# THE JAERI-KEK JOINT PROJECT FOR THE HIGH-INTENSITY PROTON ACCELERATOR, J-PARC

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*Abstract*

The J-PARC project comprises a 400-MeV linac, a 3-GeV, 1-MW rapid-cycling synchrotron (RCS), a 50-GeV main ring (MR), and experimental facilities using the 3- and 50-GeV beams. The J-PARC facility is under construction to be completed by March 2007. The J-PARC accelerators are based upon many newly developed technologies, including the RF system using the cavities loaded with the magnetic alloy (MA) and the linac components such as the RFQ linac with π-mode stabilizing loops (PISL's), the RF choppers, and others in order to realize their high beam powers. The recent results of the developments of these new technologies and the present status of the construction are reported.

## INTRODUCTION

The High Intensity Proton Accelerator Facility Project in Japan [1-7] is now referred to as "J-PARC Project", which stands for Japan Proton Accelerator Research Complex. The facility is under construction as a joint project between Japan Atomic Energy Research Institute (JAERI) and High Energy Accelerator Research Organization (KEK) at the JAERI Tokai site. The construction started from April 2001 to be completed by the end of March 2007. The facility, which was so far funded, comprises a 400-MeV linac, a 3-GeV Rapid-Cycling Synchrotron (RCS), and a 50-GeV Synchrotron (Main Ring, MR) as shown in Fig. 1.

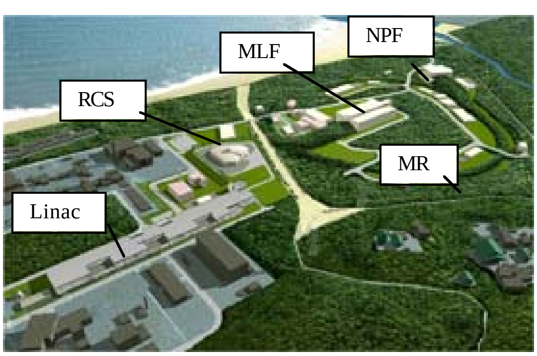


Figure 1: The expected view of the facility

The $H^-$ beam with a peak current of 50 mA and a pulse width of 500 μs is accelerated up to 400 MeV by the linac, and then injected to the RCS with a repetition rate of 25 Hz. The beam is chopped with a chopping rate of 56 % in order to avoid the beam loss during the adiabatic capture, which would have been necessary without any chopper. The linac can be operated with a repetition rate of 50 Hz, the remaining half of which will be used for the basic study of the accelerator-driven nuclear waste transmutation system (ADS) in future.

The beam accelerated by the RCS with an average current of 333 μA and a beam power of 1 MW is fast extracted and transported to the Materials and Life Science Experimental Facility (MLF) most of the time. In this experimental area, the muon and the neutron production targets are located in a series. The 10 % of the beam is used for the muon production. Every 3.5 second, the beam is four times transported to the MR and injected to it. The 50-GeV beam accelerated there is slowly extracted to the Nuclear and Fundamental Particle Experimental Facility (NPF) with a duration of 1.6 s. The Kaon rare decay experiments, the hyper nucleus experiments, and others will be conducted there. Sometimes the beam is fast extracted to the neutrino production target. The produced neutrinos are sent to the SUPER KAMIOKANDE detector located 300-km west in order to conduct the long base line experiment.

The budget for the neutrino experiment facility will be submitted to the funding agency with a top priority this year. The operational energy of the MR will be limited to 40 GeV, until the fly-wheel power supply system is afforded in the Phase II.

The features of the accelerator design are presented in Ref. [6], while the design detail is described in the Technical Design Report (TDR) [7]. The distinctive features of the J-PARC accelerator are briefly summarized in Sec. 2. Then, the results of the developments after the last EPAC [6] and the construction status are reported in this paper.

The funding so far is almost as scheduled (see Fig. 2). As a result all the contracts have been done on schedule except for the high-energy linac (190-400 MeV) for the reason presented in Sec. 3. The construction is also on schedule, although several-month delay is expected for the MR. The ancient salt-pan remains were discovered in the location for the MR and NPF. The archaeological excavation of the remains will take nearly one year. On the other hand, this will have no influence on the schedule of the linac, RCS and MLF constructions.

The civil engineering for the linac was contracted by the end of JFY (Japanese Fiscal Year starting from April) 2001, and will be completed by mid JFY2004. That for the RCS was contracted mid JFY2002, and will be completed by the end of JFY2004. That for the MR was divided to the four sections, which will be contracted year by year, being completed by the end of JFY2005, if it were as planned. The full view of the J-PARC site now is shown in Fig. 3.

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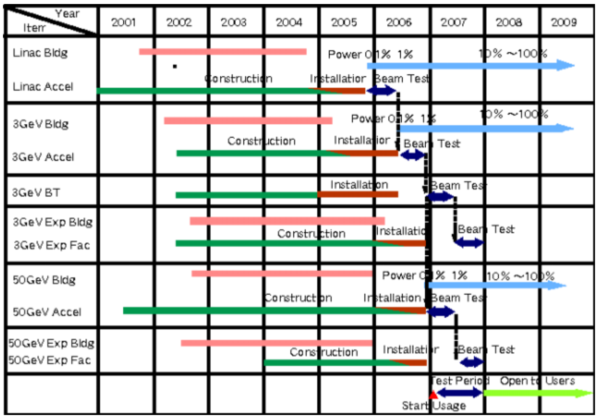


Figure 2: The schedule for the J-PARC project. The year shows Japanese Fiscal Year starting from April.

Figure 3: The present view of the facility

## DISTINCTIVE FEATURES OF J-PARC ACCELERATOR

The distinctive features of the J-PARC accelerator are arising from its multi-purpose concept: the realization of the high beam powers of MW class in both the GeV and the several 10 GeV region. The 3-GeV RCS, which plays a role of the injector to the 50-GeV MR, also provides the 1-MW pulsed beam to the MLF. Since the Spallation Neutron Source Project in US (SNS) is a single-purpose one, it can utilize the full-energy linac and the accumulator ring (AR). The RCS scheme, which the J-PARC project makes use of, has the following advantages over the AR scheme.

First, the beam current is lower for the same beam power. Second, the more beam loss is allowed during the injection process, since the radioactivity and the radiation itself are reduced in proportion to its lower injection energy and further.

On the other hand, the choice of the high-power, high-energy RCS scheme requires many problems to solve. Among them, the following items are outstanding. First of all, the fast acceleration requires a number of the RF accelerating cavities with high field gradients. This requirement has never been fulfilled until the cavity loaded with the magnetic alloy (MA) is devised [8]. Second, the magnets [9] and vacuum chambers should be immune against the eddy current effect arising from the fast changing magnetic fields. Third, the injection scheme is hard to design for the large beam aperture. Fourth, the precise tracking of several families of magnets is required.

In addition to the challenges in the RCS itself, the linac is also required to provide the beam with accurate momenta ($\Delta p/p$ less than 0.1 % for J-PARC) and with low transverse emittances (typically $4\pi$ mm mrad for J-PARC). These are typically 99 % emittances rather than that of root mean square (rms), since many parameters are required for eliminating the beam loss, which should be of an order of 1 % at most. These values are necessary for the efficient painting on the beam apertures. In order to produce these high-quality beams, we devised the $\pi$-mode stabilizing loop (PISL) [10, 11] for the RFQ linac. Also, we decided to use electro-quadrupole magnets contained in the drift tubes of the DTL in order to keep the flexible knobs for the transverse tunes. The technologies were newly developed for minimizing the size of the coils with water-cooling channels by fully using the electroforming method and wire cutting [12].

Both the RCS and the MR are designed on the base of the lattices with the low and negative momentum compaction factors, respectively, which implies no transition crossing during acceleration [13]. The beam loss inherent to the transition crossing will be thus avoided. The slow extraction with the low beam loss (less than 1 %) from the MR is the most difficult issue to solve [14].

## LINAC

The linac comprises a volume-production type of $H^-$ ion source, a 50-keV low-energy beam transport (LEBT), a 3-MeV, 324-MHz Radio-Frequency Quadrupole (RFQ) linac, a 50-MeV, 324-MHz Drift-Tube Linac (DTL), a 190-MeV, 324-MHz Separated DTL (SDTL), and a 400-MeV, 972-MHz high-energy linac . The SDTL is the DTL with the quadrupole magnets outside the tank [15]. The Annular Ring Coupled Structure (ACS) [16, 17] has been developed for the high-energy linac. Most of the accelerator components were ordered by the end of JFY2002, except for the high-energy linac. We decided to increase the beam aperture of the RCS in order to keep the sufficient margin for the space charge effect (the Lasslette tune shift is –0.16). We also lengthen the RCS circumference by a factor of 10/9. Since some budget overflow is expected for these, we decided to take the following process. Taking the results of the bidding for all the accelerator components except for the high-energy part of the linac, we will determine how much we can afford for this. The linac beam with the energy lower than 400 MeV can be injected to the RCS, while most of the components for both the RCS and MR are necessary for the experiments. The lowering of the linac energy will have the influence on the beam power. The budget request to recover the full linac energy will be submitted to the funding agency this year.

The components for all the three DTL tanks and four of the thirty two SDTL tanks in total have been completed. The four SDTL tanks and the 5-cell prototype of the DTL were already powered over their design values. The first DTL tank was assembled and the tuner positions and post coupler positions were adjusted until the uniform field distribution was realized with one percent accuracy (design value) [18, 19].

The beam test of the RFQ linac and the medium energy beam transport (MEBT) was continued in the KEK site until last March. The detail is presented in Sec. 6. The first DTL tank was then installed for the beam test to be started this summer as shown in Fig. 4.

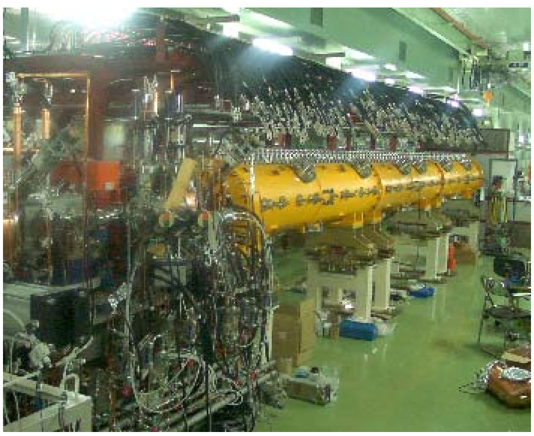

Figure 4: The first tank of DTL installed in the tunnel at KEK site for the beam study

## 3-GEV RCS

A half of the RCS components were ordered by the end of JFY2002, including all the bending magnets (BM's), all the quadrupole magnets (QM's), two thirds of the magnet power supplies for them, all the ceramics vacuum chambers for the BM's and QM's, and all the kickers and their power supplies. The remaining components for the magnet power supplies, the injection system including bump magnets and their power supplies, the vacuum chambers for these, the remaining RF sources, the RF cavities and others will be contracted during this fiscal year.

The aluminum stranded conductors are used for both the BM's and QM's, in order to avoid the temperature rise and the Q deterioration arising from the eddy current effect. The use of laminated silicon steel sheets with a thickness of 0.5 mm and the slit cuts of the end plates and/or the core ends are all to ease the eddy current effect. The approximate Rogowsky Cut is utilized in order to avoid the concentration and the saturation of the fields. The prototype of the BM's and QM's are used for these test together with computational analysis. The decrease in the AC loss by these means are vital also for the stable operation of the magnet system for the following reason. The magnet system comprises eight resonant networks, including one BM system and seven families of QM's. In order to keep the eight networks operate stably, the Q values of the networks should be as high as possible.

The aluminum stranded conductors are, however, difficult to impregnate by polyimide resin, which is immune against radiation damage, but is hard to flow. Figure 5 shows how the stranded conductors are impregnated by the resin in vacuum and pressurized later. We are now confident of the procurements of these coils.

Figure 5: The stranded conductors impregnated by the polyimid resin to form the coil

## 50-GEV SYNCHROTRON

Most of the accelerator components were ordered except for the RF system and the injection and extraction systems. The first BM among ninety six 5.85-m BM's was shipped to KEK, where its field measurement and excitation test are under way (see Fig. 6).

As mentioned in Sec. 2, the RF system makes use of the cavities loaded with magnetic alloy (MA) in both RCS and MR, since the MA-loaded cavities have many advantages over the conventional ferrite-loaded ones, including the field gradient by almost one order of magnitude higher. Also, its low Q-value (a value of less than one is possible) drastically simplifies the RF system by eliminating any tuning system. On the other hand, its high R/Q (low stored energy) with the low Q value requires the wide-band beam loading compensation via feed-forward control. As a result, even the high power system should be wide-band. In order to minimize the band width necessary for the compensation, the Q-value is optimized by adjusting the gap between the MA cores radially cut under the condition of no tuning system necessary. The Q values thus optimized are 2.9 (1.5-mm gap) and 10 (10-mm gap) for the RCS and the MR, respectively.

A prototype of the RF system, comprising an RF cavity, a high-power amplifier and others, was completed for the 50-GeV MR as shown in Fig. 7. The system was successfully tested for 49 hours with a full peak power of

500 kW and a full duty factor of 50 %. The MA is directly water-cooled.

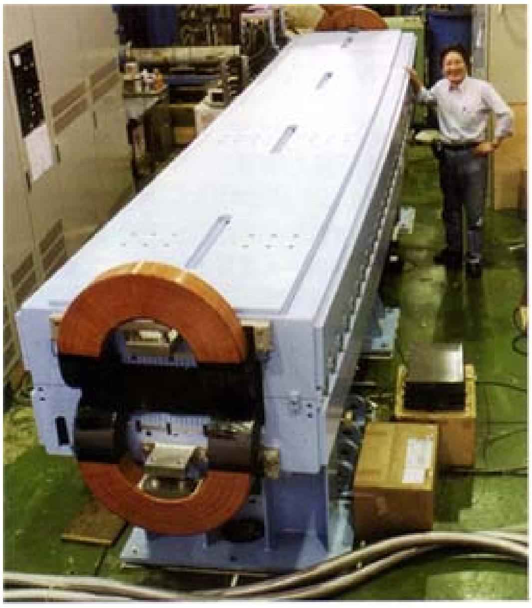

Figure 6: The first mass-produced BM for the MR

Figure 7: The RF cavity for the MR

The direct water cooling of the MA for the 3-GeV RCS gives rise to some problem during the high power test. The magnetic fields between the gap were locally concentrated and distorted, in particular for the small-gap case, since some magnetic imperfections at the gap surfaces arose from cutting the MA cores. The local heat-up damaged the polyimide resin, which are used to form the MA tapes into the cores. The indirect cooling is now under development, by sandwitching the MA core layers and the water-cooled copper layers with the polyimide resin in between. The resin includes aluminum nitride powder which is a good thermal conductor. The high-power test of this system will be started soon.

## BEAM TEST OF FRONT-END LINAC

The beam test of the low-energy front is under way in KEK site [20, 21]. The present system comprises the $H^-$ ion source, the LEBT, the 3-MeV RFQ linac, and the MEBT. At present, the first tank of DTL (20 MeV ) is installed, and is under preparation for the high-power test and the beam test.

The RFQ linac used here was designed for the Japan Hadron Facility (JHF) project [22] which would produce the 0.6 MW beams with a linac peak current of 30 mA (the 50-mA RFQ linac for the J-PARC is now under development). The peak current of 29 mA was obtained with this system. The measured horizontal and vertical emittances of the beam at the end of the MEBT were 0.252 $\pi$ mm mrad and 0.214 $\pi$ mm mrad (r. m. s. normalized), respectively, at the peak current of 28.5 mA.

The chopper at the MEBT shown in Fig. 8 were tested with the beam. The measured rise and falling times of the beam are 10 ns, being sufficiently fast for eliminating the beam loss as designed (see Ref. [20]).

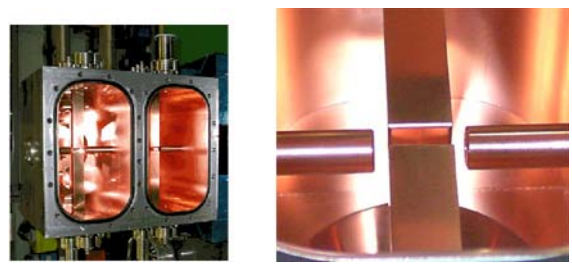

Figure 8: The RF chopper installed at the MEBT. The left figure shows the whole view of the two deflecting chopper cavities. The right figure shows the close view of the deflecting electrodes. The beam passes from left to right.

The stopper installed at the MEBT cannot stand all the 3-MeV chopped beams. The prechopper [7], which makes use of the induction decelerator made of the MA, was installed at the LEBT. The RFQ linac is designed to filter the beams, the energy of which is by 9 keV lower than the designed injection energy of 50 keV. The prechopper system was also tested with the beam. The combined test of the prechopper and the RF chopper will be done later, where the proper timing is necessary.

## SUMMARY

The J-PARC accelerator, comprising the 400-MeV linac, the 3-GeV RCS, and the 50-GeV MR, is based upon many newly developed technologies. The developments have been successful, and the orderings of the accelerator components are on schedule so far. The first beam from the RCS will be transported to the MLF in March 2007. The beam injection to the MR, which is planned at the same time, will be delayed by several months, since the ancient salt-pan remains at the MR and NPF sites will be archaeologically investigated by excavation.

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