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I.P.KARABEKOV, A.R.OTAROV

# BASIC CIRCUIT OF SYNCHROTRON POWER SUPPLY ON STANDARD UNITS

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# ՍԻՆՔՐՈՏՐՈՆԻ ԷԼԵԿՏՐԱՄԱԳՆԻՍԻ ՍՏԱՆԴԱՐՏ ՏԱՐՐԵՐԻՑ ԿԱԶՄՎԱԾ ՍՆՄԱՆ ՀԱՄԱԿԱՐԳԻ ՍԽԵՄԱ

Մշակված է բարձր հաճախականությամբ գործող էլեկտրոնային սինքրոտրոնների սնման համակարգի սխեմա, որը կարելի է կիրառել մագնիսի վրա հաստատուն և փոփոխական հոսանքների համար առանձին փաթույթների տեղադրման դեպքում: Այդպիսի համակարգը թույլ կտա ստեղծել սինքրոտրոնի էլեկտրասնման սխեմա՝ բաղկացած ստանդարտ տարրերից:

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# ПРИНЦИПИАЛЬНАЯ СХЕМА ЭЛЕКТРОПИТАНИЯ СИНХРОТРОНА НА СТАНДАРТНЫХ ЭЛЕМЕНТАХ

Представлены результаты оптимизации схемы электропитания быстроцикличного синхротрона, которую можно синтезировать из стандартных элементов.

Ереванский физический институт
Ереван 1987

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# BASIC CIRCUIT OF SYNCHROTRON POWER SUPPLY ON STANDARD UNITS

A method for creation of a power supply system for fast-cycling electron synchrotrons with separate windings in the magnet blocks for the alternating and direct currents is worked out. Such a system allows to create synchrotron power supply circuits using only corresponding industrial units.

Yerevan Physics Institute
Yerevan 1987

Fast-cycling electron synchrotrons, which not long ago were the main machines for investigations of high-energy electromagnetic interactions are and may be widely used in future as booster-injectors of stretcher [1,2] and storage [3] complexes.

The possibility for achieving comparatively high mean currents of beams (of order of tens of $\mu$A) and the simplicity for reaching the required energies, make one to consider 100 ÷ 500 MeV electron synchrotrons as perspective sources of synchrotron radiation, high-energy electrons and gamma-rays for applied investigations and industrial technology.

A special scheme of an electron synchrotron with superposition of accelerating cycles can produce up to 10 GeV external continuous beams at the mean value of current of 40 $\mu$A [4] .

However, to utilize the mentioned variants of electron synchrotron, one must thoroughly optimize its main units and the accelerator as a whole, for each particular modification.

One of the main and the most important units of a synchrotron is the power supply of electromagnets forming the magnetic cycle.

The results of optimization of the power supply of the electromagnet of the 600 MeV synchrotron's fast-cycling booster specialized as an injector in the storage complex ERSINE for generation of synchrotron radiation, are presented in this paper.

The conventional procedure to form a magnetic cycle in a synchrotron is the superposition of the alternating and direct-current components in the electromagnet's winding [5]. Such scheme allows to obtain high field increase rates, high stability of the magnetic field parameters from one cycle to another during the operation. At the same time, this scheme is most economical from the point of view of power consumption, since the alternating component is excited by means of a special generator in which the electromagnet's windings connected in series with a bank of capacitors make an oscillatory circuit with a high Q-factor. But to align the alternating and direct currents in the electromagnet's windings one must couple parallel to the capacity of the resonance circuit a coil ( a reactor) of much higher inductance than that of the electromagnet, with the aim to part the resonance frequences of the main circuit connected in series, and of the parasitic parallel-connected one. Usually, to lower the voltage on the capacitor bank, the electromagnet blocks and the capacitor bank are broken up into series-connected groups, the number of reactors in the scheme being equal to that of the groups. Such reactors are specially designed and made in small quantities when high-energy synchrotrons are constructed. But, when constructing low-energy synchrotrons the special design and production of such reactors are not economically reasonable. That is why it is necessary to work out schemes where the mentioned reactors could be substituted by conventional transformers. However, the direct substitution of a reactor by a transformer would require the installed power of the transformer to be much higher, as it is defined as the product of the direct-current component and the voltage developed by the alternating-current component in the group of magnets.

In fig.1 the diagram of the power supply of a 600 MeV synchrotron serving as a booster for the storage complex for generation of synchrotron-radiation beams is presented. The synchrotron's electromagnet consists of 12 magnets broken down into four groups. In this scheme the reactors are directly substituted by two three-phase conventional transformers for which the central core windings are the primary ones and the side-core ones are the secondary windings connected parallel with the capacitor banks. The electrical parameters of the circuit described are given in Table 1. The table shows that such scheme is not optimal, for to have transferred power of 16.2kW necessary to compensate losses in the resonance circuit the total installed power of transformers must be 3.4 MW.

Exclusion of the transformer's separating function, which led to so sharp an increase in the power, is possible if one installs on the magnet blocks two separate windings for the alternating and direct-current components, respectively. These wafer-like windings can be arranged as a "sandwich" and thus an approximate parity of the alternating and direct-current components leakage fluxes is achieved. The separate windings available will allow to make the optimisation of the direct-current source easier, since now the main requirement is not the equality of the direct current and the alternating current amplitude, but the equal number of their ampere-turns. Besides, in this scheme it is easier to minimize the reactive power of capacitors, as the choice of the number of their groups and, consequently, the working voltage are independent of the number of reactors which would increase the cost of the power supply system. A suppression filter is connected in series with the direct current source to limit the current induced in the windings of the direct-current component by the alternating magnetic flux. The resonance circuit is excited by a 25 kW transformer. The power supply diagram of the mentioned 600 MeV booster synchrotron is shown in fig.2 . Its electrical parameters and the values of active voltages and currents are presented in Table 2. As a direct current source the ИСТР - -2500/48 stabilized rectifier has been used. To improve the current utilization factor, the number of turns in the direct-current component windings is halved and, correspondingly, the current is chosen to be 2150 A. As a suppression filter a ФРОС-1250 type conventional reactor of 0.32 mH inductance may be chosen. The choice of a ФРОС type reactor and КС type capacitors is dictated by the possibility for them to be installed indoors.

As it is seen from Table 2, the reactive power of the suppression filter capacitor bank of capacity $8 \cdot 10^3$ μF, when using four in series connected reactors at 50 Hz, makes $25 \cdot 10^3$ kVAR which is by an order of magnitude higher than that of the resonsnce circuit's capacitor bank. The high cost of the capacitor bank makes the proposed scheme uneconomical despite the advantages mentioned above.

Most economical is the power supply circuit with compensation of the alternating voltage induced on the direct-current windings in blocks with separated windings. In fig.3 a power supply circuit with compensation of induced voltages is shown. Here in series with the alternating-current windings there are included ironless concrete ЛЭЗ 090001 reactor type inductance coils with inductance 3 mH . The same reactor is in series connected with the direct-current windings so, that the voltage drop on its leads were in antiphase with the voltage induced on the direct-current windings. The number of reactors required is determined by the ratio of the total voltage induced on the direct-current windings to that built up by the alternating component on one reactor. The exact equality of the voltage on the reactor and the total one induced on the corresponding blocks is realized by the displacement of the contact on the reactor's winding, which is possible owing to its open construction. It should be noted that such tuning is possible at low powers which makes it foolproof.

There must be phase difference $\Delta\varphi$ between the voltage on the reactor and that on the group of blocks owing to the fact that the leakage inductance of blocks and the resistance of windings are other than zero. But, this value is a small one and as the estimates show $\Delta\varphi < 1'$ for the synchrotron under consideration. The oscillatory circuit is excited by a transformer the power of which is determined by the losses in the circuit. For the circuit shown in fig.3 with the parameters given in Table 3, that power is 30 kW . The excitation circuit powering the transformer is realized according to the standard scheme of a full-wave inverter [6] .

In conclusion it must be emphasized that the power supply circuit elaborated for the electromagnet of a fast-cycling electron accelerator with conventional units, is possible to realize only when separate windings for alternating and direct currents are installed on the blocks. The main disadvantage of the circuit proposed is that it consumes twice as much power as the conventional circuit with combined windings. However, for small synchrotrons with low power consumption this disadvantage can be compensated for the fact that the power supply can be made up by conventional units.

The authors are sincerely grateful to S.A. Grigorian for the help in calculations.

Table 1

## Electrical Parameters of the Booster Synchrotron's Power Supply with a Combined Circuit

| Parameter | Numerical value and the unit of measurement |
|---|---|
| Efficient alternating current of the magnet | 762 A |
| Direct current of the magnet | 1075 A |
| Alternating voltage on the magnet (the efficient value) | 331 V |
| Number of boosters magnets | 12 |
| Number of magnets in a group | 3 |
| Inductance of one magnet | $1\ 38 \cdot 10^{-3}$ H |
| Capacity of the capacitor bank of one group | $2450 \cdot 10^{-6}$ F |
| Resistance of the winding of a magnet | $1\ 165 \cdot 10^{-3}$ohms |
| Total power of transformers | 5232 kW |
| Iron losses at 50 Hz | 670 W |
| Active losses in the oscillatory circuit | 16.2 kW |

Table 2

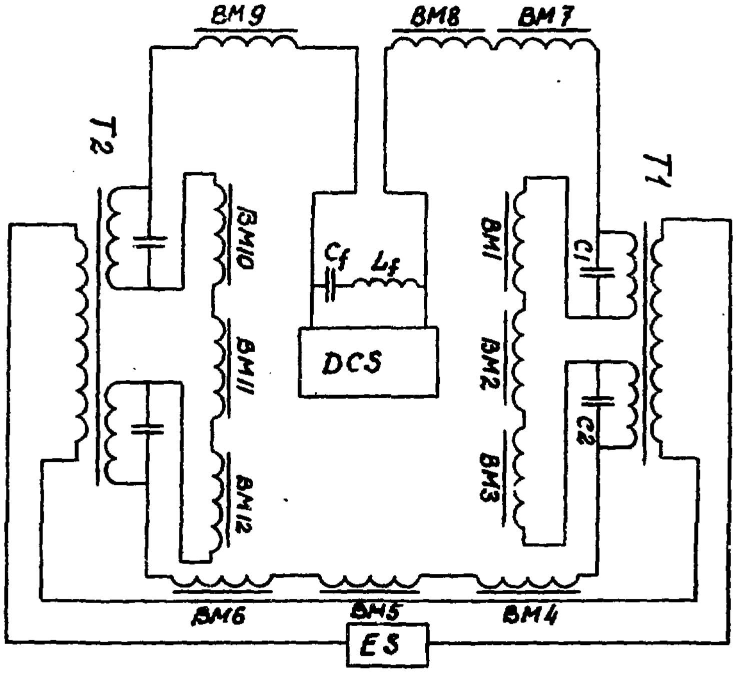
## Electrical Parameters Of The Booster Synchrotron's Power Supply With Separated Circuits

| Parameter | Numerical value and the unit of measurement |
|---|---|
| Efficient alternating current of the magnet | 762 A |
| Direct current of the magnet | 2150 A |
| Alternating voltage on one magnet (the efficient value) | 331 V |
| Number of booster's magnets | 12 |
| Number of magnets in a group | 3 |
| Inductance of one magnet | $1\ 38 \cdot 10^{-3}$ H |
| Capacity of the capacitor bank of one group | $2450 \cdot 10^{-6}$ F |
| Reactive power of the capacitor bank of a group | 848 kVAR |
| Impedance of the suppression filter (SF) | 126 3 ohms |
| Capacity of the SF | $7923 \cdot 10^{-6}$ F |
| Inductance of the SF | $1.28 \cdot 10^{-3}$ H |
| Reactive power of the capacitor bank of the SF | 24685 kVAR |
| Voltage applied to the SF (the efficient value) | 2503 V |
| Resistance of the magnet's alternating-current winding | $2{,}\ 33 \cdot 10^{-3}$ ohms |
| Resistence of the magnet's direct-current winding | $1\ 166 \cdot 10^{-3}$ ohms |
| Active losses in the oscillating circuit | 24.3 kW |

Table 3

## Electrical Parameters of the Booster Synchrotron's Power Supply with Separated Circuits and Compensating Reactors

| Parameter | Numerical value and the unit of measurement |
|---|---|
| Efficient alternating current of the magnet | 762 A |
| Direct current of the magnet | 2150 A |
| Alternating voltage on one magnet (the efficient value) | 331 A |
| Number of booster's magnets | 12 |
| Number of magnets in a group | 3 |
| Inductance of one magnet | $1.38 \cdot 10^{-3}$ H |
| Capacity of the capacitor bank of one group | $1500 \cdot 10^{-6}$ F |
| Reactive power of the capacitor bank of a group | 4673 kVAR |
| Resistance of the magnet's alternating-current winding | $2.33 \cdot 10^{-3}$ ohms |
| Resistance of the magnet's direct-current winding | $1.166 \cdot 10^{-3}$ ohms |
| Voltage induced on the direct-current winding (the efficient value) | 209 V |
| The direct current source voltage | 47.3 V |
| Active losses in the oscillatory circuit | 28.65 kW |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BM6
BM5
BM4
ES

Fig.1

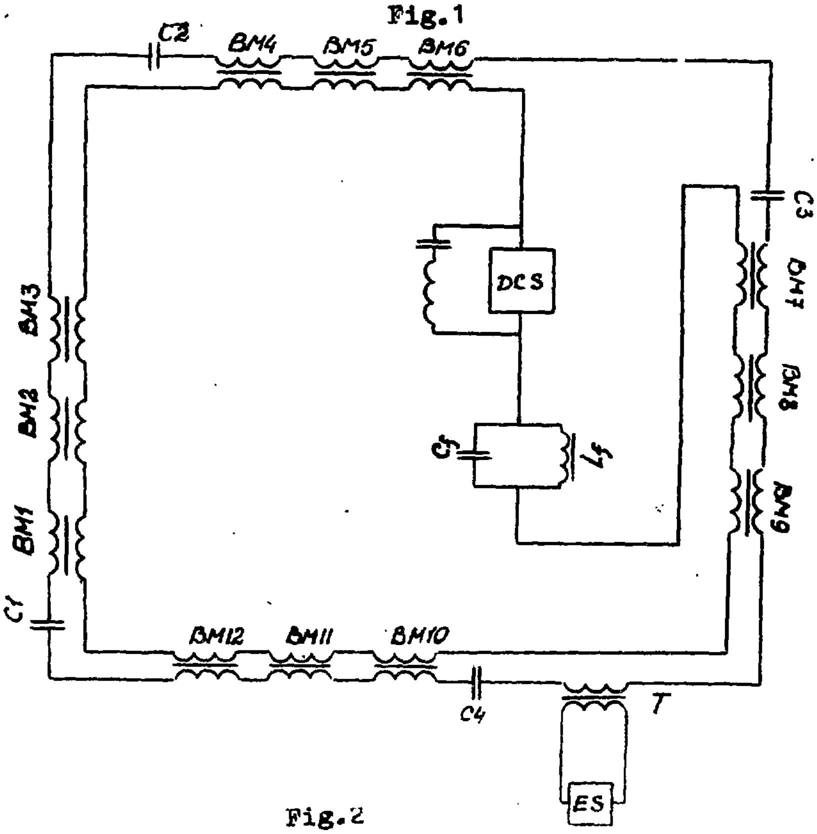
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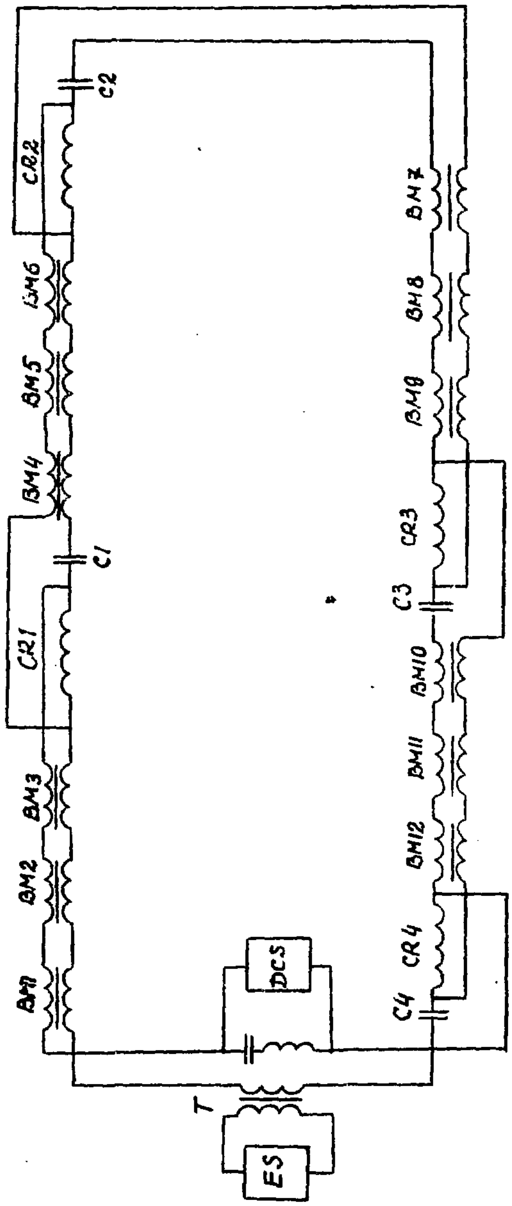
Fig.2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C1
BM4
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BM6
CR2
C2
BM7
BM8
BM9
CR3
C3
BM10
BM11
BM12
CR4
C4
DCS
T
ES

Fig.3

# Figure Captions

Fig.1 Basic circuit diagram of synchrotron's power supply with combined windings.

BM - bending magnet

T - feeding transformers

C - capacitor bank

ES - the oscillatory circuit excitation system

DCS - direct current source

$L_f$, $C_f$ - SF components

Fig.2 Basic circuit diagram of synchrotron's power supply with separated windings.

Fig.3 Basic circuit diagram of synchrotron's power supply with compensating reactors.

CR - compensating reactor.

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