QUENCH DETECTOR FOR SUPERCONDUCTING ELEMENTS OF THE NICA ACCELERATOR COMPLEX

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Abstract

A universal quench detector is designed for new superconducting accelerators of the NICA accelerator complex under construction at JINR. The presence of a two channel digital input permits the detector to be used both for comparing voltage across two nearest magnets by a bridge scheme and for separating a resistive constituent of the voltage across a controlled element.

INTRODUCTION

The Nuclotron quench-detection system was modernized in the frames of the Nuclotron upgrade project and commissioned during the runs #46-47 [1]. The detectors are based on a comparison of voltage drops across two identical elements connected in series to the supply circuit using a measuring bridge. The bridge circuit was chosen as the simplest one from the viewpoint of technical implementation. The system (Fig. 1) permits a prompt change in the number of detectors, uniform work with the group and individual detectors and implementation of the total reservation of the line controlling the energy evacuation system. The system provides monitoring of the status of all of its components, as well as signal-testing of external systems, and also indicates malfunctions. The self-diagnostic is provided by apply of pulse signals into measurement circuits between the magnetic field cycles.

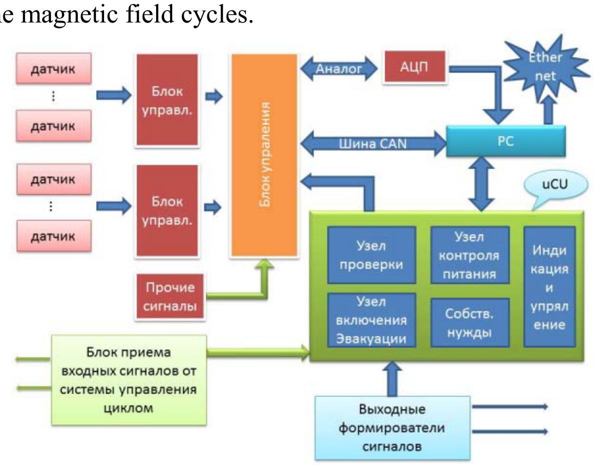

Figure 1: Block-diagram of the Nuclotron quench detection system.

Additionally, the system to control quench detectors allows all cases of protection operation to be analyzed, which yields the experimental material for further development of the detector construction. First and foremost this refers to revealing the reasons and excluding the cases of protection operation when elements do not enter the normal state. The new system permitted safe operation of the magnetic system in the regimes with long plateau of the magnetic field and operation at maximum designed magnetic field. As result, for instance, successive experiments on stochastic cooling and the beam acceleration up to maximum design energy were realized [2].

Further development of the accelerator complex is related with the realization of the NICA (Nuclotron based Ion Collider fAcility) project that presumes creation of two new Super-Conducting (SC) acceleration facilities: booster synchrotron (Booster) and collider rings, and SC transfer line from the Booster to the Nuclotron [3].

The Booster is the fast cycling synchrotron with magnetic system similar to the Nuclotron one. The Booster quench detection system can be based on the same technical solutions and the bridge scheme of the quench detector seems to be optimum.

The collider rings will be operated in the mode of a storage ring (slow beam acceleration is presumed as a reserve option only). The continuous operation is the basic regime for the SC transfer line. Two main detectors of the collider utilize the SC solenoids in a continuous mode. The quench detection is necessary for the test-bench under construction for serial production and tests of the SC magnets for NICA and FAIR facilities where different regimes of the operation are presumed.

In the mentioned cases a method of the quench detection based on separation of a resistive constituent from the measured signal by comparison with the certain reference signal can be more efficient than the bridge one. This method is rather universal: as a reference signal one can use a derivative of the magnetic field with respect to the time that determines the inductive constituent of the voltage drop. It is also possible to use the time derivative of the current flowing through the controlled element. In this case a derivative of the field is defined from the known dependence of the element inductance on the current. A difference in signals of the voltage drop across the controlled element and a signal of the derivative of the field (calculated and analyzed by the electronic circuit) indicates that the normal state is being entered.

In the continuous operation the scheme of the malfunction diagnostic has to be modified also: application of pulse signal in the measurement circuit is impossible in this case.

For use at the NICA accelerator complex and at the bench for testing SC devices, a universal quench detector was developed that is suitable for implementation in both detection schemes required.

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UNIVERSAL QUENCH DETECTOR

The universal quench detector (Fig. 2) consists of two isolated channels, each of which can receive an analog signal with a maximum amplitude of ~10 V. The channel sensitivity is regulated within wide limits by the input scaling amplifiers; therefore, a signal from both the bridge (~100 mV) and the inductive element (~10 V) can be a source signal for the circuit. Next, the input signals are transformed to the digital series code by the 12-bit ADCs and through the optical isolator they are transmitted to the processor module that analyzes them. The analysis can be performed using the signal amplitude and time characteristics as well as by comparing signals between each other for separating a resistive constituent. The control and reception of ADC data by the microprocessor is implemented through the digital high-speed isolators.

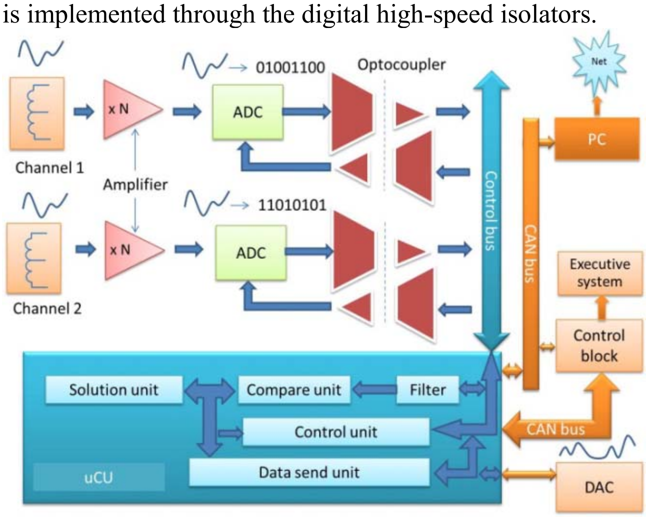

Figure 2: Block diagram of the universal quench detector.

Printed circuit board (Fig. 3) made on Eurocard 3U module with using SMD components high degree of integration [4] .

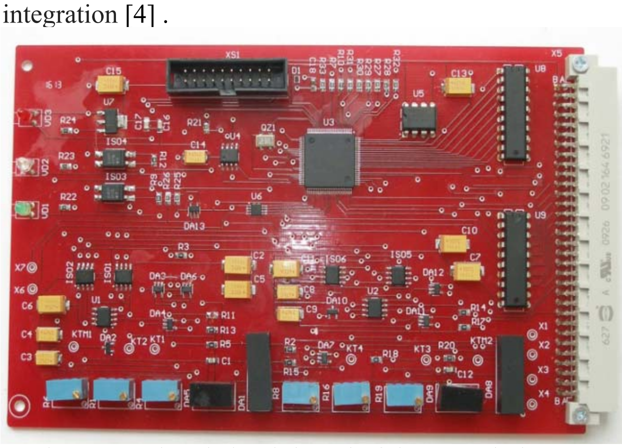

Figure 3: Printed circuit board of the quench detector

The direct connection of an inductive element made it also possible to improve the system of checking circuits of communication and detector, which now can check the galvanic coupling of all connections in the detector without the delivery of pulse signals (Fig. 4). When the testing voltage is supplied to the non-inverting input of the operational amplifier, a voltage at the amplifier output is caused by the R–R divider and equals a half of the testing value if there is no break or it equals the testing voltage if a break exists. By measuring the amplifier output voltage, it is easy to determine the integrity of communication circuits.

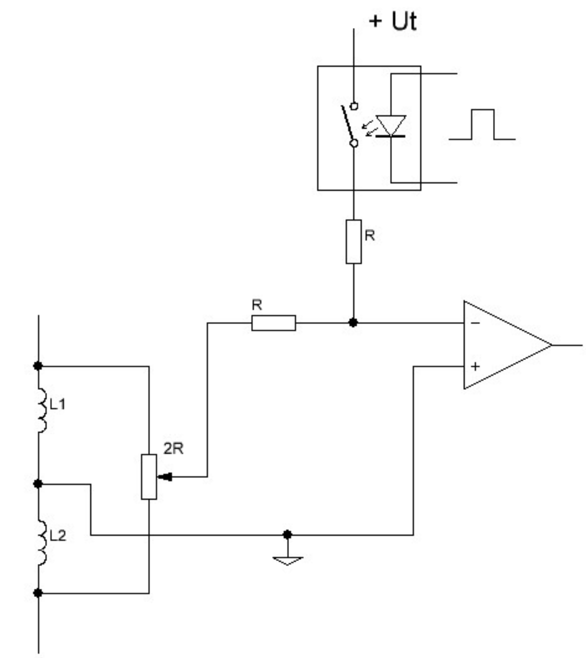

Figure 4: The system of checking circuits of communication and detector.

SUPPRESSION OF INTERFERENCES

The experience of the Nuclotron operation shows that there are places in the accelerator ring where the great noisiness of the detector input signal was noted. It is connected with disposition of powerful loads and other facilities radiating interferences near the controlled element and communication lines. The situation at the NICA collider can be sufficiently worse: the voltage at the RF stations will be of the order of 1 MV and powerful kickers will be used for the beam injection.

To suppress the noises from surrounding equipment, the method for digital filtering of input signal is used in the new detector.

Strict demands are made to the digital filter:
- realtime operation with a single sampling with a period of 4.8 μs
- minimum time delay of a signal
- absence of phase distortions
- minimum response to a jump of input signal
-simple algorithm of implementation.

According to the given criteria, a lowpass filter implemented using the “movingaverage” method was chosen. The application of the filter has shown good results for a real signal from the quench detector (Fig 5).

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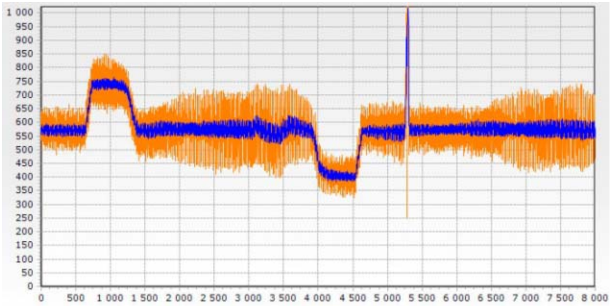

Figure 5: Signal from the quench detector at the filter input (yellow curve) and output (blue curve). Units of measure are the same as in indicated along the vertical axis; the entire scale corresponds to 3.3 V and the zero level is approximately 500. The time in hundreds of milliseconds is laid along the horizontal axis; i.e., the entire scale is 800 ms.

The degree of noise suppression is regulated by varying the filter coefficient using a program. It is possible to thus adjust the detector individually for each particular placement of it in the accelerator ring. It should be remembered that the filter introduces a time delay into the initial signal (depending on the coefficient, from 500 μs to 2 ms); therefore, it is necessary to correct the detector in its application.

CONCLUSIONS

On the basis of the experience of operation of the quench detection system of the Nuclotron SC synchrotron with account of demands from new SC elements of the NICA facility, the new universal quench detector is developed. The validity of the signal processing concept and the absence of fundamental errors in circuitry construction were checked on the detector mockup. Now a prototype is fabricated and tested during the Nuclotron run and at the test bench for the magnet production. Beginning of the quench detector serial production of s is scheduled for 2015.

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