CAPACITOR BANK MODULE FOR MULTI MEGAJOULE ENERGY STORAGE

Boris M. Kovalchuk, Evgeny V. Kumpyak, Alexander A. Kim, Anatoliy V. Kharlov[ξ],Nikolay V. Tsoy, Vadim A. Visir, Grigory V. Smorudov, Vladimir N. Kiselev, Vladimir V. Chupin,

Institute of High Current Electronics, Academichesky Prospect 2/3, Tosmk 634055, Russia

Frédéric Bayol, Laurent Frescaline, Fabrice Cubaynes, Cyril Drouilly

ITHPP, 46500 Thégra, France

Patrick Eyl, Bruno Cassany, Laurent Courtois, Patrice Patelli

CEA-CESTA, BP N° 2, 33114 Le Barp, France

Jean-Marc Mexmain, Dominique Rubin de Cervens, Claude Cavailler

CEA-DAM Ile de France, BP12, 91680 Bruyère le Châtel, France

Abstract

Within the context of the Pulsed Power Conditioning System (PPCS) development undertaken by the CEA for the Megajoule laser (LMJ) facility [1], a new capacitor bank module (CBM) has been developed by the IHCE (Tomsk) and ITHPP (France). Full PPCS of the LMJ consists of 480 CBM. Two CBMs were produced and tested in Tomsk. Main parts of the CBM are: HV power supplies, Command Control system, air conditioning system, capacitor block, and cables delivering the energy to a load.

CBM's parameters are: total rated capacitance 3000 µF, charge voltage up to 24 kV, peak current amplitude 240 kA, peak stored energy 864 kJ, pulse width at 10 % of peak power 360 µs, dimensions 2.3x1.5x2.5 m^3, weight ~ 2500 kg.

In nominal regime (24 kV, 40 m cables), the energy delivered to the flash lamps in each channel is 74 kJ (86 % efficiency). No failures were observed in more than 1000 test shots and all the CBM parameters are well within the requirements. Detailed description of the CBM design and test results are given in the report.

I. INTRODUCTION

Large number of modules (480) in the complete LMJ installation imposes strict requirements on the CBM's parameters. These include reliability of the elements (30 years estimated LMJ lifetime), cost minimization, ability to withstand failure regime, stability from shot to shot in controlled parameters, limits on size and weight, easy maintenance, and a row of other technical requirements. Basic requirements to the modular capacitive storage for large laser systems were introduced in development of first large facilities such as Shiva family (20 MJ stored) and Nova with 60 MJ. National ignition facility (NIF) at LLNL [2] is the most developed system up to now. LMJ optical output (1.8 MJ at the third-harmonic wavelength of its Nd:glass amplifiers) is the same as on NIF, but PPCS architecture is somewhat different. Extensive set of tests has been performed on the new developed capacitor bank modules at normal operation and a row of failure modes. The CBM structure, design of main elements and tests results are given below.

II. DESIGN and OPERATION of the CBM

A. Structure of the Capacitor Bank Module.

Block scheme of the capacitor bank module is given in fig. 1. Control block provides operation of the capacitor block in selected mode, control of charging voltage, current measurement in lines of energy driving from the capacitor block to the load block, discharge of storage capacitors when shot is canceled or at failure.

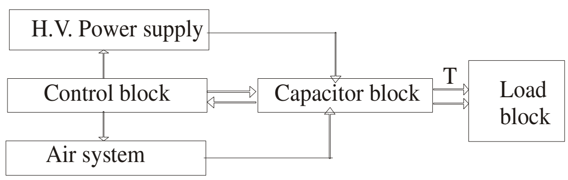

Figure 1. Block scheme of the CBM

[ξ] email: akharlov@lef.hcei.tsc.ru

High voltage power supply provides charging of storage capacitors under commands from the control block. Air system is also operated through the control block. It provides purge of air in switches of the capacitor block after shot, drives H.V. relays and pneumatic cylinders. Basis electrical schematic of the CBM is shown in fig. 2. It incorporates 2 circuits. First one is the preionization circuit which allows, by injecting a small quantity of energy, to stimulate loads before transferring them all the stored energy. It is characterized by: preionization circuit capacitor (C11), dumping device for the preionization circuit (high voltage relay K2 + and Dump_Pr resistor) and preionization circuit switch (Pr). Second one is the main circuit composed of 10 cells in parallels, a common main switch (M) and a dump device (HV relay K3 and resistors Dump_M). Each cell includes its capacitor (C1-C10), its charging resistor (R1-R10) and a pulse shaping inductor (L1-L10). Energy is driven from the capacitor to the load by 10 coaxial cables (TL1-TL10). Moreover, to check current delivered to the load, each cell is equipped with a current sensor (T1-T10).

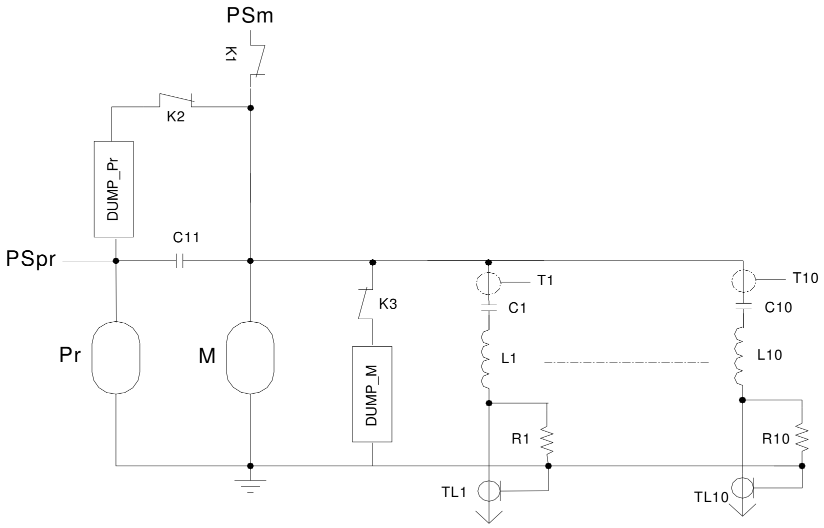

Figure 2. Electrical schematics of the capacitor bank module.

B. Operation regimes of the module

1) Preionization regime. After opening contacts of the high voltage relays K2 and K3, C11 preionization capacitor can be charged from the preionization power supply PSpr up to 24 kV. Then, preionization switch Pr is commuted and capacitor C11 is discharged on FL`s through lines TL1-TL10. Current in each lamp in this regime is ~ 2.5 kA.

2) Main regime. Contacts of the high voltage relay K2 and K3 are opened. Main circuit caps C1-C10 are charged to nominal 24 kV voltage from the main power supply PSm. At closing of the Pr switch capacitor C11 is charged by partial discharge of the C1-C10 capacitors through it and preionization pulse is formed in the TL1-TL10 lines.

At 100 ÷ 250 mks after start of the preionization pulse main switch M commutes C1-C10 on FL`s on command from the control system.

3) Dumping regime. For discharge of the C1-C10 capacitors without energy transfer to the TL1-TL10 driving lines contacts of the high voltage relay K3 are closed and energy, stored in the C1-C10 caps is dumped through dump resistors. Dumping of the C11 capacitor in the preionization regime is provided by the high voltage relay K2 closing.

C. Capacitor Block

The capacitor block appearance is shown in fig. 3. It is assembled in frame from rectangular steel tubes. Block incorporates one preionization circuit capacitor C1 and 10 main circuit capacitors C, preionization switch (Pr), main switch (M), charging and dumping resistors (mounted at the rear side), pulse shaping inductors, high voltage relays R and safety system S. High voltage power supply of the main bank PS and control system block CS are placed on the top of the capacitor block frame.

1) Capacitors from AVX company are employed in the modules: TPC-02CF128 for main circuit (rated at 290 µF, 24 kV, with -0 +4% tolerance) and TPC-04RCF065 for the preionization circuit (rated at 75.4 µF -0, +4%, 24 kV).

2) Switches for the pre-ionization and main circuits were developed and tested earlier by IHCE and ITHPP [3]. These switches are rail type spark gaps, where the spark is initiated in a three electrode layout and then accelerates due to electro-dynamical force and moves along the two extended electrodes. The switches operate in dry air at atmospheric pressure with purge after each shot. Preionization spark gap was tested at 25 kA peak current in 40,000 shots in a single polarity discharge and in 20,000 shots in bipolar discharge. Main spark gap is designed for 24 kV charge voltage and ~70 C total charge transfer. It was tested in 20,000 shots, at a current of 250 kA with a pulse length of 360 μs. No misfires were observed during tests.
3) Pulse shaping inductors are made as solenoids from cupper wire (10×5 mm^2 cross-section). Solenoid is placed inside of fiberglass tube and filled by epoxy compound. Inductors were tested at 50 kA current and no problems were detected. Current probes for each channel are mounted on the inductors.
4) Dumping and charging resistors. CBM-1 set of resistors was made on base of liquid resistors and CBM-2 set on base of solid state resistors (Ceramic Carbon disc Resistors of HVR International Ltd.).
5) High voltage relay are made on base of vacuum interrupters KDV-10-5-400. Opening of contacts is provided by air pressure supply.

Figure 3. Front view of the capacitor bank module.

III. PERFORMANCE TESTS

Extensive set of tests has been performed in order to get reliable set of the capacitor bank modules characteristics at nominal operation and check the CBM behavior in a row of failure regimes.

A. Nominal regime

1) Checking of the operation stability at variation of the charging voltage.
The CBM`s performance has been tested at 21 ÷ 24 kV charging voltage. Two CBM were operating simultaneously, one capacitor bank module is loaded on FL`s, the second on the equivalent loads (40 m cables). Typical waveforms for load voltage, current and energy are given in fig. 4. Table 1 shows statistically averaged results for these tests.

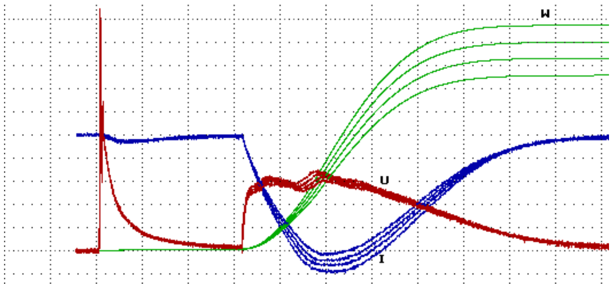

Figure. 4 FL voltage V, current I and energy W waveforms for 21, 22, 23, 24 kV charging voltage (4 kA, 4 kV, 7.5 kJ, 80 μs per division).

Table 1 Pulse parameters in one cell: current amplitude I, energy on the load E, k is ratio of load energy E to energy stored in capacitor at given charging voltage, T is pulse width at 10 % level from maximum power. Slash division means 130/250 μs delay between preionization and main currents.
Table 1

U,kV	I,kA	E,kJ	k	T,us
21	22.4/20.6	56.8/56.76	0,858/0.855	368/386
22	23.6/21.6	62.04/62.1	0,855	365.5/387
23	24.8/22.7	68/68.3	0,854/0.86	365/387
24	26.2/23.7	74.3/74.1	0,856/0.855	365/387.5

2) Tests on the cable length impact: nominal shots with 1 cable of 15 m or 65 m, the rest 40 m (24 kV charging voltage, 15 shots have been made with each length.). Table 2 shows that current, energy delivered to the FL and pulse width on 10% of maximum power level depend on the cable length.

Table 2

Cable length	Current, kA	Energy on FL, kJ	Δt, μs
15 meters	25	77	365
40 meters	23.4	74	390
65 meters	22	72	410

One can see, that variation in cable length allows to provide some variation in the pulse width and energy, delivered to the load.

3) Drawbacks search and system testing.

350 nominal shots on 2 SME with FL`s and equivalent load and 40 m cable were done. Drawbacks found during tests: a) Some sparking and erosion traces have been found on the HVR disk resistors in preionization limiting resistor (5 disks of HVR AB 886 0.2 Ohm in series). Cause: non-flatness of disks surfaces. Lead disks (100 μm) were inserted between the HVR disks and this solved the problem; b) During 300 shots it has been found that jitter in preionization switch is gradually increasing, getting close to ± 300 ns limit. After 300 shots design of the preionization switch has been modified in order to decrease total gap and self- breakdown voltage. Gap in switch was decreased on 4 mm, self-breakdown voltage was ~ 55 kV before and ~ 45 kV after modification. Jitter has been significantly decreased (from ~ 280 ns to ~ 50 ns).

B. Failure regimes tests.

1) Short circuit on 1 cable + 9 cables connected to flash lamps. Objective of this test is to check the pulse shaping inductors at breakdown on cable or FL (current through the inductor is doubled). 25 shots have been made and no changes has been observed on inductors. Temperature of inductor in short-circuited branch rises about 3° C after 10 main shots in row with 25 min. between shots Circuit inductance, derived from half-period of current pulse on short-circuited channel is ~ 44 μH.

2) Checking of transmission lines insulation in failure mode: One cable in open circuit + 9 cables connected to flash lamps. No problems with insulation has been observed in these tests.

C. Dumping regime:

Dumping of the CBM at 24 kV charging voltage at two shots with 25 min in between. Objective here is to control heating of the dumping resistors. On water resistors maximum temperature rise was about 12° C after two dumps in row. For the HVR dumping resistors stack temperature after two dumps in row is less than 150° C, and such temperature is allowed for continuous operation of the HVR resistors. After tests block of resistors has been disassembled and no damages has been observed.

D. EMC control with two CBM.

1) Two modules are charged (24 kV), only one is triggered (power supply off). Objective: Check out that second module will not trigger. Test description: 5 shots have been done when both CBM were charged and only CBM2 was triggered. Then 5 shots have been done when both CBM were charged and only CBM1 was triggered. No one self firing has been observed in all 10 shots.

2) Two modules are charged and 1 cable in one of the modules is short-circuited. Only module with short is triggered (power supply off). No one self firing of the second module has been observed in all 10 shots.

3) The two CBM modules are charged and one CBM is triggered during charging (power supply turned on), both modules are set on 24 kV charging voltage. CBM-1 is triggered manually during charging at ~ 23.5 kV. CBM-2 should finish charging and provide normal shot. 10 shots have been made and no one misfire has been observed in all 10 shots. CBM-2 was triggered in normal fashion.

4) Two modules are charged and 1 cable in one of the modules is short-circuited. One module is triggered (power supply turned on). Test description: on the CBM-2 cable in channel 6 is short-circuited. CBM-2 is triggered manually during charging at ~ 22 kV. CBM-2 should finish charging and provide normal shot. 10 shots have been made and no one misfire has been observed in all 10 shots. CBM-2 was triggered in normal fashion. Conclusion: Module noise protection satisfies to technical requirements.

5) Transient magnetic fields. Measurements were done at operation of one CBM loaded on the equivalent. Amplitude values are about 250 A/m and 80 A/m at 1 and 2 m. distance in front of the CBM, on the side it is somewhat lower. At 2 m distance field values satisfies to environmental limits. H-field follows to $1/d^2$ (distance from the bank) scaling as expected.

IV. SUMMARY

We have reported results of development efforts on the Capacitor Bank Module in frame of the LMJ project. Robust and cost effective architecture of the bank was designed. Obtained characteristics on tests satisfy well to the CEA requirements on the Power Conditioning System.

V. REFERENCES

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