CHARGING CONTROL SYSTEM OF THE ENERGY CAPACITOR STORAGE OF THE LASER DEVICE ISKRA-5

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ABSTRACT

The ISKRA-5 pulsed laser device is designed for research in nuclear fusion. It has 12 channels working synchronously against a common load to support different experiments on thermonuclear target heating. For the main power supply it uses stored capacitor energy. The power used (67 MJ) is sufficient to cause fatal damage, so safety must be guaranteed. Therefore, the ensuring of power supply reliability is one of the main functions of the control system. This requirement can be satisfied by improving power supply viability, increasing the stability of capacitor bank charge and emergency energy discharge when one of the capacitor sections fails.

1. INTRODUCTION

The physical device ISKRA-5 was designed for the study of the interaction of high power laser radiation with matter in the fusion programme [1,2]. The main part of the device is an Iodine Laser in which a light pulse, formed by a master oscillator (MO) is multiplied and amplified in 12 similar channels. Each channel has 5 cascades of amplification. The total laser output energy is 30 kJ in a 0.25 ns.

The power supply for the source of light, producing excitation of the master oscillator and laser amplifiers, is a pulsed power system based on a capacitor bank. Thr total stored energy is 67.2 MJ and the operating voltage is 50 kV. For the combination of values of stored energy and pulse length, 10-35 μs, thr capacitor bank of ISKRA-5 has no equivalent in the world. Closest to it in parameters is that of the device NOVA (USA) which has a stored energy 60 MJ and pulse length of 600 μs. Such a level of stored energy can cause fatal damage to the power supply system and the device as a whole, so safety should be guaranteed. Ensuring the reliability of the power supply system is one of main functions of the control system.

2. FUNCTIONAL REQUIREMENTS

The structure of the ISKRA-5 laser and pulsed power system is shown in Fig.1. Each of the amplifier cascade A1-A4 has its own capacitor bank (CB-A1)-(CB-A4), to ensure that the independent operation of a cascade MO, with its capacitor bank CB-MO, is common to all channels. For laser work optimization, it is necessary that the capacitor banks of identical modules are charged to the same level of voltage, which can be changed. The charge system controls the energy storage and power line and contains some types of industrially available units. The system allows the control of charge and level of voltage on the storage.

The main charge parameters of various capacitor bank modules are shown in Table 1, the total number of such modules is 738, including those of the synchronization system.

Table 1

module type	operating voltage, kV	charge error, %	charge time, ms
amplifier	50	2	90
special generator	50	2	60
synchronization system	70	2	20

The power units are assembled as the usual circuit with step-up transformers and uncontrolled rectifiers. Feed control for the power units is provided by thyristor regulators.

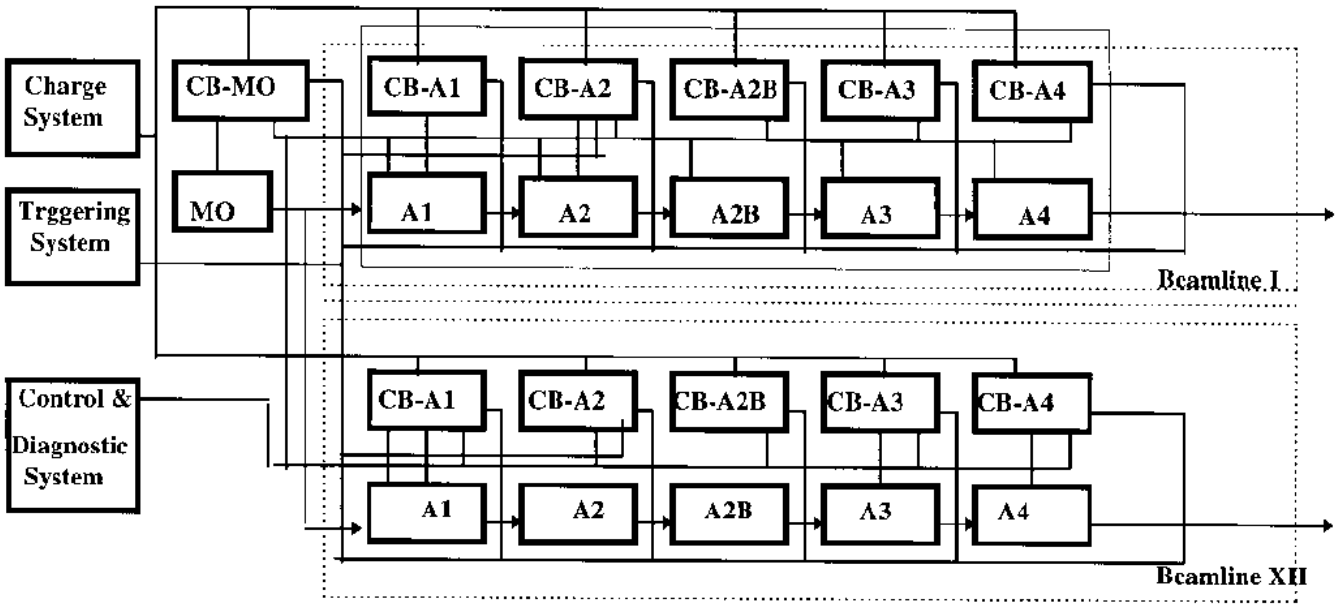

Fig.1. Structure of the ISKRA-5 laser and pulsed power system

The power supply circuit provides the following modes of capacitor bank charging:

- capacitor bank charging with fixed value of charge current,
- capacitor bank charging with fixed rate of voltage increase,
- combined charging mode.

When using the mode with a fixed value of current, the current is adjusted, as a rule, to the maximum value the power unit permits. The advantage of this mode is a stable load on the power unit, which is not changed even in the case of a short circuit. The shortcoming is that with a reduction of the bank capacitance, which is necessary for some experiments, the charging current is maintained. However all the elements of a capacitor bank module, to allow for the consequences of emergencies, should be designed on a complete charge current basis.

When charging the capacitor bank with a fixed rate of voltage increase, the charging current is changed depending on the capacitor load. This eliminates the shortcoming of the mode with fixed current. However, in case of an emergency short circuit, the charging current sharply increases and it is necessary to stop the operation.

As a rule, such a switching-off occurs as consequence of the operation disaster protection. Unfortunately we couldn't manage to obtain a good enough thyristor to maintain an output load with the levels of protection required.

Therefore a combined mode in the control of capacitor bank charging is preferable, in which a restriction of the sharp increase of charging current in an emergency situation is introduced simultaneously with a fixed rate of voltage increase. This avoids current overload and the necessity to

stop charging. This mode is used with the incomplete composition of the capacitor bank. The control mode with a fixed value of charging current is chosen for experiments with the complete composition.

The control system should provide, together with conventional tasks:

- flexibility of storage charge control,
- remote and local control of storage charge using central and technological control panels,
- automatic charging,
- high-speed electronic protection,
- diagnostics of conditions of all technological systems, forecasting emergency conditions and the formation of control commands in extreme situations,
- localization and switching-off of the emergency part of the power supply while preserving the functioning of the device as a whole.

3. IMPLEMENTATION

The thyristor regulator of the input voltage for the power unit is designed using conventional circuit phase-pulse control. A high quality of auto-control is provided by a correction system. Some kinds of protection are provided, including high-speed protection against the maximum output voltage of the power unit and maximum charging current.

For elimination of the influence of emergencies in cells of a capacitor storage bank on the workings of the charging system, the mode with a fixed value of charging current is used. This permits the stabilization of a value of charging current with changes of load.

Particular attention was given to noise immunity of the control system. The general policy was to use electromagnetic relays not only as switches but also as logic elements. As it turned out, considerable distortion of the voltage waveform on the feeder cable occurs due to the large current drawn by the charging system. These distortions resulted in failure of the control system. Complete removal of this interference was obtained only by the transfer of the control system supply to another substation.

4. MAIN RESULTS OF OPERATION OF CHARGE CONTROL SYSTEM

Experience of operation with the energy storage has shown that it is possible to ensure reliable realization of experiments with a capacitor storage of 67.2 MJ. As was expected, in a number of experiments there were failures of some modules. Therefore the design of charging system provides a continuous capacitor bank charge despite failures occurring, which is stopped only by a command of the operator from a central control panel.

The technical decisions made in the design of the charging control system have allowed the realization of these aims. On failures of different kinds, including momentary short circuit of the power supply, there is no source switching-off and only a limiting of the charging current takes place. After switching-off a broken module with the help of a special high-speed safety fuse, the charging of the rest of the capacitor bank goes on in a given mode. The transients arising at failures are smoothed sufficiently and do not influence the charging process.

5. CONCLUSIONS

The operation of capacitor banks with a total stored energy of 67.2 MJ at an operating voltage of 50 kV allows us to make the following conclusions about the practicability of energy storage designs of similar and larger sizes.

1. With an increase of the value of storage energy a bank becomes more multielement and accordingly the probability of failure of some element is increased during bank charging or discharge. Thus, the failure of capacitor elements becomes a planned event, and appropriate measures for the reduction of such failures' influence on the efficiency of the bank and the device as a whole should be adopted.

2. The reliability of experiment realization is largely defined by the charge of the capacitor bank. Therefore it is very important to fulfill the following conditions during the charging stage:

- the tolarance of the charging to emergency operation,
- the localization of an emergency in any part of the charging system and its switching-off,
- the emergency discharge of the energy stored in the capacitor bank into a ballast load,

- the minimum time between the attainment of full voltage on the capacitor bank the issue of a firing command.

The design methodology for a high-energy capacitor bank and its control system which have been developed allows the creation of a capacitor bank of order of 100 MJ with the reliability required for experiments.

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