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A MULTIPLE FLATTOP CONTROL SYSTEM FOR THE FERMILAB MAIN ACCELERATOR POWER SUPPLIES

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Introduction

The Fermilab Main Accelerator was originally designed to operate with a bending magnet guide field consisting of an injection period, a linear acceleration period, a single extraction period called a "flattop" and an "invert" or recovery period.[1] The same cycle would then be repeated at a fixed repetition rate. The main power supply system was designed and has been operating under those constraints for several years. With the advent of additional beam lines and numerous experiments, the single extraction energy and repetition cycle has become restrictive and wasteful of energy and accelerator operating time. The nonregulated recovery period has resulted in difficulties with injection remnant fields. The existing hardware consisting of individual waveform generators for each power supply was not sufficiently flexible to allow for variations in the number of flattop periods per cycle or variations cycle to cycle.

A new program to control the main accelerator power supplies was undertaken to provide sufficient flexibility to generate multiple "flattops" and multiple cycles with detailed shaping and regulation of the recovery period. A further goal of the new program was to make generation of a new program simple and fast.

General Description

The main accelerator power supply system consisted of three separate control systems.[2] The bending magnets which are regulated to an energy program, and two independent quadrupole systems which are regulated to the bending magnet energy and the desired tune of the accelerator. The power supplies of each system are interlaced between equal numbers of magnets. Each of the supplies is controlled by sequentially phasing it to its maximum voltage as required to produce the desired fields. Only one power supply is being controlled at a given time and is phased from a bypass condition to its maximum voltage. Previously this sequential control was accomplished by use of individual hardwired waveform generators associated with each power supply. The output of the generator was determined by computer set breakpoints and amplitudes. The waveform generators were built with four breakpoints and two amplitudes. This system proved to be very inflexible under operating conditions due to the limitations on the number of breakpoints. Although the original breakpoints were computer generated, a great deal of fine tuning was required to generate the optimum overall program. Changes to the old program were time consuming and multiple flattops and multiple cycles were virtually impossible.

Super Waveform Generator

Over the years of operation of the accelerator it became apparent that the MAC 16 microcomputers used for power supply regulators and communication were very reliable and the digital transmission system around the main accelerator resulted in no operational difficulties.[3] It was reasonable, therefore, to replace individual waveform gnerators with a central computer and a transmission system. A single computer which we refer to as MAC-C could operate as all the individual waveform generators providing each supply with the phase information required. Since there is a direct relationship between the phase angle of a power supply and its output voltage the computer need only know the required voltage. The required voltage for a given program is stored on the computers disc memory in terms of the voltage required for every 1/720 of a second. This stored voltage program called the profile represents the total voltage needed to generate the required field program. The profile can be calculated knowing the inductance and resistance of the magnet system and the power line voltage and system source impedance. The profile is calculated off-line to a specified program and is stored on the MAC-C disc. The disc is capable of storing five separate 12-second cycles. This off-line calculation can be made to better than 1%. To correct for power line voltage changes and imperfections in the calculations, the profile is updated by a self-correcting function generator which utilizes the errors arising from previous cycles to update or improve the accuracy of the present cycle (Figure 1). Since the turning on of supplies is a sequential system with the next supply phased on when the last supply has reached its maximum voltage, conversion of the profile to the required power supply and phase angle is straightforward. The total voltage is divided by the nominal voltage per supply which gives the supply number and a remainder. The remainder can be converted into a phase angle (Figure 2). With some attention payed to ensuring that the supplies are fully phased on or bypassed the algorithm to change the remainder to phase angle is by use of a phase table (Figure 3). A power supply list can convert the power supply number to an address of the supply to be phased. Since only one supply is operated at a time only one output is required per system. However, to facilitate the use of a fast feedback loop the first supply is not phased full on but is phased to about 100 volts of full output voltage. The output of this supply can then be changed to take care of small fast changes in the system. Both the bending magnets and the quadrupole system utilize this control.

Transmission System

An equally important element of the new power supply system is the transmission system. Since it must faithfully carry all the information from the MAC-C computer to the power supplies it must first of all be very reliable. Not only must it be reliable but it must also take corrective action in the event of a transmission error or a failure of itself or the computer driving it. The power supplies are located in 24 different service buildings around the main accelerator separated by a distance of approximately 800 feet. Communication to the buildings is by a serial transmission line (Figure 4).

Each building contains a transformer coupled repeater which isolates the repeater from the ground potential of the adjacent service building as well as conditions the words being transmitted. A word consists of 27 bits of which 16 are the data bits and the remaining specify the service building address, power supply address and word status. The words are sent at a 10 kilocycle rate with a 1 megacycle bit rate. The line is loaded by the computer through a first in, first out buffer memory which allows the computer to put up to 64 words into the buffer at anytime whether or not a trans-

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mission is in progress. The words are automatically sent out on a first in, first out basis. The word is transmitted around the accelerator and is received back again for error checking. If the word that is received does not agree with the word which was sent or if the parity of the word is even or the addressed power supply does not acknowledge the receipt of the data it is considered an error. If an error occurs the same word is retransmitted and the transmission loop proceeds to the next transmission. If errors continue to occur in excess of a set number, the transmission loop will lock itself off after commanding all supplies to go to a bypass state. The computer is notified of the errors and where they occurred.

To ensure against a break or failure of the transmission system or the computer failure the power supply drivers are designed such that if no new data or a "stay alive" command is not received within 4 milliseconds the power supply will automatically go to a bypass condition.

The error detecting hardware and the "stay alive" command are the hardware assurance that under a failure mode the power supplies will return to a safe operating condition. The design of this equipment was done by W. De Luca of Fermilab.

Computer Software

The software is divided into two separate computers known as MAC-C and MAC-B. Two computers are used because the instruction execution time is too slow to do all the calculation in only one computer. MAC-C's program, which was written by D. Jong, is primarily devoted to the super waveform generator and program storage. Disc accessory, profile convertion and outputs are its primary functions. The second computer MAC-B, program written by P. Dougherty, is used to convert the measured information from the magnets fields and currents into energy and tune. The converted measurements are compared to the programmed values provided by MAC-C and an error signal is generated. From the error MAC-B generates a fast feedback output to be used by MAC-C. MAC-B also generates the updates which are used to correct the profile. The two computers communicate by a parallel connected first in, first out buffer in order to allow each computer to operate at maximum speed.

Operation

The operation of the new program has been extremely successful. Multiple flattop programs with complex slope control can be generated off-line and stored on the MAC-C disc without interferring with normal operation. Switching to the new program or any other stored program can be accomplished without losing an acceleration cycle. The fields for quadrupoles and bending magnets are regulated throughout the cycle with no hand corrections or trimming needed. The remnant field problems have been eliminated due to the repeatability of the acceleration cycle.

The updates automatically take care of the power line voltage changes so that no interaction with the operators is required. The point-by-point programming makes it possible to program almost any conceivable acceleration cycle or sequence of cycles. The computer and transmission system have demonstrated their reliability with effectively no operational difficulties.

References

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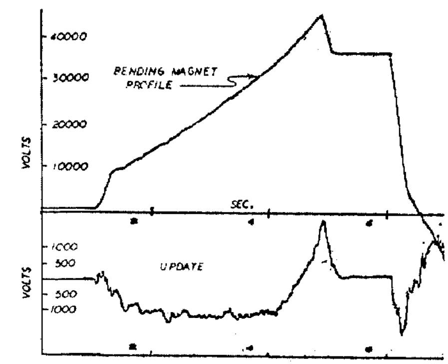

Fig. 1. 380 GEV MAGNET VOLTAGE

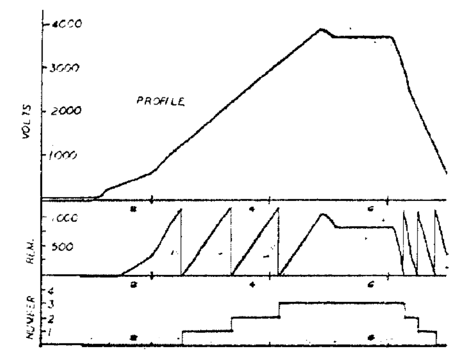

Fig. 2. 380 GEV QUADRUPOLE PROFILE

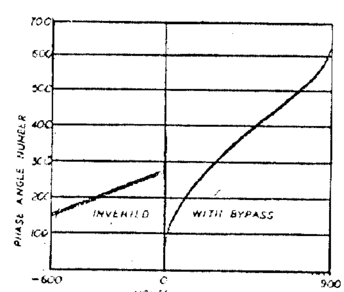

Fig. 3. VOLTAGE TO PHASE ANGLE

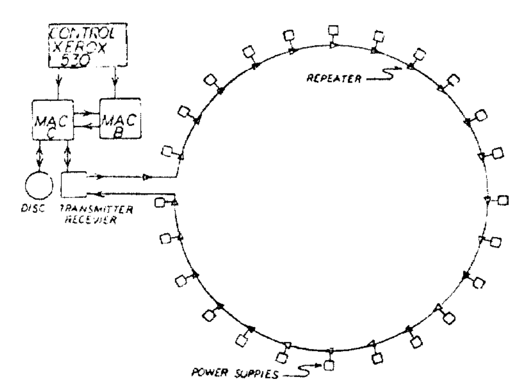

Fig. 4. CONTROL ONE LINE