論文内容の要旨

Development of a New RF Accelerating Cavity Loaded with Magnetic Alloy Cores Cooled by a Chemically Inert Liquid for Stabilizing and Enhancing the Performance of J-PARC Ring Accelerator

J-PARC リング加速器の安定化及び性能増強に向けた不活性冷媒液冷式による金属磁性体コア装荷の新型高周波加速空胴の開発

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J-PARC (Japan Proton Accelerator Research Complex) was constructed in Ibaraki, Japan. It is a proton beam accelerator consisted with a linac and two synchrotrons. The synchrotrons are named as RCS (Rapid-Cycling Synchrotron) and MR (Main Ring).

J-PARC was designed to produce the world's most intensive proton beam and provide it to advanced research facilities for the wide range of field. T2K is one of the most important experiment. It requires 5×10^{21} POT in approximately 5 years which corresponds to 0.75[MW]. To produce proton beam of this intensity, the enhancement of beam is necessary. There are three methods for the enhancement.

1. Increasing the energy of beam
2. Increasing the number of proton in the bunch
3. Increasing the repetition rate of the accelerator

The third method was accepted. This method requires the accelerating gradient to be enhanced, so that the accelerating cavity will be put in the hard environment to accelerate a large beam current in a long term. A powerful and stable accelerating cavity is indispensable.

The presently installed cavities in RCS and MR are loaded with toroidal cores made of FINEMET. FINEMET is a magnetic alloy which has characteristics listed below.

1. The permeability is high.
2. The saturation magnetic flux density is high.
3. The Curie temperature is high.

These characteristics are suited for the cavity in J-PARC. The cavity is a λ/4-wave coaxial type. It has three accelerating gaps and each gap has three FINEMET cores on both sides. A stable operation of the presently installed cavities in RCS has not established yet, because they have a problem that the FINEMET cores are damaged while the cavities are in operation. We are developing a new accelerating cavity which can be replaced with the presently installed RCS cavity in order to contribute the stabilization and enhancement for the performance of J-PARC ring accelerators.

We simulated the thermal stress in the core, and performed a test for contracting samples of the core. The cause was identified as a buckling which was caused by a thermal stress in the core. We showed the core without impregnation is favorable to prevent the buckling. The development of the new cavity is based on these results.

The new cavity has design concepts which have never been seen before.

1. The cores have a unique structure named core module.

・Each FINEMET core is radially separated into three. This structure helps to clearly differentiate between constructional materials and functional materials.

・These cores are not impregnated. The thermal stresses in the cores are relieved because the cores are soft.

2. A turbulent fluid is used to cool the cores.

・Fluorinert is used as the coolant. Fluorinert is a chemically inert liquid, so that it is suited for cooling FINEMET cores which is subject to corrosion. Fluorinert flows in the flow channel which is formed on the surfaces of the radially separated cores. The flow channel makes Fluorinert turbulent, so that a high cooling efficiency is realized.

The development of the new cavity has significances below.

1. It has a high degree of potential for solving the difficulty of the stabilization and the enhancement.
2. It can be a prototype of next-generation cavities.

We designed the RF structure of the cavity with HFSS and designed the flow channel with ANSYS CFX. HFSS is a simulation software tool for electronic design. ANSYS CFX is a computational fluid dynamics software. We assembled a prototype of the new cavity, and prepared the test facility. This is the first case to use three dimensional FEM (Finite Element Method) simulators for developing a cavity loaded with magnetic alloy cores. The process of this development is scientifically meaningful.

We carried out the performance test of the prototype cavity and measured several properties which are essential for an accelerating cavity.

1. The resonance frequency is 1.7[MHz].
2. The shunt impedance is 146[Ω].
3. The Q factor is 0.8.

Results of the measurement for the cooling efficiency are shown below.

1. The temperature on the surface of the core was measured with the thermo paint. The value was consistent to that was obtained from the simulation.
2. The effective heat transfer coefficient was obtained by measuring the time constant of the temperature decrement of Fluorinert, and the value was consistent to that was obtained from the simulation in 20%.
3. The heat transfer coefficient on the surface of the small core was obtained with the simulation. The value is consistent to that was calculated with the empirical equation. The value surpassed that of presently installed cavity over 60[L/min].

We supplied the power to the prototype cavity up to 10[kW], and it worked stably.

We accomplished following significant researches.

1. We revealed the cause of the buckling of the cores was the thermal stress in the cores. We showed the cores without impregnation is effective to avoid the buckling.
2. We assembled the prototype cavity and carried out the performance test. The results of the test satisfy the requirements of RCS so far.

The results of the researches support the feasibility of developing the new cavity.

This is the first development of the cavity loaded with magnetic alloy cores, which is able to be operated stably with the large input power of 10[kW] per core. Adopting this new cavity is the most realistic way to stabilize and enhance the performance of the J-PARC ring accelerators.