

# THE POWER SUPPLY SYSTEM FOR ELECTRON BEAM ORBIT CORRECTORS AND FOCUSING LENSES OF KURCHATOV SYNCHROTRON RADIATION SOURCE

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## Abstract

The modernization project of the low-current power supply system of Kurchatov Synchrotron Radiation Source [1] has been designed and is under implementation now. It includes transition to the new power suppliers to feed electron beam orbit correctors and focusing lenses.[2] Multi-level control system, based on CAN/CANopen fieldbus, has been developed for specific accelerator applications, [3] which allows startup and continuous run of hundreds of power supplies together with the other subsystems of the accelerator. The power sources data and status are collected into the archive with the Sitect SCADA 7.2 Server и SCADA Historian Server. The following operational parameters of the system are expected: current control resolution - 0.05% of  $I_{MAX}$ ; current stability -  $5 \cdot 10^{-4}$ ; 10 hours current variance - 100 ppm of  $I_{MAX}$ ; temperature drift - 40ppm/K<sup>0</sup> of  $I_{MAX}$ .

## POWER SUPPLY STRUCTURE CHART

As a primary power source we use industrial single output power supply, which feeds PWM switches (fig. 1). The PWM frequency is determined taking into account acceptable level of current ripple in the resistive load, which must not exceed 0.1% of maximum current value. In our case the PWM operates at 50 KHz, allowing more than 1000 primary steps for each PWM channel. High resolution PWM of the TMS320 microcontroller provides extra 120-130 PWM levels within a primary step. When unipolar operation is used, power drivers are commutated from bridge circuit to the parallel one. This provides doubling of the maximum load current, but at the same time, utilization of the only PWM channel halves output current resolution.

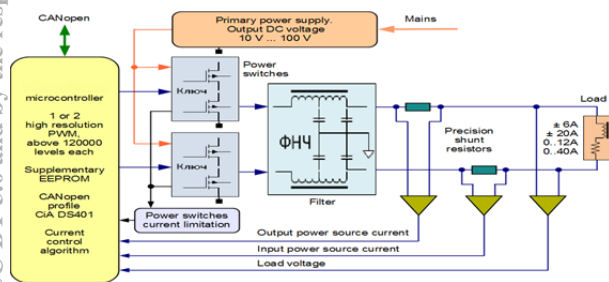


Figure 1: Power supply block diagram.

Precision shunt resistors USR4-3425 have temperature coefficient not exceeding 5 ppm/K, providing long-term calibrated current stability better than  $10^{-4}$  of maximum level. For current and voltage quantization we use fast 18-bit successive approximation ADC AD7690. All current control tasks are executed by the microcontroller software.

## POWER SUPPLY PROGRAM AND ALGORITHMS

Direct digital control methods, implemented by the power supply microcontroller, nominate additional requirements for the precision and stability of the current measurements data. 18-bit accuracy is required to utilize high resolution PWM full range. Primary measurements data is acquired by each ADC every 40 microseconds. Effective resolution of the data in service conditions is less than 14 bits. To achieve adequate accuracy two-stage data processing with trimmed mean method is applied. The first stage processing employs 1 ms data windowing with 25 primary ADC results. The second one utilizes 20 results of the first stage processing with 20 ms data windowing. Trimming parameters are chosen to provide impulse noise filtering, while data window size selection suppresses rippling from primary power source as well as mains noise. In the upshot, 18-bit resolution is achieved with the final result obtained not later than 17 mS after ADC input signal is changed.

The current control algorithm is based on optimization method and operates with stationary current value. It is assumed, that the time of the current own stability is longer, then the duration of transient process after PWM setpoint change. This means, there is explicit response function to the PWM setpoint single step. The algorithm dynamic properties are specified with two programmable parameters: the current slew rate and transient duration. Key internal parameters of the control method are slope values of integral and differential current characteristics. They are specified as the ratio of increment of the load current to the corresponding increment of the PWM setpoint. The slope values are determined by the power supply proper characteristics, like primary source voltage and by the load properties. The parameters are regularly calculated in the process of the power source operation. Their assessment is smoothed by the exponentially weighted moving average. The degree of weighting decrease for the integral current characteristics is equal to

0.75, while for differential one it is varied in the range from 0.1 to 0.7, depending on PWM setting change step.

Accurate current stabilization is realized with «regula falsi» method. Its mathematical sense is linear interpolation of PWM setting, based on the current characteristics slope at the previous iteration. Additional logic is employed to ensure stable operation of the algorithm in all modes, including unsteady. It involves adaptive constraint of the PWM setting step and maximum number of iterations, lost control situation processing and other features. These include matching of the current measurement and PWM resolutions. Load with high active resistance can lead to an inability to register output current change, caused by the minimum PWM setpoint shift. To solve the problem, the algorithm dynamically adjusts PWM resolution, considering the value of integral current characteristics.

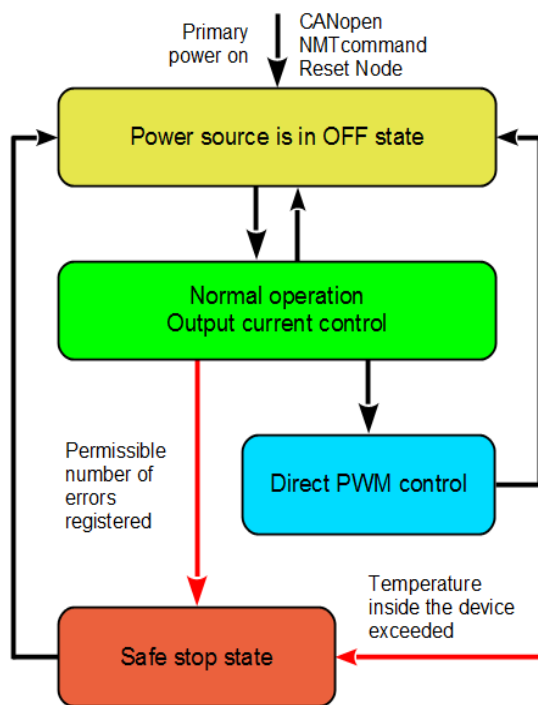


Figure 2: Power source finite state automaton.

The control program also supports power source finite state automaton (fig. 2). If emergency situation persists, the device is forced into safe stop state with zero load current. The decision to stop the supply is taken when permissible number of errors is registered. Errors accumulation time is approximately 1 second due to current exceed, 5 seconds if PWM setting is out of limits and up to 10 minutes in case the current control is lost. The latter may be the consequence of breakage of the load circuits or unsteady state of its volt-ampere characteristic. When temperature excess inside the device is registered, it is also transferred into safe stop state. Power off and stop operations are executed by the smooth current decrease and take no more than two seconds. All other state transitions are fulfilled with external control commands.

## POWER SUPPLY DATAWARE

The power supply operates as a node of CAN fieldbus. It supports CANopen protocol in compliance with CiA 301. The device application profile is CiA DS401 (device profile for generic I/O modules) with some additions. Specialized tool kit, based on CANwise software instruments, was developed for stand-alone adjustment and calibration of power sources.

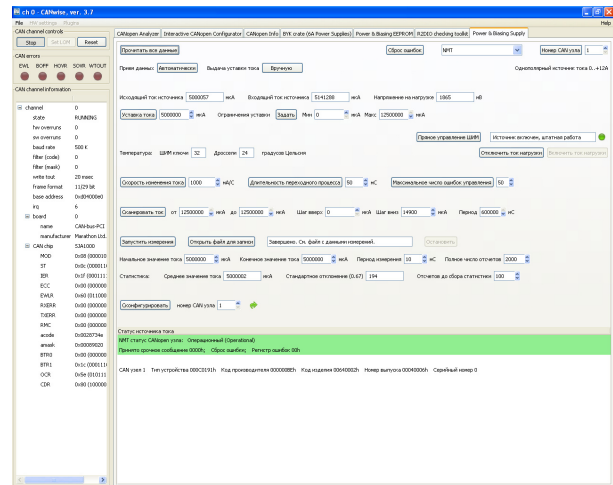


Figure 3: Power source engineering toolkit.

Engineering module (fig. 3) enables to test and configure the power source. Operational modes and parameters of the current control algorithm can be adjusted interactively. Power supply errors and fails are transmitted with emergency CANopen messages. The module provides record of the power supply current with period, varying from a few milliseconds to several minutes. This allows to measure transient characteristics of the power source, as well as to identify short term (a few seconds) and long term (several hours) current stability and variance. All the measurements are fulfilled with the standard tools of the CANopen protocol.

Another toolkit module serves for the supplementary EEPROM programming, which keeps crucial configuration and calibration power supply parameters. When the microcontroller program is upgraded, the values of the parameters remain intact, preserving individual settings of the power supply.

## POWER SUPPLY TESTS

Two types of loads were utilized for the power supply tests. As an active-inductive load we used copper-wired focusing lens. Transient process duration in this kind of load is about 500 milliseconds. The diode load was the chain of series-connected semiconductor diodes, which is characterized by a significant non-linearity of the direct volt-ampere characteristics. Transient process duration in the diode load does not exceed 50 milliseconds and is determined mainly by the response function of the power source itself.

Figure 4 shows load transient characteristics with a significant change of the current setpoint. Current slew rate value for inductive load is three and for diode – one ampere per second. Active-inductive load has linear volt-ampere characteristic, so the output current also grows linear. For the diode load the control algorithm attempts to withstand accurately the current slew rate, updating integral current characteristic on each step. For both loads the current overshoot does not exceed 5% from setpoint value, but it caused by the various reasons. In the case of the inductive load overshoot is caused by the emf of self-induction and its amplitude can be reduced by the current slew rate decrease. For the diode load current overshoot is almost independent of the current slew rate. It is caused by the insufficient clarity in defining of the differential current steepness at the operating point, which is improved in the course of further current control.

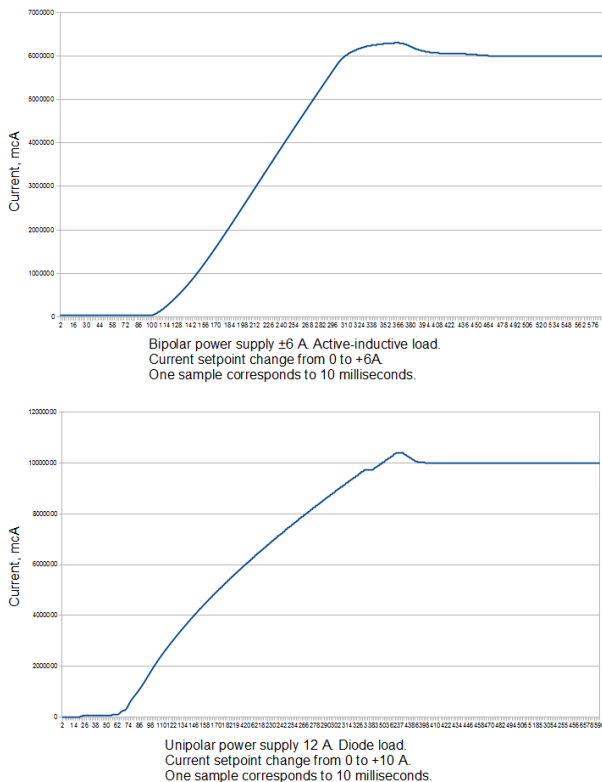


Figure 4: A significant change of the current setpoint.

A significant change of the current setpoint causes the load warming up, which leads to the unstable state of its volt-ampere characteristic. Fig. 5 shows current control algorithm behavior in the unsteady state, which duration is usually from a few to several dozen seconds. Temperature coefficient of resistance causes the situation, when smallish PWM setpoint step leads to extremely small change in current, or even the opposite in sign to that expected. This is detected as loss of control condition. Current peaks scope for the diode load recedes as refinement of the differential current steepness. As may be seen, amplitude of current oscillations in the unsteady state does not exceed 0.1% for the diode and 0.02% for active-inductive loads of the current setpoint.

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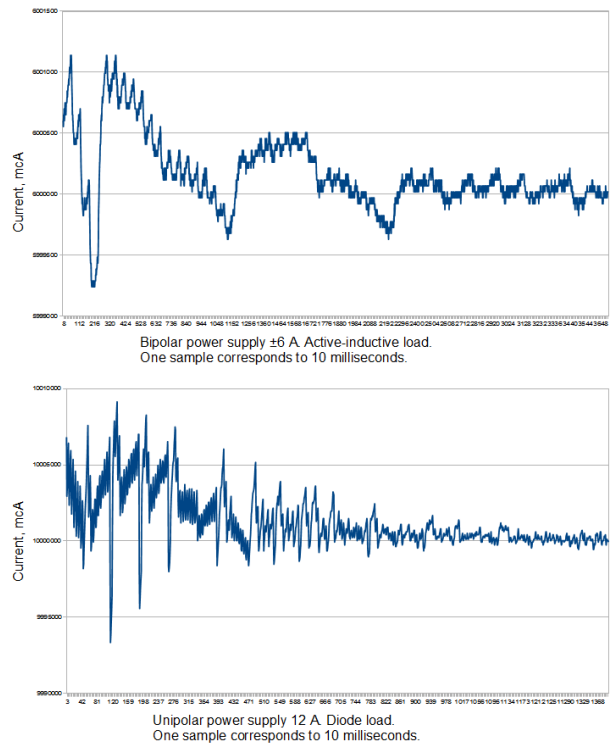


Figure 5: Current control in the unsteady state.

In the absence of significant external disturbances, current adjustment is fulfilled with a single high resolution PWM setpoint step. For active-inductive load it is about 100 mcA and the control accuracy is close to the measuring ADC resolution (four LSB units). For the diode load the differential current steepness is significantly higher and, in addition, unipolar power supply with the only PWM channel is used. So, precise current control step amounts to one milliampere.

**CONCLUSION**

In the first half of 2013 the new power suppliers were connected to electron beam orbit correctors and focusing lenses of Kurchatov Synchrotron Radiation Source. In June 2013 small storage ring “Siberia-1” was successfully started in operation with the new power suppliers.

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