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INNOVATIVE ASPECTS OF THE CONTROLS FOR THE HELIUM CRYOPLANTS IN THE CERN SPS ACCELERATOR

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Abstract

For the cooling of superconducting accelerating cavities in the CERN SPS, two identical helium refrigerators of 400 watt at 4.5 K have been required. The first one has been in operation since 1992 and the second one was commissioned at the beginning of 1994. Both refrigerators are equipped with an industrial process control system which allows fully automatic remote operation of the entire cryoplant from ambient to liquid helium temperatures. This achievement was obtained by combining the suppliers knowledge of the refrigerators and the CERN operational experience with the capability of a modern control system. The logic of the cryoplant and its integration in the state of the art software concept, based on an object-oriented approach, are presented.

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INTRODUCTION

The demand of cryogenics for the superconducting (SC) cavities in the SPS has progressively increased from 1988 until now [1]. Initial tests were carried out with a 120 watt (at 4.5 K) refrigerator and the following upgrading of the SC accelerating system required the installation of two additional 400 watt (at 4.5 K) refrigerators, respectively in 1992 and 1994. All the plants were supplied by Linde (Sulzer) U.K.

Both the 400 watt plants are remotely controlled, at about 2 km distance, via an ABB process control system (CERN standard [2, 3] for most of the cryoplants). To speed-up commissioning, the preliminary operation of the first 400 watt plant was actually done using a Satt system programmed by the supplier. Afterwards, this control was replaced by an ABB system to allow its integration into a centralised cryogenic control room. The second plant was commissioned directly by means of an ABB system. The Satt system, well suited for a local operation by a dedicated team, is controlling a third identical 400 watt plant providing liquid helium for the CERN cryogenic laboratory.

The conversion from Satt to ABB was supervised by CERN and resulted from the collaboration between Linde U.K., CERN (cryogenics and controls) and ABB experts in object-oriented programming. The logic of the refrigerator is largely inspired by the original one defined by the supplier and was modified according to the specific operational needs of the SPS superconducting cavities. The conversion was carried out with only minor modification of the electrical hardware of the cryoplants. The main challenge was to achieve a high degree of automation of the entire cryoplant (refrigerator and the superconducting cavities) to allow, on one hand, a reduction of the operator(s) assistance and on the other hand, a remote control by a team without a specific knowledge of the plants.

OPERATION LOGIC FOR THE CRYOPLANTS

Each 400 watt refrigerator (fig. 1) consists of a single stage oil lubricated screw compressor and a cold box based on a Claude thermodynamic cycle with two turbines in series and two J-T valves. A 30 meter long transfer line (shielded with helium at 50 to 70 K) supplies the saturated liquid at 4.5 K to two SC cavities assembled in the same cryostat. The distribution of the liquid takes place inside the common vacuum vessel via a bottom pipe filling in parallel the separated helium baths (2×180 litres).

These basic constituents of each cryoplant are represented in the software structure as separated entities which can be started and operated through a predefined automatic sequence of steps (fig. 2). To proceed from one step to the next one, some physical conditions have to be met, indicating that one or several components have reached a steady-state operation (e.g. compressor pressure high enough, turbines speeds above certain values, etc.). The operator can choose whether all or only part of the sequence has to be carried out.

Hereafter are presented the main aspects of the logic defining the general principles for the operation of the different components.

Compressor

If all the external supplies are available (electrical power, cooling water, compressed air and helium gas) and if the cold box and the SC cavities are in a predefined stop configuration (valves position, etc.), the compressor (CP) can be powered. The CP is the only component of the refrigerator having a built-in start-up unit as well as its own internal safety interlocks. Both are hardware controlled. The ABB system supervises the CP and can start/stop it according to the operational requirements of the cryoplant.

Cold box

If the CP is in a steady state condition, i.e. motor powered and pressure high enough, the cold box (CB) can be started by operating first the vacuum system (if not already running) and then the turbines. During the acceleration of the turbines, the inlet valve is opened slowly (with a 20 minute ramp) to its maximum. When the inlet pressure of the first turbine is high enough, the brake valves drive the turbines to their nominal speed (at start-up, these valves are in their maximum brake position). During the following cool-down, the CB by-pass valve is opened until the temperature of the J-T heat exchanger becomes low enough to allow subsequent liquefaction through the last J-T valve. The second important duty of the last J-T is to control the outlet temperature of the second turbine thus providing continuous balance between the turbines and J-T flows. The first J-T valve regulates the operating pressure of the J-T heat exchanger to improve its thermodynamic efficiency. The liquid level and the pressure in the phase separator are controlled respectively by a heater and by the flash valve. All these parameters are regulated via PID loops (4 in total) except the turbines speeds which have a digital control.

Transfer line thermal shield

Once the turbines are running in steady state (i.e. turbines speeds and inlet pressure above certain values) the cool-down of the thermal shield can be started. The inlet and outlet valves are opened fully, while a third valve maintaining a suitable pressure drop forcing the flow in the shield is set to a pre-selected position before the start-up of the turbines.

Cavities

As soon as liquid is present in the phase separator and when the other components (compressor, turbines, etc.) are running in steady-state, the cavities cooling can be initiated by opening, via a ramp, the liquid supply valve. During the cool-down, the gas is returned directly to the compressor suction side via a warm return valve, thus by-passing the CB heat exchangers. The plant is then operated as a liquefier until the outlet gas temperature of the cavities allows to return the flow through the CB heat exchangers (refrigeration mode). In this operating mode, the filling of the cavities is initiated. The liquid level in both baths is kept constant by two identical heaters driven in parallel by one of the two level signals. The second level is actually self-regulated with reference to the first one via the hydrostatic pressure difference between the two baths. The operating pressure of the cavities is established by the CP suction and the pressure drop in the CB heat exchangers.

Operational options

In addition to the above normal operating sequences, the following options were implemented.

An automatic restart of the cryoplant after interruption of one of the following supplies: CP power, compressed air or cooling water. This restart can be performed whatever the running conditions are (i.e. from ambient to liquid helium temperatures and with the SC cavities fully or partially filled).

A warm-up option for the cavities and for the refrigerator. In the first case, a heater inside the cavities is used while, in the second case, the cold box warm-up is carried out by opening the J-T and the CB by-pass valves and forcing helium at room temperature through the heat exchangers. The warm-up procedures are stopped when the cavities or the cold box have reached ambient temperature.

Finally, a cryoplant controlled stop permits a slow deceleration of the turbines by closing, via a ramp, the inlet valve, followed by the stop of the cavities (liquid supply and warm return valves respectively closed and open) and of the compressor.

OBJECT-ORIENTED APPROACH

During the development and engineering of industrial automation projects, there are two main issues that have to be mastered. The first one is the mapping problem or how to represent the real world (valves, pumps, turbines, etc.) in the abstract terms of the programming language. The second issue is to obtain software reusability and maintainability since software changes or extensions appear quite often in every automation project. Object-oriented approach (OOA) is a programming methodology [4] which makes the solution of these problems easier by structuring the software to more closely represent the real world and by offering more flexibility to design software changes.

Each object can be thought of as a real or conceptual entity with its own unique attributes, capabilities and functionalities. In object-oriented programming, all data and functions are packed together to create the object (encapsulation) and are not split as in the function-oriented approach. With the encapsulation, there is no mechanism for the outside world to know and to modify the internal structure of the object for which only its attributes (inputs, outputs, parameters) are known.

The objects are grouped in different classes and the classes are organised in a hierarchy such that each sub-class inherits all the instance (local) variables and methods (commands) of its super-class.

Finally, OOA shows polymorphism since different object classes can respond in different ways to precisely the same method.

Application of OOA to the logic

The software was structured according to these basic concepts in four levels (I, IIa, IIb and III). Control level I is the highest one and control level III is the lowest. Higher level objects link a group of lower level objects to obtain a certain degree of automation. Lower level objects are always the slaves and primitives of higher level ones. Objects at the same control level do not communicate each other.

Figure 3 shows the pyramidal structure of the software. Level III objects (the bottom of the pyramid) are simple physical entities like valves, vacuum pumps, heaters, etc. They do not need any operational logic since they can function on their own. The control level II contains most of the logic of the cryoplant and was actually divided into two

sub-levels. Level IIb links objects of level III to constitute sub components of the cryoplant (the turbines circuit, the J-T circuit and the vacuum system), while in level IIa are represented the main components (the SC cavities, the cold box, the compressor and the thermal shield). Finally, level I (the top of the pyramid) supervises and operates the entire cryoplant through a fully automatic sequence and allows the execution of the possible running options.

Whereas the definition of level III objects was fairly easy because they are simple entities with no logic, their grouping into higher level objects, by means of the operating logic, was a more difficult task requiring experience in OOA.

CONTROL SET-UP AND COMMUNICATION NETWORKS

For redundancy and maximum operational flexibility, each cryoplant was equipped with an independent local control system (fig. 4). Only the centralised remote control unit is common.

Each cryoplant has one process station (MasterPiece 200) connected to its visual display unit (MasterView 830) via a local network (MasterBus 300) using an Ethernet protocol. For the remote operation from the central cryogenic control room, a long distance communication bus (MasterBus 300E) is used to link in parallel each process station (MasterPiece 200) to an identical central visual display unit (MasterView 830). Long distance communication is carried-out via the general TDM data transmission system used for the accelerator. An interface (Hewlett-Packard bridge) is necessary to translate the signals coming from the MasterBus 300E into a V35 protocol used by the modem for transmission through the TDM system. The remote display unit is equipped with a symmetric interface.

The system is conceived in such a way that the failure of any of the above components, except the MasterPiece itself, does not affect the automatic operation of the cryoplants but only interrupts the local or remote display visualisation.

CONCLUSIONS

The application of object-oriented approach to the control software of the cryoplants and the programming by experts belonging to an external company gave good results.

Our main challenge was a high automation degree. The use of OOA made possible this achievement, at the same time satisfying the conflicting requirement of flexibility indispensable during the commissioning of the cryoplants.

Because of the good software modularity, parallel programming of each object on the different control levels was carried out independently and without knowing the specifications of the other objects. Unavoidable functional changes were implemented without modifying the software structure. Since OOA provides also a good software comprehensibility (more readable), the programming errors were minimised and bugs were easily found in the first runs. Finally, the more structured program and the creation of a base library with standard objects (software reusability) allowed, on one hand, a project planning in different steps with increasing levels of automation and on

the other hand, an easier and faster achievement of the milestones and deadlines of the project (better software productivity).

However, drawbacks of this programming philosophy were an increase of CPU load, memory needs and documentation generated by the standardisation. The strict and standardised procedures also asked for a more disciplined approach, requiring additional education and experience of programmers.

A considerable difficulty was the necessity of constant supervision by CERN to guarantee that information provided by the refrigerator supplier was adequate and understandable to the software programmers not familiar with the specific needs of cryogenic plants. We believe that most of the difficulties encountered would have been more easily overcome if a better formation of the cryogenic experts in object-oriented programming and of the software experts in cryogenics had been made possible before the start of the project. Moreover, the programming by external experts necessitates a very disciplined approach with accurate planning and a good knowledge of the cryoplants, since important changes cannot be done too frequently.

Subcontracting the software to the same external experts improved standardisation all over the CERN cryoplants [2]. We also benefited from their knowledge in programming a considerable variety of process control systems and together gained experience in modern object-oriented programming.

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Fig.1 : General synoptic of the cryoplant

Fig.2 : Sequence of operation of the components

Fig.3 : Object-oriented software structure

Fig.4 : General set-up of the control system and communication networks