Status of J-PARC Ring RF systems

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Abstract

We present the Status of the J-PARC RF systems of the Rapid Cycling Synchrotron (RCS) and the 50 GeV Main-ring (MR). The RCS RF systems are prepared for beam commissioning scheduled in September 2007. The 10 cavities, amplifiers and power supplies are installed in RCS. The cavities are loaded with improved uncut cores. The parallel inductor for Q=2 was successfully tested and installed in all systems. The long-term performance and reliability of each of the 180 cores was checked for at least 300 hours. One set of cores performed a 1000-hour power test. We operate the cavities in the tunnel together with the LLRF system to check the interoperability and prepare for 25Hz RCS operation. Some issue related to noise and grounding was solved. Unwanted resonances of the tube amplifier in the RCS frequency range were analyzed and removed. For the MR RF systems, we decided to employ the diamond polishing technique for cut-core production. The long run high power tests with cut-core loaded cavities finished at the end of July 2007. We prepare MR cavities for installation in the end of August 2007.

J-PARC Ring RFシステムの現状

１．Introduction

The RF systems of RCS are prepared for beam commissioning after middle of September [1]. Until April 2007 all 180 uncut cores were tested for at least 300 hours to get confidence in long-term stability [2]. The 10 acceleration cavities combined with tube amplifiers are installed in the RCS tunnel. The Anode power supplies, auxiliary power supplies and the transistor driver amplifiers are installed to the RCS RF power-supply room. The long run tests of 90 cut-cores for 5 cavities for the 50 GeV MR continued until end of July in the KEK test stand. Then we can set-up the cavities for installation to the MR tunnel.

２．RCS Ring RF systems

RCS will achieve high beam power by rapid cycling. A powerful RF system is necessary for acceleration and multi-harmonic beam loading compensation. The J-PARC ring cavities use magnetic alloy (MA) cores, because this material allows a higher gradient than ferrite and is stable at high fields. The optimum Q-Value for the RCS cavities is in the order of 2. This allows dual harmonic acceleration where the longer bunches reduce the space charge force and beam loading. The original design was based on a cut-core arrangement, where the space between core parts defines the Q-value while keeping the shunt-resistance. Problems with the required tolerance in the order of less than 1mm were solved with the "hybrid-configuration" [3], which combines 2 tanks with cut-cores at increased distance with 4 tanks loaded with uncut cores. The quality of the uncut core manufacturing process was improved and it was decided, that the RCS cavities use uncut cores. However, the Q-value of cavities loaded with uncut MA cores is in the order of 0.6, which limits the beam power due to higher harmonic beam loading.

Parallel inductor for Q=2

Fig. 1 explains the idea of an external parallel inductor L_2 to reach Q=2 with uncut core loaded cavities [4]. The equivalent circuit (R_1, C_1, L_1) describes the 3 parallel cavity gaps. The parallel inductor L_2 increases the Q-value and the capacitor C_2 adjusts the resonance, so that the equivalent circuit on the right (R_3, C_3, L_3) reaches $Q=R_3/\omega L_3=2$ at resonance frequency.

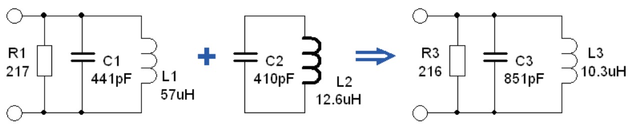

Fig. 1: Idea of parallel inductor (L_2)

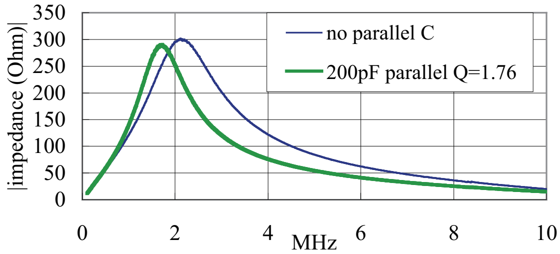

Fig. 2: Impedance with 14-turn parallel inductor

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Figure 2 shows the measured cavity impedance with a parallel 14-turn inductor. With 200pF in parallel, the resonance is adjusted to 1.725 MHz and the Q-value is 1.76. The production version inductor shown in fig. 3 is installed in all 10 RCS cavity systems (fig. 4). In several long run tests we confirmed that the inductor can operate at 15kV design voltage without getting too hot.

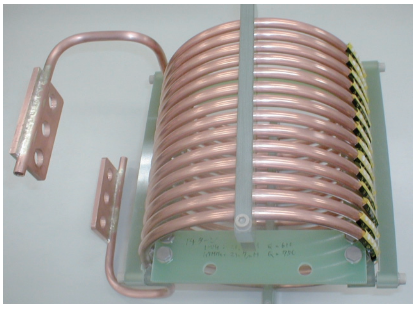

Fig. 3: 14-turn parallel inductor production version

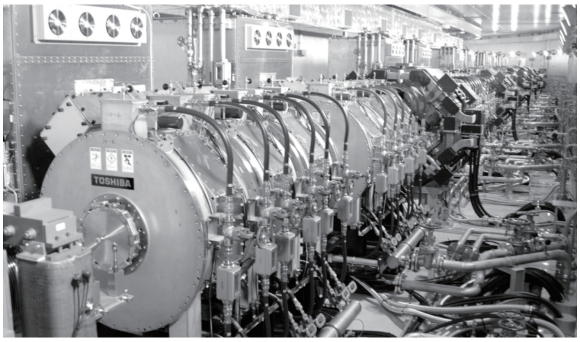

Fig. 4: 10 cavity systems installed in the RCS tunnel

Improvement of MA core performance

The long-term performance and reliability of each of the 180 cores and the 10 RCS cavities was checked [2] for at least 300 hours in a demanding schedule which finished in April 2007. Initially, the tests were conducted with 15kVpeak/gap (45kV/cavity, 23kV/m) at fixed frequency with 3s cycle time and 30% duty, so that the average power dissipation is 120kW/cavity. Some of the tests were performed with simulated 25Hz operation, also at 30% duty.

The cores were classified in 3 categories, D, C, and A, as shown in fig. 5. Type D cores were made with a vertical winding process and showed some isolation defects between the MA layers, indicated by a ribbon resistance clearly below the theoretical value. Some of theses cores showed damage after high power test. The D-type cores without damage, where the ribbon resistance shows a value not so far from theoretical value can be used for the low E-field position in the cavity tanks. The C-type cores were produced with a horizontal winding process. The isolation between layers has improved compared to type D, and they are used in the medium E-field position in the cavity tanks. The best cores are type A, which are made with a horizontal winding process like C-type cores, combined with reduced tension and MA reel selection. For these cores the layer isolation is almost perfect and they are used at high E-field position.

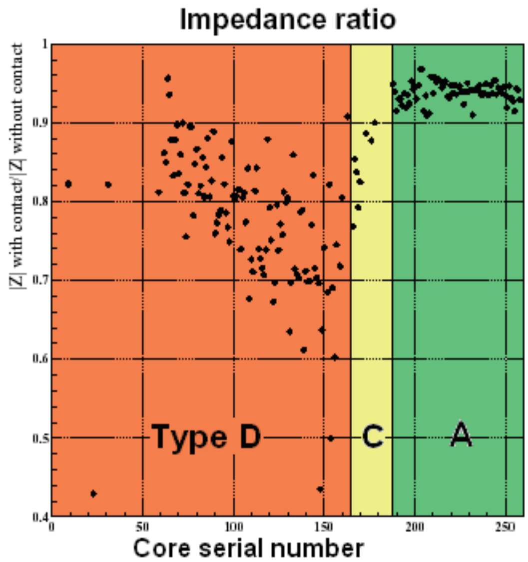

Fig. 5: MA core production summary

One set of 18 cores was tested for 1000 hours to get confidence for long-term performance. Some brown spots were detected on A-type cores after 300h, when the tanks were opened for inspection. These spots and their number did not grow, when the core surfaces were compared after 1000 hours. No reduction in cavity impedance was found and we conclude that there is no problem with RCS long run operation.

25Hz operation

For simulated 25Hz operation for the long run tests frequency and amplitude followed patterns shown in fig. 6 with 40000 points sampled at 1MHz rate by a DSP and fed to a custom-made DDS system.

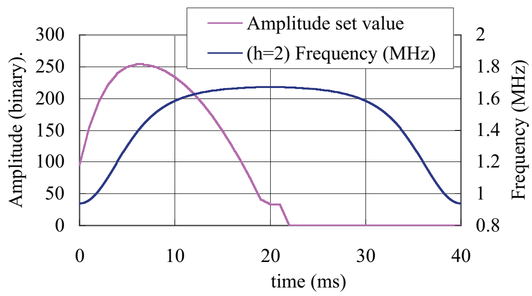

Fig. 6: Amplitude and frequency pattern for (h=2)

Results of dual harmonic tests with the RCS LLRF system using cavity #5 in the RCS tunnel are shown in fig. 7. The amplitude error with amplitude control (AVC) on is in the order of 1%. The preparation of the LLRF for beam operation [5] [6] is ongoing. Recently, all 10 cavities were operated in parallel with RF-voltage.

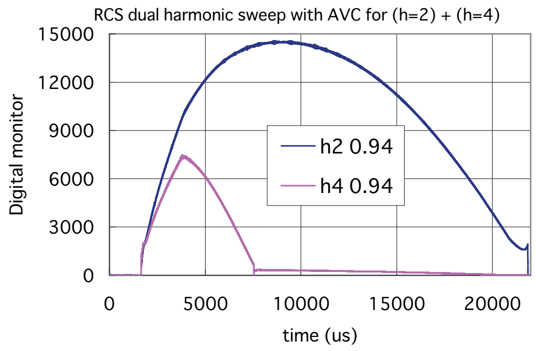

Fig. 7: Dual harmonic operation with AVC

Amplifier and power supply modifications

Fig. 8: 1.15MHz damper (left) and cathode damper (right)

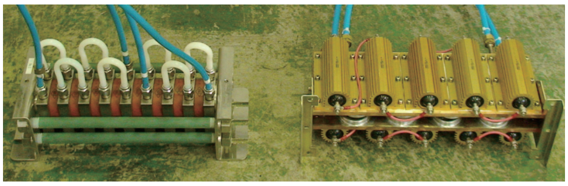

Fig. 9: Control grid DC load resistors. Right: modified.

In the tube amplifier, dampers against a 1.15 MHz resonance in the Anode power feed and against a self-resonance of cathode capacitors were installed (fig. 8). This also applies to the MR RF systems. The control grid load resistors showed long-term drift and are replaced by a metal-clad version (fig. 9). In several Anode power supply inverter modules pinholes of the water-cooling path in the oil-filled tanks have been found. Including inverters for MR, in total 180 inverters had to be checked to identify the modules, which need repair. Issues related to grounding of APS and auxiliary power supplies were solved. Control grid dummy-loads damaged by a water-hammer effect were replaced. The PLCs were modified to include the remote operation of the cavity Gap-shorts.

３. MR Ring RF systems

The 5 MR cavities operate at a Q-value of 10-20, therefore a cut-core configuration with 1cm space between the core part is used (fig. 10). The process of grindstone cutting was replaced by diamond polishing [7] (fig. 11). For confirmation, a set of cores was tested over 1000 hours. The rest of 90 cores for 5 cavities were tested until end of July for at least 300 hours. To prevent corrosion of the mirror-like cut-surface, which is difficult to coat, demineralised cooling water with reduced amount of dissolved O_2 is used for operation. Installation to MR will begin in August 2007, beam test in May 2008.

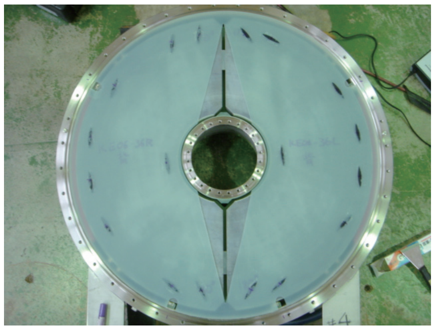

Fig. 10: Cut-core configuration in MR cavity tank

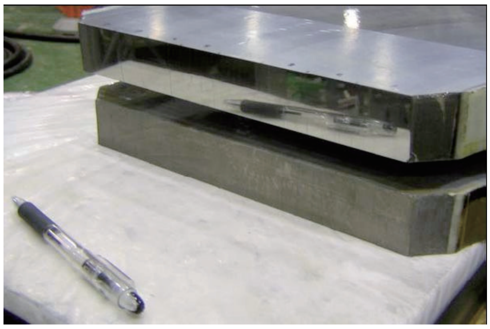

Fig. 11: Surface of diamond polished core (upper)

Outlook

The 10 RCS RF systems are prepared for beam commissioning in September. In end of August installation preparations of the MR cavities will start.

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