THE POWER SUPPLY SYSTEM OF THE 10 BEV SYNCHROTRON ELECTROMAGNET

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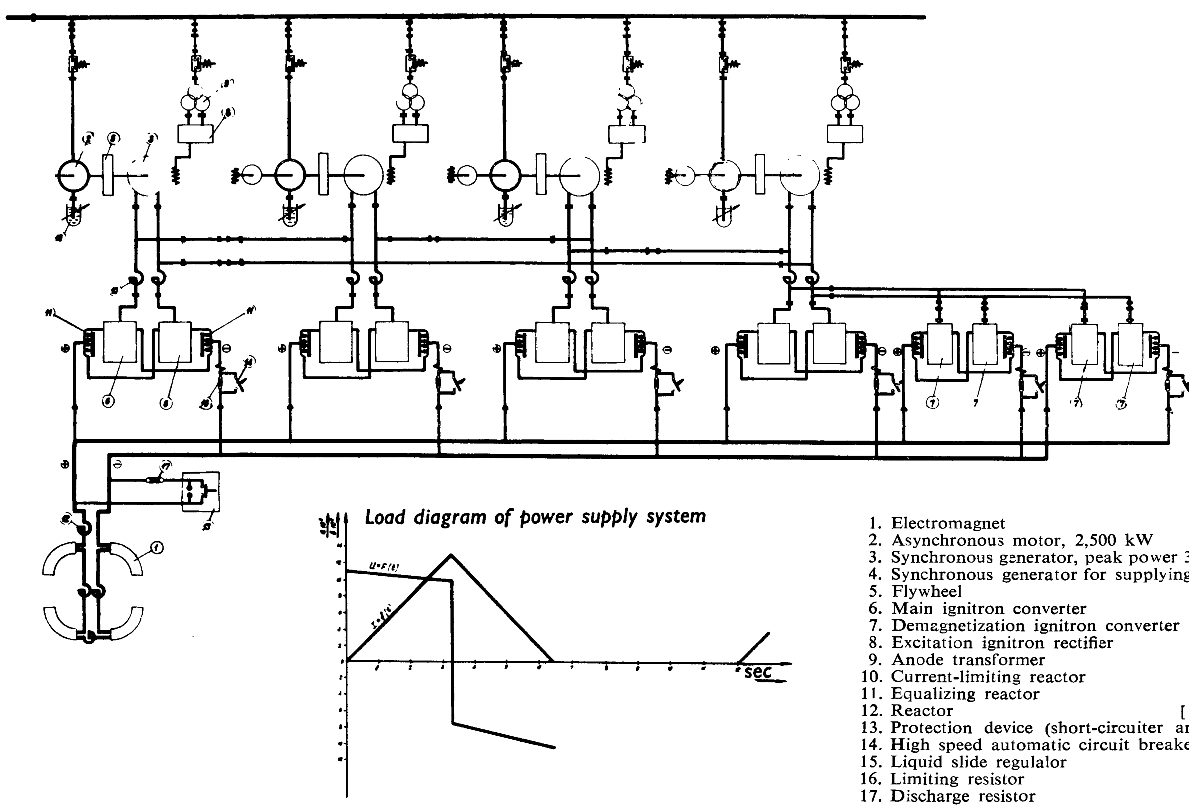
(presented by E. G. Komar)

The power supply system of the synchrotron of the Electrophysical Laboratory of the Academy of Sciences, USSR, has the following specifications:

Maximum power	140,000 kVA
Maximum current	12,800 a.
Maximum voltage	11,000 volts
Electromagnetic energy of the magnet system	148×10^6 joules
Active losses in the winding of the electromagnet	4,000 kW

In this report it is not possible to elucidate all the problems connected with the designing of the power supply system. Therefore, we shall limit ourselves to a brief description of the completed system.

The most suitable electric circuit for the power supply system of the electromagnet, the load diagram of which is shown in fig. 1, is a circuit in which the exchange of energy between the magnetic field of the accelerator and the kinetic energy of the flywheel masses is carried out by means of ionic converters operated directly from synchronous machines; the active power required to cover losses is supplied by an asynchronous motor of the unit.



1. Electromagnet
2. Asynchronous motor, 2,500 kW
3. Synchronous generator, peak power 37,000 kVA
4. Synchronous generator for supplying control circuits
5. Flywheel
6. Main ignitron converter
7. Demagnetization ignitron converter
8. Excitation ignitron rectifier
9. Anode transformer
10. Current-limiting reactor
11. Equalizing reactor
12. Reactor
13. Protection device (short-circuiter and discharger)
14. High speed automatic circuit breaker
15. Liquid slide regulalor
16. Limiting resistor
17. Discharge resistor

Fig. 1.

A model of the power supply system with a maximum power of 600 kVA. was built in the Laboratory of the Institute of Electro-Physical Instruments. Experiments carried out at this installation enabled the solution of a number of problems connected with the selection of a method of power combination, and the investigation of the caracteristics of the supply system power circuits of the circuit diagram decided upon.

The considerable peak power of the installation required the use of a large number of valves working in parallel; a circuit consisting of a number of identical blocks (machine unit and ionic converter) working in parallel appeared most advisable.

The circuit diagram given in fig. 1 was selected. It used power combination of four blocks.

Each block (fig. 2) consists of two three-phase bridge circuits operating in parallel through dividing coils. The bridge circuits are supplied from two three-phase systems of emf of the synchronous machine, which are shifted by 30 electrical degrees relative to each other.

This circuit diagram makes it possible to combine the power of two bridges, at the same time making good use of the synchronous machine.

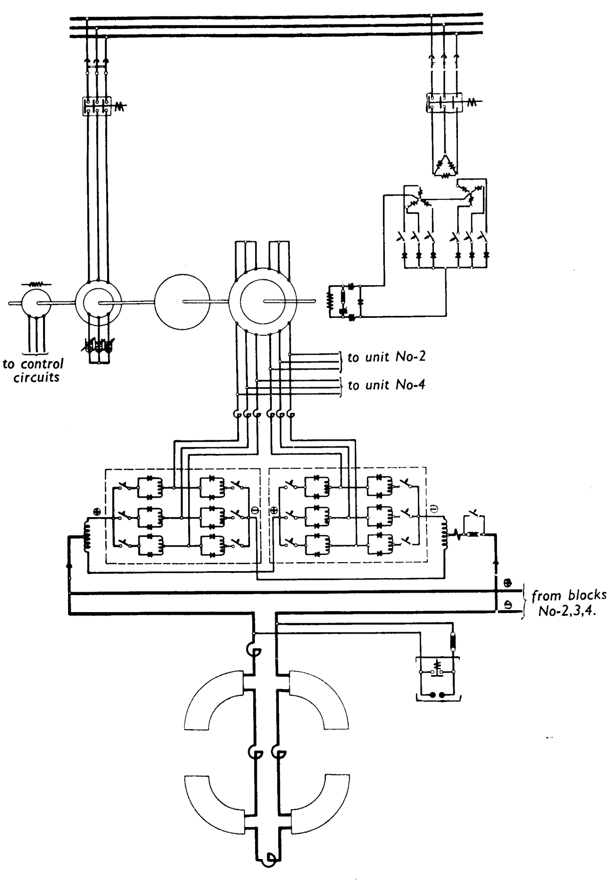


Fig. 2.

At the instant the converters pass from the rectifying operation conditions to the inverter conditions due to the shift of voltages feeding the bridges, a voltage pulse arises that causes an equalizing current to appear between the bridges. The magnitude of this current is limited by the inductance of the reactor. To reduce the nominal power of the dividing coil a system creating an initial unbalanced load of the bridges and synchronization of the beginning of inverting is provided; the equalizing current generated is directed opposite to the balance current. Such a system makes it possible to reduce by half the required nominal power of the dividing coil.

The parallel operation of the blocks consisting of synchronous machines and converters is effected by connecting the converters both on the d-c side and the a-c side (fig. 1). Coupling on a-c makes unnecessary the use of cumbersome reactors on the d-c side, designed to exclude the possibility of commutation between the converter valves of various bloks due to uncophasability in the operation of the synchronous machines. The second advantage of this coupling is that uniform load distributions are ensured between the machines without the use of special control systems.

In order to reduce the currents of emergency operation conditions, an a-c connection of the machines is made according to a ring circuit system in which short circuit currents are limited not only by the dispersion reactance of the windings of the machines but also by the dispersion reactances between systems of windings, shifted by 30 electrical degrees.

Despite this, in order to reduce short circuiting currents it was necessary to introduce additional non-iron reactors connected in such a way that when the reverse ignition currents are effectively reduced they simultaneously ensure parallel operation of converters connected in pairs on the a-c side.

Synchronization of the machines is accomplished by separate starting of the units followed by a simultaneous rise in the excitation of the generators from zero to the nominal value. The units are connected synchronously when the voltage of the generators is approximately 20% of the nominal voltage. It should be noted that splashes of equalizing currents do not exceed the nominal values.

Type IVU 100/15000 sealed pentode-ignitrons (specifications: 100 amperes of mean current and 15 kV of reverse voltage) are used as valves of the converter apparatus. They were specially designed for this installation by the USSR Electro-Technical Institute.

The sealed construction of the ignitrons offers considerable advantages during operation and makes possible a much simpler construction of the converters. Two valves in each arm of the bridge circuit are connected in parallel through an anode divider.

The reduction of excess voltages on the anode dividers connected with the commutation of the valves during operation of the converters at a control angle other than zero and caused by the capacitances in the system, is achieved by connecting the circuits R,C parallel to the windings of the anode dividers.

To ensure operation of the control system irrespective of the operation conditions of the converter power circuits, the control apparatus of the converter is supplied with power from a special generator that is mechanically connected with the synchronous machine feeding the power circuits of the converter.

Ignition of the ignitrons is controlled by means of an ordinary thyratron-condenser circuit that produces a pulse on the igniter. The catching anode and girds are supplied with sinusoidal voltages.

The thyratrons that create the igniting pulses on the igniters of all four converters are controlled from twelve peak transformers, of which six ignite the thyratrons in rectifying operation conditions of the converters and six in the inverter operation conditions. In designing the control system, account was taken of the necessity to eliminate parasitic capacitances in the control circuits, which caused disturbances in the control of the valves.

A powerful test installation was established to investigate the characteristics of the valves and to check the operation of the control system.

Processes connected with the presence of distributed capacitances in the power supply system are of great importance in the operation of the valves and converters.

The existence of such capacitances and inductances in the system produces (in the process of commutation) additional powerful high frequency oscillations of the valve voltage and currents.

These oscillation processes may lead to an almost twofold increase in the reverse voltage of the valves and to a large increase in the speed of current changes during commutation with considerable restoration speeds of the reverse voltage. This leads to a sharp increase in the frequency of reverse ignitions.

A circuit was designed for quenching the oscillations through the introduction of damping circuits consisting of chains of capacitances and resistances. The results of the experiment were in good agreement with the calculated parameters of the damping circuits eliminating excess voltages in the system.

Control of the operating conditions of the converters is done through the current of the electromagnet by means of a three-position ionic trigger.

The output voltage of the trigger is connected to the grid circuit of the thyratrons which control the ignition of the igniters.

The initial moment of the rectifying operation is given by a cycle master that has the form of a Warren motor with a contact system. As the current reaches the value given for this installation, a signal from the transducer enters the trigger, and the converter switches over to the inverter conditions of operation.

At the moment when the current of the electromagnet falls to zero, another acts on the trigger and thus ignites the valves. The rectifying operation is started in the same phase from cycle to cycle, just as it is stopped (when it passes to the inverter conditions of operation). This system of controlling the operation conditions ensures a small time constant for the transition processes.

To reduce energy losses in inverter operation conditions of the converter, the lead angle is regulated during a fall in the current and the extinction angle is kept constant.

The falling character of the external characteristics of the synchronous machine and converter, as well as the requirement for exact reproduction of the magnetic field make necessary the use of automatic excitation regulators.

To achieve a sufficiently effective system of control in dynamic operation (i.e. to put into effect a high-speed system of excitation) ionic exciters were used which speeded up excitation of the synchronous machines.

The ionic exciters are made according to the six-phase circuit converting system with the use of type IVS 200/825 ignitrons. The four ionic exciters are controlled by a common voltage regulator.

A reduction of power fluctuations in the supply system caused by variations (within a relatively broad range) in the rotation speed of the engine during a cycle is achieved with the aid of liquid sliding regulators.

To fulfil the requirements regarding the homogeneity of the proton synchrotron magnetic field and to diminish the influence of residual magnetization on the magnetic field, the magnetic system is demagnetized during the interval of the main cycle. Demagnetization is done by creating, in the winding of the electromagnet, current pulses of different polarity with a decreasing amplitude that follows a definite law.

The demagnetizing pulses are created by two ionic converters, of which one produces the positive-polarity current pulses, and the other the negative pulses.

The operational conditions of the demagnetizing ionic converters (rectifying conditions, inverter conditions, and locking the converter) are varied by means of three-position ionic triggers depending upon the demagnetization current. The magnitude of the demagnetization pulses is varied in the process of demagnetization by a scaler that varies the tuning of the transducers which send control signals to the ionic triggers. The power for the demagnetizing converters is supplied by one of the four main generators. The convertor control system is supplied from an auxiliary generator of the given unit.

The IVU 100/15000 ignitrons are used as valves in the demagnetizing convertors. The twelve-phase conversion system consists of two bridge circuits connected through a dividing coil. The current amplitude of the first demagnetizing pulse is 15% of the amplitude of the main current.

Possible resonance losses of particles due to frequency coincidences of radial-phase oscillations with field ripple frequencies make it imperative to reduce the amplitude of field ripples for resonance frequencies up to a magnitude of the order of 10^{-2} - 10^{-3} oersted. In order to simplify the setting up of a system to ensure that the accelerating-voltage frequency follows the field, it is advisable to reduce the field ripples and the non-resonant frequencies.

A feedback system is used to reduce the value of field ripples. This system has advantages over a filter in being more economical and less cumbersome. The output of the powerful audio-frequency amplifier that creates the current which makes sufficient compensation for the field ripples, is connected to a special winding. To obtain a compensation current of requisite form and magnitude, the input of the amplifier is supplied, in the corresponding phase, from the measuring winding which is situated in the gap of the electromagnet.

The source of the amplifier anode voltage is the electromotive force induced in the ripple-suppression winding by the main field.

This system makes it possible to reduce the amplitude of the main field pulsations by a factor of 5 to 6.

In considering the power supply system of the synchrotron, it is necessary to touch on problems of protection. Protection of the units is carried out in the usual way. By reverse ignitions, the converters are protected with the aid of high-speed, automatic reverse-current circuit breakers. These automatic devices are operated by a system of triple automatic repeated switching.

When excess currents are present the converters are protected by high-speed automatic devices of maximum (direct) current, which switch limiting resistors into the circuit being protected and aid in removing the excitation of the synchronous machines.

A high-speed contactor connecting the winding of the electromagnet to a discharge resistor at the moment of an accident, protects the windings of the electromagnet from puncture during overvoltages and also protects the ignitrons from a protracted passage through them of damped direct current from the electromagnet.

The electromagnet is also protected from short circuits in the turns and to ground.

The supply system of the synchrotron was worked out at the Research Institute of Electro-Physical Instruments by a group consisting of twelve scientists. The design and development work took about a year and a half, and that of erecting, installing and adjustment, approximately two years.

The adjustment work was done by a group headed by N.I. Pavlov from the Electro-Physical Laboratory of the USSR Academy of Sciences.

SUMMARY OF THE POWER SUPPLY SYSTEM SPECIFICATIONS

1. Maximum power consumption	140,000 kVA
2. Maximum current of electromagnet	12,800 amperes
3. Voltage of electromagnet at beginning of a cycle	11,000 volts
4. Operating magnitude of the current of the electromagnet	5,500 amperes
5. Maximum power of synchronous machine	37,500 kW
6. Line voltage of synchronous machine	8,200 volts
7. Nominal current of synchronous machine	$2\times$ 1,300 amperes
8. Power of asynchronous motor	2,500 kW
9. Flywheel moment of unit	212 tons/sq. m.
10. Number of units	4
11. Repetition rate	5 cycles/min
12. Rise time	3.3 sec.
13. Number of conversion phases	12
14. Number of the IVU 100/15000 valves	120
15. Average valve current	70 amperes
16. Maximum valve current	800 amperes
17. Number of the IVS 200/825 valves	36
18. Number of high-voltage high-speed circuit breakers	77
19. Number of low-voltage high-speed circuit breakers	36