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Real-time impedance matching system using liquid stub tuners in ICRF heating

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Abstract

For steady-state operation with ion cyclotron range of frequencies (ICRF) heating, real-time impedance matching is necessary in order to inject ICRF power into the plasma against variations in the antenna impedance. Two methods of the real-time impedance matching were employed during a long pulse discharge in the large helical device (LHD). One was the manual-frequency control method and the other was the automatic control of liquid heights in liquid stub tuners using trial-and-error method. Both of these methods entailed disadvantages; a limitation of bandwidth in impedance matching by a frequency control, and in trial-and-error method an abrupt increase of the reflected power fraction and a slow reduction rate of the reflected power fraction. A new real-time impedance matching method solving these problems was developed utilizing liquid stub tuners. The impedance of the resistor attached to the outlet of the stub tuners was measured using a directional coupler attached to the coaxial line near the outlet of the final power amplifier. Optimum liquid heights were predicted and liquid heights were adjusted in real-time using pulse motors. The reduction of the reflected power fraction was demonstrated and was kept low against variations in the impedance of the resistor.

Keywords: ICRF heating; LHD; Liquid stub tuner; Steady-state operation

1. Introduction

A long pulse discharge has been conducted in the large helical device (LHD) [1]. Internal current is not

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necessary to sustain plasma, making the LHD suitable for long pulse operation. Ion cyclotron range of frequencies (ICRF) heating devices have been developed for high power and long pulse plasma heating. An impedance matching device is an important component for the high power injection into the plasma and for the protection of the oscillator, because such an impedance matching device reduces the power reflected from an antenna to an oscillator.

By fixing the tuning of the impedance matching device, reflected power gradually increased during long pulse operation in LHD in spite of the constant plasma parameters [2]. This phenomenon may be related to the temperature increase of an ICRF antenna. Therefore, we began to study real-time impedance matching in the hope that it will provide the oscillator effective protection from the reflected power and maintain constant input power against variations of the plasma conditions as well as the antenna conditions. The real-time impedance matching will be also necessary in ICRF heating of steady-state plasma in fusion reactors. One possible method for real-time impedance matching involves the use of liquid stub tuners. To establish real-time impedance matching, a low power test was conducted in LHD using such tuners.

Section 2 describes the impedance matching device with liquid stub tuners in the LHD. Previous real-time feedback control methods in the LHD will be described in Section 3. In Section 4 we review a prediction method for application to real-time impedance matching. The system of real-time impedance matching using the prediction method, as well as the experimental results will be shown in Section 5. Section 6 provides a summary.

2. Impedance matching device

An antenna impedance changes depending on the plasma conditions, the distance between the ICRF antenna and the plasma, or the temperature of the antenna. Therefore, a tunable impedance matching device is necessary. A liquid impedance matching device [3,4] has been developed for high power and steady-state operation under a wide bandwidth. This device consists of two or three liquid stub tuners and a U-shaped link as shown in Fig. 1. The liquid stub tuners utilize the difference of the wavelength in gas (N_2) and liquid (silicon oil) due to the difference of the dielectric constants. In a bench test, a liquid stub tuner withstood 63 kV for 10 s and 50 kV for 30 min, and was thus determined to be a reliable component. The liquid height is adjustable during high power injection, demonstrating that this device is also suitable for long pulse operation. The height of the liquid of the stub tuner is measured with the precision of 1 mm by the difference of the pressure between the top and the bottom of the stub tuner. The liquid height is adjusted utilizing a device comprised of a pump and a tank or a cylinder, as shown in Fig. 2. The pump and tank is suitable for the large shift of the liquid surface level,

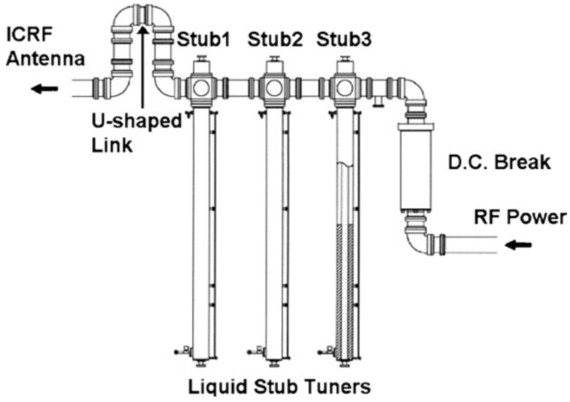

Fig. 1. Impedance matching device with liquid stub tuners.

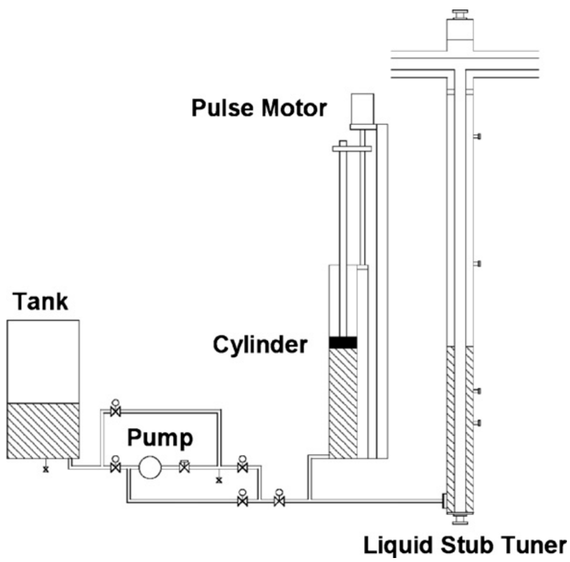

Fig. 2. Mechanism of liquid height shift.