THE HERA QUENCH PROTECTION SYSTEM - A STATUS REPORT

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Abstract

The quench protection system of the HERA proton ring has worked routinely since 1992. It protects a chain of 424 superconducting dipole and 224 quadrupole magnets in case of a quench. The operating experience since 1992 is reported. A general description of the system emphasizing the recent upgrade is given.

1 INTRODUCTION

The HERA proton ring consists of a chain of 424 main dipole and 224 main quadrupole magnets connected in series and powered by one common power supply. The maximum magnet current during routine operation is 5025 A corresponding to a proton beam energy of 820 GeV. The quench protection system protects the magnets in case of a quench and is indispensable to avoid damage of magnets. The system has worked routinely since spring 1992 and is the primary safety system of HERA. Its complexity requires a high degree of reliability of all components involved. Any problem of the quench protection system prevents HERA from running and influences negatively the operating efficiency of the storage ring.

The main items of the quench protection system are

- quench detection by bridge circuits across single magnets as well as groups of magnets,
- cold diodes to by-pass a quenched magnet,
- heating of quenched magnets to avoid local hot spots and
- dump resistors distributed around the ring to absorb the energy stored in the magnets.

A description of the quench protection system and the initial operating experience was already presented elsewhere [1]. The present paper deals with the operating experience since 1992 and reports the recent upgrade of the system.

Although failures of the quench protection system contributed very little to the unscheduled machine-off time of HERA an upgrade was performed in two steps during the winter shutdowns 94/95 and 95/96. This was motivated by the following reasons:

- loss of the second safety layer due to performance deficits of the micro controllers involved if a large number of magnets simultaneously quench and
- conceptual deficiencies like poor modularity, use of non-standard electronics and bad accessibility and service possibility.

The general guideline for the upgrade was to use as much as possible state-of-the-art industrial standards and components which are commercially available and supported.

2 COLD DIODES

At HERA, all magnets can absorb their own magnet energy but would be destroyed by the energy stored in the total ring. Therefore, by-pass diodes carry the current during a quench of a magnet [2]. The current starts flowing through the corresponding diode if the resistive voltage exceeds about 2.7 V. The voltage drops rapidly to about 1.5 V by heating of the silicon. To date, no degradation effects of the diodes's behaviour could be observed.

Only a couple of diodes installed in the magnets had to be replaced. Three diodes were damaged during HV isolation tests exposed to a too-high reverse voltage transient. Another diode was destroyed by overvoltage during a severe malfunction of the quench protection system following a main power fault. Utilizing consequently the redundancy features of the quench protection system the insensitivity to power faults could be increased to a reasonable level.

In order to enlarge the very limited number of spare diodes a collaboration with IHEP in Protvino/Russia was established. About 200 dipole-type and 100 quadrupole-type diode packages will be produced and pre-tested to be ready for installation in HERA.

3 LOCAL QUENCH DETECTION

The HERA quench detection system is subdivided in eight autonomous parts representing the eight octants of HERA. The quench detection of each octant is realized in two separate safety layers, (1) each magnet is controlled by an adjusted bridge ("single-magnet detection") and (2) a group of 3-4 magnets is supervised by a common circuit ("group detection").

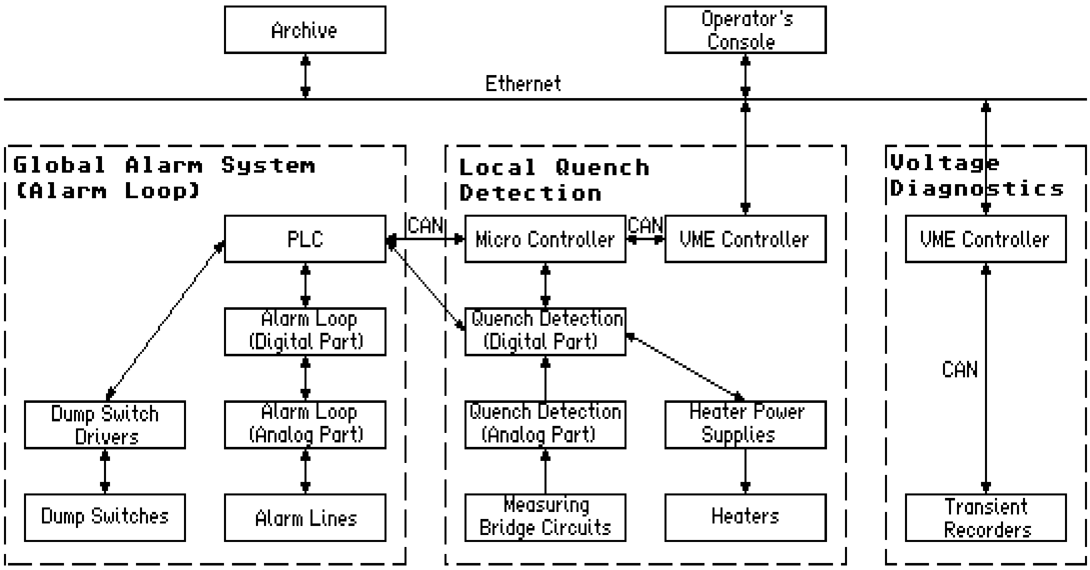

Figure 1: Schematic sketch of the HERA quench protection system

The first safety layer relys completely on hardware components. The second layer involves digital systems like micro controllers. It turned out that the performance of the four micro controllers installed and the SCSI-bus connection between those was too limited to handle a large number of simultaneous quenches. As a consequence, the controllers were replaced by a system of faster programmable field bus controllers and a powerful contoller housed in a VME crate communicating via the CAN field bus protocol. A schematic sketch of the system is shown in Fig. 1.

The programmable field bus controller (IX1 from DELTA t) consists of a 12-bit 16 MIPS processor, 4k progam and 1k data memory, a configurable serial (fieldbus) interface and a flexible 36 pin user port integrated on a single chip. The operating system and the application software is programmed in FORTH. The controller supervises according to the information available from the user interface the quench detection hardware attached to it, heats magnets on request or if the hardware fails and performs the bookkeeping of the quench history. Via its field bus interface it talks to the CAN bus.

The CAN bus was developed by Bosch, a supplier of car equipment like ABS, to be used in trucks. It is characterized by an event hierarchy of the messages and peer-to-peer connections. The transmission rate chosen for the purpose of quench detection is 500 kbits/s.

One VME controller (MVME162 from Motorola) is used for the quench detection of two octants. The heart of the controller is the MC68040 CPU. Two IndustryPack interfaces are installed to connect to the corresponding CAN bus lines of the two octants. For redundancy a second controller configured and programmed in the same way is closely connected to the first one forming a master-slave system with automatic switching between those in case of trouble. Both controllers are connected to the Ethernet talking IP as well as to the two CAN bus lines. The operating system running is VxWorks having real-time and multi-tasking capability. The application programs are written in C++.

The VME controller together with the micro controllers represent the second safety layer. If the bridge of a magnet group detects a quench before a quench message of a single magnet of this group shows up, all magnets belonging to this particular group are heated on request from the VME controller by the corresponding micro controller. Redundancy checks of the quench detection electronics are routinely performed by the VME controller. Finally, the VME controller is used as data server for the operator’s workstations connected to the Ethernet keeping all informations about the status of the magnets and the quench detection system.

4 GLOBAL ALARM SYSTEM

In case of a quench the energy stored in the magnets must be quickly dumped to protect the diodes. In order to avoid too-large inductive voltages each HERA octant has its own dump resistor which will be switched in series with the magnets. Therefore, a reliable and fast global alarm system (“alarm loop”) is necessary.

Actualy, this system distinguishes between three types of alarms:

- alarm level 3: fast switching off and dumping the beam, e.g. triggered by a quench event,
- alarm level 2: slowly switching off and dumping the beam, e.g. triggered by a less severe malfunction of the quench protection system and
- alarm level 1: dumping the beam, e.g. triggered by the HERA-p beam loss system.

In the past, all electronics of the alarm system was realized in TTL/CMOS technique. In addition, important components were located in the HERA tunnel. Changes, improvements and service work were hard to accomplish.

During the recent upgrade of the quench protection system the amount of electronics in the tunnel was reduced to a minimum and the accessibility was improved.

Almost all logical decisions are now performed by Programmable Logic Controllers (S5-115U from Siemens). Each octant has its own PLC and a ninth controller is devoted to special purposes. The turn-around time of the PLC program cycle is about 3 ms. All PLCs are controlled and read out from the corresponding VME controller via the CAN field bus. The large flexibility of the PLC programming turned out to be the most useful innovation in the system.

As interfaces to the three 100 V alarm lines running around HERA I/O modules are used which can be freely configured using PALs. All signals which have to be processed quickly like dumping the beam are handled by these units. Finally, the alarm loop master unit powering the alarm lines was newly designed utilizing the same technique. Alarm loop interfaces and alarm loop master unit are controllable by the corresponding PLCs.

5 VOLTAGE DIAGNOSTICS

From the beginning, HERA-p was equipped with transient recorders measuring the voltage to ground at different locations around the ring. It turned out that in addition the recording of the differential voltages across each magnet could be useful to observe what really happens in a magnet during a quench, to get an early diagnosis of the onset of problems or to disentangle the consequences of different events.

Therefore, a voltage diagnostics system was installed in the HERA tunnel. The differential voltage across each half coil of each magnet as well as the voltage to ground at the beginning, the middle and the end of each octant are measured. In total, more than 1400 voltage transients are recorded permanently.

The transient recorders installed consist of two analog boards with 4 channel each standing 2 kV voltage to ground. The characteristic curve of the voltage divider is split into two parts, 0 ... 5 V and 0 ... -200 or -1000 V, respectively. A digital board samples the 8 channels with a rate of 200 Hz per channel. The voltage is digitized by a 12 bit ADC. A history of the last four seconds is stored locally. The digital board is controlled by the same micro controller as used in the local quench detection.

The transient recorders are remotely accessible via a CAN field bus. Due to the long cable distances in the tunnel the transmission rate is limited to 25 kbit/s.

A third VME controller controls the status of the data taking and reads the data stored in the memory. In case of a quench, the data taking of the transient recorders is stopped all at once via a CAN broadcast message. The frozen memory contains the history one second before and three seconds after the stop telegramme.

6 ARCHIVE

A very useful tool for the off-line error analysis is the archive system. In case of an alarm, the present status of all components of the quench protection system is instantaneously archived in a file. Quench data will be recorded for 2 minutes after the alarm message. This file can be displayed at the operator´s console using the same software usualy showing the actual status of the system. The programme guides the operator to the source of the alarm. The data of the transient recorders are archived only in the case of alarm level 3.

REFERENCES

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[2] L. Z. Lin et al., Cryogenics 30 (1990), Suppl. 599-604