NUCLOTRON HELIUM PLANT CONTROL SYSTEM

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Abstract

The heavy ion superconducting synchrotron Nuclotron intended to accelerate nuclei and multicharged ions with q/A = ½ up to an energy of 6 Gev/u was put into operation in the Laboratory of High Energies of the Joint Institute for Nuclear Research (Dubna, Russia) in 1993. The Nuclotron cryogenic supply is based on three helium refrigerators of 1600 W capacity at 4.5 K each which cools the accelerator ring with a "cold" mass of about 80 tons. Cryogenic system parameters control is described in this paper. The measured and controlled parameters are cryogenic temperatures, turboexpanders speed of rotation, mass and levels of liquid nitrogen and helium in the separators and storage tanks, nitrogen and helium pressures, helium flow rates.

Home industry carbon and platinum sensors are used for temperature measurements at ranges of (4.5 – 300) K and (20 – 300) K respectively. The electromagnetic sensors we use for rotation speed registration of small size turbine expanders and manometers for pressure measurements. The helium flow rates are measured by the thermosensitive quartz resonators with a temperature sensitivity of 2 mK at 300K. The hardware interface is in CAMAC and PC standard.

INTRODUCTION

The successful operation of a superconducting accelerator depends first of all on high efficiency and reliability of its cryogenic supply. The Nuclotron [1] cryogenic system is based on three helium refrigerators of a nominal capacity of 1600 W at 4.5 K each [2]. Two of the three refrigerators are connected to the accelerator half-rings that can operate independently. The reserve third one is intended for increasing the total capacity in case of peak repetition rates and maximum energies of the accelerator. Because of a rather long Nuclotron perimeter of 251 m and adequate cold mass of about 80 tons the cool down process of the whole magnet system requires a relatively long time of about 80 hours. A very wide spectrum of the refrigerator operation modes is used during the starting period: cooling, liquefaction, refrigerating and their combinations. Besides, in dependence on the accelerator tuning regime (energy and sort of the accelerated particles, main magnetic field parameters, etc) various refrigerators capacities are required. So, all the enumerated above reasons require the creation of the efficient control system for the helium plant. The control subsystem of the cryogenic supply is part of the Nuclotron control system [3] and is connected to the local area network of the accelerator complex of the Laboratory of High Energies. It is based on the industrial rack-mountable PC from ADVANTECH equipped with I/O and communication boards. The measuring hardware interface is mainly in CAMAC standard and includes two crates of digital and analog measurement, timing and logical modules developed and manufactured in the LHE, JINR. CAMAC electronics with a PC is located in the data acquisition room at a distance of about 30 m from the sensors and cryogenic supply equipment.

SENSORS AND MEASUREMENT EQUIPMENT

The most important parameters of the cryogenic supply system that must be controlled first of all are the temperatures of the refrigerator components and so, the home industry refrigerator is provided with 14 standard platinum sensors for temperature measurement over an interval of (30 – 300) K with a sensitivity of 0.05 K at 30 K. In addition to the platinum detectors, each of the three refrigerators used is supplied by 8 home manufactured carbon sensors for temperature control over a range of (4.2 – 300) K with a resolution of 25 mK at 4.2 K.

Each of the 42 platinum sensors has an equal nominal resistance of 125 Ohm at room temperature. The resistance dependence on the cryogenic elements temperature is described by the 4-th power polynomial

$$T = A + B*R(T) + C*[R(T)]^2 + D*[R(T)]^3 + E*[R(T)]^4,$$

where T – temperature, K; R(T) – measured resistance, Ohm; A = 34.390171; B = 2.244610; C = $0.165370*10^{-2}$; D = $-0.276650*10^{-5}$; E = $0.488020*10^{-8}$. Each of the 14 platinum sensors of each refrigerator is connected in serial and supplied by three identical current sources of 20 mA with an output impedance of 10 MOhm.

Because the carbon sensors have nominal resistances around 1000 Ohm at room temperature with a deviation of about 20%, each of 24 sensors used was preliminarily calibrated by the standard germanium thermometer TCG-1 with a sensitivity of 0.02 K. More than 8 calibration points over a temperature interval of (4.2 – 300) K were used for the calibration [4]. The carbon sensors resistance dependence on the temperature is described by the 7-th power polynomial

$$T = \sum_{n=0}^{7} K_n*(R_0/R)^n,$$

where R_0 = 1000 Ohm; T – temperature, K; R – measured resistance, Ohm; The coefficients K_n are defined by the least squares method. Like platinum sensors carbon ones of each refrigerator are connected in serial as well and are supplied by three current sources of 20 μA to avoid the sensors heating.

So, all of 42 platinum and 24 carbon sensors form six independent circuits with two precise resistors connected to each circuit for calibration.

The sensors signals of 10 – 50 mV amplitude are transmitted to 64-channel multiplexers with an output differential amplifiers of 80 dB common mode rejection and 100 amplification factors. The home manufactured 8-channel 16-bit integrating ADCs based on AD1170 perform the analog signals digitizing.

To optimize the cryogenic system operation, it is necessary to measure and control some parameters of liquid helium and nitrogen, such as pressure, flow rates, mass and levels. The helium pressure in the direct and back flows together with the mass and levels of liquid nitrogen and helium in the storage tanks and separators are measured by means of home industry absolute and differential manometers. Using the same integrating ADCs for digitizing provides the measurement accuracy of 0.5%.

To increase the efficiency of the cryogenic supply four small-size and high speed expanders are put into practice at each of the three Nuclotron refrigerators. The turbines are capable to work at a speed of 300000 revolutions per minute. Much lower operation speed of about 200000 rev/min provides a high reliability of these machines. The single expander is supplied by electromagnetic sensor for a speed of rotation registration which generates a pulse of 2 V amplitude per revolution. The digital circuits of each registration channel forms a gate of 1 sec duration filled by the generated pulses. It provides together with 16-bit counters used an accuracy of 0.02% at a speed of 200000 rev/min.

The cost of refrigeration extremely depends on measurement and control of helium flow rates. The measurement principle is based on the registration of the cooling helium flow temperatures at inlet and outlet of the heater of given power

$$G = Q/[C_p*(T1 – T2)],$$

where G – helium flow rate, g/sec; Q – heater power, W; C_p – helium heat capacity of 5.1955 J/(g*K); T1, T2 – helium flow temperatures at inlet and outlet of the heater respectively, K. The electrical heater and thermosensors are installed in a helium tube with a high thermal insulation. Because the temperature alteration at permissible heater power of 2000 W is very small (~0.1 K), it is necessary to use thermosensors with a sensitivity of less than 5 mK to provide the required measurement accuracy of better than 0.5% at 300 K. Neither platinum nor carbon sensors can supply such sensitivity over a range of (4.2 – 300) K. So for temperature measurement we used the thermometers based on the thermosensitive quartz resonators with a resolution of 2 mK at 300 K developed and manufactured in the Institute of Solid State Physics of Bulgarian Academy of Sciences [5]. The temperature-frequency characteristic of the resonator remains linear within the temperature range of (300 – 170) K with a sensitivity of 1012 Hz/K at a resonance frequency of 26.916 MHz. Special generators are placed close to the quartz resonators at a distance of ~2 m to form pulses of resonance frequency. The 16-bit counters together with digital circuits are performed in CAMAC standard and are located in the data acquisition room at a distance of ~30 m from the sensors.

SOFTWARE

The software includes two C++ programs. One of them executes the measurement of the cryogenic system parameters, data processing, acquisition and transmitting to the Nuclotron local area network server. Another program named Viewer allows one to observe the current and archive information on any network computer. The measurement, processing, data transmitting and archiving take about 3 sec. So the enumerated above phases are performed between the active parts of the accelerator main magnetic field cycles of ~9 sec duration to reduce the noises from the RF equipment. As an example, Fig.1 illustrates the information representation in the numerical form. .

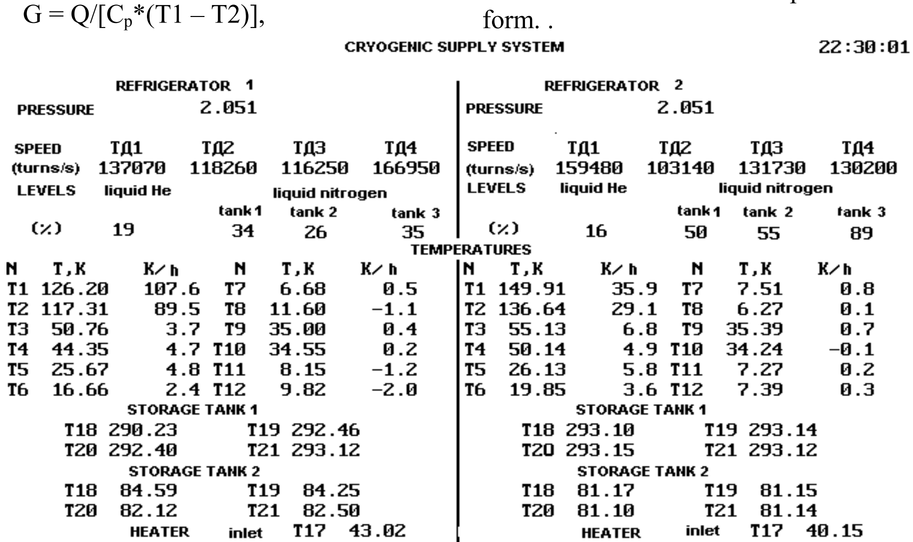

Figure 1: Cryogenic supply system parameters represented in the numerical form.

The graphical form of representation of the measured parameters of two helium refrigerators is shown on Fig.2. The temperature derivatives during the given period (usually 30 min) are calculated and presented in each accelerator cycle, as well.

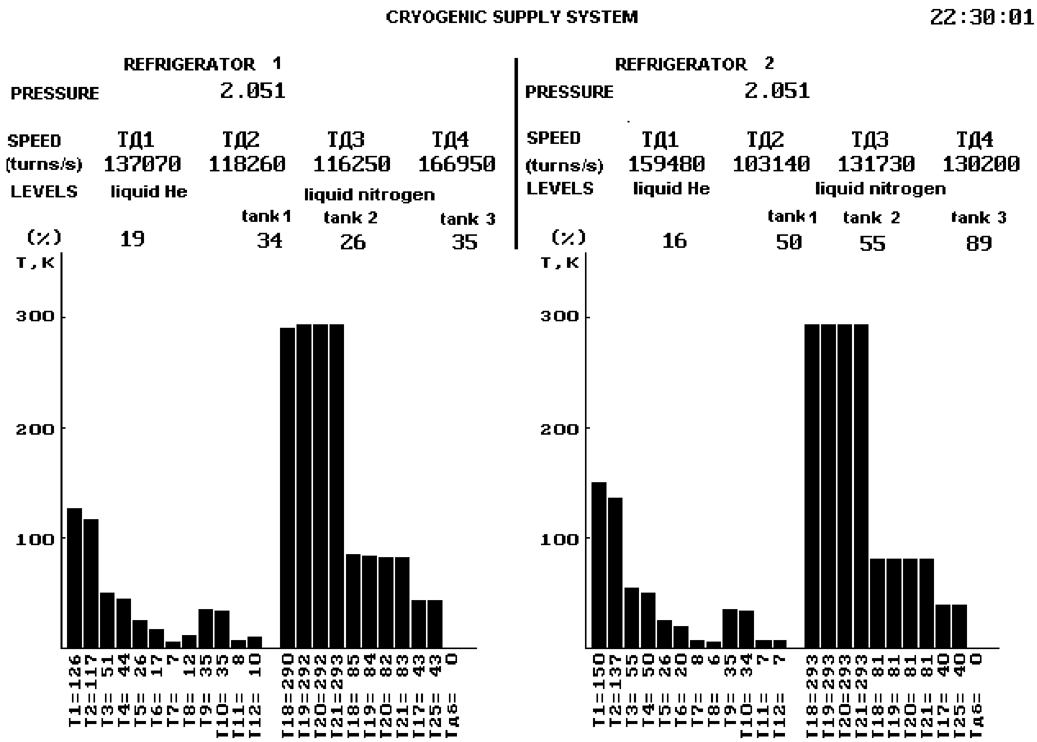

Figure 2: The measured parameters of two helium refrigerators in the graphical form.

CONCLUSION

The Nuclotron helium plant control system has been successfully operated since 2000. It permits, in the main, to reduce the fault situations and to investigate, in more detail, the operational characteristics of the cryogenic supply system, to decrease the tuning process duration of the new modes of operation, as well.

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