The UNK Control System

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Abstract

The IHEP proton Accelerating and Storage Complex (UNK) includes in its first stage a 400 GeV conventional and a 3000 GeV superconducting ring placed in the same underground tunnel of 20.7 km circumference. The beam will be injected into UNK from the existing 70 GeV accelerator U-70. The experimental programme which is planned to start in *1995, will include 3000 GeV fixed target and 400*3000 GeV* colliding beams physics. The size and complexity of the UNK dictate a distributed multiprocesssor architecture of the control system. About 4000 of 8/16 bit controllers, directly attached to the UNK equipment will perform low level control and data acquisition tasks. The equipment controllers will be connected via the MIL-1553 field bus to VME based *32-bit front end computers.* The TCP/IP network will interconnect front end computers in the UNK equipment buildings with UNIX workstations and servers in the Main Control Room. The report presents the general architecture and current status of the UNK control.

1.Introduction

The UNK complex will combine - in one tunnel of 20.7 km circumference - a 400 GeV conventional magnet synchrotron (UNK-I) and a 3000 GeV superconducting synchrotron/storage ring (UNK-II). At a later stage a second superconducting ring (UNK-III) may be added with the aim of *doing proton-proton* collider physics at 6 TeV (Figure 1).

The UNK-I is injected at 70 GeV from the existing proton synchrotron U-70. For one filling up to 12 pulses from U-70 may be stacked, accelerated to 400 GeV and transferred to the UNK-II which in turn accelerates them up to 3 TeV.

Three main modes of operation are presently foreseen.

1. Fixed Target at 3 TeV: fast or slow extraction will send the 3 TeV beam to the fixed target experimental area. During the acceleration in the superconducting ring, U-70 may produce beams for its own 70 GeV experimental area.
2. Colliding Beams at 3 + 0.4 TeV: the beams from the UNK-II and UNK-I are made to collide. For this the UNK-I is operated first as booster and, after field reversal, as a storage ring run at 400 GeV.
3. Colliding Beams at 3 + 3 TeV: the UNK-I will first inject into one superconducting ring and, after field reversal, into the second one.

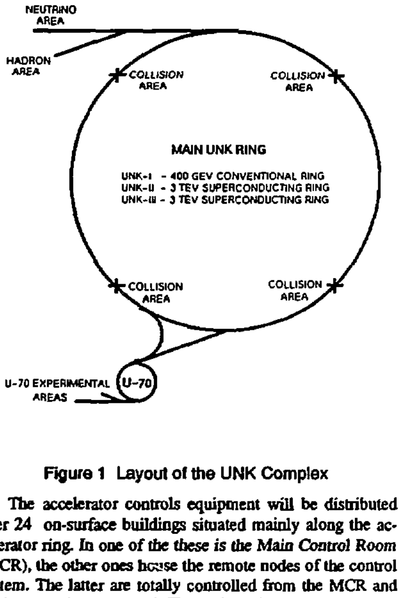

Figure 1 Layout of the UNK Complex

The accelerator controls equipment will be distributed over 24 on-surface buildings situated mainly along the accelerator ring. In one of the these *is the Main Control Room* (MCR), the other ones house the remote nodes of the control system. The latter are totally controlled from the MCR and are in general not manned. The typical distance between any two adjacent buildings is about 1.8 km and the maximum is about 3.5 km.

The more than 3500 superconducting magnets require a cryogenic plant and elaborate distribution, recovery and safety installations and their concomitant controls in the surface buildings around the ring tunnel.

The UNK operation is supported by general electricity and water distribution networks, tunnel ventilation, radiation protection, fire safety and other utilities which require highly reliable controls with 24 h/day 365 d/year availability.

The secondary beamlines and external experimental areas cover an area of roughly 12 km length. Controls for their equipment may follow closely the principles of the accelerator controls.

The upgrade of U-70, for meeting UNK injector specifications, requires intensive machine studies which in turn make a controls upgrade mandatory. Since this must precede UNK, the principles and equipment may differ somewhat from UNK controls proper.

2. HARDWARE ARCHITECTURE

The size and complexity of UNK, together with real time and other requirements, dictate a multilevel multiprocessor controls architecture (see figure 2).

Various components of the accelerator equipment are driven by more than 4000 equipment controllers (EC) which perform low level control and data acquisition tasks in hard real time and provide a uniform equipment representation for the upper levels of the control system.

A typical EC is Euromechanics crate with Multibus I compatible backplane bus, contains a single board microcomputer, a fieldbus interface and a number of equipment specific I/O cards. The standard EC microcomputer is based on microprocessors similar to the Intel 8086/8087. In the UNK-I control system about 800 of such ECs will be used for beam instrumentation, power suplies, RF and vacuum system controls.

Similar technology will be used in the UNK-II and cryogenics complex equipment interface. The main difference is in the EC microcomputer type which in this case is based on the LSI-11 compatible microprocessors (see chapter 4). There will be about 1300 of such ECs in the UNK-II and cryogenics complex controls.

About 1500 of the UNK-I correction magnet power supplies will be controlled by embedded ECs based on the Intel 8051 microcontrollers. The EC is implemented on two standard Eurocards and perfoms all the power supply control functions, including timing and function generation. It has direct interfaces to the MIL-1553 fieldbus, timing and fast alarm systems.

A general timing system distributes reference events and clock trains to all ECs. A separate alarm and interlock network collects signals from all ECs monitoring vital accelerator subsystems. These signals may be used to trigger the beam abort system and inhibit beam injection.

The next higher level of control is represented by the front end computers (FEC) spread around the main UNK ring and beam transfer lines and interconnected with the upper level computers by the UNK controls network. The FECs will drive EC clusters through the 1 Mbit/s MIL-STD-1553 serial multidrop bus, which provides a cheap solution on a standard chip, noise immunity and galvanic insulation. Physically, the FEC is a modular board assembly in a standard VMEbus crate. The basic FEC configuration will consist of a 32-bit processor board, a network interface and a number of MIL-1553 bus controllers. It may also include I/O modules for direct interfacing to equipment needing full network functionality or/and bandwidth to handle high data rates (e.g. for sophisticated beam diagnostic devices).

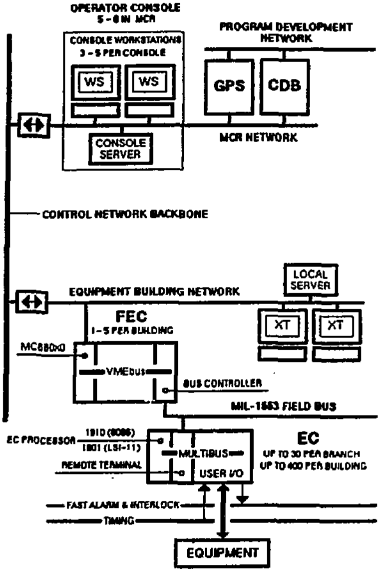

Figure 2 General Hardware Architecture

The FEC's main purpose is providing access for the upper level control software via network to the ECs. It may thus be considered as a gateway linking the MIL-1553 field bus to the UNK controls network and as a specific kind of network server, providing a set of equipment access services for application tasks running in the networked computers.

In addition to this general task, a number of FECs may be dedicated to certain functions through their own set of I/O modules. For example, one presently considers dedicating certain FECs to a task of UNK-II superconducting magnet main power supplies control and quench protection. Finally, a FEC may run some application tasks, in particular for local closed loop control and local equipment access, test and diagnostics. It will also perform ECs downloading and surveillance via the MIL-1553 field bus.

The network will be layered: a so-called backbone will interconnect the buildings and a number of LANs will interconnect equipment at the MCR and inside other buildings. The development infrastructure forms a sub-network which will be attached to the backbone. LANs will mostly be Ethernet. The backbone will be fiber optics FDDI or 16Mb fiber optics Token Ring. The LANs and backbone will be connected by bridges/routers. Most networking hardware will be standard commercial products.

The UNK operator's consoles, 5-8 *in total*, will each be equipped with 3-5 graphics workstations and one server. The latter will provide common services (file, print, plot, etc.) and can also be used to execute certain run-time application software.

There will be a dedicated UNK control system's data base management server CDB and a general purpose server GPS for number crunching, modelling. The latter also caters for general user program development, thus supporting numerous workstations and terminals spread around the buildings.

3. SOFTWARE ARCHITECTURE

Experience in development of accelerator control system software packages world wide shows that certain functionalities are existing in one form or another in the majority of them. The general trend, which we try to follow, is therefore to extract these common parts and provide them as standard facilities which may be used by each *specific application* task. This would allow to eliminate multiple code and improve system reliability and maintainability. The software implementation of those common functionalities may be called the *application environment* (Figure 3).

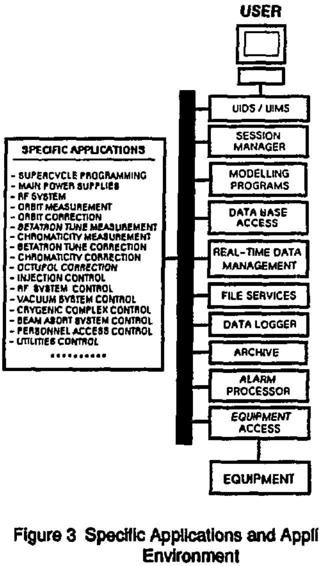

Figure 3 Specific Applications and Application Environment

In contrast with a general purpose application independent system software the application environment is problem (controls) oriented. It is supposed to be relatively stable and only evolve slowly during a control system's life cycle.

Application Software

A first analysis of the UNK control system functionality has been made using the SASD methodology. Thus the main procedures, data flows and data stores were identified. The application software functionality can be represented by the following broad groups of tasks.

1. Process modeling and preparation of data sets which determine the operation of accelerator devices. Advanced modeling programs can simulate a particle behavior for the different modes of operation of the accelerator and in such a way test a validity of the data set prepared.
2. Data down-loading, acquisition and trimming.
3. Routine surveillance of the technological accelerator subsystems (like electricity, vacuum, etc.) Alarm signal generation and processing, fault recovery.
4. Data logging and archiving services which allow to keep working track and history of the accelerator operation.

This analysis, design and data structure development will be pursued using a modern integrated CASE tool package. The latter should also provide project management and documentation support, which are important when numerous programmers of different level must cooperate.

System Software

The application environment is built on the basis of elementary functions provided by the system software. The general UNIX operating environment has been chosen for the UNK control system.

The UNIX (Ultrix) will be used in the operator workstations and servers while a Unix-like real-time sytem will be chosen for FECs. For this part the LynxOS from the Lynx Real-Time Systems Inc. is in the process of evaluation.

The TCP/IP, RPC, NFS packages, now a standard features of most Unix and real-time systems, will be used in the general network.

For the 8086 based ECs, two operating systems are considered now: the MTOS-UX from Industrial Programming Inc. and Intel RMX compatible DOS-86 which is available on the USSR software market. A final choice will be made by the end of this year. The LSI-11 based ECs will use an operating system similar to the DEC RSX-11.

User Interface

The user interface is based on graphical workstations and windowing techniques. Commercially available UIDS/UIMS (User Interface Development/ Management Systems) built on the basis of the X-Windows and OSF/Motif standards are considered now for the user interface creation and management (XFaceMaker, TAE+, Teleuse, VUIT). Such systems allow easy interface design and quick prototyping.

Much recent work in this field is concerned with specific extension of commercial products to a standard set of control tools and screen layouts which would allow to unify human interaction procedures for a wide range of applications. Early specification, prototyping and demonstartion of such a tools would allow to start application software development and meet user's requirements.

DBMS and Real-Time Data Management

Off-line data preparation, including descriptions of machine and control system objects and relations, will be done using the Oracle DBMS and related tools.

One presently considers organizing all data inside of the control system in a specialized home-made real time DBMS. It should contain both static read-only data, derived from Oracle and dynamic data of the current machine state, some number of pre-defined UNK states for pulse-to-pulse modulation (PPM) and accelerator development, etc. This real time DBMS will support access to read/write data for fixed and off-line prepared data structures. It will serve a number of distributed data bases. Each DB is a standard file, containing data in the form of three-dimensional tables, some of which may be duplicated in the memory of specified computers..

Equipment Access

The diversity and multiplicity of process devices, requires some uniformisation, i.e. hiding the device specifics from the operational applications. For doing so, the device specifics shall be encapsulated in software envelopes having a standardized access protocol.

This concept leads naturally to the object-oriented approach to logical equipment representation. An equipment object can model a real, physical unit of the equipment or abstract entity, like a feedback loop or a data buffer.

The applications' vision of equipment is strictly limited to a relatively small number of logical device classes. Each logical device corresponds to a physical component or group of components of the accelerator equipment able to perform a complete task and considered as a single entity in context of the accelerator operation. A device object class can represent, for example, an ion pump with all its attribures (e.g., status, voltage, pressure, etc.) and services, which it provides for an application task (switch on, set voltage, read pressure, etc.). Each particular ion pump in the system will be an instance of the ion pump class.

A logical device is a complex object that encapsulates a collection of cooperating component objects. Each component object class represents a stable partial functionality inside of a logical device (input/output, local data buffering and processing, surveillance, timing, etc.). The set of the component object classes forms a toolkit for logical device construction. The set of component objects constituting a device, with their relationships and dependencies, formally represent logical device model.

A logical device undergoes the following main phases during its "life cycle" in the control system.

1. Device class creation: positioning of the class in device class hierarchy, definition of new logical device attributes and services using the component objects class library.
2. Implementation: integration of standard software modules, corresponding to the library classes, and, possibly, writing of a code reflecting a new device specific features. It should be noted that the same logical device can be implemented in several versions on different hardware platforms.
3. Instantiation: creation of a particular device object which is an instance of the device class. The object identifier, implementation version and equipment network address are specified at this phase.
4. Initialization: downloading of the device software into the specified platform, initial test and device setting in a predifined initial state.

Commercial Control Software Packages

Standardization trends result in the appearance of "generic" integrated commercial controls software packages which can be configured to realize a wide range of functionalities. Examples are V-System from VISTA, G2 from Gensym Corp., GENESIS from Iconics, etc.

For the purpose of thorough evaluation the V-System software will be used as a kernel of a relatively small prototype control system . The system will support commissioning of the U-70 to UNK-I beam transfer line, planned for the middle of 1992. The V-System will run in the VAX/VMS workstation connected via Ethernet to front-end computers (MS-DOS IBM/PC). Each of these front-ends will control a certain number of technological subsystems (including all types of power supplies, beam instrumentation, vacuum and utilities subsystems like electricity, ventilation etc.) by using equipment controllers connected via RS-232 interface. These PCs will be used as local consoles for equipment tests at the begining and thereafter they will work as a "data pumps" to supply data for the V-System data base.

4. CRYOGENICS ASPECTS

The cryogenics and related equipment is a substantial part of the UNK project and falls into three broad groupings.

1. The cryogenics complex that provides cooling of the superconducting magnets placed in the UNK ring tunnel.
2. The quench protection system.
3. The superconducting magnet main power supplies with their ramping and dc programs.

By their nature these systems have a close internal binding and require only a weak coupling with the main UNK control system. A fair degree of autonomy and stand alone capability is therefore foreseen, which is helpful in commissioning and later servicing.

According to the functionality and geographical distribution of the equipment, the cryogenics complex control is subdivided among four relatively independent subsystems.

1. The gaseous helium storage, compression and purification control. The corresponding equipment is located in three compressor station buildings placed around the UNK ring.
2. The helium liquefiers control. There are 6 helium liquefiers located in the central helium liquefier building.
3. The satellite refrigerators and magnet cooling control. There are 24 refrigerators located in 12 buildings regulary distributed around the UNK ring. Each refrigerator supports operation of one superconducting magnet string.
4. The Nitrogen Storage and distribution control.

Local access to the cryogenics equipment will be provided via local consoles in each cryogenics complex equipment building. The local consoles will be used in the equipment commissioning, autonomous tests and troubleshooting. The normal operation will be performed from the Cryogenics complex Control Room (CCR) located in the central helium liquefier building. The CCR will be equiped with the same sort of tools as the UNK MCR and provide 5-7 operator's workplaces.

Cryogenics complex controls will, like the main UNK control system but with some special flavours, use the Multibus-I based ECs with 16 bit processors connected by MIL-STD-1553 to the standard UNK FECs.

A specialized Multibus-I programmable controller module (SPC) has been developed and will be used at the lowest control level in the cryogenic system. The module consists of the general purpose 16-bit Multibus-I processor card and a functional card which is connected to the processor via a private bus. There are few types of the functional cards developed for interfacing to various kinds of transducers and actuators used in the cryogenics equipment. The SPC will autonomously realize closed loop control and relay logic algorithms according to the program stored in its PROM. A Multibus-I crate may house a number of SPCs working in parallel under supervision of the main EC processor. The total number of SPCs in the cryogenics complex control will be more then 2000.

In collaboration with CEA, Saclay, a first version of a FNAL-like quench protection system will be tested on an experimental sector of 8 protection units, each consisting of 12 dipoles and 2 quadrupoles. The front-end electronics and emergency heating power supplies are located in shielded cavities in the ring tunnel.

The main power supply controls will form a closed subsystem, loosely coupled to the main controls and interlocked with the quench protection system.

5. UTILITIES AND SERVICE NETWORK

The UNK complex includes a number of various utilities providing, as a whole, the safe and reliable environment for the main accelerator subsystems and personnel working in the accelerator area. These utilities are the general electricity and water distribution networks, tunnel ventilation and gas analysis system, radiation protection, fire safety and personnel access control to restricted access areas.

The utilities controls shall be supported by relatively slow, but very reliable and uninterruptable control system . A special highly reliable service network will interconnect a number of regional control nodes with central utilities control room. The service network will be linked to the main control network and access to the utilities can be provided also from the MCR consoles.

The market study, evaluation of commercially available components and prototyping have been started. A part of this work is design and implementation of utilities control system for the beam transfer line from U-70 to UNK-I (BTL). The system is based on the standard industrial programmable logic controllers (PLC). The PLCs perform low level control and monitoring functions and are linked via RS-232 lines to the IBM PC compatible console computer in the temporary beam treansfer line control room. The IBM PC collects data from the PLCs, performs data analysis and generates alarm messages and interlock signals in case of faults. It makes also periodic data logging and keeps a log of the system operation.

6. EXTERNAL BEAM LINES

The external beam lines will comprise a 12 km long neutrino channel, leading up to the neutrino experimental area, and three 6 km long hadron beamlines leading to their own experimental area each. The operational patterns of the beamline zones are, by their nature, different from the accelerators. The essential aspect is the more frequent and rapid changes, following the experiment's requirements.

The technology of the equipment used in these beam lines and experimental areas is similar to the one of the accelerators proper, including the use of superconductivity hence cryogenics. A strongly different aspect, however, form the target areas and splitting stations with their radiation problems and remote handling requirements. Some advanced devices such as polarimeters and crystal bending and focusing may be used.

One presently considers a controls architecture which is very close to the one described for the main UNK ring. There will be workstations with the modern windows and graphics oriented software, these will be interconnected with a TCP/IP based network, which in turn connects to the accelerator network, and at the frontend to VME based 32 bit microprocessors driving ECs over the MIL-STD-1553 fieldbus. In contrast with the accelerator system, the ECs of the external beam zones controls may still be CAMAC based.

Powerful number-crunching multiprocessor assemblies will be used for digital signal and image processing in the polarization hodoscopes, electron-gammas tagging system and TV- cameras based beam instrumentation.

Systems software will essentially be the same as for the accelerators. Applications will be strongly data driven and model oriented and an expert system is being contemplated for operator support.

Although routine operation may be done from a central MCR, a strong local access and stand alone component remains essential.

7. U-70 CONTROLS UPGRADE

Contrary to the situation for the accelerator and beam zones controls, for which options were open, the U-70 injector group has a strong historical bias since both booster and U-70 proper are largely computer controlled. Moreover, the upgrade must be done virtually without interruption of the U-70 experimental programme. Finally, the urgency of this upgrade practically dictates using products now readily available in the USSR and using a stepwise implementation, converting small slices during the short planned shutdowns.

The FECs for the U-70 upgrade will be the Multibus I based SM1810.30 computer with an Intel-like 16 bit 8086/8087 processor board, using an RMX compatible real time kernel. They will have appropriate RAM capacities, a LAN interface and a parallel branch highway CAMAC driver. Each of the about 12 FECs, spread over 4 buildings, maximum 4 km apart, drives up to 3 CAMAC crates catering for I/O. Servers for files and data base, 4 to 6 in total, will be enhanced configurations of the FECs, featuring larger memory, hard disk and a more complete generation of the operating system. Interaction will be using PC-AT computers under DOS. A commercial LAN product is still being sought in the USSR.

8. PRESENT STATUS

A conceptual design study of the upper part of the control system has been made and is accepted. Prototype partial integrations of the main control system and front end assemblies, as well as a quench protection test facility, are being prepared and should be available early 1992. An applications development environment with servers and workstations is being prepared. The external beam zones controls are in the conceptual design phase. The U-70 controls upgrade has been largely defined and frozen and implementation has started.

The Multibus-I based ECs have been largely defined, prototypes of most modules exist, industrial contracts are being negotiated. All ECs for the BTL are assembled and tested *and installation in the equipment buildings is in progress*. The V-System applications for the temporary BTL controls are largely prepared and corresponding communications and PC front-end software is under development.

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