UPGRADE SCHEME FOR THE J-PARC MAIN RING MAGNET POWER SUPPLY[#]

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Abstract

Japan Proton Accelerator Research Complex (J-PARC) is under construction at the Tokai campus of Japan Atomic Energy Agency (JAEA) as a joint project between KEK and JAEA. The accelerator complex, which is constructed as an 181 MeV linac, a 3 GeV RCS synchrotron, and a 40 GeV main ring in phase-I. The main ring magnet power supply is under construction as the energy of 40 GeV in phase-I and will be upgraded up to 50 GeV in phase-II. A large amount of pulse electric power, which is + 105 MW and -65 MW peak-to-peak, is required for 50 GeV operation and this large pulse power will give unallowable disturbances to a power network. In order to compensate the disturbances to an allowable level, we need some energy storage system. A SMES system will be one of the promising means for the purposes as well as the fly-wheel system. We will describe energy storage systems for the compensation and also possible limit to increase the repetition rate without an energy storage system.

INTRODUCTION

An accelerator complex called J-PARC with a joint project between KEK and JAEA is under construction at the Tokai campus of JAEA to be commissioned in 2007 (2008 for main ring)[1]. The complex in the final stage will be composed of a 600-MeV linac[*], a 3-GeV rapid cycling synchrotron (RCS) and a 50-GeV main ring synchrotron (MR). The MR will be operated with the repetition rate of around 0.3 Hz in order to extract a proton beam for the nuclear and particle physics experiments and neutrino experiment. The project is processing with two steps, Phase-I and Phase-II. Although the main ring will be operated at 40 GeV in phase-I, it will be upgraded to 50 GeV in Phase-II. The demanded pulse electric power at the 50 GeV operation will be almost double of that of the 40 GeV operation. This large pulse power will disturb an electric power network connected over a permissible limit. Therefore some means is needed to equip for the pulse power compensation.

50GEV MAIN RING POWER SUPPLY AND ELECTRIC POWER DEMAND

The MR has a three-superperiod configuration with a family of 96 bending magnets and eleven families of 216 quadrupole magnets. The bending magnets are divided into three sections and six groups in total. Each group is excited with a unit of power supply. Therefore, the power supply for the bending magnets consists of six power supply units, while each family of the quadrupole magnets have one power supply unit [2, 3].

One of the typical excitations for the MR magnets at 50 GeV operation is that after the injection period of 0.17 seconds, the magnetic field is linearly increased up to 2 T at the flat top (FT) in 1.9 s, kept for 0.7 s at FT, and decreased to the initial value for the next step of beam acceleration in 0.87 s. The total cycle time is 3.64 s.

The pulse electric power is required to excite the magnets corresponding to the resistive and inductive parts at the 50 GeV operation. Since the power supply adopts the self-commutated converter system utilizing IGBT or IEGT, no reactive power is generated and power factor is unity.

The typical pattern of the active power for 50GeV operation is shown as pattern c in Fig. 2. The peak power is generated at the end of the full excitation and the beginning of the de-excitation of the magnets. The peak powers at each timing are +105 MW and -65 MW, respectively, and the total pulse power amplitude is 170 MW. The big active power swing affects a connected network with disturbances over a permissible level. In order to reduce such disturbances, some compensation device has to be installed. When the MR is excited up to 40 GeV in Phase-I, the pulse power will be about a half of that of the 50 GeV operation, and the disturbance level is allowable. That is, the result of the original design indicates that the disturbance level is allowable if the total pulse power amplitude is less than 100MW[†].

PULSE POWER COMPENSATOR

Two kinds of devices may be considered for the pulse electric power compensation: one is the FWG and the other is SMES.

Flywheel Generator System (FWG)

For the original design of the energy storage system, a doubly-fed FWG system has been under consideration as shown in Fig. 1[2, 3].

A doubly-fed flywheel generatator-motor of a wound-rotor induction machine and a cycloconveter or a voltage-source rectifier-inverter which is used as an ac exciter. Adjusting the rotor speed makes the generator-motor either release the kinetic energy to the power system or absorb it from the power system. Thus, the generator-motor has the capability of achieving, not only reactive power control, but also active power control based on a flywheel effect of the rotor.

[*]In Phase-1, an 181 MeV linac is under construction for a 400 MeV linac.

[#]Work supported by Joint Development Research at KEK.

[†]Simulation results by Tokyo Electric Company.

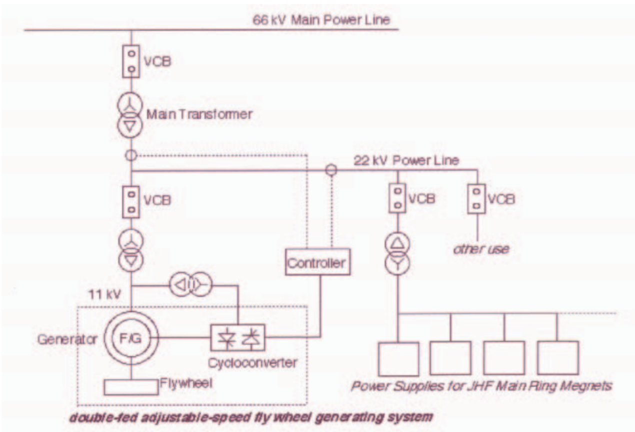

Figure 1: Conceptual block diagram of the power supply system with FWG for 50-GeV MR.

For example, the 200 MJ ROTES (Rotary Energy Storage System) was successfully commissioned at the Chujowan substation in Okinawa island of Japan[4]. The ROTES is an excellent system designed to suppress frequency fluctuations caused by sudden and frequent load changes in the power network system.

The preliminary investigation has been carried out for the FWG and performed the 75 kW class model experiment[5, 6]. A 50 MVA flywheel energy storage system should be installed for the MR 50 GeV operation. However, the number of pulse repetition will be 10^8 times in the lifetime of the MR. In case of the FWG, therefore, this large number of repetitions have to be carefully considered because of repetitive mechanical and thermal stresses.

Superconducting Magnetic Energy Storage System (SMES)

The other solution for the pulse power compensation is a SMES system. In case of the SMES, the system can be installed at an ac line as like as the FWG system, and also at a dc line of the power supply for the MR magnets.

As mentioned above, we assume that the pulse power over that at the 40 GeV operation has to be compensated by the SMES system. This means that the pulse power over around 60 MW is to be compensated by the SMES as shown as patterns b and c in Fig. 2.

The energy for compensation over 60 MW is estimated as around 30 MJ. If 30% of the stored energy in the SMES system is assumed to be used with a conservative estimate, a SMES system, which has the capacity of 100 MJ, is necessary. We designed two types of SMES systems; one is a simple type installed at an ac line as like as the FWG system and we propose the other excellent system configuration with which six SMES units are connected at the dc side of the power supply. Moreover, we have performed the design study in which the total system capacity is divided into six units: 17 MJ/10 MW × 6 [7].

For the case of ac link, SMES will be installed at the proposed site of FWG system, but there is a difficulty of installation site for the case of dc link and refrigerator system installation.

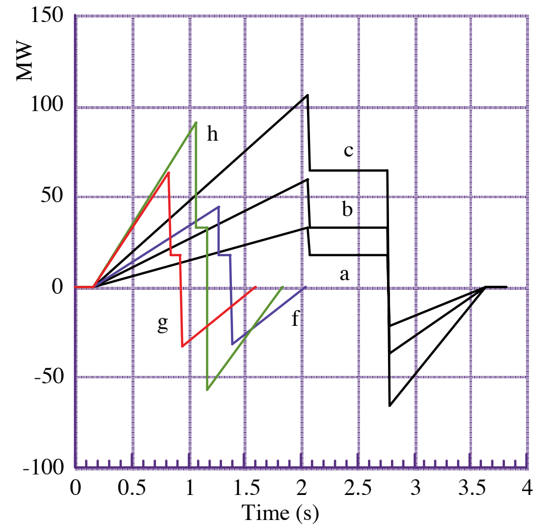

Figure 2: The active power of the MR (bending magnets and quadrupole magnets) for the various operation patterns. Parameters of each pattern are shown in Table 1.

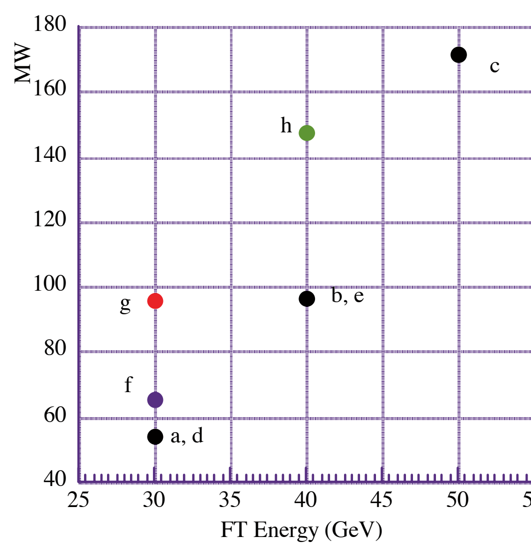

Figure 3: Total pulse power amplitudes for the various patterns as shown in Table 1. The disturbance level is allowable if the total pulse power amplitude is less than 100 MW, such as pattern a, b, d, e, f and g. However, pattern g requires the power supply upgrade. Patterns c and h require both of power supply upgrade and some energy storage system.

UPGRADE SCHEME WITH /WITHOUT POWER COMPENSATOR

Power supply system in phase-I can excite the MR magnets up to 40 GeV if it is the standard pattern (3.64 s repetition), without an energy storage system. In order to excite up to 50 GeV, it is necessary not only an energy storage system, but also transformer replacement and rectifier upgrade to increase the voltage. However, for the long-baseline neutrino oscillation experiment at J-PARC, the flat top length is adequate less than 0.1 s for the fast extraction. However, the pulse power amplitude is the same as that of the typical one

To reduce the upgrade construction budget, the scheme of the power supply excitation pattern can be divided into the following three types. Considerable power supply patterns are listed in Table 1 and the active power swing of the MR is shown in Fig. 2 and the total pulse power amplitude is shown in Fig. 3.

1) No upgrade, only increasing of the repetition rate with short FT length and rapid excitation during acceleration such as patterns of a, b, d, e and f in Table 1.

2) Transformer replacement and rectifier upgrade without energy storage system such as pattern g in Table 1.

3) Transformer replacement and rectifier upgrade with energy storage system installation such as patterns of c and h in Table 1.Beam power of the standard patterns a (30 GeV), b (40 GeV) and c (50 GeV) are 263 kW, 352 kW and 440 kW, respectively. However, as a result of shorting the repetition rate, the beam power will be expected, 315 kW, 421 kW and 470 kW for patterns d (30 GeV), e (40 GeV) and f (30 GeV), respectively‡.

‡For the case of 181 MeV linac operation and 2 bunches injection to RCS.

CONCLUSION

A 50 GeV operation of the J-PARC MR in phase-II requires some compensation device to reduce unallowable disturbances to a power network and transformer replacement and rectifier upgrade to increase the voltage. Typical pattern of the 50 GeV operation such as pattern c in Fig. 2 induce the power swing +105 MW and -65 MW peak-to-peak. Two kinds of devices, FWG and SMES systems have been considered. However, in order to perform the long-baseline neutrino oscillation experiment as early stage as possible, the scheme of the fast repetition rate operation pattern has been examined. If the total pulse power amplitude is less than 100 MW, the disturbance level is expected less than allowable level. Then, 30 GeV or 40 GeV operation can be done without power supply upgrade and compensation devices, as shown as patterns d, e and f in Table 1 and Fig. 3. The beam power will be expected, 315 kW, 421 kW and 470 kW for patterns d, e and f, respectively.

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Table 1: Considerable Power Supply Patterns

Pattern	FT Energy (GeV)	Acc. (s)	FT (s)	Reset (s)	Peak Power (MW)	Power Amplitude Swing (MW)	Av. Power (MW)	Beam Power (kW)
a	30	1.9	0.7	0.87	28.8	54.1	14.6	263
b	40	1.9	0.7	0.87	56.4	96.7	26.3	352
c	50	1.9	0.7	0.87	98.5	171.5	50.7	440
d	30	1.9	0.1	0.87	36.0	54.1	14.0	315
e	40	1.9	0.1	0.87	66.4	96.7	25.0	421
f	30	1.1	0.1	0.67	44.2	76.1	18.1	470
g	30	0.66	0.1	0.66	63.4	96.2	21.1	603
h	40	0.90	0.1	0.67	90.4	147.6	34.3	695

* Injection period is the same time of 0.17 s for all patterns.
a, b: 30 GeV and 40 GeV standard patterns for the slow extraction (3.64 s repetition), respectively.
c: 50 GeV standard pattern for the slow extraction (3.64 s repetition), needs both of power supply upgrade and energy storage system. d: 30 GeV, FT 0.1 s (3.04 s repetition). e: 40 GeV, FT 0.1 s (3.04 s repetition).
f: 30 GeV, FT 0.1 s, rapid excitation of 1.1 s (2.04 s repetition), no power supply upgrade.
g: 30 GeV, FT 0.1 s, rapid excitation of 0.93 s (1.59 s repetition), with power supply upgrade but no energy storage system.
h: 40 GeV, FT 0.1 s, rapid excitation 0.90 s (1.84 s repetition), needs both of power supply upgrade and energy storage system.