BUNCH SHAPE ANALYSER WITH TRANSVERSE SCANNING OF THE LOW ENERGY SECONDARY ELECTRONS

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Abstract

The bunch shape analyser is developed and used for INR linac tuning. The operation is based upon a transverse scanning of the low energy secondary electrons emitted from a thin target crossed by an accelerated beam. The phase resolution is less than 1° (f=198.2 MHz). The third harmonic (f=594.6 MHz) is used for phase separation of electrons. RF deflector power consumption is 1.5 W. The experience of bunch shape measurements and analyser possibilities are described.

Introduction

The longitudinal bunch density distribution is one of the most important characteristics of accelerated beam. The bunch shape analyser with a transverse scanning of the low energy secondary electrons has been developed in INR and one is used for linac tuning. The preliminary test results of the phase analyser have been described elsewhere [1]. During last years the analyser was essentially improved and now the experimental phase spectra are used for proton beam tuning in INR linac.

Principle of operation

The schematic diagram of the analyser is given in Fig. 1. The beam being studied passes through the target 1 and secondary electrons are emitted. The potential of the target is negative so the electrons are accelerated up to energy 4 KeV by electrostatic field. Electrostatic lens 3 is installed downstream collimator 2 to obtain a beam image at collimator 5. The transverse modulation of electrons is created by the deflector 4. The deflecting field is synchronous with the rf field in accelerating cavities. The deflection angle depends on the phase of deflecting field. As the time of flight of electrons from the target to the deflector is constant the collector 6 registers electrons knocked out by protons having a definite phase. That is the current downstream collimator 5 is proportional to the number of particles in a definite point of longitudinal charge distribution. Total density longitudinal charge distribution is obtained by changing a phase of deflecting field. The secondary electrons are extracted under acute angle to the primary beam to exclude δ-electrons, which can destroy the proportionality between electron current on SEM and bunch density. Moreover it allows to measure phase spectrum of low energy ions when the particle run in the target is less than target thickness.

The accelerating frequency of 198.2 MHz was originally used for electron deflection, but it was found the proton beam passing through analyser causes the rf resonant discharge in the deflector. As no practical means to avoid this effect at this frequency it was decided to use the third harmonic, which is equal to 594.6 MHz, because in this case the operating voltage is less than the discharge threshold. To provide RF synchronization of deflecting field the phase reference line of accelerator is used. The power supply circuit includes (Fig. 2) directional coupler, two mechanical phase shifters and frequency multiplier. Special care should be taken for matching of rf lines because the reflections lead to errors of bunch length measurements due to nonlinearity of the phase shifter characteristics. The maximum error $\Delta\Phi_{max}$ of bunch length measurement can be written:

$$\Delta\Phi_{max}=2|\Gamma_g||\Gamma_l|\mathrm{Sin}\Phi ,$$

where Γ_g and Γ_l are reflecting coefficients from the generator (directional coupler) and a load (frequency multiplier) measured in a phase shifter position.

To measure a secondary electrons current downstream the collimator 4 a secondary electron multiplier is used. It is possible to change the gain of multiplier by adjustment of supply voltage. This allows to weaken the specifications to the following electronics. The output multiplier signal about 10^{-6}A is amplified up to a few volts, is transmitted to the control room and after further processing (integration or sampling) enters to the computer.

The tungsten wire of 0.1 mm diameter is used as a target. To tune electron optics the target has been heated by electric current and the image was visually observed at the collimator plates (Pos. 5 in Fig. 1) covered by phosphor. The thickness of a bright line was less than 1mm.

Bunch shape analyser test

The bunch shape analyzer was tested at the exit of the first accelerating cavity (20 MeV) of INR linac with the pulse currents up to 40mA and pulse length of $6\ 10^{-5}$s.

The main characteristic of a bunch shape analyser is a phase resolution. The resolution is determined by: time jitter of electron emission , initial energy and angular dispersion of secondary electrons, distortion of electron bunch density due to mechanical misalignment of the target, the finite dimensions of target, nonuniformity of accelerating and focusing electrostatic fields and nonzero dimension of the electron beam image ΔX_L. The component of resolution $\Delta\varphi_K$ due to quantity of ΔX_L depends upon the amplitude of deflecting field and can be written as

$$\Delta\varphi_K = \frac{\Delta X_L}{n X_{LM}} ,$$

where X_{LM} is a maximum deflection of electrons in the collimator plane, n is the harmonic number of the deflecting frequency (n=3). The experimental value of X_{LM} has been found from the measured phase spectra. For this goal the various potentials was applied to the electrostatic lens in order to focus into the collimator plane on a distance of X_L from the deflector axis. Then if the deflector rf field phase is adjusted in wide range the measured phase spectra are located biperiodically with the distances between adjacent spectra Φ_1 and Φ_2, moreover $\Phi_1 \neq \Phi_2$ and $\Phi_1 + \Phi_2 = 2\pi/n$. In Fig. 3 the phase spectra measured at X_L=12mm are shown ($\Phi_1=31^\circ$, $\Phi_2=89^\circ$). The maximum deviation of X_{LM} is found from expression:

$$X_{LM} = \frac{X_L}{\sin \frac{\Phi_2 - \Phi_1}{4}}$$

and X_{LM}=48mm. Following expression has been used to find $\Delta\varphi_k$:

$$\Delta\varphi_k = \frac{1}{n X_{LM}} \left[(\Delta X_{LO})^2 + (\delta X_{SEM})^2 + (\delta X_{Ld})^2 \right]^{1/2}$$

where ΔX_{LO} is a termoelectron beam size on the collimator plane ($X_{LO} \approx$ 1mm), δX_{SEM} is a beam size growth due to the initial electron distribution on energy and angle, δX_{Ld} is a beam size growth due to deflector field nonuniformity, n=3. The values of δX_{SEM} and δX_{Ld} , found from the calculations, are equal to 0.02mm and 1.3mm correspondently. Therefore $\Delta\varphi_k \approx 0.6^\circ$. Then the final value of resolution of the analyser is 0.9°.

To confirm the phase resolution value the compact bunches have been formed by adjusting the rf field level in the first Alvarez tank of the INR linac. If a monochromatic beam is injected the bunch shape at the tank exit extremely depends on the longitudinal phase advance. If the latter $\psi=\pi/2+\pi n$ (n=0,1,2...) then the phase width of bunch is extremely small, for instance, for rf accelerating field level $E=0.986E_0$ (E_0 is a nominal calculated value) FWHH of the phase spectrum is equal to 2° only. In Fig.4 the measured phase spectra are shown which coincide with the calculated ones if to take into account the uncertainties of rf amplitude and phase which are less than 0.5% and 1° correspondently and injection energy error is $\leq$ 0.3% .

In order to take into account the space charge influence of the proton beam on secondary electron motion the measurements of phase spectra have been done for 20 MeV and 20 mA beam with and without 0.5mm collimating slit located upstream the target. The results of repeated measurements in Fig. 5. which show the weak influence of the space charge forces on phase spectrum measurement in our conditions.

Using the secondary electrons for diagnostics goal it is possible to measure the beam being investigated in wide intensity range. It is important particularly for the high intensity accelerators. By using the phase analyser the fraction of accelerated 20MeV beam has been determined. The unaccelerated particles on the tank exit are smeared uniformly on phase. In Fig. 6 the phase spectrum measured with various SEM gain is shown. The analysing shows that more than 99% of particles are within the bunch. The phase analyser sensitivity allows to measure the beam fraction up to 10^{-4}

Conclusion

The phase analyser tests as well as the experimental data of longitudinal beam dynamics study shown the high reliability and possibility to receive many useful information. Now this device is used to measure the longitudinal emittance of 100MeV proton beam.

Reference

[1] A.V. Feschenko and P.N. Ostroumov, "Bunch

Shape Measuring Technique and Its Application for an Ion Linac Tuning," Proc. of 1986 Linac Conf., Stanford, June 2÷6, pp. 323÷327.

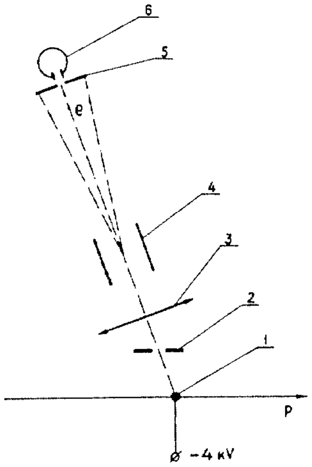

Fig. 1. The principle of operation.

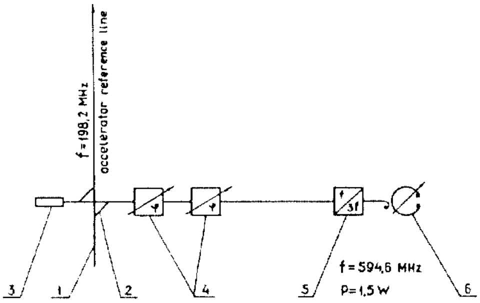

Fig. 2. The circuit for rf feeding of analyser (phase reference line (1), directional coupler (2), matched load (3), mechanical phase shifter (4), frequency multiplier (5), rf deflector (6)).

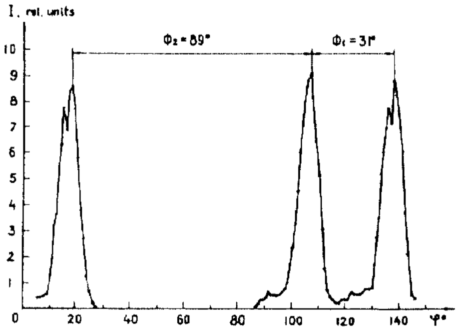

Fig. 3. Phase spectrum of electrons deviated relatively of rf deflector axis.

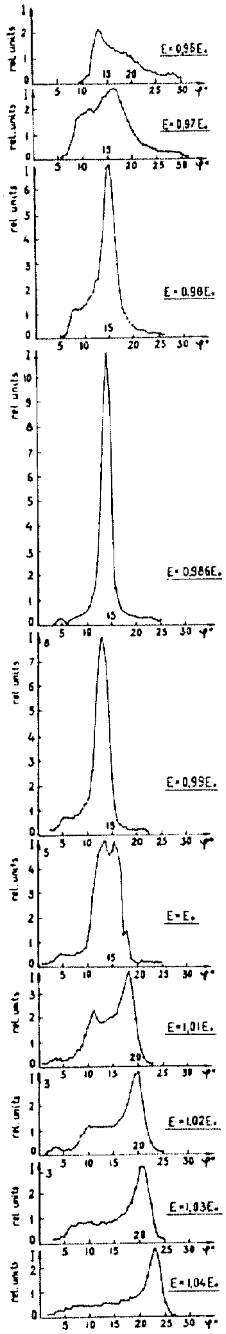

Fig. 4. Phase spectra for various rf field level in the first cavity of INR linac.

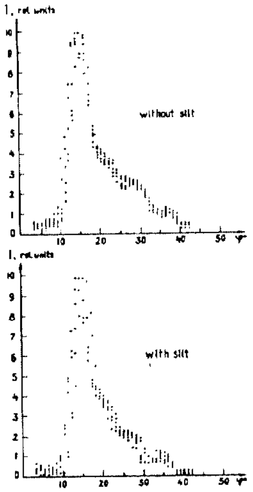

Fig. 5. The change of phase spectrum being measured for collimated and uncollimated proton beam.

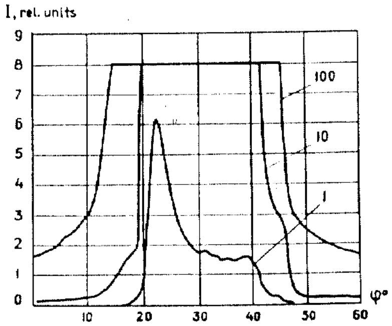

Fig. 6. Phase spectrum measured for various SEM gains.