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MEASUREMENTS OF SHOCK WAVES USING THOMSON– AND RAYLEIGH SCATTERING ON AN EXPANDING PLASMA

M.C.M. van de Sanden, G.M. Janssen, J.M. de Regt, B. van der Sijde and D.C. Schram

Eindhoven University of Technology, Department of Physics, P.O.B. 513, 5600 MB Eindhoven, The Netherlands

To understand the physical phenomena in expanding plasmas with and without a magnetic field knowledge of plasma parameters such as the electron density n_e, the electron temperature T_e, and the neutral density n_0 is essential. To be able to calculate mass, force and energy transfer local measurements of the plasma parameters are needed. Scattering of visible light from free and bound electrons, Thomson– and Rayleigh scattering respectively, gives a means to measure these parameters locally in the plasma [1], and to study shock wave phenomena occurring in these plasmas.

The Thomson scattering (see fig. 1) set–up consist of a frequency doubled Nd:YAG laser as a light source (λ=532 nm, E=0.16 J/pulse, τ=8 ns, f_{rep}=10 Hz). The laser beam is focused in the plasma with a lens L1 (f=500 mm) to a waist of 0.5 mm, after passing two dichroich mirrors S1 and S2 to select the second harmonic. Diaphragms are placed in the tube to reduce the stray light which originates from the scattering of the window. The incident laser light is absorbed in a laser dump which consists of a glass plate under the Brewster angle. The detection optics consists of two plano convex lenses (f=500 mm), L2 and L3, which image the detection volume one to one on the entrance slit of the polychromator. On the opposite a viewing dump is installed. The entrance slit of the polychromator has a height of 1 mm and a width of 0.5 mm resulting in a detection volume of 0.25 mm^3. The scattered light is dispersed by a holographic concave grating (HCR, R=500mm, 1800 l/mm, dispersion 1.1 nm/mm, Rowland geometry). The solid angle of the two detection lenses are matched to the solid angle of the grating (0.021 sr). The entrance angle α and the exit angle β are determined to achieve minimal astigmatism at the exit slit. The calculated width of the apparatus profile is equal to 0.36 nm (FWHM). On the exit slit a gated light amplifier LA (amplification 10^4, τ_{gate}=20 ns) is placed, with the photo cathode parallel to the Rowland circle. The amplified Thomson signal is detected with an optical multi channel analyzer (OMA). The OMA integrates the scattered signal during 600 shots, after which the analog signal is digitized with an ADC plug–in unit inside a personal computer.

The plasma set–up consists of a cascaded arc (flow=500–5000 ml/min, I_{casc}=30–90 A) which serves as a plasma source. The plasma expands into a vessel at low pressure (p_{back}=0.05–2.0 torr). The plasma column between the anode plate of the cascaded arc and the end anode has a length of approximately 700 mm. A magnetic field can be applied (B=0–0.4 T) parallel to the plasma column. The plasma parameters are measured locally by moving the plasma in the radial and axial direction.

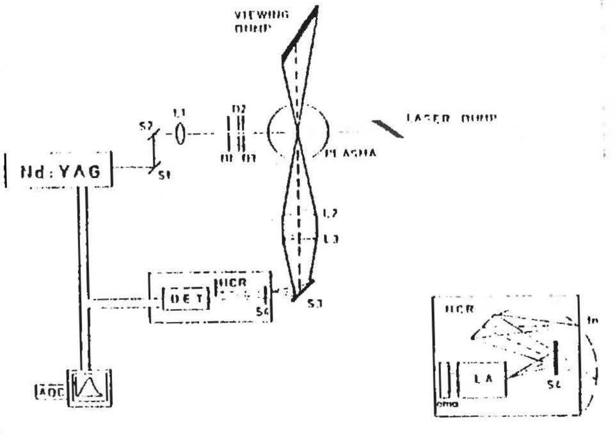

Figure 1 The Thomson setup (explanation see text). S3 and S4 are mirrors.

An important characteristic of the described Thomson set–up is the fact that the *total* Thomson spectrum is measured. Therefore deviations from a Maxwell electron velocity distribution parallel to the scattering vector can be determined. Furthermore using the absolute Rayleigh

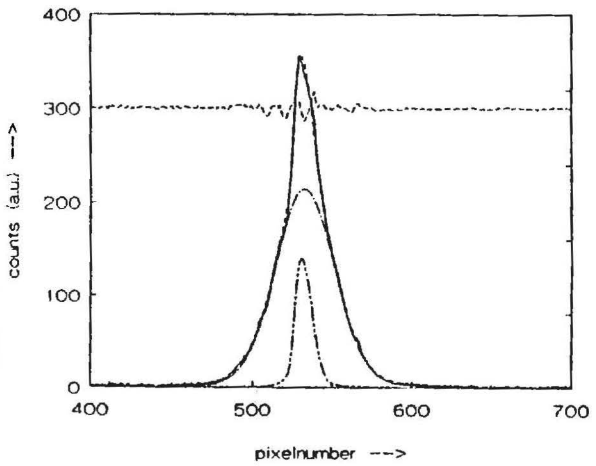

Figure 2 A measured Thomson– and Rayleigh and the least mean squares fit of the measurement (dashed line). The components are also given: a gaussian, representing the Thomson contribution, convoluted with the apparatus profile and a scaled apparatus profile on top of this representing the Raylcigh contribution. The residue is shown on the same scale.

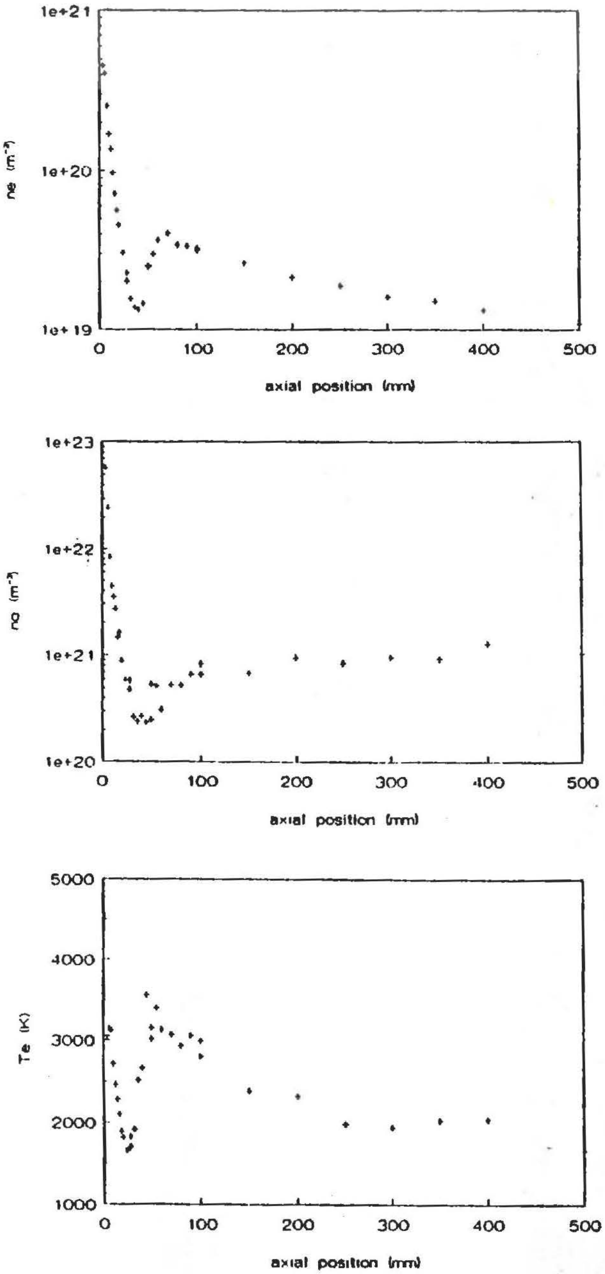

Figure 3 The electron and neutral density and the electron temperature on the axis of the plasma jet for $I=45$ A, $B=0$ T, flow=3500 ml/min, $p_{back}=0.3$ torr

calibration as a measure of the apparatus profile, deconvolution methods can be used in the least mean squares analysis to attain a higher accuracy (for n_e 2–5%, for n_0 10–50% and for T_e 2–6% depending on the conditions). Figure 2 shows a measured profile vs. the pixel position together with the least mean square fit, consisting of a gaussian,representing the Thomson component, convoluted with the apparatus profile and a scaled apparatus profile to account for the Rayleigh component. The measured profile is corrected for the dark current of the detector and for the plasmalight. The residue is also shown on the same scale. Because the analysis takes into account the structure of apparatus profile a very large dynamic range is attained (for T_e: 2000–50000 K, for n_e: $7\cdot10^{17}$–10^{21} m^{-3} and for n_0: 10^{20}–$1.5\cdot10^{23}$ m^{-3}). This is necessary for two reasons. First the density gradients in expanding plasmas are large and can amount to density variations of three orders of magnitude. Second going from the situation without to with an applied magnetic field the electron temperature varies in the most extreme case one order of magnitude. Another aspect of the set up is the low stray light level of 0.02 torr Argon, resulting in a detection limit of 10^{20} m^{-3} for the neutrals and $7\cdot10^{17}$ m^{-3} for electrons both with an accuracy of 50%.

Using the set up several conditions are measured for different current, flow and magnetic field. A typical measurement is shown in figs. 1 of n_e, n_0, and T_e on the axis of the plasma jet vs. axial position. The occurrence of the shock wave is clearly seen in all the three pictures although the position of the temperature shock is different from the density shock. This is probably due to current generation caused by the large pressure gradient. More measurements will be presented both in axial as in radial sense and the influence of the conditions on the structure and position of the shock wave will be analyzed.

[1] J. Sheffield, Plasma Scattering of Electromagnetic Radiation, Academic press, New York, 1975.