STATUS OF THE NUCLOTRON MAIN POWER SUPPLY SYSTEM

B.Omelchenko, V. Karpinsky, A.Kovalenko, A.Smirnov, A.Tsarenkov, B.Vasilishin, V.Volkov,
JINR, Dubna, Russia

Abstract

The designed and achieved parameters of the Nuclotron main power supply system (MPSS) are presented. The MPSS consists of two separate circuits for dipole magnets and quadrupole lenses connected by feedback units.

The MPSS was used during 12 runs of the Nuclotron operation. The essential experimental results of the MPSS at the superconducting synchrotron are described.

1 INTRODUCTION

The Nuclotron is intended to accelerate nuclei and multicharged ions including the heaviest ones (uranium) up to an energy of 6 GeV/u for the charge to mass ratio Z/A=1/2 [1].

The Nuclotron magnetic ring has a circumference of 251.1 m. The synchrotron magnet strings comprise 96 dipole SC-magnets (bending magnets BM, the summary inductance is about 100 mH) and 64 quadrupole SC-magnets (QM, the summary inductance is about 20 mH) separated into two groups (focusing and defocusing magnets) and connected in-series. In addition, two reference dipole SC-magnets (BRM) and four reference quadrupole SC-magnets (GRM) are installed to measure the magnetic field, especially for B-clock and G-clock detection.

The maximum value of the magnetic field is about 2 T. There are a field current of 6 kA, a flat-top long-time of 10 s and a repetition rate of 0.05...0.2 Hz.

2 MPSS EQUIPMENT

2.1 BM power supply

The power supply (1) for the BMs is shown in fig.1. There is a 12-phase thyristor rectifier (TR_1, output 300V, 6kA). The TR_1 is built of two 6-phase Kubler's thyristor rectifiers (C and E), which comprise interphase reactors (F and G) and have a cascade connection. The required phase shifts of the voltages that feed the TR_1 are due to the ± 15°el phase shift mains windings (W_1 + W_2 and W_3) of the rectifier transformers (B and D).

The mains windings connected in zigzag schemes. The zigzags are formed with precision sinusoid shifts:

$$K_z = \frac{W_3}{W_1 + W_2} = 0.36604,$$

while the theoretic value of K_z is 0.36603.

The secondary windings (W_4 and W_5) of B and D are connected in classical Kubler's schemes. In addition, there are balancing windings W_6 that have delta connections.

The windings W_6 form short circuits for triple - frequency harmonic currents and equalize of triple - cores magnetic inductions.

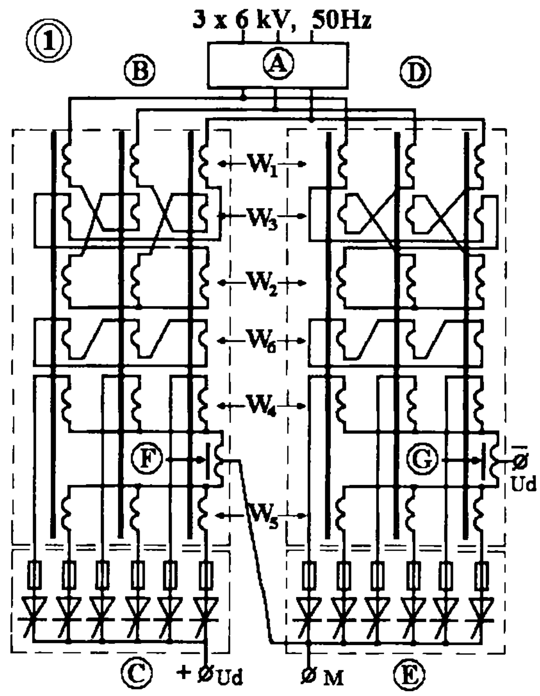

Figure 1: The BM power supply. The A is a high voltage circuit breaker. The M is a middle point of a cascade rectifier

2.2 QM power supply

The power supply (2) for the QMs is shown in fig.2. There is a 12-phase thyristor rectifier (TR_2, output 150V, 6kA).

The TR_2 is built of two 6-phase twin-star thyristor rectifiers (C and E, windings W_4 and W_5), which together with the interphase reactor (F) form a quickly-operating 12-phase Kubler's thyristor rectifier. The operation of the transformer windings $W_1 + W_2$, W_3 and W_6 is described in 2.1. Besides, both rectifier transformers (B and D) are provided with power symmetric superbalancing windings W_7 and W_8.

The windings W_7-W_8 envelop of the transformer triple-cores and essentially increase of the winding W_6 effect.

The winding W6-W7-W8 operation secures a big load current possibility for the TR_2, that has the zigzag-star mains windings connections.

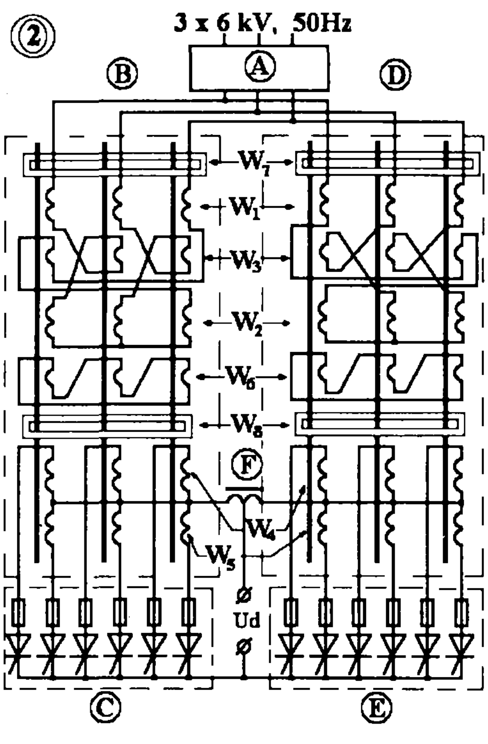

Figure 2: The QM power supply

2.3 Power load circuits

The power load circuits (PLC) of the BM (1) and QM (2) power supplies are shown in fig.3.

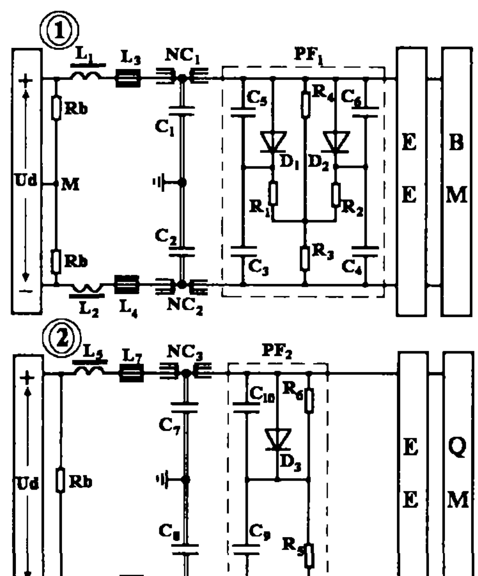

Figure 3: The power load circuits. L_1=L_2=L_5=L_6=3mH, L_3=L_4=L_7=L_8=180...15μH, Rb=3.0Ω, R_1=R_2=0.1Ω, R_3=R_4=1.5Ω, R_5=R_6=0.75Ω, C_1=C_2=C_7=C_8=12μF, C_3...C_6=C_9=C_{10}=3.2mF

There are only single-stage low-frequency passive filters (LPF, L_1 - PF_1 - L_2 and L_5 -PF_2 - L_6) and single-stage high-frequency passive filters (HPF, L_3 - C_1 - C_2 - L_4 and L_7 - C_7 - C_8 - L_8).

The LPFs are provided with silicon diode commutations for energy economy at the inverting of the rectifiers.

The HPFs comprise bus chokes (L_3 - L_4 and L_7 - L_8), which packed from laminated transformer iron, and electrical noise busbar concentrators (NC_1 - NC_2 and NC_3 - NC_4).

The NC construct is formed by a transition of a four-barbus system to a single-bar circuit and back (see fig.3).

The NCs are shunted with damping capacitors (C_1 - C_2 and C_7 - C_8), that a are inserted with flexible bar waveguides.

Besides, PLC are equipped with energy extraction thyristor switches (EF) for the quench protection of the SC- BMs and QMs. The BM d.c. circuit resistance is about 10.7 mΩ and the QM d.c. circuit resistance is about 8.5 mΩ.

3 MPSS CONTROL CIRCUITS

The control circuits of the BM (1) and QM (2) power supplies are shown in fig.4. The control system consists of a single-stage one-term controller for the magnetic induction control of the BMs and of a single-stage two-term controller for the gradient magnetic induction control of the QMs, which form an automatic following system (AFS).

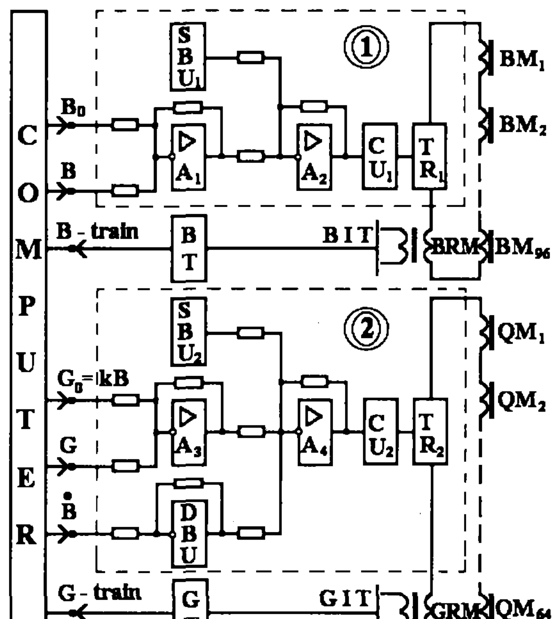

Figure 4: Schematic diagram of the control circuits

Fundamentally, the control equipment consists of control units of the TR_1 and TR_2 (CU_1 and CU_2), summing amplifiers (A_2 and A_4), an error signal amplifier

(A_1), a following error signal amplifier (A_3), statical bias units (SBU_1 and SBU_2), a dynamical bias unit (DBU), a B-induction transducer (BIT), a G-induction transducer (GIT), a B-timer (BT), a G-timer (GT) and a computer.

The DBU employment ensures a essential dynamic character improvement of the AFS, in particular at the flat-top forming.

4 CONCLUSION

The achieved performance of the power supplies and control system ensures the reproduction of the desired B and Q fields to better than $5 \cdot 10^{-4}$ at the injection point.

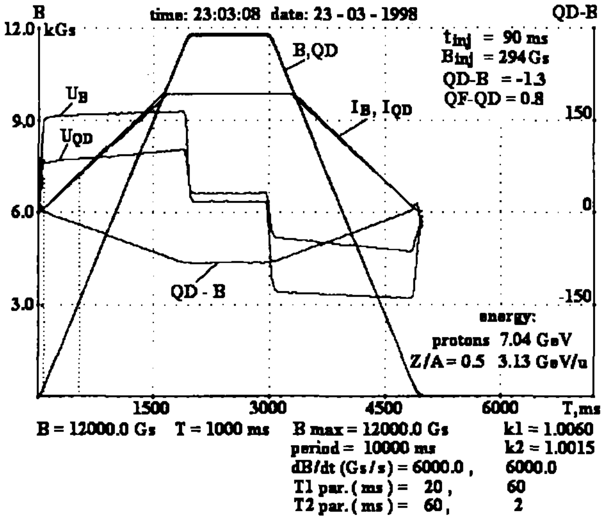

Figure 5: Example of magnetic field cycle parameters

The 600 Hz flat-top field ripple is smaller than $5 \cdot 10^{-7}$ (peak-peak). Long term stability has been tested intensively. The system operation shows that this characteristic is good within the specification.

The MPSS has been successfully used in all Nuclotron runs being fully capable of generating precision ramps ranging from a fraction of kGs/s up to 10 kGs/s.

The real mains power cycle (see fig.5) has the following parameters: the total average power is about 0.112 MW, the total peak power is about 2.6 MW.

The high dynamic AFS secures a lot of current flat-landing. This technical particularity ensures exceptional possibilities for the slow extraction of the Nuclotron beam at the large range of a particle energy.

At present, thanks to the system potentialities, energy ramping has become a routine procedure[2].

5 ACKNOWLEDGEMENTS

We would like to thank our colleagues who have contributed the MPSS development. The authors are grateful to L.Sveshnikova for help in preparing this paper.

REFERENCES

[1] A. D. Kovalenko, "Status of the Nuclotron", EPAC'94, London, June 1994.

[2] V.Gorchenko et al, "Nuclotron main magnet power supply control system", EPAC'98, Stockholm, June 1998.