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A MINI-COMPUTER BASED DIGITAL RF CONTROL SYSTEM FOR THE ZGS*

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Abstract

The system includes a high-resolution, field-dependent RF frequency program generator, an optically coupled digital-to-frequency converter, and a fast-sampling frequency monitoring section. The frequency program originates as a 500 point field-indexed table of frequencies. Off-set, gain, non-linearity correction, and operator control are provided by software. Linear interpolation between break-points is accomplished by dedicated arithmetic logic to provide frequency updates as often as every 20μ s. An optically coupled digital-to-analog, (D-A) converter controls the 4 to 14 MHz output of the RF section. The output frequency is monitored by a fast sampling, high accuracy logic system, whose output is fed back to the computer for comparison to the desired program.

Introduction

The original master oscillator (MO) in use at the Zero Gradient Synchrotron (ZGS) is a 15 break-point diode function generator driving a vari-cap oscillator. The break-points are manually adjusted in gain and magnetic guide field level. Since the transfer function of the diodes matches the desired curve fairly well, relatively few break-points are needed. However, the setting process is a long and laborious one when dealing with a new or unknown set of accelerator conditions.

Since several different modes of acceleration are being considered for the ZGS in the near future, a more versatile, more reliable, and easily changed method of MO function generation was desired. These new modes are: injection from a booster at 500 MeV (instead of 50 MeV) and acceleration on the 4th harmonic (instead of the 8th); acceleration of deuterons (and/or polarized deuterons) which require a shift in harmonic from 16th to 8th during the acceleration cycle.

Design Objectives

To obtain the desired degree of flexibility, it was decided to use a digital technique. Besides the obvious advantages in ease of modification and storage of different functions, a computer could be made part of the total system. The computer could then aid in the manipulation of the function, perform some seemingly intelligent tasks such as linearization and learning, and provide controls and readouts of useful parameters in understandable terms.

Whenever a D-A converter is used to simulate a curvilinear function, the number of steps (in what is essentially a "staircase" output) should be as high as possible. This is of course coupled with the usual and conflicting desire to use as little memory space as possible.

A method must be provided to compensate for gain errors, non-linearities, and other distortions caused by system components encountered both during and after the D-A conversion. The system should also have the capability of "learning" a frequency program that is corrected by external means such as beam-position feedback and then providing this "learned" function on the next accelerator cycle. Both of these requirements necessitate the measuring of the final output frequency to an appropriate accuracy in a time comparable to the function break-point time.

Final System Configuration

The final configuration of all major system components is shown in Fig. 1. Precise timing (guide field dependence) is provided by a bi-polar voltage-to-frequency (V-F) converter. The input voltage is obtained from $\dot{B}$ coils located in the accelerator guide field magnets and provides an output frequency of 1 MHz at the nominal maximum $\dot{B}$ of 20 kG/s, (corresponding to a resolution of 0.02 G). The V-F outputs are integrated by an up-down counter called a field clock. The field clock is calibrated (preset) at 433 G by a pulse from an electron resonance probe and provides precise real-time guide field information to control the function generator as well as providing the computer with field values for interrupt-driven measurements and displays.

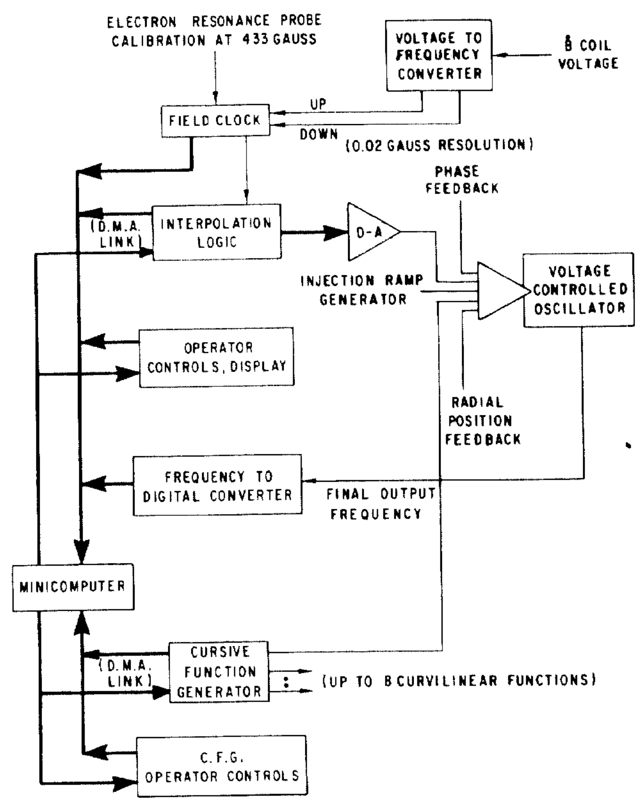

Fig. 1. Computer based RF control system block diagram

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Function Generator Design

In order to meet the objective of maximum digital resolution with minimum memory usage, the function is generated by an arithmetic unit which performs a linear interpolation between frequency values obtained from memory. Moreover, since the frequency and rate of change of frequency are changing more rapidly (and are more critical to beam capture and acceleration) during the early part of the acceleration cycle than during the latter part, a dual resolution system is used. Up to 1600 G (or about 450 MeV) memory break-points are 12.8 G apart while after this point they are 51.2 G apart. The interpolation logic further divides these intervals into 32 parts or 0.4 G steps for the high resolution portion and 1.6 G steps for the remainder. Thus with only 500 memory locations utilized for the final output array, frequency updates as often as every 20 μs are provided.

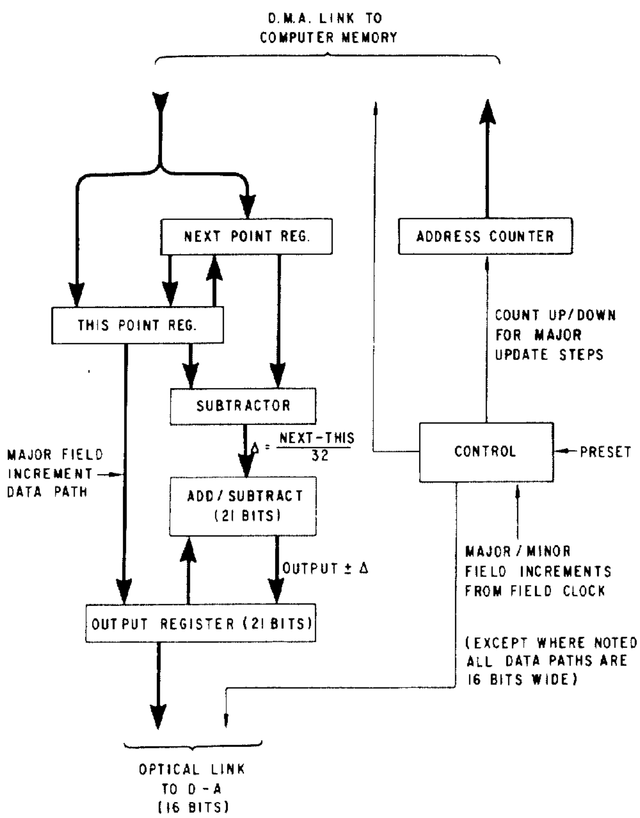

Fig. 2. Digital function generator interpolation logic

Figure 2 shows the principle components of the interpolation logic. Frequency data are obtained from the computer memory via the direct memory access (DMA) channel with the address counter being controlled by the appropriate signals from the field clock depending on the resolution employed. The "next" and "this point" registers contain frequency data for adjacent break-points and are used to obtain the interpolation increment. The extra data paths between these registers are necessary because the system must be able to track guide field up as well as down (as in the case of flat-top or intermediate "front porch" programs where the field slopes up or down for targeting requirements). The address counter must also track the proper memory addresses in the same way. The interpolation increment is divided by 32 by shifting the wiring 5 bits, but all resolution is retained so that output register adjustments are carried to 21 bits. All frequency data is carried with 16 bit resolution (matching the computer memory and D-A converter) resulting in a least bit resolution of 152 Hz (since only the 10 MHz range from 4 to 14 MHz is controlled).

In order to reduce unwanted noise transferred both from the digital section into the highly sensitive front-end amplifiers and from the RF amplifiers into the digital logic, optical isolators are used to transfer data to the 16 bit D-A converter which is located in a temperature-controlled and electrically shielded enclosure. The converter is provided with a "de-glitcher" which removes the binary roll-over switch transients by holding the analog output while the transients occur and then following the new output.

Other inputs to the voltage controlled oscillator (VCO) are: phase feedback to provide bunch stability; the injection ramp generator which provides a 200 μs ramp to match the changing frequency program to the constant energy injected beam; radial position feedback which will maintain beam position in a central orbit or any desired position program; and one or more inputs from a multi-channel cursive function generator (CFG) which can be used for open-loop frequency control or through radial feedback as position control. The CFG is similar in design principle to the above-described system in that it uses the computer DMA channel to obtain data to generate arbitrary curvilinear functions. The functions are of much lower resolution however and extensive operator controls are provided for their generation and manipulation.

Frequency to Digital Converter

The output frequency is measured by a short sample time, high speed logic system. Upon receipt of a trigger pulse from the computer, (or from the function generator logic in the case of a total frequency map) the next positive zero crossing of the unknown frequency enables two counters. One counter totals the number of cycles of the unknown frequency, while the other counts the output of a high stability 100 MHz oscillator. This oscillator is resynchronized at the zero crossing time to reduce the uncertainty due to the two asynchronous frequencies. After a present sample time, the next positive zero crossing of the unknown frequency will disable both counters. After interrupting the computer, the two counter states are transferred to the computer for calculation of the frequency:

$$F_x = \frac{C_x}{C_s} \times 10^8$$

where

F_x = unknown frequency
C_x = number of cycles of unknown frequency
C_s = number of cycles of 100 MHz oscillator

Tests of this system have shown measurement accuracy of better than 0.01% with a 100 μs sample time. Since the break-point spacing is about 640 μs for the high resolution portion of the function; the hardware/software system can provide corrected frequency programs in time for implementation on the next acceleration cycle.

Operational Features

Linearization

When first initiated, the computer provides a frequency program corresponding to the theoretical relationships involved, but due to gain errors and non-linearities in various components this program is not actually obtained. With all other auxiliary inputs removed from the VCO, the computer linearizes its program by measuring output frequency and providing appropriate corrections to each break-point value. This is done essentially in real time with the corrected program available on the next acceleration cycle.

Learn Mode

Of course, this program is not expected to be optimum for accelerating beam for a large variety of reasons, some of which are never well understood. After beam acceleration is achieved through the use of beam position feedback and other closed and open-loop VCO inputs, the computer can be instructed to learn the resultant frequency program. The frequency measuring procedure is the same as that used for linearization, but the software has the additional task of "de-linearizing" the frequency map. To do this it uses the previously obtained relationship between theoretical and required programs obtained in the linearization process. At this point all open-loop VCO inputs are removed and progress checked.

Controls

Figure 3 shows the front panel controls of the digital MO function generator. The only two operator controls provided to influence the generated function are gain and offset. These are essentially traditional operations found to be useful in tuning the ZGS and the software enables these controls to emulate their analog counterparts. These lockable controls drive optical incremental encoders, (instead of potentiometers) which through interrupts enable the computer to maintain these parameters in software.

The digital read-out and selector switches allow the computer to provide read-outs of the above two parameters, (gain and offset frequency) as well as measured and theoretical frequencies at a variety of trigger times. Guide field values can also be read, with the computer providing all necessary translation and scaling so that read-outs are in kilocyles or gauss.

Other controls such as those which initiate linearization and learning, the off-line storage or retrieval of functions, and those which provide various self-test and diagnostic features are located inside the chassis to avoid their accidental activation.

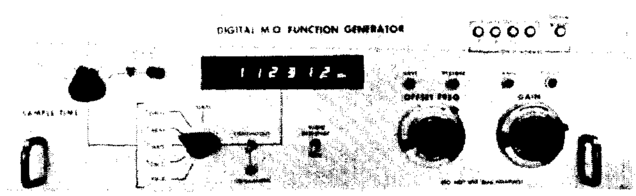

Fig. 3. Digital function generator control panel