STUDY OF UNK QUENCH PROTECTION SYSTEM ON THE STRING OF 4 UNK SUPERCONDUCTING MAGNETS

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Abstract

The prototypes of the elements of UNK quench protection system — quench detectors on magnetic modulators, quench stopper, safety leads, bypass switches — are studied on the string of 4 UNK superconducting magnets. The string simulates the operation of two quench protection units (QPU). Many quenches at the various parts of SC circuit from 1kA up to UNK nominal current 5kA were induced. No quench propagation from one to another QPU was observed. Parameters of quench protection system elements corresponded to tolerated ones.

I. INTRODUCTION.

The quench protection system (QPS) for the UNK ring electromagnet is based on breaking the whole ring into cells (QPU), shunting them with thyristor switches placed at the exterior of the cryostats at the ambient temperature and energy removal from the remaining part of the ring onto dump resistors [1]. QPUs, each consisting of 12 dipole and 2 quadrupole magnets, are separated by quench stoppers, containing a pair of safety leads. Each QPU is shunted with two quench bypass switches. The status of the SC circuit is monitored by the quench protection monitor system. It consists of 24 quench protection monitors (QPM) placed equidistantly along the ring and connected by one network. Each QPM monitors 8 QPU.

The QPM contains a bridge type quench detector on magnetic modulators (QDMM) [2]. Such system has two advantages: all of the elements have high radiation resistance, and magnetic modulators have the output signal isolated from power circuit of SC magnets, possessing an appreciable amplitude on low output impedance. This allows one to place QDs in the tunnel just near magnets and to transmit noise-immune signals at distances of about 1km to the technological buildings.

The study of QPS components — QPM prototype, quench stoppers (QS), safety leads (SL) and quench bypass switches (QBS) — was carried out on the string of 4 SC magnets [3].

Results of this tests are presented below.

II. DESCRIPTION OF THE EXPERIMENTAL FACILITY.

The string of 4 UNK SC dipoles simulates an action of two QPUs. Each QPU consists of two SC dipoles (Fig.1).

In first QPU the coil of M1 and return bus of M2 are shunted with QBS1 while the coil of M2 and return bus of M1 are shunted with QBS2. In second QPU both dipoles and their return buses are shunted with single QBS3.

Bypass switches with their firing systems were placed inside a steel tube 200mm in diameter for imitation the cooling conditions at the UNK tunnel, where they have to be placed into special holes in the wall of the tunnel to be protected against irradiation.

The QS is two massive copper pieces with a copper radiator, connecting them. The SC cable is soldered to one piece, while the safety lead — to another one. Two such packets are placed inside one jacket and cooled by helium flow.

The SC circuit is monitored with 4-channel quench detector (QD) based on extraction of resistive voltage of the coil by means of compensation technique. The threshold of this QD is 1V. When there is a quench in one of the magnet, e.g. M2, the QD fires the strip heaters in M1 and M2, the coils of these magnets are shunted with QBS1 and QBS2, and power supply is turned out to the reverse mode. As a result the current in the magnets M1 and M2 decays very quickly and dissipates the energy inside coils, whereas the current in M3 and M4 falls down with certain velocity through SL1, SL2, QBS1 and QBS2.

Numerous spot heaters and voltage taps, placed at various parts of SC circuit, are employed to induce the normal phase and observe the quench propagation.

Tests of QPM prototype were made in passive mode, i.e. its output signals were recorded but made no actions. Fig.1 shows the scheme of connecting magnetic modulators (MM) to the magnets. Four MMs (MM1-MM4) are connected to the diagonal of the bridge circuit (BC), two arms of which are combined by two half coils of each dipole. The fifth MM (MMg) is connected to the diagonal of the BC, two arms of which are combined by two coils each. One MM (MMu) is connected directly to power leads and used in the mode of linear amplifier to measure the voltage drop of the string. The BCs with MMs are enclosed into steel boxes which are fixed directly at SC dipole cryostats and connected with QPM by means of cables 700m long.

Fig.2 shows the structure of the QPM prototype. It contains modules needed for registration of signals from one QPU only (instead of 8 for the series QPM [2]): an amplifier-shaper (AMP), module of the cell, module of counters and also some modules common for all cell: timer, 16-bit microprocessor, RAM, interface and input/output module.

AMP supplies all of MMs with ac voltage (meander having a frequency of 1kHz and amplitude of 40V). The cell module is used to convert signals from output coils of all MMs. Each conversion channel contains a scheme to detect breaks of wires in the input circuits of MMs, a differential amplifier, demodulation scheme, filter and voltage-frequency converter (VFC). Signals from outputs of all VFCs are converted into a parallel binary code with the help of 20-channel module of counters, whose measurement time, 20mS, is specified by timer.

All status signals are collected and steering signals are

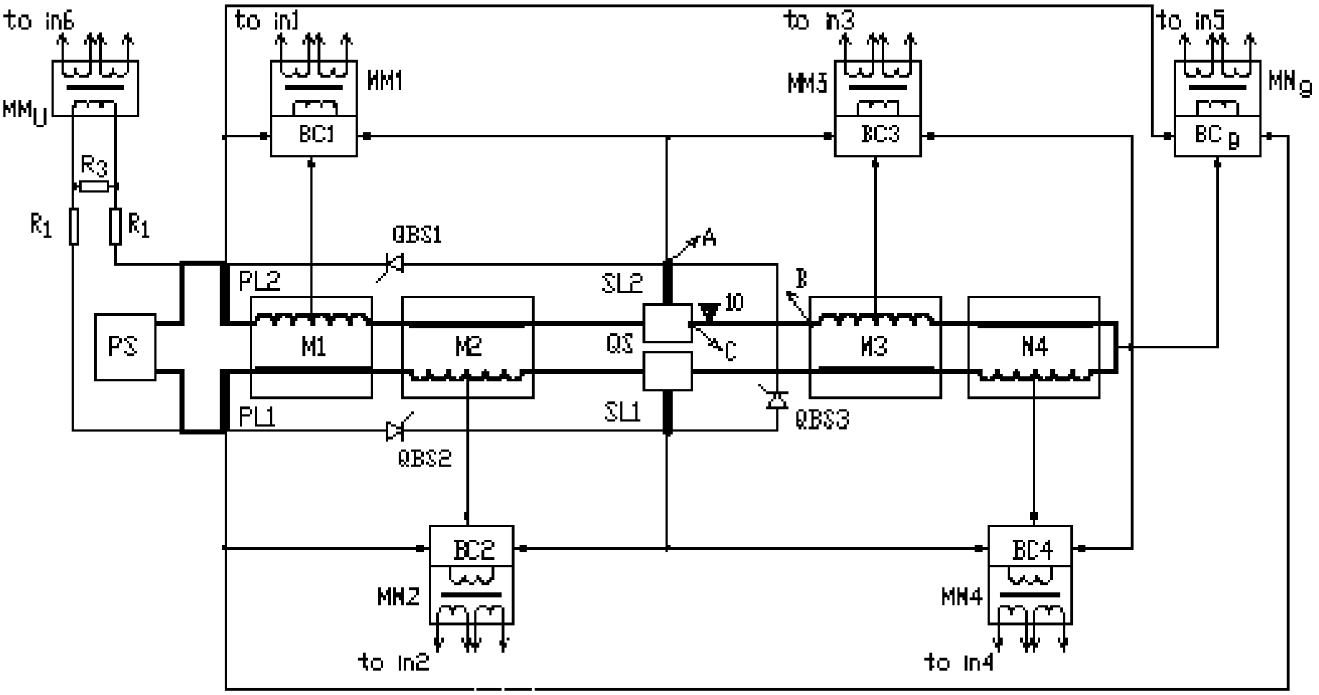

Figure 1. Electrical diagram of 4 magnet string with quench detectors: M1-M4 - SC dipole magnets, PS - power supply, PL - power leads, SL - safety leads, QBS - quench bypass switches, ∇ - spot heater, A,B,C - potential taps, BC - bridge circuits, MM - magnetic modulators.

sent to executive blocks through the input/output module. A K1810BM86 microprocessor monitors the operation of all blocks as well as performs the on-line data acquisition task, so the information before and during quench is recorded. IBM PC-AT serves as an operator's console and allows one to set the QPM operation mode and to stock quench data.

III. TEST RESULTS.

Quenches in some QPU were induced by strip or spot heaters on various currents in the string. The current in magnets, where quench induced, is dumped within $\sim$1s whereas the string current is forced to fall down with constant rate 170A/s through safety leads and bypass switches. This fall down rate was chosen so, that on the UNK operation current, 5250A, the load integral $\int i^2 dt$ at SL and QBS to be slightly above of the UNK operational level (260 MIITs). The maximum energy dissipated in thyristors was 80kJ but their temperature increased for 20-30 C only.

The maximum temperature of cold part of SL attained 10K whereas the temperature of copper piece of QS where the SC cable is soldered did not exceed 6K and caused no quench in the SC cable. In all cases of quenches induced in some QPU, no quench propagation to another QPU was observed at the range of currents from 600 to 5250A.

The balancing of bridge circuits was carried out at ambient temperature by means of powering the string with ac of 50Hz frequency and 16V voltage. After string cool down the balance was verified on the 500A triangular current pulses with a nominal UNK ramp rate of 120A/s. The string voltage was $\sim$20V. The disbalance of MM1-MM4 did not exceed some millivolts and the MMg disbalance — 40mV . For magnet protection purposes the threshold of quench detection on the single dipole should be $\sim$250mV and on group of dipoles — 0.5–1V. So, the MMs disbalance is ten times less than tolerated threshold levels.

During tests the QPM reliably detected all induced quenches as well as spontaneous ones. For the illustration Fig.3 and 4 show output signals of MM2 and MM3 during the quench induced in dipole M3 at the current 2000A, while there were no quenches in M1 and M2. It is seen that after heater firing the output signal of MM3 (Fig.3) rapidly increased up to threshold level (further behavior of this signal is determined by MM core saturation as well as by quench development in the coil and is not yet essential for quench detection purposes). The MM2 output signal was 20 times less than the threshold level (Fig.4).

In order to investigate the possibility to use the QDMM for quench detection in long SC cables the following test has been done. Instead of voltage tap A (Fig.1) the voltage tap B was connected to the BC1, i.e. a piece of SC cable BC 2.5m long from the half cell M3 was additionally introduced into an arm of BC1. The quench was initiated in SC cable BC by spot heater ∇10 (Fig.1) at the current 5000A. The normal phase propagated into coil of dipole M3 and was detected by QD as a quench in dipole M3. There was no quench in the half cell M1, but the

MM1 output signal had shown the quench development in the SC cable BC (Fig.5).

The analysis of these results lead to the conclusion, that the reliable detection of normal phase in the long SC cable can be acheeved, choosing the proper transfer function of the MM.

For checking the possibility to localize shorts of the power circuit onto ground the string was powered by ac like in the case of MM balancing, and different points of the power circuit connected onto ground through potential taps. Short circuit points were localized by QPM.

IV. CONCLUSION.

The string tests demonstrated good operational performances of quench protection system components — quench stopper, safety leads, quench bypass switches. Their parameters correspond to tolerable ones for the reliable protection of UNK SC magnets during a quench. Simple and nonexpensive quench detectors on magnetic modulators can be used for developing of reliable quench protection system for the high energy accelerators.

References

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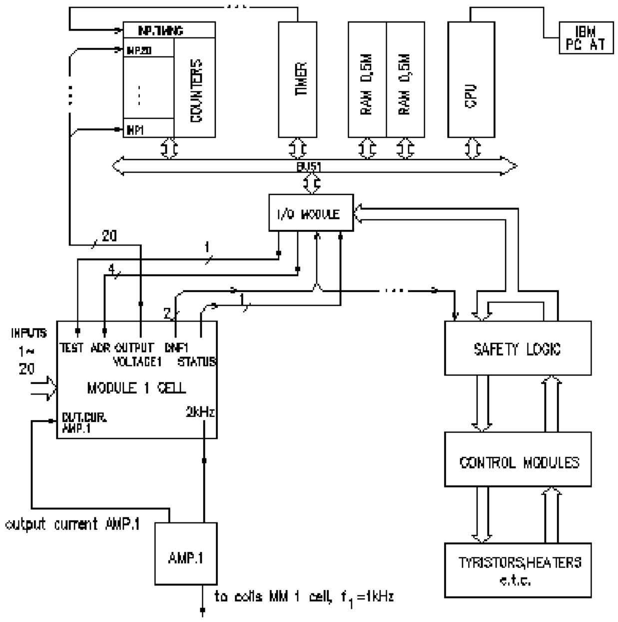

Figure 2. Diagram of QPM prototype.

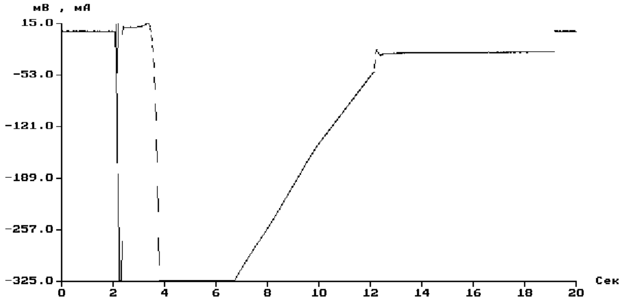

Figure 3. Output signal from MM3 during the quench induced in dipole M3 at the current 2000A.

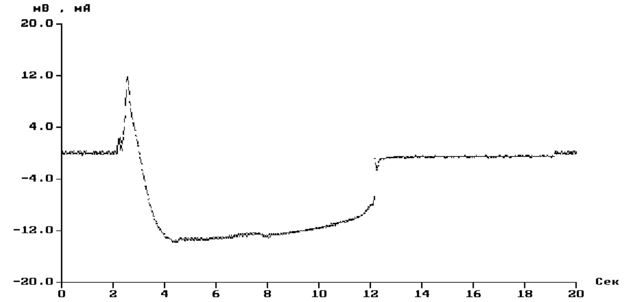

Figure 4. Output signal from MM2 during the quench induced in dipole M3 at the current 2000A.

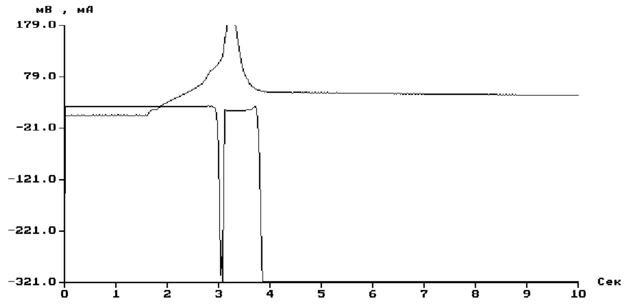

Figure 5. Output signals from MM1 corresponded to normal phase in the connecting cable (up) and from MM3 (down).