STATUS OF VEPP-4M COLLIDER AT BINP

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Abstract

Since 2002, the VEPP-4M electron-positron collider is operating with the KEDR detector for high-energy physics experiments in the 1.5-2.0 GeV beam energy range. In these experiments, masses of the J/ψ, ψ', ψ'', D-mesons and of the τ-lepton have been measured with a record accuracy. In the immediate future, furthe experiments are scheduled in 1-5 GeV energy range for study of hadron production in continuum and for precise measurement of the R constant. Current status of the VEPP-4M collider and the near future plans are reviewed.r

OPERATION TIME DISTRIBUTION

The VEPP-4 is a multipurpose accelerating-storage complex [1]. It includes the VEPP-4M electron-positron collider (6 GeV maximal beam energy), the VEPP-3 booster storage ring (2 GeV), and the Injector (350 MeV) composed of an electron beam source, linear accelerator, electron-to-positron converter and the booster synchrotron.

Since 2002, the VEPP-4M collider is operating with the KEDR detector for high-energy physics (HEP) experiments in the 1.5-2.0 GeV beam energy range.

In addition to high-energy physics, scientific research and advanced technology development are also performed using synchrotron radiation at the VEPP-3 and VEPP-4M storage rings. Principal subjects are: material science, nanotechnologies, chemistry, geology, archaeology, biology and medicine, etc.

Moreover, a set of beam dynamics and accelerator physics experiments have been performed. The most recent of them are: record-high resolution experiments on comparison of spin precession frequencies of electron bunches [2], direct comparison of the methods of beam energy spread measurement [3], and beam dynamics study during crossing of betatron resonances [4].

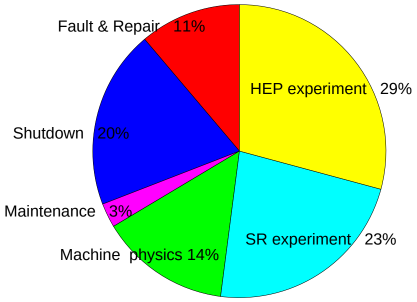

Figure 1: Operation time distribution

Figure 1 shows average distribution of operation time of the VEPP-4 accelerating-storage complex in 2004-2007. As one can see, total operation time is mainly divided between two experimental programs: high-energy physics (29%) and synchrotron radiation (23%). Machine physics shifts (14%) are used both to keep the machines in operating condition required for the experiments and to perform investigations on beam dynamics and accelerator physics. Regular maintenance works (3%) are executed every week. Shutdown time (20%) is formed mainly by summer vacation period and used for upgrade and maintenance of the accelerators, particle detector, and support systems (incoming power supplies, water cooling system, etc). Quite a big time loss caused by various equipment faults (11%) may be accounted for multiplicity, complexity, and age of the equipment.

HIGH-ENERGY PHYSICS EXPERIMENTS

The VEPP-4M is the modernized VEPP-4 collider, which has been commissioned for the first time in 1977. A range of particles masses has been precisely measured at the VEPP-4 complex during last 20 years, see Table 1.

Table 1: Masses measured at the VEPP-4.

	E, MeV	$\delta E/E$	Years
J/ψ	3096.93±0.10	$3.2\cdot10^{-5}$	1979-1980
ψ'	3685.00±0.12	$3.3\cdot10^{-5}$	1979-1980
ϒ	9460.57±0.09±0.05	$1.2\cdot10^{-5}$	1983-1985
ϒ'	10023.5±0.5	$5.0\cdot10^{-5}$	1983-1985
ϒ''	10355.2±0.5	$4.8\cdot10^{-5}$	1983-1985
J/ψ	3096.917±0.010±0.007	$3.5\cdot10^{-6}$	2002-2005
ψ'	3686.119±0.004±0.008	$2.5\cdot10^{-6}$	2002-2005
ψ''	3772.9±0.6±0.8	$2.7\cdot10^{-4}$	2002-2005
D^0	1865.43±0.60±0.38	$3.8\cdot10^{-4}$	2002-2005
D^+	1863.39±0.45±0.29	$2.9\cdot10^{-4}$	2002-2005
τ	$1776.69^{+0.17}_{-0.19} \pm 0.15$	$1.3\cdot10^{-4}$	2005-2007

At present, the most principal of the HEP experiments is precise measurement of the τ-lepton mass at the production threshold [5]. Data collection for this experiment has been finished in 2007; the data processing is now close to be completed. Exact value of the τ-lepton mass is required to verify the lepton universality principle which is one of the postulates of the Standard Model, the most complete theory describing fundamental properties of matter. Measurement accuracy reached in this experiment is the best in the world.

A series of experiments to measure masses of the J/ψ, ψ' and ψ'' mesons has been also performed [6]. The data measured specify an energy scale in the range around 3 GeV (center of mass) which is a basis for accurate determination of masses of all charmed particles. Measurement accuracy reached in these experiments is 2 times better than the world average value for ψ', and 3 times better for ψ''. In high-energy physics, masses of only 5 particles (electron, positron, neutron, μ and π mesons) have been measured with better accuracy.

The crucial parameter of a collider is the luminosity. Fine tuning of the machines and improving of the VEPP-4 complex reliability result in gradual increase of average luminosity. The luminosity integral collected in 2004-2008 is shown in Figure 2. Peak luminosity of $2\div3\cdot10^{30}$ cm^{-2}s^{-1} is reached; average value of luminosity during HEP experiments is about $0.6\cdot10^{30}$ cm^{-2}s^{-1}.

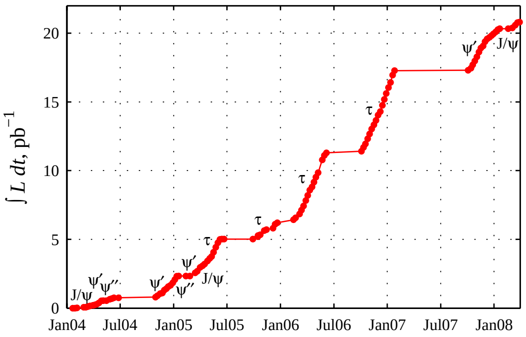

Figure 2: The VEPP-4M luminosity integral

In spite of quite big lack of luminosity as compared with the modern colliders, the VEPP-4M has some advantages providing a possibility to contend with other facilities. The principal advantages are:

- Unique beam energy range of 1.0÷5.5 GeV.
- High-precision calibration of absolute beam energy based on the resonant depolarization technique [7]. A world-record 10^{-6} relative accuracy (about 2 keV absolute) of beam energy measurement has been achieved.
- Routine monitoring of the beam energy realized with the Compton back-scattering [8]. This technique provides $5\cdot10^{-5}$ relative accuracy (about 100 keV absolute) of the mean beam energy and 10% accuracy of the energy spread.

In the coming working season, further experiments are scheduled for study of hadron production in continuum and for precise measurement of the R-ratio in the 1-4 GeV beam energy range.

WORKING CYCLE AUTOMATION

For the HEP experiments, the KEDR data collection period is determined by lifetime of the electron and positron beams colliding in the VEPP-4M in 2×2-bunch mode. During the data collection, two electron or positron bunches of 20 mA each should be accumulated in the VEPP-3 booster storage ring. Accumulating rate of positrons is 30-50 μA/s (dependent on accumulated current) whereas for electrons it is about 2 mA/s.

Figure 3 shows the luminosity L, the VEPP-4M electron I_{e-} and positron I_{e+} current, the VEPP-3 beam current I_{e-}, I_{e+} and energy E during a typical experimental run. The working cycle includes: accumulation of positrons in the VEPP-3 (15-20 minutes), acceleration up to the extraction energy (5 minutes), bunch-by-bunch extraction and injection into the VEPP-4M, magnetic cycle and polarity change of the VEPP-3 and Injector (5 minutes), electron accumulation (1-2 minutes), acceleration and injection into the VEPP-4M. The VEPP-4M electron and positron beams should be separated in the interaction point during injection to prevent the beam loss. Total time required to refill beams in the VEPP-4M is 30-40 minutes.

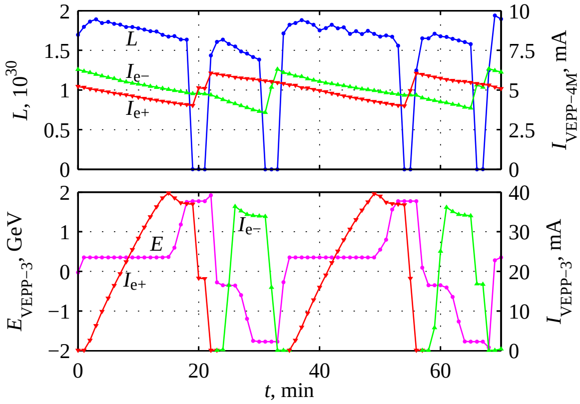

Figure 3: Working cycle

At the beginning of HEP experiments with the KEDR detector, all these processes were controlled manually by an operator. Furthermore, to optimize the luminosity, an operator should control permanently a set of parameters such as betatron tunes, coupling of betatron oscillations, matching of beam position in the interaction point, etc.

Basing on the operation experience, an automation procedure has been developed. An artificial intelligence element called "autopilot" is supplemented to the control system as an additional highest level. The "autopilot" acquires a set of beam and accelerator parameters, performs data processing and generates a proper command set for the control software. Working conditions are set by an operator in a configuration file. The "autopilot" performs all the operations required for luminosity optimization and beam injection. This automation procedure has been found very useful for operators. Moreover, it also helps to equalize shift efficiency of both experienced operators and beginners.

Certainly, this automation works only if there is no any fault. Besides, an important procedure performed manually is the beam energy calibration by resonant depolarization method. Now we try to automate this procedure in spite of its complexity.

PERFORMANCE IMPROVEMENT

One of peculiarities of the HEP experiments realized at the VEPP-4M is the high-precision beam energy evaluation. To estimate the beam energy between absolute calibrations by the resonance depolarization method, an empirical formula is used. This formula provides 20 keV accuracy of energy interpolation using the dipole magnetic field and temperature of the magnets, tunnel walls, cooling water, etc.; it requires on-line monitoring of these parameters. Furthermore, the HEP experiments require routine recording of a lot of other beam and accelerator parameters for further off-line analysis.

To analyze and control of the parameters, a PostgreSQL database has been developed [9]. The database provides systematization and unification of the data archiving and observation. To control all the facilities of the VEPP-4 complex, about three thousands parameters are set and measured by the control system. Current values of the parameters coming from the control and measuring electronics are stored in many files by different programs working in local workstations. The data storing intervals vary from one second for the pulse systems to several minutes for the slowly changing parameters. Twelve independent processes running under Linux provide permanent data transfer from the source files to the database as soon as they are renewed. 1-second samples are available during last 24 hours, 30-second samples are stored for 1 year, older data are relocated to archive storage.

The graphical interface is developed for user’s access to the database. It provides observation of the stored data in graphical or textual form and monitoring of the current parameter values. The interface allows us to observe any collection of parameters in a single or in different windows for any period of time.

To optimize the machine performance, new systems of temperature monitoring and thermal stabilization have been developed. The temperature monitoring system is based on high-precision digital temperature sensors with the resolution of 0.0625˚C and absolute accuracy of 0.5˚C in the 0÷70˚C temperature range.

Continuous temperature monitoring had shown considerable diurnal and seasonal variations of the VEPP-4M magnets temperature, which cause beam energy variation up to 80 keV/˚C. To stabilize temperature of the magnets, a system of thermal stabilization is used. This system keeps the magnet cooling water temperature stable within 0.1 degree range while the service water temperature dependent on many external factors such as ambient temperature, atmospheric humidity, wind, etc., can vary in more than 5 degree range.

During the HEP experiments, one of the principal efficiency decreasing factors is a longitudinal beam instability, which occurs due to parasitic high-order modes (HOM) of the VEPP-4M RF cavities. Fine tuning of remote-controlled HOM suppressors allows us to find stability regions of longitudinal beam motion. But the cavity thermal expansion leads to a shift of HOM conditions away from the stability regions. To stabilize the RF cavity temperature, automatic thermal stabilization system was developed. Using of the system, temperature variation of the RF cavities has been reduced from 5˚C down to 0.2˚C. As a result, probability of the instability excitation is reduced more than in 100 times.

In 2×2-bunch mode of the VEPP-4M operation, further improvement of longitudinal beam stability is expected with a new feedback system designed to suppress both synphase and antiphase oscillation mode [10]. There are two identical systems, one for electrons and another for positrons. Beam oscillation is measured using resistive pickup and synchronous detector. An analog super-heterodyne modulator is developed to produce proper output signals for each mode. Power amplifiers provide 100 W output RF power per channel, applied to a broad-band resonance kicker. At present, the kicker and all the signal processing electronics have been manufactured and installed, the system is under commissioning.

To suppress transverse mode coupling instability (TMCI) limiting the VEPP-4M single-bunch beam current, a broad-band bunch-by-bunch digital feedback system is developed. Beam signals are measured by sensitive strip-line BPMs. Digitized data is processed by a digital signal processor, which calculates amplitude of short pulse kick for each bunch. These pulses are converted by digital-to-analog converters and amplified by 200 W wide-band power amplifiers. To reduce required voltage of the kick pulse, 1.9 m-long electrostatic separators are used as the kickers. All the electronics for one feedback channel is now designed, produced and installed at the VEPP-4M, first beam measurements were done. At these experiments, the TMCI threshold current was exceeded more than 3 times.

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