Development of FINEMET-cores Loaded Wide-band RF Cavity For a High Intensity Proton Ring

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Abstract

The RF system is the most important issue of the high intensity proton ring. The longitudinal simulation code has been developed and some simulations have been done. As a result of simulations, the multi-harmonic cavity system is very useful for high intensity proton ring, especially for the storage ring. The FINEMET-cores loaded wide-band RF cavity has been fabricated and tested. This cavity has a wide operating frequency range because of the high imaginary part of the permeability and so multi-harmonic RF-powers are simultaneously supplied to one cavity. Furthermore, the FINEMET-core has many advantageous characteristics for the high intensity ring, such as high-permeability and high Curie temperature.

1. Introduction

Recently several high intensity proton rings, for instance SNS, ESS, AUSTRON, etc. are proposed in the world. Many technical problems, for example the multi-turn H^- injection, storage or acceleration and extraction have to be solved for these high intensity proton rings. The RF system is relevant to all these problems, because it is only method of control the bunched structure in the ring. We also have been proposed a high intensity proton storage ring for neutron science experiments [1-2]. In this storage ring, the bunched structure of stored beam has to keep for the fast (single turn) extraction. If the bunched structure can not keep the bunch length, the beam loss increases at extraction process. We also have to make the bunching factor sufficiently large for reducing the effects of beam loading and space-charge force. For these reasons mentioned above, the longitudinal simulation code for the estimation of storage process has been developed. In the following, the brief explanations of this code are reported and some simulation results are shown in section 2. The FINEMET-cores loaded RF Cavity based on these simulations has been fabricated for the storage rings and low power test was started. The construction of model cavity and the results of low power test are mentioned in section 3. FINEMET-cores loaded wide-band RF Cavity was already fabricated for the low power ring [3-4]. Over the past few years a considerable number of studies have been made on this type cavity for high power at KEK [5-7].

2. Longitudinal t simulation

2.1 model parameters

We have studied a high intensity proton storage ring for neutron science experiments [2]. The parameters of injection beam and storage ring are shown in Table 1 and Table 2. Energy of injection beam is 1.5GeV. Pulse structure of injection beam is 400nsec-on and 270nsec-off. In this ring, the hands-on maintenance is required and the uncontrollable beam loss in accumulating process must be reduced enough to do it. Therefor the stable and optimized RF system is essential to reduce the beam loss. Furthermore the stored beam is extracted with fast extraction method for the neutron scattering experiments. A rise time of field of kicker magnets is roughly 150nsec, so we have to keep a non-beam area wider than 150nsec at the extraction stage.

Table 1. Injection beam parameters

Energy	*1.5GeV*
β and γ	*0.923 , 2.599*
Pulse structure	*400ns-ON,270ns-OFF*
Emittance; εx ,εy	*2.0π.mm.mrad*
$\Delta p/p$	*±0.4%*

Table 2. Model ring parameters

Type	*FODO20cell,Triple-bend*
Circumference	*185 m*
Super period	*4*
Operating tune	*(4.84,4.78),(2.75,2.75)*
Transition γ	*4.51,4.7*
Acceptance; εx ,εy	*200.π.mm.mrad*
$\Delta p/p$	*±0.7%*

2.2 Longitudinal simulation

The longitudinal simulation code is multi particle tracking code using the following difference equations in longitudinal phase space.

$$\Delta E_{i,n} = \Delta E_{i,n-1} + qe\left\{V_{rf,n}\left(\sin\phi_{i,n} - \sin\phi_{s,n}\right) + V_{sci,n} + V_{bl,n}\right\}$$

$$\Delta\phi_{i,n} = \Delta\phi_{i,n-1} + \frac{2\pi}{\Omega_s}\frac{h\eta}{PR}\Delta E_{i,n}$$

Here E, P, q and e are the energy, momentum of beam, the charge-state and 1, respectively, and ϕ, R and η are the phase for RF voltage, the average radius of ring and the slippage factor, respectively. V_{rf}, V_{sc} and V_{bl} are the RF voltage, the space-charge voltage and the beam-loading voltage. The subscripts i and n are particle number and turn number, respectively, and the subscript s stands for the parameter of synchronous particle. The phase of synchronous particle is 0, because the beam is not accelerated in this ring.

At first, the simulation of fundamental RF system was done by developed code. Figure 1 shows the beam distribution at the end of injection in a longitudinal phase space. The horizontal axis shows phase for radio frequency. In this figure, the solid curve shows separatrix, which is formed by the fundamental RF voltage. V_{rf} and I_{beam} mean the gap voltage and the circulating beam current, respectively. The bunch length in time increased from 400nsec to 425nsec, when the beam loading is corrected by feedback control using fundamental RF. The non-beam area is enough to extract with a fast extraction method, but the momentum spread and the I_{beam} are very large. The bunching factor is about 0.33. Secondly, the simulation of 1st, 2nd and 3rd harmonic RF system was done for reducing the space-charge force at the beam center and increasing the bunching factor. The RF voltages at acceleration gap are 15kV, 15kV and 6kV, respectively. Figure 2 shows the beam distribution at the end of injection in a longitudinal phase space. In this figure, the solid curve shows the separatrix, which is formed by the 1st, 2nd and 3rd harmonic RF voltages. This result shows that the density distribution is close to uniform shape. The peak current of circulating beam was reduced to 75A from 125A of fundamental RF system. The bunching factor was about 0.67. The maximum momentum spread was about 0.5.

3. The model Cavity for multi harmonic RF system

3.1 model cavity

The photo of the model cavity and its structure are shown in Figure 3 and Figure 4. The cavity is the half wavelength coaxial resonator that is installed the FINEMET-cores at both sides of the accelerating gap. The inner and outer diameters of the FINEMET-core are 520mm, 930mm, respectively. The inner and outer diameters are decided by the requirements, which is caused by beam size, inductance and impedance. It is difficult to make a large ferrite core, but FINEMET makes it possible to fabricate a large core. Furthermore, the FINEMET-core has many advantageous characteristics, such as high permeability, high Curie temperature and some good magnetic properties. For the reasons given above, we selected the FINEMET-core as a magnetic core for the cavity. There is another important reason that the FINEMET-core has a large imaginary part of the complex permeability. Therefore the cavity has a wide operating frequency range and so multi-harmonics of RF-power are supplied to one cavity. The length of the model cavity is 1180mm and the designed gap voltage is 8kV at eight cores. The cooling system is forced air-cooling but it is possible to modify to water-cooling system.

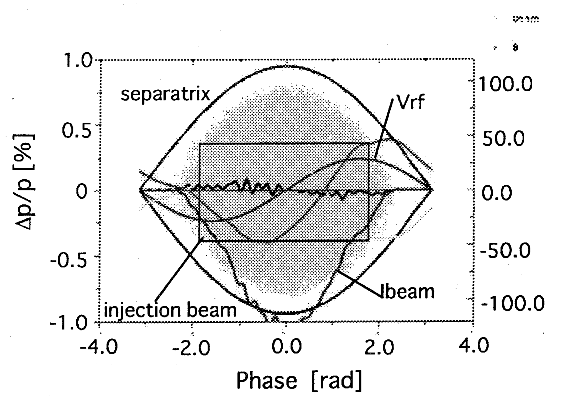

Fig. 1 Longitudinal phase space distribution
Fundamental only

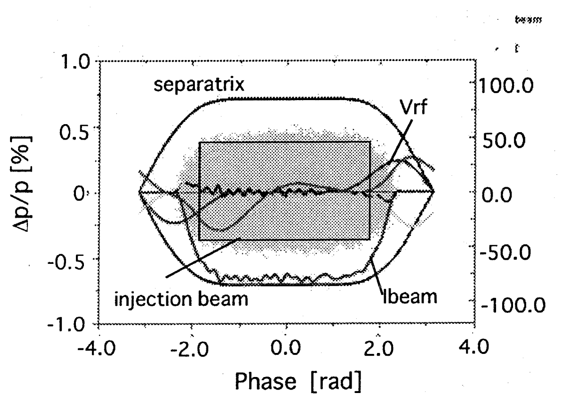

Fig. 2 Longitudinal phase space distribution
1st, 2nd and 3rd harmonics

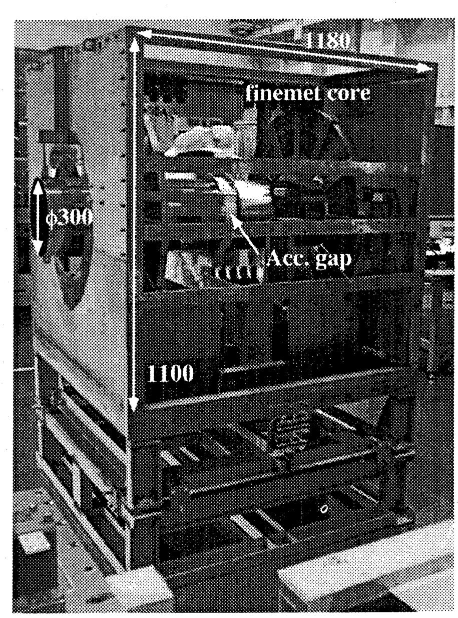

Fig.3 The photo of the model cavity

3.2 low power test

The RF characteristics of the model cavity were measured by a network analyzer. The model cavity was installed two FINEMET-cores. The measurement diagram is already shown in Figure 4. The Figure 5 shows the frequency dependence of cavity impedance and phase in low power test. In these figures, the solid line and dotted line mean the data of measurement and calculation. The cavity impedance is over 50 ohm from 0.5MHz to 6MHz for the fundamental frequency 1.5MHz. The resonant frequency was 2.6MHz and the cavity Q was 0.6. These results are slightly different from designed values. In future, the low power test must be performed in detail.

3. Summary

The longitudinal simulation code has been developed, and some simulations have been done. The model RF cavity based on these results has been fabricated and tested.

We can summarize these results as follows: First, the results of beam simulation showed that the multi-harmonic cavity system is very useful for high intensity proton. In case of the 1st, 2nd and 3rd harmonic RF system, the peak current reduced about 40% and the momentum spread reduced about 35% compared with one of fundamental RF system. The bunching factor becomes 0.67. Secondly, multi harmonic RF system was adopted for the storage ring. We selected the FINEMET-core as magnetic core by reasons of some good magnetic properties and the flexibility of core size, and the model RF cavity has been fabricated. Finally, we started the low power test and measured the basic RF characteristics of the model cavity. Continuously, the measurement of the RF characteristics of the cavity, which is installed the different type core or additional cores, will be done. Furthermore, the measurement of the dependence of the bias current and high power test will be done.

4. References

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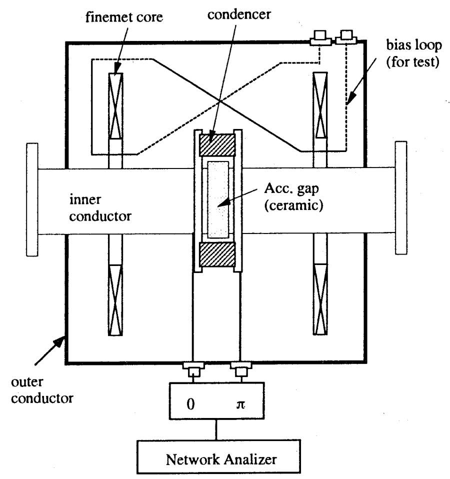

Fig.4 the structure of the model cavity and measurement diagram

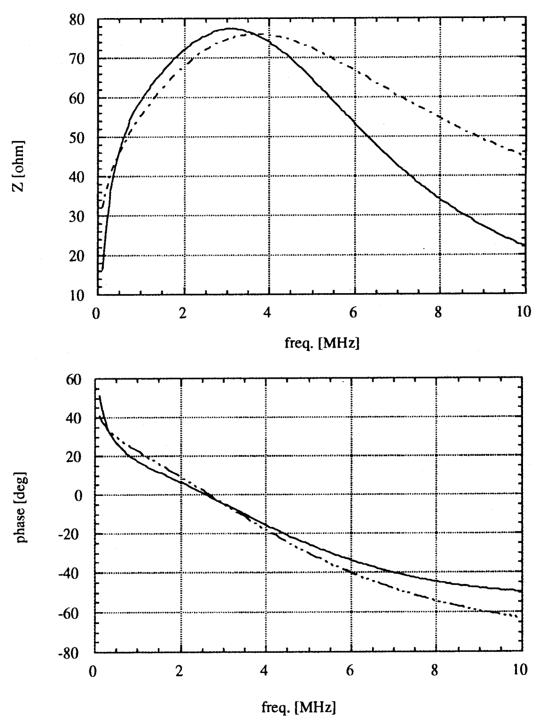

Fig.5 the frequency dependence of the cavity impedance and the phase
Solid line: measurement, Dotted line: calculation