Short Bunch Length Detector for Ion Beam with High Bunch Density

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Abstract

The secondary electron rf monitors for short ion bunch phase distribution measurement are presented. Construction particularities of the monitors, influence of space charge of both the primary and the secondary electron beams on the phase resolution, thermal regime of the target during beam-target interaction are considered.

I. INTRODUCTION

The secondary electron bunch longitudinal profile monitors have the best prospects for detailed study of the particles longitudinal dynamics, precise beam longitudinal matching and for setting up the rf parameters of cavity accelerators operating in a low or intermediate energy region especially.

These monitors have been designed during last about twenty years at MEPhI. Two monitors proposed and designed at MEPhI in 1978 and 1980 for ion linacs have been successfully tested respectively at IHEP in the I-100 injector (Protvino, 1980) and at INR (Troitsk,1988). These monitors use low energy secondary electrons and their bandwidths were not less than 20 GHz.

In this report a short review of this activity relative to the monitors for L band ion linac with high bunch density similarly to project beam parameters of linacs at SSCL or INR is presented.

These monitors must satisfy the next major requirements as a rule their phase resolution has to be not worse than two degrees at the frequency of bunches. In many cases the detector size along the accelerator axis must be about 0.1 m. The detector must permit its inspection without disassembling. To use the same type detector for entire accelerator the major monitor parameters must be independent of the beam energy.

Our studies have shown that the secondary electron rf monitors satisfy the above mentioned requirements most completely. In these devices the phase distribution of the high energy primary beam is isochronously transferred into the same distribution of the low energy secondary beam. Then this secondary distribution is coherently transformed into transverse one through rf modulation allowing direct presentation on a low frequency display.

It is known that the secondary electron emission is divided into low energy and high energy components. The time dispersion of the former was found to be less than 6 ps [1], which is acceptable for measurements in L band linac. As to the latter, its dispersion may be made less than 0.1 ps [2,3]. Note that one of the first detectors with rf transverse scanning of low energy secondary electrons was that above [1].

II. PRINCIPLE OF OPERATION

The detectors for ion beam analysis consist of the primary convertor (PC) and rf shutter (RFS) with single channel collector on its exit or rf-modulator (RFM) with multichannel collector.

PC is either a target unit with threadlike focusing electrodes or wire target without electrodes. In first case the target-emitter is a strip [3]. Fig.1,2 make the electrostatic focusing and relative position of the electrodes clear for this case.

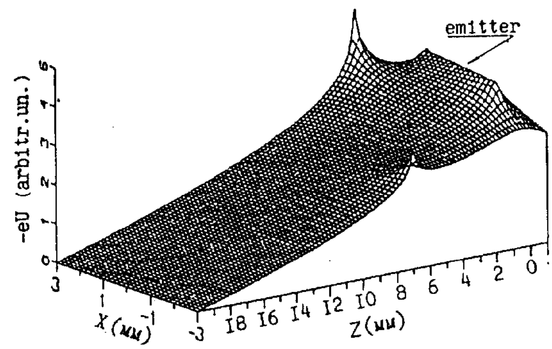

Fig.1. Distribution of electrons potential energy in electric field of PC.

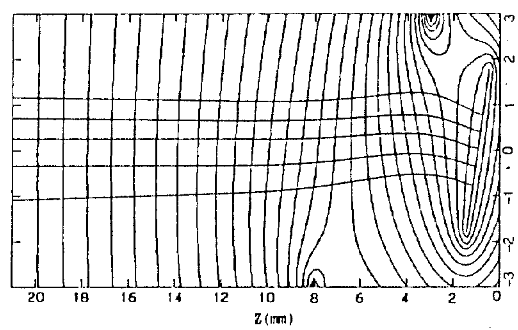

Fig.2. Electrons trajectories and equipotential lines of field as above.

RFS of longitudinal or transverse types are used. In the former the electrons are energy modulated by either the same or multiple rf used in the linac and then spatially separated with a spectrometer. The latter contains a rf scanner of the beam and the electron spatial separation is accomplished in a drift space with the slit collimator on its exit. Replacing in RFS the collimator and the single channel collector with the multichannel one and choosing the special monitor operation regime we get RFM and the corresponding monitor with resolution better than 2° over a range of entry phases not less than 90° [3]. In this case the rapid longitudinal profile measurements can be carried out.

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The principle of the monitor operation consists in the following. By applying high negative voltage to the target and the focusing electrodes in PC the secondary electrons produced as a result of the primary beam-target interaction are accelerated and formed as a narrow beam at the entrance of rf resonator of RFS (or RFM) so that the axes of the electron and ion beams are orthogonal to each other. Only for some interval of input particle phases the electrons will pass through the RFS. Recording the collector output signal as a function of the RFS phase we get the bunch phase distribution averaged over the ensemble of the beam bunches. The monitor with RFM allows to record the bunch phase distribution of single bunch.

III. RESOLUTION OF THE DETECTORS

The monitor phase resolution is basically determined by the secondary electron phase debunching in PC and the RFS resolution. The phase debunching is mainly defined by the finite transverse spot sizes of the primary and secondary beams on the target and the initial secondary electron energy spread. By choosing geometry and potential of the target (for corresponding ion beam energy) the debunching caused by the finite transverse beam sizes may be reduced to negligibly small value in comparison with the latter [3]. Note the initial secondary beam spread in energy takes effect within the electron path length in the detector from the target to the half rf modulator gap length. To minimize the electron phase debunching caused by this last reason the distance between the target and the gap and also the electron path length in the rf modulator gap must be as small as possible. In the known detector [4] the rf modulator gap with length of about 5 mm is placed on the ion beam pipe boundary. It ought not to place the RFS gap in the accelerated beam area, otherwise the electrons will be modulated by resultant rf voltage one component of which is induced by the ion beam and another - by the RFS generator.

Using a toroidal cavity as the rf modulator of the electrons a suitable degree of uniformity of rf field in electron transit slot is achieved with the ration of the gap length to the entrance slit width not less than 5.

However, there are some other important effects which can lead to a degradation of monitor phase resolution.

IV. INFLUENCE OF SPACE CHARGE

The space charge forces of both the primary and the secondary electron beams disturb the electrons motion in the monitor. As a result of this interactions the electron beam was got an added broadening of momentum spectrum (δ,%), an additional angular divergence ($\Delta x'$,rad), and added phase debunching ($\Delta\varphi$).

These parameters as function of equivalent target radius R_o and distance x_f from target to the resonator wall are displayed in fig.3,4 where: for fig.3 - target potential u_t=-4kV, x_f=20mm, distance from the ion beam axis to the wall is equal 20mm; for fig.4 - u_t=-4kV. Proton beam parameters were: proton energy - 100 MeV, beam diameter - 5mm, bunch phase length 10° of 0,2 GHz and pulsed beam current - 50mA.

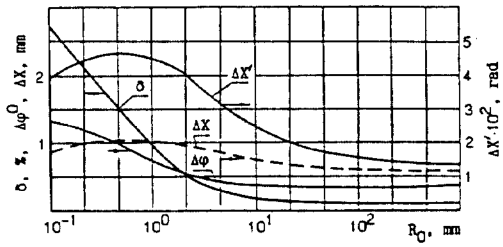

Fig.3. Dependences of δ, $\Delta\varphi$, Δx, $\Delta x'$ vs the target radius R_o.

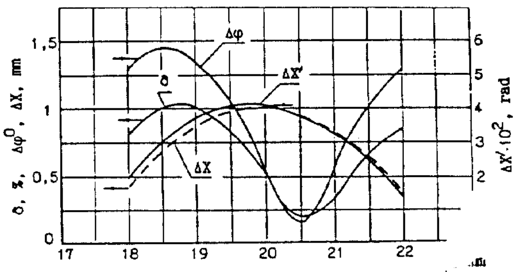

Fig.4. Dependences of δ, $\Delta\varphi$, Δx, $\Delta x'$ vs the target position x_f relative to the resonator wall.

As it follows from these figures the radius R must be not less than 2mm and the target have to be in maximum of the ion beam current density [3].

The influence of space charge of the secondary electron beams is illustrated in fig.5,6 where the electron phase debunchings $\Delta\varphi_2$ of 427,6 MHz as function of the target potential U_t and the gap length L_g are shown. In fig.5 for curves 1 and 2 the secondary electron bunch charges Q are 2 pC and 0,4 pC respectively and for 3,4,5 Q are equal to 38 pC, 25 pC and 7 pC. In the first case the bunch phase length $\Delta\varphi$ is 30° of 427,6MHz and the primary beam energy W - 2,5 MeV. In the second case $\Delta\varphi$=10°, W=70 MeV. The target material may be either carbon or tungsten or tantalum because the ion bunch charge is transferred into the secondary charge with corresponding coefficients are equal to the secondary electron coefficients for the above mentioned material. All curves in fig.6 are defined at the electron energy W=10 keV but curve 1 - for W=4 keV and Q=25 pC. The initial beam radius for all curves is 1 mm but for curve 5 of fig.5 one of the transverse bunch size is equal to 0,1 mm.

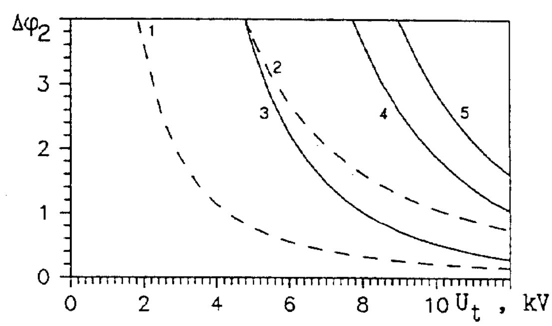

Fig.5. Dependences of phase debunching vs u_t.

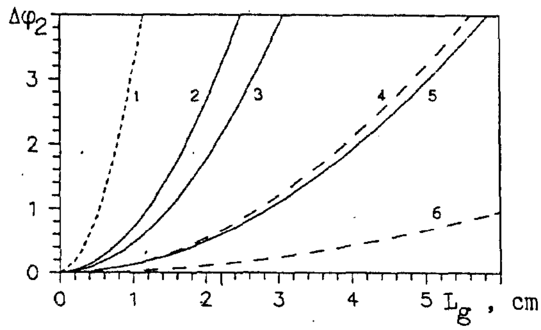

Fig.6. Dependences of phase debunching vs L_g.

As it follows from these figures the target potential is to be about 10kV and the gap length - about 1cm.

V. BEAM HEATING OF EMITTER

The monitor emitter heating up to temperature when thermocurrent density can excess 1 % of corresponding secondary electron current density restricts the device range of operation. To determine time dependence of the emitter maximum temperature when it is being pulse beam heated an unstationary heat transfer equation with a radiant heat trasfer term has been solved. Thermophysical coefficients for temperature profiles calculation have been taken from [5]. The beam current density distribution was taken Gaussian.

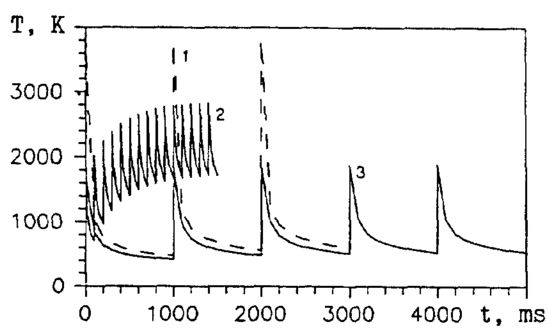

Fig.7. Dependence temperature of wire-target vs time.

Fig.7 shows tungsten temperature vs time at 2,5 MeV proton beam heating. Beam parameters for 7(1): beam impulse frequency f = 1 Hz, rms r =1mm; for 7(2): f = 1 Hz, rms r = 0,5mm; for 7(3): f = 10 Hz, rmr r =1mm. The emitter wire length - 30mm, radius - 0,05mm. Fig.8 shows carbon strip-emitter maximum temperature vs time for the same ion beam: for 8(1) and 8(3) - rms r =1mm, for 8(2) rms r=0,5mm. For 1 and 2 curves the thickness of target is 0,1mm and for 3 - 0,2mm. The target geometry for fig.8 is shown in fig.2.

From these figures it is clear the strip target has advantage over the wire target.

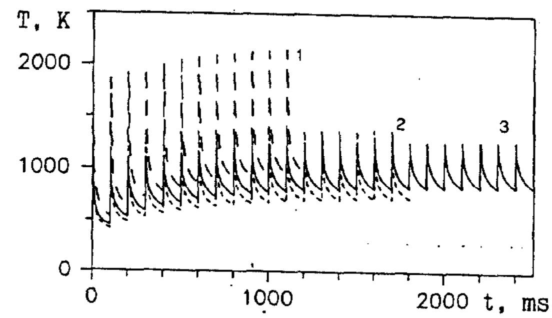

Fig.8. Dependence temperature of strip-target vs time.

VI.CONCLUSION

Our consideration demonstrates the design of the monitor must take account of the influence of space charge of both the primary and the secondary beams and the thermal regime of the target on the monitor operation. Our studies shows the rf monitor using the low energy secondary electron can achieves its bandwidth up to 50 GHz.

VII. REFERENCES

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