LOW FREQUENCY OSCILLATIONS IN U-2M CONDITIONING RF DISCHARGES

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MHD oscillations were studied in low magnetic field ($B_0 = 0.01$ T) radio frequency discharges of the URAGAN-2M (U-2M) stellarator. Coherent oscillations are observed by bolometers, triple Langmuir probe microwave interferometer (140 GHz) and magnetic pick-up coils in different toroidal cross-sections of U-2M. Modified diagnostics show, that the plasma beta ($\beta = nT/(\mu_0 B^2)$) is rather high in these discharges in spite of the low temperature ($T_e = 10…50$ eV) and density ($n_e = (0.5…1)\cdot 10^{12}$ cm^{-3}) due to very low magnetic field. Variation of the magnetic configuration of U-2M substantially modifies fluctuations amplitude, oscillating modes type and frequency. Rotated m = 2 mode is transformed into the Sawtooth-like oscillations in different magnetic configurations. Strong dependence on the magnetic configuration indicates that observed in U-2M phenomena can have similar nature as in stellarator high temperature plasmas.

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INTRODUCTION

The magnetic topology is a very important ingredient of plasma confinement in magnetic traps, having a greater influence than the magnetic configuration on the transport in the several collisionality regimes. Stellarators rely on currents in external coils to provide the magnetic fields with the rotational transform needed for plasma confinement and stability. The radial profile of the rotational transform, $\iota(r)$, is one design parameter of these configurations and it can be chosen to exclude low order rational surfaces inside the plasma. Nonetheless, the current in the plasma of stellarators can be substantial, as well as finite plasma beta effects cannot be completely compensated. These factors can modify designed vacuum rotational transform profile and introduce rational surfaces. The presence of rational surfaces that can break the magnetic topology of nested flux surfaces does affect the particle and heat fluxes as well as the turbulence and electric fields. Strong plasma current can cause deterioration of stellarator discharge. Disruptive-like events accompanied by a fast energy loss were observed as low order rational resonances appear in the outer region of the W7-AS [1] plasma in discharges with a significant contribution of net toroidal current densities. The $m = 2$ MHD mode (at rational surface $\iota = 1/2$) was observed as the precursor of the observed energy loss in W7-AS discharges. The MHD mode properties depend on the rational surface. In the case of $\iota = 1/2$ rotated m = 2 mode is observed. In the case of $\iota = 1$, Sawtooth-like oscillations, similar to tokamaks Sawtoothes are observed in stellarators [2, 3]. The rational surfaces can deteriorate plasma confinement, but in can improve plasma confinement as well via ITB formation [2]. The role of rational surfaces in the transport barrier formation accompanied by the sawtooth-like oscillations was discussed in the case of hot plasma of TJ-II [1]. Similar Sawtooth-like oscillations were recently observed in W7-X discharges with rational surfaces [3]. Various MHD oscillations of the U-2M plasma were observed recently. In particular, MHD instabilities are observed in the low magnetic field low temperature radio frequency (RF) discharges. These types of RF discharge are routinely used for the U-2M wall conditioning [4]. Main advantage of these discharges is related to the low temperature plasma conditions. It is possible to use simple Langmuir probe and magnetic probe diagnostic techniques for the measurement of electron temperature, density, radial electric field, and plasma current profiles. It is substantially more difficult to measure these set of profiles in high temperature plasmas (and impossible in U-2M due to luck of complicate diagnostics). First demonstration of MHD activity in various magnetic configurations of the low magnetic field discharge of U-2M is present in our work.

CONDITIONS AND DIAGNOSTICS

In our experiments, the frame-type antenna (FTA) and three half turn (THT) antenna simultaneously were used in low magnetic field $B = 0.01$ T ($\omega >> \omega_{ci}$) hydrogen discharges. Top view of the U-2M torus with involved diagnostics is shown in Fig. 1.

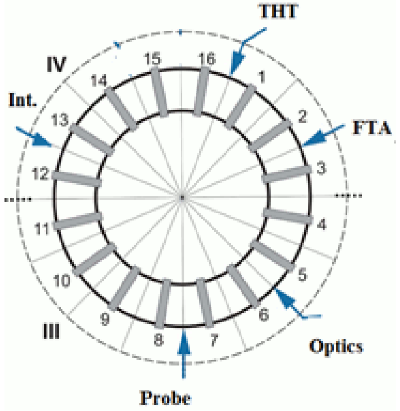

Fig. 1. Toroidal location of bolometric arrays, Triple probe, 2 mm interferometer , THT and FTA RF antennas

The Langmuir probe (LP) is used for measurement of complete profiles up to plasma center (Fig. 2) in cold, low density RF discharges under consideration. New electronics was designed and manufactured for T_e, n, V_p measurements with high time resolution via triple Langmuir probe (TP) technique.

A comparison of the TP measurements and conventional single pin scanned LP measurements shows good agreement (Fig. 3). Two multichannel pinhole cameras were recently installed in U-2M for monitoring the oscillations of visible light emission from two positions in the same plasma cross-section (Fig. 4). Strong noise suppression technique was used in hardware design [5].

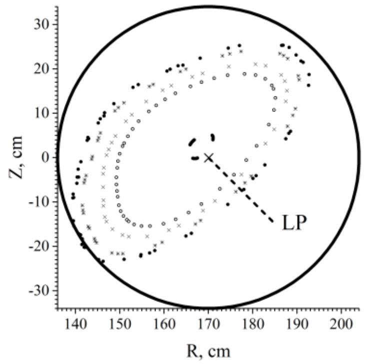

Fig. 2. LP manipulator positions

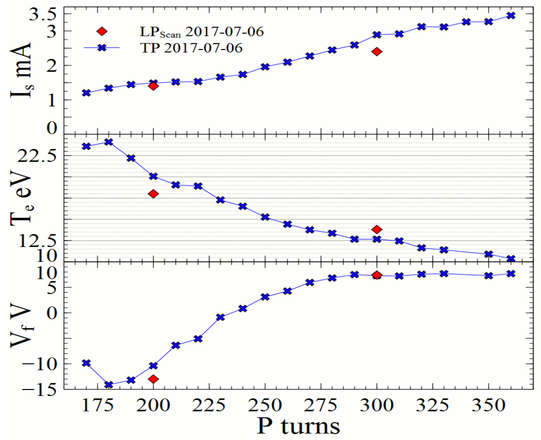

Fig. 3. TP (blue crosses) and conventional single pin scanned LP (red squares) data of ion saturation current, electron temperature and floating potential

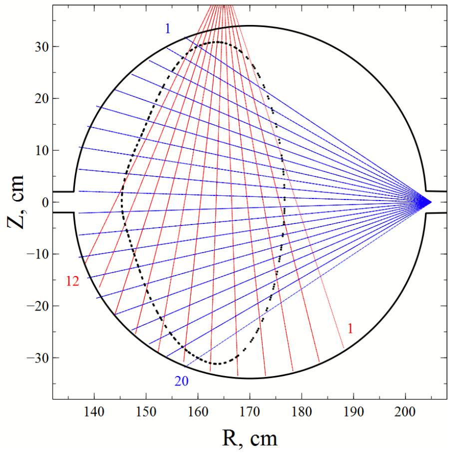

Fig .4. Lines of sights of two arrays of bolometers

A magnetic pick-up coil was installed outside of the vessel. The thickness of bellow section of U-3M vacuum chamber is about 1mm. It is thin enough for the frequency range of 0.5…20 kHz under consideration.

EXPERIMENTAL RESULTS

Fluctuations in conditioning discharges (B=0.01 T) were observed recently [6]. These coherent fluctuations are observed in set of diagnostics, as it is shown in Fig. 5.

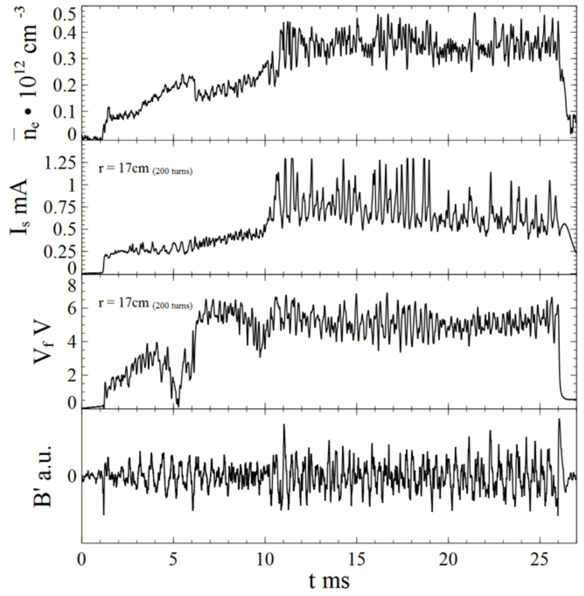

Fig. 5. Signals of interferometer, probe ion saturation current and floating potential, magnetic pick-up coil

This is the discharge in one of the magnetic configurations. Variation of the magnetic configuration of U-2M substantially modifies the features of the oscillations in the plasma of such low magnetic field discharges (Fig. 6).

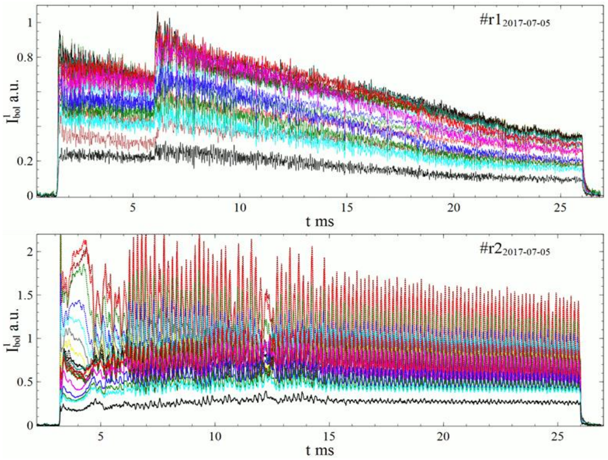

Fig. 6. Signals from 20-channals bolometer in two magnetic configurations (r1, and r2)

Significant dependence of the fluctuations amplitude is clearly observed in this figure. In present work three representative configurations are considered, as it is shown in Table. In addition to significant variation of the fluctuations amplitude, the modification of the oscillating modes types and frequency ranges were also observed.

Representative configurations

	Kφ	B Gs	I_h A	I_t A	I_{corr} A	$P\cdot10^{-5}$ Torr
r1	0.32	100	340	150	-	9
r2	0.26	122	340	200	150	19
r3	0.22	145	340	250	-	19

An oscillating part of the 20-channals bolometer signals is shown in Fig. 7 (see data of r2 discharge from Fig. 6). The phase delay between channels demonstrates that the poloidal mode number is $m = 2$ and it is rotating in the electron diamagnetic direction.

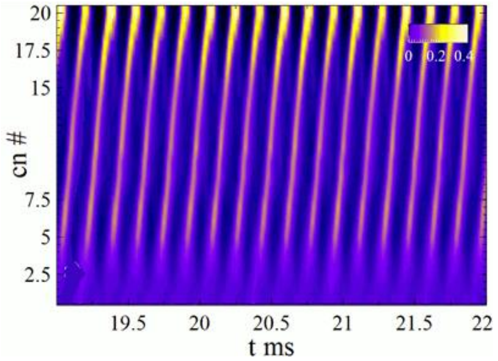

Fig. 7. Fluctuations observed by 20-channals bolometer

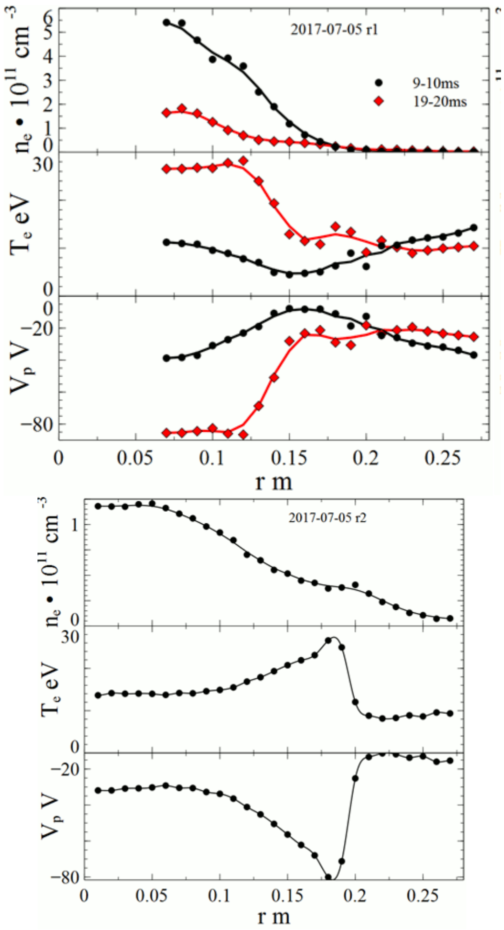

Fig. 8. Profiles of TP density, temperature and plasma potential in two instances of r1 and in r2 pulses

Different shapes of the plasma profiles are observed in different configurations (Fig.8). In particular, one can see a shear of electric field in configurations with fluctuations. This shear can be caused by presence of rational magnetic surfaces in magnetic configurations with oscillations. Due to variation of magnetic configuration rotating $m = 2$ mode in r2 is transformed into the Sawtooth-like oscillations in r3.

Clear phase inversion of the Sawtooth-like oscillations is observed both in 12-channal and 20-channal bolometers (as it is seen from Fig. 9). In spite of different conditions, i.e., low temperature and partially ionized plasma in RF conditioning discharges of U-2M in comparison with hot plasma of TJ-II [2] and W7-X [3], a qualitative similarity of the oscillations behavior was observed. Strong dependence on the magnetic configuration indicates that observed phenomena can have similar origin in different plasma conditions.

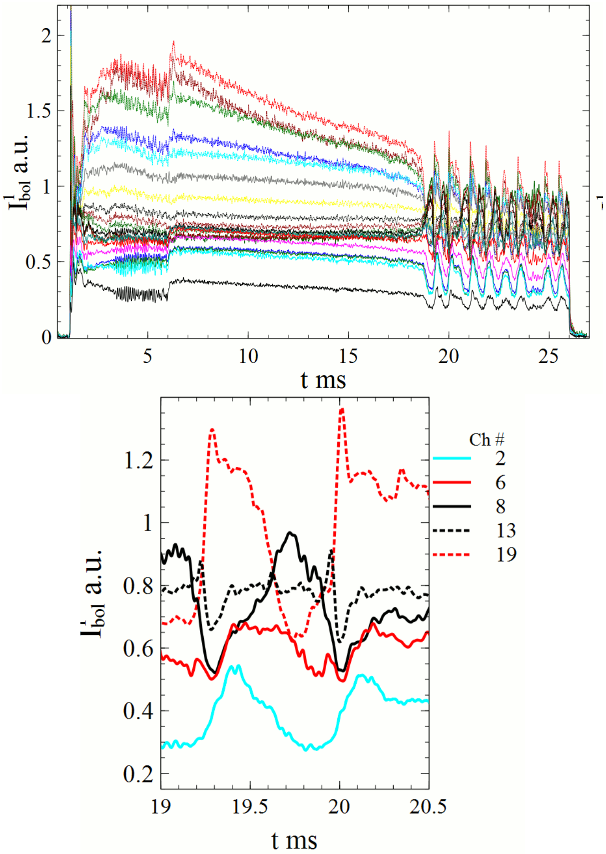

Fig. 9. Signals from 20-channals bolometer r3

SUMMARY AND CONCLUSIONS

An appearance of various 1…20 kHz oscillations was observed in URAGAN-2M (U-2M) low magnetic field (B=0.01 T) discharges. New measurements by modified diagnostics show, that the plasma beta parameter is rather high in these discharges in spite of the low temperature and density. Variation of the magnetic configuration of U-2M substantially modifies the features of the oscillations (amplitude, frequency, mode type) in the plasma of such discharges. Rotated *m = 2* mode is transformed into the Sawtooth-like oscillations in different magnetic configurations.

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НИЗКОЧАСТОТНЫЕ ОСЦИЛЛЯЦИИ В ЧИСТЯЩИХ ВЧ-РАЗРЯДАХ У-2М

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МГД-осцилляции плазмы изучались в высокочастотных разрядах стелларатора У-2М при малом магнитном поле (B_0 = 0,01 Тл). Когерентные осцилляции наблюдаются болометрами, тройным ленгмюровским зондом, СВЧ-интерферометром (140 ГГц) и магнитными зондами в различных тороидальных сечениях У-2М. Обновленные диагностики показывают, что β-параметр ($\beta = nT/(\mu_0 B^2)$) достаточно высок в этих разрядах, несмотря на низкие температуру (T_e = 10…50 эВ) и плотность (n_e = (0,5…1)·10^{12} см$^{-3}$). Благодаря низкому магнитному полю вариация магнитной конфигурации У-2М значительно изменяет амплитуду флуктуаций, тип моды и частоту. Вращающаяся мода $m = 2$ трансформируется в пилообразные колебания в различных магнитных конфигурациях. Сильная зависимость от магнитной конфигурации указывает, что наблюдаемый на У-2М феномен может иметь схожую природу с осцилляциями в горячей плазме стеллараторов.

НИЗЬКОЧАСТОТНІ ОСЦИЛЯЦІЇ В ЧИСТЯЧИХ ВЧ-РОЗРЯДАХ У-2М

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МГД-осциляції плазми вивчалися у високочастотних розрядах стеларатора У-2М при малому магнітному полі (B_0 = 0,01 Тл). Когерентні осциляції спостерігаються болометрами, потрійним ленгмюрівським зондом, НВЧ-інтерферометром (140 ГГц) і магнітними зондами в різних тороїдальних перерізах У-2М. Оновлені діагностики показують, що β плазми ($\beta = nT/(\mu_0 B^2)$) досить висока в цих розрядах завдяки низькому магнітному полю, незважаючи на низькі температуру (T_e = 10…50 еВ) і густину (n_e = (0,5…1)·10^{12} см$^{-3}$). Варіювання магнітної конфігурації У-2М значно змінює амплітуду флуктуацій, тип моди і частоту. Мода $m = 2$, що обертається, трансформується в пилкоподібні коливання в різних магнітних конфігураціях. Сильна залежність від магнітної конфігурації вказує, що спостережуваний на У-2М ефект може мати схожу природу з процесами, що і аналогічна поведінка осциляцій в гарячій плазмі стелараторів.