Historical Background to Stellarators at the Australian National University

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TOKAMAKS 1964-1984

Toroidal plasma studies started at ANU in the Research School of Physical Sciences (under the late Bruce Liley) in 1964 with a versatile, capacitor-bank-powered apparatus known eventually as LT-3. This had a high-resistivity (Inconel) toroidal vacuum vessel, major radius 40 cm, minor 10 cm, inside a 10mm-thick copper shell (to provide equilibrium and gross stability) upon which were wound close-fitting toroidal-field windings. Ohmic heating plasma currents induced via an iron core provided the poloidal field, the arrangement being termed a "θ-z pinch" apparatus since it could operate over a wide range of toroidal to poloidal magnetic field ratios, i.e., from q << 1 to q >> 1. It soon showed better results when the toroidal field rather than the poloidal was dominant to form the "diffuse pinch" configuration with q > 1 rather than a Zeta-like compressed pinch with q << 1, ie as a tokamak. This independently established the only line of tokamak research outside USSR until the Dubna meeting of 1969 led to its global spread.

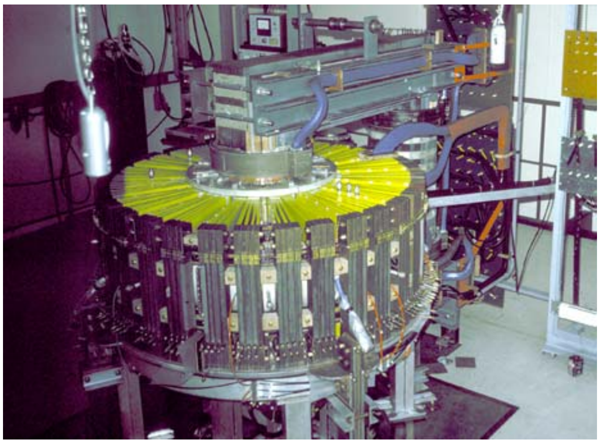

Figure 1. LT-4 Tokamak

Despite modest resources LT-3 produced pioneering results eg on the significance of rational q-values and their relation to MHD modes and to disruptions, runaway phenomena, the "Ware pinch" phenomenon, etc

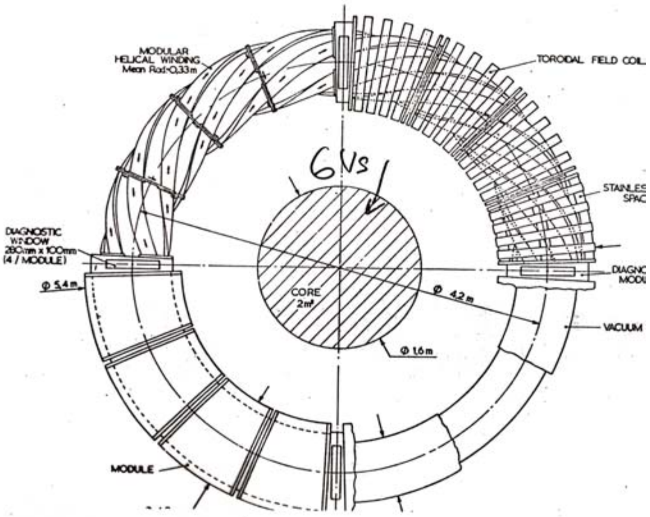

Fig. 2. Layout of Large Modular Stellarator

In the late '70s this was replaced by a more "modern" tokamak LT-4, (R=50cm, a=10 cm) with greatly improved diagnostic access, a stronger and extremely smooth toroidal field (B=4 T) provided by the very large homopolar generator, very fast penetration toroidal shell with poloidal windings for equilibrium, and an unusually fast-responding position feed-back control. A full range of up-to-date diagnostics and data acquisition facilities were installed. Typical operating conditions were : B=3T, I=100kA for 100ms, T(e)=300eV. Studies concentrated on MHD phenonena, disruptions, runaways, novel diagnostic development eg using scintillations of 10 micron radiation to measure small-scale turbulent fluctuations. Observations of disruptions were greatly aided by the ability of the feedback control to maintain plasma position during even large disruptions and so allow internal plasma structure to be studied throughout the process.

STELLARATORS 1978-PRESENT

The availability of the large homopolar generator, with its high current (~MA) capability led to design studies to attempt to tackle some of the main engineering problems facing stellarators evident in the late '70s,(eg the modularity needed for a reactor, helical winding support at high fields as shown by problems in W-VII, optimisation of plasma volume inside winding space) by using large cross-section single-conductor techniques for

Fig. 3. Model of single LMS module.

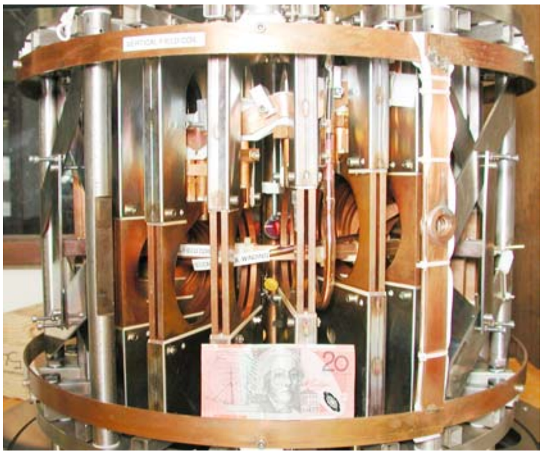

Fig. 4. The SHEILA device

winding fabrication. A design emerged based on the concept of combining toroidal and l=3 helical winding elements into self-supporting, cage-like modular structures using large cross-section forged copper-alloy conductors. A series of computational studies were used to find, by numerical iteration, the optimal winding law to provide the greatest plasma volume, largest rotational transform, best magnetic well properties, etc. The final design had parameters : $B < 4T$, $R = 3.1$ m, $\langle a \rangle = 0.34$ m, $\iota(a) > 0.6$, $\iota(0) = 0.2$. Fortunately, it was never built! Later and more sophisticated computational techniques developed at Garching provided much more elegant solutions to the above.engineering problems.

The planned closure of the homopolar generator in the early '80s, future reliance on capacitor bank power supplies and a limited mains supply (10 MVA) meant the abandonment of the tokamak line, and the need for a new and forward-looking approach to toroidal studies, based on available resources, concentrating on fundamentals rather than parameters. The hitherto untried suggestion at the 1982 Cape May Workshop by Princeton of the heliac was attractive because it avoided the need for highly stressed helical windings, and resulted in the construction of the table-top device SHEILA ($R = 19$ cm, $\langle a \rangle \sim 3$ cm) intended to test the principle, since there was some doubt whether useful closed surfaces could even be generated in such an unusual system. Soon after its first operation in 1984 it was modified to incorporate the helical control winding as proposed by the ORNL group and demonstrated the great versatility and ease of operation of the flexible heliac. Despite its modest initial aims, it not only verified in great detail every feature of the computed vacuum fields, including the effects of positional errors, but proved sufficiently versatile to enable detailed studies of drift waves, effects of islands on confinement, RF and ECRF heating, etc and to give practical experience of working in an unfamiliar (PEST) coordinate system. Altogether it confirmed the value of the heliac as a desirable and flexible research tool and led to the choice of H-1 as the basis for the Laboratory's future toroidal confinement studies.

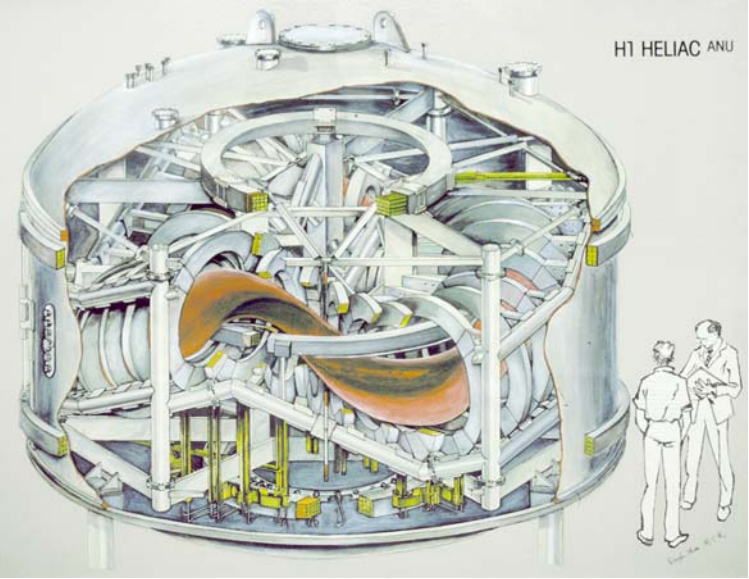

Fig. 5. Cut-away drawing of the H-1 heliac

H-1 was designed around the available resources, including existing copper conductor stocks (originally intended for a synchrotron), machine tools, power supplies, local skills and laboratory access. The "coils-in-tank" design avoided complex vacuum vessel fabrication and provided great plasma access at the expense of vacuum difficulties. Apart from the main fabrication of the vacuum tank, all construction was performed in-house at a rate constrained by budgets. First plasma was obtained in 1992.