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Capacitor bank of power supply for J-PARC MR main magnets

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ABSTRACT

The main ring (MR) of the Japan Proton Accelerator Research Complex (J-PARC) is a high-intensity proton synchrotron that supplies proton beams for the long-baseline neutrino experiment, called the Tokai to Kamioka (T2K). To satisfy the experimental condition for the T2K, the increase in the present beam power of 450 kW to 750 kW and beyond is mandatory. The scheme of the high-repetition-rate operation is adopted for the MR upgrade. The repetition cycle is planned to be shortened from 2.48 s at present to 1.28 s in this scheme. This upgrade involves the increase in the power variation of the electrical system. To suppress the power variation, an energy storage that consists of capacitor banks (CBs) was developed and installed in the power supply of the main magnets, since the main magnets are the primary source of power variation. The CB was designed with a sufficient consideration to avoid serious failures. The number of fuses were installed in the CB to avoid energy concentration on a short-circuited capacitor. The scheme for the safe dissipation of the concentrated energy was also employed. A fuse arcing test was carried out to clearly show the fuse reliability since the CB safety is strongly dependent upon the fuses.

1. Introduction

The main ring (MR) of the Japan Proton Accelerator Research Complex (J-PARC) is a high-intensity proton synchrotron. The specifications for the MR are listed in Table 1. The MR provides proton beams for the long-baseline neutrino experiment, called the Tokai to Kamioka (T2K), that requires the high-powered proton beams.

The upgrade of the MR is in progress to increase the beam power. The averaged beam power, P_b, is obtained as

$$P_b = E_b I_b \tag{1}$$

where E_b and I_b represent the beam energy and the averaged beam current, respectively. I_b is increased by increasing the repetition rate of the beam shots from the MR to the target station. The present repetition cycle of 2.48 s is planned to be shortened to 1.28 s.

The beam bunches are accelerated from 3 GeV to 30 GeV, and the excitation currents of the main magnets are needed to ramp along with the beam energy. The excitation-current pattern and the output voltage of the PS in the 2.48 s cycle are illustrated in Fig. 1. These are the PS patterns for a single bending magnet family. There are 6, 11, and 3 families for bending, quadrupole, and sextupole magnets, respectively. The slopes of the excitation-current pattern become steeper after the upgrade. The PS output voltage is described as

$$V = RI + L\frac{dI}{dt}, \tag{2}$$

where R, L, and I are the resistance, inductance, and excitation current of the magnets, respectively. The output power of the PS, VI, increases as dI/dt increases. Moreover, the excitation energy is transferred back to the electrical system in each repetition cycle. Subsequently, the power variation in the electrical system is expected to increase. The main magnets are the dominant sources of the power variation in the MR owing to their large excitation energy. The dashed line in Fig. 2 shows that the present power variation in the electrical system that is induced by the all main magnet families is approximately 60 MVA (peak to peak). This value is expected to increase beyond 100 MVA after the upgrade, and is not accepted by the electrical company.

One promising scheme to reduce the power variation is the capacitive energy storage. The capacitor bank (CB) that consists of parallel-connected capacitors are employed in the PS for the main magnets.

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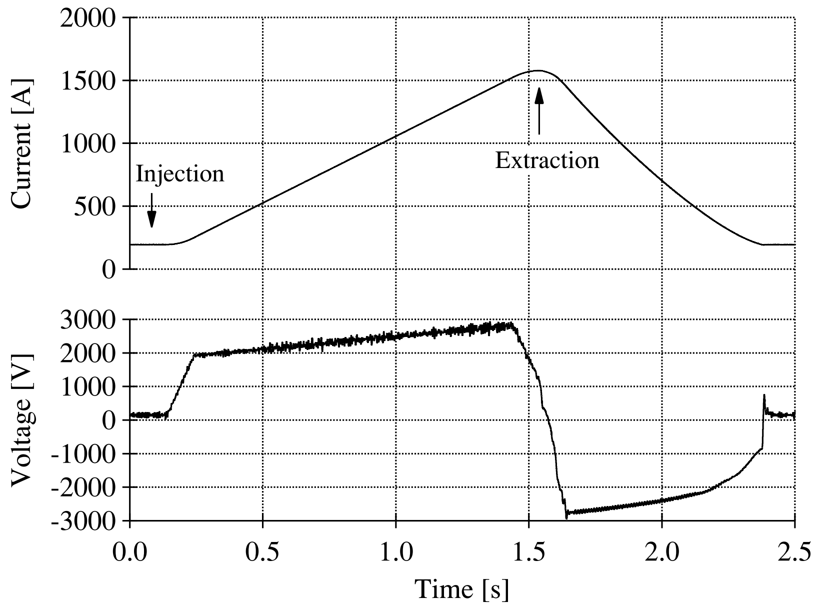

Fig. 1. Measured patterns of the excitation current and the output voltage of the PS of a single bending magnet family in the MR.

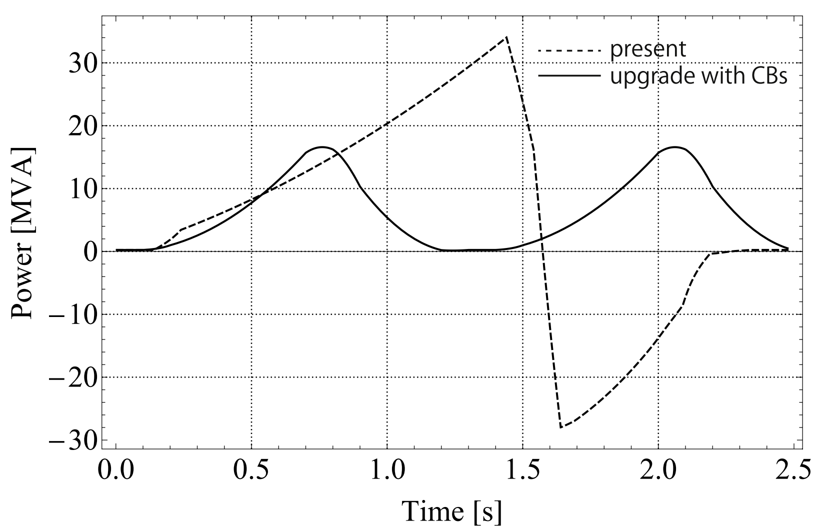

Fig. 2. Power variations in the MR. The dashed line indicates the calculated power variation at present. No tracking error of the excitation current is assumed. The solid line represents the calculated power variation with the CBs after the upgrade.

Table 1
Specifications for the MR.

Beam energy [GeV]	3 (injection) 30 (extraction)
Beam power [kW]	450 (present) >750 (upgrade)
Repetition cycle [s]	2.48 (present) 1.28 (upgrade)

When the magnets are de-excited, the excitation energy of the magnets are transferred to the CB. Subsequently, the stored energy is transferred back to the magnets for the excitation in the next repetition cycle. This scheme reduces the energy flow between the PS and the electrical system. As shown with the solid line in Fig. 2, the power variation in the electrical system is suppressed to below 60 MVA even after the upgrade.

The designs of a new CB was developed with sufficient safety considerations and the CBs in typical applications were reviewed. The typical applications are listed in Table 2. The laser Megajoule (LMJ) is a laser facility in France built by the French nuclear science directorate (CEA) [1,2]. The National Ignition Facility (NIF) is a laser fusion driver at the Lawrence Livermore National Laboratory (LLNL) [3–6]. The power for proton synchrotron (POPS) is a power supply system for the magnets of the proton synchrotron in the European Organization for Nuclear Research (CERN) [7–10]. It is noteworthy that the CB of the POPS has similar applications as that of the J-PARC's project. E_{total}, E_{CBM}, N_{CBM}, E_{cap}, and V_{chrg} represent the total stored energy of the CBs, the stored energy of a single CB module (CBM), the number of CBMs, the stored energy of a single capacitor, and the charged voltage of the capacitors, respectively.

Main issues to be considered for the CB design are listed below.

Capacitor type The capacitor with dielectric fluid is not accepted. The short-circuit fault can vaporize the dielectric fluid; subsequently, the pressure in the space where the capacitors are installed drastically increases. Thus, the gas vent structure should be equipped if the capacitors are installed in the closed spaces. Fire protection should also be considered. Consequently, the dry-type self-healing (SH)