FUNCTION GENERATOR FOR VOLTAGE RAMPING OF A LEP RF ACCELERATING UNIT.

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Summary

Each of the eight presently installed RF units of LEP contains a function generator which can be loaded with a desired voltage ramp function. Once loaded repetitive ramping and ramping down are controlled by timing events and simple commands from the control system. The function generator hardware is in the form of a 6U G64 module, contained in one of the digital control crates which handle the low level system of the RF unit. The ramp is loaded as an array of up to 800 fixed interval samples of the desired function. The function generator output is generated digitally by incrementing a 12 bit DAC according to a sequence of rate values calculated at download time and stored in dual port memory. The hardware design ensures that LSB increments are spaced regularly. Software for loading the function generator ensures that rounding errors are not cumulative. The accuracy of the function generator for the constant synchronous tune function normally used is better than 0.1 per cent of maximum level.

Introduction

Acceleration of beams in LEP [1] requires synchronous ramping of magnet power converters and the RF system. Power converters are ramped to maintain a linear energy increase and constant tune. The RF voltage must increase to compensate increasing synchrotron radiation losses during acceleration, and at the same time maintain specified synchrotron tune (Qs) to avoid harmful synchro-betatron oscillations. The RF system is made up of 8 accelerating units which are essentially independent, apart from their common frequency source. The RF voltage of all units is made to increase synchronously such that the total voltage ramps according to a predefined function. Each unit is provided with a function generator which can be downloaded via the general control system. Ramping for all units can be started or stopped simultaneously by events sent over the general machine timing system (GMT). The function generator also returns the RF voltage to the starting level in preparation for the next acceleration (rampdown).

The ramp function for the RF unit is expressed as an array of samples. These are the values which specify the value of the RF level in % of maximum at T second intervals. Between these specified values the level should vary linearly. The value of T is dictated by the power converters. They can take new function slope values (vectors) and respond to timing events at the end of 256 millisecond intervals during the ramp. For compatibility this is taken as the value of T. This gives more than adequate resolution for the control of the RF voltage during the ramp. A ramp from 20 GeV to 50 GeV beam energy is done in 240 intervals. The total time thus taken would be 61.5 seconds. However ramping is normally done more slowly because of magnetic effects in the vacuum chamber and the possibility to slow the ramp down by factors of 2,4, and 8 is required.

RF Voltage Control in an RF Unit

The RF unit, comprising 16 coupled cavity assemblies, is powered by two 1 MW CW klystrons. Klystron output power is controlled by varying the voltage on a modulating anode via a tetrode. An amplitude control system [2] drives the modulators, via a feedback loop, such that the summed detected RF voltage of all the cavities can be set by a variable reference level. The function generator drives this reference and therefore controls the total RF voltage of the unit. The precision of the RF voltage control is of the order of 1 % of maximum. The maximum possible rate of ramping of the voltage is determined by the feedback loop and is approximately 20 % of maximum per second. In order to ensure that no performance limitation is introduced by the function generator it should have 0.1 % resolution and allow a maximum ramp rate of at least the maximum allowed by the loop.

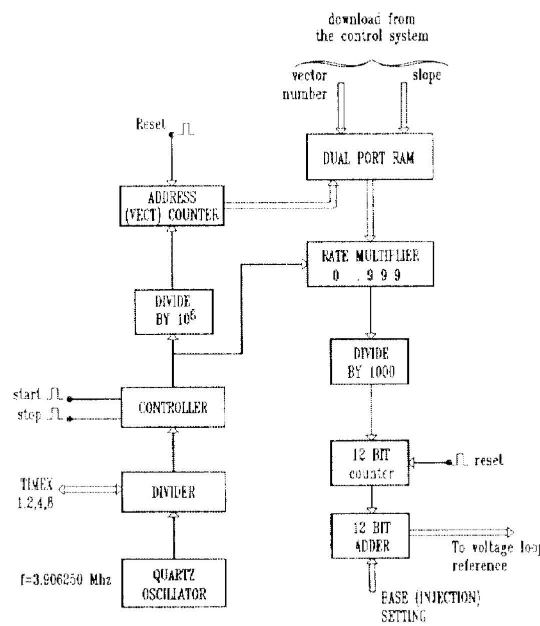

Figure 1: Block Diagram of the Function Generator

Function Generator Hardware

The function generator is a competely self contained hardware module in the form of 6U Eurocard with a G64 interface. It is placed in one of the Equipment Controllers (ECs) [3] dedicated to control of low level electronics the RF unit. The EC provides the interface to the control system required for setting up and loading of the function generator. There are two parts to the reference level supplied by the function generator to the amplitude control system. A fixed base (injection) level, independent of the ramp state, is set by the low level EC. The base level can be set directly or slowly ramped to the appropriate injection level by internal software in the EC. The dynamic contribution of the function generator proper, zero at injection energy, is added to this. Once the function generator is loaded the ramp is entirely independent of the EC and can be controlled directly by timing events from a LEP GMT timing module.

The ramp function is produced digitally with 12 bits binary resolution. Rather than setting the ramp function sample values directly at the start of each period, the ramp function is generated by regularly incrementing a counter during the interval, at a predetermined rate, to produce evenly spaced Least Significant Bit (LSB) increments. This ensures that the increment is never more than one LSB at a time and that the error is never greater then one LSB. This corresponds to 0.025 % of maximum range and is well within than the required resolution.

The quantity of interest over each interval is the rate at which the counter must be incremented. Local software in the EC takes the array of ramp function samples, calculates the corresponding array of rate values and stores them in a dual port memory. The memory allows storing of up to 1000 values. During the ramp these rate values are clocked out of memory at T second intervals o a three stage decade rate multiplier. This determines the rate at which fixed frequency pulses from a quartz oscillator are fed to the output counter. Since the rate multiplier produces an irregular pulse train an input frequency 1000 times greater than the required maximum rate is used. This, divided by 1000 at the output, results in an even pulse train at the specified rate. The oscillator frequency used is 3.906250 MHz., This is divided by 10^6 to give the required 256 millisecond period for controlling the dual port memory. The maximum rate at which the output counter can be clocked is 999 bits per interval. With the 12 bit binary output resolution used this corresponds to a rate of 100% of maximum per second, well above the maximum rate which the RF can be ramped.

Control of the function generator is principally by the GMT timing events. Start and stop events, via simple control logic, enable or inhibit the clock to the rate multiplier and interval counter. A general reset resets all counters and dividers. Provision is made for automatic stop at the end of the ramp, Use is made of a spare bit in the data words which store the rate values in the dual port memory. This can be set for the last sample of the ramp. When detected during the ramp the control logic generates an internal stop event at the end of the interval.

Stretching of the overall function for slow ramping is accomplished simply by dividing the oscillator clock by a setable fixed 'timex' factor, i.e. 1, 2, 4, or 8.

The rampdown of the RF back to injection level for the next acceleration is accomplished by loading a linear downward ramp starting at a given interval (800 is arbitrarily chosen) and positioning the memory address counter at this value. Rampdown starts when a start event is received. At the end of rampdown a reset is generated and the address counter positioned at the start of the ramp. The memory is not cleared, and the function generator is immediately ready to repeat the another ramp without re-downloading.

Loading of the Function Generator and Software

Software for the loading and control of the function generator is at three levels.

1) Application program software at the level of the Prévessin Control Room (PCR) consoles which prepares the ramp for the RF system and produces the ramp sample arrays required for the units.

2) Software in the Data Manager (DM) which interfaces the RF unit to the control system to pass the sample array and control commands to the EC containing the function generator.

3) Software in the EC which controls the function generator, calculates the rate values and loads them to the function generator hardware.

There are two ways in which application programs in the PCR can obtain the total voltage function for the ramp. The ramp for the machine is defined as a series of 'ramp states' which specify the files containing settings for all power converters at various energies, typically at 5 GeV intervals. Files containing total RF voltages are also specified. An application program can use linear interpolation to obtain the voltage function. Alternatively calculation of total voltage can be done directly by the program using, for example, a constant Qs criterion, the value Qs being specified by the operator. Information on machine parameters is taken from the LEP optics data base and operating conditions from the LEP run table. In both cases the arrays of sample values required by the RF units to enable them to provide the overall function are calculated and sent down. Operational states of the units and maximum available voltages, from the RF reference data set, are taken into account in these calculations.

A typical ramp function which is downloaded to an RF unit for a constant Qs ramp is shown below.

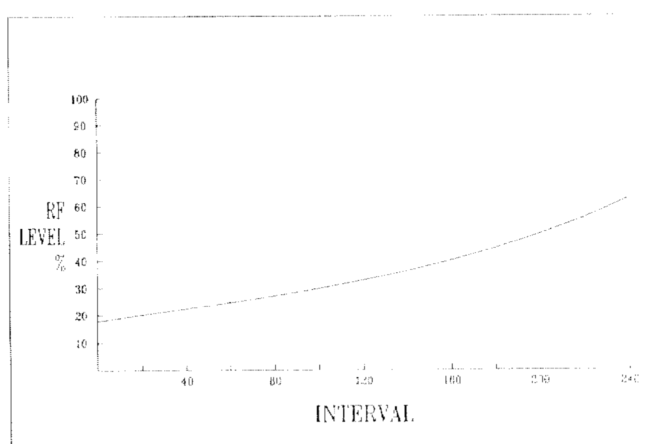

Figure 2: RF Unit Ramp Function for Constant Qs Ramp (Qs = 0.082)

The main role of software in the DM is to allow the array of ramp values sent by the application program to be transmitted to the EC containing the function generator. The function, after being sent to the DM can be read back for checking by the application program. The DM can also calculate simulated constant Qs ramps for local testing of the function generator and test ramping of the unit. The ramp samples are sent by IEE488 bus which links the DM and the EC. Software in the EC calculates the required array of rate values required for the dual port memory. Since the function can only be set with a resolution of one LSB any resulting error is taken into account for the calculation of the value for the next interval. This avoids cumulative errors. The slow ramp of the base setting is carried out by the EC. The EC can start, stop and reset the function generator independently of the external GMT timing. The rampdown is generated in the function generator by a single command to the EC. The rampdown is done linearly at a fixed rate. The EC calculates the number of intervals which will be required depending on the current level and loads the rate values starting at the rampdown interval. The address counter is the set to this value to await the start event which will initiate the rampdown. Since the rampdown remains permanently loaded after the end totally cyclic operation, independent of control commands, could easily be implemented.

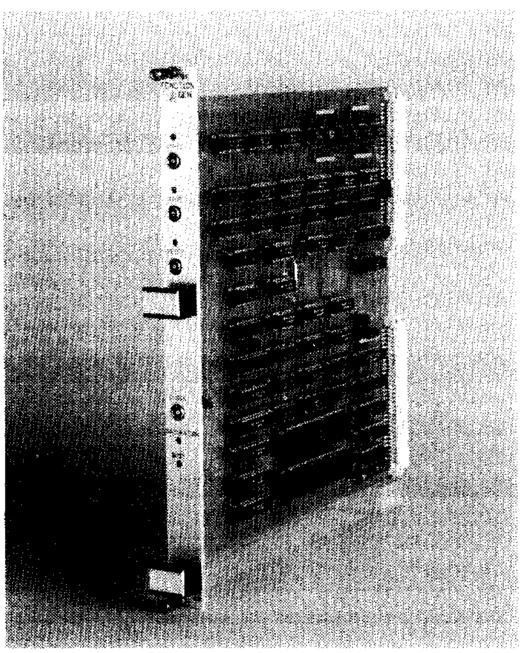

Figure 3: Function Generator Module

Tests on the accuracy of the function generator were carried out during development. The functions used were constant Qs functions like the one shown above. Measurements were carried out by measuring the actual voltage produced on a DAC and comparing it with the ideal value at many points during the ramp. Points in between T second intervals were also taken. All values were within one LSB of the ideal (0.025 % of maximum level).

Extensive Pascal based software has been written to permit testing of the function generators before installation and to aid fault finding.

Conclusions

The function generators for RF voltage control of the accelerating units of the LEP RF system permit synchronous ramping of all units. The manner of operation is consistent with the strategy for energy ramping in LEP and is compatible with the mode of operation of the magnet power converters. Rampdown is provided and totally cyclic operation is possible. Dynamic variation of RF voltage is not limited by the function generator and any function which can be followed by the voltage loop may be programmed. The upgrading of LEP to higher energies with the addition of new RF units containing superconducting cavities will, in addition to voltage function generators, require function generators for dephasing of RF units and cavity retuning for Robinson instability during the ramp. The function generators described are suitable for both applications.

Acknowledgements

The original development of the function generator and EC software was carried out by M. Dietlemeier, who worked as a technical student at CERN for 8 months in 1986. He also carried out extensive testing of the function generator and set up the measurement system.

References

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[2] P. Brown, E. Ciapala, S. Hansen, E. Peschardt and J. Sladen, "The LEP Radio-Frequency Low Power System", **IEEE Trans. Nucl. Sci.**, Vol. NS-32, p2032.

[3] E. Ciapala, P. Collier, M. Disdier and S. Hansen, "The Distributed Local Control System for a LEP-RF Unit", paper presented at this conference.