A Proposal to Move from the LEP Topological to an LHC Functional Control System Architecture

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Abstract

Our knowledge of the fundamental particles of matter is governed by the available particle energy in accelerators. In order to address this issue, and physicists have been designing ever larger accelerators and colliders for the last forty years engineers. This has led to increasing complexity of both the components and the control signals that have to be relayed to and from an operations centre. Whereas simple cabling was more than sufficient for the early accelerators, distributed control systems are now essential for large accelerators. At CERN, such developments were pioneered by distributing computers around the SPS accelerator, which were then interconnected through proprietary communication links. Networking with an emerging Token Ring was a major breakthrough for the LEP collider. While the evolution of accelerator control systems has matched the progress of technology, industry has, for its part, developed very attractive generic solutions to meet the needs of manufacturers for automation, control and supervision. The clear advantages of industrial control solutions in today's economic climate lead us to consider their integration into modern accelerator systems. Following an analysis of the actual LEP control system, an evolution of its architecture is proposed for the control of the LHC.

INTRODUCTION

During the 1960’s, the ever increasing need for data processing was an incentive for the development of computer technology. Experimental physics is certainly one of the most demanding applications in this respect. Concurrently, the ever increasing need for energy in the collision of particles leads to the development of ever larger accelerators. Accelerator control requires communication with the equipment from an operations centre, in the same way that musicians in an orchestra need their conductor. The economic necessity of reducing the numbers and the sizes of the cables to reasonable dimensions led to today’s distributed computer control architecture. Our pioneering activity in this domain sheltered us from the outside evolution, steered by industrial needs. The benefit we can expect from using industrial controls certainly requires adaptation of our control architecture for optimal integration. Since 1990, CERN has taken an increasing interest in industrial controls for many applications, which leads us to believe that they will be extensively used in LHC.

THE EVOLUTION OF THE MACHINES

Created in February 1952, CERN started operating its first proton and nuclear accelerator, a Synchro-Cyclotron of 600 MeV, in 1957. The machine, essentially a magnet, was 5 m in diameter. At the end of the 1950’s the PS, a circular proton accelerator of 26 GeV for which CERN was built, delivered its first beam. The PS circumference is ~630 m. Then the ISR was constructed in 1971, the world’s first proton collider, of 63 GeV and 940 m in circumference. Next came the SPS, a 450 GeV proton synchrotron accelerator, launched in 1976, 7,000 m in circumference and, finally, in 1989 LEP, a 110 GeV electron-positron collider, 27,000 m.

Control of the equipment inevitably relies on cables for the transmission of electrical signals.As the machines were small enough, laying cables from the equipment to a central control room for the SC and the PS was not a problem. The construction of the ISR and the upgrading of the PS at the end of the 1960’s provided the opportunity to introduce the emerging computer control technology within a centralized computer architecture. The size of the SPS called for pioneering distributed computer control architecture, in order to keep the computers near the equipment. The result was a system based on Norsk Data ND100 computers, connected in a TITN star configuration [1]. The LEP, the world’s largest collider, also depends upon a distributed computer control architecture, but the computers are connected to a Token Ring running around the accelerator [2] (Figure 1).

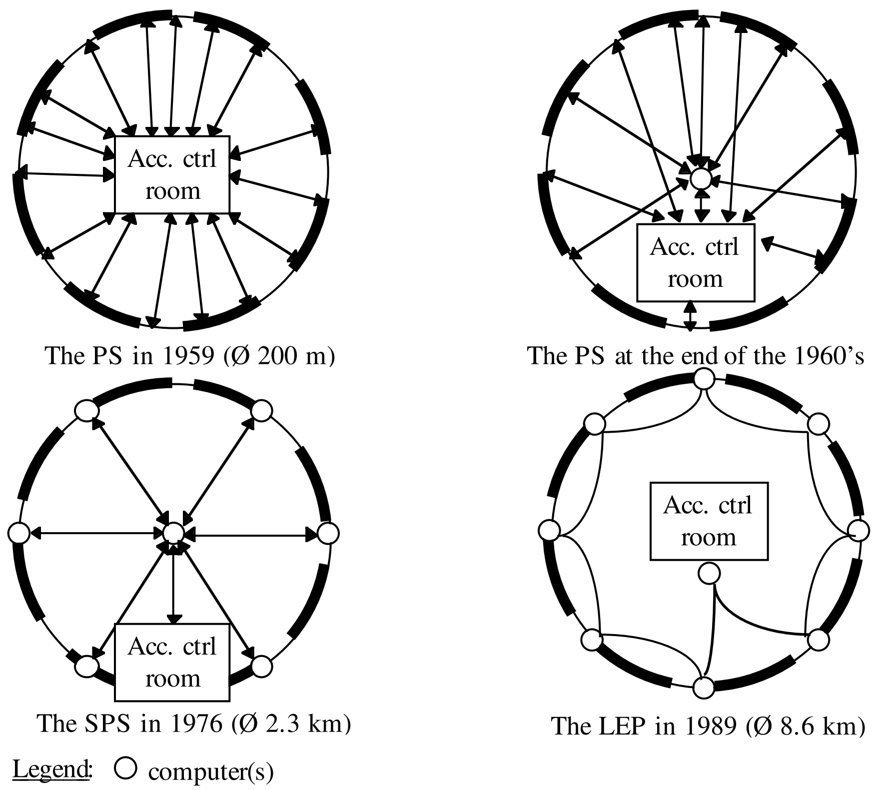

Figure 1. Evolution of accelerator basic control architecture.

THE EVOLUTION OF INDUSTRIAL CONTROLS

The industrial products

Industrial controls really took off with the advent of Programmable Logic Controllers. PLCs appeared in the United States around the year 1969 in response to the automotive industry which wanted to develop automated production lines that were able to follow the evolution of the models [3]. This led to the development of products from two of the largest manufacturers, Modicon and Allen-Bradley. Europe came in two years later with products from Merlin-Gerin and Alspa. The first aim was to replace the cabled solutions which were very rigid and costly. The first specifications for the PLCs included operation in a harsh industrial environment, simple implementation and low cost.

PLCs are designed to work in a harsh environment caused by three main types of aggression:
- physical and mechanical: vibrations, shock, humidity, temperature, etc.
- chemical: corrosive gas (chlorine, hydrogen sulphide, sulphur oxide, etc.), metallic dust, etc.
- electrical: electromagnetic and electrostatic interference, etc.

PLCs are designed to provide a simple tool for the user.
- The design of an application is made easy by the presence of a programming console, which is matched to the mind and the needs of the process technician. Attaching the software to the hardware is a simple task of filling in parameters. The modularity of the hardware and the flexibility of the software allows for easy reconfiguration.
- The operation and supervision are provided through specific consoles. These consoles are easily configurable through application enabling programs, without programming, to perform a wide variety of functions:
- PLCs can provide
    - graphics screen editing
    - alarm monitoring and logging
    - control
    - data acquisition
    - report generation
    - real-time and historical trending
    - data analysis

- help for maintenance
- etc.
- Large installations are controlled by Distributed Control Systems which, in addition, offer:
  - access to multiple clusters of PLCs through LANs or peer to peer communication links
  - distributed applications running on different platforms

The industrial users

It is difficult today to find an industrial sector that does not use automation. The following industries account for two thirds of the market: motor, metallurgy, textile-wood-paper, chemicals-petroleum and energy. The last third is split between mechanics, machine-tools, agro-food and the tertiary sector. [4]

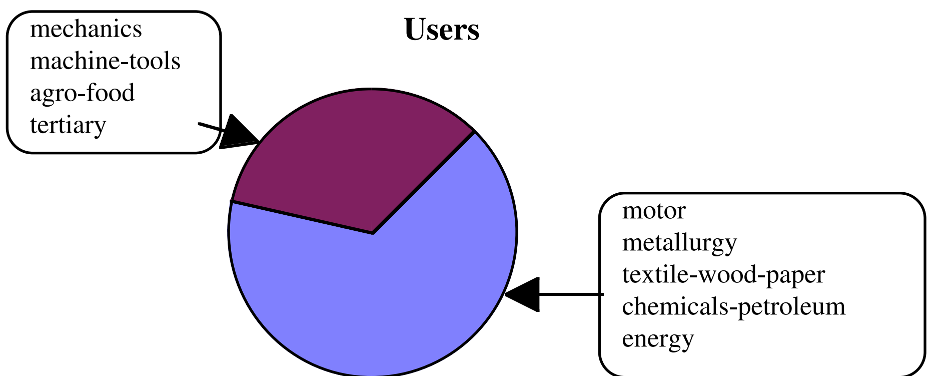

Figure 2

The manufacturers

The world-wide market for PLCs was estimated at $2.5 billion in 1987 and is approximately $5.5 billion today. The growth rate for revenue is around 10% per year, with Europe and the United States being the largest PLC markets. According to Siemens [5] in 1992, as well as stated in Control Engineering [6] in 1995, Siemens and Allen-Bradley were manufacturers number one and two for sales . Mitsubishi ceded its position in third place to Schneider, mainly because of company regrouping. The market for Distributed Control Systems is still led by their inventor, Honeywell (1975), followed by ABB, Yokogawa, Bailey and Siemens.

The world market shares for PLCs and DCSs are illustrated below.

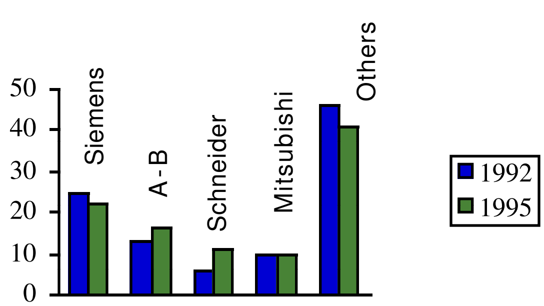

Figure 3. - **World PLC market share**

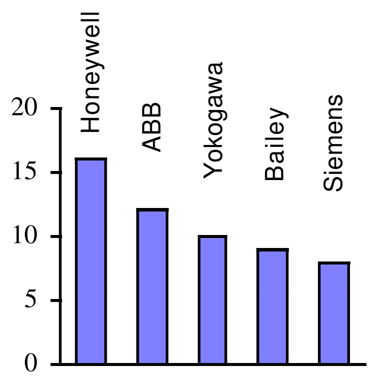

Figure 4. - **World DCS market share**

CONTROL NEEDS OF AN ACCELERATOR

An accelerator is made up of equipment that can be classified into two categories:

- the <u>utilities</u> which are characterized by their capacity to supply a product or provide a service. In this category, we find
    - the production and distribution of:
        - water: raw, drinking, cooled, chilled, heated, demineralized, waste, etc.
        - electricity: high voltage, medium voltage, low voltage, security network, no-break supply, 48V security network, etc.
        - air: ventilated, compressed, conditioned, heated, exhausted, etc.
        - gas: nitrogen, helium and gas mixtures for detectors, etc.
        - cooled helium: liquid, fluid, superfluid, etc.
        - etc.

    The evolution of the physical processes which are involved is slow in comparison to the particle production process of the accelerator. These utilities have a very simple interface with the equipment of the accelerator. Their process is of the continuous type. It consists of maintaining a few specific physical parameters within limits that have been specified with the objective of not affecting the particle production in the accelerator. These parameters are, for example, temperature, pressure, voltage, etc. Industrial actuators and sensors are their control elements.

    - and the services for:
        - access control
        - fire detection
        - radioprotection
        - etc.

    These are made of sequential processes which do not contribute to the particle production in the accelerator. They are slow processes. Industrial actuators and sensors are their control elements.

- the <u>production equipment</u> which is characterized by direct involvement in the particle production. In this category, we find
    - the electromagnetic equipment and their power supply: dipoles, quadrupoles, sextupoles, kickers, etc.
    - the electric equipment: radiofrequency cavities
    - the electrostatic equipment: deflectors, separators, etc.
    - the beam instrumentation: electrostatic pick-up's, beam scanners, intensity monitors, etc.
    - etc.

    The particle production process involves a perfect synchronization between the thousands of pieces of equipment spread along the accelerator. The current of the power supplies and the electric field in the radiofrequency cavities are tightly coupled. The physical phenomena which govern the production of particles are fast. Electromagnetic, electric and electrostatic equipment are the actuators and beam monitors are the sensors. They are not industrial. Industrial actuators and sensors are not their control elements.

THE LEP CONTROL SYSTEM

As illustrated in figure 1, the LEP control system is a distributed computer control system. The circumference of LEP has been split into eight equal sectors, in order, for one thing, to have reasonable distances to supply the equipment with what it needs in order to perform its functions. The control system fits closely with this structure and acts like a funnel for data coming from, and commands going to, the equipment.

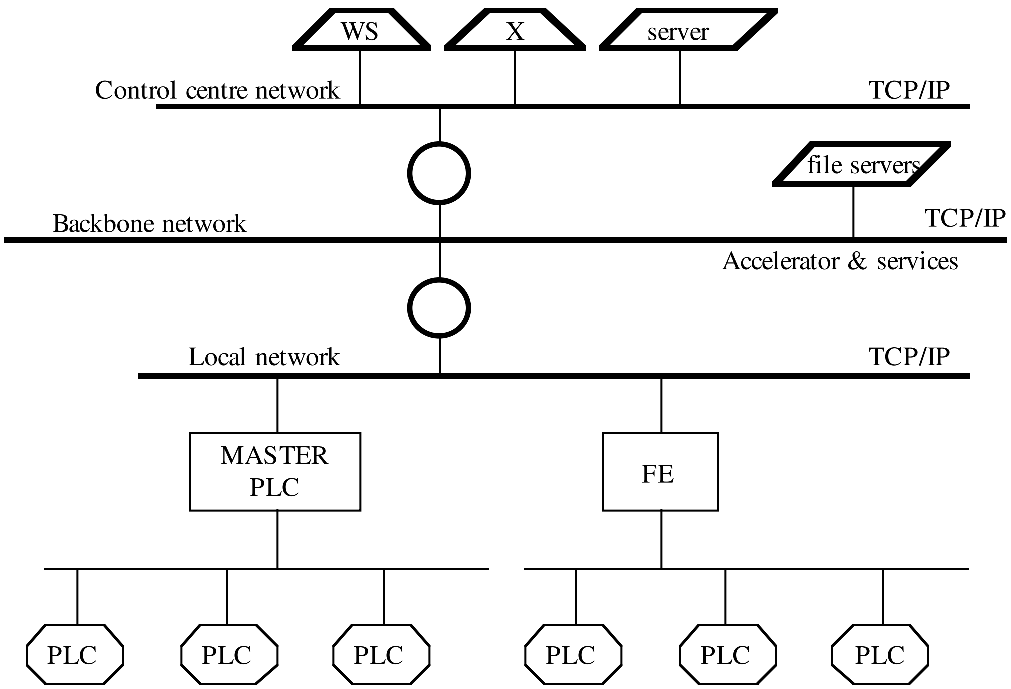

Figure 5. Integrating PLCs today in the LEP Control system

Figure 5 shows the possibilities today of integrating PLCs in the LEP control system. It must be recalled that the particle production equipment described above is not considered here.

The Front End computer [7] [8] or controller imposes a very rigid frame structure which makes the original structure of the equipment control layer completely disappear. A direct consequence is the difficulty of integrating an industrial Distributed Control System which the manufacturer has designed to give a central global view of the equipment. It is much easier to use PLCs at a lower level, that is at network level. However, integrating Master PLCs into the network and reconstructing the supervisory functions at the level of the accelerator control room can only be done at the expense of considerable effort. In addition, this structure has the serious drawback of dividing into two parts the responsibility of the people in charge of the equipment. This is due to the topological structure.

The pressure to use industrial controls could be satisfied by the possibility of a more global integration. Splitting the equipment into functional domains (centres) would immediately remove the inconvenience of breaking the split of responsibility and allow for much better integration of industrially available control solutions. Moreover, this structure fits much better with the requirements concerning the flux of exchanged data or commands for the types of equipment concerned. The specific Centre may apply a constructive filtering to the whole flux of data coming from the equipment to the benefit of the accelerator operation. Figure 6 shows the resulting functional arrangement.

The organization to functional elements is something which, interestingly, can be adapted to the human resources structure. The Water Centre, in order to fit with distributed responsibilities, may itself subdivide in more specialized Centres like Waste Water Centre, Chilled Water Centre, Raw Water Centre, etc., as there is no intrisic reason to restrict the water processes to a single Centre.

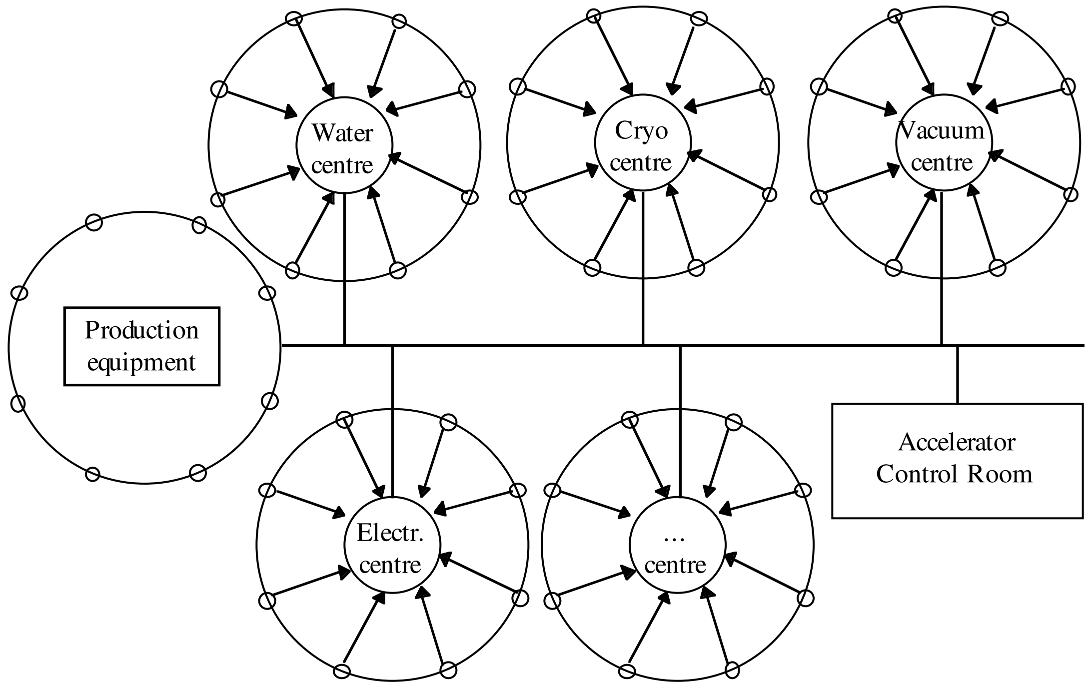

Figure 6. The functional approach

CONCLUSION

The vital necessity for our research laboratories[9] to make as much use as possible of industry leads us to adapt our concepts to the industrial world. The industrial world is naturally organized into specific domains which match the specialization of the individuals from whom expertise is expected. Tendering for equipment on the basis of functional specifications will result in industrial offers from which we can only expect the maximum benefit if we do not impose restrictions on the overall system. This naturally leads to a functional architecture.

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