VEPP-2000 COLLIDER CONTROL SYSTEM*

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Abstract

Electron-positron collider VEPP-2000 has been commissioned at Budker Institute of Nuclear Physics. The first experiments on high energy physics has been started at the end of 2009. The paper presents architecture, implementation and functionality of hardware and software of the collider control system. The hardware of the system consists of high current main field power supplies, steering coils power supplies, pulse-elements, RF subsystems and some other special subsystems (such as vacuum, temperature, etc.). The system is based on modern industrial protocol CAN-bus and specialized electronic BINP manufactured blocks according the standard. The paper describes implementation of different subsystems based on CANbus devices, and operating characteristics and their possibilities. Other standards and protocols like CAMAC, VME and so on also used in the system. The software according to hardware system consists of interacting subsystems responding on different acceleration facility parts. Control system software is based on several TCP/IP connected PC platforms under operating system Linux and uses client-server techniques.

VEPP-2000 PROJECT

VEPP-2000 is a new collider with luminosity up to 10^{32}cm^{-2}s^{-1} and the beam energy up to 2×1 GeV [1, 2].
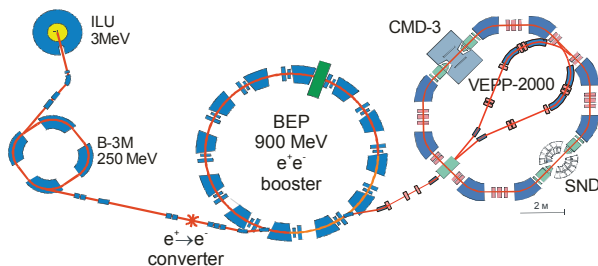

Figure 1: VEPP-2000 facility layout.

This project is a development of a previous facility of VEPP-2M which has worked at BINP over 25 years in energy range up to 1.4 GeV in c.m.s. and has collected of about 75 pb^{-1} integrated luminosity. New collider uses the existing beam production chain of accelerators: ILU – a pulsed RF cavity with a voltage of 2.5 – 3 MeV, a 250 MeV synchrotron B-3M and a booster storage ring BEP with the maximum project beam energy of 900 MeV (see Figure 1 and Table 1). The lattice of VEPP-2000 has a two-fold symmetry with two experimental straight sections of 3m length, where Cryogenic Magnetic Detector [3] and Spherical Neutral Detector [4] are located. Two other long straights (2.5m) are designed for injection of beams and RF cavity, and 4 short technical straight sections accommodate triplets of quadrupole.

To avoid dispersion in the detectors, RF cavity and injection straights, a pair of dipoles together with the triplet in between constitute 4 achromats. Chromaticity corrections are performed by two families of sextupole magnets located in the technical straight section, where the dispersion is high.

The closed orbit steering and gradient corrections are done with 1-2% coils placed in the dipole and quadrupole magnets.

The accelerating HOM-damping RF cavity operates at the 14-th harmonic of the revolution frequency (172.0MHz). It provides for a bunch length of about 3 cm at the top energy and stability of design bunch current of 200 mA.

Beam diagnostics is based on 16 optical CCD cameras that register the synchrotron light from either end of the bending magnets and give the full information about beam positions, intensities and profiles. In addition to optical BPMs, there are also 4 pick-up stations in the technical straight sections and one current transformer as an absolute current monitor.

The magnetic field of 2.4 T in the bends is required to reach the design energy of 1 GeV in the constrained area of the experimental hall.

Table 1: VEPP-2000 Collider Main Parameters

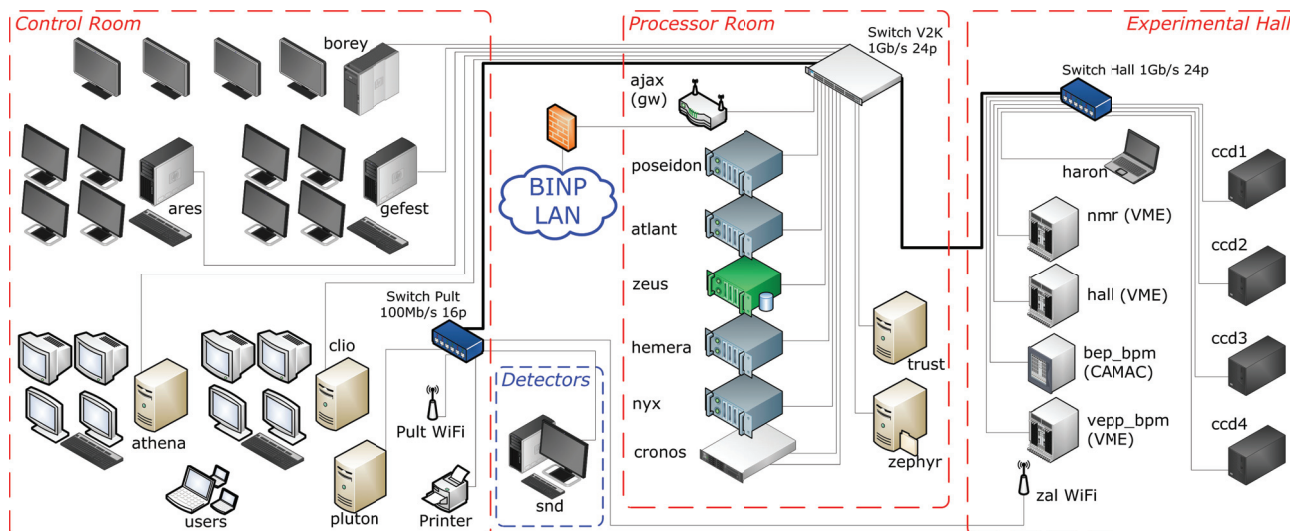| Parameter	Value
Circumference, Π	24.39 m
Energy, E	1 GeV
Betatron functions at IP, $\beta^*_{x,z}$	10 cm
Betatron tunes, $\nu_{x,z}$	4.1, 2.1
Beam emittance, ε	1.4×10^{-7} m·rad
Particles per beam, N	1×10^{11}
Momentum compaction, α	0.036
Synchrotron tune, ν_s	0.0035
Energy spread, $\sigma_{\Delta E/E}$	6.4×10^{-4}
Beam-beam parameters, ξ	0.075
Luminosity, L	10^{32} cm^{-2}s^{-1}

Figure 2: VEPP-2000 acceleration complex network layout.

VEPP-2000 HARDWARE

From the point of view of automation accelerator complex VEPP-2000 is a complicated system. Over than 1200 control channels and 2400 monitoring channels and their joint usage apply rigid restriction on control system.

Acceleration complex VEPP-2000 consists of five main subsystems: ILU and channel to B-3M, B-3M and channel to BEP, BEP booster ring, channels from BEP to VEPP-2000 for electrons and positrons and VEPP-2000 collider ring. Each of subsystems includes several sub-subsystems: pulse elements, steady elements, RF-systems, and some additional systems like vacuum, temperature or radiation monitoring, as well as beam parameters measurement system which description is beyond the scope of this paper.

The control system of the VEPP-2000 complex is based on several PC platforms under Linux operating system, connected into VEPP-2000 private net. The layout of the system is presented in Figure 2.

As it was mentioned above VEPP-2000 complex is a modernization of old VEPP-2M facility. This leads to necessity of taking into account a wealth of 20-year experience on the one hand and using modern automation solutions on the other hand.

On choice of hardware protocol one should be guided by capacity, support and standards. For automation system for VEPP-2000 facility two main protocols was chosen: well-known CAMAC and modern CAN-Bus [5]. Table 2 specifies subsystems and used protocols with approximate number of channels.

Control units, used at VEPP-2000 complex, are made in BINP [6,7]. CAMAC standard is used at the places where heavy traffic is needed (fast ADCs) and also at the

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[1] More information about VEPP2-2000 Beam Measurement Systems one can find at [8,9].

systems where migration on a new standards during modernization was considered inadequate (old systems like ILU or B-3M) which will be removed in future. CAN-Bus protocol is used at the complex automation as a base protocol. It is very convenient for spatially distributed automation systems and allows reduce wire commutations significantly. More one standard – VME – is used only in beam parameters measurement systems: pickups, etc. A very simplified scheme of the control system hardware is shown in Figure 3. Beam measurement hardware of VEPP-2000 is beyond this paper so it is not shown in the figure in detail[1].

Table 2: Subsystems and Channels

System	Subsystem	Protocol	N of chan.
ILU & channel	Pulse	CAMAC	50
		CAN-Bus	40
	DC	CAN-Bus	40
B-3M & channel	Pulse	CAMAC	50
		CAN-Bus	40
	DC	CAN-Bus	40
	RF	CAN-Bus	20
BEP	Steady	CAN-Bus	500
	RF	CAN-Bus	20
BEP–VEPP-2000 channels	Pulse	CAMAC	30
		CAN-Bus	100
	DC	CAN-Bus	50
VEPP-2000	DC	CAN-Bus	500
	RF	CAN-Bus	20
Technological	Vacuum	CAN-Bus	50
	Temperature	CAN-Bus	80
	Cryogenics	CAN-Bus	50
	Radiation	CAMAC	10

VEPP-2000 SOFTWARE ARCHITECTURE

Principles of software construction arose from the hardware architecture. The architecture of VEPP-2000
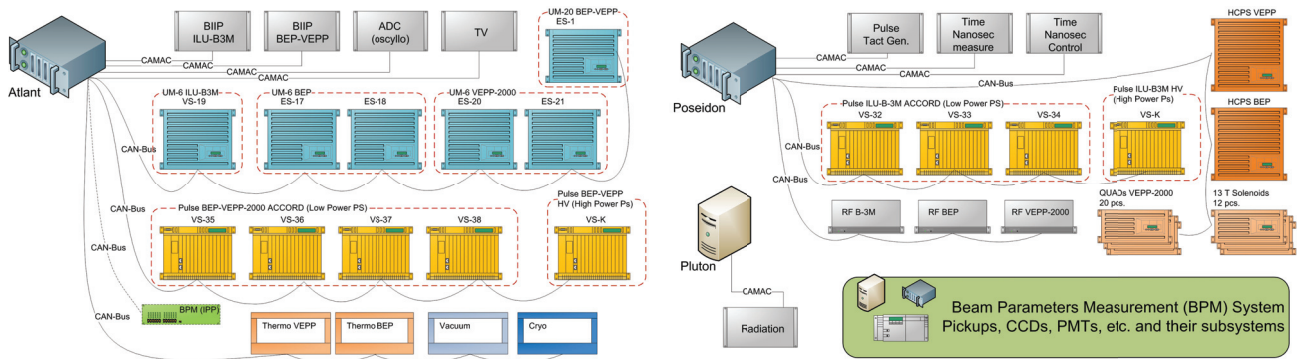
Figure 3: VEPP-2000 Control hardware.

software is based on traditional three-layer structure. Specialized services (hardware layer) control one or several CAN or CAMAC buses and allow client applications to have access to hardware.

The main application of Middleware layer is VCAS (VEPP-2000 Channel Access Server). VCAS is a universal communication media, which provides access to the data to any other application in the control system or to the other purposes, i.e. for detectors control systems or for status pages in the Web, etc.

Third level is presented with GUI applications, which provides to facility operator powerful and convenient instrumentation for beam tuning and diagnostics of possible systems malfunctioning.

For the high loaded data channels like control systems of magnetic structure of storage and collider rings it is possible direct communication between GUI and hardware layers.

Another important application in the middleware layer in specially designed Log Server [10]. Its purpose is to archive all necessary automation system data to special hard disk storage. All foresaid is schematically shown on Figure 4.
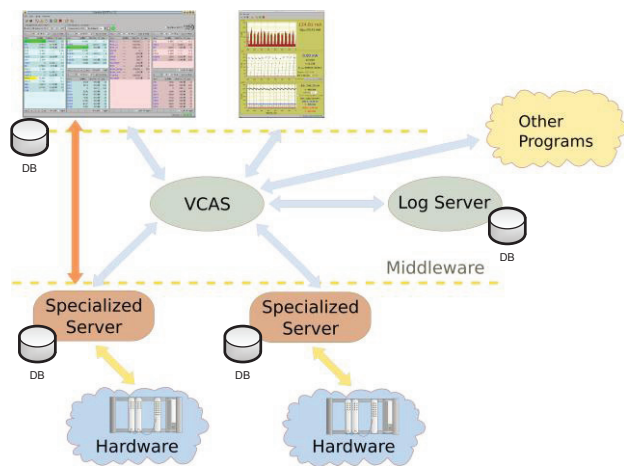

Figure 4: VEPP-2000 Software scheme.

The point is to hide from operator details of hardware configuration and implementation of each hardware service. All information about hardware configuration contains in special databases or configuration files, personal for each server. Each control system application can store its own data of properties in personal databases or files if it is necessary.

The second point is modular principle of VEPP-2000 automation system construction. This allows including new features and hardware without significant reconstruction of on-line operating software from one hand and fast and clean searching and removal of any hardware of software faults.

Thus, software system allows facility operator to manage and monitor different hardware subsystems sometimes very different from each other in one manner. Operator uses very similar applications GUI-styled as well as console-like to steer different parts of VEPP-2000 acceleration complex.

VCAS APPLICATION

The key concept of VCAS application architecture is the *Data channel* concept. Data channel is named data storage and distribution unit which has several properties addition to the unique name: value, units, description, type and some others. Properties of VCAS data channel are described in Table 3.

Application, needed to manipulate with VCAS channels data, can set value to the channel, get value, get full channel data including all channel properties, subscribe the channel (data will arrive to application only being set to VCAS), release (after subscribe, when the channel is no more needed) and free (for exclusive channels).

There are some utility data channels of VCAS itself: "*ChannelsList*", containing the list of the names of all VCAS data channel, "*error*", which represents the last error in VCAS operation and others.

The schematic of VCAS operation is shown at Figure 5. First, incoming data arrive into the network subsystem of the server, where they channel own is analysed. In the absence of errors, the data is transferred to internal structure of addressed channel. Then the data are sent to subscribers and to the logging system if it is necessary another network interface.

Table 3: VCAS Data Channel Properties

Property	Description
name	The unique name, addressing the channel
type	Channel permissions: *rw*, *ro* or *ex*[1]
descr	Description of the channel
time	The time of last update
value	The channel value
units	Units of the channel
is_log	Flag, meaning channel logging necessity

To access to VCAS data simple text protocol based on TCP/IP stack and contains *key:value* pairs is used. During the server development several text protocols like JSON [11] or XML [12] was analysed. But, finally, pairs of text fields of key-value were chosen due to the parsing and encoding simplicity and, in turn, their fast operation from the one hand, and sufficiency of such approach to most of the automation tasks from the other.
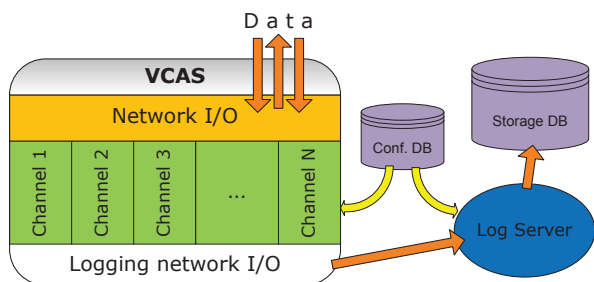

Figure 5: VCAS and Logging service scheme.

At the present time VCAS application is implemented in C++ code using QT framework [13]. This framework was chosen for several reasons: author's wide experience with C++ and QT development, perfect documentation of the framework, fast application development and some others. The performance of VCAS implementation allows serving 5000-7000 channels updates per second on office-class PC with reasonable client application subscribed to VCAS data.

VEPP-2000 GUI APPLICATION EXAMPLES

The software of VEPP-2000 automation system consists of more than 70 different applications. Most of them are GUI ones. Here are presented two different programs: one from the beam parameters measurement system – CCD data (see Figure 6) and other from control system of VEPP-2000 (see Figure 7).

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[1] *rw* – any application can read or write the channel value, *ro* – applications can read only the value (utility channels of VCAS itself), *ex* – exclusive, only the first updated the value application can write to the channel.
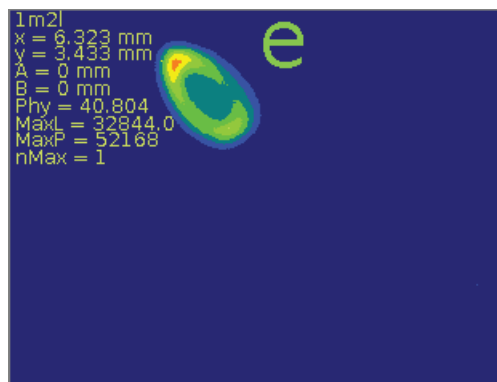
a)
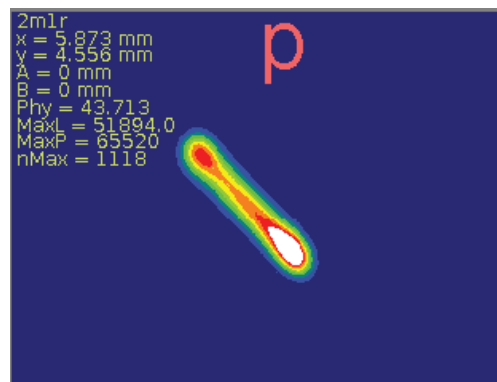
b)

Figure 6: Electron a) and positron b) beams images from two CCDs of the beam parameter measurement system. Large betatron oscillations at the coupling resonance make the beam unusual ring-shaped (at top). Data from every 16 CCD are available to the control system via VCAS server.
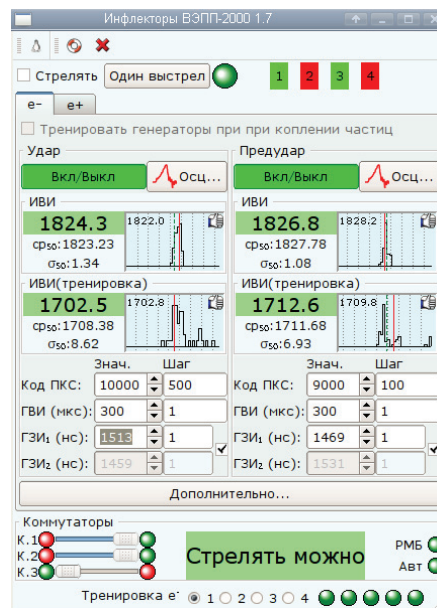

Figure 7: GUI for VEPP-2000 collider inflectors.

Figure 8: VEPP-2000 main control room. A. Senchenko at the middle ground.

CONCLUSION

VEPP-2000 automation system is based on hardware made at BINP (Novosibirsk) in the proven CAMAC and modern CAN-Bus field bus standards. The software system substantially corresponds to hardware system and has a three-layer architecture.

The separation of hardware peculiarities from GUI with so-called middleware allows to operator independently steering of different VEPP-2000 subsystems like ILU, B-3M and BEP, VEPP-2000 and beam channels.

New VCAS application was specially designed to provide to other automation system programs universal communication media – so called data channels.

Two experimental seasons in 2009-2012 have been done and two detectors SND and CMD-3 have collected about 30 pb^{-1} of integrated luminosity.

The control system of VEPP-2000 collider (see Figure 8) proved good flexibility and allows very fast development of a new, more powerful application.

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