ICRF HEATING FOR THE ASDEX-UPGRADE TOKAMAK

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ABTRACT

The 12 MW of additional power for ASDEX Upgrade will be provided by 6 MW of neutral beam injection and 6 MW of ICRH. Such a combination has proved to be very efficient in ASDEX. In order to enable minority and second harmonic heating schemes, 4 equal RF systems with a frequency range of 30 - 120 MHz and a generator output power of 2 MW each are being built. The water-cooled, wide antennae allow the radiation of waves with different K-spectra by exchangeable central conductor geometries at a moderate voltage level.

INTRODUCTION

The major aim of ASDEX-Upgrade is to investigate a tokamak plasma and its interaction with the walls in a reactor relevant open poloidal divertor configuration and with an energy flux density in the plasma boundary comparable to reactor conditions /1, 2/. To reach this aim a heating power in the plasma of about 12 MW for hydrogen and 8.5 MW for deuterium seems necessary /3/, this estimation being based on a confinement similar to the H-mode found in ASDEX.

The heating power of 12 MW was decided to be supplied partly by Neutral Injection and partly by ICRH. If experimental results call for even more power, the concept of ASDEX-Upgrade allows to add further ICRH or NI devices as well as the application of other RF heating methods.

ICRH GENERAL CONCEPT

To provide 6 MW heating power in the plasma 4 equal systems will be built with a generator power of 2 MW each. This power should be available for standard magnetic field values of ASDEX-Upgrade in the single- and double-null divertor - and the limiter configuration. Heating should be possible, too, up to the maximum magnetic field, a somewhat reduced power being unavoidable.

High field side antennae being nearly impossible due to the poloidal divertors, heating by mode conversion is not practicable. The ICRH application is thus restricted to second harmonic and minority heating. Figure 1 gives the frequency ranges necessary for these heating methods for the main operational regimes of ASDEX-Upgrade.

In view of the still experimental status of ICRH it was decided to build a system providing maximum experimental flexibility:

- A frequency range of 30 - 120 MHz allowing second harmonic heating in D and H as well as minority heating with H or He_3 in D.
- An antenna concept allowing variations of the $k_\parallel$-spectrum as well as fitting the antennae to different plasma cross-sections (single- and double-null divertors) by relatively simple modifications.

Every provision has been made for a possible later increase of the heating power by 2 additional systems. If needed, the total number of antennae could even be increased to 8.

EXPERIMENTAL EXPERIENCE

Besides the large experimental experience of PLT and TFR /e.g. 4, 5/, more recent results of ASDEX, JET /6/ and TEXTOR /7/ can now be taken into account. Especially ASDEX results /8, 9/ are highly relevant due to the divertors and the similar heating scenarios. A summary of these results in view of the choice of heating methods for ASDEX-Upgrade show:

- Second harmonic and minority heating are very efficient heating methods, the measured heating efficiencies of 20-25 kJ/MW being larger than for NI in the L-mode.
- A combination with NI improves the available parameter range for ICRH (e.g. the impurity problems being reduced).
- ICRH is accompanied by high-Z impurities leading to about 30 % of power radiation from the plasma centre. This can largely be reduced by low-Z wall material (e.g. carbonization). The physics of the impurity release is still under investigation.
- It is possible to get the H-mode with ICRH /9/. This seems to be somewhat easier with minority heating. Further intense investigtions are necessary in this field.
- Second harmonic heating is largely independent of the gas composition (e.g. for $2\Omega_H$ the content of H ions should only be $\gtrsim 40$ %) allowing a larger experimental flexibility than minority heating.

So the choice of a combination of NI and ICRH as well as the large frequency range allowing second harmonic and minority heating are fully justified by recent results. A restriction to a smaller frequency range and only one ICR-heating scheme, despite of its attractiveness from the economic point of view, seems not yet reasonable for the next generation of experiments.

ANTENNAE

The development of antennae for ASDEX-Upgrade has the following aims:

- Optimization for single-null operation and second harmonic heating (80 MHz). The antenna will be used for minority heating, too, with somewhat worse coupling characteristics.
- The antenna should allow different spectra for $K_{\parallel}$ by using different centre conductor geometries.
- Fitting to different plasma cross-sections (single-null, double-null divertor and limiter operations) is possible by changing simple side wall elements, the Faraday screen and side limiters being reused.
- The antenna has to be cooled.

The antenna geometry was optimized with respect to the electric field and voltage levels in the antenna and transmission lines. For this purpose the coupling calculations with 2- and 3-dimensional codes were combined with ray-tracing calculations in order to take into account the effect of the geometry on the power absorbed in the plasma, not only on the power radiated by the antenna /10/ (Fig. 2).

A simple loop antenna leads to a $k_{\parallel}$-spectrum peaked at $K_{\parallel} = 0$, mainly exciting fast waves with small $k_{\parallel}$ which are weakly damped by the plasma. It possibly excites coaxial waves, too, which may contribute to the impurity release. Since experimental results are still contradictory concerning these questions, the spectra of the ASDEX-Upgrade antenna will be variable by exchanging the centre conductor array (Fig. 3a,b). 2D- calculations show, that for an antenna wide enough the voltage necessary for radiation and absorption of a certain power, e.g. in an array like Fig. 3b must not be larger than for a single loop antenna (Fig. 2). It can be seen further in Fig. 2, that for such an array and with a given antenna width there exists an optimum for the widths of the centre conductors and gaps.

Figure 4 shows the principle design of the antenna. It is based on the technology of the ASDEX antenna providing TiC-coated, optically open Faraday screens /11/, carbon protection limiters and water cooling. For single null operation the antennae are asymmetric with respect to the midplane of the experiment in order to utilize the full available space for a large distance between central and return conductor.

LINE AND MATCHING SYSTEM

The antennae are fed at their both ends by 6 1/8" vacuum lines with bellow sections to compensate thermal expansions. They are connected to the pressurized 9" lines by two feedthroughs with intermediate vacuum. First stubs near the upper and lower antenna feeder will reduce the VSWR for the major frequency range ($2\Omega_{CH}$ corresponding to about 80 MHz) and allows cooling of the inner conductor of the vacuum line. The antenna impedance is matched to that of the generator by double stub-tuner systems near the experiment, the distances between the two stubs and between stubs and antennae being adjustable by exchangeable elements.

RF GENERATORS

The 4 RF generators will be very similar to those of ASDEX-W VII /12/. Besides minor modifications based on the operation experiences with ICRH experiments on ASDEX and the extension of the upper frequency limit from 115 to 120 MHz the output power of each generator will be extended from 1.5 to 2 MW up to 80 MHz and up to 1.2 MW at 120 MHz. Special tests with an ASDEX-W VII generator showed that these values can be achieved /13/. At least at lower frequencies a further increase of the power should be possible.

REFERENCES

/1,2/ IPP Garching Reports Nr. 1/197, 1/211 (1982) and 1/217 (1983)

/3/ Additional heating for ASDEX-Upgrade, IPP Garching Rep.1/237 (1985)

/4/ e.g. J. Hosea et al., Proc. of 4th Int. Symp. on Heating in Toroidal Plasmas, Roma 1984, P.261-275
Proc. of 12th European Conference on Controlled Fusion and Plasma Physics, Budapest, 1985

/5/ e.g. J. Adam et al., 4th Int. Symp. on Heating in Toroidal Plasmas, Roma 1984, P.277-290

/6/ J. Jacquinot et al., 12th Europ. Conf. on Controlled Fusion and Plasma Physics, Budapest, 1985, or P.P. Lallia, this conference

/7/ A.M. Messiaen et al., ibid

/8/ K. Steinmetz et al., ibid

/9/ K. Steinmetz et al., this conference

/10/ J.-M. Noterdaeme, M. Söll, 12th Europ. Conf. on Controlled Fusion and Plasma Physics, Budapest, 1985

/11/ F. Wesner et al., 4th Int.Symp. on Heating in Toroidal plasmas, Roma 1984, P.1103, and J.-M. Noterdaeme et al., this conference

/12/ W. Schminke, F. Hofmeister, F. Wesner,10th Symp. on Fusion Engineering, Philadelphia, 1983, p. 1498

/13/ J. Wyss, K.Holm, Applications of RF Waves to Tokamak Plasmas, Varenna, 1985, p.882

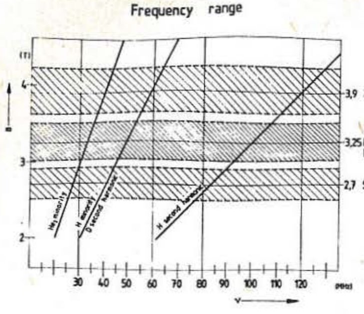
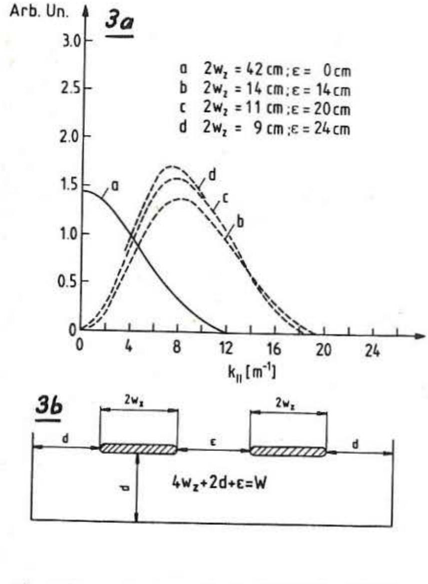


Fig. 1: ASDEX-Upgrade operational regimes and ICRH frequencies



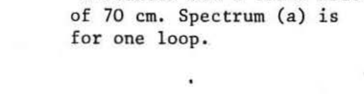


Fig. 3a: Spectra of an antenna array like Fig. 3b for different distances and a total width of 70 cm. Spectrum (a) is for one loop.

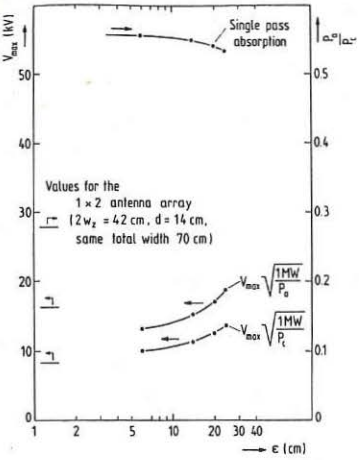


Fig. 2: Power absorption and antenna voltage for an array like Fig. 3b and simple loops

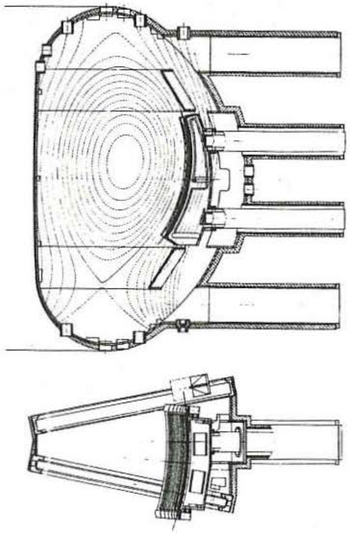


Fig. 4: Cross sectional views of the ICRH antennae in the vacuum vessel.