

THE QUENCH DETECTION SYSTEM FOR SUPERCONDUCTING ELEMENTS OF NUCLOTRON ACCELERATION COMPLEX

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Abstract

New quench detection system for Nuclotron is described. The system provides highly effective detection of quenches in superconducting elements of Nuclotron. Full information about quench element is transmitted to control room. Diagram of analogue quench signal could be displayed on screen for further analysis. The system performs scheduled self-test diagnostics in real time and controls power elements of energy evacuation.

INTRODUCTION

Cryogenic magnetic system of the Nuclotron accelerator facility consists of the Nuclotron ring and measurement superperiod [1]. The last one includes four dipole and four quadrupole (two focusing and two defocusing) magnets. The Nuclotron ring includes 96 structural dipole magnets, 64 structural quadrupole magnets, two lambertson magnets and four quadrupole magnets of slow extraction system, inflector magnet of the injection system and a few tens of dipole, sextupole and octupole corrector magnets. Quench protection of the corrector magnets is provided by individual low current supply units. Quench protection system of all other elements is based on energy evacuation system including thyristor power switches and dump resistors. Status of the magnets is monitored by quench detectors based on a bridge scheme. For main part of the magnets the arms of the bridge are formed by inductivity of the coils of nearest identical magnets (dipole, quadrupole or lambertson), the balancing resistor is located outside the cryostat (Fig. 1).

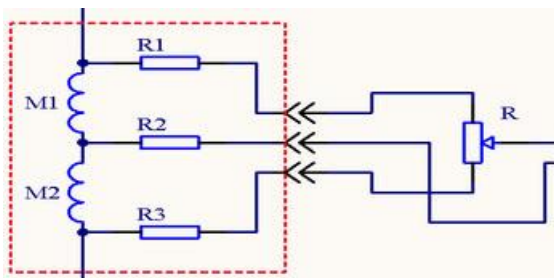


Figure 1. Scheme of the Voltage comparison: M1 and M2 – coils of nearest identical magnets, R1 – R3 – protective resistors, R – balancing resistor.

Currents of four structural dipole magnets, which are used to provide an orbit bump in the slow extraction area, are adjusted by additional suppliers. The quadrupole magnets of the slow extraction system are supplied individually also. For these magnets, and for inflector magnet of the injection system, the bridge arms are

formed by two halves of the magnet coil using potential feed through.

First quench detection system at the Nuclotron was created in the end of 80-th. In reality it was full scale prototype which was in operation during about 15 years without serious modifications. The system of the quench detector monitoring and control became outdated and obsolescent. In 2007 the modernization of the accelerator facility was started in order to prepare the Nuclotron as an element of an injection chain of heavy ion collider creating in the frames of the NICA project [2]. One of the goals of the Nuclotron upgrade was to provide safe and stable operation at maximum design magnetic rigidity, that corresponds to 2 T field of the dipole magnets. New power supply and energy evacuation systems are successfully tested at this field during the Nuclotron run #42 (December 2011) [3]. Creation of new quench detection system is in the final stage now. This system based on modern technical and design solutions is described in this paper.

DESCRIPTION OF THE SYSTEM

The new quench detection system was designed on the basis of serial interfaces: all the detectors are connected to the common CAN bus used for information exchange. This solution permits to change operatively number of detectors, to work uniformly with group and individual detectors and realize total reservation of the line controlling the energy evacuation system. The system provides monitoring of current status of all its elements, signals testing of external systems and indication of malfunctions. Such a design requires more complicated electronics but sufficiently simplifies operative service and improves reliability of the operation.

General element of the system is quench detector aiming to compare two signals in order to detect a change of one of them due to appearance of active component of resistance after loss of the superconductivity.

Peculiarity of the quench detector design relates to the requirement that each detector has to be galvanically insulated from common ground circuits as well as from other detectors. Parasitic leakages in the electrical circuits of the accelerator have to be avoided as well. Accordingly the detector consists of two constructive parts: insulated from the ground, which detects and amplifies an input signal, and grounded part, at which the obtained signal is processed, analyzed and so on. Insulated and grounded parts are connected using insulated analog amplifier.

The quench detector consists of the following elements (Fig. 2):

at the insulated part:

- bridge balance resistor Rbal
- amplitude limiter of the input signal,
- preliminary scaling amplifier with function of integration,
- insulated analog amplifier;

at the grounded part:

- insulated analog amplifier,
- amplitude comparator,
- analog switch,
- microcontroller,
- bus drivers,
- insulated DC/DC converter,
- power supply.

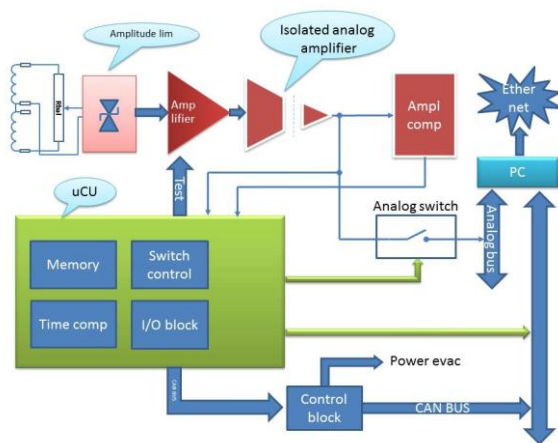


Figure 2. Schematics of the quench detector.

The bridge is a passive element and it can compare the signals in wide dynamical range: from 0 V up to maximum voltage at the magnetic elements. It is general advantage of this detection scheme. One of disadvantages – the bridge can be balanced exactly at one frequency only (for direct current in the real work) and therefore it can have parasitic disbalance at the interference frequencies or at fast variation of the power supply voltage.

The signal from the bridge is amplified by amplifier-integrator. The integration diminishes influence of short pulses of interferences. To eliminate wrong widening of short pulses with large amplitude by the integrator the amplitude limitation is applied at the entrance of the amplifier. This protects the amplifier input from an overload as well. Thereafter the amplified signal is transferred to the grounded part of the detector using the insulated analog amplifier.

Due to small amplitude of the differential signal one can use an insulated amplifier with relatively small dynamic range of the input signal (0 – 300 mV). The Nuclotron quench detectors use the amplifiers HCPL7800.

The obtained signal of the disbalance is transferred to the input of amplitude comparator and to the ADC input of the microcontroller. This signal can be commutated

also to analog bus to transfer it to remote ADC for visualization with external PC.

The microcontroller analyses the disbalance signal and, if an amplitude and duration are larger than limiting values, activates the energy evacuation system.

Digital signal from ADC is recorded into internal memory of the microcontroller for further analysis and visualization if necessary.

The microcontroller provides connection of the detector with external devices and PC via CAN bus for control signals exchange.

During each pause between the magnetic field cycles the controller generates the signal “TEST” to check-out the total tract of the signal processing as well as integrity of the cable connection lines. In case of malfunction the controller generates the signal blocking the field cycle.

COMMISSIONING RESULTS

First prototype of the new quench detector was tested during the Nuclotron run #39 (June 2009). The results confirm correctness of the signal processing concept and absence of principal mistakes in the schema technical solution. The minimum frequency for the signal digitizing, required for reliable visual monitoring of the signal shape, was specified. On the basis of the test the required modification of the prototype was provided. During the Nuclotron run #41 (March 2010) the real quench process at one of the Nuclotron magnets was recorded using the new quench detector. Heater of the magnet coil was used to initiate the quench process. The heating was performed at three values of the heater power: 17, 12 and 3 W. At large heating power (Fig. 3, left) the appearance and development of the active phase requires about 20 ms thereafter the quench detector switches on the energy evacuation system. At small heating power (Fig. 3, right) the process duration is sufficiently longer.

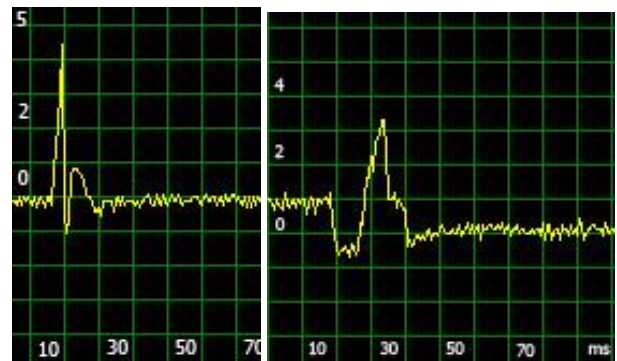


Figure 3. Signals from the quench detector at the heater power of 17 W (left) and 3 W (right). The Nuclotron run #41.

In these experiments the dynamics of the quench process in the superferric magnets during the accelerator operation was recorded for the first time. The stable and

reliable work of the quench detector was demonstrated and after the run the serial production of the detectors has been started. Total number of the detectors (including reservation and detectors for magnet clusters) is 200. The equipment is mounted in the Euromechanics U3 crates using standard elements (power suppliers, buffers and so on). To the beginning of the Nuclotron run #44 (December 2011) 20 quench detectors were constructed and prepared for operation (Fig. 4). During the runs #44 and #45 (March 2012) the test operation of the fragment of the new quench detection system was provided.



Figure 4. Quench detector and crate containing 20 detectors and power supply.

During operation dynamical misbalances (does not related to quench) at two magnetic elements were detected at the initial phase of the magnetic field cycle. At the initial stage of the field cycle the field is changed in time in accordance with parabolic law and then the field increases in time linearly. Correspondingly the voltage at the magnet coil increases linearly in time during the parabolic phase and is constant during the linear phase of the field. Unexpected misbalances appear during linear increase of the voltage when the voltage derivative was sufficiently increased. At the duration of the voltage increase below 10 ms the dynamical misbalances provoked false actuation of the energy evacuation system. The signal shape after ADC is shown in Fig. 5. A small artificial disbalance between the arms of the bridge was introduced to see all phases of the field cycle.

Analysis of this unwanted effect was performed by numerical simulation of the processes in the bridge using PSPICE simulator in the OrCad CADENCE package. This simulation shows that the dynamic disbalance is driven by parasitic capacities between midpoint of the bridge and the ground in the cable feed through into the cryostat. During the phase of voltage fast increase the capacitive leak current creates voltage on the protective resistors located at the edges of the magnetic elements (see Fig. 1).

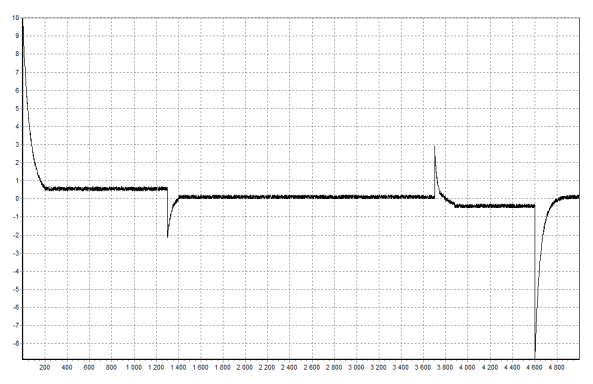


Figure 5. Misbalance signal during magnetic field cycle. The Nuclotron run #45.

The dynamical misbalance takes a place when actual values of the protective resistors are not equal to each other (usually the resistance value is at the level of $\pm 10\%$). To the nearest Nuclotron run the protective resistors at all magnets will be checked and replaced by new ones if necessary.

CONCLUSIONS

In the frame of the Nuclotron upgrade program a new quench detection system was designed. Prototypes of the quench detector were consequently tested during two runs of the accelerator. On the basis of the test results the serial production of the quench detectors was started in 2010. During two runs of the accelerator the fragment of the new quench detection system including 20 quench detectors was operated during more than 1500 hours. Stable and reliable work of all elements was demonstrated. The system performs scheduled self-test diagnostics in real time and controls power elements of energy evacuation. Full scale implementation of the new quench detection system is scheduled for nearest Nuclotron run (at the fall of 2012). The expertise obtained during construction of the Nuclotron quench protection system is used to design the quench protection systems for new accelerators of the NICA facility – the Nuclotron booster and heavy ion collider.

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