DIGITAL CONTROL SYSTEM FOR THE ISIS SYNCHROTRON MAIN MAGNET POWER SUPPLY

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Abstract

The main magnet power supply control system of the ISIS 800 MeV rapid-cycling proton synchrotron is described. With the machine currently operating with beam intensities in excess of 185 μA, acceptable performance is dependent on the stability of the main magnet power supply, and the performance of the closed loop systems used to control the supplies.

1. INTRODUCTION

On the ISIS synchrotron the dipoles, doublet quadrupoles and singlet quadrupole magnets are connected in series using a configuration known as a "White" circuit, see Fig 1. This circuit is resonated at the operating frequency of 50 Hz to reduce the reactive load on the make up supply. It also has the advantage of ensuring that the same current, (leakage current excepted), flows in all the magnets. A DC supply is used to bias the sinusoidal magnet waveform . This has the advantage of increasing the efficiency of the White circuit by reducing the total power requirement for the same change in magnetic field from injection to peak energy. The DC bias is connected by splitting and centre-grounding one element of the White circuit . For further information on the White circuit see [1].

The AC make up power supply is supplied to the primary of the White circuit , and the digital control system is used to ensure that the stability of the system is better than 1:1000 of the set value.

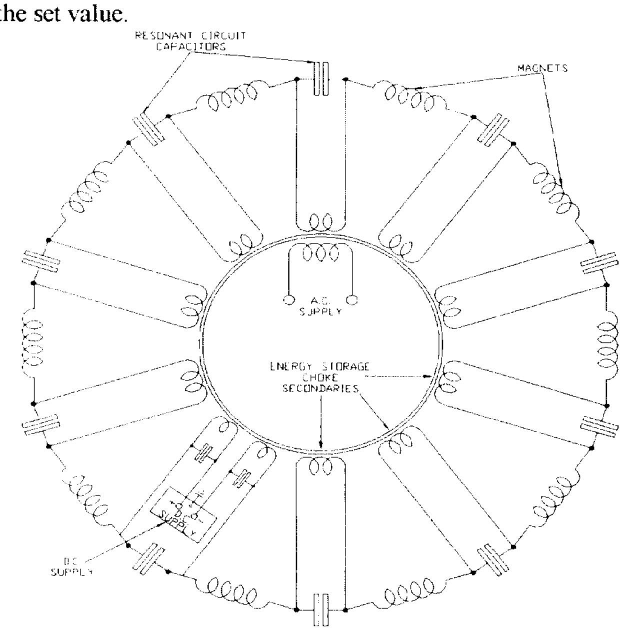

Figure 1. ISIS Ring Magnets 'White' Circuit Schematic

2. A.C. SYSTEM

2.1 A.C. Make Up Power Supply

The ISIS A.C. make up power supply consists of an A.C. single phase generator driven by a variable drive D.C. motor using a resilient coupling. The A.C. generator used has been converted to single phase from a three phase 50 Hz generator. The required drive to the D.C. motor is via two 400 kW A.C. to D.C. converters coupled in series. A variable voltage alternator rotor excitation supply, which is directly coupled to the rotor slip rings is then used to control the amplitude of the A.C. . A schematic diagram of this arrangement is shown in Fig 2.

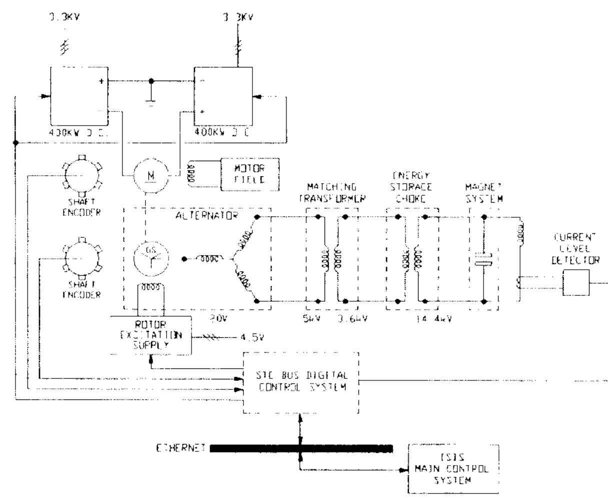

Figure 2. ISIS A.C. Make Up Power Supply

Control of the A.C. make up supply is via a system which utilises two separate closed loop systems to effect accurate control of the A.C. magnet phase and amplitude .

2.2 Single Phase A.C. Generator

The alternator used was originally a three phase 50 Hz generator. To enable it to be used as a 50 Hz single phase source the following modifications have taken place. The stator has been fitted with magnetic slot wedges, and copper plates and connecting rings have been fitted to the rotor pole tips.

These modifications have been undertaken to reduce the pole flux to a minimum. Without these alterations the resultant pole flux will produce at twice the operating frequency large losses in the rotor magnetic circuit, and induce high voltages in the field windings. The theory of A.C. generators and modifications for single phase use can be further studied in

[2]. Even with these alterations the remaining flux reacts with the excitation winding, generating a 100 Hz pulsating emf. (see Fig 3.). This emf. is superimposed upon the direct voltage output of the excitation supply. Therefore the rotor excitation supply used must be capable of withstanding a ripple current of approximately 20 Amps . Also any control system used for the amplitude control of the A.C. must also take this into consideration.

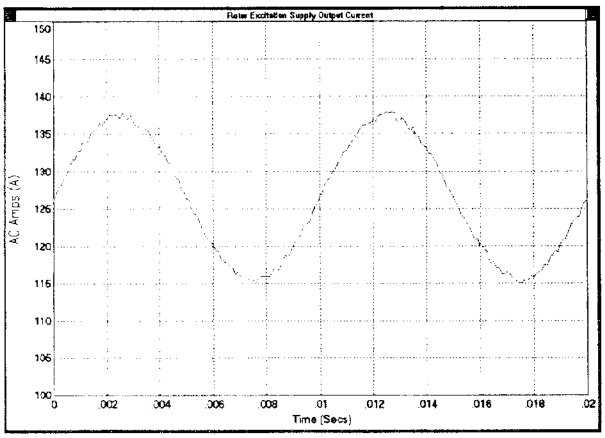

Fig 3. Alternator Rotor Excitation Supply Output Current

3. CONTROL SYSTEM

3.1 System Configuration

The control system consists of an STEbus IEEE1000 system using a Motorola 68000 16 MHz microprocessor, running 0S-9 real time operating system. The schematic of the system is shown in Fig 4.

STEbus was already in use for other microprocessor based systems on ISIS. This combined with the wide range of commercially available I/O and signal conditioning boards from a multitude of companies meant that , STEbus was an ideal and cost effective choice for the system.

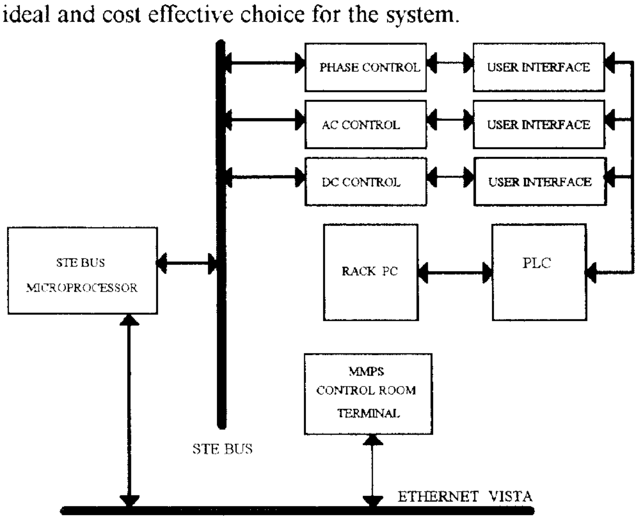

Figure 4. MMPS Digital Control System Schematic

The control system is required to provide a high degree of stability in an environment which includes rotating plant, magnetic fields , large power supplies and electric cooling fans. It is therefore safe to assume that any form of signal interference that can be thought of will be present, and must be eliminated from the control signals. Noise reduction techniques such as signal isolation , differential signals , shielded cables, signal ground and ground loop considerations, signal filtering and cable locations were all employed. There was no point in building a control system for 16 bit performance if the control signals picked up 50 mV of noise on their way to the power supply.

3.2 OS-9 Operating System

OS-9 is a multi-tasking real time operating system which was originally developed for the Motorola range of microprocessors. This means that as it was developed for the 68000 range , it can make optimum use of the devices capabilities such as interrupts, whilst optimising the code required in terms of code size and speed.

The interrupt driven aspect of the software means that code for updating the screen display, communicating with the user or ethernet, and dealing with interlocks need only be run when required. This allows the microprocessor to concentrate on the PID software loops for the phase and amplitude control of the A.C. waveform.

The real benefit from using OS-9 comes from its ability to multi task programs on a time sliced real time prioritised basis. These priorities determine the amount of CPU time allowed for a program and can be changed by the user or by the software itself. The software for sampling the feedback signals also uses the OS-9 feature of 'cyclic alarm'. These ensure that the signal sampling interval is fixed on a periodic time interval determined by the user. Further technical details of OS-9 can be found in [3] .

3.3 Phase Control

Phase control of the A.C. waveform is obtained by phase locking the feedback signal of a shaft encoder to a master oscillator. This control of the phase is performed in two stages. First the D.C. motor is run up to its normal 1000 rpm operating speed . When the motor has stabilised, the phase of the shaft encoder signal is compared with the phase of the master oscillator signal by a class 2 phase comparator on a phase locked loop IC. The output of the voltage controlled oscillator section of the PLL is then converted into a 16 bit digital representation of the phase difference.

This digital phase difference is then used as the error signal into the phase PID software loop. The demand to the converters which power the motor is then adjusted by the PID loop . This ensures that the phase of the A.C. waveform does not vary by +/- 0.25 Hz and is locked to the master oscillator.

The shaft encoders are free floating so that they survive any end thrust of the shaft due to magnetic centre off-set at motor start up and stop. Two encoders are located on the shaft , at the motor and alternator respectively. This is in case of failure of the selected encoder, but it also allows us to measure the degree of rotational twist in the motor alternator shaft.

3.4 Amplitude Control

The feedback signal for the amplitude control is derived from a direct current current transducer (DCCT), which is located in the magnet current line of one of the super-period elements of the ISIS 'White' circuit. This composite magnet current signal is filtered to extract the A.C. component, which is used as the error signal.

This error signal which is a 50 Hz sine wave is converted into a dc level representing the peak amplitude of the A.C. magnet current, by a peak detector and a 16 bit resolution sample and hold circuit. This circuit is refreshed at 50 Hz to ensure that a valid peak A.C. value is always seen by the PID software . See Fig 5.

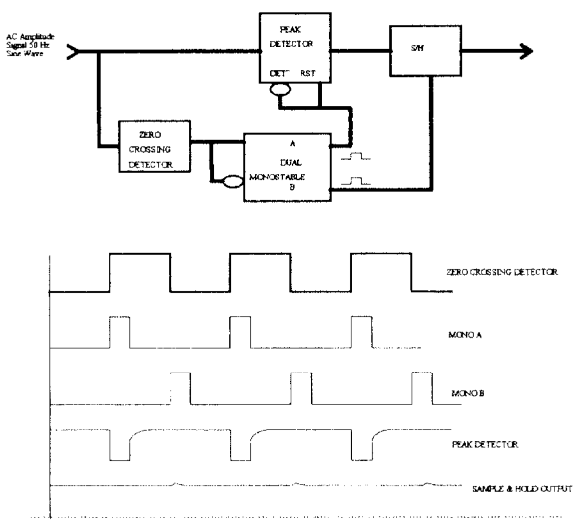

Fig 5. A.C. Amplitude Error Signal Generation.

The resonant magnet network has low intrinsic damping and excessive corrections by the PID loop to the amplitude of the A.C. can cause overshoot and subsequent damped oscillations. For this reason and to limit the effect of any noise on the error signal, the response of the PID loop is limited to a maximum error that it can correct.

4. SOFTWARE

4.1 General Software

The software is written in a modular format so that each block deals with a different aspect of the control system. This is to make full use of the multi-tasking interrupt driven aspect of the OS-9 operating system.

Each module is capable of operating as a stand alone program and has been written so that it does not interfere with the PID control loop software modules. The separate modules are linked via a common data module which is used to pass data from one module to another and for updating the screen displays.

4.2 PID Loops

The algorithm of a proportional + integral + derivative (PID) controller is shown below (Fig 6), along with its block diagram implementation. This use of a software PID system allows the user to tune the system whilst the plant is in operation.

$$c(t) = \frac{1}{Kp}\left[e(t) + \frac{1}{Ti}\int e \; d(t) + Td\left[\frac{de}{dt}\right]\right]$$

Steady State Gain = $1/Kp$. System Error = e(t)

Intergral Action Time = Ti . Derivative Action Time = Td

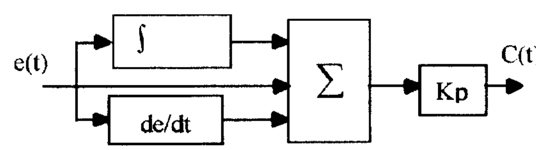

Figure 6. PID Algorithm & Block Schematic

The software version also allows coefficient settings that would be extremely difficult to implement accurately with discrete components on an analogue controller. These coefficients can be adjusted independently which is not always the case with the analogue version.

The nature of a software PID controller implies the use of sampled data. This has both advantages and disadvantages. The sampled data can be filtered to remove any noise or false readings before it enters the controller. However sampled data integration implies an approximation due to the non time continuous nature of the data. This subsequently introduces an error. The higher the order and complexity the integration algorithm is the smaller the error, but the CPU takes longer to compute the result. The integration algorithm used was selected on a trial and error basis of finding the simplest and lowest order which gave the required accuracy.

Another advantage of using a PID software module is that the separate blocks can easily be reconfigured to reduce certain types of system responses. Sensitive control to system fluctuations, but smooth changes to set point changes can be achieved by removing the deriative action from the set point . This reconfigures the controller into a IP-D system.

5. REFERENCES

[1] W. Bothe, Resonant Excitation of Synchrotron Magnets, in Proceedings of Power Converters for Particle Accelerators, Montreux, Switzerland, March 1990, pp 271 - 303.

[2] J.H. Walker, Large Synchronous Machines, Oxford: Oxford Science Publications, 1981, pp 232 - 237.

[3] Microware Systems Corp., OS-9 Manual ver 2.4, Des Moines, Iowa, March 1991.