NUCLOTRON CRYOGENIC THERMOMETRY

V.I. DATSKOV[1], L.V.PETROVA, G.P.TSVINEVA Cryogenic Dpt., Joint Institute for Nuclear Research, Laboratory of High Energies (JINR/LHE), Dubna, Russia

[1] E-mail: datskov@vxjinr.jinr.ru

ABSTRACT

The industrial production of cryogenic thermometers for the NUCLOTRON accelerator was accepted about 10 years ago as a result of JINR/LHE Cryogenic Department researches, begun in 1979. After the comparison of the thermometer various types, the TVO carbon-ceramic resistor has shown the best long-term stability of thermometric characteristics after various tests such as: strong magnetic field, neutron-gamma irradiation, thermal cycling and mechanical durability. Above 700 thermometer-screws have shown reliable work during many years of NUCLOTRON /1/ accelerator runs. This article discusses the results of TVO thermometer research, the design and the technology of thermometer installation in superconducting magnets and in the cryogenic maintenance system of the NUCLOTRON accelerator. Questions of temperature measurement error in the large long-life cryogenic acceleration installations are discussed.

INTRODUCTION

The development of accelerator engineering on the base of superconducting magnet systems requires reliable, precise and inexpensive cryogenic thermometers. Accurate temperature measurements throughout the system allows the possibility to /2/:

(a) monitor and safely control the cool-down and warm-up of large mass accelerator magnets,

(b) locate high heat leaks and carry out thermal diagnostics of main cryogenic components during accidents, etc.

(1) Many commercial cryogenic thermometers carry warranties for only 1 or 2 years that may not cover the harsh conditions found in accelerators. Recalibration or verification is typically recommended at frequent intervals.

(2) Thermometers are expensive and requires technicians with highly specialized training. Reducing thermometer costs is possible by developing a thermometer in-house based on an inexpensive electronic component, and organizing verification and calibration facilities.

(3) Very harsh conditions exist in superconducting accelerators including: high magnetic field, high irradiation dose, many cycles of warm-up and cool-down, high voltage electrical insulation over 500 V for thermometers in magnet windings, especialy during the quench etc.

Through all the world the Allen-Bradley, Speer and Matsuchita carbon resistors are widely used as temperature sensors. Calibrated temperature sensors are also produced by VNIIFTRI (Russia), Lake Shore Cryotronics, Scietific Instruments (USA) and others. Known commercial cryogenic thermometers are rather expensive and do not answer all requirements for the work in cryogenic-magnetic systems of the JINR created accelerator. As a result of the research work in 1979 at JINR/LHE Cryogenic department for the first time it was offered to use the composite carbon-ceramic resistors of TVO type /2-5/ in cryogenic thermometry.

TVO CARBON-CERAMIC RESISTANCE TEMPERATURE SENSOR

The JINR has developed a cryogenic temperature sensor based on the commercial TVO-0.125 W /2-5/ carbon-ceramic resistor of nominal resistance 1 kOhm suitable for measurements in the range 1.6-450 K in cryogenic systems in both vacuum and gas/liquid (pressures 0-5 MPa), and also in the range 0.01-10 K in dilution refrigerators.The thorough research and 19 year of exploitation experience has made it sure that, according to their technical characteristics, the TVO sensors are equivalent to those of Allen-Bradley, Speer or Matsuchita. Moreover the temperature range is even wider and long term stability better.

The typical qualities of TVO sensors are: high reliability, zero inductance and high electrical insulation resistance up to 1000 V.

The TVO nonlinear resistance-temperature dependence in the range 1.8-300 K is approximated within accuracy 0.5 % by the polynom:

$$T = K_1 + K_2 *(R_0/R)^1 +..K_n*(R_0/R)^{n-1} \qquad (1)$$

where 7 polynom factors Kn are defined by a method of the least squares, R_0 usually is equal 1000 Ohm.

The JINR calibration facility has been tested in the VNIIFTRI and compared well against the Russia metrology standard. That installation is able to calibrate about 1000 temperature sensors per year.

Basic characteristic of the TVO temperature sensors at 4.2 K are:

- long term (19 years) stability better than 0.4%;

- sensitivity 570-1600 Ohm/K;

- magnetic field error < 1 % for B < 6 T;

- neutron radiation error < 1 % for $F < 10^{17}$ n/cm^2;

- heat capacity $1.3*10^{-4}$ J/gK;

-time response < 0.001 s; weight 0.075 g; dimensions 1.4x2.5x8 mm.

NUCLOTRON MOUNTING FIXTURE: DESIGN AND CHARACTERISTICS

For the NUCLOTRON indirect temperature measurement techniques were developed to avoid installing thermometers in helium flow lines eliminating many vacuum feedthroughs there by reducing the possibility of leaks. The mounting fixture for a helium tube is shown in Figure 1. Twisted wires (8) from the hermetic connector at 300 K sink feed into the screw-thermal anchor (9) on copper plate (6), which is soldered on helium tube (7).

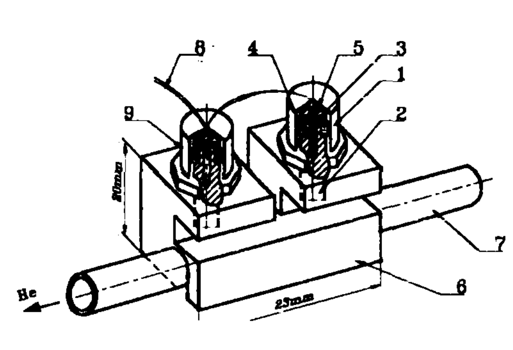

Figure 1. Thermometer mounting fixture.

The screw-thermometer (2) measures the temperature of helium tube (7) with a < 1 % error over 4 - 300 K. The thermometer (3) is a TVO and bifilar winding (4) using a special technique for mounting in the screw (2) covered by a copper cover (1). All surfaces are polished and nickel plated.

The threaded parts of screws (2) and (9) in advance are greased by thermal conducting paste, which consist of a mixture of the silicon vacuum grease 60 % and aluminum powder 40 %. The research of the temperature error measurement of the proposed thermometer mounting fixture was carried out in the dependence of the external heat loads via wires in the calorimetric vacuum device /7/, inserted in dewar with liquid helium. At the temperature 4.3 K the heat load via two teflon wires with the length of 1200 mm from a 300 K hermetic connector to thermometer was measured to be of 0.03 W, and the value of the thermal conductivity of thermometer thread joint was of 0.08 W/K. Without the additional screw-anchor the error of the temperature measurements at 4.3 K grows up to 0.6-1 K. The dependence of the temperature measurement error dT, due to self-heating by the measuring current, is shown at Fig. 2 curve 1.

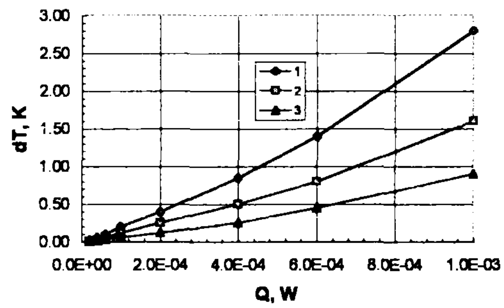

Figure 2. Temperature measurement error.

The following curves are represented for a comparisons: 2- for the thermometer, mounted with the silicon grease and manganin wires in a hole of copper block, 3- for the immersed in liquid helium thermometer itself. The analysis of curves in a Fig. 2 shows, that thermal anchoring in proposed thermometer mounting fixture is negligible. In the given thermometer mounting fixture at 4.3 K the error of temperature measurement dT is better 0.1K at measuring current I = 10 mkA and heat load to helium being $Q<4*10^{-5}$ W. These data correspond to paper/8/ results, where various ways of thermometers fastening in vacuum on a cryogenic surface are investigated. The installation of the created at JINR/LHE thermometer mounting fixture is much easier than in /8/ and can be to carried by an technician. That is very important for testing, mounting and possible repairing of many thermometers in the serial accelerator magnets.

In the case of thermometers being glued into the screw a significant error of thermometer indications dT = 0.1-1 K may be observed at 4.3 K depending on the epoxy type and subsequent heat treatment. The original epoxy technology was found with the error dT better than 0.1K. The measurement of the thermometer resistance is carried out by the two-wire electrical scheme with a stable (10^{-4}) measuring current of 10 mkA. After the thermometer manufacturing a 5-multiple check during 1-2 months of the indications is carried out at three temperatures (300 K, 77.4 K, 4.2 K) and a test of the electrical isolation thermometer-case at a voltage value of 500 V is performed as well.

CONCLUSIONS

Measurements in vacuum of helium flow temperature at input and output superconducting magnet windings, iron yoke and etc /6/ have been performed using the technology of indirect temperature measurement. Above 700 of these serial mounting thermometer fixtures are installed in the NUCLOTRON accelerator on helium tubes in vacuum and have performed well for over 7 years. For the superconducting accelerator it is necessary to keep a small group of highly skilled, professional specialists and a calibration and test facility. This group should do full input control of all thermometers in real conditions, test and analyze damaged thermometers, model and predict future characteristics. In-situ calibration/verification techniques using advanced thermal modeling of large sections of particle accelerators must be used to reduce the need for thermometer replacement.

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