Status of the VEPP-4M Collider

V. Smaluk for the VEPP-4 team

XX-th Russian Conference on Charged Particle Accelerators
Novosibirsk
September, 10-14 2006
Contents

- High-energy physics experiments
- Energy spread measurement
- Beam energy measurement and stability
- Temperature monitoring system
- Thermostabilization systems
- Fast transverse feedback
HEP: $\tau$-lepton mass measurement

Precise measurement of the $\tau$-lepton mass at the producing threshold is the principal high-energy physics experiment at the VEPP-4M – KEDR facility. The $\tau$-lepton mass is used to test the lepton universality principle which is one of the postulates of the Standard Model.

Preliminary result of the 2005-2006 runs:

$$M_\tau = 1776.74^{+0.45}_{-0.35} \pm 0.07 \text{ MeV}$$
**HEP: experiments to improve measurement accuracy of the ψ(2s) and ψ(3770) mesons**

Precise measurements of the J/ψ and ψ(2S) meson masses provide the energy scale in the range around 3 GeV which is a basis for accurate determination of masses for all charmed particles.

These measurements are also important for the accurate determination of the τ-lepton mass.

\[
M_{\psi(2S)} = 3686.117 \pm 0.012 \pm 0.015 \text{ MeV} \\
M_{\psi(3770)} = 3773.5 \pm 0.9 \pm 0.6 \text{ MeV}
\]

There are only 5 masses (e, p, n, μ, π) measured with higher accuracy.
Distribution of the operation time

2005

Operation time of the VEPP-4M facility

- 31.9% scheduled shutdown
- 16.1% maintenance
- 26.1% repair
- 14.5% injector + VEPP-3
- 8.0% SR experiments
- 3.0% HEP experiments
- 0.4% machine physics
- 0.4% HEP experiments
Distribution of the operation time

1998 – 2006

12-hour shifts

HEP experiments
accelerator

Year:
- 1998/99
- 1999/00
- 2000/01
- 2001/02
- 2002/03
- 2003/04
- 2004/05
- 2005/06

Legend:
- Red: HEP experiments
- Blue: accelerator
Luminosity integral 2004 – 2006

2004  1.75 pb$^{-1}$
2005  4.51 pb$^{-1}$
2006  5.03 pb$^{-1}$
Total  11.28 pb$^{-1}$
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**Average luminosity 2004 – 2006**

Maximal peak luminosity of $2.1 \cdot 10^{30} \text{ cm}^{-2}\text{s}^{-1}$ was achieved

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Machine performance improvement

Operators professional skill

Average luminosity in HEP shifts

Automatic luminosity adjustment

Hardware modernization
- new interpolating digital-to-analog converters
- upgraded BPM front-end electronics
- new RF master oscillator
Energy measurement – resonant depolarization

Resonant depolarization – high-precision periodic calibration

We have managed to increase the polarization lifetime near the strong spin resonance $\nu=4$ from 10-20 minutes up to 1 hour.

Reliable energy calibration above and below the $\tau$ production threshold.

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Energy measurement – Compton back-scattering

Compton back-scattering – routine energy monitoring during HEP experiment runs

Mean energy and energy spread measurements

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Energy measurement

1-week energy monitoring during $\psi(3770)$ scan

- resonant depolarization
- Compton back-scattering

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Energy spread measurement

More details in the report: V.A. Kiselev, O.I. Meshkov, V.V. Smaluk, A.N. Zhuravlev
Beam Energy Spread Measurement at the VEPP-4M Electron-Positron Collider

In the experiment of the \( \tau \)-lepton mass measurement, it is important to know beam energy spread for evaluation of its contribution into the total systematic error.

**Measurement methods:**
- \( \psi \) meson scan – high precision but time-consuming procedure can not be repeated frequently
- Compton back-scattering – routine monitoring, but accuracy is now 15-20%

**Additional measurements required**

**Analysis of chromatic synchro-betatron harmonics of coherent betatron oscillation**

Method I: measurement of amplitude ratio of synchrotron satellites to the main betatron peak in dependence of chromaticity


Method II: fitting the measured oscillation envelope with the theoretical curve

[N.A.Vinokurov et al., The influence of chromaticity and cubic nonlinearity on kinematics of betatron oscillations, BINP preprint 76-87, Novosibirsk, 1976 (in Russian) ]

Method III: measurement of current dependence of the energy spread using measured bunch lengthening and grows of the horizontal bunch size

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Energy spread measurement

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Beam Energy Spread Measurement at the VEPP-4M Electron-Positron Collider

Method I:
\[ R_m(y) = \frac{1}{y^2} \int_0^\infty J_m^2(x)e^{-\frac{x^2}{2y^2}} \, dx \]

\[ y = \left( \frac{\omega_\beta \alpha}{\omega_s} + \frac{\omega_0 C_y}{\omega_s} \right) \delta_E \]

Method II:
\[ A(t) \propto \exp\left(-\frac{t^2}{2\tau^2}\right) \exp\left(-\frac{\partial \omega_\beta \sigma_E}{\partial E} \cdot (1 - \cos(\omega_s t))\right), \]

where \( \tau = \left(2 \frac{\partial \omega_\beta}{\partial a^2} b \cdot \sigma_y \right)^{-1} \)

Method III:

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Goals:
For the VEPP-4M beam energy estimation, it is necessary to measure precisely the temperature of the magnets, because the most important factor perturbing beam energy is the temperature of the dipoles (up to 80 keV/deg).
For thermostabilization of the VEPP-4M magnets.
To control the RF cavities temperature, because the RF cavities thermal expansion results in excitation of unstable longitudinal beams oscillations.

Hardware:
High-Precision Digital Thermometers DS1631 with the resolution of 0.0625°C and absolute accuracy of 0.5°C in the 0–70°C temperature range.
32-channel controller developed in BINP:
- automatic scanning of the temperature sensors every second and data writing to the internal memory;
- relay interlock function to prevent overheat is also implemented.

Software:
Control program running in PC reads data from the all controllers and writes it to PostgreSQL database once per minute. Motif-based GUI is also developed.
New temperature monitoring system


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Cooling water temperature during 2.5 months (red – out-stream, black – in-stream)

Temperature of the N5F magnet during 2 months
Thermostabilization of the Magnets

Measured diurnal variations of the VEPP-4M beam energy.
Main factor - temperature variations of the VEPP-4M magnets.
Perturbing factors: ambient temperature, atmospheric humidity, conditions in a cooling tower, etc.

Double-loop water cooling system
High-precision thermal sensors
Computer-controlled valve
Control program

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Thermostabilization of the Magnets

Thermostabilization OFF

Thermostabilization ON

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Thermostabilization of the RF cavities

Unstable phase oscillation occurs due to parasitic high-order modes of the VEPP-4M RF cavities. This instability is one of the main efficiency decreasing factors, because it reduces luminosity drastically. High-amplitude phase oscillation leads to particle loss and can be dangerous for the KEDR detector.

RF cavity temperature variation results in the cavity deformation and then leads to a shift of working conditions away from the stability regions.
Thermostabilization of the RF cavities


Temperature is measured by thermo-sensors with a sensitivity of 10 mV/°C. For each RF cavity, 5 kW flowing water heater is switched on/off by controllable electronic switches. Temperature analysis and power control is provided by a microcontroller.
Maximal bunch current in the VEPP-4M collider is limited by TMCI. At the 1850 MeV energy, threshold current is about 10 mA.

\[ I_b \leq \frac{\sigma_s}{\sqrt{2\pi R}} \frac{8\pi R e Q_s}{\langle \text{Im} Z_{BR} \rangle \beta} \]

**Head-tail instability**

positive chromaticity: 0-th oscillation mode (center of mass) is stable, other – unstable;

negative chromaticity: center of mass is unstable, other modes – stable.

The idea is to suppress 0-th oscillation mode using resistive feedback, while to keep other modes stable due to negative chromaticity.

Calculation based on the hollow-beam model shows that it is possible to exceed the instability threshold 3-5 times.

**Transverse bunch-by-bunch feedback**

<table>
<thead>
<tr>
<th>Energy</th>
<th>1.8 – 5.2 GeV</th>
<th>Upper frequency limit</th>
<th>20 MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of bunches</td>
<td>2 x 2</td>
<td>ADC/DAC digit capacity</td>
<td>12</td>
</tr>
<tr>
<td>Bunch current</td>
<td>40 mA</td>
<td>DSP TMS320C6713</td>
<td></td>
</tr>
<tr>
<td>Number of kickers</td>
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<td>processor frequency</td>
<td>225 MHz</td>
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<tr>
<td>RF power per kicker</td>
<td>400 W</td>
<td>memory</td>
<td>2Mx32b</td>
</tr>
</tbody>
</table>
Fast Transverse Feedback

More details in the report: V. Cherepanov, E. Dementev, A. Medvedko, V. Smaluk, D. Sukhanov, The VEPP4-M transverse bunch-by-bunch feedback system (poster 43)
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Sensitivity:
- beam current 40 mkA
- kick amplitude 0.5 kV

Betatron oscillation
- beam current 2.8 mA
- kick amplitude 1.0 kV
References

- V.A. Kiselev, O.I. Meshkov, V.V. Smaluk, A.N. Zhuravlev, Beam Energy Spread Measurement at the VEPP-4M Electron-Positron Collider
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