TUNING LOOP CONTROL SYSTEM FOR THE FERMILAB DEBUNCHER DRF1 CAVITIES

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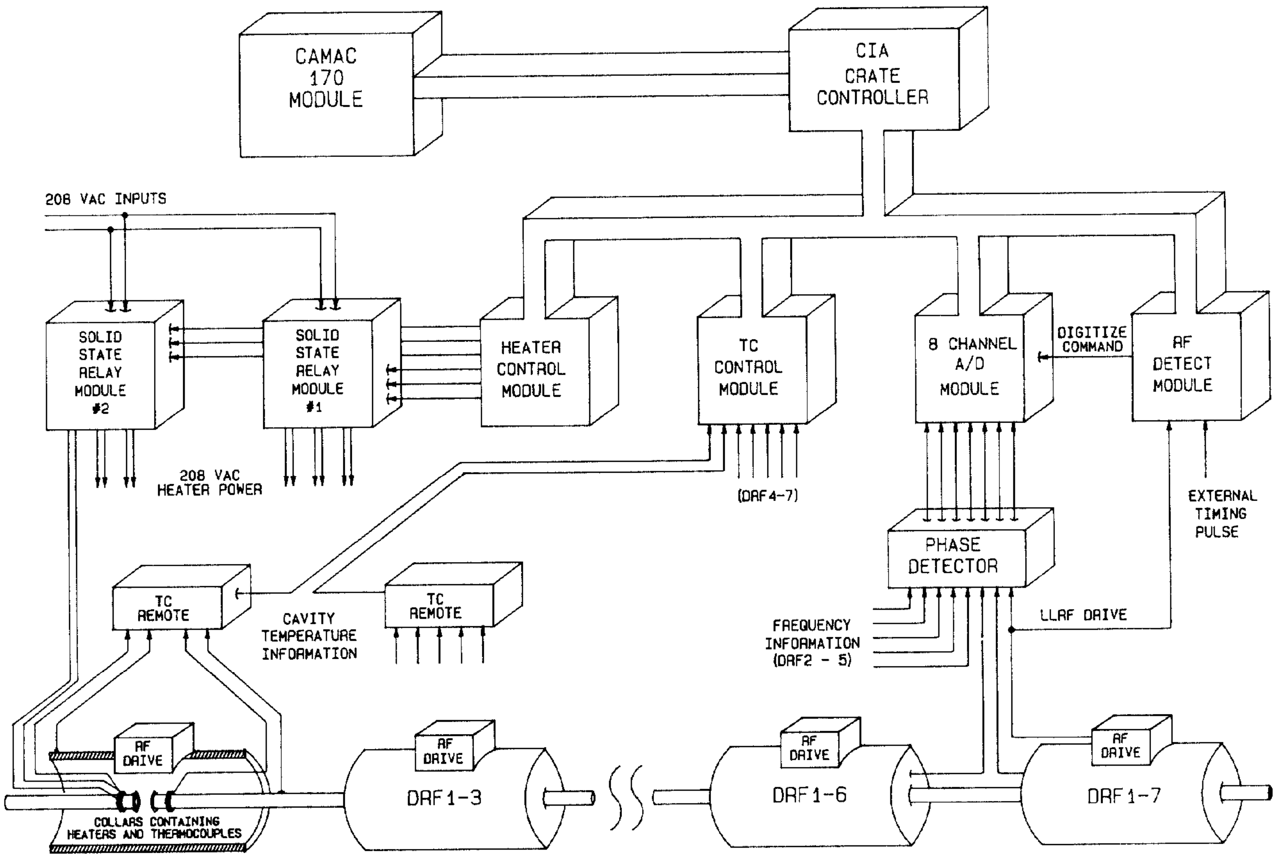

Fig. 1 - DRF1 Tuning Loop Block Diagram

Abstract

The DRF1 cavities are tuned by heating the beam pipe. When beam is present a phase detector compares the cavity RF drive signal with its RF output. The output of the phase detector is digitized and phase errors are read by a Z80 microprocessor which then calculates the heater settings. A low cost thermocouple temperature monitoring system provides a means of keeping the cavities approximately in tune when beam is not present. The thermocouple system incorporates an inexpensive 1MBit Manchester encoded digital link to collect digitized temperatures up to 1000 meters away using twisted pair cable. The hardware and software that effect the tuning loop control are discussed.

DRF1 Tuning System Overview

The Debuncher DRF1 RF system consists of six narrow band, high Q cavities which rotate the incoming antiproton beam in longitudinal phase space and two lower Q adiabatic cavities that perform post rotation debunching. These cavities momentum cool the tightly bunched, large momentum spread antiprotons that come from the Main Ring to the Debuncher ring at Fermilab.[1] The rotator cavities have a bandwidth of 10Khz and operate at 53Mhz.

A tuning range of 10^{-3} (ie. 50kHz in 50Mhz) can easily be accommodated by heating the beam pipe inside the cavities thereby changing the RF gap and hence the resonant frequency. Heating is achieved by eight 100 watt "bullet" heaters at the central ends of the beam pipes. Temperature stabilization is provided by 55 degree water which is circulated in copper tubing wrapped around the other ends of the beam pipe. The feedback loop for these heaters has the following operational considerations. The cavities are on only for a few hundred microseconds every beam pulse. The beam pulses are not necessarily regular instead they depend on what else is happening in the supercycle. The cavities may be off for periods of time. These considerations preclude a passive feedback loop to keep the cavities on resonance.

Figure 1 is a block diagram of the tuning loop hardware. For each cavity a phase detector compares the cavity drive RF signal with its output RF signal. The output of the phase detector is digitized using an ADC which can be triggered either with a timing signal or by the RF drive itself. This ensures that we measure the phase error between the drive and

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output RF at the correct time. These phase errors are read by the Z80 microprocessor in the DRF1 CAMAC-170 card which then calculates the heater setting. The heater value is converted into a 8 bit number which is used by the heater control cards to set the heaters on for a fraction of the two second DRF1 cycle.

The CAMAC-170 and CIA Crate

The hardware to implement the loop controller was adapted from equipment originally designed to interface the Fermilab Tevatron Vacuum system into the ACNET control system.[2] The intelligence for the system is in the two slot CAMAC-170 module. All input/output to the real world is through the Controls Interface Adapter (CIA) Crate. Five new cards for the CIA Crate were designed to handle the RF detection, eight channels of A/D conversion, thermocouple control, heater control, and solid state relay mounting.

RF Monitoring

The RF Detect module controls the sampling of the cavity phase outputs by generating the "start convert" command for the 8 Channel A/D module. It allows selection between an internally generated pulse developed from the cavitiy 53 MHZ LLRF drive or an externally generated timing signal developed from the Tevatron Clock. In the internal mode it utilizes the same discriminator circuitry employed by the Tevatron Serial Link and enables the A/D conversion to be initiated at any point within the 500 microsecond RF drive envelope.

The A/D module contains eight individual AD574, 12 bit converters used to digitize cavity phase information. Using one low cost, high accuracy converter per cavity allows all eight channels to be sampled simultaneously without the need for either sample and hold amplifiers or analog multiplexer circuitry and their associated errors. Once a conversion has been completed on all eight channels, nominally 25 usec, the A/D module sets a "new data available" flag which is sampled by the 170 module at a 3 HZ rate.

Heater Control

The Heater Control Module, in conjunction with two Solid State Relay Modules, is responsible for regulating the amount of 208 volt ac power delivered to the internal heaters of the DRF cavities. Each cavity's heater relay is energized for that portion of the Debuncher cycle time consistent with the amount of power requested as follows:

$$N \text{ (duration)} = (\text{Power} * 0.32) * 0.0083 \text{ sec.}$$

The relationship between the Debuncher cycle time (~ 2.13 sec) and the 60 cycle AC power (0.0083 sec) allows the requested power to be represented by an 8 bit binary number N. The magnitude of N corresponds to the number of half cycles of AC power the relay will be energized per debuncher cycle. The maximum power available is 800 watts.

The Heater Control Board's timing circuitry consists of a Hewlett Packard 3700 AC voltage sensor and a pair of synchronous up/down counters. They produce a 2.12 second cycle of 255 counts in 8.3 millisecond increments whenever 208 volt ac power is present. The outputs of the counter pair are compared to the requested duration count (N) for each cavity using eight independent identity comparators.

When the output of the cycle count reaches 255 (signaling the end of the previous cycle), new duration counts are clocked into the identity comparators. On the next transition of the counter all of the solid state relays are energized. Any relay that has a duration count greater than zero will remain energized until the output of the synchronous counters equals the requested duration count. At that time the relay will be de-energized until the beginning of the next cycle. New duration counts may be downloaded at any time however they do not become active until the end of a cycle.

Thermocouple System

Each of the cavities is equipped with five "K-type" thermocouples to monitor the beam pipe and RF electronics deck temperature. To avoid the expense of long runs of thermocouple extension wire and the associated electrical noise problems, a simple data collection system called the Thermocouple Remote (TCR) is employed. The thermocouples are connected to a remote unit that is physically attached to each cavity. This unit is capable of accepting up to six thermocouples, linearizing the values, multiplexing, converting to digital values, and returning status for each channel.

Communication to each TCR is by a 1 Mbit, Manchester encoded link that uses a single chip Advanced Micro Devices AM7960 Codec at each end. This link uses inexpensive twisted pair cable and is transformer coupled at both ends for noise immunity. To avoid placing microprocessors and memory chips in the low level radiation environment of the Antiproton Source tunnels, a simple set of sequencers programmed into fuseable link IFL devices is used.

Linearization of the thermocouples is accomplished with AD597 thermocouple conditioners. These conditioners incorporate the ability to detect an open thermocouple and provide a status output. The analog outputs are multiplexed and converted in a TLC540I analog to digital converter. The selection of these particular devices allows for a single 5 volt system at the remote location.

Each cavitiy is served by a dedicated multiple twisted pair cable. The TCR system utilizes two of the pairs in this cable. Data from all eight cavities are collected on the CIATC Module which allows the CAMAC-170 to obtain temperature values and status from the TC Remote Stations. Errors in any of the links are reported via the status byte from each channel and a semaphore is provided such that the 170 can request a test pattern for diagnostic purposes.

A GAS System

Software for the DRF1 170 was also built from an existing base previously designed to support vacuum systems. The communication protocol called GAS[3] was implemented to provide a uniform interface for exchanging data between smart modules and front-end computers.

Data collection within the processor is table driven. A configuration table is built describing the physical location of all card types to be accessed. For each card type, templates exist describing the addressing of control, status, and data items to be collected or set. At initialization, the DRF1 smart module uses these structures to build a table of addresses. All data collection will be driven at a 3 HZ rate from this table.

Collected data is formated into the described records for presentation to the user. GAS provides user control in describing which record items or blocks of items to return. Common elements such as an alarm monitor, are written once and easily interfaced to a variety of modules such as the DRF software.

Feedback Loop Control

The DRF CAMAC-170 provides the tuning feedback loop. Tuning is effected by setting a heater value called the DAC setting. When an rf cavity is tuned to resonance, there is no phase difference between excitation current and the voltage developed in the cavity. When a phase error exists it is used as an entry to a correction table to determine the proper heat value. This setting is loaded to the heater control card which in turn determines the on time of the associated solid state relay.

Each of the cavities has an independent loop. The user controls which cavities should be loop tuned. When a loop is disabled the average DAC setting will be sent to its heater.

The Tuning Algorithm

The algorithm for calculating the required heater settings can be simply stated as:

$$(\text{heat val})_i = (\text{ave val})_i + \text{func1}(\text{ err } i \text{ })$$
$$(\text{ave val})_i^{1} = (\text{ave val})_i^{1} + \text{func2}(\text{ err } i \text{ }).$$

The first part of this algorithm is a fast loop and corrects for minute to minute changes in the tuning of the cavities. The second part moves the average heater value much more slowly and is designed to automatically account for the environmental changes around the cavities or if one of the bullet heaters dies. The algorithm is implemented by having two look-up tables that represent function1 and function2. In this way fairly general functions can be loaded into the microprocessor.

Operational Experience

The cavities have a large heat capacity however all of the cavities can be tuned from a dead start in about 1-1/2 hours. When the cavities are tuned and running with a fixed frequency VCO, the cavity phases are kept constant to better than $\pm 1^{\circ}$, and the point to point variation for any particular cavity is better than $\pm 1/4^{\circ}$. The temperature variation is within 1°C.

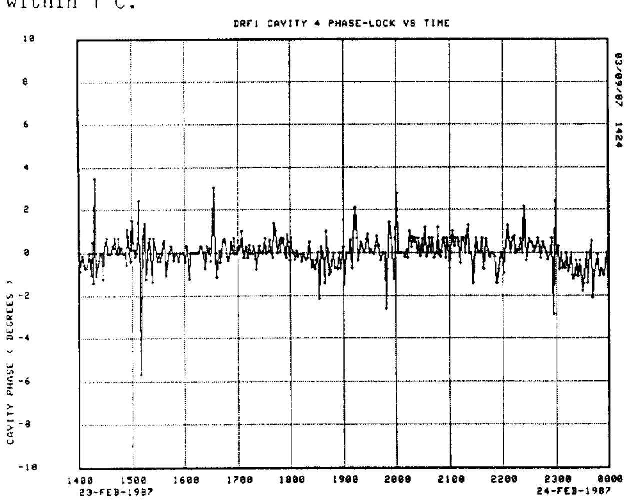

Fig. 2 - Phase Lock

Figure 2 shows the DRF1-4 phase when the system is phase locked to the Main Ring RF. Here the phase is maintained to within $\pm 2^{\circ}$. The extra excursion comes from the pulse to pulse variations in the main ring. The large spikes arise when there is no beam and the main ring to debuncher phase lock circuit goes to a limiting value.

Plans exist for addition of a thermo-couple feedback loop to keep the cavities approximately in tune when the rf drive is disabled. By regulating the heaters to the known temperature profile for a particular cavity, the tuning time can be minimized at system startup. This loop would be disabled, or used as a gross error backup, when the rf tuning system loop is re-enabled.

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