PRESENT STATUS OF THE J-PARC ACCELERATOR

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Abstract

Construction of the Japan Proton Accelerator Research Complex (J-PARC), which consists of a 400 MeV Linac, a 3 GeV Rapid Cycling Synchrotron (RCS), and a 50 GeV Main Ring (MR), commenced in 2001. J-PARC is a multipurpose accelerator complex. The RCS uses 1 MW proton beams to generate pulse neutrons that will be used for various research projects ranging from basic science to applied science at Materials and Life science Facility. A muon target is inserted at a position before the neutron target to generate high-intensity muons for use in various experiments. The MR has a fast-extraction mode and slow-extraction mode, to be used for neutrino experiments and hadron experiments, respectively. The Linac will start beam acceleration in December 2006, the RCS in September 2007, and the MR in May 2008.

INTRODUCTION

The J-PARC, which stands for Japan Proton Accelerator Complex, comprises a 400-MeV linac, 3-GeV Rapid-Cycling Synchrotron (RCS), and a 50-GeV Synchrotron (MR) [1-3]. In Phase I, however, the MR will be operated up to 40 GeV, since a fly-wheel electric power system will be available in Phase II. Furthermore, the Linac will start with a beam energy of 180 MeV, then the RCS beam power will be reduced from 1MW to 600 kW. The Materials and Life Science Facility (MLF) in Phase I is equipped with a full-power neutron target of 1 MW. A muon target is inserted at a position before the neutron target to generate high-intensity muons. The Hadron Experimental Facility utilizes a slow-extracted beam form the MR for hadron physics experiments. The Neutrino Experimental Facility to perform a long base line neutrino-oscillation experiment utilizes a high-power fast-extracted beam from the MR. The detector SUPERKAMIOKANDE locates at the distance of 300 km west from the J-PARC facility. Beam commissioning of the linac will start this December, the RCS in Sep. 2007, and the MR in May 2008.

CONSTRUCTION STATUS

Linac

The Linac, which has a total length of approximately 340 meters, accelerates a peak current of 50 mA at a beam energy of 400 MeV (180 MeV in the first stage). Its pulse width is 500 μsec and its repetition rate is 50 Hz, of which 25 Hz is used for injection into the RCS and the remaining 25 Hz is used for testing of accelerator driven nuclear waste transmutation system (ADS) in future. Testing from the ion source to Drift Tube Linac (DTL) 1 was completed by September 2003. A current of 30 mA was accelerated at a beam energy of 20 MeV, and the resulting emittance was very close to the expected value obtained by computation [4]. After testing, the accelerator was transported from Tsukuba to Tokai and reassembled, and the other accelerating tubes, DTL 2 and 3, and Separated Drift Tube Linac (SDTL) 1 through 32 (31 and 32 to be used as buncher and debuncher), were installed. Fig. 1 shows the linac installed in the tunnel. In March 2006, high-power testing of klystrons started in the klystron gallery, and the testing of all the klystrons to be used was completed. A klystron under test is shown in Fig. 2. Microwave aging of the RFQ, three DTLs and 32 SDTLs will start in September, and beam acceleration in December.

Fig. 1: All accelerating structures are installed in the LINAC tunnel.

Fig. 2: The klystron under test.

RCS

The RCS is a synchrotron that accelerates the Linac injection energy (400 MeV or 180 MeV) to as high as 3 GeV at 25 Hz. When 400 MeV is injected, it outputs 333 μA at an energy of 3 GeV and a proton beam of 1 MW. The RCS uses 24 bending magnets and 60 quadrupole magnets of seven families. Magnetic field measurement of all these magnets has been completed and their installation has started. The bending magnets and quadrupole magnets use ceramic ducts to prevent eddy current generation. An RF shield is mounted on the surface of the ceramic duct and its inside surfaces are TiN coated [5]. These ceramic ducts will be incorporated into the magnets in the RCS carry-in area. Fig. 3 shows installed bending magnets in the tunnel.

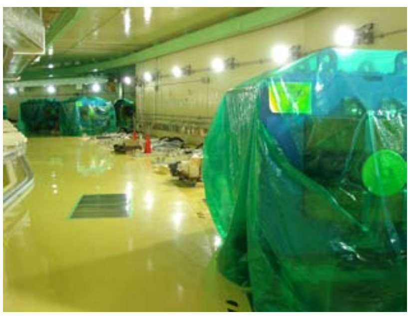

Fig. 3: Bending magnets installed in the RCS tunnel.

MR

The MR, 1567.5 meters in circumference, is a synchrotron capable of accelerating to a maximum of 40 GeV at an injection energy of 3 GeV [6]. When the energy storage equipment, such as a fly-wheel, is installed on it during the second stage, acceleration to as high as 50 GeV will be achieved [7]. A total of 96 bending magnets, 216 quadrupole magnets, 72 sextupole magnets, and 186 steering magnets are to be used. Magnetic field measurement of all these magnets has been completed [8,9]. Approximately one-third of the magnets have been installed in the tunnel as shown in Fig. 4. Magnets in the beam line from the RCS to the MR have been installed as well (Fig 5). All housing buildings will be completed in December 2006, and all the magnets will be installed by the end of March 2007. Test operation of the entire magnet power source is planned to start in December 2007, and beam acceleration in May 2007.

Fig. 4: Bending magnets and quadrupole magnets installed in the MR tunnel.

Fig. 5: Beam transport line from the RCS to the MR.

CHALLENGE TO DEVELOP NEW TECHNOLOGIES AND THE PRESENT SITUATION

As a multipurpose accelerator complex, J-PARC will serve a broad range of research areas from materials and life science to elementary particle and nuclear studies. For this reason, we have chosen to introduce high-current, high-power rapid cycling synchrotrons, not accumulation rings. Let us now take a look at some statements about the possible disadvantages of rapid cycling synchrotrons as compared to accumulation rings, which appeared in a paper concerning the technical design report (TDR) written in 2003 [10].

1) The lower injection energy implies a higher space charge effect. Large-aperture magnets are required in order to overcome the space charge effect. Large magnets and powerful power supplies are necessary. The large aperture gives rise to large fringing fields.
2) A powerful RF accelerating system is necessary.
3) A ceramic vacuum chamber should be used to avoid the eddy current effect. Then, RF shields need to be attached to the ceramic vacuum chambers in order to prevent electromagnetic waves radiating from the beams.
4) Stranded coils need to be used to overcome the eddy current effect on the magnet coils in some cases.
5) Precise magnet field tracking is necessary for each family of magnet.

The following is a report on the challenges listed above and the current developments in these areas.

RCS Injection

The circumference and the length of the straight sections of the RCS were limited to certain values due to the pulse length requirements determined by the neutron experiment and the limited land area where the RCS is to be installed. The RCS ring has three-folding symmetry, with its three straight sections and three arc sections. For a high-power proton accelerator, it is necessary to install the injection and extraction equipment, ring RF, and transverse beam collimator on its straight sections. This necessitates installation of the ring RF on one straight section, the extraction equipment on another, and the injection equipment and ring collimator on the remaining straight section. As a result, the injection section is crowded with a variety of equipment. The designs of all the equipment for the RCS have been finalized, and all the components have been ordered. To alleviate the high space charge strength, the beam duct of the RCS has a large diameter and the quadrupole magnet has a large bore diameter. The magnets cause magnetic field interference with other equipment installed nearby, reducing field strength and/or generating multi-pole components. We have therefore started to measure the field strength and multi-pole components of the magnetic fields caused by magnetic interference, such as that between the quadrupole magnet and the sextupole magnet as shown in Fig. 6. We are planning to conduct orbit analysis based on the results of these measurements.

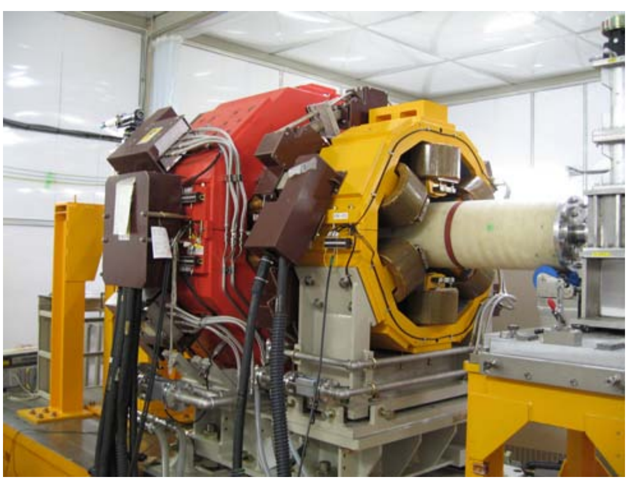

Fig. 6: Measurement of magnetic field interference between a quadrupole and sextupole magnet.

Ring Microwave

The RCS has a circumference of approximately 340 meters. When one straight section with a length of 46.8 m is dedicated to the ring RF cavity, the available length for 12 cavities will be 21.6 meters. The maximum necessary voltage is 450 kV in total, and a maximum field intensity of about 22.5 kV/m is required, keeping one of 12 cavities on standby [11]. To achieve this high field intensity, we are currently developing an acceleration cavity using a magnetic alloy. In our tests applying the field strength of 25 kV/m, we observed some damage on the cores. We found that all of the damaged cores were installed on the high field side. Fig. 7 shows the calculated result of the field distribution of this acceleration cavity, indicating that the surface of the core near the acceleration gap showed the highest field intensity [12]. It is assumed that the core damage was caused by the electric field applied to the core, not by the magnetic field. The Proton Synchrotron (PS) of KEK Tsukuba, which employs similar cores, has been steadily using an acceleration cavity with forced-air cooling at about 15 kV/m for more than three years [13]. In the acceleration of the PS, they devised a measure by which most of the electric field is applied to the gap between the core and the acceleration electrode, thus limiting the voltage applied to the core. Electric field strength required in J-PARC is substantially higher than existing ones. Any new technology development is accompanied by difficulties, but we are solving them one by one [14,15]. A diagnostic system which finds cores possibly damaged at high field strength has been developed. We have started developing a core which will withstand higher electric field. An accelerating cavity with a configuration that reduces an electric field to the core surface will be investigated as well.

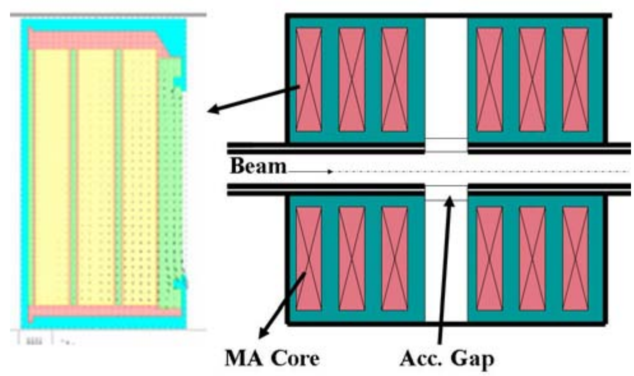

Fig. 7: Schematic cross sectional view of accelerating cavity (right) and calculated field distribution (a quarter) in the cavity are shown.

Ceramic Duct

The ceramic duct in the RCS has many elements to be developed. The ceramic duct for use with the bending magnet has a racetrack shape, 18.7 cm in height and 24.5 cm in width. The ceramic duct has a curvature corresponding to the bending angle of the magnet. There were many difficulties in the development of this duct, but finally all ducts were completed. Each end of the duct will have a titanium flange, and the inside surface of the duct will be TiN coated. The RF shield will be insulated with a ceramic capacitor to avoid the eddy current effect.

Stranded Coil and Magnet Field Tracking

The stranded coil impregnated by the polyimid resin is one of the well-developed components. Used for the bending magnets and quadrupole magnets, the stranded coil contributes greatly to the reduction of eddy current generation. The RCS uses eight resonant networks including the bending magnet and seven quadrupole magnet families. A high Q value is desirable to stabilize this power source. The magnets using strand lines met our expectations by generating little AC loss and achieving a high Q value. It is technically difficult to impregnate strand lines with polyimide resin, but after much trial and error we have finally established a method that allows sufficiently stable production of strand lines.

Tracking the quadrupole magnets of seven families in the RCS is considered to be one of the more difficult tasks. By adding the magnet saturation properties and adjusting the phase of the AC power source and fractions between the AC and DC power source, the tune shift caused by tracking error is expected to be significantly smaller than that caused by the space-charge effect. With the RCS, we have prepared a schedule that will allow energization of the magnets installed in the tunnel at the earliest stage possible so that sufficient time can be used for tracking.

OTHER TESTS AND PROGRESS

In the RCS, the test of the four horizontal shift bump magnets is a matter of big concern. These shift bump magnets have an aperture larger than 460 mm in width and 270 mm in height. The magnetic field measurement showed that the magnet has enough flat field through wide aperture. When injection is completed, the system attempts to restore the bump orbit very quickly. For this purpose, a power supply for the shift bump magnets fall down from a current of nearly 20 kA to zero in 135 μs. Thus the magnet temperature rise due to ohmic loss and eddy current is a matter of concern as well. Long-hour test has been conducted and results showed the temperature rise was within the permissible range of value [16]. The manufacture of kicker magnets and their power supplies was completed, and magnetic field measurement was carried out [17]. In the MR, all injection and extraction devices except those for slow extraction have been delivered. Tests of these devices have been continued [18.19]. Thus both in the RCS and the MR, tests of various devices have been continued. Accelerator system commissioning without beams in the RCS will start in December 2006 and that of the MR in December 2007.

Beam monitors for three accelerators, beam collimators of the RCS, beam collimators of the 3-50BT and control systems have been well progressing.

OTHER IMPORTANT CHALLENGES

In addition to the issues in the development of the TDR outlined above, other important challenges include the development of stripping foil for the RCS and securing of the site near the coast.

Stripping Foil

The stripping foil installed in the injection section of the RCS is one of the key components of the accelerators in J-PARC. The charge stripping foil used in the RCS becomes extremely hot (higher than 1,800 K) due to the high current, and conventional foils would therefore only have a very short life span if used. We have been involved in the development of a foil for this special application, and have successfully developed a foil that can be used at extremely high temperatures. The foil was tested using a neon beam, and in a test simulating the conditions of use with the RCS, it showed a life span approximately 100 times longer than that of diamond foil. This foil is currently undergoing a life span test using a 650 keV H^-beam [20,21].

The J-PARC facilities are installed in a coastal location. For this reason, tunnel sinkage is a serious matter of concern. Since the completion of the MR tunnel, its movement has been constantly monitored. As other buildings are currently being constructed, the J-PARC building shows vertical fluctuations due to the effects of the construction work. Continuous monitoring is being carried out by monitors installed inside the building [22].

SUMMARY

Beam commissioning of the Linac will start in December 2006. Orders for all the components of the RCS have already been placed, and bending magnets are being installed in the tunnel. Magnets are being installed and wiring work is currently under way in the MR in parallel with the ongoing off-line testing of the injection and extraction equipment. Beam commissioning scenario is also progressed.

REFERENCES

[1] Y. Yamazaki, “The JAERI/KEK Joint Project for High-Intensity Proton Accelerators”, Proc. 2002 European Part. Acceler. Conf., TUBZ003 (2002).

[2] Y. Yamazaki, “The JAERI/KEK Joint Project (the J-PARC Project) for the High Intensity Proton Accelerator”, Proc. 2003 Part. Acceler. Conf., ROPA002 (2003).

[3] Y. Yamazaki, “J-PARC Construction and Its Linac Commissioning”, Proc. 2004 European Part. Acceler. Conf., pp. 1351 (2004).

[4] K. Hasegawa, “J-PARC Commissioning Results”, Proc. 2005 Part. Acceler. Conf., ROPC002 (2005).

[5] M. Kinsho et al., “Alumina Ceramics Vacuum Duct for the 3 GeV-RCS of the J-PARC”, Proc. 2005 Part. Acceler. Conf., RPPE 039.

[6] M. Yoshioka et al., “Installation and Radiation Mentenance Scenario for J-PARC Main Ring”, Proc. 2005 Part. Acceler. Conf., RPPE002.

[7] H. Sato et al., “Upgrade Scheme for The J-PARC Main Ring Magnet Power Supply”, these proceedings, WEPLS129.

[8] K. Niki et al., “Results of field Measurements for J-PARC Main Ring Magnets”, these proceedings, WEPLS072.

[9] M. Tomizawa et al., “Position Shuffling of the J-PARC Main Ring Magnets”, these proceedings WEPCH028.

[10] "Accelerator Technical Design Report for High-Intensity Proton Accelerator Facility Project, J-PARC", KEK Report 2002-13(2003), JAERI-Tech 2003-044.
[11] C. Ohmori et al., "High Field Gradient Cavity for J-PARC 3 GeV RCS", Proc. 2004 European Part. Acceler. Conf., pp123 (2004).
[12] Courtesy of KEKB RF group.
[13] S. Ninomiya et al., "Non-Resonant Accelerating System at the KEK-PS Booster" Proc. 2004 European Part. Acceler. Conf., pp. 1027 (2004).
[14] C. Ohmori et al., "New Cutting Scheme of Magnetic Alloy Cores for J-PARC", these proceedings, TUPCH128.
[15] M. Yamamoto et al., "High Power Test of MA Cavity for J-PARC RCS", these proceedings, TUPCH131.
[16] T. Takayanagi et al., "Experimental Results of the Shift Bump Magnet in the J-PARC 3-GeV RCS", these proceedings, TUPLS111.
[17] J. Kamiya et al., "Measurement of the Extraction Kicker System in J-PARC RCS", these proceedings, TUPLS110.
[18] K. Koseki et al., "Pulse Bending Magnet of the J-PARC MR", these proceedings, TUPLS106.
[19] I. Sakai "Operation of the Opposite Field Septum Magnet for the J-PARC Main Ring" these proceedings, TUPLS107.
[20] I. Sugai et al. "Realization of Thick Hybrid Type Carbon Stripper Foils with High Durability at 1800K for RCS of J-PARC", these proceedings, TUPLS108.
[21] A. Takagi et al., "An Irradiation System for Carbon Stripper Foils with 750 keV H-Beams" these proceedings, TUPLS028.
[22] S. Takeda et al., "Ground Motion Study and the Related Effects on the J-PARC", these proceedings, MOPCH120.