Transactions of the Korean Nuclear Society Autumn Meeting
Busan, Korea, October 27-28, 2005

Feasibility study of Gas Cooling for High Power ICRF Transmission Line

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1. Introduction

Temperature increment of Ion Cyclotron Range of Frequency (ICRF) transmission line delivering MW level of rf power from amplifier to antenna causes several problems like overheating of insulators and mechanical/electrical mismatch due to the thermal expansion of conductors. To reduce the increment, several techniques have been developed. Radiative cooling by coating high emisivity materials on the surface of conductors has been proved not enough for the MW level of rf power transmission line. Water-cooling of inner conductor requires complicated mechanical structures for water inlet/outet and anchor connectors. Even more, possible water leakage may cause severe damage on the electrical performance of the transmission line. Another option is gas cooling by running turbulent flow between conductors so that radial heat transport is increased to remove heat generated on the inner conductor to outer conductor. The preliminary calculation and measurement of the effect of turbulent gas cooling are presented.

2. Calculation

ICRF system[1] of KSTAR tokamak has approximately 50 m of pressurized transmission line running from each rf source to the antenna which delivers 2 MW of power with near I=300 A of surface peak current at each coaxial conductors when the impedance is perfectly matched. Power dissipated by finite surface resistance is written by

$$P = \frac{1}{2}\left(\frac{1}{2\pi r}\sqrt{\frac{\pi f \mu}{\sigma}}\right) I^2 \ \text{W/m} \quad (1)$$

where f is frequency, μ is magnetic permeability, σ is conductivity and r is a radius of inner or outer conductors. When the characteristic impedance of 9-3/16" transmission line made of Cu inner conductor and Al outer conductor is 50 Ω, dissipated powers are P=204 and 111 W/m for inner and outer conductor respectively. If slight mismatch is assumed to be VSWR=1.5, which corresponds rf field reflection coefficient ρ=0.2, local maximum current is increased and then the P should be multiplied by 1.5. Assuming no cooling effect at all, temperature increment may be written as

$$\Delta T(t) = \frac{P}{mC_p} t \quad (2)$$

where m and C_p are mass and specific heat of conductors, and t is time since the power is applied. When t=300 sec with VSWR=1.5, temperature increments are ΔT = 65 and 10 °C for inner and outer conductor respectively.

Figure 1 shows calculated steady state temperature of inner conductor with the active cooling by pressurized gas flowing between inner and outer conductor. In this calculation, dissipated power is assumed to be P=700 W/m, which corresponds to the maximum current of the resonant loop, and 3 atm of 30 °C N_2 gas is supplied with the flow velocity from 0 to 10 m/sec. This result shows that inner conductor may be maintained quite cool with the moderate flow of pressurized gas.

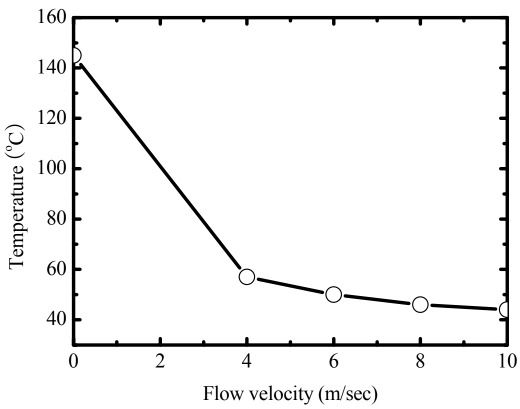

Figure 1. Steady state temperature of inner conductor with 3 atm of N_2 gas.

3. Experiment and Result

High current resonant transmission line for testing KSTAR ICRF antenna[2] is targeted to measure cooling effect of turbulent gas. The antenna is consisted of four center grounded straps with eight feeding ports. One of antenna strap is fed through lower port with one wavelength long resonant transmission line having tee-port for rf input and upper port is connected to the three fourths wavelength long resonant transmission line. To prevent electrical breakdown, the transmission line is pressurized by up to 3 atm of N_2 gas. The gas pressure will be varied to investigate the effect of pressure to the cooling effect. Because the isolation between lower and upper parts of strap is not perfect, there is power coupling between these two transmission lines. Therefore, significant power is flowing to the upper transmission line, in spite of no direct power is supplied to the upper transmission line. Figure 2 shows voltage and current distribution of upper transmission line coupled by almost 66 % of the voltage and current of lower transmission line.

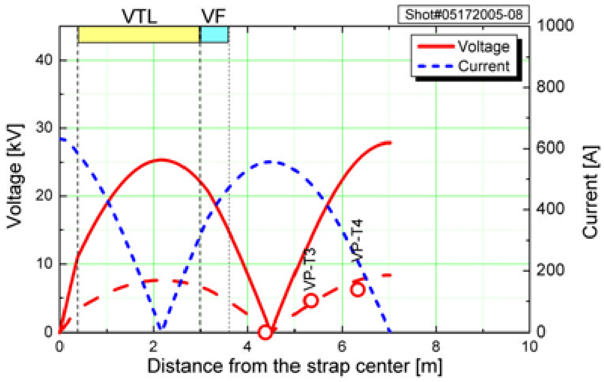

Figure 2. Voltage and current distribution along the upper resonant transmission line with an antenna strap.

Figure 3. shows typical measurement of temperature on the outer surface of resonant transmission line without any active cooling. Near 40 kW of rf power is supplied, and the temperature is increased by about 23 ^{o}C. From Eqs.1 and 2, the ratio of temperature increment of the inner conductor to the outer conductor is 6.5. Therefore, the temperature increment of inner conductor may be about 143 ^{o}C.

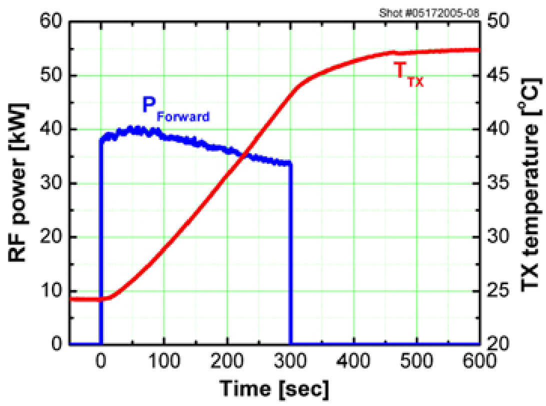

Figure 3. Temperature increment of outer conductor without active cooling in transmission line.

As illustrated in Figure 4, to make closed loop for pressurized gas, the blower should be enclosed in the pressurized gas chamber inserted in the loop. By this way, pressure drop between inlet and out of the blower can be minimized and no net force is applied on the wall of the blower. Therefore, the blower is not required to have high pressure capability. The vortex type flow meter at the outlet of blower chamber measures gas flow rate, and several thermocouples measure gas temperature and outer conductor temperature. An IR thermometer is installed with ZnSe window at the maximum current location of transmission line so that it measures the surface temperature of inner conductor.

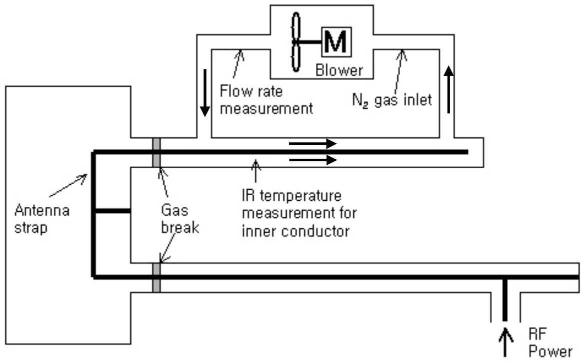

Figure 4. Illustration of experimental setup.

The detailed measurement of the effect of gas cooling is under way. The dependency of temperature increment on the gas flow rate and pressure will be measured and compared to the calculated results

4. Conclusion

Temperature increment of inner conductor of ICRF transmission line is not bearable when there is no active cooling. Among several cooling techniques, pressurized flowing gas cooling method has been investigated, and the preliminary calculation shows effective result. To measure actual cooling effect, a closed gas loop was installed at the existing KSTAR ICRF antenna test stand in KAERI.

REFERENCES

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