FERRITE EVALUATION TEST FOR MUSES

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Abstract

Construction of the RI Beam Factory (RIBF) at RIKEN is started and the 2nd stage project MUSES of RIBF, a complex of a synchrotron and storage rings for radioactive ion experiments, is in progress. The ferrite evaluation test has been performed for Accumulation Cooler Ring (ACR) and Booster Synchrotron Ring (BSR) in MUSES.

In the ACR, frequency sweep width of a few MHz in frequency range of 18 to 38 MHz, 10Hz cycling operation and the gap voltage of 100kV are required for a capturing and RF stacking. While in the BSR, frequency sweep of 25 to 52 MHz, 1Hz cycling operation and the gap voltage of 50kV are required for acceleration.

The test cavity had been manufactured to measure characteristics of large size ferrite core under bias field at the high RF power level used for acceleration. Calibration of the test system was made carefully.

The measurement of ferrite sample has performed with varying relative permeability of 2 to 18 by adjusting bias current. High loss effects[1] has been observed over $0.5 J/m^3$ of the RF energy density.

1 TEST CAVITY

The parameters of the test cavity are listed in Table 1. Figure 1 shows a schematic diagram of the ferrite test cavity. It consists of three coaxial arms: ferrite (F), short (S), and capacitance (C) arms. The F and S arms are aligned in line and form a λ/2 resonator loaded with a tuning capacitance (‘3’ in Fig.1) in C arm. In order to operate under the above frequency range at high power and high loss threshold, a water cooled vacuum variable capacitor (30-650 pF) is employed. Ferrite is tightly in contact with the cavity wall on both sides, and cooled through the wall by water. The size of ferrite is fixed to be 5 inches in inner diameter, 8 inches in outer diameter (O.D.) and 1 inch in thickness.

Impedance matching between 50Ω of RF source and an input impedance of the cavity is necessary to perform the test in high RF power level. A Variable capacitor (6-500 pF, ‘4’ in Fig.1) connected in series was adopted as an impedance converter. A current transformer and a voltage divider (‘7’ in Fig.1) were installed at the entrance of the matching section in order to monitor the input impedance and input RF power. The voltage near the ferrite ring was measured by a pickup monitor (‘8’ in Fig.1).

Table 1: Parameters of the ferrite test cavity.

Cavity type	λ/2 coaxial resonator loaded with capacitor
Frequency range	18-60MHz
Ferrite size	5”(I.D.) × 8”(O.D.) ×1”(thick)
Tuning elements	Bias current, Variable capacitor
Bias conductor	10 turns of water cooled hollow conductor
Cooling of ferrite	Water in cooling plate
RF source	A 3kW solid-state wide-range amplifier
Bias current	2500A max.
Impedance matching	Variable capacitor

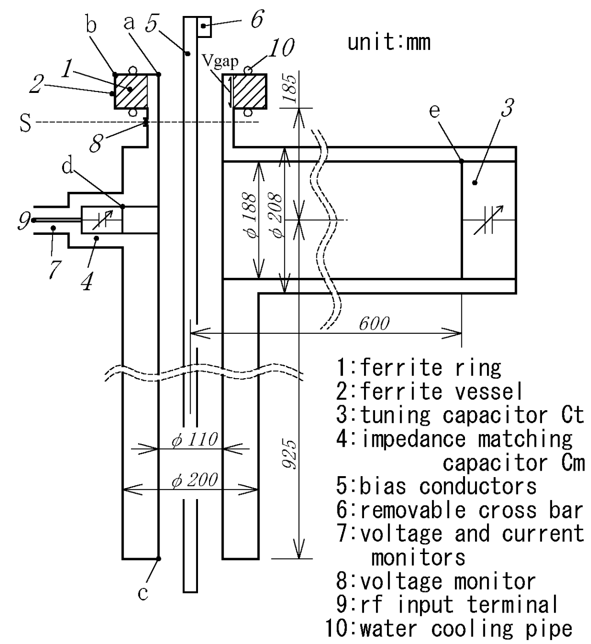

Figure 1: Schematic diagram of the test cavity.

The calibration of the system were done as following: The system is divided into two parts, as seen Fig. 1, by taking the junction plane at S. The admittance of the upper half with the ferrite is denoted by Ym and that of the lower half, by Yc. The entire system is formed by the parallel connection of Ym and Yc. Ym is inductive at the resonance frequency and Yc, capacitive. Hereafter, G and B denote the real and imaginary parts, respectively, of the admittance Y, e.g., Ym = Gm + *i*Bm and Yc = Gc + *i*Bc. The resonance condition is given by Bm = −Bc.

The relative permeability, μ, and magnetic Q value, Qm, of ferrite are determined from Ym. This process depends on the electrical model describing the ferrite vessel containing the ferrite. The simplest model is one that ignores the radial dependence of μ due to the bias field and assumes a low frequency limit. This yields an effective μ by $(f{\cdot}Bm{\cdot}\mu_o{\cdot}t{\cdot}\ln(b/a))^{-1}$ and Qm by |Bm|/Gm, where f is the measuring frequency, μ_o is the permeability of vacuum, and t, b and a are the thickness and the outer and inner radii of the ferrite ring, respectively. We used a model based on the transmission line approximation, in which the vessel is treated as a radial mode transmission line and a radially constant μ is assumed. This model is appropriate for the frequency range studied here and can be solved numerically.

With the value of voltage, V, across Ym, and input power, P, at the resonance frequency, Gm is directly obtained from (P/V^2) - Gc using a precalibrated value of Gc. Bc is dependent on the frequency and the value of the tuning capacitor, Ct, while the impedance matching capacitor contributes only a small correction. Bc can be estimated with reasonable precision on the basis of the transmission line calculation but Gc must be estimated by measurements, because of the contribution from the resistance of the structural contact surfaces and the loss factors of the tuning capacitor. Therefore, both quantities were estimated using calibration measurements as a function of frequency and division number of the revolution dial of the tuning capacitor.

2 CHARACTERISTICS OF FERRITE

2.1 Ferrite Material

The Ni-Zn typed ferrite sample, called as V2F, were manufactured by TDK co. Ltd. The typical characteristics on a catalogue are the following: the initial permeability μ_i is 30, the tangential loss factor $\tan\delta/\mu_i$ measured at 50 MHz is $240{\times}10^{-6}$ (Qm is 140.), curie temperature is 300°C.

The ferrite core was installed into the cavity with painting thermo-conducting paste on surface because the another ferrite sample had been broken by partial heat expansion during experiments. A radiation thermometer were added the system to observe ferrite surface temperature.

2.2 Measurements

The RF power was fed into the cavity under the operation of 10% duty, 20msec pulse. In Fig. 2, typical RF waveform envelopes measured at the pickup monitor are shown, in which the RF power was 1.5kW (above) and 3kW (below), respectively. The frequency was 41.3MHz and the permeability was 3.8 at both cases. At the beginning of the waveform there was no quite difference between the measured Qm and calculated one. After about 1~3msec the voltage decreased and it was estimated that the high loss effect might occur. The data were measured at 2 positions in time scale. One was the point of 0.5 msec after the beginning of input power, the other was the point of 16msec after the beginning. Both were corresponded to before and after the voltage drop with the high loss effect, respectively.

Changing the μ and RF power level as parameters, the Qms' are shown in Fig. 3, where the ferrite gap voltage at inner radius means the Vgap in Fig. 1.

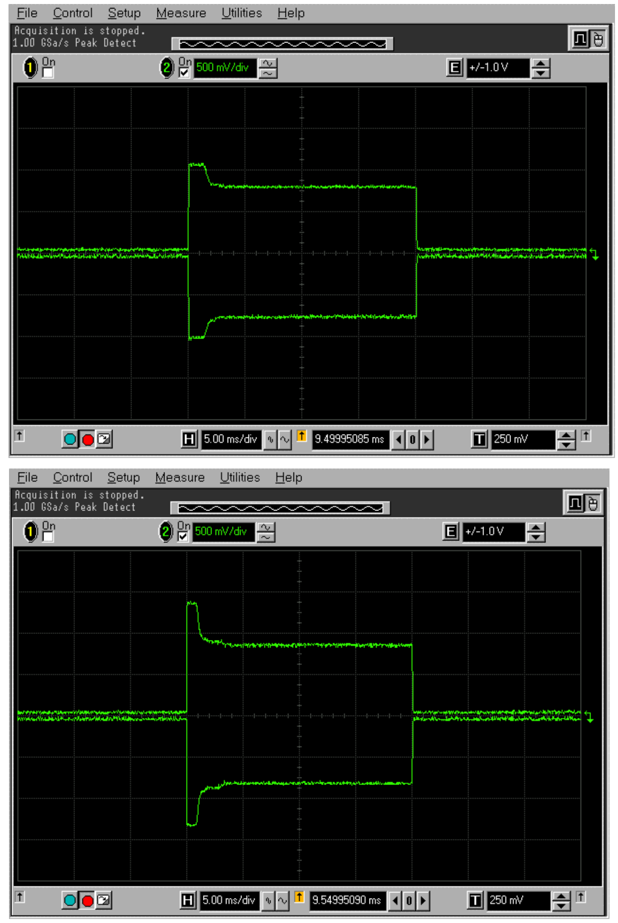

Figure 2: Waveform envelopes measured at the pickup monitor. Above: peak power is 1.5kW. Below: one is 3kW.

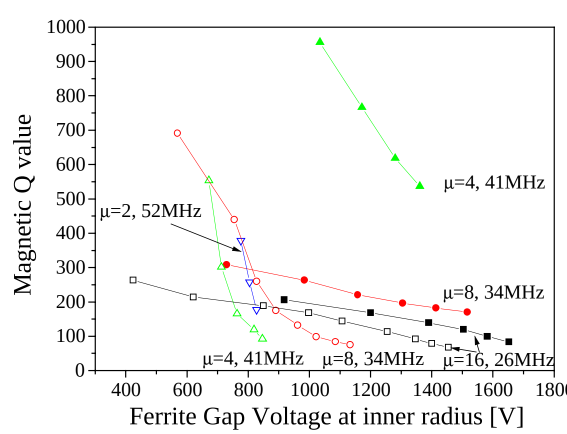

Figure 3: Magnetic Q at various permeability and power levels. Filled marks indicate before the voltage drop, empty one after the voltage drop, respectively.

There were same tendencies in all cases that the Qm decreased when the RF power level increased. These properties became more obvious when the bias current became larger, in other words, the μ became smaller. In the condition of loss effect, these phenomena were emphasized.

The dissipation power per one ferrite core could be calculated from the measured Qm and the input power and plotted in Fig. 4. It seems the phenomena of high loss effect may start at the dissipated power level of 200-300W per one ferrite core.

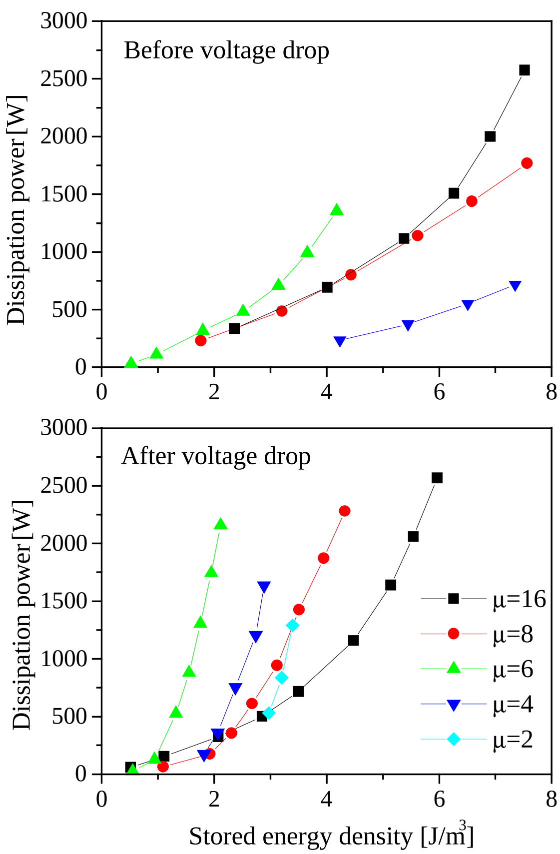

Figure 4: Dissipation power per one ferrite core with various permeability and power levels. Above indicate before the voltage drop, below after the voltage drop, respectively.

2.3 Note

The typical waveform measured at the voltage pickup monitor was shown in Fig. 5.

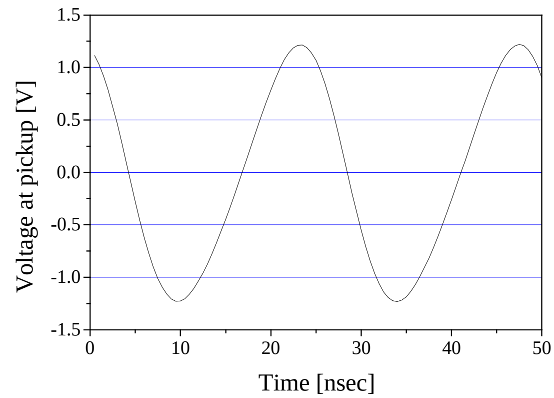

Figure 5: Waveform measured at the pickup monitor.

The distortion in the waveform was observed in Fig. 5. Also it was frequent that the momentary amplitude variation in a few tens of second of time scale were observed in many times though the temperature of ferrite surface was still 35 °C. The instable condition occurred often when the permeability was near 4 or the input power exceeded 500W. The value of input power corresponds to the value of high loss effect threshold, 3×10^{-1}J/m^3 reported by [1]. The further careful experiments and analysis should be performed in future to design the cavity.

REFERENCES

[1] J.E. Griffin and G. Nicholls : IEEE Trans. Nucl. Sci., **NS-26**, 3965 (1979).