Controls in the Past Year of ELETTRA Operation

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After a successful commissioning phase, ELETTRA, the Italian third-generation synchrotron light source facility in Trieste, is operational. The paper describes the experience gained during the past year with the control system of ELETTRA. Emphasis is given to the operational aspects and to the major system upgrades developed to improve the machine performance.

1. INTRODUCTION

ELETTRA smoothly moved from commissioning to regular operation during 1994 [1] [2]. Since the beginning of 1995 the percentage of beam time dedicated to experiments is about 80 %, which corresponds to a total of 3800 hours in the past year. Figure 1 shows the cumulative operating hours for machine studies and user experiments from the beginning of the commissioning in October 1993. The 1995 efficiency of the machine, which is defined as the ratio between the delivered and the scheduled beam time, exceeds 90 %.

Five insertion devices (ten undulator sections, three wiggler sections) are presently installed. Four beamlines are fully operational and open to external users, another five will be completed by July 1996.

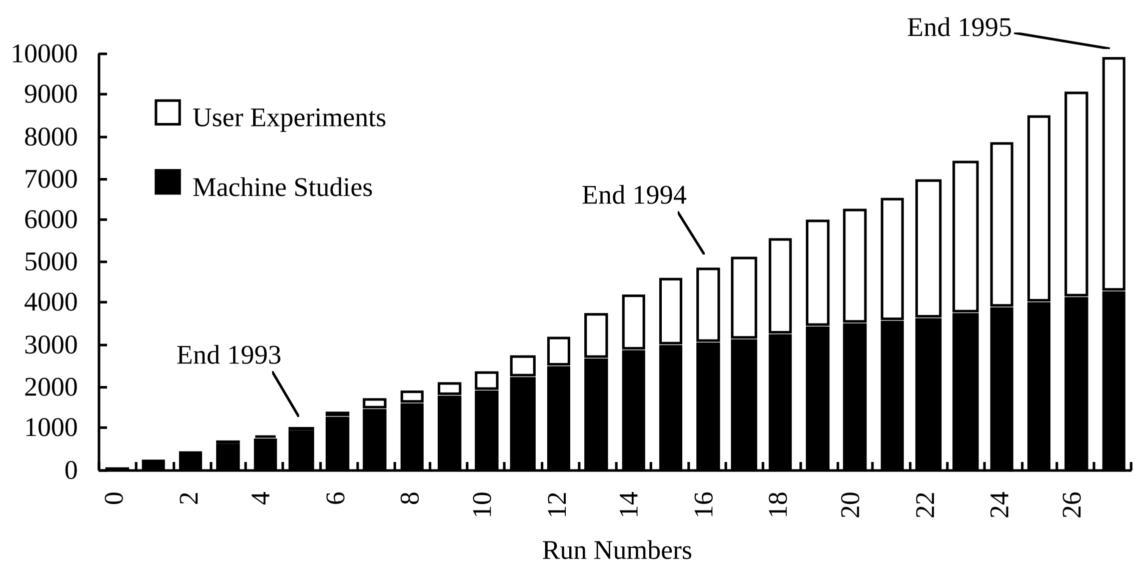

Figure 1. Cumulative operating hours for machine studies and user experiments from the beginning of the ELETTRA commissioning.

2. OPERATIONS

A 1.0 GeV electron beam produced by a linac is transferred via an underground transfer line to the storage ring where the synchrotron light is produced. A ramping mechanism, which will be discussed later, has been installed to provide the higher-energy electron beams which are requested by the users and this allows flexible operation of the facility in a wide energy range.

Two kinds of shift are scheduled. Machine physics studies are performed in the so called "machine shifts" where the ring is operated at different currents, filling patterns, energies and optics. During the "user shifts" the ring is 80% filled with an initial current of 250 mA at an energy of 2.0 GeV and synchrotron light is delivered to the experiments. Injection is performed once a day.

The linac, which was bought as a turn-key machine, is presently controlled by its proprietary control system from a local console whereas the transfer line and the storage ring are fully controlled by the ELETTRA Control System from the storage ring control room.

Preparing for injection during a user shift, the control room operator has first to dump the stored beam, open the gaps in the insertion devices (ID), close the front-end shutters and valves, cycle the storage ring magnets and load the machine file [3]. After filling the ring with to requested current value, he has to execute a ramp to the final energy, close the ID gaps, correct the orbit to zero position and slope at the centre of the IDs and open the front-end shutters and valves to provide light to the users.

As the machine is more and more dedicated to user experiments, a number of control system improvements have been designed and/or installed in order to optimize the operation of the facility during the user shifts. The following sections describe such developments focusing on automatization and speeding up of machine preparation, ID and linac control.

3. IMPROVEMENTS

3.1 Ramping

The ramping process at ELETTRA consists of synchronously setting the currents of the storage ring magnet power supplies (46 main magnet (bending, quadrupole, sextupole) and 164 corrector power supplies) in order to bring the machine to a higher energy state with arbitrary (usually constant) optics. The definition of the path in the optics space and the specification of the DAC setting values (called "steps") are completely decoupled. This allows a free choice of the parameters for the first whereas the power supply hardware characteristics can be dealt with by the latter. The system is based on a general purpose mechanism which uses MIL-1553B broadcast packets for the synchronization of the software processes executed by the different interface computers (Equipment Interface Units, EIU). The measured jitter of the DAC setting times is kept between 10 and 300 µs. The ramping process does not affect the control system operation and is transparent to the control room operator.

The earliest implementation and results of ramping at ELETTRA have been presented in [4] [5]. The system also featured the so called "file ramping" which enabled a smooth transition to any machine file. The first successful energy ramping from 1.1 to 2.0 GeV was performed in January 1994, after only one hour of ramping tests**.** Saturation effects in the combined-function magnets led to variations of the betatron tunes above 1.6 GeV. During simple energy or file ramping the tunes were stabilised with the use of a feedback system.

Electron beam energies from 600 MeV up to 2.31 GeV were easily achieved. The ramping speed was however limited by the tune feedback repetition rate and by the power supplies which were set to follow a linear ramp whose maximum slope was fixed to 1 DAC bit/10 ms step. Ramping from 1.0 to 2.0 GeV during a user shift, including large safety margins, took about 12 minutes.

A further improvement called "multiple-file ramping" which was installed in May 1995 overcomes the limitations above. The ramping is now performed through a set of machine files which are optimized and measured in advance on the machine, taking into account tune shifts, optics and closed-orbit distortion. Such a procedure avoids the use of the tune feedback. The setting of the power supply currents with time is done using a 1 - cos(wt) function which gives zero derivative at the beginning and end of the ramp with the maximum in between, therefore minimizing the total time. The ramping speed is changed by varying the duration of each step from a minimum of 1 ms to the desired maximum value. The minimum time achieved for a 1.0 to 2.0 GeV ramp is 100 s. The typical time during user shifts is about 3.5 minutes.

Multiple-file ramping has also proven to be a flexible tool during machine shifts, allowing synchronized transitions between different machine file**s**.

3.2 Insertion Device Loops

A closed-loop system on each ID compensates for the residual closed orbit distortions during gap closure [6]. The correction system for each undulator consists of a set of correction coils which act in the horizontal plane and is powered by one four-channel power supply. Twelve (four per section) permanent magnet rotating blocks moved by stepping motors are used for the wiggler.

The currents (positions) which minimize the orbit distortion are first measured at different intermediate gap values and a look up table is generated. When the gap is changed the software loop sets the currents (positions) accordingly by interpolating the measured values. A tracking scheme based on a predicting algorithm is implemented for the wiggler. The closed loop takes into account the speed of the motors and the delays caused by the "slow" serial lines which interface the stepping motor and the ID gap controllers to the control system EIU.

3.3 One Button Machine

The progressive knowledge of the behaviour of the machine, together with its increasing operational stability led to the development of application programs that summarize several repetitive and disjointed actions into one single command. A small library of such programs is normally collected at control room level and used by the operators on shift.

The one button machine (1bm) application has been designed taking into account the following issues:

- keep the already developed and well tested programs
- define a logic flow control of the various tasks
- provide extended step-by-step help for each task action
- avoid operator intervention during flow execution
- provide the choice between manual or automatic error recovery in case of task failure
- use a robust Motif interface

The one button machine (1bm) is a simple task-spawner that uses conventional UNIX routines for process execution and communication. Once tasks are identified with letters, 1bm can understand basic Boolean strings such as "AB+Cd" which is interpreted as: "execute the next task if task A and task B were correctly executed, or if task C was executed and task D was in error or was not run at all". At each step, i.e. at each task termination, the control logic is checked: if the condition is true, one or more tasks can start concurrently.

The exit condition is used to validate task termination and to establish a simple error reporting convention. The standard output is redirected towards the spawner for tracking purposes and special characters are used to isolate automatic error recovery strings.

Processes jump over a basic state diagram in which manual intervention may execute, stop, abort or freeze any selected task, without invalidating the control flow dependencies.

If a foreseen task is not implemented, the extended help boxes guide the operator through the necessary steps and wait for a final "Done" acceptance that allows the automatic flow to take control again.

3.4 Linac Control

The linac proprietary control system does not provide the requested level of reliability and the design of a new system based on the ELETTRA Control System has started. Both software and interface hardware have to be replaced. A modular installation is being considered in order to minimize the effect on the facility running schedule. The new system will allow complete control of the linac from the control room workstations where a number of essential analog signals can already be displayed.

As a short term solution, a remote procedure call server has been installed on top of the original linac software. It allows monitoring and control of the main linac parameters from the control room.

3.5 Other Developments

Two different RF signal generators provide the 500 MHz driving signal to the storage ring RF plants and the linac. They can be phase locked or decoupled in order to perform synchronous or asynchronous injection and to independently change the storage ring RF frequency [7]. An automatic procedure searches for the phase value between the linac and the RF plants and optimizes the synchronous injection rate by acting on a phase shifter installed after the RF plant signal generator.

As the storage ring magnets have to be cycled before each injection, the procedure has been speeded up by a new dedicated server at the processing level which uses an S-like function for the setting of the power supply currents with time. The requested time has been reduced from twelve to about three minutes.

A service has been developed to share information and commands between the ELETTRA and the Beamline Control System [8]. It is installed on the ELETTRA general purpose server computer and is accessed by a set of remote procedure calls. The service has a multiprocess architecture with a common data area. For each active client there is a corresponding server process handling the data requests and the data is stored in a memory area shared by all the server processes. Typical information consists of general machine parameters (i.e. beam energy, current and lifetime) and ID and front-end status (i.e. valves, photon shutters and vacuum values). The possibility of sharing commands will allow each beamline user to control the corresponding ID.

General real-time machine status information is available through our World Wide Web server whose URL address is http://waxa.elettra.trieste.it:8080/ELETTRA.html.

4. PERFORMANCES AND REMARKS

The ELETTRA Control System has been comprehensively presented in previous publications and details can be found in [9] [10] [11].

The system architecture and the effective distribution of the control resources at each level provide a very high degree of flexibility which allows easy expansion or addition of new schemes to the original configuration.

Hardware and software modularization is fundamental. System changes and upgrades can be transparently installed to face specific needs using state-of-the-art technology. Taking advantage of the modular multi-master architecture, an upgraded Local Process Computer (LPC) equipped with Motorola 68040 microprocessors has been set up in few hours.

Fibre-optic Ethernet and its associated hardware did not give any trouble. The CERN LEP-NC rpc [12] worked very well on both the UNIX and OS-9 platforms. Measured Ethernet loading during machine working time is below 4% and no bottleneck situation has been experienced in two years of operation.

The MIL-1553B hardware confirmed its robustness and the long branches (about 500 m) covering the whole ring can work at 1 Mbit/s without problems. The installation of the OS-9/NET tools (e.g., remote login and distribution of the file system over the network) on top of the basic MIL-1553B communication software gives the system a powerful debugging environment at the lower layers.

The overall behaviour of the VME hardware, which has been almost completely purchased from the market, is good. The special DAC and ADC boards for the control of the magnet power supplies, which have been subcontracted, present outstanding temperature stability. Some of the serial lines which are used for interfacing intelligent controllers presented difficulties in terms of response time and protocol reliability.

The Man Machine Interface (MMI) provides the operator with an intuitive working environment and machine operation requires no special knowledge of the control system details. About forty non-professional operators alternate on shifts and use the control system. The scalable MMI organization leads to a coherent enhancement of the available tools. Higher level applications merging the functionality of different pieces of equipment are located within the existing logical frame and complement the "old" control panels.

The home-made Control Panel Editor (CPE) and its associated library boosted the production of Motif panels and high level software programs [13]. Non-expert programmers can take advantage of the resultant simple C language skeleton which hides the Motif technicalities. Also, a consistent style is also preserved amongst the different applications.

Developing ORACLE applications can be quite time consuming. The Motif implementation of the FORM is not satisfactory and third-party products are being tested to provide a better graphical user interface to the database. A number of improvements, such as integrity checking of the input data and permission control, are implemented with the last release of ORACLE (version 7).

Interlock Programmable Logic Controllers give reliable hardware and software flexibility, but they do not offer a comfortable program development environment. Both the interlock and the alarm system were subcontracted to external companies. They worked satisfactorily from the beginning of the commissioning but gave some problems with maintenance and the acquisition of the associated know-how took some time.

5. CONCLUSIONS

The ELETTRA Control System has effectively provided all the resources needed for the commissioning and operation of the machine. Its operation is reliable and no limitation in performance has been experienced so far. It can be expanded following the "natural" evolution of ELETTRA and permits major system upgrades, for example ramping to be carried out.

The complete installation of the tools aimed at optimizing the machine preparation during user shifts will reduce the time from beam dump to user readiness from 45 to about 20 minutes.

Beside the design and installation of the linac control system, a series of new projects are foreseen for the future. Among these are: a systematic monitoring and archiving of the machine parameters featuring various statistics on equipment operation; a new alarm server with extended capabilities, used as a pilot project in C++.; the development of Digital Signal Processing techniques for machine feedbacks; and the control of FERMI [14], an infrared Free Electron Laser.

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