THE CONTROL SYSTEM OF THE HARMONIC DOUBLE SIDED MICROTRON AT MAMI*

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Abstract

The MAMI (Mainz Microtron) electron accelerator cascade of three Racetrack Microtrons (RTMs) has been upgraded by a 4th stage, a Harmonic Double Sided Microtron (HDSM, Fig.1), raising the output energy from 0.855GeV to 1.5GeV [1]. The control system for this worldwide unique machine has been built by extending and updating the well proven system of the three RTMs described in [2]. To accomplish this, software to control a couple of new devices had to be implemented, the operator interface was rebuilt and new PC-based VME-front-end computers were developed. To supply the large number of correction dipole steerers on the 43 recirculation paths, a new type of multi-channel power supply was developed in-house. An enhanced system for digitising the signals of the rf-position monitors on the linac axes has been set up to improve the automatic beam position optimisation in the RTMs and to enable it in the HDSM.

INTRODUCTION

The MAMI accelerator is a normal conducting machine with hitherto 855MeV energy at 100µA maximum c.w. current, operated for 15 years for experiments in nuclear physics. Now its energy has been almost doubled by adding a HDSM as 4th stage. This new type of microtron has been built in parallel to regular operation of the existing cascade of RTMs. Its commissioning started in December 2006 and the first beam for a nuclear physics experiment was delivered in February this year, for 240 hours with a 10µA polarised beam [3]. More than 80% of this time the beam was available on target. Already 60µA beam current were achieved for testing purposes. Since March 2007 the machine runs in routine operation for various experiments in nuclear physics. Its handling has to be as simple as possible, because it is operated by students at night and on the weekend. This enforces a very clear, straightforward and reliable control system, which should be able to assist the operator in a self-acting manner as well.

HISTORY

Starting in 1979 with the commissioning of the first RTM (14MeV) the MAMI accelerator facility was successively extended stage by stage followed 1983 by the second one (180MeV). During the five years of operation with two microtrons new accelerator halls were built, and a third RTM delivering 855MeV at 100µA was put into operation in 1990. The control system was growing with machine development. Its basic design originates from the 1980ies, but it has been extended and re-developed continuously with the increase of complexity of the accelerator. Starting with two HP1000 process computers with CAMAC adapters for the first two microtrons, an object-name based, message-oriented interprocess communication system was developed (MIPC). Although there was no networking standard available at that time (the connection between computers was a very special in-house hardware), basic networking abilities were built in. On the basis of this system a database system and several processes to control various hardware devices were programmed. While constructing the 3rd stage, the MIPC and a lot of the control processes were translated into C and ran on a MicroVax with VMS operating system, which was equipped with a CAMAC adapter. The network interface of the MIPC was adapted to IP, by what it was possible to introduce VME-computers into the control system, in the beginning with OS9 operating system, later on with Unix. These VME-computers substituted the CAMAC/VAX adapter. Furthermore a graphical user interface (GUI) was introduced [4], using the commercial "Dataviews" package. In the following years the demands on the control system due to the increasing complexity of the machine – mainly by additional beam-guiding systems and a polarised electron gun facility – could be satisfied by adding more VME-crates and -computers (at this time SPARC-CPUs with SunOS). However, the VMS-computer (later on a DEC-Alpha) running the central database began to become a bottleneck. Due to the operating system independent design of the control system, it was a minor task to introduce Windows operating systems. Thus the Alpha/VMS could be exchanged by a Windows Server, which still runs some crucial Ratfor programs not easily portable to a state of the art Unix system. This was the status of the MAMI control system when the HDSM project started in 1999.

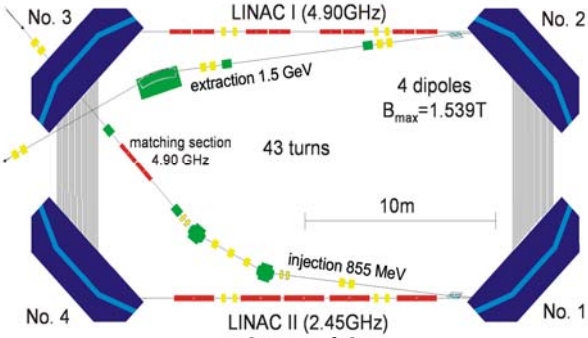

Figure 1: Scheme of the HDSM

MAIN FEATURES OF THE MAMI CONTROL SYSTEM

The interprocess communication system MIPC connects a set of computer nodes together to a distributed computing environment, using (mostly simple) messages.

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The addressees of these messages are objects in terms of (sub-)units to control, e.g. beam line elements. All message routing-information is stored in a central database and is configurable online. This means that names can be added or changed and processes moved among the nodes at any time without disrupting normal control operation. The MIPC is adapted to various operating systems and is easily portable to a new one. All programs in the control system rely on the MIPC and therefore are typically operating-system independent. The database is furthermore the central storage of all parameters and measured data of the machine. It has a built-in event mechanism, enabling the definition of composite states and the supervision of the machine status via a proprietary description language. The MAMI control system has also a GUI and a multilingual operator announcement system. Additionally an easy to use, BASIC-like interpreter simplifies complex operator actions. These comfortable interfaces enable the operation of the machine by sparse trained persons.

CONTROLLING THE HDSM

At the beginning of construction of the HDSM a brainstorm concerning the future of the MAMI control system was induced. One idea was to use a standard control system, e.g. EPICS. Such an investment in new hardware, new software (VxWorks) and manpower to adapt the numerous existing controls, only would have made sense, if not only the control of the HDSM but that of the whole machine is converted to the new system. But an additional imperative demand was not to affect the operation of the accelerator, because it was fully used for experiments in nuclear physics during the whole construction period of the HDSM. These constraints led to the decision to update the existing system and extend it with further VME-crates and some other equipment described below, to make it capable to control all microtron stages with an uniform system. So it was possible to do all development on-line and only short breaks for the exchange of hardware were necessary, which could be placed in the regular one or two days maintenance periods of the accelerator.

NEW HARDWARE DEVICES

New VME Bus CPUs

One main part in the old control system to be replaced were the VME-CPUs, out-dated SPARC-CPUs running SunOs. The upgrading with commercial VME-computers would have been a major expense factor. However, our electronic department had already developed PC-based CAMAC-controllers and with this know-how it was possible to build the VME-CPUs ourselves [5]. As base board an embedded PC named ETX module (Kontron) is mounted on a single width VME board. The CPU's PCI bus is connected to the VME bus-drivers via a CPLD, which converts the PCI bus signals directly into those according to VME standard and vice versa. No VME bus chip-set is used, therefore special software is dispensable by the direct use of memory mapped I/O. Nevertheless this involves some restrictions: no bus-arbiter and no VME bus-interrupt handling are present, but avoiding a device driver makes very fast VME bus cycles possible (approx. 150ns/cycle). The VME bus PC is equipped with an 1.3GHz Celeron M processor with 512MB RAM and a hard disk is connectable via the VME-P2 connector, yielding a price of less than 1500$ per unit, including a hard disk. The ETX board can be easily exchanged by a more recent one if available. Free-BSD, installed on the local disk (30GB), is used as operating system at the moment. The running from a local disk avoids any confusion in error-diagnostics in case of a network failure. All VME-requests are typically handled via direct memory access using the /dev/mem device. The MAMI control system would make it easy alike to run alternatively Windows on these computers, if a driver enabling direct memory access is provided additionally. The new CPUs are in operation since beginning of 2006, first in the existing 3 RTMs, and proved their reliability. Tests verified that the susceptibility to nuclear radiation is not greater than that of their precursors.

Multi Channel Power Supply

For supplying the approx. 400 beam steerers in the HDSM new multi-channel power supplies were built in-house, providing 128 bipolar channels with 6A and 20V maximum each. The devices are not only used for the steerers but also for several quadrupoles and some dipole correction coils. Via a special VME bus module the supply is connected using LVDS standard. Thereby the VME-computer of the control system is able to write down the current-data of the various magnets and to check the actual currents regularly. Four supplies of this type feed the predominant fraction of all smaller magnets. An appropriate control system process enables the setting of each magnet in the usual way in physical units (typically in mrad) by a simple message to the magnets name, and hides any information about the supply, its functioning and the computer node it is connected to.

Serial Interfaces

Several devices (e.g. some power supplies, vacuum pumps) provide a serial RS232 interface for control and data acquisition. These connections are now established with commercially available RS232-Ethernet servers with up to 16 serial ports. Multithreaded processes serve for the handling of the serial ports and the translation from port addresses into message names or vice versa. This solution avoids any compatibility problems among different operating systems concerning the tty-APIs.

Rf-Beam-Monitors

One crucial task while operating the microtrons is the alignment of the recirculated beams on the linac axes. To accomplish this, a high intensity, short (12ns) diagnostic pulse is set on top of the c.w. beam, which induces a signal for each turn in the microtron's rf-cavities located at the beginning and at the end of each linac line. The demodulated signal of such a cavity is a pulse train, yielding information about the turn by turn transverse beam posi-

tion (or its phase and intensity, dependent on the cavity geometry, TM_{110} respectively TM_{010}). These signals are required amongst others by programs to optimise the setting of the steerers in the recirculation paths (respectively to optimise the phases and the energy gain per turn). The previous system to condition and to digitise these pulse trains was not flexible enough to treat the additional signals of the HDSM and had to be replaced. The improved system consists of three units, a programmable signal cross bar switch, a set of digitisers and a programmable signal chopper [6]. The cross bar switch and the chopper were built in-house. The former provides the distribution of the pulse trains of consecutive diagnostic pulses among a variable set of fast digitisers. This enables the parallel digitisation of as many signals as the digitiser-set permits, but also the digitisation of several required signals (with in worst case only one digitiser) sequentially. For digitising commercial 2GS/s ADCs with 256kB memory on board (acqiris/Agilent) are used, which also allow a repeated trigger mode using different memory segments. In order to provide analogue display at the operator console, the pulse trains are additionally chopped in up to 8 signals on up to 4 oscilloscopes. A certain process of the control system manages all these devices. On request it initiates the acquisition of the appropriate pulse trains, uses the intensity train to extract the exact points in time, at which the pulse passes the monitors for each turn, and then calculates the area of the corresponding peaks in the position pulse trains. The areas then are scaled linearly to beam position deviations in mm. Due to the slight beam movement induced by electromagnetic interference, the data have to be averaged over one mains-period (20ms) before they are delivered to the requestor, which is typically the program for automatic beam optimisation. In the present setup 20 measurements are acquired during one mains-period by using 6 digitisers simultaneously. This offers a fairly fast correction of the steerers.

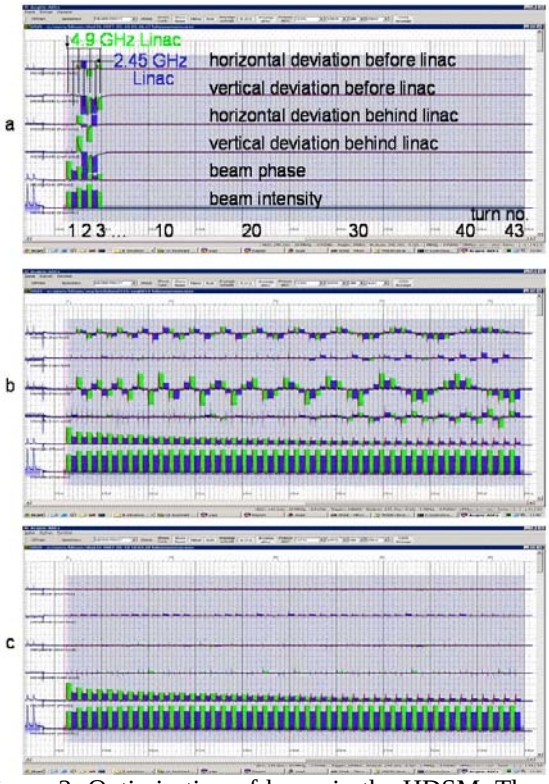

Figure 2: Optimisation of beam in the HDSM. The digitised signals of a diagnostic pulse running through the machine are shown. (a) Only 3 turns are covered. (b) During optimisation all turns get visible, but still deviations are present. (c) Signals of optimised beam.

OPERATOR INTERFACE

The touch screen and the digital rotary knobs used as MAMI operator interface have been already described in [7]. Meanwhile the knobs have been rebuilt mechanically, keeping their physical dimensions, and have been provided with a 48 character LED display (previously 32), enabling the indication of more information about the element in use. Also more push buttons for saving, restoring, toggling etc. are now available. The main operator console is presently provided with one large touch screen, sometimes used by two persons simultaneously, and 12 knobs. The GUI for displaying the machine status and also providing control actions was redesigned and moved from a DEC-Alpha machine (OSF/1) to Windows systems. To maintain the very numerous dynamic drawings (about 500) already created for the hitherto accelerator cascade along with their bindings to the corresponding data in the database, the same commercial software for presentation is used as before (Dataviews/Gipsy). Only drawings and data bindings concerning the HDSM had to be added. This rather easy task was and still is primarily done by student assistants.

SUMMARY

The MAMI control system has been successfully improved and extended to additionally control the 4th accelerator stage, a HDSM. The accelerator now is run in routine operation; only a few weeks were needed for commissioning. This was not at least rendered possible by the very reliable and flexible control system, which has a long history but has been continuously kept up-to-date.

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