TOKOLOSHE: A LOW ASPECT RATIO TOKAMAK

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Abstract

A brief description is given of Tokoloshe, a new low aspect ratio tokamak, which has recently become operational. Some preliminary results are presented.

1. Introduction

Tokoloshe is a medium sized Tokamak intended for the study of electron energy containment and MHD equilibria of low aspect ratio plasmas. It has been designed to operate with circular and non-circular cross-section plasmas (ellipses and D shapes) and with variable cross-sectional area.

2. Machine description

The design parameters of Tokoloshe are shown in TABLE I. There are 16 toroidal field coils of Bitter design which produce a field of 1.5 T on axis, at the peak design current of 30 kA. The maximum toroidal field ripple is 2%. This field should allow stable operation with plasma currents up to 200 kA for $q \approx 2.5$ at the limiter and $R/a = 2$. A series resistor allows for four discrete values of the operating field.

The low aspect ratio of the machine dictated an air cored ohmic heating transformer. This has sufficient volt seconds for current pulses of duration 50 msec at the peak current of 200 kA. The maximum voltage during breakdown can be varied down to 40 V. The stray field in the vacuum chamber due to the ohmic heating field is less than 20 gauss over half the cross sectional area of the chamber during the breakdown phase. At present either no preionisation or a hot wire preioniser is used.

There is no copper shell for equilibrium. The 3 mm thick stainless steel vacuum chamber slows down plasma motion, but gross equilibrium must be provided by a set of external windings carrying currents of up to 10 kA. The winding configuration can be altered by external tap changing to select the required plasma cross section, circular, elliptical or "D" shaped. A programable thyristor rectifier supplies the required coil current.

The vacuum chamber is normally pumped to a base pressure of 8×10^{-8} torr before continuous pumping with hydrogen to a working pressure of $\geq 1.4 \times 10^{-4}$ torr. Both Taylor [1] and glow discharge cleaning [2] methods have been used. The former method uses a 0.03 T toroidal field with 20 kA current pulses of a few msec duration at half second intervals. For the glow discharge, an anode was inserted into an observation port, flush with the vacuum chamber wall. Typical continuous operating currents of 1 A were used. The adjustable stainless steel limiter allows operation at aspect ratios in the range 2 to 4. Additional protection of the chamber is provided by 4 circular bumpers, also constructed of stainless steel.

3. Diagnostics

The positions of the various diagnostics on the machine are shown in FIG. 1.

Total plasma current, vertical and horizontal column displacements and MHD oscillations are measured with a series of sin $n\theta$ and cos $n\theta$ coils (θ = poloidal angle). These are inserted in fast response ($\approx$ 30 kHz) thin walled tubes mounted on the inner vacuum chamber wall at three azimuthal positions.

Electron temperature and relative electron density measurements are made with a standard 90° Thomson scattering system using a 20 J, 1 GW, single pulse ruby laser. The scattered spectrum is recorded with a 10 channel photomultiplier system on a 0.5 m grating spectrometer. A stepping motor control system allows horizontal and vertical scans of the plasma to be performed.

Soft X-ray spectroscopy is done with a Si(Li) detector and an analogue-to-digital convertor controlled by an interface unit, which enables temporal and energy dependences of the observed flux to be recorded. The whole system can be tilted to view along different chords of the plasma. A similar system with a NaI detector is used for hard X-ray spectroscopy.

Line averaged electron densities are measured with a single channel 0.337 mm HCN laser interferometer of 10 mW power. This system can also scan in the radial direction.

The ion temperature is deduced from the measured energy distribution of the charge exchanged neutrals coming from the plasma. The plates of the electrostatic analyser are driven by a saw tooth voltage of variable amplitude and frequency allowing temporal as well as energy distributions to be measured.

4. Data Acquisition and Machine Control

Data acquisition, machine control and monitoring between shots are done by a single computer, interfaced to the experiment with a standard CAMAC system. A few hundred status sensing lines are provided for monitoring purposes, while output is effected through a number of multi-channel switch registers. Most analogue signals are multiplexed to fast analogue-to-digital convertors for digitisation and storage in buffer memories for later retrieval. The time resolution can be varied down to a few microseconds. Special units were designed to allow particular options through pre-programming on some diagnostic systems.

Dedicated machine control during a discharge sequence, which lasts roughly 3 seconds, is achieved through flexible microcoded computer instructions. These instructions allow for dynamic decision making and have a basic time resolution of 100 μs. User access to the functions of machine control and data acquisition, as well as preliminary data reduction and final production of either graphical or alpha numerical hardcopy, is done by means of a software control file which is easily edited to suit requirements. The entire system is optimized to allow a discharge every 90 seconds.

5. Results

To date, the machine has been successfully operated at plasma currents in excess of 100 kA at toroidal fields of 0.9 T. A typical shot with a peak plasma current of 90 kA is shown in FIG. 2. About 3.0 V of the total measured loop voltage of 4.5 V is resistive. The initial decay of current is due to insufficient compensation by the ohmic heating coil for resistive losses. Towards the end of the pulse the column can be seen to move slowly inwards leading ultimately to interaction with the limiter, a rapid loss of current and hard X-ray production.

Some difficulty has been experienced in avoiding persistent runaway discharges (FIG. 3) which are characterised by very low loop voltages (≈ 0 V) and copious hard X-ray production (up to 2 MeV). The runaway discharge is believed to originate near the inner wall of the vacuum chamber. Poor containment leads to very large excursions (≈ 40 cm) of the channel before it interacts with the outer limiter. Preliminary measurements confirm that the plasma in these discharges is rather tenuous ($\bar{n}_e \leq 6 \times 10^{12}$ cm^{-3}) and cool ($T_e \leq 100$ eV) as is normally observed [3]. The problem of runaway discharges may be worsened by the low aspect ratio of this machine.

Present efforts are aimed at avoiding this runaway regime through more careful wall preparation, gas puffing and additional pre-ionisation.

REFERENCES

[1] OREN, L., TAYLOR, R.J., Nucl. Fusion 17 (1977) 1143.

[2] DYLLA, H.F., A Review of the Wall Problem and Conditioning Techniques for Tokamaks, Princeton Plasma Physics Lab. Report PPPL-1666 (1980).

[3] SWAIN, D.W., ZWEBEN, S.J., Nucl. Fusion 20 (1980) 711.

TABLE I. Design Specifications of Tokoloshe		
Plasma Parameters:		
major radius	0,52 m	
minor radius	0,13-0,26 m	
shape	circular, D, ellipse (ε = 1.5)	
maximum current	≈ 200 kA	
pulse duration	≈ 50 ms	
Vacuum:		
turbomolecular pumps	2 x 450 ℓs^{-1}	
titanium sublimation pumps	2 x 2400 ℓs^{-1}	
base vacuum	8 x 10^{-8} torr	
Toroidal Magnetic Field:		
number of windings	126	
maximum current	30 kA	
pulse length	2 s	
maximum field (on axis)	1.5 T	
maximum field ripple	2%	
Ohmic Heating Transformer:		
number of windings	158	
maximum current	10 kA	
maximum flux	0,45 V s	
Equilibrium Field:		
number of windings	44	
maximum current	10 kA	
Power Supplies:		
ohmic heating	1500 V	10 kA
toroidal field	350 V	30 kA

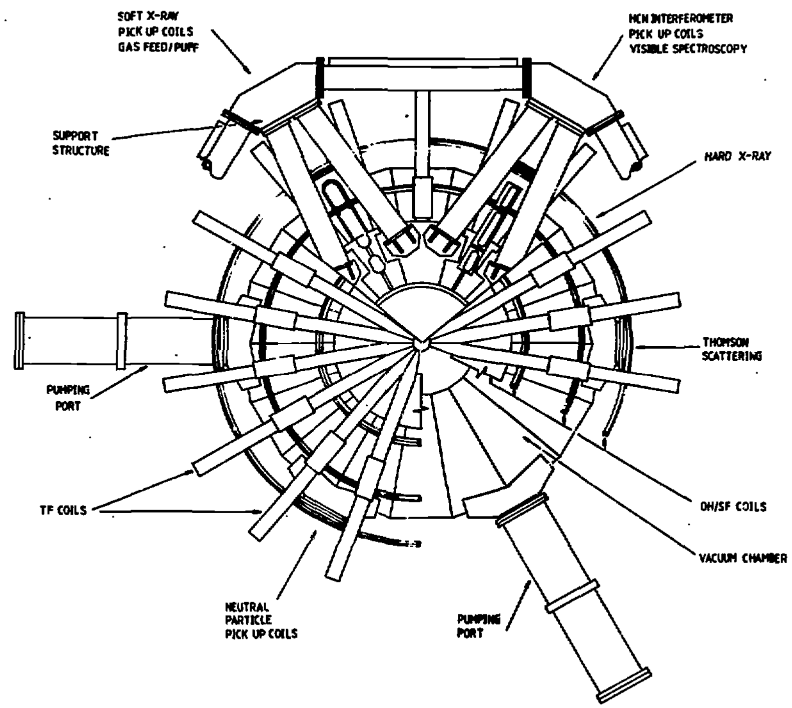

FIG. 1. Layout of machine and diagnostics

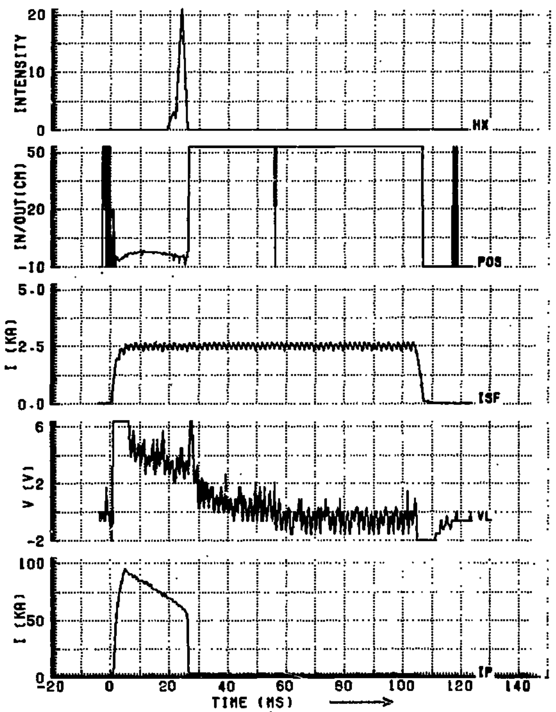

FIG. 2. Some typical data for a Tokamak discharge. The traces from top to bottom are hard X-ray flux (HX), horizontal position (POS), shaping field current (ISF), loop voltage (VL) and plasma current (IP).

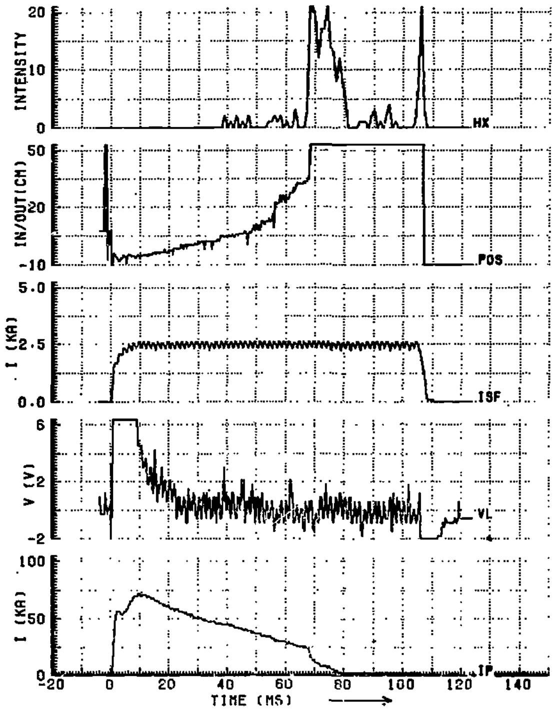

FIG. 3. Some typical data for a runaway discharge.