*31st EPS Conference on Plasma Phys. London, 28 June - 2 July 2004 ECA Vol.**28G**, P-1.211 (2004)*

Overview of Recent Results from WEGA Stellarator

M. Otte, J. Chung, K. Horvath, J. Lingertat, Y. Podoba, F. Wagner and D. Zhang

Max-Planck-Institut für Plasmaphysik, Euratom Association, Wendelsteinstr. 1, 17491 Greifswald, Germany

Introduction

The WEGA is a medium sized classical stellarator operating at the Greifswald branch of the IPP in a modernised version since 2001 [1]. The machine is mainly used for educational training, testing of new diagnostic equipment and for basic research in plasma physics [2].

In this article an overview of recent results obtained from various operating scenarios and data obtained from Langmuir-probes, bolometry and spectroscopy are presented.

The dependence of plasma parameter on the magnetic configuration, the ECRH power and the gas (Ar, He and H_2) will be discussed.

Plasma heating

A special subject of interest is the plasma heating process using ECRH at 2.45GHz (O-Mode). Under those conditions the vacuum wavelength (λ~12cm) is comparable to the plasma radius (a~10cm) and the physics of plasma-wave interaction becomes complicated.

Nevertheless, it was found that the plasma density profiles were peaked, with the density nearly 10 times higher then the cut-off density $n_{cut\text{-}off} = 7.5 \times 10^{16} m^{-3}$ [3]. In order to obtain such overdense plasma a mode conversion into the electrostatic electron Bernstein waves (EBW) is necessary. The proposed O-X-B scheme [4] requires the launch of an O-mode wave with an optimal k-vector in respect to the magnetic field. In this heating scenario the O-wave is launched from the low field side of the torus and converts to X-wave on the cut-off layer, then the X-wave to an EBW on the upper-hybrid resonance layer.

For maximum conversion efficiency of an O-wave to an X-wave, the O-wave has to have a K-vector with an angle of 45° to the magnetic field. In order to maximise the emitted microwave for such conditions, the emission pattern (K-spectrum) of 3 different types of cylindrical antennas (straight, 45° cut and double slit) was calculated using the HFSS code and compared with measurements. The efficiency of O-X-conversion for the cases discussed above has been estimated by calculating the emission pattern of the antenna with the HFSS code and folding the result with the OX-transmission function T from [3]. For the three O-mode cases described above conversion efficiencies of 7%, 9% and 22% were estimated, respectively. However, since the wavelength at 2.45 GHz (λ~12 cm) is comparable with the minor radius and most models of the OXB-process assume $\lambda \ll a$ or even $\lambda \ll n_e/\nabla n_e$, the obtained values for the conversion efficiency are rough estimates only. In Fig. 1 results from Langmuir-probe measurements are shown obtained with the different ECRH antennas mentioned above. Optimum heating (peaked density profiles and most energy inside the last closed flux surface (LCFS)) was achieved using a double slit antenna (right), which has the highest conversion efficiency. The heating efficiency and the pressure profile show strong dependence on the magnetic field and peak at ~0.65 of the resonant field.

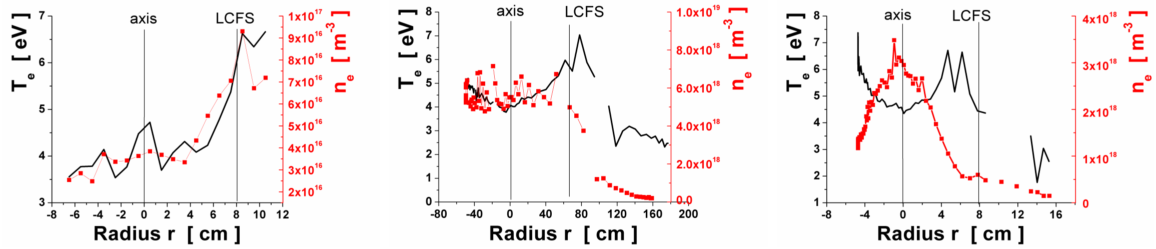

Fig. 1 Typical temperature and density profiles for straight (left), cut under an angle of 45° (middle) and double slitted antenna (right).

In order to prove the proposed heating mechanism probe measurements in the vicinity of the ERCH antennas are planned in the near future.

In the following results are presented for the optimal heating scenario using a double slit antenna.

Bolometric Measurements

A 12 channel bolometer camera has been installed on the WEGA stellarator to measure the radiation power losses of ECR-heated plasmas. Each channel has a gold foil absorber and a reference. The absorbed power is monitored by a resistance change due to the temperature rise of the foil [6]. The camera is positioned in the mid-plane, viewing the plasma from the low-field side with a spatial resolution of about 6cm. The viewing angle is chosen to cover poloidally the whole cross-section of the plasma. A toroidal extension of about ±14° is necessary to achieve an acceptable signal to noise ratio.

Radiation behaviour of different working gases such as H, He and Ar has been investigated. In the following bolometer data obtained in Ar plasmas for different magnetic configurations and ERCH powers are discussed. The total radiated power, which is obtained by linear extrapolation of the integrated radiation power measured in the viewing region to the whole plasma or torus volume, is generally <30% of the ECRH power and depends on the net ECRH input power and the magnetic configuration, as shown in Fig. 2.

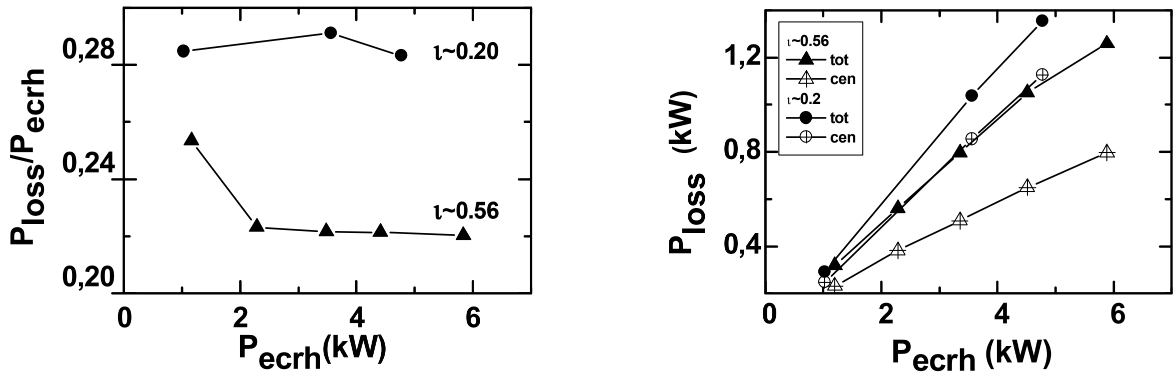

Fig. 2 Relative (left) and total radiation loss (right) vs. ECRH power in dependence on the magnetic configuration for Ar plasmas (T_e=4-7eV, n_e~$10^{18}m^{-3}$).

Since no evident impurities are observed by spectrometer measurements, the radiation loss is mainly from the Ar ions and Ar atoms. The increment of the measured total radiation loss with ECRH power is consistent with the increment of the electron temperatures and the line integrated electron densities, which can be explained through the radiated loss function of Ar [6]. It has been observed that the edge radiation depends strongly on the shape and size of plasma (hence the magnetic configuration) facing the used ECRH antenna. Through radial inward shifting of the plasma or changing the polarity of the helical field as well as the toroidal position of the used ECRH antenna the edge radiation can be reduced. The non-negligible edge radiation outside the confined plasma region, as shown in Fig. 2 (right), indicates a broad deposition profile of the input ECRH power.

Comparing different working gases less edge radiation appears in H and He discharges. It was found that for a given working gas and in case of high ι_0 the radiation power fraction decreases with increasing ECRH-heating power.

Results obtained from MOSS and optical spectrometer

The MOSS (Modulated Optical Solid State) spectrometer monitors the temporal coherence of an isolated line by polarisation interferometric technique. It is designed to operate in the optical region of the spectrum, and the heart of the device are electro-optic birefringence crystals that modulate the wave delay [5]. The first 2D imaging MOSS spectrometer using a high-resolution 2D CCD camera was constructed to study ion temperatures and flow velocities using the 468.6 nm He II line emission. The investigations were done by changing the primary machine control parameters such as ECR heating power and neutral gas pressure.

The measured ion temperature of He plasmas is T_i =1.5 – 2.0eV (T_e = 7eV, $n_e = 2 \times 10^{18}m^{-3}$)

at maximum of 25kW ECRH power. The ion temperature T_i from the MOSS spectrometer was crosschecked with a high resolution Echelle grating spectrometer. Using the measured plasma parameters the ion energy confinement time is estimated to be around 0.1ms for pure He plasmas in WEGA at the maximum ECRH power.

Furthermore, it was found that the poloidal flow velocity was around 500 - 1000m/s, and it slightly increases with higher ECRH power. To make sure that the velocity was induced by the plasma the toroidal magnetic field direction was reversed and the line shift using the Echelle grating spectrometer for both the standard and reversed toroidal magnetic field directions was measured. The plasma flow velocity perpendicular to B is given by the sum of the $E \times B$ and diamagnetic drift, and both have the same direction for ions. Here the poloidal flow in WEGA is mainly due to $E \times B$ drift, since the electron density profile measured with the fast Langmuir probe is flat inside the LCFS, and the radial electric field near the LCFS (50 - 70 V/m) agrees with the measured flow velocity.

Future plans

Up to now we have only indirect evidence on the proposed OXB conversion process using ECR heating. It is planned for the near future to verify this assumption by HF probe measurements. For bolometric measurement, investigations on the neutral contribution to the measured results are planned since the gold foil is also sensitive to the neutral influx. Furthermore, it is planned to modify the MOSS spectrometer which will make measurements in Ar plasmas possible.

References

[1] J. Lingertat et al., 30 EPS Conference on Plasma Phys. and Contr. Fusion, St. Petersburg, 7-11 July 2003, P-1.10 (2003)

[2] M. Otte et al., 30 EPS Conference on Plasma Phys. and Contr. Fusion, St. Petersburg, 7-11 July 2003, P-1.9 (2003)

[3] Y. Podoba et al., 14th International Stellarator Workshop, Greifswald, September 22 - 26, 2003, P.Mo27

[4] H.P. Laqua et al., PLR 78, 18 (1997)

[5] J. Howard, Applied Optics, Vol 41, No.1 (1997)

[6] K.F.Mast et al, Rev. Sci. Instrum. 62, 744 (1991)

Acknowledgement

The technical support of D. Aßmus and N. Paschkowski is gratefully acknowledged.