CLM - P 432

CLM - P 432

E MINIMIS MAXIMA

UKAEA RESEARCH GROUP

Preprint

EMPIRICAL TOKAMAK SCALING

J HUGILL

CULHAM LABORATORY
Abingdon Oxfordshire
1975

CLM-P 432

EMPIRICAL TOKAMAK SCALING

J. Hugill

Culham Laboratory, Abingdon, Oxon, OX14 3DB, UK
(Euratom/UKAEA Fusion Association)

A B S T R A C T

Data from various experiments are fitted to three types of empirical scaling laws, for which τ_E varies as a^2, a or a^0. The results are used to predict the performance of future large tokamaks.

(Paper for presentation at the Seventh European Conference on Controlled Fusion and Plasma Physics, Lausanne, 1-5 Sept. 1975)

August 1975

Symbols R = major radius (m), a = limiter radius (m), I = plasma current (A), q_a, q_o = safety factors at limiter and magnetic axis, n_e, n_i = mean electron and ion densities (m^{-3}), T_e, T_i = mean electron and ion temperatures (eV), V_R = resistive loop voltage (V), β_θ = poloidal beta, τ_E = plasma energy/input power (s), B_φ = toroidal field (T), Z_{eff} = effective ion charge.

Introduction This paper attempts to predict the performance of future large tokamaks by using empirical expressions derived from the data of present experiments (Table I). Attention is restricted to hydrogen discharges, for which there was no large anomalous resistance due to turbulence. The implicit assumption is that the physics of the discharge will be unchanged in larger devices; a big assumption. However, no specific physical models are assumed, a priori.

The two basic parameters of interest are the plasma pressure which can be sustained by ohmic heating alone, and τ_E. The latter allows an estimate of the additional heating required to reach a specified condition.

Effect of Varying q_a q_a is an independent variable, but q_o tends to be near unity. The ratio determines the basic geometry of the discharge. It has been found on T3 and T4(1), and, more recently on TFR(16), that τ_E increases as q_a increases up to

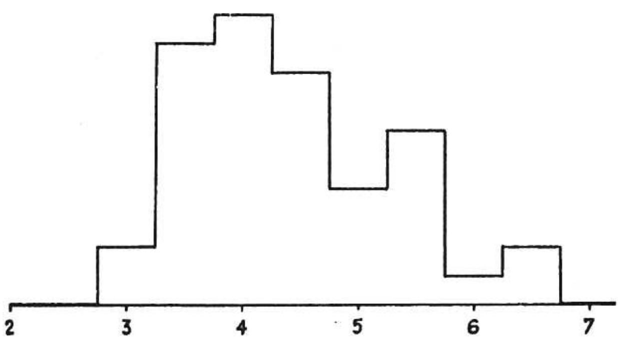

Fig. 1. Histogram of q_a.

~ 6, then remains constant. Conversely, when $q_a \leqslant 2$, τ_E decreases sharply and large disruptive instabilities are seen. For 90% of the data analysed here $3 < q_a < 5.5$, as shown in Fig. 1, a value which gives optimum plasma parameters for a given B_φ. In this sense, q_a is not a proper independent parameter.

Effect of Varying n Many experiments of moderate size now show that τ_E, β_θ vary as n_e^{α}, where $\alpha \sim 0.4$ in the early Russian experiments (1), to ~ 0.8 in ST (5), and 1.0 in Ormak (12) and Alcator (18). This implies the amount of plasma in the discharge does not have a big effect on the energy loss rate, or on T_e. It confirms the idea that particle balance and energy balance are controlled by nearly independent processes. In some experiments (14,16) n_e increases linearly with I, possibly due to plasma-wall interaction.

Scaling with I and a It is difficult to disentangle the effects of increasing I and a independently, since larger experiments tend to run higher current discharges. In any case, the range of a is limited to a factor ~ 3. Therefore, three possible types of scaling are tested, for which τ_E varies approximately as a^2(A), a(B) or a^0(C). We always have $\tau_E = 3\mu_o IR\beta_\theta/8V_R$, so a knowledge of V_R, or the plasma conductivity, is sufficient to relate τ_E and β_θ. It is remarkable that 95% of the data points considered have $2 < V_R < 4$, but it is not possible to distinguish the constancy of V_R from that of V_R/R.

Type A was first suggested by workers on TM3 and T3 in the form

$$\tau_E \sim a^2 n_e^{0.3} B_\theta \sim a\, n_e^{0.3} I.$$

A test of this scaling is shown in Fig. 2. It does not look very convincing, and the corresponding scaling for $\beta_\theta \sim n_e^{0.4} I^{-0.3}$ predicts a plasma resistivity lower than classical for large devices. The mean value of τ_E/aI is $\sim 5 \times 10^{-7}$ ($sm^{-1} A^{-1}$).

Type B is illustrated in Fig. 3. 85% of the data is within a factor of 2 of the expression $\tau_E = 8 \times 10^{-25} n_e I^{\frac{1}{2}}$, though a higher exponent for I, up to about 1, would fit the data equally well.

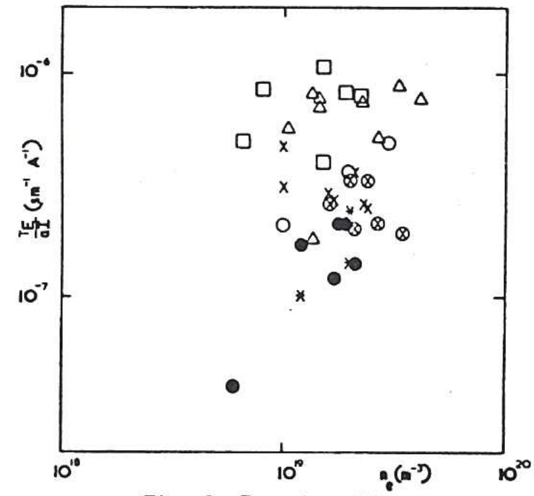

Fig. 2. Type A scaling.

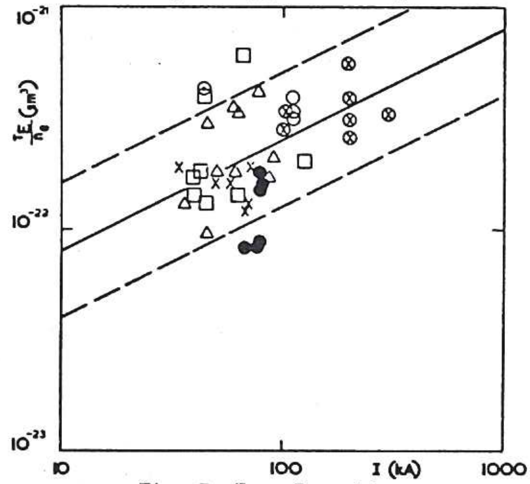

Fig. 3. Type B scaling.

Type C is illustrated in Fig. 4. The data fits the expression $T = T_e + (n_i/n_e)\, T_i = 1700$ [mean ohmic power density (MW/m^{-3})]$^{\frac{1}{2}}$
which leads to

$$\tau_E = 10^{-23}\, n_e\, T^{\frac{1}{2}}.$$

This expression is similar to that suggested by recent results in Alcator (18), and also agrees with the scaling found on ATC (11), in the form $\beta_\theta/n_e\, Z_{eff}^{\frac{1}{2}} = 5.8 \times 10^{-18}/I$, if $Z_{eff} = (T/T_\sigma)^{3/2}$.

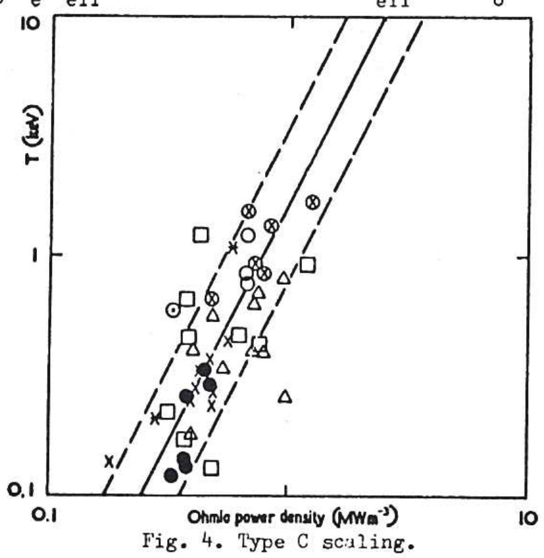

Fig. 4. Type C scaling.

Table II shows the results of applying the three types of scaling to PLT (Princeton Large Tours) and JET (Joint European Torus), assuming $Z_{eff} = 4$.

Conclusions There is presently insufficient data to choose between scalings for type B or C, but type A looks improbable. Type C scaling favours the high field, high current density type of experiment.

References

1. E.P. Gorbunov et al, Nuclear Fusion 10, (1970), 43.
2. A.M. Anashin et al, JETP 33, (1971) 1127/Zh ETF 60, (1971) 2092.
3. L.A. Artsimovich et al, Nuclear Fusion Special Supplement (1972) 41.
4. V.V. Afrosimov et al, JETP Letts 18, (1973) 300/Zh ETF Pis, Red. 18, (1973) 510.
5. Princeton Plasma Physics Laboratory Report MATT Q29 (1972) 14-19.
6. D.L. Dimock et al, Princeton PPL Report MATT-906 (1972).
7. W. Stodiek 5th Conf. on Controlled Fusion and Plasma Physics, Grenoble, Vol II (1972) 1.
8. E. Hinnov et al, 3rd Int. Symp. on Toroidal Plasma Confinement, Garching Paper B13 (1973)
9. D.L. Dimock et al, Plasma Phys. and Controlled Nuclear Fusion Research I (1971) 451.
10. Princeton Plasma Physics Laboratory Report MATT Q30 (1973) 21.
11. P.E. Stott et al, submitted to Nuclear Fusion (1975).
12. L.A. Berry et al, Proceedings of the Toyko Conference IAEA-CN-33/A5-1 (1974).
13. G.G. Kelley et al, 3rd Int. Symp. on Toroidal Confinement, Garching Paper B3-I (1973).
14. J.G. Cordey et al, Culham Laboratory Preprint CLM-P 407 (1974).
15. T.F.R. Group, 6th Conf. on Controlled Fusion and Plasma Physics, Moscow, Vol II (1973) 20.
16. P. Lecoustey, J.P.Girard, Private communications (1974, 1975).
17. O. Klüber, Private communication (1974).
18. B. Montgomery, B. Coppi, Private communications (1974, 1975).