# STUDY OF BEAM TAILS WITH THE OPTICAL CORONAGRAPH

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*Abstract*

We have applied white light coronagraph to the VEPP-3 [1] storage ring to study the "tails" of transverse beam profile. Design of the instrument is based on the classical Lyot optical configuration. The comparison with the simulations has been done.

## INTRODUCTION

Particle density distribution into the beam of a cyclic accelerator is close to normal along all the three degrees of freedom *x, y, s* (*x, y* are the transversal and *s* is the longitudinal coordinates). The typical mean square size is $\sigma_{x,y,s}$. Beam may be separated in two areas: the central one (within the limits of $5\div6\sigma$) and the tails (outside the size of $6\sigma$). The central part is body of beam; it determines such characteristics as collider luminosity or brightness of synchrotron radiation. The beam lifetime and detector background have direct connection to tails particle distribution. These are the major parameters of the accelerator, hence we need reliable information on particle distribution of the tails as well as of the body of beam.

The ability of on-line measurements of the tails distribution is sufficient to tune the accelerator. Nowadays, two methods are widely applied for this purpose; these are scraping collimator [2] and a wire scanner [3]. Both methods include interaction with beam, changing its properties and even destruction it. Moreover, scraper application takes long term and poor combines with other experiments carried on the machine. The advantage of both diagnostics is a wide dynamic range (up to $10^6$).

The development of non-disturbing method which enables on-line measurement of the beam distribution function within the limit of $5\sigma$ seems relevant. We have applied the optical coronagraph for this purpose.

## CORONAGRAPH LAYOUT

We applied the white light Lyot coronagraph [4] for the study of the beam tails at the distances, exceeding $5\sigma_y$ (Fig. 1). The coronagraph was tested at VEPP-3 storage ring and after that it was added to the VEPP-4M collider optical diagnostic.

Coronagraph is an astronomical tool, applying to solar corona studies. The layout of the VEPP-3 coronagraph is represented at Fig. 1. The "artificial moon" (blackened wire) obscured beam image within the limits of $\pm5\sigma_y$. The optical system of coronagraph is designed for suppressing of the stray light and the light diffracted on the optical elements. The tails image was projected on the CCD camera. The independent measurement of the beam position and size was performed.

The device was tested with the light source that had the beam sizes (0.8 × 3 mm) and SR divergence. The test results are shown on the Fig. 2.

The coronagraph suppressed the source light at five orders of amplitude. The level of a stray light in the work area had the level of $10^{-4}$ of the source intensity. The reached value was sufficient for planned experiments at the accelerators.

## EXPERIMENTAL RESULTS

The coronagraph was applied for study of the beam scattering on the atoms of residual gas. This process can be simulated theoretically and then the comparison with experimental data is possible. Another advantage of the experiment is an ability to control variations of vacuum in the VEPP-3 storage ring.

The average residual pressure during the experiment was $2\cdot10^{-9}$ Torr. This value could be changed to $3\cdot10^{-9}$ Torr with shutting off of distributed pumping sections. It enables us to study the influence of the residual gas on the tails distribution. Mass mixture of the vacuum was determined of CO (Z=7) and Ar (Z=18) atoms. The influence of vacuum conditions on the tails was studied at the different beam energy 350, 600 and 1200 MeV.

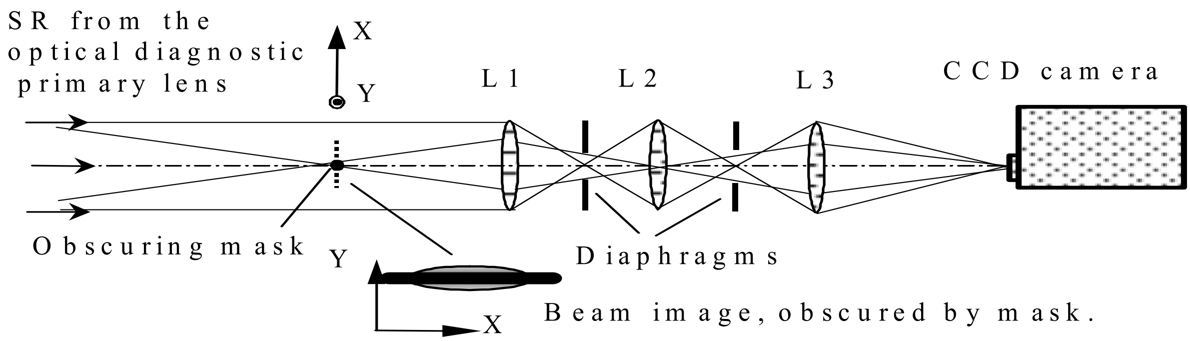


Figure 1: Layout of the VEPP-03 coronagraph.

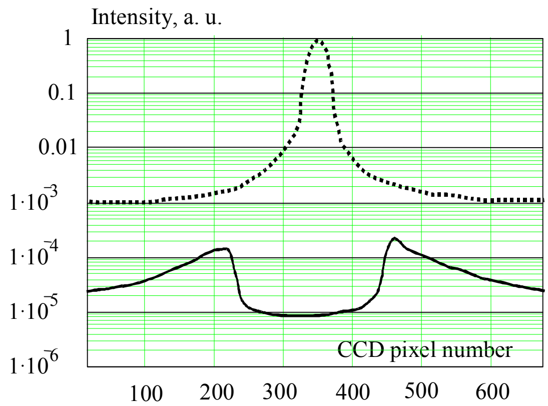


Figure 2: Coronagraph test. Upper curve is a source image. The down curve is the source obscured by mask.

Cycle of measurements was the following. The pumps turned off during a few seconds. The vacuum deteriorated to another stable value during the same period of time. The measurements of the tail distribution and integral value continued during a few minutes, after that the pumps turned on and the cycle repeated. Fig. 3 represents the normalized integral signal of the coronagraph.

$$I_c(t) = \frac{\sum_{i,j} p_{i,j}(t)}{J(t)} \cdot I_0^{-1}(0) - 1,$$

where $I_0(0) = \frac{\sum_{i,j} p_{i,j}(0)}{J(0)}$ and $p_{i,j}(t)$ is signal from *ij* camera pixel. The data relates to the beam energy of 356 MeV and initial current of $J(0)$=10 mA. We didn't find any changes of tails at other energies of the beam.

## SIMULATION OF BEAM SCATTERING ON RESIDUAL GAS

We followed the approach developed in [5]. Differential cross-section of the scattering process is

$$\frac{d\sigma}{d\theta} = \pi \left( \frac{2Zr_e}{\gamma} \right)^2 \frac{1}{\left( \theta^2 + \theta_{\min}^2 \right)^{3/2}},$$

where $\theta_{\min} = \frac{Z^{1/3}\alpha}{\gamma}$, $r_e = 2.8 \cdot 10^{-15}$ m, $\alpha = 1/137$.

The total cross-section is

$$\sigma_{tot} = 4\pi \frac{r_e^2 Z^2}{\gamma^2 \theta_{\min}^2} \approx 2.5 \cdot 10^{-23}\ \text{m}^2.$$

Besides the differential cross-section two another parameters are sufficient: $N_d = N\tau$, and $\Theta = \frac{\theta_{\min}}{\sigma_0'}$. N is scattering frequency and $\tau$ is a betatron dumping time, $\sigma_0' = \sigma_0/\beta$ - beam size. Another data, used for simulations, are represented at Table 1.

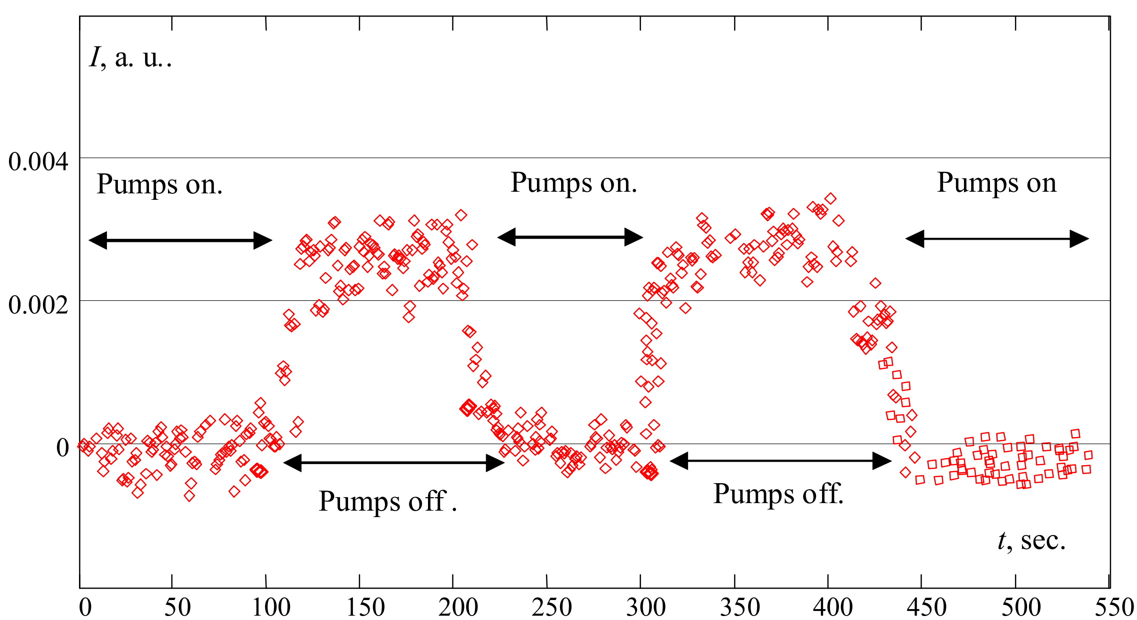


Figure 3: Coronagraph integral signal vs time at the beam energy of 356 MeV and current of 10 mA. The modulations caused by vacuum variations are seen.

Table 1: VEPP-3 parameters used for tails simulations

| | E-350 MeV | E=2000 MeV |
|---|---|---|
| $\tau$, sec | 0.87 | 0.0043 |
| $\varepsilon$, rad*m | $0.00905\cdot10^{-6}$ | $0.292\cdot10^{-6}$ |
| $\sigma_0$. mm | 0.2 | 1.27 |
| $\theta_{min}$, rad | $2\cdot10^{-5}$ | $3.5\cdot10^{-6}$ |
| $N_d$ | 0.9 | 0.005 |
| $\Theta$ | 0.5 | 0.015 |

The corresponding tail distributions are presented at Fig. 4.

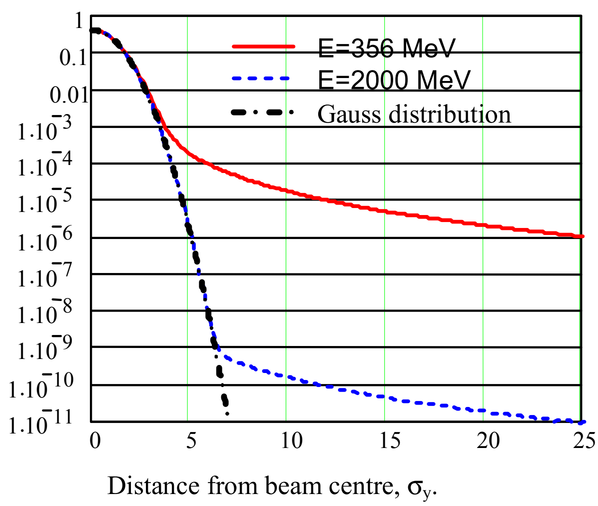


Figure 4: Beam distribution function for different energy of VEPP-3. P=$2\cdot10^{-9}$ Torr.

Fig. 5 represents the comparison of the experimental data and the result of simulation. It demonstrates the difference between tails distributions with equal beam energy, but corresponding to different residual gas pressure.

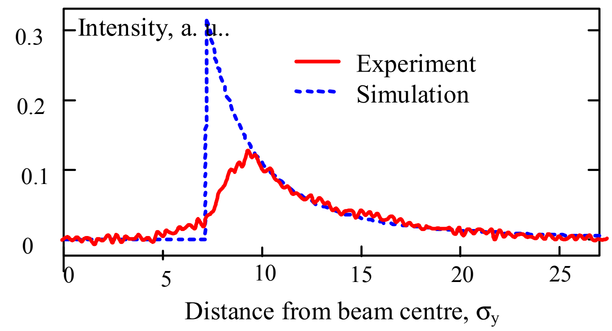


Figure 5: Difference between the measured and simulated distribution functions at the same beam energy of 356 MeV and different vacuum pressure of $2\cdot10^{-9}$ Torr and $3\cdot10^{-9}$ Torr.

## CONCLUSION

Influence of the vacuum conditions on the tail of the beam has been studied on the VEPP-3 storage ring with optical coronagraph. Comparison with the simulation results has been done. The experimental data demonstrate good coincidence with the theoretical results. At present, the coronagraph is implemented into optical diagnostic of VEPP-4M collider. The authors are grateful to I. N. Nesterenko for the consultations on the coronagraph design.

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