POSSIBLE UPGRADE SCENARIO FOR J-PARC RING RF

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Abstract

The beam in J-PARC RCS (Rapid Cycling Synchrotron) was successfully accelerated to 3 GeV final energy, and extracted in Autumn 2007. In the Main Ring, RF capture of the injected 3 GeV beam was successfully achieved in May 2008. Both Ring RF systems are based on a modern technology using MA (Magnetic Alloy) loaded cavities and have achieved higher field gradients than existing ferrite-base RF systems for the same frequency region. For the future upgrade of the J-PARC Main Ring, a short cycle time is required to increase the average beam current. In this paper, a possible upgrade scenario for both Ring RF systems will be described based on recent improvements of the magnetic alloy ring cores.

INTRODUCTION

The J-PARC RCS is the first accelerator, which was designed based on MA technology for high field gradient cavities [1]. When the RCS was designed the circumference was limited by the beam pulse length requirement of less than 1 µs for neutron production. The RCS energy has to be at least 3 GeV for injection to the 50 GeV MR in order not to compromise the field quality of the MR magnets. It was required to accelerate the beam to 3 GeV by RCS with a circumference of about 350 m. Because the 3-fold symmetry was chosen for the lattice, one long straight section was dedicated for the RF system. The length of the RF section is 44 m including the Quadrupole magnets. 10 RF stations are installed and a total RF voltage of 360 kV is obtained [2-4]. It is planned to install more cavities to be able to increase the beam current. The observed field gradient of the RCS cavities is more than twice compared to existing ferrite-loaded cavities with same beam aperture as shown in Fig. 1. Using MA cavities [5], the RCS satisfies difficult requirements: beam pulse length, 3 GeV energy, large beam aperture, rapid cycling and high intensity [6,7].

The MR RF system is also based on the MA technology [8,9]. Like RCS the MR lattice is using 3-fold symmetry. A half of one of the long straight sections is used for the RF system. Nine systems can be installed there. There are several spaces in other straight section. There is an upgrade scenario to increase the beam power [10, 11]. As the space for RF systems is limited, it will be necessary to increase the field gradient of the MA cavity. In this paper, possible upgrade scenarios for both ring RF systems will be described.

MAGNETIC ALLOY

The first Magnetic Alloy cavity was built for MIMAS injector synchrotron around 1990 [12]. Cobalt-based amorphous magnetic alloy was used. The reason why the MA was used was cover the very wide frequency sweep of 130 kHz to 3 MHz. In Japan, development of MA cavity was started in 1995. The purpose of development was to use it for a high intensity proton synchrotron. A soft-magnetic nanocrystalline material was used. It has the following characteristics:

(1) Permeability and shunt impedance are stable with high RF magnetic field because the saturation field level is high.
(2) Characteristics are stable with changing temperature, as the Curie temperature is high.
(3) It has larger permeability than ferrite material.
(4) Quality factor is low and impedance is wide band.
(5) It is possible to make a large size core.

Because of (1) and (5), the MA cores are used for high field gradient cavities. In contrast, such cores are used for ion accelerators like MIMAS [12], FAIR-HESR [13] and CERN LEIR [14] because of (3) and (4).

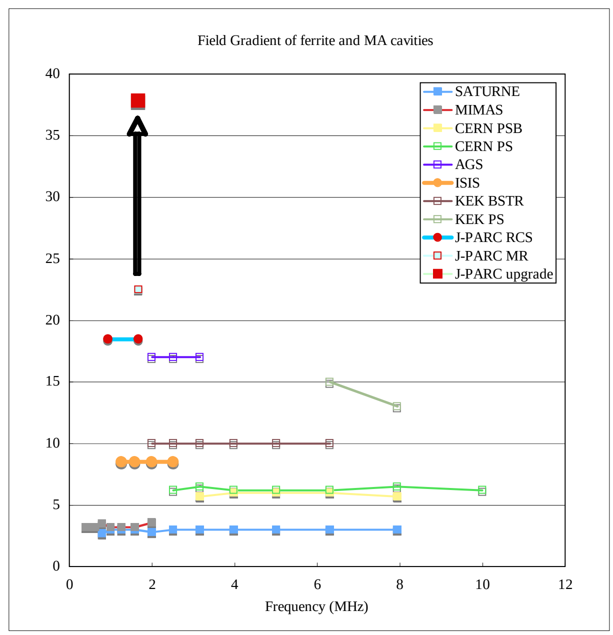

Figure 1: Field Gradient of ferrite and MA cavities. Based on the core technology, the field gradient will be 38 kV/m.

Recently, it was discovered that the characteristics of MA cores are improved by applying a magnetic field during the production process. It is understood that the axis of easy magnetization of nano-meter size crystals will be aligned. The effect becomes pronounced when the thickness of the MA ribbon is thin. Figure 2 shows the comparison of characteristics. Comparing with the present cores, a new core shows a two times higher impedance by applying a magnetic field during production.

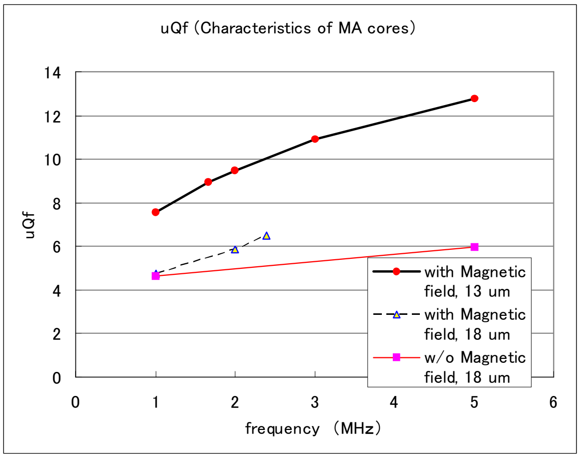

Figure 2: Characteristics of MA cores. The μQf product indicates the shunt impedance of MA cores. By applying a magnetic field during the annealing process of the cores, the impedance will be twice larger compared to ordinary MA cores.

UPGRADE SCENARIO

As the development of the MA cavity made the circumference of the RCS compact, the RF system development using new MA cores will improve the performance of the J-PARC rings. Table 1 shows an upgrade scenario of J-PARC MR to increase the beam power over 1 MW. The scenario is based on the following steps: 1) Energy upgrade of the linac, 2) fast rise time of extraction kicker, 3) fast rise and fall time of MR magnets and 4) higher field gradient of MR cavities. It requires 550 kV for the fundamental frequency (1.7 MHz) and half of this amplitude for the 2nd harmonic. The space for the RF systems is limited and therefore a higher field gradient than that of the present systems is necessary.

Table 1: Upgrade scenario of MR

		Present	Upgrade
Energy	GeV	30	30
Linac Energy	MeV	181	400
Particles in bunch		2.5e13	4.1e13
Number of bunches		6	8
Kicker Rise time	μs	~1.8	1
Total RF voltage	kV	160	550
Number of cavities (1st)		4	8
Number of cavities (2nd)		0	4
Voltage per cavity	kV	40	70
Cycle time	s	3.64	1.42
Acceleration time	s	1.9	0.63
Duty factor	%	56.9	56.3
Beam Power	kW		1100

RF SYSTEM

Based on the new core technology, we designed a cavity with 4 acceleration gaps instead of 3 gaps in the present cavity. The length of the cavity is almost same as that of the present one to fit to the space in MR. The core thickness is reduced to 2.0 cm instead of 3.5 cm. Because the μQf product of the new core is 2 times larger than the present core, the resulting core impedance is still 14 % higher. The total impedance seen by the tetrode amplifier becomes 14 % lower because of 4 gaps. It is still marginal level for the present anode power supply. The total length of the 4-gap cavity is 7 cm longer than the present one, which is acceptable.

The gap voltage will be increased from 15 kV to 17.5 kV. The power dissipation in each core will be 68.5 kW in average, which is same as has already been tested in long run tests, which were performed for over 1000 hours [6,9]. Although the power density in the core becomes 40 % higher, the maximum temperature in the core will not increase, because the thickness is also 40 % smaller. Expected field gradient is also shown in Fig. 1.

OTHER OPTION FOR MR

It is considered to increase the gap voltage without increasing number of gaps and without changing the core thickness. In this case, the required voltage per gap will be 23.3 kV. As the gap impedance will be two times larger, the power dissipation will be 69.5 kW. However, the maximum voltage of the anode power supply is 13.0 kV and it might be difficult to get 23.3 kV on the gaps. And, it is considered that there is another risk to cause damage on the MA cores nearest to the acceleration gap because of higher voltage.

CORE FOR RCS

As the cycle time of the RCS is limited by the synchrotron magnets and power supplies, it is not easy to increase the repetition rate. However, it should be reminded that the present design is optimized to accelerate 8×10^{13} ppp. At maximum intensity, the anode power supply needs to deliver full current and full power. To increase the intensity beyond that, it is more efficient to replace the cavity cores by new ones than replacing or modifying the expensive anode power supplies. Although the relative loading parameter (Y~ 0.7) of whole system will become larger, the beam loading will be manageable by feed forward compensation.

FUTURE PLAN

So far there is no large oven to produce the MA core with high magnetic field. It is considered to produce large-size MA cores in J-PARC, as there are magnets, which have very large aperture: 1.0 m X 1.4 m X 0.4 m. This is wide enough to install an oven for J-PARC core production.

CONCLUSIONS

An upgrade scenario of the J-PARC ring RF systems is presented. A new core technology will improve the field gradient of the MR RF systems. Applying this technology to the RCS RF systems will reduce the cavity loss and increase the available anode power for higher beam current.

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