LOW LEVEL RF CONTROL OF ITEP-TWAC FACILITY

P. Alekseev, S. Barabin, A. Milyachenko, V. Zavodov, ITEP, Moscow.

Abstract

Digital LLRF control system was developed to improve the RF system mobility in multimode operation of the ITEP-TWAC booster and main synchrotrons. High precision mapping of the magnetic field derivative signal to the reference function of accelerating frequency f(B) allows to accelerate ions of any type in both rings up to relativistic energies even without feedback loops. The first modification of the LLRF control module is based on a fixed point DSP, which operates with the frequency lookup table to calculate the accelerating frequency. This module is now used in the booster synchrotron. Upgraded module has a floating point DSP, which allows calculation of the accelerating frequency "on the fly". This module is in operation in the main ring. Short description of the systems is given. Some results and experience obtained at operation with the number of types of particles, such as protons and ions of carbon, aluminium, iron and silver, are presented.

INTRODUCTION

ITEP-TWAC Accelerators facility consists of two synchrotrons: УК booster and У-10 main ring [1]. At present we have two injectors:

- И-2 – for protons which are transported directly to the У-10 where they are accelerated up to 10 GeV. This is the classic mode of ITEP accelerator.
- И-3 – for ions injection into the booster. The Ions are accelerated and transported to the main ring where they may be stored or additionally accelerated up to the relativistic energies.

The RF system of the booster synchrotron consists of two accelerating cavities [2]. The first cavity operate in the range from about 700 kHz to 2.5 MHz, after that the second cavity continues operation up to 12 MHz. All five accelerating cavities of У-10 operate in the range from 1 MHz to 5 MHz. The frequency provided for each of the accelerating cavities should correspond to the beam energy at each moment of the acceleration process. The dependency is described by well known formula (see Eq. 1) that should be reproduced by the master oscillator from the available diagnostic signals.

$$f(B)=\frac{h\cdot c}{L}\cdot\frac{p}{\sqrt{\left(\frac{m_o A}{Z}\right)^2+p^2}}, \qquad (1)$$

where h - harmonic number, c – velocity of light, L – the length of the equilibrium orbit, m_0 – atomic mass unit, A – atomic weight, Z – ion charge and p is momentum per unit charge of the ion.

Additionally independent control of phase and amplitude of the accelerating voltage should be provided for each cavity. All of the functions described are provided by digital LLRF control system of the ITEP-TWAC facility.

MASTER OSCILLATOR

The core part of the LLRF system is the master oscillator unit (see Fig. 1) based on a digital signal processor. We are using standard Texas Instruments DSK boards available on the market. Originally the master oscillator unit was based on TMS320C6211DSK with processor clock frequency of 150 MHz and 4 MB of on-board memory. Self-designed daughter board is connected to the DSK. It contains an ADC circuit and control logic for six DDS submodules.

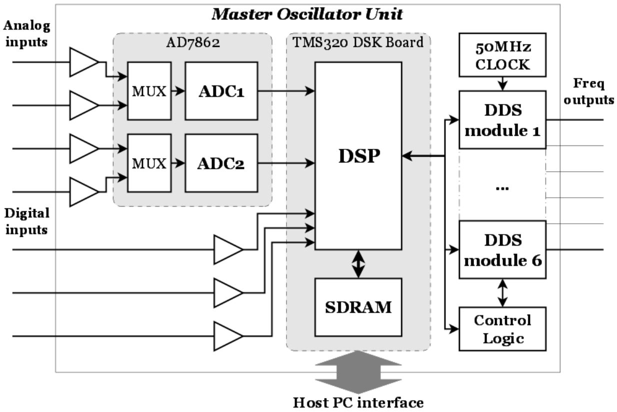

Figure 1: Master Oscillator block diagram.

All the DDS modules are connected to the common data bus. Common clock source of 50 MHz is used for all the DDS modules. All the modules could accept write commands simultaneously (on the same clock pulse) but only selected modules will store the data. Operational mode of each DDS could be selected individually by the software.

The signal of the derivative of the magnetic field induction is used as source information for producing the RF function of the magnetic field. This signal is presented in a digital form by an analog-to-digital converter with sampling frequency of 50 kHz and is integrated by a signal processor. Calculated value of the magnetic field induction then used as an address in the frequency lookup table. The table of 256 kB size should be calculated on the host computer software and stored in the SDRAM. Output frequency value is calculated by linear interpolation of the nearest tabulated values. DSP algorithm is illustrated on the figure 2.

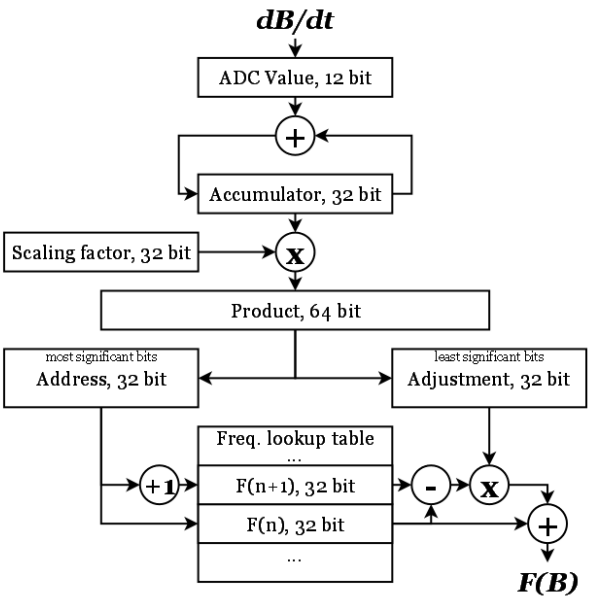

Figure 2: Diagram of the DSP algorithm.

The only trouble is the process of the ADC calibration. To get the first approximation of the conversion coefficient we use the signals of the B-timer which is rather well calibrated. To get better accuracy we should recalculate and reload the table several times. That takes a lot of time. On the other hand the coefficient that was found once may be used during the long time. For example presently used table for carbon ions acceleration in the booster was calculated in the October of the last year when some changes was made with the signal of test coil. Previous file is corresponds to the 2007.

AMPLITUDE CONTROL

To control the amplitude of the RF-cavities we are using the functional generators. The unit is quite simple. It's based on the ADuC814 microcontroller chip with RS485 serial interface and 12 bit DAC output (see Fig. 3).

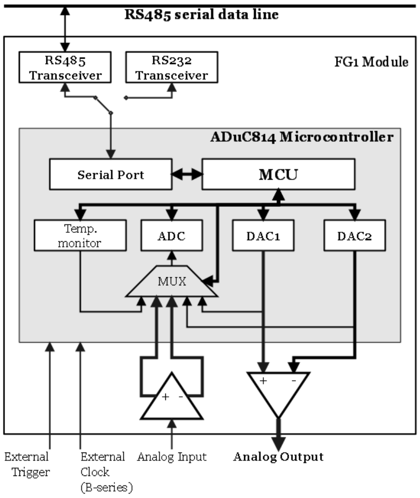

Figure 3: Functional generator block diagram.

Separate functional generators are used for each accelerating RF-cavity. All the generators are connected to the front-end computer which provide access to them over the LAN.

Application of the master oscillator in conjunction with the functional generators allows as to easily configure and reconfigure the RF system of the booster for the acceleration of various types of ion. In addition, the system allows to implement complex modes of operation such as an adiabatic capture [3].

MODERNIZATION

This year a new DSP-board was tested in the master oscillator module of the У-10 synchrotron. Old DSK was replaced by the TMS320C6713 board. This board is the same family but improved performance. Installed processor has build-in floating point operations support. Last feature allows as to abandon of using the "frequency lookup tables". Instead of it we can calculate the frequency on-the-fly by integrating the signal of the magnetic field derivative and applying the equation 1 directly.

Upgraded master oscillator module was tested at the high energy proton cycle in У-10. It is much easy to control this module because we don't need to upload the table each time when the calibration of ADC should be tuned. We also found the significant moment in tuning of the master oscillator that was not noticed before. The length of the equilibrium orbit in the equation 1 should be carefully tuned to achieve the expected compliance between the magnetic field and the RF-frequency because orbit length L is the function of momentum offset Δp.

In the result of the tests the maximum possible energy of protons for current DSP software version was achieved even without processing of the feedback signals. This limit is the transition energy of protons in the synchrotron. So, that is the first task for the next time.

CONCLUSION

The only LLRF control system is used in the booster is digital, while the LLRF system of the У-10 still not fully functional and old analogue system is used for acceleration of protons up to the energy of 10 GeV. All the other modes of У-10 is controlled by the new digital LLRF system.

At now the work is in progress on upgrading the RF-systems of both synchrotrons. In the result four cavities will be installed in each of them. No hardware modifications should be made in the existing LLRF control system in conjunction with that upgrade. The only thing we should do is to upgrade the software of the master oscillators.

REFERENCES

[1] D.G. Koshkarev et al., XV Workshop on Charged Accelerators, Protvino, v.2 (1996) p.319

[2] V.P. Zavodov et. al., XVII Workshop on Charged Accelerators, Protvino, v.1 (2000) p.138

[3] P.N. Alekseev et al, IET, 2007, Vol. 50, No. 4, p. 437