ISBN: 978-3-95450-254-7 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS1991-S04SRS07

Multi-Microprocessor Control of the Main Ring Magnet Power Supply of the 12 GeV KEK Proton Synchrotron

T. Sueno, K. Mikawa, M. Toda, T.Toyama and H. Sato
National Laboratory for High Energy Physics

and S.Matsumoto,
Physics Division, Dokyo University School of Medicine

Abstract

A general description of the computer control system of the KEK 12 GeV PS main ring magnet power supply is given, including its peripheral devices. The system consists of the main HIDIC-V90/25 CPU and of the input and output controllers HISEC-04M. The main CPU, supervised by UNIX, provides the man-machine interfacing and implements the repetitive control algorithm to correct for any magnet current deviation from reference. Two sub-CPU's are linked by a LAN and supported by a real time multi-task monitor. The output process controller distributes the control patterns to 16-bit DAC's, at 1.67 ms clock period in synchronism with the 3-phase ac line systems. The input controller logs the magnet current and voltage, via 16-bit ADC's at the same clock rate.

1.INTRODUCTION

The main ring magnet power supply consists of 10 twelve-pulse thyristor rectifiers with dc filters, of 2 reactive power compensators [1] with tuned ac harmonic filters [2] and of an analog and digital hybrid control system [3]. A schematic diagram of the power supply is given in Fig. 1. Fig.2 shows the principle layout of the hybrid control system. Eight rectifiers feed the bending magnets and the other two excite the horizontally and vertically focusing quadrupole magnets. Fine adjustment of the current at injection and of the ratio between currents of the bending and the quadupole magnets is required to tune the acceleration. The current of the quadrupole magnets must be tracked separately from the current of the bending magnets for precise Q-tuning and optimum beam acceleration.

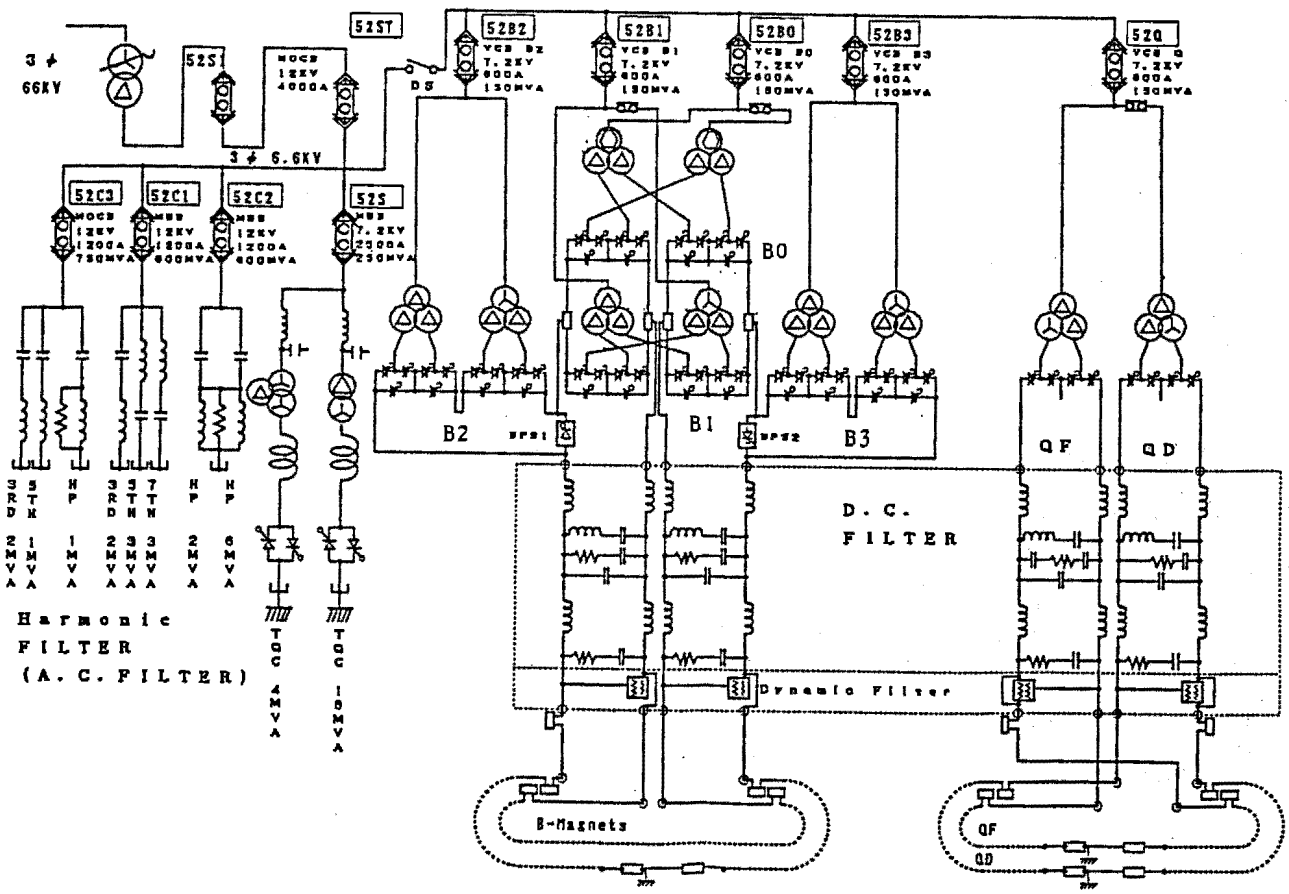


Fig.1 Schematic Diagram of the KEK 12 GeV PS Main Ring Power Supply.

ISBN: 978-3-95450-254-7 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS1991-S04SRS07

The desired magnet excitation currents are obtained by controlling the output voltage of the thyristor power converters through the SCR gate firing pulse. The rectifier voltage reference patterns are implemented by the common action of two negative feedback loops, i.e. a low-gain automatic voltage regulator (AVR) and a high gain automatic current regulator (ACR). These patterns are elaborated by the control computer and fed to the regulation through a DAC, synchronized at 600 Hz on the zero crossing of the two 3-phase ac line systems. While providing the voltage reference patterns the computer implements a repetitive control algorithm on the base of measured deviations of the magnet current from reference. The digital system is in charge of the fast feedforward pattern control and of the repetitive control via the ACR.

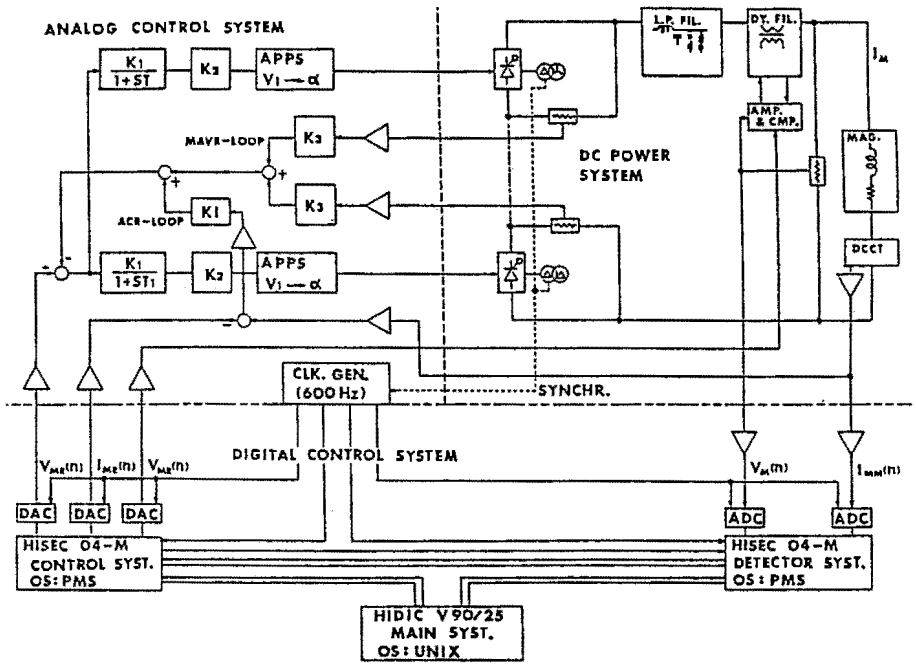


Fig.2 Schematic Diagram of the Hybrid Control System.

2. MULTI-MICROPROCESSOR CONTROL

2.1 General Layout

The multi-microprocessor control system has been introduced in 1985 [4]. Initially the main CPU was a V90/5 (8MHz without cash-memory); this was then upgraded to a V90/25 (16MHz with cash-memory) in order to improve the speed of the main system and of the communication loop. The main parts of the digital system are based on a 16-bit-microprocessor and on LSI components, connected to an industrial standard bus and to standard peripherals, supported by an universal operating system. Consequently a high level language and powerful utilities facilitate development and maintenance of flexible software for the pattern control system which consists of the main CPU HIDIC-V90/25 and of the input and output controllers HISEC-04M. The three distributed systems have no hierarchical software but are rather independent even at assembler level because of the difference between the CPU families and in particular of different addressing for memory access. The main components are LSI of the MC-68020 CPU family. The direct digital control system, as main part of the controller, consists of I-8086 and home-made LSI modules. Fig.3 shows a layout of the multi computer system.

2.2 HIDIC-V90/25 system

The system, equipped with memory management unit and 16MB DRAM on the internal bus, has a floating processor. Two local area network (LAN 1 and 2) loops provide the interconnection between main system and standard peripherals, i.e. 5-inch 80 MB hard disc and 8-inch 1 MB floppy disc drive, two CRT terminal stations , a typewriter and a printer. These resources are supervised by the UNIX compatible main OS. One of the network-loops, LAN 1,

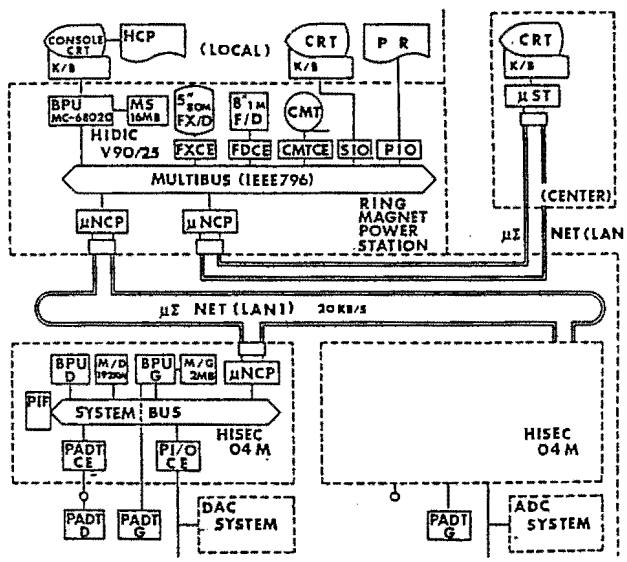


Fig.3 Layout of the Control Computer Netwok System.

exclusively devoted to input or output network communication, transfers patterns or logged data between the main and the input or output controllers. The fact that this communication is rather slow, due to time sharing operation on the same system bus, limits the speed of response for fine adjustments.

The local terminal is supported by a serial I/O full duplex link. The remote terminal, located in the Center Control Room (CCR) of the 12 GeV PS, is linked by an optical cable to cope with the 350 m distance between CCR and power station, where the main system is installed.

The application programs are written in the system language C and FORTRAN 77 [5]. The parameter files of

ISBN: 978-3-95450-254-7 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS1991-S04SRS07

the programs displayed on a CRT terminal can be communicated to the central control system. Powerful UNIX utilities are used not only for program development but also for maintenance of the application programs, controlling and monitoring the whole system by file management, screen editor and shell command.

Pattern generation can be done while the power supply is running by using the main CPU and storing the new pattern in its memory. Therefore the operating pattern can be changed without interrupting power supply operation. Fine adjustment of the injection current and of the tracking ratio between bending magnet and quadrupole current is done from either terminal in the CCR or the local power supply control room. The main tasks are control operation, e.g. start-stop and status monitoring, calculating the correction patterns of the repetitive control and fine adjustment of pattern data. As far as additional supporting tasks concerns, the system works on pattern generation, processing of pattern and operational data, control program development and background processing. The main operator commands are shown in Table 1.

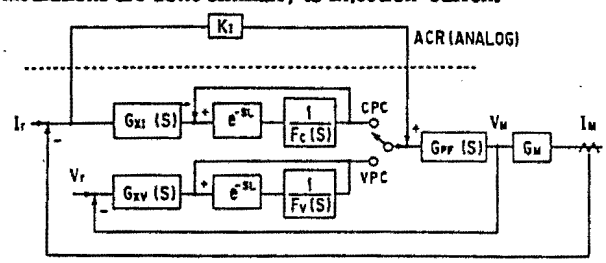
Table 1.

**** MR-PS OPERATOR COMMANDS****

f1 [pattern No.]	: run
f2	: stop
f3 pattern No.	: pattern exchange (with repetitive control)
f4	: IQ tracking adjust
f5	: B inj. adjust
f7	: pattern generation
f8	: PS status display
f9	: pattern No. display
f10 [pattern No.]	: pattern save
f11 pattern No.	: pattern remove
f33 pattern No.	: pattern exchange (without repetitive control)
menu	: command menu display
menu2	: command menu next page display
pc20	: repetitive control start
cpcstop	: periodic control stop

Footnote: [default pattern number] can be neglected

Generated pattern files are used for fine adjustment of injection level of the bending magnet current (without tune shift) by additional smoothing corrections calculated in the same pattern generation algorithm. Tracking offset calculations are done similarly to injection current



GX(n) : Transfer function for compensation.
F(s) : Transversal finite impulse response of low pass filter.
L=mT : Dead time of m times period T, m : integer.

Fig.4 Block Diagram of the Repetitive Control.

corrections. Concerning the B2 and B3 rectifiers, the reference voltage pattern is subdivided and distributed to each of the 12 pulse thyristor converter groups in order to obtain the desired magnet voltage with minimum reactive power generation [6]. In both fine adjustment cases a step variation is smoothed out by applying optimum polynomials in a fixed interval. The main and the controller systems are linked in a LAN with an effective transfer rate of 20 kB/s. Typical response time, on fine adjustment of tracking or of injection current for beam tuning, was 20 to 50 s for the V90/5, even after the control programs have been optimized by fixed point calculation, but becomes less than 10 s in case of the V90/25. Table 2 shows as an example display of injection current adjustment by function f5 (see Table 1).

Table 2.

MR-PS injection tuning (on line)
page - 1/1 proton/q05066

Ib	injection	: 198.88
Iqf	injection	: 116.73
Iqd	injection	: 116.29

Binj. [G] 1450.0

UPPER LIMIT > INITIAL > LOWER LIMIT
Injection [G]
1598.9 > 1449.0 > 1285.5

Repetitive magnet current control has been performed to suppress the deviations from a given current reference pattern and repetitive voltage control has been used to reduce the parasitic voltage ripple [7]. The principle is based on the control method applied to a repetitive reference input [8]. The excitation current in the respective magnets is to be controlled according to periodical patterns. The frequency response of the correcting transfer function has been confined in a lower frequency region, about 15 Hz or less, to track a periodic input and assure the stability of the power system. Fig. 4 shows an algorithm of the repetitive control of current and voltage. In Fig. 5 the convergence of the repetitive control, from the initial pattern to the corrected one, for an ACR deviation of the bending magnet current pattern is shown over eight correction cycles. (Timing pulses, P1,P2,P3 and P4 are injection start, acceleration start, flat top start and flat top end, respectively.)

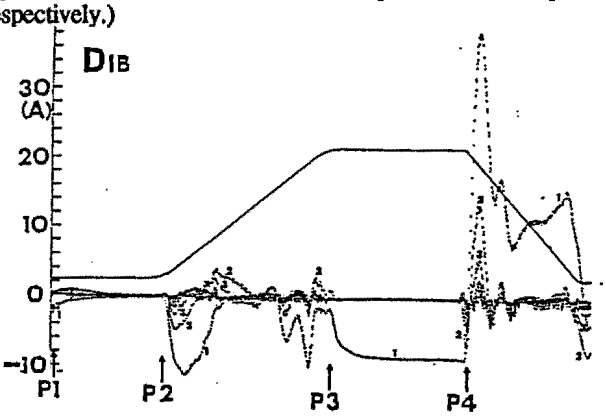


Fig.5 Converging of Current Deviation by Repetitive Control.

ISBN: 978-3-95450-254-7 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS1991-S04SRS07

2.3 *Controller System*

The HISEC-04M/D and G controllers, belonging to different families i-8086 and HD-68000, are subdivided into two sub-system working on the same system-bus. The first one works as direct digital control and feeds operational patterns through 16-bit DAC's at 600 Hz clock. The other one acts as a data processing system and a support to the direct digital control; it logs the magnet current from the DCCT and the group voltage through a sets of 16-bit ADC's working at the same clock. It communicates through LAN 1 with the V90/25 and reads or writes data or messages on the memory of the HISEC-04M/D.

The output controller, supervised by the process monitoring system, executes application programs such as start-stop as well as process timing and sampling synchronization. The routine output processing function distributes 15 data patterns in memory through parralell I/O to the 16-bit DAC's.

Eleven sets of DAC's serve the bending magnet power supply: eight of them give the voltage reference patterns to the thyristor converter groups, two are for the ripple detectors of the dynamic filters and one gives the current reference for the analog ACR. Each focusing and defocusing magnet power supply has three sets of DAC's. Two serve as voltage and current reference to the analog loops and one is used for the dynamic filter. The system ouputs the pattern data to the seventeen sets of DAC at every 1.67 ms clock period and the data conversion is synchronized to the zero-crossing of the six phase ac power line. Control signals of by-pass thyristors and gate pulse suppress signals are distributed by the system.

The input controller is dual with respect to the output controller as far as hardware and system software concern, except the digital input and output. Its main task is to collect the data from the ADC's through paralell I/O and to accumulate and save them at every control clock.

Simultaneously the system reads data from six sets of 16-bit-ADC's through a Sample/Hold amplifier at the same clock as the DAC system. Three sets serve for the DCCT current signals and the others for the dc voltages applied to the B, Qf and Qd magnets. The clock is sychronized on ac voltage zero-cross pulses but has a constant delay of 100 microsec corresponding to about twice the conversion time. The DCCT current data serve in the repetitive control loop for calculation of corrections to the voltage references.

3. CONCLUSION

The hybrid control scheme of an analog and a digital system and the multi-microcomputer control system HIDIC-V90/25 and twin HISEC-04M have been implemented in the main ring magnet power supply of the 12 GeV PS. The HIDIC-V90/25 and HISEC-04M system perform fast feedforward pattern control at 600 Hz clock and slow but high gain feedback control of current pattern for steady deviations according to the repetitive control method. The analog system works as real time feedback control loop of the voltage and current reference pattern fed by the digital system.

The repetitive current control is not yet used routinely, despite its effectiveness, due to the cumulative effect of small errors produced by the intrinsic ripple of the present DCCT. It is used for initial pattern correction and fine adjustment of the injection current and of the tracking ratio between bending and quadrupole magnet currents. It is easy to change the operating patterns without stopping the power supply. During the extension of the flat top duration [9], memory and hard disc capacity has been increased and the application software modified. When operation is performed with a long magnet current flat top, the control clock is synchronized at 300Hz to save memory space. At present the multi-microcomputer control system allows to perform stable operation of the PS and to achieve effective utilization of the slow extracted beam spill.

Acknowledgements

The authors would like to thank Prof. Michio Nakano (Tokyo Institute of Technology) for the many technical discussions concerning the control system design. They are indebted to Prof. M. Kihara for his advice and encouragement during this work. They also thank many colleagues of PS group for their effective cooperation.

References:

[1] S.Matsumoto, H.Baba, H.Sato, T.Sueno and K.Mikawa, "Improved Control System of the Thyristor Flicker Suppressor for the KEK 12GeV PS," IEEE Transactions on Nuclear Science, NS30(1983)2932

[2] T.Shintomi, M.Masuda and S.Matsumoto,"Harmonic Current AC Filters at a Large Accelerator," Particle Acc. 8(1978)87

[3] S.Matsumoto, T.Sueno, K.Mikawa and N.Kumagai, "Control of the Main Ring Magnet Power Supply for the 12 GeV PS," Proceedings of the 6th Symp. on Acc. and Tech., 1987, Tokyo, Japan, pp.158.

[4] S.Matsumoto, T.Sueno, K.MIkawa, M.Toda and H.Baba,"New Multi-Microprocessor Control System of the Main Ring Magnet Power Supply for the KEK 12 GeV PS," Proceedings of the 1987 IEEE Particle Accelerator Conference, 1987, Washington D.C., pp.689.

[5] T.Sueno, M.Toda, S.Matsumoto and K.Mikawa, "Software Systems of the Main Ring Magnet Power Supply for the 12 GeV PS," Proceedings of the 6th Symp. on Acc. and Tech., 1987, Tokyo, Japan, pp.155.

[6] H.Sato, T.Sueno, T.Toyama, M.Mikawa, T.Toda, S.Matsumoto and M.Nakano, "Performance of the Main Ring Magnet Power Supply of the KEK 12 GeV Proton Synchrotron", Proc.of the 1991 IEEE Nuclear Science Symposium, 1991, Santa Fe, to be published.

[7] T.Sueno, S.Matsumoto, K.Mikawa, M.Toda, H.Sato, N.Kumagai and H.Baba,"Repetitive Voltage Control of the Main Ring Magnet Power Supply for the KEK 12 GeV PS," Proceedings of the 14th Int. Conf. on High Energy Accelerators, 1989, Tsukuba, Japan, Particle Accelerator. 29(1990)133.

[8] T.Inoue, M. Nakano, T.Kubo, S.Matsumoto and H.Baba,"High Accuracy Control of a Proton Synchrotron Magnet Power Supply," Contl.Sci. & Tech. for Prog. of Soc. (IFAC 82) Vol.6, 3137, Pergamon Press(1982)

[9] H.Sato, T.Sueno, T.Toyama, M.Mikawa, T.Toda and S.Matsumoto, "Upgrade of the Main Ring Magnet Power Supply for the KEK 12 GeV Proton Synchrotron", Proc.of the 1991 IEEE Particle Accelerator Conference, 1991, San Francisco, to be published.