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LONGITUDINAL BEAM MEASURUMENTS ON DAMPING RING BINP'S INJECTION COMPLEX WITH NEW RESONATOR

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Abstract

Injection Complex VEPP-5 feeds two BINP's colliders – VEPP-4M and VEPP-2000 with the electron and positron beams. 700 MHz 64-harmony damping ring resonator was replaced with 10.94 MHz first harmonic one in 2017. The key parameters for IC damping ring are particles storage rate and extraction beam parameters. In order to figure out how collective beam effects influence them with the new resonator we explore longitudinal beam distribution during the injection and storage, length during the extraction and effects, which influences on them. The results of research are presented at this paper.

INTRODUCTION

VEPP-5's injection complex (IC) is the electron and positron beam source for the VEPP-2000 and VEPP-4M colliders. It was introduced in 1994 and turned into regular operation in 2015 [1]. VEPP-2000 upgraded his injection chain in 2014-2015 [2], VEPP-4M switched into IC in summer 2016 [3]. The BINP's accelerator facilities layout is presented on Fig. 1. Beam Transportation Chanel K-500 connects injection complex and colliders.

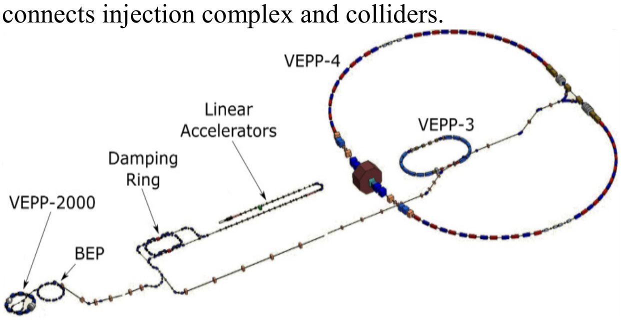

Figure 1: BINP's accelerator facilities layout.

The key parameters of injection complex are presented in Table 1.

Table 1. IC Key Parameters

Parameter	Value
Energy (2016/17 run)	385-420 MeV
Electron storage rate	$2*10^{10}$/s
Positron storage rate	$2*10^{9}$/s
Repetition time	up to 12 Hz
Maximum e- extraction	up to $1.2*10^{11}$
Maximum e+ extraction	up to $1.2*10^{11}$

BUNCH LENGTHENING THEORY

Beam interaction with electro-magnetic fields, emitted by it in vacuum chamber, leads to beam lengthening and shape-distortion effects, which depends on number of particles inside the ring. It efficiently decreases the RF voltage and called potential well distortion. It is possible to observe the influence of this effect from small beam current.

Potential Well Distortion

It is well known that for Gaussian beam with sigma σ_z the peak current I_p depends from average I_b current as $I_p = \frac{\sqrt{2\pi}R}{\sigma_z} I_b$ (R is an average accelerator radius) beam length vs. current is defined by formula:

$$\left(\frac{\sigma_z}{\sigma_{z0}}\right)^3 - \left(\frac{\sigma_z}{\sigma_{z0}}\right) - \frac{e}{\sqrt{2\pi}}\frac{\alpha I_b}{EQ_{s0}^2}\, Im\left(\frac{Z_{||}}{n}\right)\left(\frac{R}{\sigma_{z0}}\right)^3 = 0, \quad (1)$$

where $Q_{s0}^2 = \left(\frac{\omega_{s0}}{\omega_0}\right)^2 = \frac{neV_0|cos\varphi_s|}{2\pi E}$, E is a particle energy and α – momentum compactor factor [4].

In addition, synchronous beam phase shift is occurred [5]:

$$\Delta\varphi = \frac{2\pi I_b}{V_0\cos(\varphi_s)}\frac{\sqrt{2\pi}}{\omega_0\sigma} Re\left(\frac{Z_{||}}{n}\right). \quad (2)$$

Potential well distortion leads not only beam lengthening, but longitudinal beam profile distortion, too. The beam density along longitudinal coordinate z in case of resistive impedance (with the wake-function $W'_0(z) = S\,\delta(z)$,) is determined by:

$$\rho(z) = \frac{\sqrt{2/\pi}\, e^{-\frac{z^2}{2\sigma_z^2}}}{\theta\sigma_z\left[\coth\left(\frac{\theta N}{2}\right) - \mathrm{erf}\left(\frac{z}{\sqrt{2}\sigma_z}\right)\right]}, \quad (3)$$

where $\theta = r_0 S/\alpha\sigma_\delta^2\gamma C$, $\mathrm{erf}(x) = \frac{2}{\sqrt{\pi}}\int_0^x e^{-t^2}dt$, C – accelerator circumference, σ_δ - rms beam energy spread. Full description of this process is shown in [6].

STREAK-CAMERA MEASUREMENTS

For measuring damping ring (DR) beam parameters during the injection and after it, we used the PS-1/S1 streak-camera (SC).

SC was synchronized with inflectors trigger, and it allowed tracking the beam injection process in the damping ring RF bucket and measurement the longitudinal beam size dependences with precision about 1 turn.

IC VEPP-5 linear accelerator produces the beam, which consists from 16 bunches (Fig. 2).

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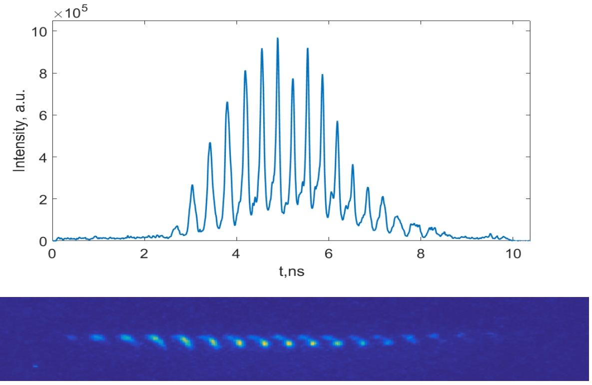

Figure 2: 16 bunches from linear accelerator.

After injection into RF bucket beam is grouped into one bunch. One hundred turns were enough to group it (about 10 μs). This time is much lower than radiation damping time (18 ms), and we believe this grouping is defined by collective effects or uncoiling of synchrotron oscillation. However, it is necessary to make more measurements for sure. On Fig. 3 you can see the specific beam grouping stages.

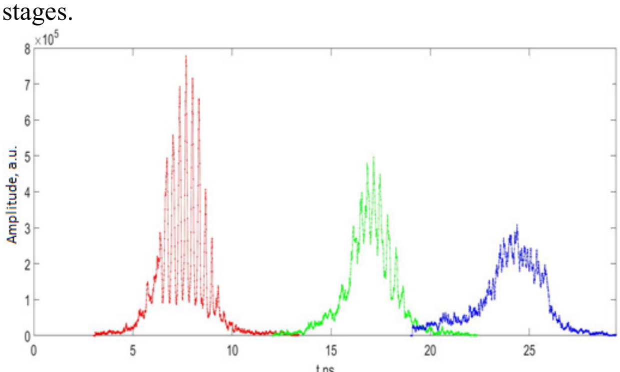

Figure 3: Specific beam grouping stages (red – 5th turn, green – 25th, blue – 115th).

Measurements of the beam length vs. the beam current were made with usual voltage of damping ring cavity – 9.4 kV. Beam particle distribution and their profile (27 mA current) are presented on Fig. 4. The experimental measurement data and model approximation function are on Fig. 5.

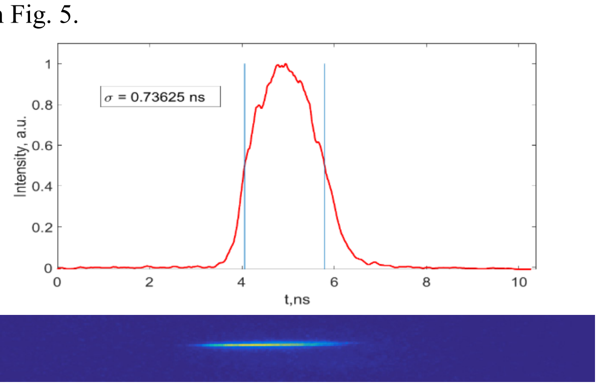

Figure 4: Beam particle distribution and beam profile (27 mA current, about 22 cm length).

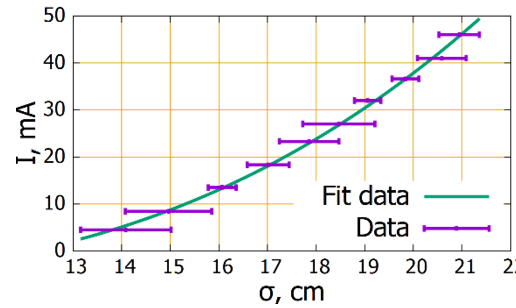

Figure 5: Longitudinal beam size vs. beam current (streak-camera).

As it was described above (1), it is possible to use fitting model $\frac{A}{\sigma_0^3} * I = \left(\frac{\sigma}{\sigma_0}\right)^3 - \left(\frac{\sigma}{\sigma_0}\right)$, where $A = \frac{e}{\sqrt{2\pi}}\frac{\alpha}{EQ_{s0}^2} Im\left(\frac{Z_{||}}{n}\right) R^3$. From this fitting data, we can evaluate the imaginary part of normalizing impedance: $Im\left(\frac{Z_{||}}{n}\right) = 6.15 \pm 0.18$ Ohm.

DISSECTOR MEASUREMENTS

Dissector is used on injection complex for continuous monitoring of longitudinal beam distribution. All data processing result is available for IC operating staff anytime.

With dissector it is possible to measure the dependences of beam size from beam current and RF-system voltage, too.

From the dissector data (Fig. 6), we found the value of longitudinal impedance, too: $Im\left(\frac{Z_{||}}{n}\right) = 5.71 \pm 0.5$. Ohm. It is in a good agreement with streak-camera result.

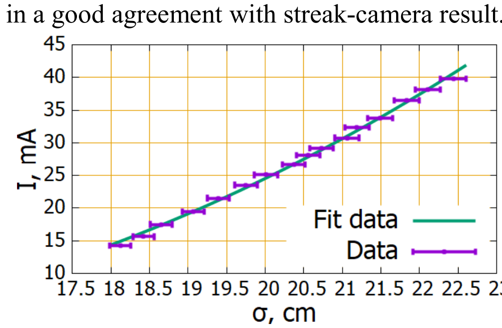

Figure 6: Longitudinal beam size vs. beam current (dissector).

Operating with low-current beam it was clear that the longitudinal beam distribution is described by Gauss distribution (Fig. 7).

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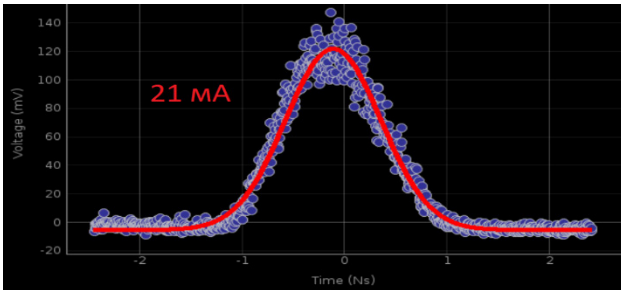

Figure 7: Longitudinal beam distribution (21 mA current) fitted by Gauss.

In the high current limit, beam distorted potential well and the beam longitudinal profile changing (Fig. 8).

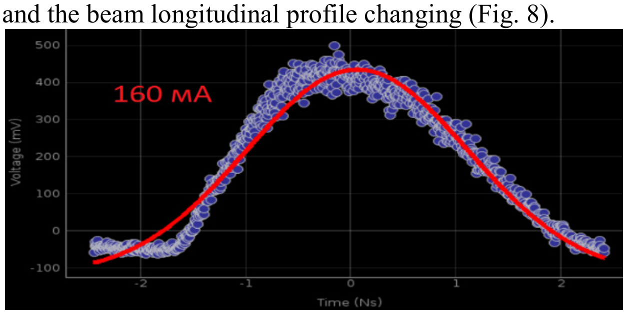

Figure 8: Longitudinal beam distribution (160 mA current) fitted by Gauss.

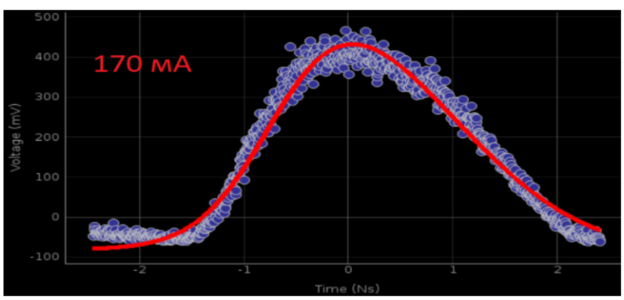

Figure 9: Longitudinal beam distribution (170 mA current) fitted by model (3).

Gauss approximation became incorrect, and we should take into consideration model (3). The approximation result with this model is presented Fig. 9.

Instead of shape-distortion, the synchronous beam phase shift was observed (Figure 10). Using formula (2) the real part of normalizing impedance can be estimated: $Re\left(\frac{Z_{||}}{n}\right) = 15.68 \pm 0.47$ Ohm.

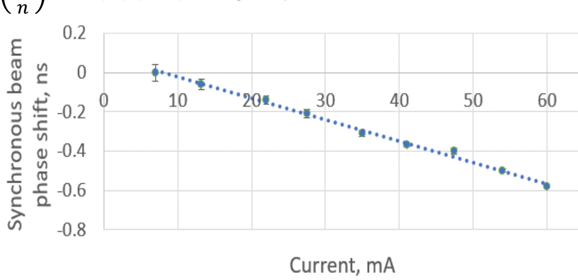

Figure 10. Synchronous beam phase shift vs. current.

SUMMARY

The longitudinal impedance of damping ring was measured with $\mathbf{5.71 \pm 0.5}$ Ohm (dissector), $\mathbf{6.15 \pm 0.18}$ Ohm (streak-camera) imaginary part and $\mathbf{15.68 \pm 0.47}$ Ohm (dissector) real part. The influence of beam current to it shape and synchronous phase was detected.

Collective beam effects do not limit IC to accumulate high-intensity beam in DR and for increasing the electron gun impulse length or beam intensity in linear accelerator.

Nevertheless, the beam length with 150 mA current is about 5 ns, BEP bucket length is 5.5 ns (with 180 MHz resonator). As a result, it occurs the top limit for the extraction beam current to BEP (close to 150 mA). Operating with higher currents means extra particle loses during beam injection onto BEP.

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