Development of Coaxial Fast Ferrite Tuner for KSTAR ICRF System

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1. Introduction

The high performance plasma of fusion research facility usually shows fast time varying characteristics such as H/L mode transition or EML (Edge Localized Mode) which result varying RF loading impedance of ICRF antenna.[1] Traditional method of matching transmitter output impedance to the antenna impedance for the high power ICRF system is accomplished by several motor-driven stub tuners. However, mechanical contact finger is used for the tuners, the system cannot be adjusted during a shot at which the high RF current is flowing and even more the tuners are not fast enough to match time varying loading impedance having millisecond characteristics. One of remedy for matching fast time varying antenna impedance is using ferrite tuners instead of motor-driven tuners.

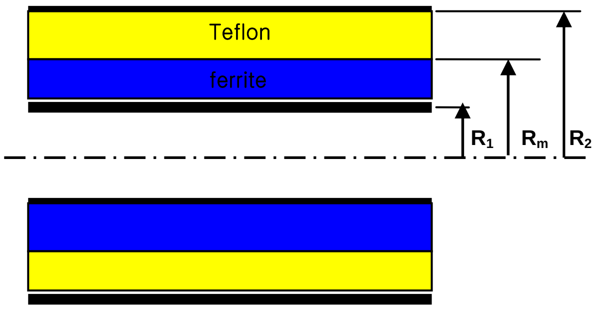

Figure 1. Coaxial arrangement of the conductors of transmission line, stacks of ferrite ring and Teflon. Teflon is inserted for mechanical supporting purpose.

2. Coaxial Fast Ferrite Tuner

A CFFT (Coaxial Fast Ferrite Tuner) is a peace of coaxial transmission line where the space between the conductors is partially filled with coaxial ferro-magnetic materials (ferrite) as illustrated in Figure 1. Remaining system is consisted of solenoidal electro-magnet, magnet power supply with control devices. Schematic diagram of completed CFFT is shown in Figure 2. The electrical length of ferrite loaded transmission line can be changed dynamically by controlling ferrite magnetization because phase velocity of RF wave V_{ph} and characteristic impedance Z_0 are dependent on the magnetic permeability of medium as flowing.

$$V_{ph} = \frac{1}{\sqrt{LC}} \,(m/\mathrm{sec}), \quad Z_0 = \sqrt{\frac{L}{C}} \,(\Omega).$$

Where capacitance C and inductance L are evaluated as

$$C = \frac{2\pi}{\frac{1}{\varepsilon_1}\log\left(\frac{R_m}{R_1}\right) + \frac{1}{\varepsilon_2}\log\left(\frac{R_2}{R_m}\right)} \,(F/m),$$

$$L = \frac{1}{2\pi}\left(\mu_1 \log\left(\frac{R_m}{R_1}\right) + \mu_2 \log\left(\frac{R_2}{R_m}\right)\right) (H/m).$$

R_1, R_m and R_2 are the radius of inner conductor, ferrite core, and outer conductor respectably. Between ferrite and outer conductor, there is dielectric material such as Teflon for the supporting purpose. ε_1, μ_1 and ε_2, μ_2 are relative dielectric constant, magnetic permeability of ferrite and dielectric material.

In the mean time, the magnetic permeability μ_1 of ferrite which having saturation magnetization M_0 can be controlled external magnetic field H by using solenoidal electro-magnet. Magnetic permeability as a function of external magnetic field around saturation magnetization can written as

$$\mu_1 = 1 + \frac{M_0}{H}.$$

Therefore, μ_1 can be controlled from unity to higher value by varying H from low to high compared with M_0 . It is well known that the RF loss of ferrite greatly reduced by applying external magnetic field around saturation magnetization and above[2], so there are upper limit of magnetic permeability when the RF loss is higher than bearable.

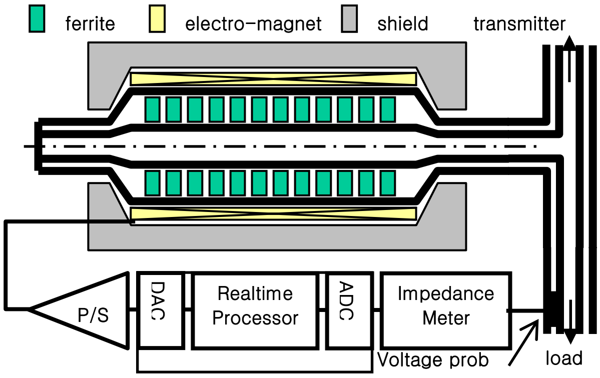

Figure 2. Configuration of cFFT with magnet power supply and control system

3. Fabrication and Test

A low power CFFT is constructed to test the feasibility of the tuner. For the ferrite material, ring shaped Al doped YIG (Yttrium Iron Garnet) having saturation magnetization of near 600 Gauss is chosen. Low cost ferrite such as NiZn or MnZn has higher saturation magnetization of near 3000 Gauss, therefore external magnetic field needed is significantly high. Figure 4. (a) shows loss factor of cFFT with YIG and NiZn ferrite. CFFT with YIG is almost lossless above 300 Gauss of external magnetic field. Loss factor of CFFT with NiZn ferrite is too high to use in this range of external magnet field. Figure 4. (b) shows phase shift effect of CFFT. Higher phase shift effect of NiZn is meaningless because of high loss factor. It is seen that 40 cm long CFFT with YIG provide about 40 degree of phase shift at 30 MHz.

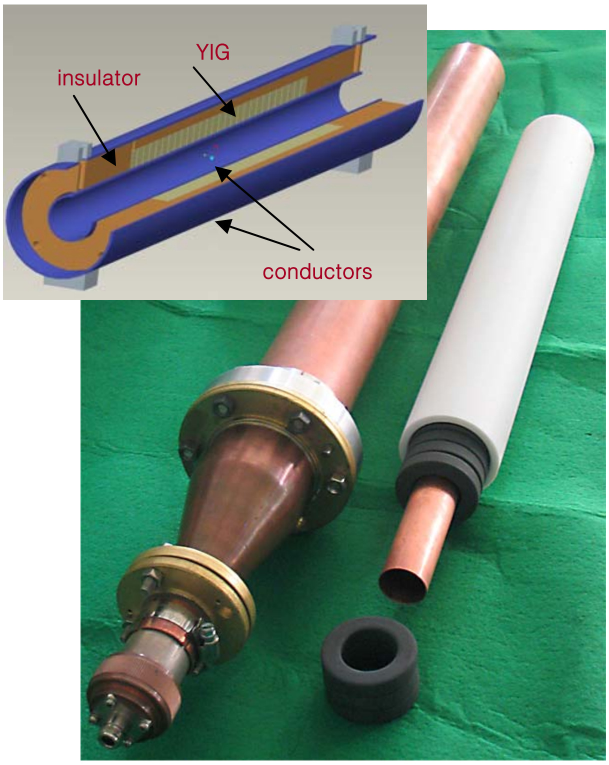

Figure 3. Fabricated CFFT with YIG ferrite rings.

VME real-time processor is being installed in which loading impedance is calculated using collected RF voltage and current signals of transmission line. This feedback subsystem will control magnet power supply. With this real-time feature, the tuner will match the time varying load within millisecond order.

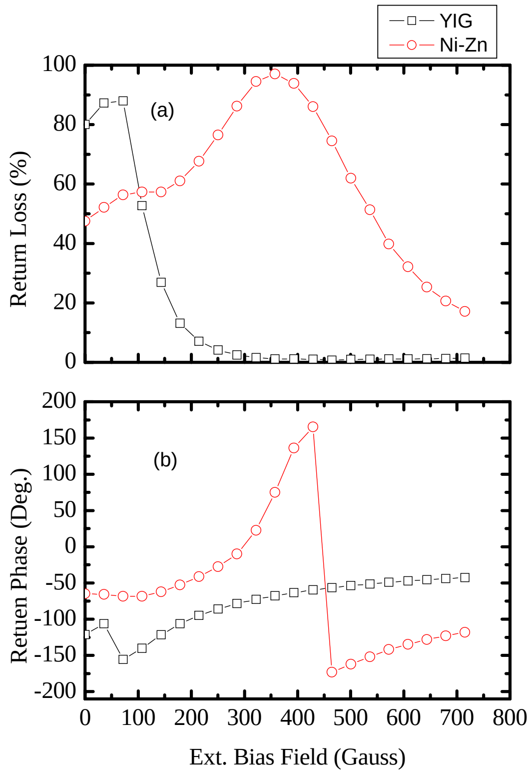

Figure 4. Return loss and shifted phase of CFFT with YIG and NiZn at 30 MHz of RF.

3. Conclusion

Low power CFFT is fabricated and tested with different ferrite materials. CFFT with YIG shows significant low loss compared to NiZn ferrite. CFFT assembled with real-time control system will be tested on the actual time varying load conditions for simulating high power ICRF system of KSTAR.

REFERENCES

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[2] R. M. Hutcheon, "A perpendicular-biased ferrite tuner for the 52 MHz Fetra II cavities", Proc. 1987 IEEE Particle Accelerator Conference.