HIGH PRECISION DIGITAL LOOP FOR STABILIZATION OF UNK PULSED MAGNET EXCITATION

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Abstract: The results on the development of a high stable pulsed power supply based on a widely used principle of a capacitor discharge in inductance circuit are presented. Current stabilization problems for magnet excitation of the UNK injection channel are complicated because of long cable lines and the refusal of water cooling in magnet windings. A current amplitude stabilization at the level of $\pm 5 \cdot 10^{-5}$ is ensured by digitizing and handling of current probe signal and by use of digital feedback according to the dedicated algorithm. A precise charging supply regulator, high resolution ADC and DAC are described. The structure of a current stabilization loop, the digital feedback algorithm and the experimental results illustrating the accuracy parameters of the designed pulsed power supply are given.

Pulsed magnetic optic elements (MOE) having the required field amplitude stability of the order of tenth and hundredth of percent are widely used in accelerator fast ejection and beam transfer systems. The exciting MOE current pulses are usually formed by storage capacitor discharge via their coil. In most cases a charge/discharge cycle, including stabilization of capacitor battery charging voltage, should be equal to the fixed time slot as short as a part of a second [1]. An exciting current amplitude repeatability from cycle to cycle for such device during long time is restricted mainly by a temperature drift of the discharge loop parameters. A long time exciting current stability better, than 0.1 % cannot be obtained without a MOE coil and transmitting line thermostating.

A set of MOE's in the UNK injection channel requires essentially higher pulsed exciting current stability. However, to obtain such a stability level with a considerable length of transmitting lines up to 0.5 km, feeding the tunnel magnets from the surface buildings is a complicated problem. It has been successfully solved using digital current feedback principle, based on a microcomputer [2]. According to this principle, the current stabilizer operates simultaneously with a charge/discharge cycle, making reference voltage corrections into a charging supply regulator before a next cycle (fig.1) proceeding from the results on the previous measurements of the exciting current amplitude. Thus, systematic errors and slow fluctuations of parameters are compensated in circuits with stabilizing feedback.

As a result, a long time current amplitude stability is affected mainly by a driftage and a sensitivity of a current/digit conversion link. A stabilization loop has also its own noises, not eliminated by a feedback, in the form of errors in prediction, discreteness and conversion into a charging voltage, which cause a cyclewise spread of discharge current amplitude. The high-stability ADC, the algorithm of a reference voltage correction with respect to a driftage speed, high-resolution DAC and the precise charging supply regulator have enabled to obtain a long time stability and a 0.005 % cyclewise spread of the current amplitude.

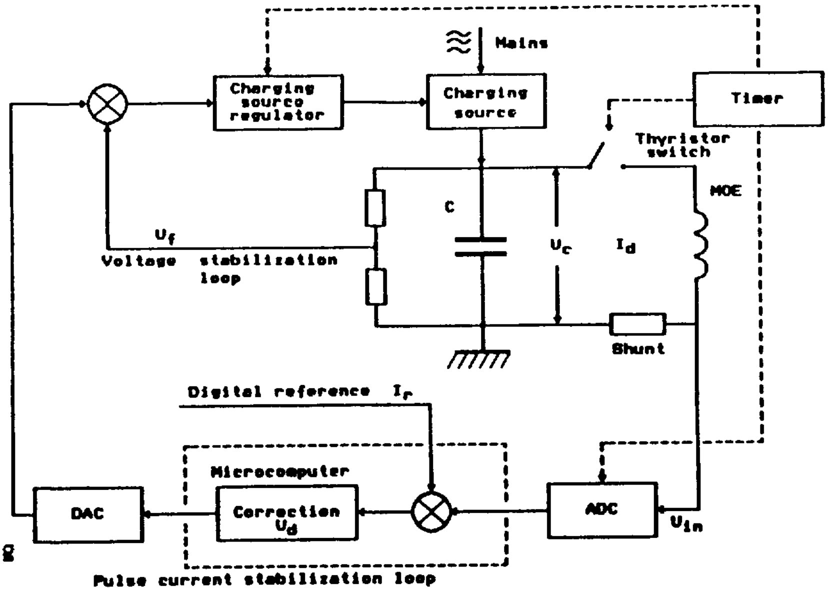

Fig.1.
Functional diagram for MOE exciting current stabilization

The ADC is the unit providing the source precision and stability. The converter is built in accordance with the known principle of charging the capacitor during a short-time sampling up to the level of the voltage to be measured and afterwards discharging it by DC to a certain fixed level (-100 mV in this device). A discharge time interval proportional to the measured voltage is filled with pulses with a quartz repeating frequency. The ADC measures 3 voltages with a 100 ms interval: U_{in}, U_r, and finally, U_o. A microcomputer reads out these values and corrects the measured results computing:

$$U_x = U \cdot \frac{U_{in} - U_o}{U_r - U_o} ,$$

where U is the calibrated value of a reference voltage.

An ADC resolution is equal to $5 \cdot 10^{-7}$ of the full range of the measured voltages. The temperature drift of an internal reference voltage doesn't exceed $1 \cdot 10^{-6}/^{o}C$, and its stability exhibited during 1000 hours is as good as $20 \cdot 10^{-6}$. A precise manganinum shunt, compensated by a copper insertion, is used as a probe of discharge current. The temperature resistance coefficient of the shunt is in the range of $5 \cdot 10^{-6}/^{o}C$.

The digital stabilization loop is characterized by a current/reference voltage transfer ratio

$$K = \frac{U_x}{U_y} .$$

Its value allows to find the most probable reference voltage value U_d, needed in a digital feedback algorithm to obtain the given MOE current amplitude U_s in the next cycle. The necessary information to compute the current value of K is available in each cycle, nevertheless statistical fluctuations and driftage of K prevent to obtain the accuracy needed. Thus current values of K are stored in a microcomputer's memory and the predicted transfer ratio for the next cycle

$$K_o = \frac{\sum_{n=1}^{N} n^2 \cdot \sum_{n=1}^{N} K_n - \sum_{n=1}^{N} n \cdot \sum_{n=1}^{N} n \cdot K_n}{N \cdot \sum_{n=1}^{N} n^2 - \left(\sum_{n=1}^{N} n \right)^2} ,$$

where n is the cycle number (the cycle numeration is in reverse chronological sequence), is computed according to the given cycle number N of previous cycles using the known [3] mathematical statistics methods (regression analysis). Then the predicted value of the reference voltage is defined as

$$U_d = \frac{U_s}{K_o} .$$

In the algorithm considered some precautions are taken to protect a stabilization loop from pulsed noises, looking like spikes in the results on measurements which exceed the tolerable value. In such cases a current value of transfer ratio for the given cycle is to be replaced by its value predicted.

The 16-bit DAC is composed of two parts: digital - a pulsed/width modulator (PWM), and analog - a demodulator and filter, positioned in the block of the charging supply regulator. A specific feature of the modulator is a connection pattern of the ring counter with a digital comparator. It enables to use a simple low inertial filter simultaneously conserving a high

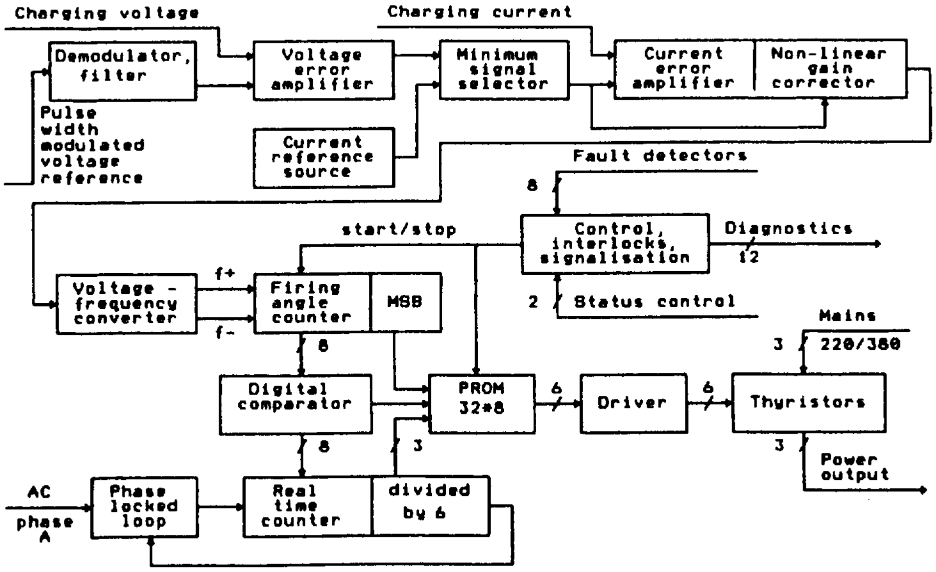

Fig.2. Structure diagram of charging source regulator

resolution. Using PWM-signal as an intermediate information carrier also simplifies a galvanic isolation of digital and analog parts of the DAC.

To get a high accuracy the charging supply regulator uses the two feedback loops: the charging current loop and the capacitor battery voltage one. The former consists of the current error amplifier and the phase regulator. With respect to performance this phase regulator can be compared with the multi-channel synchronous system of pulsed phase control [4]. Nevertheless due to the uniform digital channel it has a high symmetry of firing pulses. The integrating link in a current loop (bipolar voltage/frequency converter with a firing angle counter) provides a low static error of regulation.

The voltage stabilization loop is connected only at the end of charging, when the diminishing signal of the voltage error becomes lower, than the reference current, and replaces it, i.e. there is a transition from current stabilization to voltage stabilization. To make the time of this transition process as short, as possible, the non-linear corrector of amplification is used, which compensates the square current dependence of the thyristor rectifier transfer ratio. The charging supply regulator provides the charging current rise and fall times of ≈ 20 ms and the time of full voltage set (after the end of current stabilization) no more than 200 ms, its precision remains within the DAC resolution (16 bit).

The metrological characteristics of the measuring and regulating tract are shown on the plots, obtained as a result of long time tests of the charging supply designed. As fig.3 shows, the results on the measurement of discharging current amplitude with the digital feedback loop disconnected temporarily and then connected reflect the quality of the prediction for reference voltage. In this test the reference voltage was not regulated during the first tens of cycles and was kept at a fixed level. The relative drift of the current amplitude during all this time (with a 5-sec cycle) was equal to $2\cdot10^{-4}$. Then the correction program was run and the reference voltage, computed from eight previous cycles, has provided the required discharging current (10^6 units) with no extra iterations, and its cyclewise relative spread being $2\cdot10^{-5}$.

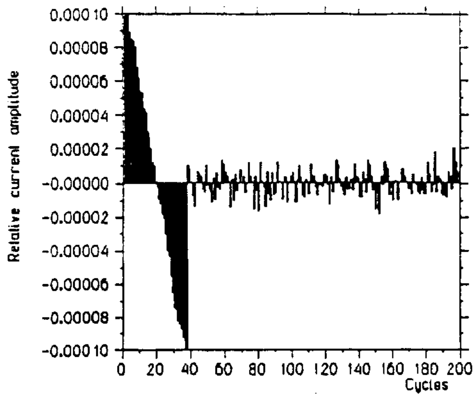

Fig.3. Relative current amplitude time variation

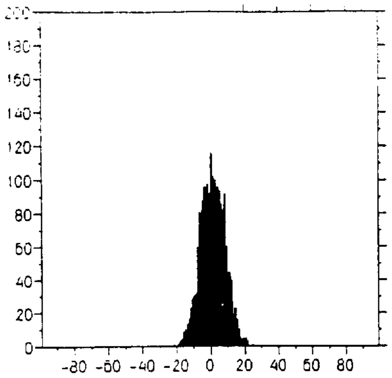

Fig.4. Relative current amplitude distribution

The histogram in fig.4, symmetric in the given discharging current (10^6 units) and drawn for the data accumulated within more than 2 thousand records (this corresponds to 3 hours of pulsed charging supply operation while the temperature condition of MOE coils was not reached) confirms that the hardware and software complex designed ensure a long time stability of the current amplitude. In this case its own noises in the stabilizing feedback loop remain at a comparatively low level.

References

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