A Microcontroller Based Temperature Measurement Module for the LEP2 SC RF Cavities

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Abstract

For each of the 272 SC cavities of the LEP2 RF system a total of 24 temperatures at various points around the cavity and in the cryostat must be continuously monitored. In the event of certain limit values being exceeded appropriate actions must be taken to protect valuable equipment. These temperature measurements are most conveniently done within the G64 based equipment controller (EC) that provides the interface and low level control functions for the cavity. Since reliability and fail-safe action is of utmost importance the tempera-ture measurement and equipment protection functions must be completely independent of the other EC tasks, although temperature data and limits status must be available to the EC. A dedicated temperature measure-ment module has been developed to meet these require-ments. The design is based on a general-purpose intelli-gent base acquisition module with an on-board industrial microcontroller. A mezzanine board provides the specific functions such as temperature measurement signal condi-tioning and digital I/O for external control functions. A protected dual port memory allows the main EC CPU access to all local information without direct interaction with the local CPU. The design can be easily adapted for other similar applications, making use of the same base acquisition board but with different firmware and specific versions of the mezzanine board.

1 Introduction

The RF system for LEP 1997 consists of a total of 240 super-conducting (SC) cavities together with 84 of the original room temperature copper RF accelerating/storage cavity assemblies. The SC system has routinely supplied a circumferal accelerating voltage of over 2300 MV during the 1997, allowing an operating energy of 91.5GeV. A further 32 SC cavities will be installed in 1998.

Four SC cavities in a common cryostat make up an RF module, up to two modules being driven from a single klystron. One or two klystrons are powered from a single HV power converter, the HV converter, klystrons, cavity modules and associated equipment making up an RF unit.

Within the RF unit the various pieces of equipment associated with each major element of the RF unit are grouped together and controlled by a G64 'Equipment Controller' (EC) [1]. There is one EC for each cavity, to acquire data such as RF powers, cavity fields, tuning parameters, interlock states and temperatures.

Cavity temperatures (24 per cavity) are measured inside the cryostat tank, on helium gas lines, magneto-strictive (MS) and thermal (TH) tuner bars and on critical compo-nents such as the main coupler. Measurements are used for control of feedback loops such as cavity tuning and for monitoring and alarms. Most importantly, some are used to protect equipment from overheating or the effects of being too cold. When temperatures are outside pre-set limits, RF power, MS, TH and helium bath heater power supplies must be switched off via the interlock system.

Temperatures are measured using Pt100s connected in series around the various points in the cavity and driven by a 1mA current source. 2-wire measurement is used to minimise cryostat cabling and measurements are more prone to noise than for conventional 3 or 4-wire conne-ction. Many of the temperatures measured are well below the linear range of the Pt100 sensors.

The fundamental requirement is no failure in the prima-ry function to protect equipment. Much of the equipment is inaccessible and difficult to repair. Failure of an RF window would result in loss of vacuum and make it necessary to remove the cavity module for repair and re-processing.

An original temperature measurement interface was based on conventional logic. The temperature channels were scanned, voltages digitised, stored in shift registers then compared sequentially with upper and lower limit values in EPROM. Standard TTL logic was used with a large number of ICs. False out-of-limit detection occurred due to noisy readings and internal logic glitches. As SC cavity installation progressed these problems had increa-singly detrimental effects on the operational reliability of the RF system.

2 Microcontroller acquisition system

The new cavity temperature measurement system is based on a standard intelligent acquisition base module onto which is mounted a special I/O mezzanine. The base module has on-board microcontroller, memory, G64 inter-face and it provides the basic analog input channels and digital I/O. Application specific input signal filtering and amplification, logic operations and buffering of digital I/O are all done on the mezzanine board.

2.1 Intelligent acquisition module

The specifications of the base module are:

- 32 analog input channels, i.e. 24 temperature input channels with spares to cover other applications.
- 12-bit resolution.
- Control output lines for fault (interlock) states, each set

according to preset high/low limits on predetermined sets of channels.

- Less than one second update time for all channels and control outputs.
- Fail-safe protection, i.e. automatic setting of all fault states in the event of acquisition failure.
- Readout of all values and states via the G64 bus.
- Complete independence of the local acquisition and control processes from the EC software and G64 bus.

The design is based on an existing G64 module for the measurement of liquid helium level in the cavity cryostats. A microcontroller has been incorporated to allow on-board acquisition and control. A prototype version verified the basic principles of operation but some problems were encountered with buffer memory control logic and micro-controller peripheral access logic.

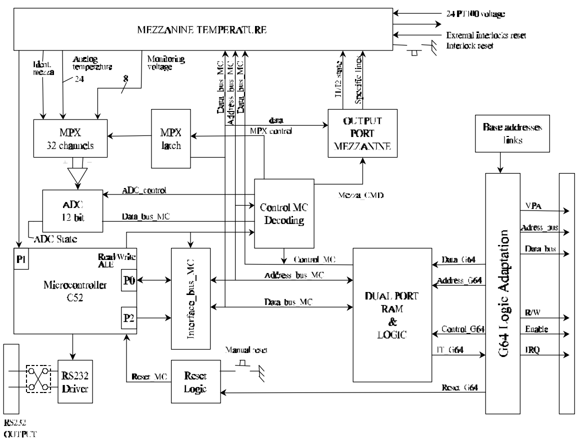

Figure 1. Intelligent acquisition module

The block diagram of the CERN redesigned final version is shown in Figure 1. Analog data from the mezzanine is taken via two 16-channel multiplexers to a differential amplifier and 12-bit ADC. One input of each multiplexer is connected to remote ground allowing each channel to be measured with respect to that ground. An 80C52 microcontroller controls the multiplexers and ADC, collecting the data sequentially for each channel. Voltage readings are converted to temperature values in Kelvins, using a close fitting logarithmic approximation to the standard Pt100 characteristic. The temperature readings are compared with limit values stored in microcontroller EPROM and the appropriate interlock is set via the mezzanine board if an out-of-limit value is detected. Automatic calibration is used. Spare measure-ment channels are used to read a fixed voltage reference and ground periodically, giving gain and offset correction factors for the conversion software.

All temperature readings and limit states are stored in a Dual Port Memory (DPM). The G64 bus has access via the DPM only and has no direct action on the temperature measurement and limit detection processes. Data such as fault history is also stored in the DPM. G64 instructions for the microcontroller, for example interlocks reset, are written as data in the DPM. General information such as time-of-day for fault time-stamping is also written.

Some main features of the DPM implementation are:

- ***Data protection***

Memory is divided into two parts. Either can be read by both microcontroller and G64 interface but each can only write to its own part.

- ***Two access protocols***

Both polling (using handshake and status flags) and interrupt driven mechanisms are available for DPM access arbitration.

- ***Timeout handling***

If G64 access cannot be obtained within a fixed time-out period a fault indication is given. If the microcontroller cannot gain access it assumes that the G64 process has failed and forces access.

Software running on the EC provides local display of all temperature values, limit states, and fault history. Data is transmitted to control room applications on request.

The microcontroller's internal UART and a local monitor program allow in-situ control and debugging.

2.2 Temperature measurements mezzanine board

This connects external I/O (on the top connector of the base module) and local I/O. It provides pre-treatment of the Pt100 voltages and a number of logic functions. Interlock lines are latched and can be reset locally or remotely. A watchdog provides fail-safe action, a counter must be reset every 10 seconds by the microcontroller. If not, all the interlock lines are hardware activated.

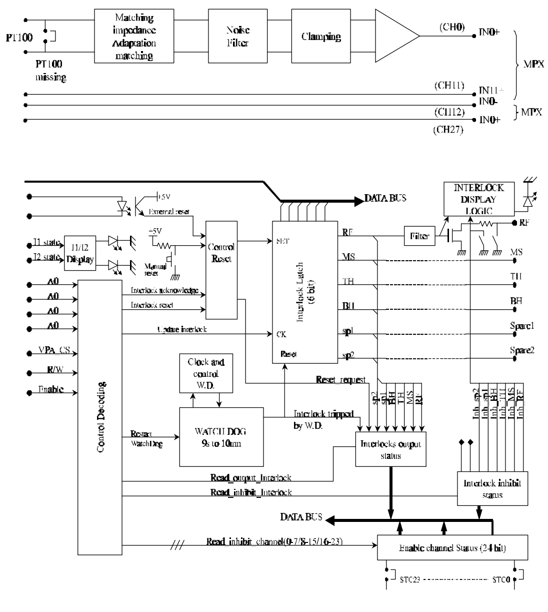

Figure 2. Temperature measurement mezzanine

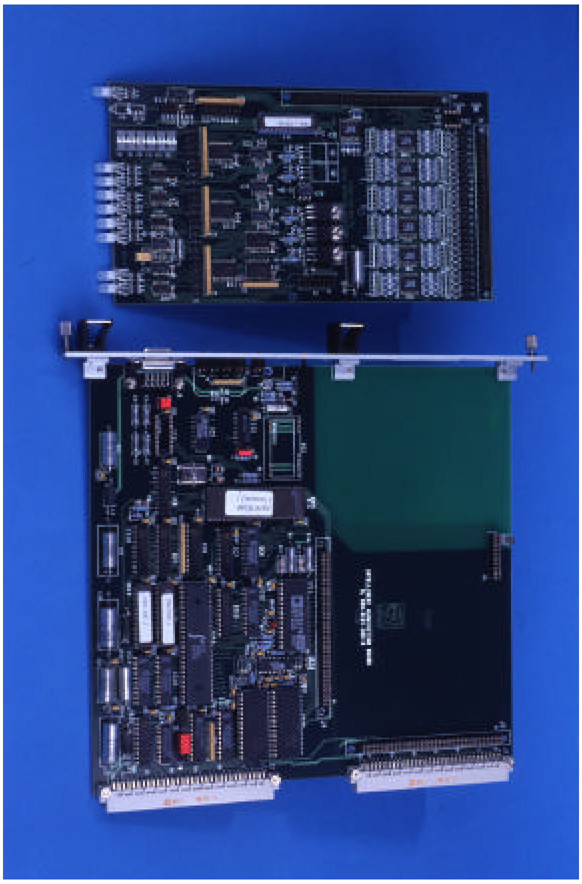

Figure 3 Temperature mezzanine and acquisition module.

The signals on each side of the Pt100 are filtered, amplified and the difference voltage produced by a differential mplifier. The overall gain is 50, providing 5V for 100 ohms (273K). The variation in reading due to noise in the LEP tunnel is less than plus or minus 2 bits, allowing measurement repeatability within 0.3 Kelvin.

Remaining spare analog channels are used to measure local power supplies.

2.3 HOM coupler temperatures

Additional temperatures are measured separately on the higher order mode power couplers and cooling circuits. Here Allen Bradley 100 ohm carbon resistors are used to measure cryogenic temperatures. These have high resistance at cryogenic temperatures, varying in a pronounced but non-linear way from 100 ohms at 4.5K to 220 ohms at 20K. These temperatures are measured in a separate ʹHOM Temperature interfaceʹ module in the EC. The main purpose is to switch off RF in the event of a quench of the HOM coupler. A quench is indicated by a rapid and sustained temperature rise. Detecting this with analog circuitry is relatively complex and the present simple interface uses level comparison. This is imprecise due to the spread in values of the resistors. Since the signal levels are low spurious fault indication due to noise is sometimes encountered. A new version of this interface uses the intelligent acquisition base module with a specific HOM temperatures mezzanine module. The mezzanine has the current sources for the Allen Bradley resistors, the necessary input signal filtering and amplification and the control outputs. The microcontroller program detects quench on the basis of a sudden increase by a given amount from one cycle to the next, re-confirmed by a second reading. For this application there are fewer channels but the measurements must be rapid. A cycle time of less than 10mS is easily achieved with four channels.

3 Present status

At present over 100 microcontroller acquisition modules with temperature measurement mezzanine have been installed. These have replaced the most fault-prone of the original temperature measurement modules, resulting in a considerable improvement in the operational reliability of the RF system.

During the 97/98 LEP shutdown all remaining cavities will be equipped, which together with the 32 new cavities will make a total of 272 installed modules and mezzanines.

The mezzanine module for the HOM temperature measurements is in the prototype stage and installation is planned for 1998.

A VME version of the base module and a stand-alone version with a WorldFIP field bus connection are planned.

Acknowledgments

The success of this project is due in great part to the high level of competence and the dedicated efforts of P. Fantini, both in the prototype development stage and in the test of production material and its installation in LEP. High quality printed circuit design work by W. Billereau has greatly contributed to the excellent performance of the hardware. We are also grateful to him for complete documentation. Thanks are also due to C. Stocklin who provided basic microcontroller software routines.

References

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[2] R. Brun, "Temperature Measurement and Protection of SC cavities by Microcontroller", internal technical report. (1998)