LONGITUDINAL BEAM DISTRIBUTION MEASUREMENTS IN DAMPING RING OF VEPP-5 INJECTION COMPLEX

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Abstract

Injection Complex VEPP-5 was turned into operation in the end of 2015 in the Budker Institute of Nuclear Physics (Novosibirsk, Russia). The main task of the facility is production, acceleration and transportation of high intensity electron and positron beams for two BINP's colliders. Now, VEPP-5 successfully delivers electron and positron beams to VEPP-2000 and ready to start operation with VEPP-4M. Beam diagnostics issues are very important for VEPP-5 facility tuning during the operation. Longitudinal beam diagnostic based on synchrotron radiation in the VEPP-5 Damping Ring is presented in the article. Equipment operation principle, main measurement results and future prospects are presented in this paper.

IC VEPP-5 OVERVIEW

Injection complex (IC) VEPP-5 [1] was constructed for production, acceleration and transportation of high intensity electron and positron beams for two BINP's colliders – VEPP-4M [2] and VEPP-2000 [3]. IC [4] consists from thermionic electron gun, two linear accelerations, conversion system, damping ring (DR) and transporting channels (transfer line K-500).

DISSECTOR OPERATION PRINCIPLE

One of the main method of measurement of fast processes is electro-optical chronography. Stroboscope method is used in the circular accelerators, where dissector is used as converter (Figure 1).

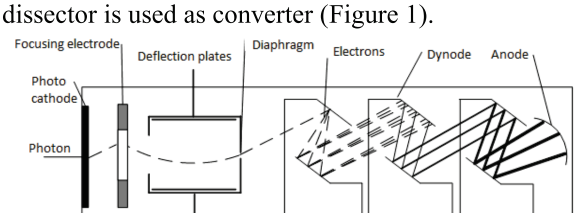

Figure 1: Dissector structure.

Let the light signal reached the dissector photocathode has time distribution $I(t)$. If high frequency sweep and incoming light impulses are synchronized, electron distribution $q(x)$ occurs in the plane of the diaphragm seal. Distribution $q(x)$ precisely imitates time distribution of light signal $I(t)$. Average anode current of photomultiplier $I_a(t)$ is proportional to light intensity falling onto photocathode. It is possible to shift different parts of distribution $q(x)$ on diaphragm seal changing voltage phase on dissector's deflection plates (see on Figure 2). Thus, photomultiplier's anode current will follow the shape of studied signal $I(t)$, if the parameters of incoming photocathode light signal be stable.

All temporal characteristics are true for distribution $q(x)$, but system applying dissector has some features:

- Researched object's information represented as electrical signal;
- Electrical signal precisely imitates temporary structure of light impulse, because there is no phosphor and microchannel decay;
- There is possibility to observe fast shape and duration changes of researched signal (the scale of hundreds synchrotron oscillations).

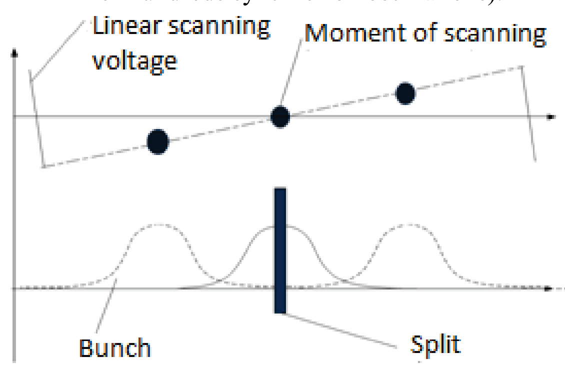

Figure 2: Scanning process.

Electron bunch length is far less than the perimeter of DR ($\sigma_z \ll \Pi$). Thus, it is necessary to scan distribution $q(x)$ with low frequency voltage applied to the deflection plates synchronously with high frequency voltage (see on Figure 3).

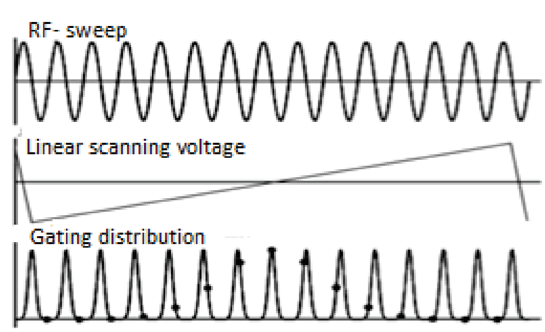

Figure 3: Synchronously scanning process.

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Exceptional performance of the device allows using dissector for precise measurement of longitudinal bunch structure and monitoring occurrences of longitudinal oscillations.

DISSECTOR ON THE DAMPING RING

The dissector is installed in the synchrotron radiation (SR) bunker. Optical channel delivers the SR from damping ring to bunker (Figure 4).

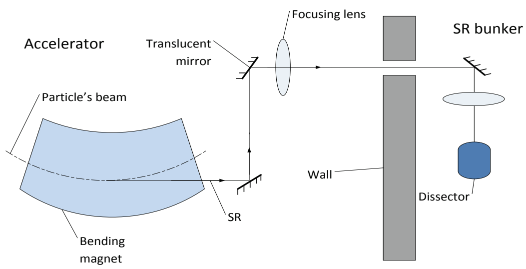

Figure 4: Optical channel to dissector.

The main dissector's characteristics are given in Table1 and the instrumental function is given on Figure 5.

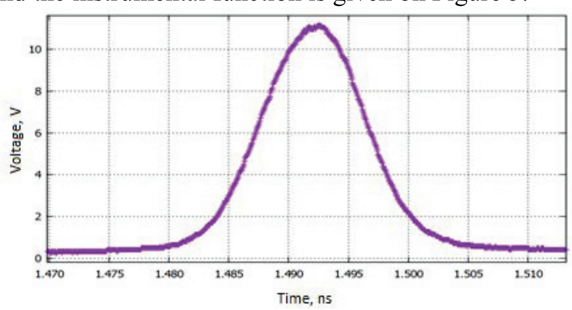

Figure 5: The dissector instrumental function.

The instrumental function defines precision of the measurements.

Table1: The Dissector Parameters

Photocathode voltage, kV	12
Grid voltage, kV	10
Focusing electrode voltage, kV	9
Photomultiplier voltage, kV	2
Frequency, MHz	78.6
Dissector resolution, ps	4.88

LONGITUDINAL BEAM STRUCTURE

Damping ring has high frequency cavity (700 MHz). Frequency of beam circulation is 10.9 MHz. Consequently, there are 64 buckets in the DR and only filled buckets can be detected by the dissector. At this moment Damping Ring operates with 3 filling mode buckets (Figure 6)*.

Moreover, it is possible to measure dependence of bunch size from parameters of DR, such as beam current, cavity voltage, lattice function of Damping Ring, etc.

Such difference between experimental result and model function in both cases (Figure 7, Figure 8) is explained by multibunched beams structure. Model function is proportional to $I^{1/3}$ and $U^{-1/2}$ for beams current and cavity voltage respectively in the one-bunched approximation. But discrepancy appear in experimental results due to neighbor bunches interaction.

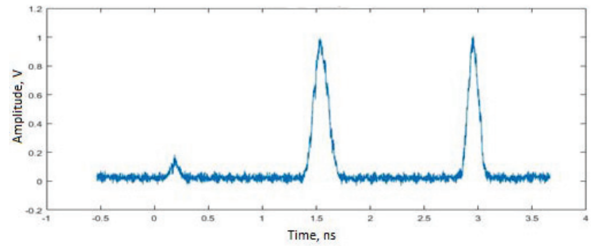

Figure 6: Damping ring beam structure.

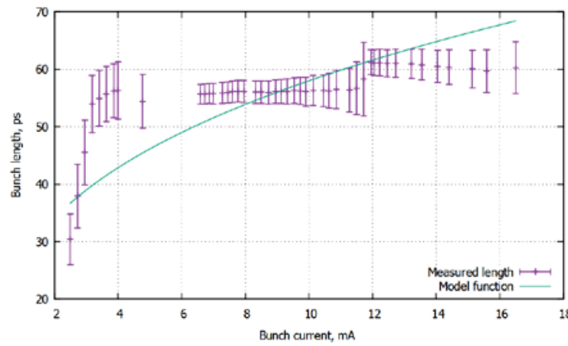

Figure 7: Bunch length vs beam current.

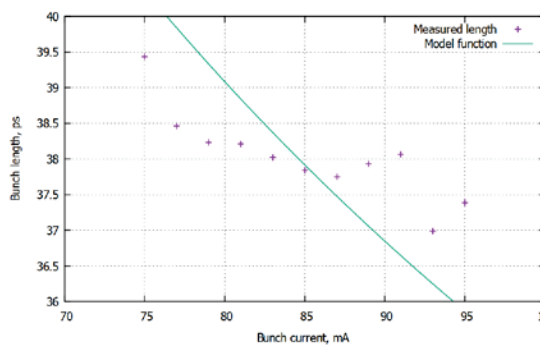

Figure 8: Bunch length vs cavity voltage.

Another application of the dissector is observing the phase oscillations (Figure 9). If phase oscillations excite, injection complex won't be able to transport electron or positron beams to colliders VEPP-4M and VEPP-2000. That's why, appearing of oscillations should be monitored.

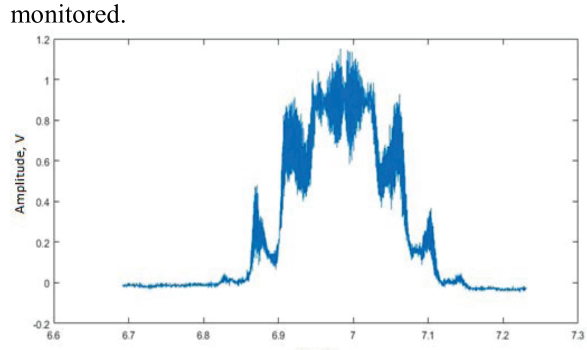

Figure 9: Phase oscillation observed by the dissector.

* Such filling of buckets defines by beam length injecting from linear accelerator.

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ANOTHER APPLICATIONS ON DAMPING RING

The dissector has a lot of applications on damping ring. First of all, it is opportunity to observe the DR beams structure during the operation of accelerator complex. It is possibility to observe the whole evolution of bunch train parameters in during of injection cycle (Figure 10).

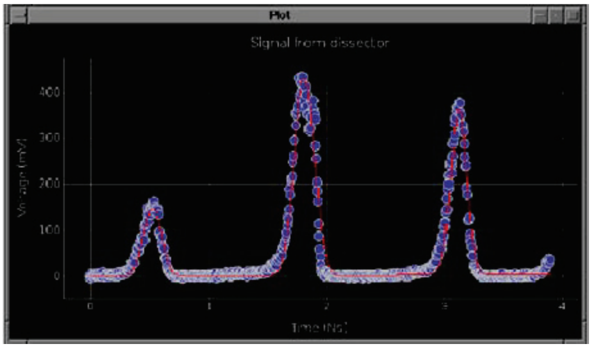

Figure 10: Signal from dissector and fitting Gaussian curves.

Secondly, there are a few methods of measuring the longitudinal and transverse impedance of accelerator vacuum chamber [5].

The bunch length above longitudinal mode coupling instability threshold is given by (for Gaussian beams shape):

$$\left(\frac{\sigma_z}{\sigma_{z0}}\right)^3 - \left(\frac{\sigma_z}{\sigma_{z0}}\right) = -\frac{\alpha I_b \mathrm{Im}\{[Z_{||}/n]_{eff}\}}{\sqrt{2\pi}(E/e)Q_s^2}\left(\frac{R}{\sigma_{z0}}\right)^3$$

Where σ_z is the rms bunch length, I_b is the average bunch current, $[Z_{||}/n]_{eff}$ is the longitudinal coupling impedance, R is the average accelerator radius, α is the momentum compaction factor, Q_s is the synchrotron frequency.

$\sigma_{z0} = \frac{\alpha R}{Q_s}\frac{\sigma_E}{E}$ is the zeros bunch length, $\frac{\sigma_E}{E}$ is the energy spread.

Below longitudinal mode coupling instability threshold is described by this equation:

$$\left(\frac{\sigma_z}{R}\right)^3 = \frac{\alpha I_b}{\sqrt{2\pi}(E/e)Q_s^2}\left[\left(\frac{Z_{||}}{n}\right) - \mathrm{Im}\left(\frac{Z_{||}}{n}\right)_{eff}\right]$$

Thus, after approximation $\sigma_z(I_b)$ of necessary functions longitudinal impedances can be calculated.

Moreover, it is possible to measure azimuthally impedance distribution. If bunch is deposed from equilibrium orbit transverse shift is expressed by formula:

$$\Delta x(z) = \frac{\Delta I_p}{\sqrt{2}E/e}\mathrm{Im}Z_\perp x_0 \frac{\sqrt{\beta(x_0)\beta(z)}}{2\sin(\pi Q_b)}\cos(\Delta\varphi - \pi Q_b)$$

$$I_p = \frac{\sqrt{2\pi}R}{\sigma_z} I_b$$

Where φ is the betatron phase, Q_b is the betatron frequency, β is the beta function, x_0 is the value of bump, and $\mathrm{Im}Z_\perp$ is the transverse localized impedance.

It is necessary to take into consideration contribution of dispersion function $D(z)$ in orbit distortion during horizontal measuring:

$$\Delta x_D(z) = \Delta x' \frac{D(z_0)D(z)}{\alpha\Pi}$$

$$\Delta x' = x\frac{I_p}{\sqrt{2}\,E/e}\mathrm{Im}Z_\perp$$

Using data from beam position monitors azimuthally impedance distribution will be calculated.

Another application of dissector is studying the condition of phase oscillations raising. It helps to tune linear accelerator, damping ring and their timing system more precisely for operation under absence phase oscillations. The estimated value of $\left[\left(\frac{Z_{||}}{n}\right) - \mathrm{Im}\left(\frac{Z_{||}}{n}\right)_{eff}\right]$ is about 10 Ohm.

One more application of the dissector is the Wakefield accelerating experiments (Figure 11). This outcast pipe is intended for transporting channel to Wakefield section on IC VEPP-5.

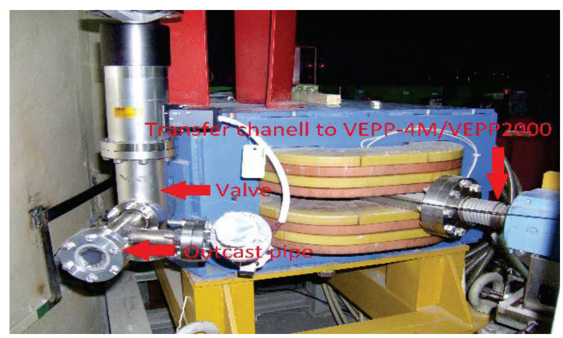

Figure 11: Outcast pipe for Wakefield section.

SUMMARY

The usage of the dissector and results of longitudinal beam size measurements are presented in this paper. Such type of diagnostic is everyday routine on Damping Ring now. It is possible to monitor bunches length and DR beam structure on-line. Operating staff are able to observe the changing in beam or bunches structure in each injection cycle. It is the opportunity for fast estimating the stability of injection process.

Moreover, the dissector gives an opportunity to estimate the longitudinal coupling impedance and azimuthally impedance distribution. And the method of measuring frequency of phase oscillation by analyze of the bunch structure modulation was suggested

Finally, the dissector measured data can be used for simulating and developing the Wakefield accelerating in Injection Complex.

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