INTERNATIONAL ATOMIC ENERGY AGENCY
UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION
INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
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H4-SMR 393/60

SPRING COLLEGE ON PLASMA PHYSICS

15 May - 9 June 1989

Symposium on Third World Fusion Programmes
and South-North Collaboration

THE FISSIBILITY STUDY OF FISION-FUSION HYBRID REACTOR (NEUTRON FACTORY) IN CHINA

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The Fissibility Study of Fision -Fusion Hybrid Reactor(Neutron Factory) in China

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1. Why we should consider the Hybrid Reactor in China?

* China has the largest population in the world.
  The Economics grows very quickly.
  Thus, the energy demand will grow very fast!
* Though the Nonfissil-Fuel still will be the main energy source ,at least, in next 50 years, but:
  * The main Nonfissil Fuel will be the coal.
  * To fire 2-3 billion tons of coal in a narrow coast area, it lead to many un-soluvable problems.
  * We should develop our nuclear power .
* How to develop a large nuclear energy system, the electrical power should be at least near 10^{11} W.
  * We began to build PWR.
  * We have only limited Uranium resource. Therefore, it is necessary to consider to develop the technologies of breeder type reactor.
  * The technologies of the Fast Neutron Reactor have also just begun to develop in China.
  * The Plasma Physics knowleges and Fusion technologies, needed for Hybrid Reactor , mainly for producing fission fuel, seem to be well developed.

Thus, as the near-term application of fusion research, a program, for to develop the Hybrid Reactor for producing fission fuel in China, has begun to be carried out. It is the aim of recent five years to study the feassibility of building a Hybrid Reactor in the begining of the next century in China.

2. The Basic Requirements for HR(NF):

* For a HR(NF), the main parameter of the plasma core is the <u>production rate of fusion neutron</u> :

  $dN_n/dt = V_p * N_D * N_T * \langle \Sigma V \rangle$.

  For example, if the production rate of ^{239}Pu of a HR(NF) equals 1ton/year , then the fusion neutron production rate of the plasma core should be near 10^{20} n/s . Of course, the exact value depends on the detail design of the blanket, and that the operation cost should be reasonable.
* We needn't to consider the energe balance in plasma.
  Generally, the high temperature of the plasma core could to be

mantained by some extenal heating power. So the fusion driver is a passitive system, transforming the heating power into fusion neutrons.

The energe confinement time of the plasma could be much lower than the value for ignition condition, the only limitation is to ensure that the heating power which mantain the fusion temperature could be acceptable.

* The fission part of the HR(NF), blanket, could always be sub-critical, and thus, a passitive system.
  * The power density in blanket can be designed as low as acceptable by the existing technology .
  * The blanket can easily be fission-suppressed or partial fast-fissional.
  * The Tritium breeder region can be seperated from the fission region, and can be controled easily.
* NB. and ICRF heating can produce a high energy tail in ion distribution function, and thus, can increase the fusion reaction rate significantly.
  * The predicted high energy tail produced by NB and ICRF heating have been confirmed by experiments on different devices.
  * The enhenced D-D reaction rates by NB and ICRF also have been observed.
  * The parameters of existing Tokamaks are already near enough for fusion driver of an experimental HR(NF).
* Steady operation:
  * For economic consideration, it is necessary to use the superconductive toroidal coils.
  * To mantain the plasma current, the most promising way is LHCD. It is possible now, $f \sim 4$ GHz, $B_t \sim 4T$ and the density $n \sim 5*10^{13} cm^{-3}$, if $P_w \sim 10MW$ then drived current could be arrive $I_p \sim 1.5$ MA.

    There are other way to use LHCD.
  * We do not know the properties of the plasma with high power ICRF heating and LHCD.
* boundary control:
  * Except the engineering aspect, the only advantage of the plasma with non- circular cross-section is the possibility to form divotor .
  * It seems possible to arrive H mode operation of high power heating plasma with different boundary condition.
  * Very weak perturbation on the boundary layer can influence the global properties of the plasma seriously.

3. The Parameters of a Possible Experimental Hybrid Reactor:

$R = 3.5m$, $a = 0.8m$, $B_t = 4T/8.2T$, $V_p = 44.2\ m^2$,
$S_p = 110.5\ m^2$,

$n_e = 5*10^{13} cm^{-3}$, $T_i = T_e = 10$ kev, $q(a) = 2.5$
$I_p = 1.5$ MA,

$E_p = 7$ MJ, $t_e = 350$ ms, => $P_{ICRF} = 20$ MW,
LHCD: $I_p = 1.5$MA, Eff $= 0.15$ka/kW, => $P_{LH} = 10$MW,

If ICRF heating enhances D-T reaction rate for 10 times, then

$$dN_n/dt = 3*10^{19}\ n/s,$$

Neutron energy flux of the first wall:

$$P_n/S_p = 0.6\ MW/m^2,$$

The yield of ^{239}Pu: 200 kg/year.

The Blanket: total thickness 1m

* In Pb, Be and ^{238}U layer, fast neutron fission reaction and neutron mulpilification have been proceeded, and the energy of output neutron is less than 1 Mev.
  * ^{238}U layer is fission- suppressed, and mainly produce ^{239}U
    * ^{6}Li layer is T breeder.

  Bleeder material: $LiAlO_3$ and Li_2SiO_3,

  Tritiu carrier: He

  * B_4C layer : Reflection

Coolant: He

4 Program for fissibility study:

* *As part of National HyghTech Program directly Controled by the National Commission* of Science and Technology:

There is an expert committee for coordination;

there is a special budget for this program;

Different institutes have been involved:

Institute of Plasma Physics, Hefei,

Southwestern Institute of Physics, Leshen.

Institute of Applied Physics and computational Math., Beijing

Institute of Atomic Energy, Beijing;

Southwestern Institute of Nuclear Physics, Mianyang;

....

* *Program combines the Plasma Physics and Nuclear Technology* :

Reactor Conceptyre Design;

High Power ICRF Heating;

LH Wave Current Drive;

Particle Cycling, Pump Limiter and Pellet Injection;

Material Testing;

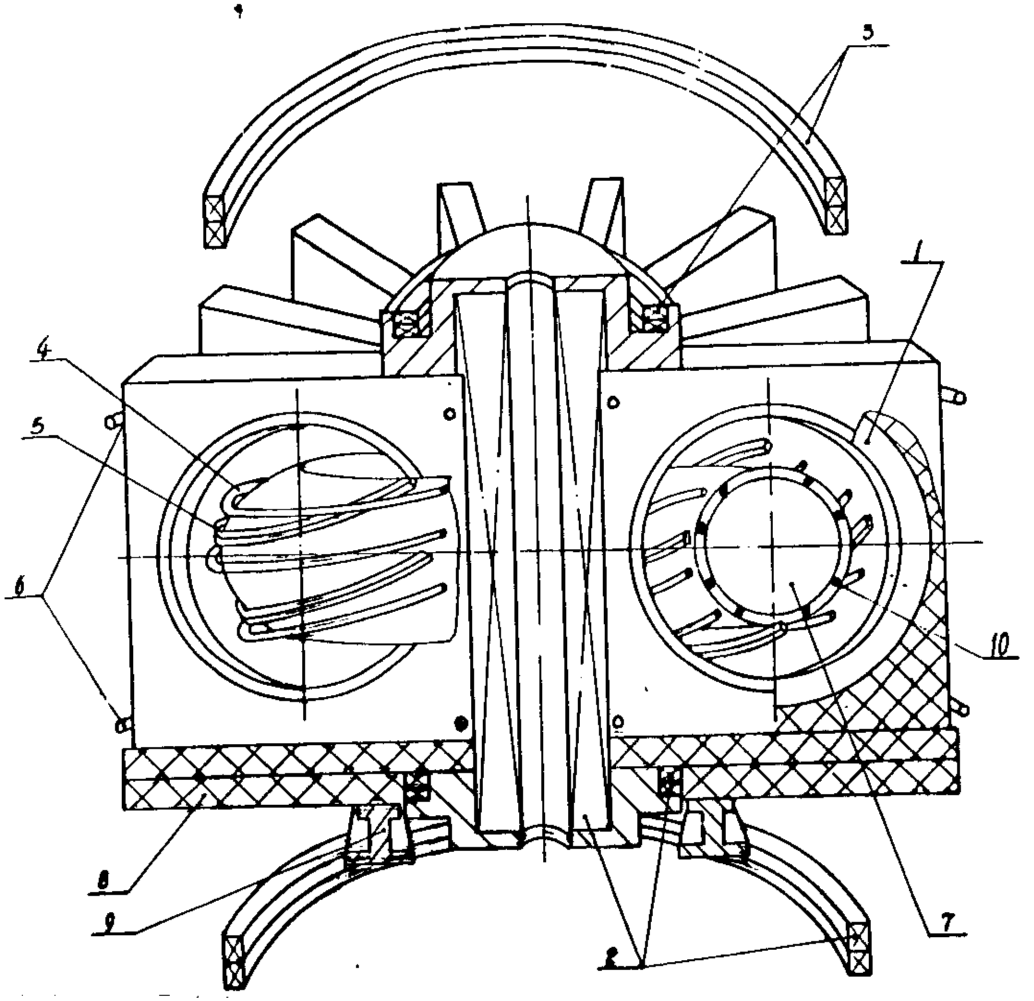
Tritium Technology.

reveal more and more properties of the plasma which still haven't been studied detailly.

Our Tokamak, Diagonostics system and data aquisition system should be the experimental devices to study the plasma behavior conveniently.

I will only report the experimental results which can reveal some new aspects of the properties of the Tokamak plasma.

The global structure of the MHD mode in Tokamak Plasma



1. Toroidal field coil.
2. OH transformer coils.
3. Programmable vertical field coils.
4. Helical wires l=3/n=1.
5. Helical wires l=2/n=1.
6. Horizontal field wires.
7. Vacuum vessel.
8. Bottom supporting plate.
9. Guides.
10. Feed back vertical field coils.

FIG.1. Schamatic view of HT - 6B tokamak.

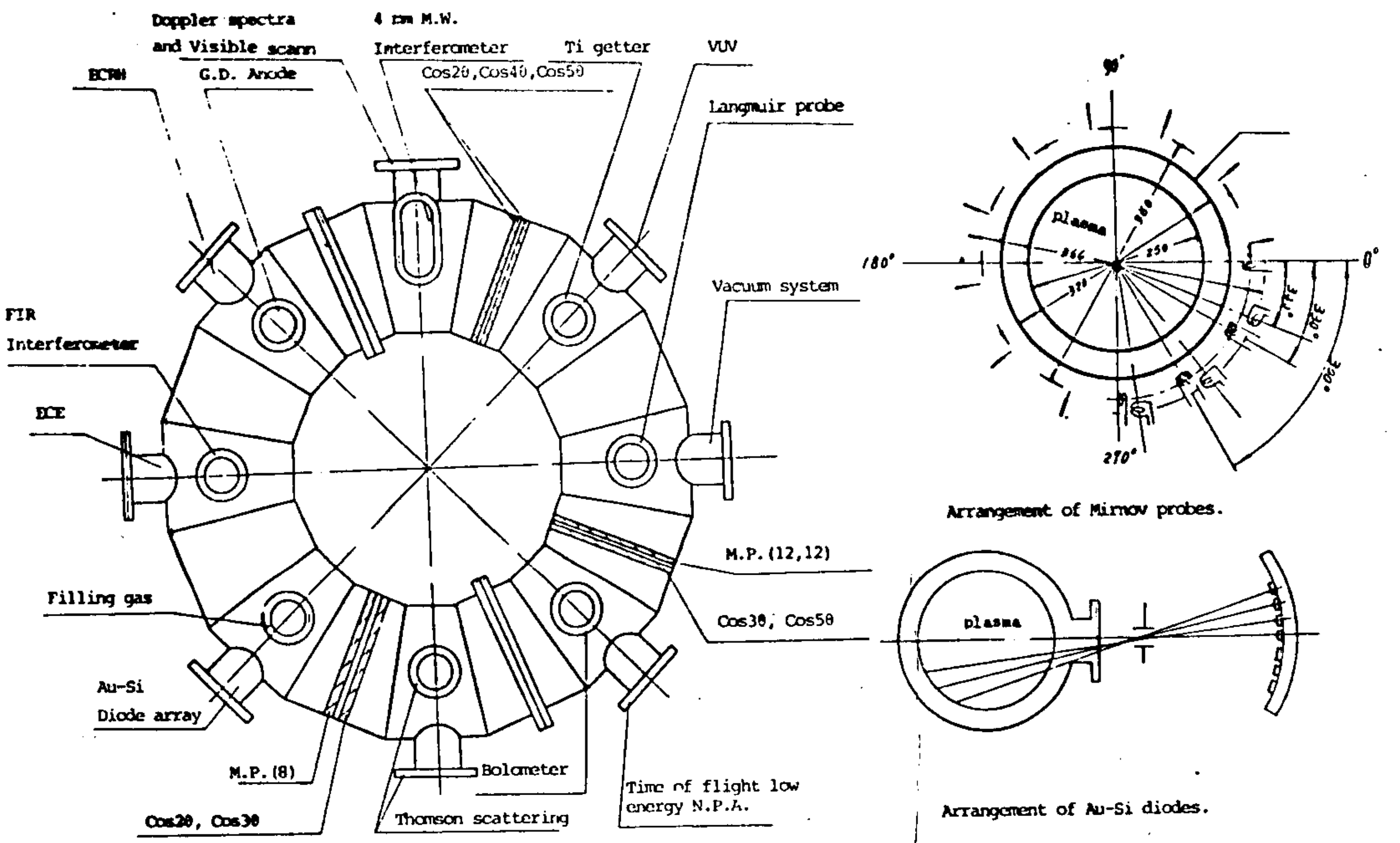


FIG.2. Diagnos cs of HT-6B tokamak

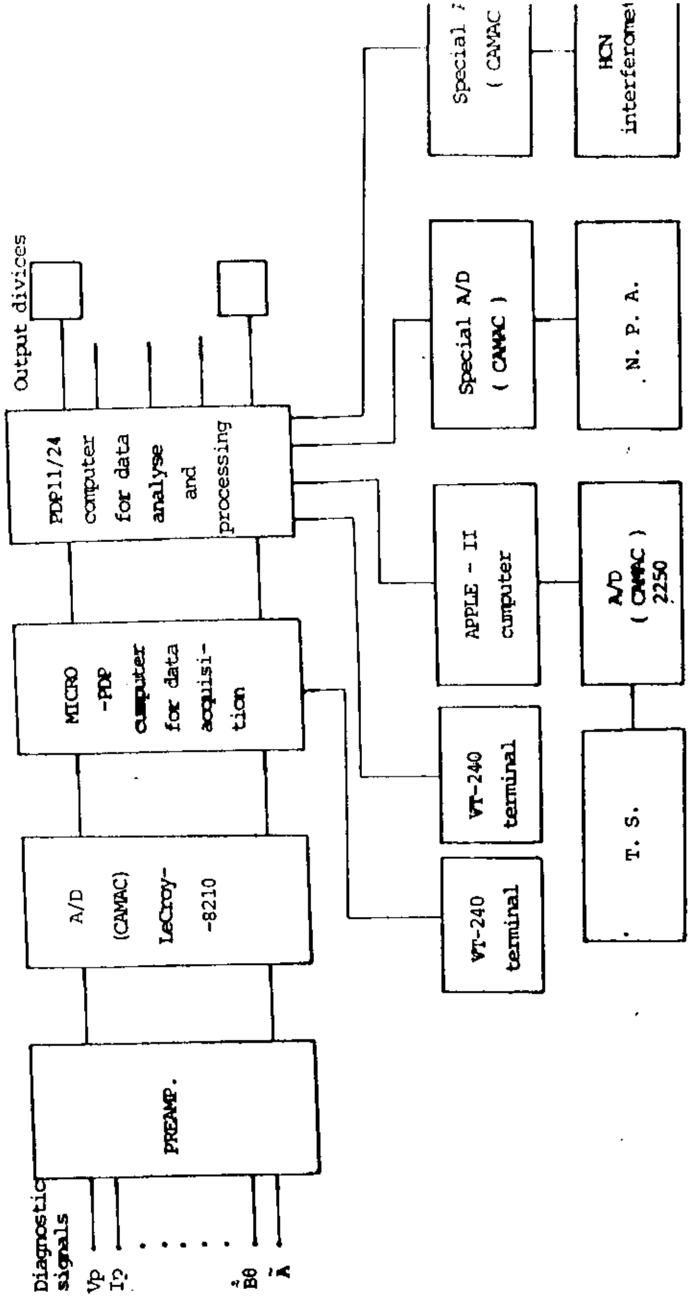


FIG.3. Block diagram of data acquisition system for RHF experiments on HT - 6B.

Global Structure of the MHD Mode in Tokamak Plasma.

1) There are two helical windings(L=2/n=1 and L=3/n=1) installed on HT-6B Tokamak.

The side-band components were less than 15% of the total value.

The helical field (RHF) was very weak in our experiments, only near 1% Of the poloidal field B_p, it only can directly change the magnetic structure near the corresponding rational surfaces (q =2 or q =3 surface)

RHF are really the local disturbances. $q_a \sim 3.7-4.0$

2) The L=2 RHF can suppress m=2/n=1 fluctuation as already widely observed. It also can suppress m=3/n=1 fluctuation totally.

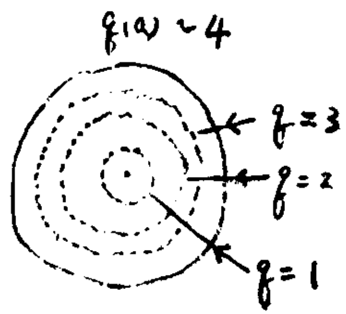
The L=2 RHF suppressed m=1/n=1 signals from soft X-ray detector array, which could not be thought as the side-band component of m=2/n=1 mode.

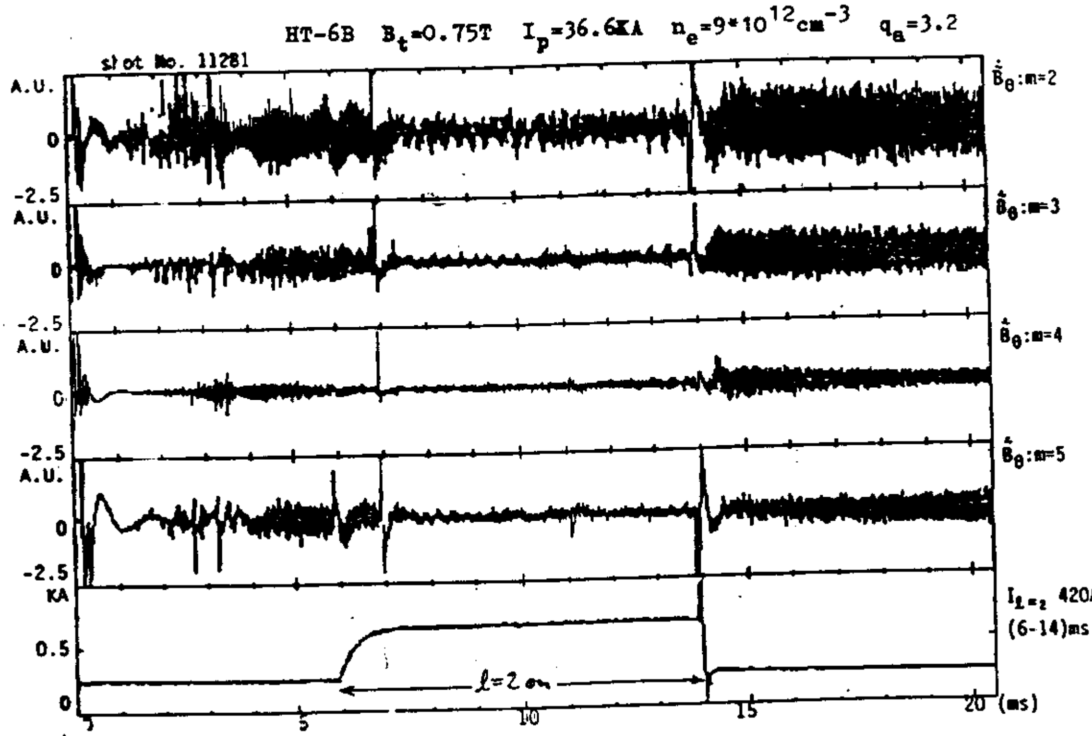
3) The L=3 RHF, which only disturbs q=3 surface, can suppress m=3 fluctuation as well as m=2 magnetic fluctuation. Thus, m=3 signal could not be the side-band of m=2 mode due to toroidal effect.

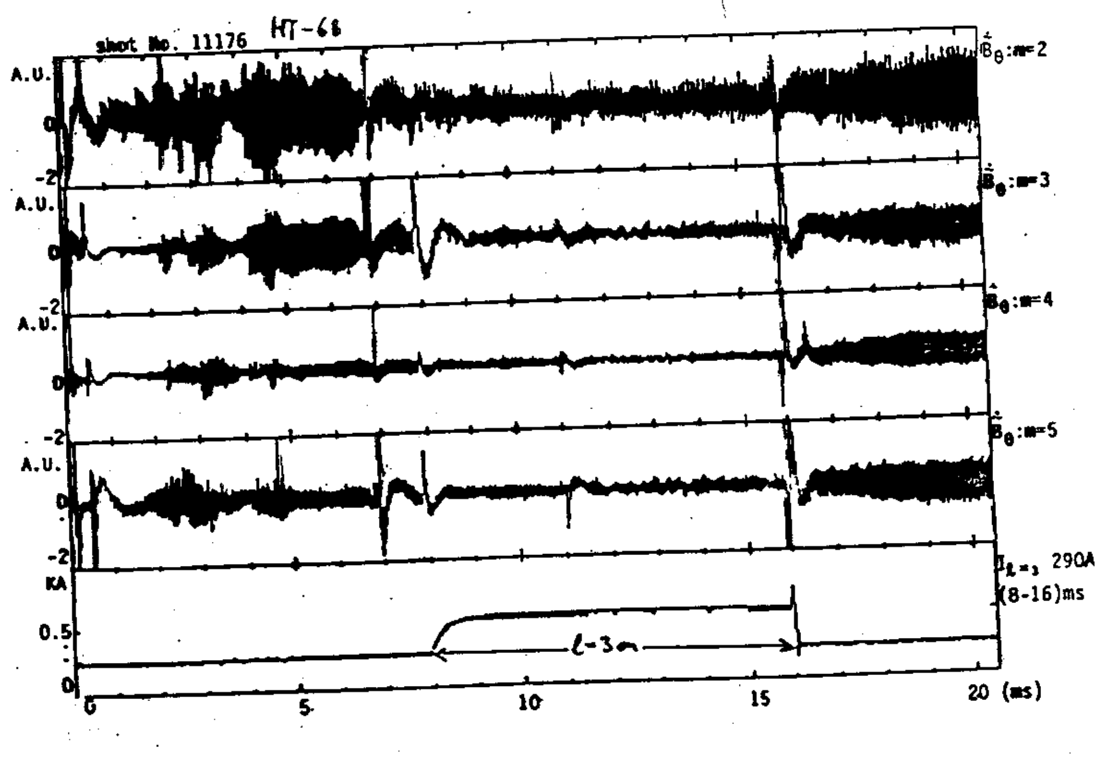
The L=3 RHF also can suppress m=1/n=1 fluctuation of soft X-ray emission from central core of the plasma.

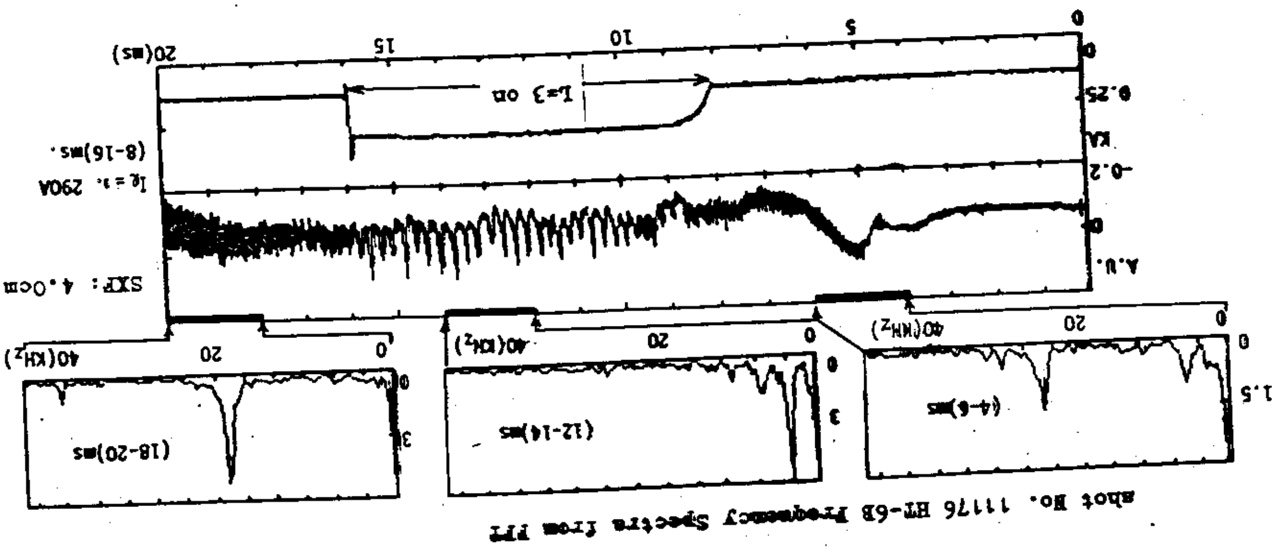
4) All these fluctuations have the same frequency, which could not be due to the toroidal rotation of the plasma.

It is conclusive that, there is only one mode which has different m components and extends to the whole plasma.




HT-6B B_t=0.75T I_p=36.6KA n_e=9*10^12 cm^-3 q_a=3.2
shot No. 11281
A.U.
0
-2.5
Ḃθ:m=2
Ḃθ:m=3
Ḃθ:m=4
Ḃθ:m=5
KA
0.5
I_l=2 420A
(6-14)ms
l=2 m
5
10
15
20 (ms)


shot No. 11176
HT-6B
A.U.
0
-2
Ḃθ:m=2
Ḃθ:m=3
Ḃθ:m=4
Ḃθ:m=5
KA
0.5
I_l=3 290A
(8-16)ms
l=3 m
0
5
10
15
20 (ms)


shot No. 11176 HT-6B Frequency Spectra from FFT
(4-6)ms
(12-14)ms
(18-20)ms
40(KHz)
SXP: 4.0cm
$I_{\ell=3}$. 290A
(8-16)ms.
L=3 on
A.U.
-0.2
KA
0.25
20(ms)

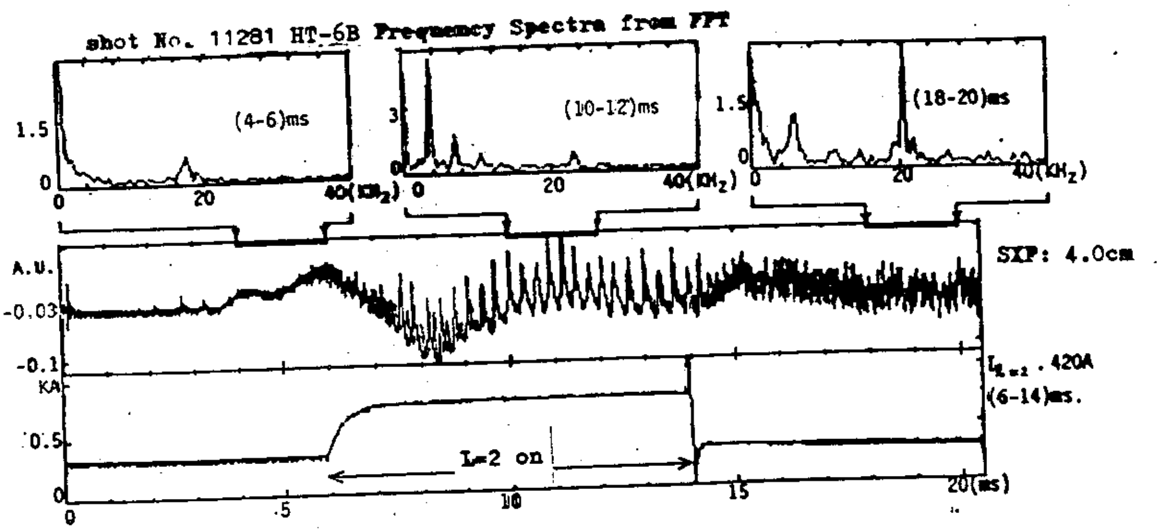
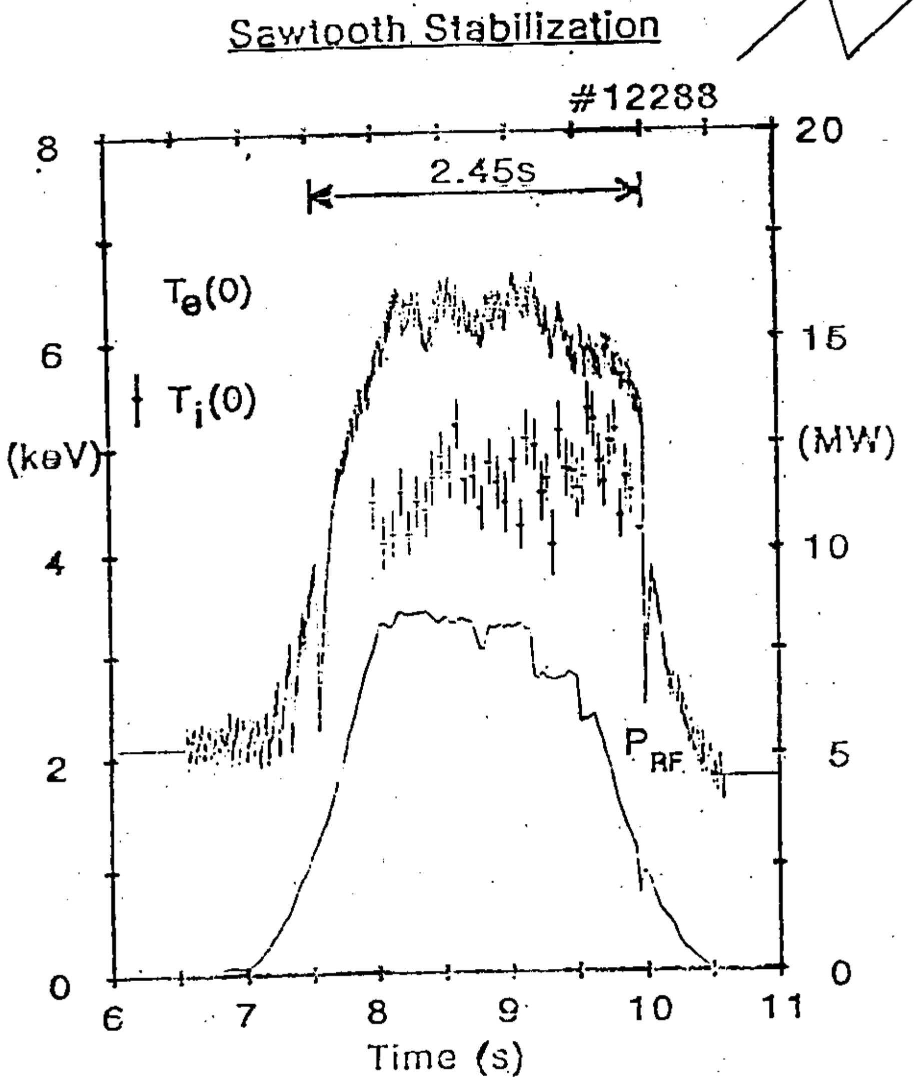

shot No. 11281 HT-6B Frequency Spectra from FFT
(4-6)ms
(10-12)ms
(18-20)ms
40(KHz)
SXP: 4.0cm
A.U.
-0.03
-0.1
KA
0.5
$I_{\ell=2}$. 420A
(6-14)ms.
L=2 on
20(ms)

Fig.3c.

Super-low density discharge experiment on HT-6M:

1) The Monster sawtooth process observed on JET seems to show that, in some cases the plasma can keep in the top state of sawtooth process for long time if the central heating power is enough. Therefore, it is hopeful to observe such phenomena in low density ohmic heating discharge.



2) How to enter super-low density (SLD) region:

400Hz discharge cleaning to reduce the outgassing rate of the limiter and wall;

Compansation of the stray field to reduce the electrical field;

Controlling the plasma displacement to prevent the excessive outgassing;

DC glow discharge cleaning for 1-4 hours to improve the wall condition;

Gradually reducing the initial pressure to $3*10^{-5}$ τ ;

Pre-ionization.

SLD is really the typical Tokamak discharge with few runaway electrons:

Loop voltage was about 0.7-2.0V, only had negative peaks;

Hard X-ray appeared only in set-up and disruption phases;

Soft X-ray PHA only show single Maxwellean spectrum of T_e=600-1000 eV;

Z_{eff} from Spitzer resistivity agreed with the directly measured value Z_{eff} = 3.3 .

3) Taking $N_e(r) = N_{e0} [1 - (r/a)^2]^a + N_{eb}$ and

$T_e(r) = T_{e0} [1 - (r/a)^2]^b + T_{eb}$.

from data of 300 SLD within the parameter range:

$N_e = (0.2 - 0.4) * 10^{13}$ cm^{-3},

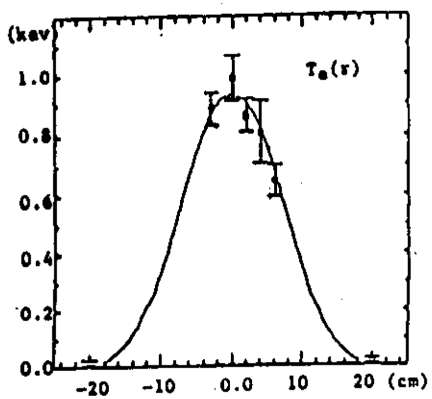
I_p =65 kA, V_l =0.7 - 1.4V ,

we obtained: N_{e0}=0.47 $*10^{13}$ cm^{-3} ,

N_{eb} = 0.07 $*$ 10^{13} cm^{-3},

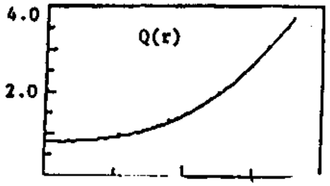
T_{e0} = 900 eV , T_{eb} =30 eV .

$a \approx 0.8$, $b \approx 2.7$



q(0) = 0.8 from Spitzer resistivity.

q(0) = 0.46 from neoclassical formula.



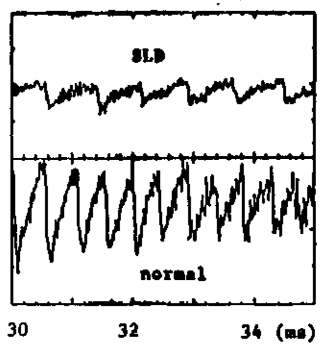
This q(0) value was confirmed by inner inductance measurement: L_i =1.8 .

4) Other features of SLD:

$\overline{N}_e$ was independent of P_o ;

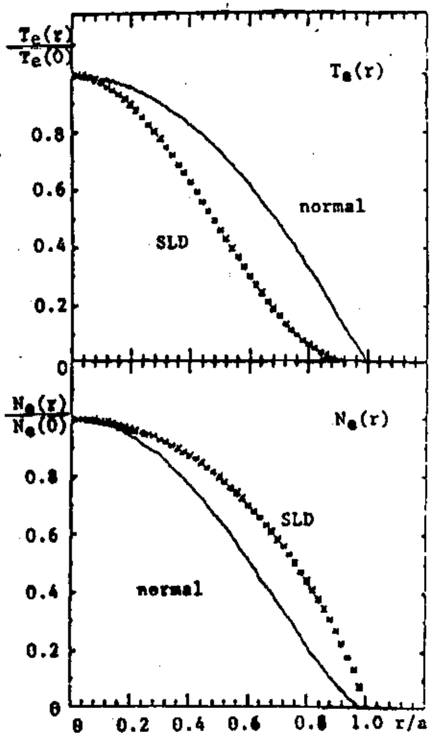
Sawteeth did not appear in most of discharges(80-90%), or were very weak;

S - X



MHD fluctuations(m=2, 3) level were very low;

Confinement time of SLD was increased to 2 - 4 times of the value of Alcator Scolling.



A7

Changes of the confinement properties of the Plasma in HT-6B Tokamak due to weak Helical Field.

It has been found that, the very weak L=3 (or L=2) helical field,which can only directly modify the magnetic structure near the edge of the plasama, strongly changes the transport ,or confinement, properties of the whole plasma.

1) In the case of low density discharge($\overline{N}_e < 1.5*10^{13}cm^{-3}$), sawteeth would be amplified by a factor of 2.5 to about 1/3 of the mean value of the central chord (Fig.).

Ramp up slope: from 0.9V/ms to 1.5V/ms, collapse slope: from 3.6V/ms to 7.6V/ms.

In the case of $\overline{N}_e > 1.5*10^{13}cm^{-3}$, the magnetic and soft-X ray signals all had near 20kHz oscillation. The RHF could suppress all high frequency (near 20kHz) oscillation, and make the sawteeth evident (Fig.).

RHF could increase the amplitude, ramp-up and collapse slopes of sawtooth oscillation . It is similar to ' giant sawtootrh' process, but without the heating power in central region. The collapse of the oscillation could not be totally due to the grouth of m=1 mde.

2) RHF improved the confinement f the plasma:

Increasing the ramp-up slope of sawtooth ;

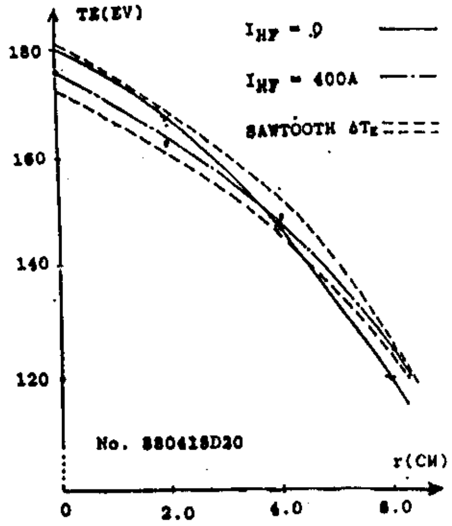
The thermal conductivity estimated from phase shift of the sawtooth oscillation of different chorts(Tab.)

shot 11176	X_e (M^2s^{-1})	
	r = 0 cm	r = 7.6 cm
without RHF	3.38 ± 0.49	7.76 ± 0.15
with RHF	?.37 ± 0.38	4.30 ± 0.30

The T_e profile was broadened.

The T_e profile was broadened, the central electron temperature $T_e(0)$ was reduced.

N_e was increased gradually by RHF (from $1.1 * 10^{13} cm^{-3}$ to $1.6 * 10^{13} cm^{-3}$ in 20 ms).



3) RHF enhanced the impurity line (OIII and CIII lines) emission.

The H_α radiation did not be enhanced by RHF. Hydrogen influx was unchanged.

All were 1.5cm and 8.7 cm chorts.

4) The effectiveness of RHF depends on the plasma condition.

RHF was totally non-effective in high Z_{eff} discharge.

Generally, L-3 RHF was more effective than L-2, if q_a was near 4 .

L-3 RHF was non-effective if q_a was less than 3 .

The optimal value of RHF was related to plasma density.

The RHF discharge could be a new state of Tokamak Plasma:

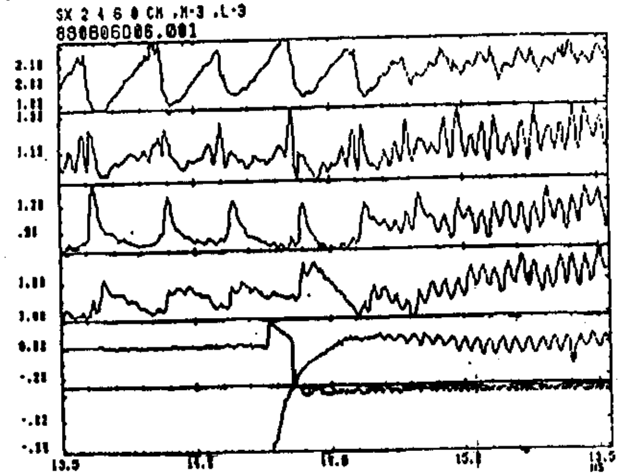
RHF could

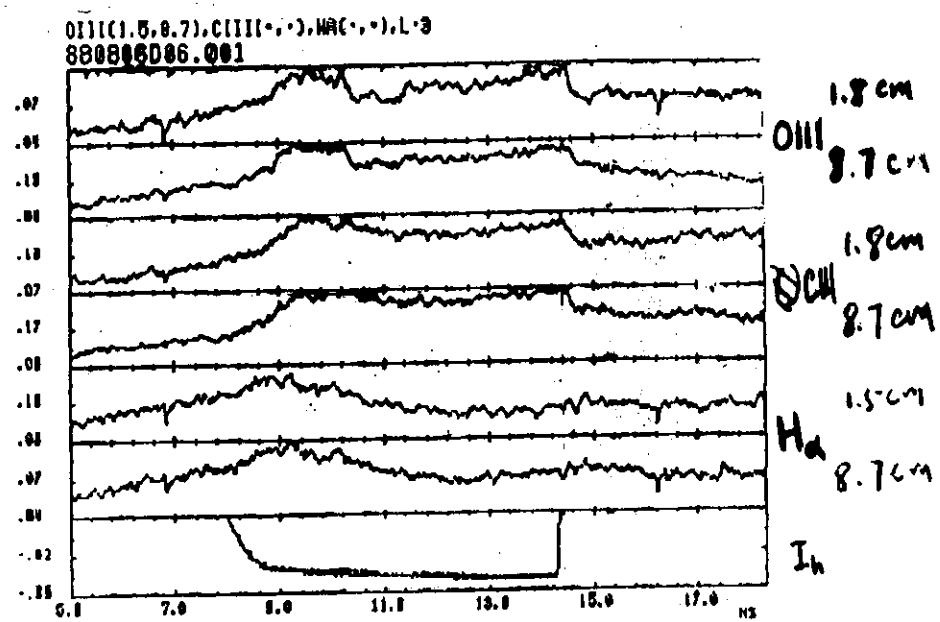
Suppress the Mirnov oscillatin;

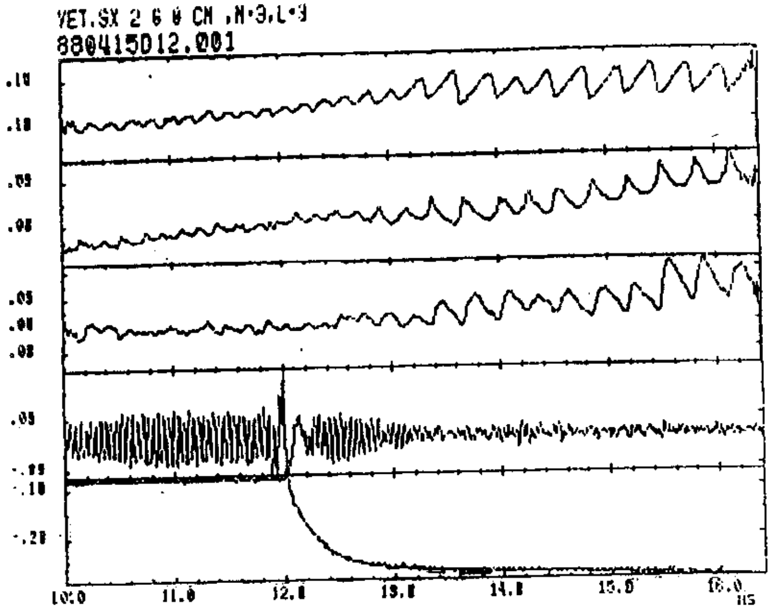
Improve the confinement;

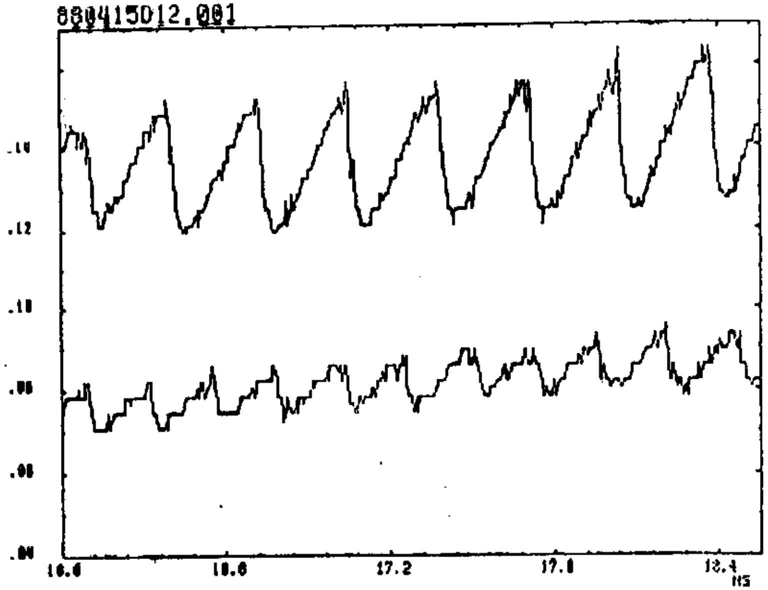
Amplify the sawteeth;

Enhance the impurity radiatin but keep the H radiation unchanged; ....






VET.SX 2 6 0 CN ,N=3,L=3
880415D12.001
MS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MS