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OPERATIONAL PROTOCOLS FOR CONTROLLING ACCELERATOR EQUIPMENT

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ABSTRACT

The equipment used to operate an accelerator is varied. However the different devices may be divided into a limited number of classes for which operational protocols can be defined.

Operational protocols permit :

- i) A uniform operation.
- ii) A clear definition of responsibility between the various specialists.
- iii) Independent development of programs and use of the most appropriate technology.
- iv) The change of hardware and the transportability of software.
- v) The fabrication of devices by industry for general use.

An operational protocol should be independent of any given controls system and it must not be confused with a transmission protocol.

As a first step, one defines an operational model of the device to be controlled. The model must represent a high-level description of the device as seen by the user. It will be characterised by a set of parameters and a set of rules. Although the particular requirements of specialists are not included in the operational protocol, allowances should be made for them.

Emphasis will be placed on studies carried out on power converters and beam instrumentation. A general purpose control message architecture is reported.

1. Introduction

A control methodology for power converters has been in use in the CERN PS control system for the past ten years⁽¹⁾. As a result of the many advantages it provides, new control methodologies -referred to as operational protocols- for instrumentation^(2,3), power converters^(4,5) and vacuum have been proposed at CERN⁽⁶⁾ under the auspices of its Technical Board on Controls and Electronics for Accelerators (TEBOCO). A first proposal for power converters has been produced by specialists from all accelerator divisions at CERN. The operational protocol for instrumentation is being prototyped on a practical case : the PS Booster beam current transformer⁽⁷⁾. Results are reported at this conference⁽⁸⁾. A study for an operational protocol for vacuum equipment is presently under way at CERN.

The need for a more systematic approach to control problems at the device level has been felt lately in many high energy physics laboratories. Under the auspices of the Experimental Physics Control Systems (EPCS) group of the European Physical Society (EPS), a working group involving specialists from 12 European organisations is studying operational protocols for both instrumentation and power converters. The operational protocol for power converter is sufficiently advanced to enter the prototyping phase, but the collaboration for instrumentation has just begun. It is hoped that this international collaboration will soon involve industry too.

The object of this paper is to present the concept and the state of the art of operational protocols⁽⁹⁾ at CERN, together with the many problems that must be solved, from the very first classification to the final version of the documentation for the operational protocols. We will start by recalling our experience with operational protocols and list the advantages they offer to users.

2. Problems to be solved

2.1. Motivation and historical background

Particle accelerators are getting larger and more complex. Thus the number and the variety of controlled devices increase considerably. One needs some standardization procedure to reduce the resources needed for control and interfacing, however any standardization contains conservative features precluding efficient use of fast evolving technologies. A comprehensive control methodology is preferable to a mere standardization.

Ten years ago, at the CERN PS, a control methodology for power converters was set up and hardware and software modules were designed. This procedure presently allows access from the main control room, in an identical way, to more than 1500 power converters. As technology evolved, dumb interfaces were replaced by equipment containing microprocessors. To cope with this situation, only one interface module needed to be redesigned, while the whole control software chain stayed unchanged. New local tools could be implemented more efficiently, but the functionality of the power converters as seen from the main control rooms was preserved. Similar procedures took place at the LEP control system⁽⁵⁾.

2.2. Evolution and definition.

The controls methodology developed for power converters proved to be sufficiently effective to extend the example to other families of devices. The power converter protocol is being reviewed to incorporate all the operational functions that can be dealt with by present technologies.

It should be stressed that the operational protocol is neither a hardware nor a software standard for control systems and intelligent devices, nor is it a support for communication.

We can give the following definition of an operational protocol : "Given a control system and a certain number of intelligent devices interconnected by a communications support, the operational protocol is a set of rules permitting the operation of all devices belonging to the same family in a unique and identical way".

Emphasis is put on "intelligent device", that is the device must contain a local data processing unit and realisation in hardware alone would be impractical. This is true for most modern devices.

At this point, a practical example will clarify the concept of operational protocol. At present a power converter is controlled by a user from two items :

- Its operational state :
For all types of power converters, there are only three states regardless of their internal complexity and power.

- Its reference :

A single parameter is used for current control and a single parameter is used for current acquisition. These parameters may be scalars or functions.

The protocol defines the physical and operational meanings of the three states (state diagram techniques are used), the transitions between the states (state names, possible transitions, transient time, etc), the reset procedure in case of fault, the standardized commands to set the power converter in the desired state (Actuation : [ON, STAND-BY, OFF, RESET]), the status word describing the state the power converter is really in (one standardized byte for operation and one free byte for specialist), the various arguments defining the reference and acquisition parameters of the current (Unit, maximum, minimum, Least Significant Bit values, etc). A high level data structure must be defined for the application programs, as an example a single status bit may be seen as a boolean variable and a current as a 16 bit integer. All these rules must be strictly obeyed when designing the power converter, its interface and the controls. The operational protocol includes all these rules and definitions.

Many physical implementations may be envisaged depending on the control environment, but the operation of the power converter from the control room will be the same. The timing features will be incorporated in the new version of the operational protocol.

2.3. Operational protocols versus transmission protocols.

In presenting operational protocols to various audiences, we noticed frequent confusion with transmission protocols. In data communication text books, it is clearly stated that the Application Layer of the Open Systems Interconnection (OSI) model is concerned with providing a set of network services to the user application programs such as file transfer, message transfer, document transfer, electronic mail, etc. The message is considered to be a scaled envelope and a possible standardisation of its contents is never mentioned.

The International Organization for Standardization (ISO) has recently proposed a standard⁽¹⁰⁾ for Manufacturing Message Specifications (MMS, ISO/DIS 9506) that gives rules and procedures for transferring data and control information from one user to another. The emphasis is more on transfer than on the data itself, with the possible exception of device aspects. In this domain, the MMS has recently defined some features referred to as physical status (operational, partially-operational, inoperable, needs-commissioning) which correspond to most of the aspects defined for power converters (see below).

For the time being, the conclusion must be that the operational protocol and the application layer (level 7 of the OSI model) are two separate entities. In future, the MMS might issue recommendations better adapted to our requirements, but experience teaches us that this type of international agreement takes several years before it is proposed, approved and recommended. One should follow this evolution, but, for the time being, one should proceed with operational protocols as described in this paper.

2.4. Reasons for designing and using operational protocols

2.4.1. Uniform operation

As its definition implies, an operational protocol is meant for the normal operation of a device but provisions must be made for the extra requirements of the device specialists. Seen from the application level, the

control of each member of a family is built from a set of predefined components. Some of these components are optional, e.g. some timing elements may not be used for DC power converters, but other converters must comply fully with the rules when used for kickers or bumpers.

At the level of operational protocols, the devices are considered as independent objects, all operational interactions between them are treated at the application level or by the operator.

For the time being, operational protocols have been envisaged at CERN for power converters, instrumentation and vacuum and some other families may follow. Some features of the operational protocols are common (e.g. device aspect, operational states, reset procedure) so they will be treated in the same fashion for better operational consistency. Experience shows that exploitation and maintenance are made easier by extensive use of operational protocols.

2.4.2. Reduced complexity and ease of expansion

Processes are continuously expanding and their control can only be implemented by the joint action of many teams. This collaboration is made easier by reducing the extrinsic complexity of the devices to be controlled ; this is achieved by hiding unnecessary technical details. The addition of new components to a system will not thus bring new operational difficulties, other than those due to a larger number of members from known families. This will permit smooth expansion without putting too much pressure on the operations staff who may then concentrate on machines rather than on additional control tools.

2.4.3. Clear cut definition of responsibilities.

Control systems lead to lengthy discussions about responsibilities in design, implementation and maintenance. Operational protocols provide a clear cut definition of responsibilities between the control specialists and the

equipment specialists. Human communication becomes clearer and friendlier. Designers can make decisions locally, where required, use most appropriate technologies and focus on their own work without spending too much effort on interfacing and controls.

2.4.4. Interface standardization, transportability and agreed documentation

Operational protocols are not equipment standardizations per se, but they prove to be an invaluable tool for standardizing hardware and software interfaces within a given environment. They represent a top-down approach to interfacing problems. The definition of an operational protocol naturally leads to a single and agreed documentation which drastically limits design errors. They cannot by themselves provide hardware and software transportability, however transportability will be impossible if operational protocols are not applied consistently throughout.

2.4.5. Participation of industry.

The interfacing and controls parts of equipment supplied by industry are often a source of problems. Industry is reluctant to invest in interfacing efforts for low volume productions. Operational protocols permit collaboration and recuperation of initial investments, since future designs will be interfaced following the same principles.

2.5. Price to pay for operational protocols

2.5.1. Coordination effort

A multidisciplinary team of motivated specialists must be involved in the detailed analysis of a family of devices. All peculiarities must be considered and fundamental operational functionalities must be identified. To

cover all the families, a long term commitment is necessary and in particular, coordination is essential during the prototyping phase.

2.5.2. Providing a proposal document

A written proposal document must be provided. The writing of this document is a long and delicate task since it incorporates the definition of norms. After this first study, the principles of the operational protocol must be verified for all types of devices in all families. This requires complete prototyping in a given environment, the results of which will be used to amend the original document.

3. Definition and description of the operational model

3.1. Classification into families

First, devices must be classified into families. Even after this first classification, accelerator devices of the same family are very different from each other in their physical principles and in their realization. This diversity is reflected in the variety of control and acquisition sequences, which may range from a few control words to several hundreds. This clearly produces a problem if one wants to design an operational protocol that must, at the same time, be as general and still as easy to use as possible.

3.2. Creation of an operational model

An operational model for each family must be produced. This non-specific device can be represented as a kind of black box where the internal activities are not specified, but only the input and output information defined. The studies of a few families show that many operational features are common (e.g. operational states, timing). The competence and the experience of the device specialists on one side, and of the operations specialists on the other side, are used to carry out the following two steps :

- a) Identify the control functions according to the operational requirements. While a device may require a large number of control functions, most of them are clearly intended for the device specialists use, operations specialists are generally interested in a smaller number of functions and setting parameters.
- b) Limit the number of control functions that are made available for operational use. This is possible when using intelligent devices ; activities such as calibration, range setting (autoranging), selecting scaling factors etc, should be executed automatically by the device without any external intervention. Examples of this exist at CERN and elsewhere.

3.3. High level description of the device

After a complete definition, the operational model must be described unambiguously by specifying all parameters and procedures to be used by application programs. At this level, parameters must be defined as in highly structured languages (eg PASCAL, C). For example the command which controls the operational state of a power converter is called an actuation : this is a parameter which can take three, or possibly four, different values : ON, OFF, STAND-BY(optional) and RESET. A more general operational state structure, fully compatible with that for the power converters, is being provided for instrumentation and will probably be suitable for vacuum equipment as well.

The exact meaning of the three corresponding operational states must be clearly defined so that it is understood the same way by everyone concerned. When actuation has the value RESET the device will execute an internal procedure leading to well defined results for the user. All numerical control parameters must be defined in dimensions (scalar, vector), type (real, integer, etc), units (volt, Ampere, mm etc), control and acquisition resolution, domain of existence, etc. Names for the various parameters and procedures should be standardized. This high-level data structure is completely independent of the controls system and may span several technology

revolutions. It is used as the source for generating the control protocol message (see below).

3.4. Error reporting

Any physical device is likely to fail. In case of failure, the fault state is reached and the operator must be warned. One compulsory fault indicator is required per device, whilst detailed error reporting depends on the device in question and is left to the initiative of the designer. Operational error handling procedures are beyond the scope of operational protocols.

3.5. Accessing the devices

Each device must be accessible an the applications program by its name. The operational protocols assume the existence of a name but do not specify any particular naming structures of the devices. The correspondence between the name and the actual physical address(es) of the concerned hardware depends on the particular controls system implementation and will be treated accordingly.

3.6. Aspects of a device

Every physical device is accessed via a communications network and its interface, which must function correctly to ensure access. Furthermore the device can be under local control possibly preventing any remote control action. The operational protocols specify these broad aspects to help operation and exploitation ; this feature can be the same for all families.

4. Definition of the control protocol message

4.1. Communication and control protocol

In practice, one must set up a communications means to carry information from the application down to the various devices to be controlled, using the local control system implementation. At present, the degree of sophistication of these

communication systems depends on the working environment. As already mentioned, new data transmission systems may, in the long term, help a lot in the field of communication, but, for the time being, a fixed message structure is proposed. This structure may seem rather conservative but it can be used without drastic modifications in the present CERN control systems and the same message structure can be used for power converters, instrumentation and possibly for vacuum equipment. The control protocol defines the structure of the exchanged message^(8,11).

The commands coming from the application level or from operation are translated into functions to fill the messages. The translation is generally done by a software module ; the functions performed by this module are specified in the model but the actual implementation strongly depends on the controls architecture. In a given control system, a single translation level should be in charge of all devices of the same family.

4.2. The control and acquisition messages

In this early simple form, the messages are composed of a sequence of contiguous bytes. All the information exchanged between the application and the device are coded inside the message in the form of functions, each function occupies one or more bytes in a fixed position and in a fixed order.

Experience with the beam transformer at the PS Booster shows that, **paradoxically**, this standardized and apparently rigid structure does permit flexibility. The dilemma between flexibility and rigidity is found in any standard. However a standard cannot be used unless it has a degree of flexibility which allows it to cover a majority of the cases in question. A good standard makes a judicious compromise between two aspects : it will tend toward the maximum rigidity which is compatible with convenient economic use. Consequently, there is a need for judicious interpretation in the implementation of any standard.

4.3. Control and acquisition message for the device specialists

The contents of the proposed control message have a one to one relationship with the model so they are mainly intended for use for operation. However, the device specialist is given sufficient flexibility to allow tests and verifications. By putting special codes in particular bytes, the specialist has 255 different ways of interpreting the rest of the message. This mode is particularly useful for introducing into the device those settings that are changed rarely or which require the direct expertise of the device specialist.

4.4. Device oriented versus function oriented messages

A device oriented message sends all the control values each time. A function oriented message sends only the requested message and corresponding control values, this is a widespread technique, which presents a lot of flexibility⁽¹²⁾. In our case, within our environment, we chose the device oriented message for the following reasons :

a) Communication time

When using a network for transmitting messages of limited length, most of the time is taken up by the transmission protocol, so there is no noticeable advantage in fragmenting the message : on the contrary, a series of functions (e.g. initialisation) will take less time.

b) Coherence of functions

The functions in the message represent the last valid values. The message is accepted or refused as a whole, so inconsistencies between different functions are strongly reduced.

c) Processing time

When sending functions in separate messages, some activities and checks must be repeated each time. This increases the overall processing time.

d) Standardization in the software

The logic of the program that processes the message can be standardized.

4.5. Evolution of the control protocol message

As long as the model of the device satisfies the needs for operation, the high level description structure seen by the application will remain unchanged. However a moderate evolution of the control protocol message is not only inevitable but also advisable to keep pace with progress in the computer field.

The control protocol message described previously is composed of a sequence of binary bytes where the meaning of each byte is defined by its position in the message ; this is a very crude representation but it has the important advantage of being simple, and for that reason easily accessible to any kind of local processor. Modern control systems often include powerful facilities that greatly ease the life of the users : for example data are organized in structures that can be easily and securely manipulated as "objects" by using suitable procedures. The control protocol message should take advantage of these facilities, where implemented, without losing in generality.

5. Conclusion

Operational protocols represent a top-down approach to control accelerator equipment. They permit control of all the members of a family in a single and identical way. Furthermore, different operational protocols should have as many features as possible in common. This systematic approach is being carried out at CERN for instrumentation, power converters and vacuum devices. A prototype is presently working for instrumentation in a particular environment and it is hoped that all types of power converters will also soon be prototyped. Small industrial companies have shown interest in operational protocols.

The proposed control protocol message can easily be installed in existing control systems, it is simple while providing flexibility for both operations and device specialists. Whilst the model and the high level definition of the operational protocol is likely to remain unchanged for many years, future development in data

communication in controls may be used to implement new, more efficient versions of the control protocol message.

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