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HIGH-SENSITIVITY BUNCH CHARGE MONITOR

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Conceptual design of high-sensitivity bunch charge monitor is presented. The device operates with short, spaced bunches. For the optimal performance, the bunch duration should be less than 10 ns and bunch spacing should be more than 100 ns. Sensitivity of the monitor is near 10 V per nanocoulomb. The equivalent scheme and the output signal shape are also presented. Such kind of monitor seems to be promising for bunch charge measurements of the beams like those in the TESLA or ILC projects.

Представлена концептуальная конструкция высокочувствительного датчика заряда сгустков заряженных частиц. Прибор предназначен для измерения коротких, разнесенных по времени сгустков. При оптимальных условиях длительность сгустков не должна превышать 10 нс, а промежуток между ними должен быть более 100 нс. Чувствительность датчика составляет около 10 В на 1 нКл. Представлены эквивалентная схема и форма выходного импульса. Такого рода датчики представляются перспективными для измерения заряда банчей в установках типа TESLA или ILC.

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INTRODUCTION

Monitors for beam intensity measurement are necessary elements of any accelerator. Therefore, this area of beam diagnostics is well developed. A lot of various types of monitors, nondestructive as well as with destruction of a beam, are developed by now. Current transformers, pickup-electrodes and wall current monitors are most widespread among devices for pulse beam monitoring.

However, recent development of accelerating technique has led to appearance of beams with unique parameters to which traditional diagnostic approaches though are acceptable, but unlikely are optimums. First of all, it concerns linear accelerators with photoinjectors. For example, on the test accelerator TTF at DESY [1], a relatively long electron beam consists of extremely short (from tens up to shares of picoseconds) bunches, separated from each other by about 110 ns or 1 μs, depending on a mode.

This article presents a variant of the monitor for intensity measurements of such beams with sufficiently separated short bunches.

THE CHARGE MEASUREMENTS OF SUPERSHORT BUNCHES

First of all, it is necessary to note that it is rather complicated to measure the real shape of a short bunches current even for durations of several nanoseconds. Measurement of the real shape of current by means of electric or magnetic fields measurements becomes impossible at all for picoseconds durations.

One of rather widely spread methods of bunch intensity measurements is usage of broadband pulse current transformers. Such transformers are used, for example, on the linear accelerator TTF at DESY [1]. The integration time of these transformers is several milliseconds and is achieved by means of significant number of turns in a winding. Thus, the current sensitivity is decreased respectively.

However, actually there is no necessity to have a long integration time for beam structure with short bunches following one after another with rather large intervals. It is quite sufficient to have an integration time more than duration of one bunch and to achieve relaxation time of the device less than the interval between adjacent bunches. As current sensitivity of a transformer grows with reduction of number of turns, the maximal sensitivity is reached with single-turn transformer. In this case a measurement can be performed not by means of a secondary winding, but with primary winding that is directly on a dielectric gap.

The conceptual design of such a device is shown in Fig. 1.

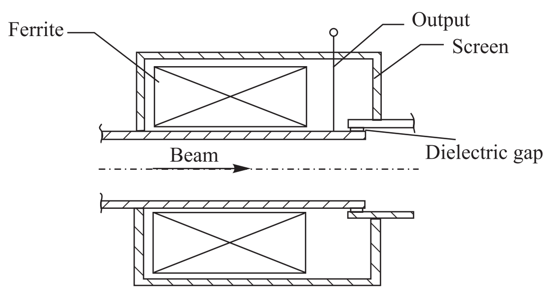

Fig. 1. Conceptual design of the monitor

When the charged bunch moves along the vacuum chamber of the accelerator, the image charge equal to it moves in the conductive wall of the chamber. When the image reaches a dielectric gap, it becomes charged like a capacitor. The fast discharge of the capacitor through the screen (current bypass) is protected by the ferrite core. After that there is rather slow oscillatory discharge of capacity with high damping rate. The oscillation should be finished before the next bunch if the parameters of the ferrite core are chosen correctly.

The device is directly connected to a coaxial cable, and measurement of the signal amplitude at the beginning of a pulse allows easy calculation of the bunch charge. This method of charge measurements is known, but it was not widely used. By analogy to the wall current monitor, such a device can be named the wall charge monitor.

At very low intensity of bunches, for example, in ion accelerators, it is possible to use the symmetric scheme with the differential amplifier as shown in Fig. 2.

The simplified equivalent electric circuit of the monitor is shown in Fig. 3.

In the circuit L1 is the inductance of the ferrite core measured at low frequencies, and R1 is full equivalent resistance of the ferrite core and a coaxial cable. The parameters of elements that are shown on the circuit correspond to the experimental device.

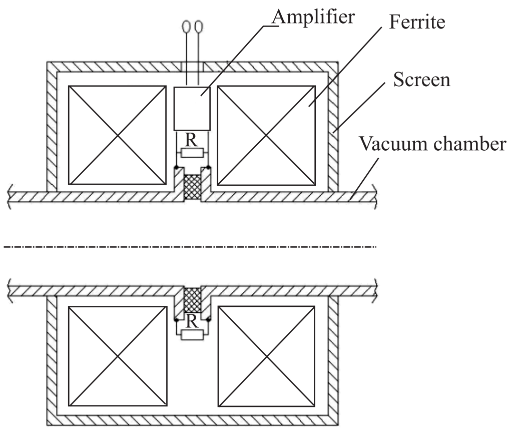

Fig. 2. Design of the symmetric monitor

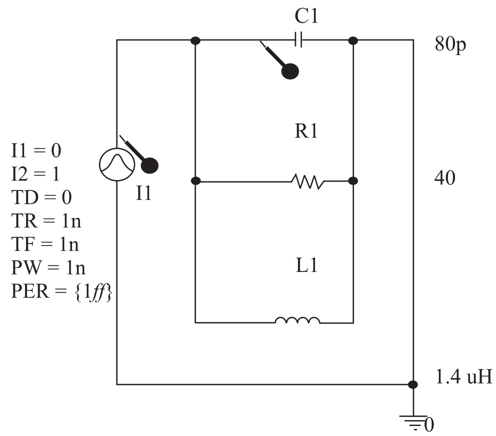

Fig. 3. The equivalent circuit of the detector

In Fig. 4 the calculated curve of an output pulse is shown when a short pulse of a current is applied.

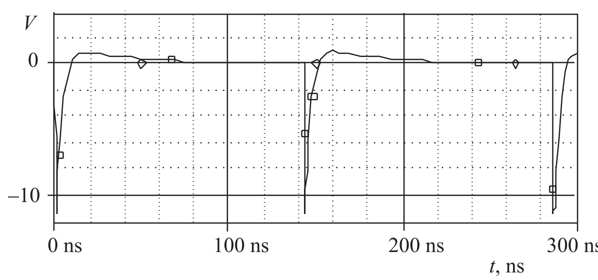

Fig. 4. The calculated curve of an output pulse

Oscilloscope traces of the input current and the output voltage of the experimental device are shown in Fig. 5.

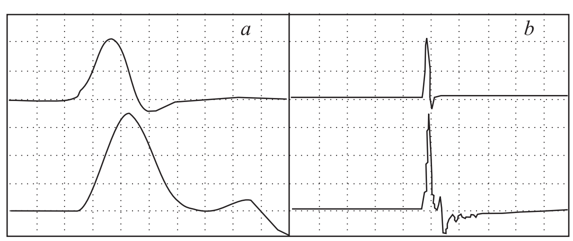

Fig. 5. Input current (upper trace) and output pulse (lower trace). *a*) 2.5 ns/div; *b*) 25 ns/div

MEASUREMENT OF LOW INTENSIVE BUNCHES

High sensitivity of the device allows using of wall charge monitor for measurements of low-current beams intensity, for example, ion beams in output channels of cyclotrons. Beams of cyclotrons represent a continuous stream of nanosecond bunches with relative pulse duration ~ 0.1. Low integration constant of the device does not allow one to complete integration of every bunch current. But as a rule, it is not required because average current is usually measured in cyclotrons. In this case, it is reasonable to optimize parameters of the device so as to have the maximal amplitude of the second harmonic and to use the resonant amplifier. Precision calibration of the monitor should be performed, for example, by means of Faraday cup because calibration depends on main frequency.

The experimental device has been developed, manufactured and successfully tested at the cyclotron U400.

The design is shown in Fig. 6.

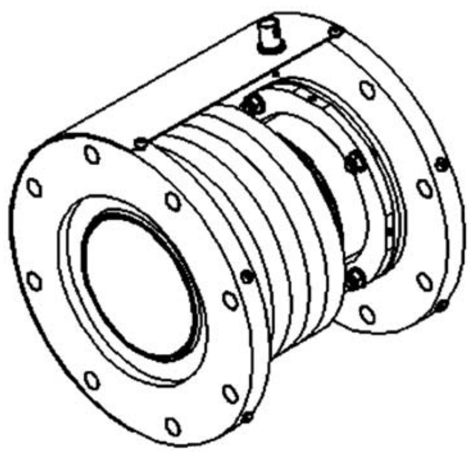

Fig. 6. The design of the experimental device

Results of test measurements have shown a capability to measure currents with average intensity of a fraction of microampere.

CONCLUSION

The described type of monitor can be used for measurements of intensity of beams with structure of short (less than several nanoseconds) bunches separated by rather large intervals.

Peculiar features of such kind of monitors are:

— high charge sensitivity;

— simplicity of calibration;

— simplicity of a design.

The most perspective areas for using such devices are the beams with the beam structure similar to linear colliders TESLA or ILC beams, where bunch duration is from several tens up to shares of picoseconds. They can also be used in heavy-ion cyclotrons.

REFERENCES

1. *Nolle D., Wendt M.* TTF2 Beam Monitors for Beam Position, Bunch Charge and Phase Measurements // LINAC 2004, Lubeck, Germany, 2004. P. 435–437.