§ 5. Excitation and Measurement of Alfvén Waves in the Hyper-I Device

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To study the kinetic nature of Alfvén wave from the viewpoint of its spatial structure, the HYPER-I device with an inner diameter of 30 cm and a length of 2 m has been used. To fill plasmas in the large volume of the device, we adapt ECR by means of a microwave source with the frequency of 2.45 GHz and the maximum power of 80 kW. The typical plasma density is about 8×10^{18} m^{-3}, when helium, neon or argon is used as working gas.

In order to excite Alfvén wave in the plasmas, a three-turns loop antenna with a diameter of 30 mm was set at z=1555 mm (measured from the microwave window placed at an end of the vessel) and x=65 mm or x=0 mm (from the axis of the vessel). The currents into the antenna were supplied by an amplifier with variable frequency of 95-500 kHz and the maximum power of 10 kW. Then, excited magnetic perturbation was detected by magnetic probes. Since the magnetic probes have to maintain in the plasma with high power microwave, a high heat resistant magnetic probe has been developed and its illustration is shown in Fig.1. A pick-up coil with 2 mm diameter and 1.5 mm long is made of 100-turns of a heat resistant enameled wire with 0.1 mm diameter and is installed in a stainless tube with an inner diameter of 4.01 mm with the help of a Cu rod. The pick-up coil detects time variation of magnetic field that penetrates from the slit on the stainless tube, which is needed to keep the pick-up coil away from intense microwave. The dimension of the slit can be determined from the combination of the two facts. The Cu rod may also keep temperature of the pick-up coil moderate because of its good heat conduction. The assembly is set in a ceramic tube with 8 mm diameter for plasma insulation.

For the antenna currents with, say, f =100 kHz, a signal was detected by a magnetic probe placed at z=500 mm and x=65 mm when a plasma was filled in the vessel, but not when no plasma was filled in the vessel because the cutoff frequency of the vacuum tube with 30 cm inner diameter is about 600 MHz. When a plasma was filled in the vessel, we also found a phase shift between the signals of the magnetic probes placed at z=500 mm and z=1155 mm, from which we derived a phase velocity and/or a wave number. By repeating this measurement for various plasma conditions and frequencies of the antenna currents, we have obtained dispersion relations, which are depicted by solid circles and open triangles in Fig. 2. Here, Ω is the frequency normalized by the ion cyclotron frequency ω_{ci} and K is the wave number normalized by k_A (= ω_{ci}/V_A ; V_A=$B/(\mu_0 nM)^{1/2}$) and the solid circles were data taken when the antenna was placed at x=65 mm and the open triangles were those taken when the antenna was placed at x=0 mm, respectively. Error bars of the data are derived from the uncertainty of the plasma density and the duration of the antenna currents. The slope of a dotted line indicates Alfvén velocity, that is, ω/k=V_A. Solid curves with letters CAW and SAW indicate the dispersion relations of compressional Alfvén wave and shear Alfvén wave in a uniform plasma, respectively. The data for f=95 kHz in the argon plasma, f=476 kHz in the helium plasma and f=100 kHz in the neon plasma almost agree with the solid curve of CAW. The datum for f=100 kHz in the argon plasma shows that the phase velocity is extremely faster than V_A, so it seems to be the cutoff mode of CAW with m=0 (m: azimuthal mode number). It is vague whether the data for f=100 kHz and 95 kHz in the helium plasma correspond to CAW or SAW, because the difference between the phase velocities of CAW and SAW are small. The mode of the waves could be cleared if the measurements of their azimuthal mode numbers and radial distributions of the wave field and polarization are made.

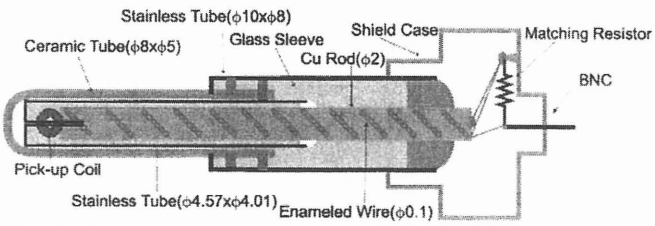

Fig. 1 High heat resistance magnetic probe.

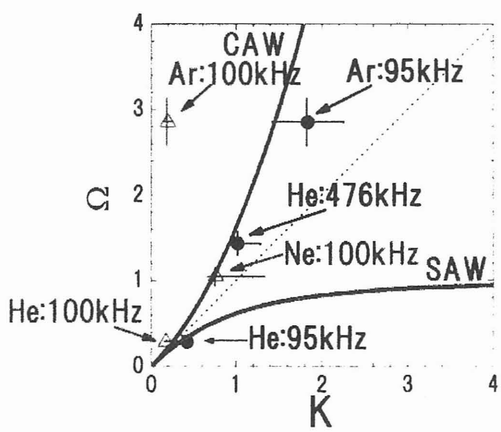

Fig. 2 Dispersion relation, K v.s. Ω, with dotted line indicating the relation of Ω/K = V_A.