THE MEASUREMENTS OF THE LONGITUDINAL BEAM PROFILE ON THE PREINJECTOR VEPP-5.

S.M.Gurov[1], P.A.Bak[1], Yu.D.Chernousov[2], P.V.Logachev[1], V.M.Pavlov[1], E.E.Pyata[1].

[1]Institute of Nuclear Physics, 630090 Novosibirsk, Russia.
[2]Institute of Chemical Kinetics and Combustion, 630090 Novosibirsk, Russia.

E-mail: S.M.Gurov@inp.nsk.su

Abstract

For effective work of preinjector VEPP-5 it is necessary 3 ns bunch with charge 1*10**10 electrons from termogun compress to bunch with 40 ps duration on the positron target. A new streak-camera with RF cavity on the main linac frequency is used. Streak-camera with circle scanning allows see 350 ps single light signal with sub-ps resolution. An additional slow scanning can obtain the trochoidal scanning. Thus one can see with picoseconds resolution and with less then 1psec synchronization the train of ten bunches which are spacing by 350psec. The results of worked streak-camera with RF-cavity for circle scanning are presented.

INTRODUCTION

The compression system

A single bunch mode is a basic one for the injector complex operation with electron-positron colliders (VEPP-4 and VEPP-2000) in BINP. In fact, the electron beam of 200 kV energy, 4 A current, and 2.5 ns width produced in the electron source should be almost 100 times compressed in the longitudinal direction, so that the pike current in the bunch and the bunch length should be 400 A and 6 mm, respectively. The compression occurs in two cavities that operate at the 16th RF Subharmonic (178.5 MHz) and RF buncher that operates at the main accelerator frequency (2856 MHz). The maintenance of the transverse beam size within a given range is ensured by the increasing value of a magnetic field in the longitudinal direction. The stable operation of accelerator in a single bunch mode requires steady amplitudes and phases for all elements of RF system. In case of compression system detuning, there is a train from 20 – 40 ps bunches which follow every 350 ± 20 ps.

Electron Beam Probe and Streak Camera

The single bunch mode can be very easy tuned by an Electron Beam Probe [2]. The operation of this non-destructive beam diagnostic tool is based on scanning of a thin low energy electron beam in the electromagnetic fields of a short relativistic bunch. This device allows measuring the accelerated charge in each bunch of the train as well as to control relative transverse bunch positions and sizes.

However, the Electron Beam Probe still cannot measure the distance between bunches in train and the longitudinal beam profile of each bunch with picoseconds resolution.

A streak-camera is conventional device for this purpose. The good review of streak-camera for accelerators has been done K.Scheidt [3].

Limitation of sub-picoseconds resolution

For streak-cameras the time resolution is depended from different effects: spot size of focused beam at MCP, scanning velocity, velocity spread of electrons at photocathode and other.

At time resolution progress in sub-picoseconds domain for visible light signal the next inter agnostic effects are more significant. On the one hand, for good signal-noise ratio it is necessary at least 10-100 photoelectrons in time resolution interval. On the other hand, at sub-picoseconds resolution of single light signal the space charge effect becomes significant. In this case the time resolution t_r depends from photoelectrons number N and its velocity V as:

$$t_r \propto \frac{N}{V^3}$$

There are next ways for improving time resolution. First way is accumulation signal during series light pulse. This method does not work if the synchronisation between light source and streak camera bigger then desired time resolution or if the light signal changes from pulse to pulse. Second way is spreading of light to photocathode slit and then calculation the photoelectrons for each moment.

However, more fruitful way is increasing energy of photoelectrons. But the maximum photoelectron energy is limited by scanning system.

Our decision

We suggest use the high quality RF cavity for fast scanning. This allows increase the photoelectrons energy up to 70 кВ and more in comparison with 10 – 20 kV for conventional streak cameras. As result, the space-charge effect can be reduced significantly.

This advantage can be use for obtaining time resolution up to 100fs or for creation streak-camera with circle scanning and 0,5 – 2 ps resolution.

Historical remarks

In itself the idea of circle scanning is not new. The streak cameras are used in colliders from the very outset. In the paper [4] it is mentioned that in 1965 for observation the bunch of 10 cm length on the collider VEP-1 was used streak-camera with time resolution of 30 psec and circle scanning.

Streak cameras with circle scanning based on the different principles have been developed in the different countries [5-7].

Streak camera with trochoidal scanning

Streak camera with circle scanning based on the RF cavity has been created. The high quality cavity operates on the main accelerator frequency of 2856 MHz. This cavity produces a rotating magnetic field that is cross for photoelectrons motion [8]. The circle scanning allows see single light signal no longer then 350ps. At that the 1 µs synchronisation between light signal and streak camera is enough.

Moreover, pair of deflecting plates has been introduced just after cavity. In that way the trochoidal scanning has been obtained. The trochoidal scanning allows see with picoseconds resolution the train of several ten bunches which follow every 10 cm. At the same time the problem of synchronization between bunches is absent.

As registration system has been took assembling of MCP and Phosphor screen from old oscilloscope with 200µm spatial resolution. In our case this is restrict time resolution of our streak camera on the level of 1ps.

Measurements on the preinjector

Choice of radiation

For instrumentation by streak camera it is necessary obtain the light from accelerator electrons. The valuations for beam of 260 MeV energy and 10^{10} electrons gives 9×10^{7} photons of visible range for synchrotron radiation in isochronous bend, 2×10^{8} for transition radiation and $1{,}6\times10^{12}$ for Cherenkov radiation. For our case the synchrotron radiation is enough, nevertheless for obtaining first results we have decide to use the Cherenkov radiation.

Radiation source and glass

The Cherenkov radiation was obtained by means of the quartz cone of 1 cm length. The cone angle of 23 degrees was equal half of Cherenkov angle for quartz. This allows collecting of all photons in Cherenkov cone to parallel light beam (see Fig.1).

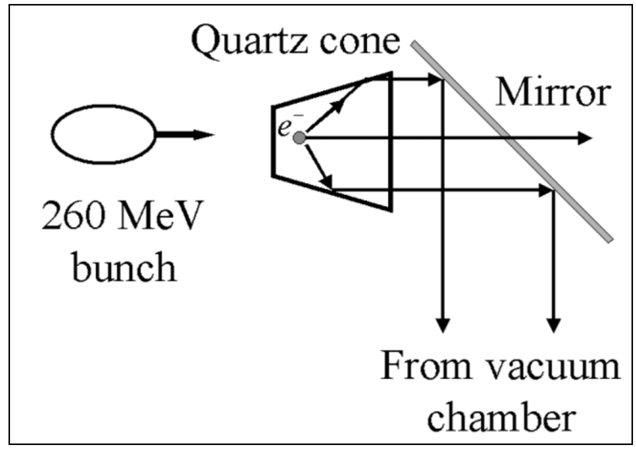

Figure 1: Scheme of quartz cone and mirror assembling.

The quartz cone and mirror have been introduced on the beam axis by manipulator.

The cone must be created from material remained transparency under beam influence. The experiment in search of the available glass was done on the accelerator of 3 MeV energy and 2 x 10^{12} electrons per pulse. The required glass has been found.

Measurements results

The diameter of circle scanning was obtained up to 45 mm. The spot size of focused beam was defined by spatial resolution of registration system (micro channel plate – phosphor screen – CCD camera) and was equal 0.4 mm. Therefore our streak camera has time resolution of 1ps.

When the sub-harmonic cavities are switch off the 2.5ns beam from 200 kV electron source is cut into 8 - 10 bunches by RF buncher (Fig.2). The trochoidal scanning was produced by anticlockwise circle scanning of 350ps period and slow linear scanning top-down.

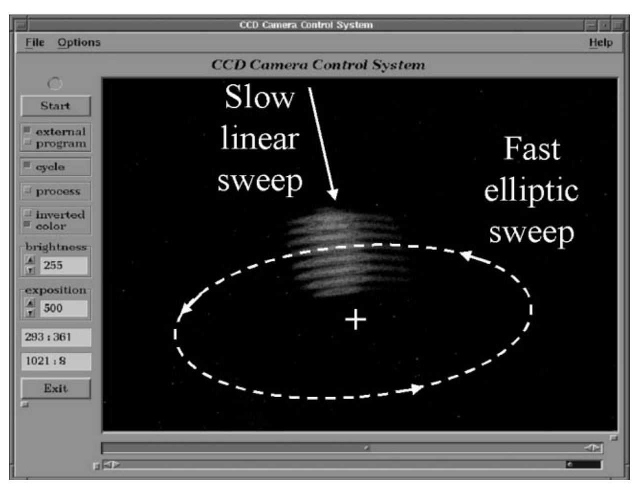

Figure 2: Two Sub-harmonics RF cavities switch off.

Tuning the amplitude and phase of Subharmonic cavities it is possible see longitudinal beam dynamics (Fig.3).

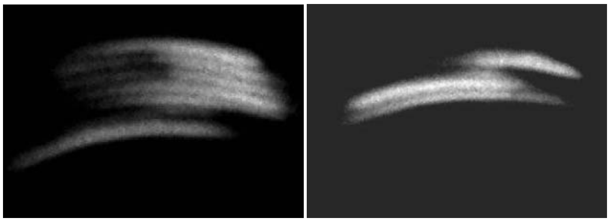

Figure 3: The longitudinal beam dynamics during single bunch tuning.

In that way the single bunch mode can be very easy tuned by new streak camera based on the RF cavity scanning.

The photoelectrons in our streak camera have energy of 70 kV. When the energy is reduced up to 10-20 kV the result of space-charge effect is easy observed.

SPIRAL SCANNING

Idea of spiral scanning

Idea of using high quality RF cavity for scanning system in streak camera gives a good account of oneself in experiments on the VEPP-5 preinjector. This achievement allows creating a streak camera with spiral scanning. The idea is based on the effect of amplitude beating at adding two harmonic signals with close frequencies. The frequency detuning must be enough in order to the circle scanning amplitude changes for one tune more than focused spot size on the registration system.

If the scanning part will be based on two RF cavities and each separate cavity will produces circle scanning on the little different frequency than result scanning will be spiral.

The valuation shows that at proper parameter choice it is possible create the streak camera with spiral scanning which can see single light signal of ten nanoseconds duration with time resolution on the all interval better than 1 picoseconds.

Status of streak camera with spiral scanning

The assembling of 4 cavities has been produced. Two cavities from four produce circle scanning of 2856 ± 2 MHz frequency and other two cavities produce circle scanning of 2786 ± 2 MHz frequency. So scanning system allows see single light signal of up to 5 nanoseconds duration with time resolution on the all interval better than 2 picoseconds. In this moment the production of RF amplifier on this frequencies is go on.

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