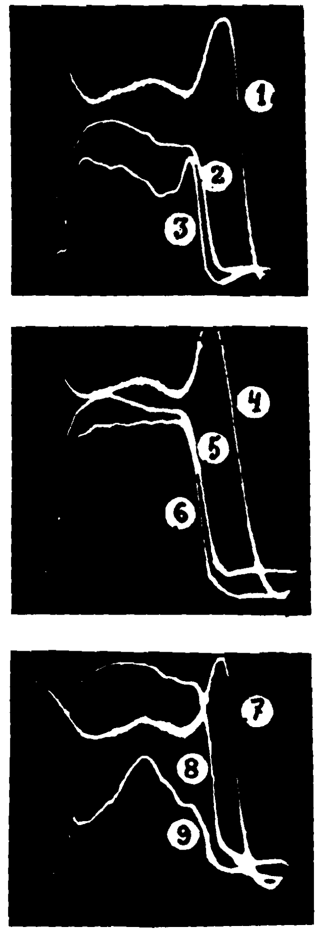

Fig. 5. Oscillogram of signals from the spectrum pick-up depending on the accelerating field level in the linac cavity.
1,4,7. Variation of the accelerating R.F. field at U R.F.= U nom + 0.015 U nom; U R.F. = U nom; U R.F. = U nom - 0.015 U nom, respectively.
The oscillogram gives only the amplified vertex of the plane part of R.F. impulse.
2,5,8. Current impulse at the linac output.
3,6,9. Signal from the spectrum pick-up

References

1) Yu.F. Beznogikh, M.A. Voevodin. Preprint JINR 9-5253, Dubna, 1970.

2) V.A. Batalin et al. Proceedings of the Conference on Accelerators of Charged Particles, Moscow, 1968, v.1, p. 551.

3) R. Bergere et al. Nucl. Instr., 15, N 4, 327, 1962.