Effects of Plasma Compression in JT60-U

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1. ABSTRACT

The compression experiments described here have been aimed at increasing plasma performances. The adiabatic compression has the advantage of relatively simple physical process, in JT-60U compressional speed to make a compression experiment was available, but not the flux control to make an adiabatic compression. The compression time was 100-150ms. Before compression the plasma volume was 75-78m^3. The compressed volume was 35-40m^3. The effects on the plasma parameters were:

1) In an ohmic plasma discharge the plasma energy increases and the neutron production doubles during the compression.
2) With NB heating the neutron rate doubles, whilst the plasma stored energy increases by 25%. The increase in neutron rate depends on the increase of both ion and electron temperatures. The post compression values of the neutron rate increase approximately with the square of the injection power.

2. INTRODUCTION

The technique of plasma compression was devised for increasing the plasma performances in which the compressional work is somewhat equivalent to that of additional heating. In the adiabatic compression the poloidal and toroidal fluxes are conserved and the plasma is subjected to only mechanical work [1,2]. The adiabatic compression, studied in the pioneering work by Furth and Yoshikawa in 1970 [3], besides its conceptual simplicity, requires constraints on the poloidal circuit. For example, in the case of a radial compression, the inductive coupling between the equilibrium coil and the plasma causes an injection of flux in the plasma, which must be counterbalanced by changing (reducing) the current in the primary coil. This operation, easy in small size tokamaks, requires values of voltages which in larger tokamaks, may become non-practical. In JET and JT-60U it is possible to have available compressisonal speed to make a compression experiment. Some effects were reported in JET [4]. In the case of divertor configuration as in the case of JT-60U a combination of radial compression and reduction of the plasma volume by moving the X-point position further into the vacuum vessel, by increasing the current in the divertor coil, was achieved.

are shown in Fig. 4. The plasma control quantities are similar to those shown in Fig. 3. With constant NB power the neutron source increased and the plasma stored energy also increased by ~ 2MJ in ~ 50ms. The compressed plasma often underwent H-mode transitions such as shown by the D_α at 5.18s.

In Fig. 5 three ion temperature radial profiles, taken during the compression, are shown. The increase in ion temperature took place over the whole cross section. The increase in neutron production, achieved with compression, plotted against NB power is shown in Fig. 6. In this figure the values of the neutron rate before and after the compression are reported with a time interval of 100-150ms. On average plasma compression increased neutron production by approximately a factor of two. The post compression values increase approximately with the square of the injection power.

During the compression the plasma current profile changed. The time evolution of the internal inductance was measured for a series of plasma discharges. Although there are probably large error bars in the determination of the internal inductance, the time evolution showed that the internal inductance increased sharply during compression (from li = 0.9 up to li = 1.7) and then relaxed with resistive timescale (to li = 1.0). Under extreme conditions quasi stationary modes and disruptions developed.

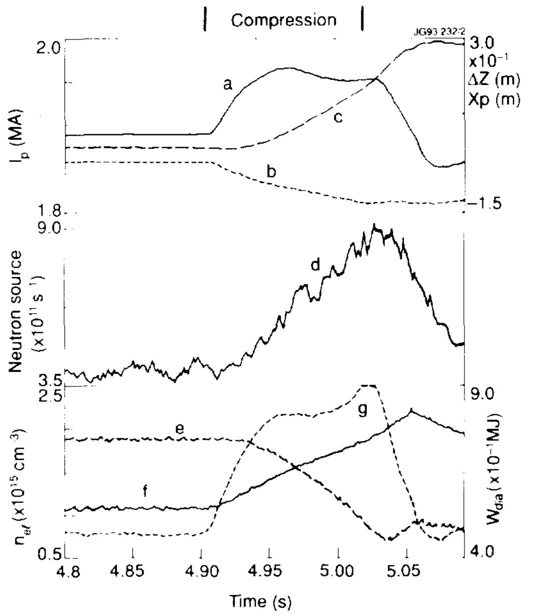

Fig. 3: Time evolution of plasma quantities during compression of an ohmic discharge: a) Plasma current, b) and c) Vertical plasma position and position of the X-point. d) Neutron rate, e) and f) Line density of the two interferometer channels, g) Plasma stored energy.

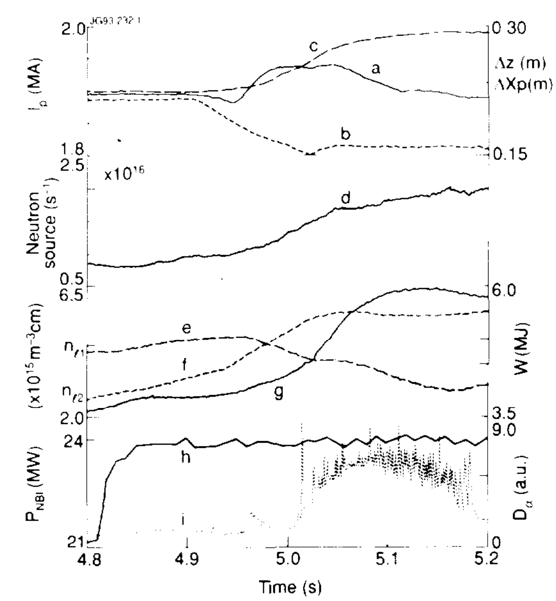

Fig. 4: Time evolution of plasma quantities during compression of a discharge with additional heating: a) Plasma current, b) and c) Vertical plasma position and position of the X-point, d) Neutron rate, e) and f) Line density of the two interferometer channels, g) Plasma stored energy, h) NB injected total power, i) Intensity of D_α light in the X-point region.

3. PLASMA CONTROL DURING COMPRESSION

The flux plots of the initial and final configurations are shown in Fig. 1, the plasma volume was reduced from 75-78m^3 to 35-40m^3, the plasma magnetic axis moved from R = 3.4m to R = 3.0m, (major radius compression). The value of the plasma current was kept constant by the feedback system, it increased by only 20-40kA in a fast transient. Due to the increase of plasma elongation and of the toroidal field, caused by the radial movement, q_{eff} decreased only moderately, from 6-7, to values of the order of 5. The small compressed plasma was more vertically unstable than the initial one, due to the reduced vessel shell effect

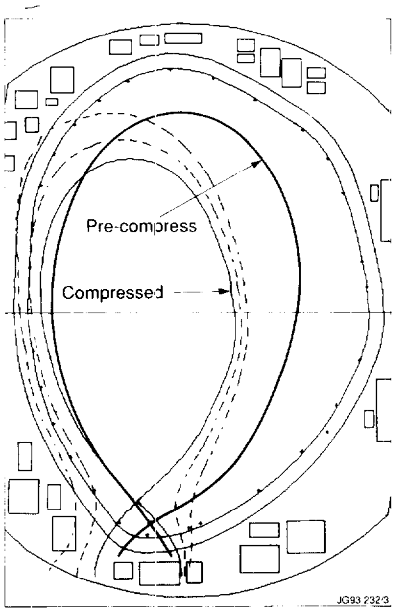

Fig. 1: Poloidal flux plot of the plasma before and after compression, plasma current = 1.9MA.

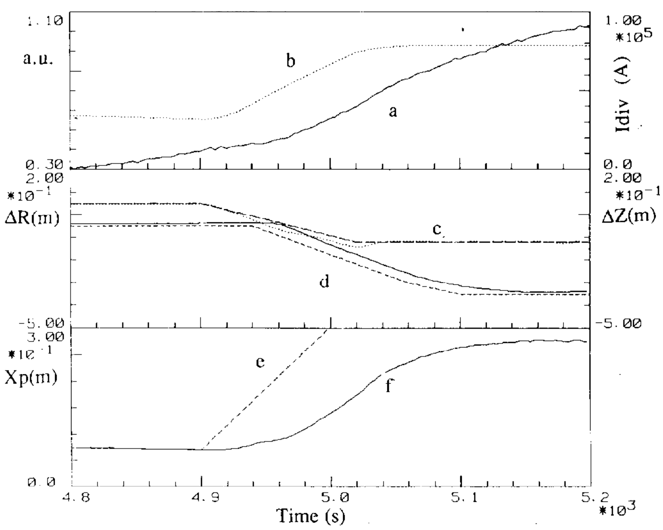

Fig. 2: Time evolution of the control signals and coil currents. a) Intensity of soft X-ray central channel, b) Divertor coil current, c) vertical displacement, d) radial displacement, e) requested X-point position, f) X-point position.

and the larger elongation, requiring adjustment in the control of the vertical position. A vertical instability occurred in one of the plasma discharges. The time evolution of the coil and control currents is shown in Fig. 2.

4. COMPRESSION OF OHMIC PLASMAS

The effects of compression on an ohmic plasma are shown in Fig. 3. The X-point vessel distance is increased to 0.3m while the magnetic plasma axis is lowered by ~ 0.14m. The neutron rate increased sharply from 3.5 to 8.5 10^{11} n/s^{-1} and the plasma stored energy, from 450 to 900 kJ. The total number of electrons in the plasma was approximately constant. The outer interferometric channel (line e in fig. 3) crossed most of the plasma cross section before compression, whilst the inner one line (line f in fig 3) crossed most of the plasma cross section after the compression. D_α measurements confirmed that only a modest outflux of particles took place. The time evolution of the main plasma quantities in a NB heated plasma

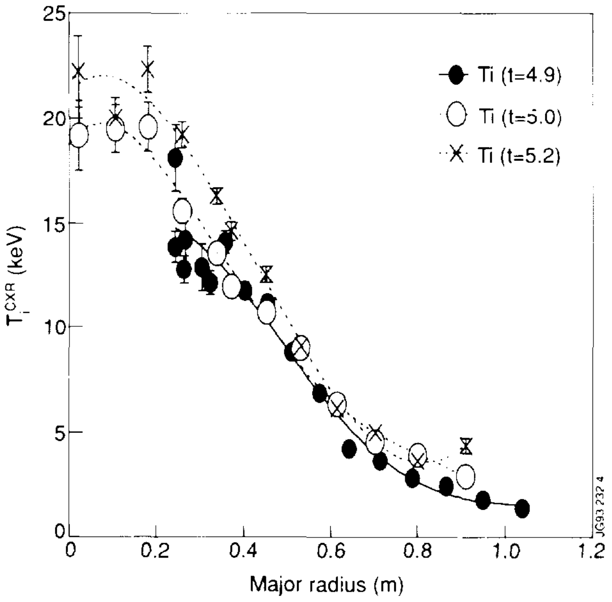

Fig. 5: Ion temperature radial profiles: a) Before compression, b) After compression.

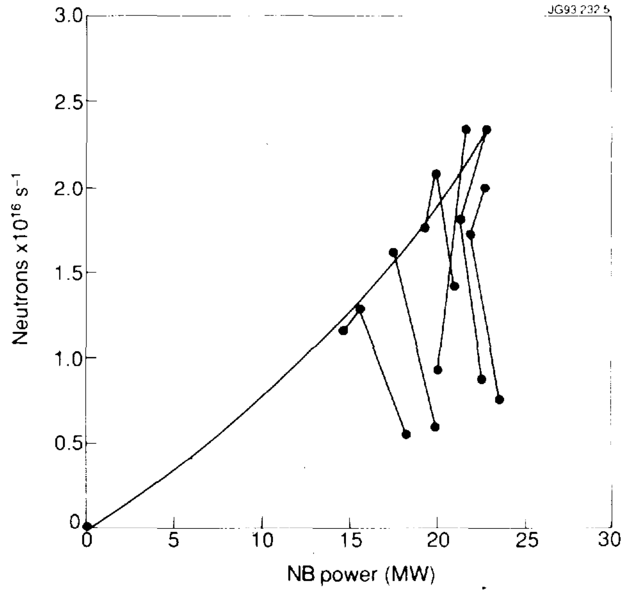

Fig. 6: Neutron rate before and after compression plotted versus NB power. The starting lower points were taken just before compression, the second points are 150-250ms later, the last points were taken at the maximum value achieved in the same discharge. In four cases the maximum neutron rate was achieved at the compression.

5. CONCLUSIONS

The compression results show that with non adiabatic compression there is a strong increase of stored energy and neutron production. This is a reflection of the fact that the compression is broadly equivalent to a power input in the ten megawatt region. Complete energy transport analysis is still outstanding. There is evidence that in the strong volume reduction much of the plasma particles are retained, indicating that there is a poloidal compression effect, with increase of plasma density and temperature. It could be a useful for producing and for studying thermonuclear plasmas. In non adiabatic compression, the plasma current profile is changed during and after the compression which may become unstable, but it could be also a useful technique to explore plasmas with different current profiles.

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