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URAGAN-2M GAS MIXING SYSTEM

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Gas mixture system (GMS) was developed, created and installed at Uragan-2M (U-2M) device. GMS is based on already known gas mixing method – successive puffing. It is implemented through successive puffing of several gases from separate high pressure cylinders into working volume. A number of experiments were carried out to create a He+H_2 gas mixture with different percentages. The results of measurements of the He+H_2 percentage in the GMS and the U-2M vacuum chamber are in good agreement each to other. This system allows you to change the pressure of the mixture in the U-2M chamber at a constant percentage of gases in the mixture.

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INTRODUCTION

For the functioning of thermonuclear devices, and especially plasma experiment preparation and execution, different gases and gas mixtures are required. Gases used in gas supply systems can be divided into two big groups: working and conditioning gases. Gas puffing and gas mixing system [1 - 3] is a main part of a fusion device. Wendelstein 7-X (W7-X) gas supply system provides required gases and gas mixtures for all gas consumers (gas puffing system, diagnostics, technical components) during all working stages [1, 3]. Gas input should work both with short plasma discharges that lasting several seconds and with long impulses that reach 30 min because of different scheduled W7-X regimes.

Similar system is required at Uragan-2M (U-2M) for solving tasks of plasma creation and heating [4], and for vacuum surface cleaning experiments [5, 6]. The gas mixture preparation at U-2M went through several stages in the past. The device vacuum chamber was pumped out to the pressure of $3\cdot10^{-7}$ Torr and the first gas was puffed until certain pressure. Then the second gas was added through another gas puffing channel, which increased general pressure until required one. The gas mixture pressure was maintained constant during experimental work. The gas percentage ratio was determined through partial gas pressures measurements by the mass-spectrometer.

Changing gas mixture pressure inside the chamber required to repeat described steps from the beginning in order to keep constant gas percentage. It was also important to maintain both gases flows constant during experiment. Such gas mixing method required constant mass-spectrometer control of gas percentage ratio inside U-2M chamber. As a result, it took more than 30 minutes to change the working pressure of the gas mixture in the chamber. Such situation couldn't allow efficiently change gas mixture pressure inside chamber during experiments.

To achieve more flexibility in gas supply, the gas mixture system (GMS) was developed, created and installed at U-2M device. This paper presents first results of gas mixing system usage.

1. URAGAN-2M VACUUM SYSTEM

Fig. 1 shows scheme of U-2M vacuum chamber. The vacuum chamber has toroidal form with minor radius r_c=0.34 m, volume V_c=3.879 m^3 (excluding vacuum ports), torus surface area S=22.819 m^2. The chamber has 48 ports, which are used for diagnostics, working gas puffing and vacuum pumping. The chamber was vacuum pumped with three turbomolecular pumps TMP-500 (see Fig. 1, TMP numbers 1, 2, 3) with pumping speed of 0.5 m^3/s, through cryogenic (N_2 liquid) traps. The vacuum chamber general pressure was measured with vacuum ionization manometers PMI-2, PMI-32-1, PTR-225S.

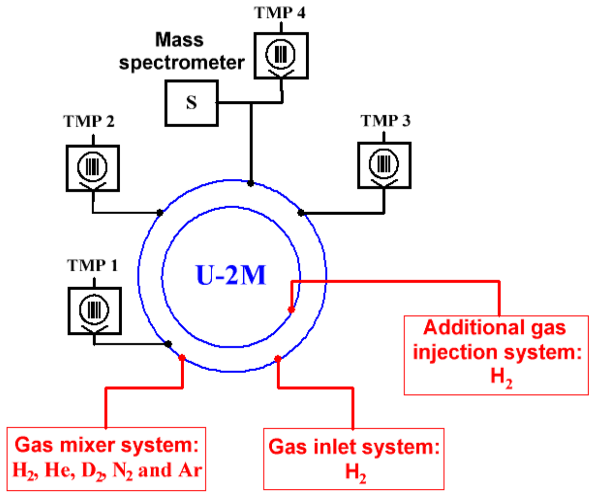

Fig. 1. The scheme of U-2M vacuum system. TMP 1-4 denotes number turbo-molecular pumps

The partial gas pressure inside vacuum chamber was measured with mass-spectrometer IPDO-2 (partial pressure meter omegatron OPPM-2) based on omegatron tube RMO-4S (resonant radio frequency mass spectrometer). The mass spectrometer has an independent high-vacuum pumping system (see Fig. 1, TMP number 4). IPDO-2 is ion-resonance mass-spectrometer. Its principle of operation is based on ion-cyclotron resonance [7]. The sensitivity coefficient for nitrogen at electron current of 10 μA is range (4…10)$\cdot10^{-7}$ A/Pa. The maximal working pressure of RMO-4S is (1…4) $\cdot10^{-3}$ Pa, the minimal – 10^{-8} Pa. The precision of residual gases partial pressures measurements without calibration is about 25% [8, 9]. The mass-spectrometer calibration with a single pure gas allows to achieve 10% precision. The quantitative gas mixtures analysis took into account dissociation fragments and multiply charged ions according to the method described in [10]. Retrieving the partial pressure values requires solving linear equation system which connects output mass-spectrometer signal and separate components partial pressures of analysed gas mixtures.

The working gases were puffed into the U-2M vacuum chamber via gas puffing system SNA-2-01. The two-channel gas puffing system SNA-2-01 is intended for remote and controlled gas puff through two channels in different vacuum devices. When feedback with a vacuum meter is available SNA-2-01 allows maintaining pressure automatically. SNA-2-01 consists from two-positional inlet valve with piezoelectric actuator connected to the control block. The maximal gas flow (nitrogen) at atmospheric pressure is not less than $7\cdot10^{-2}$ ($m^3\cdot Pa$)/s. The automatic mode maintains set pressure level inside vacuum chamber acording to feedback from vacuum-meter. An additional impulse gas puff system is also used at U-2M (see Fig. 1). The pulse gas puff is made with piezovalve model PEV-1, manufactured by Key High Vacuum Products. The gas flow can be adjusted up to 500 sccm.

Fig. 2 shows how the pressure inside vacuum chamber varied during puffing and pumping systems work in real time. High-purity (99.998%) nitrogen was used as working gas. The pressure was measured with PENNINGVAC transmitter PTR-225S, installed inside the pumping branch (see Fig. 1, TMP number 3). The range of this vacuum-meter measurements is from $0.75\cdot10^{-9}$ to $0.75\cdot10^{-2}$ Torr. The pressure measurement results were saved with a system which is based on the high-speed ADC modules L-CARD E-20-10 with maximum acquisition frequency 10 MHz.

The vacuum chamber U-2M was preliminary pumped to the pressure of P=$4.7\cdot10^{-7}$ Torr. Then, at the moment of time t_1 (see Fig. 2) nitrogen puffed was started up to the value P=$1.5\cdot10^{-4}$ Torr (time t_2). Within five minutes, 5 different pressure values in the chamber were adjusted (time t_3, t_4, t_5, t_6, t_7). The nitrogen puff was stopped at the moment t_8. The chamber pressure returned to the initial value during ≈ 90 s (see Fig. 2). We should note that working gas pressure range is from $5\cdot10^{-6}$ to $5\cdot10^{-4}$ Torr inside U-2M during experimental campaign.

2. GAS MIXTURE SYSTEM

Gas mixture system (GMS) provides needed gases and gas mixtures for most of the experiments at U-2M. GMS prepares specified gas mixture composition reasonable mixture components ratio precision. Such precision is achieved through keeping to all stages of gas mixing with the method of sequential puffing [11, 12].

GMS consists from mixing chamber (MC), gas supply lines from gas-bottle, mixing chamber vacuum-pumping system and measuring devices. The mixing chamber (Figs. 3, 4, MC) has volume of ~$1.4\cdot10^3$ cm^3 and is made from stainless steel. The gas supplies lines are made from copper pipes with inner diameter of 6 mm. There are also gas reducers (see Figs. 3, 4, *VT1…VT10*) and gas regulating valves KS 7153-05 (see Figs. 3, 4, *V2…V7*).

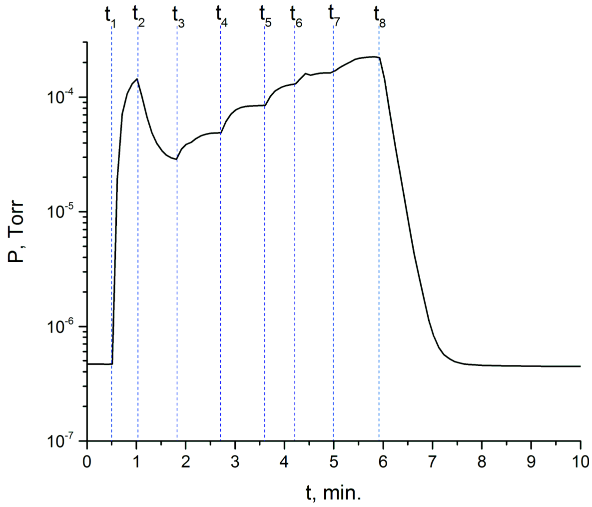

Fig. 2. The pressure measurements inside U-2M vacuum chamber during nitrogen puff (t_1 – start of puff; $t_2…t_7$ – time range when pressure was adjusted; t_8 – gas puff off)

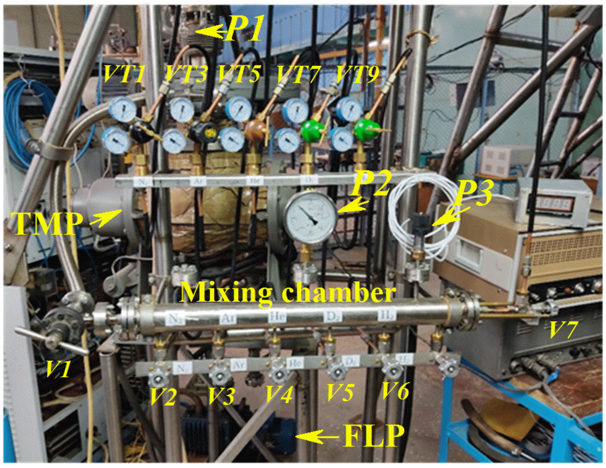

Fig. 3. Photo GMS in U-2M hall

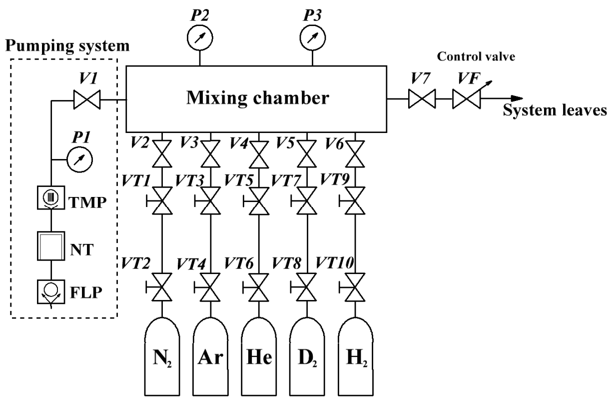

Fig. 4. GMS scheme

Working gases (H_2, He, D_2, N_2, Ar) are supplied to the system from the high-pressure (150 atm, 50 l) gas bottles (see Fig. 4). The vacuum-pumping system consists of turbo-molecular pump TMP-500 (see Figs. 3, 4, TMP), nitrogen trap TNF-32, fore-vacuum pump (see Figs. 3, 4, FLP) 2NVR-5DM with the pumping speed of 5 l/s and measuring device VIT-3 (see Figs. 3, 4, *P1*). The current pumping system allows to vacuum mixing chamber and connected devices to the pressure of

$1\cdot10^{-5}$ Torr. The mixing chamber was cut off with vacuum valve 15ng40p Ru40 (see Figs. 3, 4, *V1*). The overpressure and vacuum were indicated with gauge DA 05 (see Figs. 3, 4, *P2*) in the range of -100…500 kPa, it has precision class 1.5. The MC gas pressure is measured with pressure sensor PD-I-30 (see Figs. 3, 4, *P3*) in the measuring range 0…1 MPa and output DC 4…20 mA, with precision class 0.5. The PD-I-30 signal is sent to the technological parameters indicator MikRa IZ. The gas mix is puffed into U-2M through gas puffing system SNA-2-01 (see Fig. 4, *VF*).

The gas mixing method consists of three stages. The first stage is GMS vacuum pumping to the pressure of $1\cdot10^{-5}$ Torr to eliminate the influence of the previous gas mixture. The second stage is cyclic MC purging at least three times with one of the mixture gases. The purging is a successive gas puffing until certain pressure and pumping the chamber. The third stage is a successive puffing of gas mixture components until the needed partial pressures ratio. Dalton law states that MC pressure is equal to the sum of partial gas pressures of the mixture:

$$p_\Sigma = p_A + p_B + ... + p_i, \quad (1)$$

where p_Σ – the sum MC pressure, p_A and p_B – gas A and B partial pressures in the MC; p_i – gas *i* partial pressure. This method advantage is only one needed gas pressure gage that can have high enough precision [12]. The percent gas ratio (k_A or k_B) in the mixture can be determined through following expression:

$$k_A = \frac{p_A}{p_\Sigma}\cdot 100\,\%, \quad (2)$$

where $p_\Sigma = p_A + p_B$. The utilized method is widely used in laboratory routine [13, 14], while final mixture composition is controlled with gas chromatographs. The gas mixture at U-2M is controlled with mass-spectrometer IPDO-2 after its puff into stellarator chamber.

The gas mixture components concentrations equalization time in the mixing chamber volume is determined by the interdiffusion time. The diffusion time scale for long cylindrical MC and two component gas mixture can be estimated with the formula:

$$\tau = \frac{\Lambda^2}{D_{12}}, \quad (3)$$

where D_{12} – two gases binary diffusion coefficient, $cm^2\cdot s^{-1}$, Λ – diffusion length, cm, determined as:

$$\Lambda = L/\pi , \quad (4)$$

where L – total system length, cm. The mixing chamber length is L = 71.5 cm. Provided D_{12} for some gas mixtures [15] to estimate diffusion time in the MC. The calculated results and coefficient D_{12} are listed in Table 1. The table data shows that diffusion time varies from several minutes to an hour depending on gas mixture. So the time for gas mixing before puffing mixture into U-2M should be about an hour.

Table 1

Gases	D_{12}, $cm^2\cdot s^{-1}$ [15]		τ, min	
	0°C	20°C	0°C	20°C
Ar-H_2	0.698	1.228	12.4	7
Ar-He	0.645	1.088	13.4	7.9
Ar-N_2	0.168	0.29	51.4	29.8
D_2-H_2	1.079	1.846	8	4.7
H_2-He	1.32	2.255	6.5	3.8
H_2-N_2	0.686	1.162	12.6	7.4
He-N_2	0.619	1.052	13.9	8.2

3. EXPERIMENTAL RESULTS AN DISCUSSION

The experimental series was carried out to create gas mixtures He+H_2 with different percentages. This gas mixture was created for plasma experiments at U-2M. The used hydrogen had 99.99% purity and helium – 99.995%. First, the needed percent ratio was calculated with (2). Then this gases were puffed successfully beginning from the one with higher percent ratio**.** The mixing chamber pressure was controlled with pressure sensor and indicating pressure gauge (see Figs. 3, 4, *P2, P3*). The pressure sensor PD-I-30 measurements determined gas pressures. The gas percent ratios were calculated with (2) knowing their pressures. The measurement results are listed in the Table 2. The calculated according Table 1 time span was kept to equalize gas mixture components concentration inside MC volume. After that, SNA-2-01 gas puff system was used to set needed for experiment mixture pressure inside U-2M chamber (see Table 2). The percent He and H_2 ratio in the mixture was determined through partial gas pressures measurements inside U-2M with mass-spectrometer IPDO-2 (Table 2). The Table 2 clearly shows that He-H_2 percent ratio measurement results inside MC and U-2M vacuum chamber are well matched. The small differences of percent ratios from both methods result from errors of measurements. Note that changing mixture pressure inside U-2M chamber didn't change percent gas ratio in the mixture. Therefore this system allows to change mixture pressure inside U-2M chamber keeping constant gases ratios in the mixture. That is why this GMS was used for plasma creation and heating experiments at U-2M.

The stability of mixture puffing with set components ratio is important for U-2M plasma creation and heating experiments which can last 30…180 min. So the gas composition was measured before and after plasma discharges in strong magnetic fields (B_0≈0.3…0.4 T). The mass spectrum of residual atmosphere in U-2M chamber was measured before experiment (Fig. 5, value 1). Then He+H_2 gas mixture was puffed (percent ratio 88%He-12%H_2 inside MC) and partial pressures were measured in prepared gas mixture (percent ratio 87%He-13%H_2 inside U-2M chamber) with set experimental pressure (seeFig. 5, value 2). The third measurement of partial gas pressures inside the device was made after 120 min experiment during gas mixture puff (see Fig. 5, value 3). The percent ratio inside U-2M chamber was 87.5%He-12.5%H_2.

Table 2

№	Percent ratio He-H_2, in mixing chamber, %	U-2M chamber pressure, Torr	Percent ratio He-H_2, U-2M chamber, %
1	97.4-2.6	1.3×10^{-4}	97.2-2.8
2	93-7	6.1×10^{-5}	93.3-6.7
3	86-14	1.7×10^{-5}	85.8-14.2
4	72.5-27.5	3.7×10^{-5}	73.5-28.5
5	85-15	5.4×10^{-5}	87-13
6	88-12	5×10^{-5}	87-13

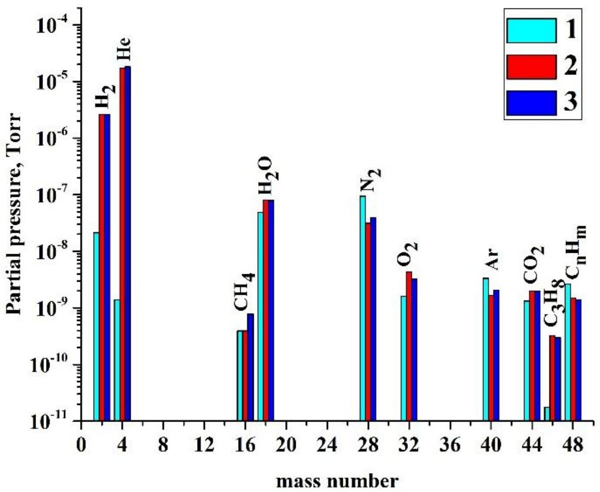

Fig. 5. Partial pressures of gas components in U-2M: 1 – before gas mixture puff (turquoise); 2 – after mixture puff into U-2M (red); 3 – after 120 min plasma creation experiment (blue)

The IPDO-2 mass-spectrometer measurements allow to conclude that main mixture gases ratios doesn't noticeably change during 120 min of working regime in strong magnetic field. The significant N_2, Ar, C_nH_m decrease argues microleakages in vacuum chamber at the level of 10^{-7} Torr, and CH_4 increase can be explained with long plasma-wall interaction during experiment. With that GMS allows stable gas mixture puff of needed percent ratio into U-2M chamber during plasma creation and heating experiments.

CONCLUSIONS

GMS was developed, constructed and installed at U-2M device to create gas mixtures with successive gas puffing method. The experimental He+H_2 gas mixing series were carried out with different percent ratios. The He+H_2 percent ratio measurements in the MC and U-2M chamber have a good fit. The small differences between both methods results are explained with their errors. This system allows to change gas mixture pressure inside U-2M chamber while its percent ratio being constant. Its puff has also stable percent ratio during long U-2M plasma creation and heating experiments.

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СИСТЕМА СОЗДАНИЯ ГАЗОВЫХ СМЕСЕЙ ДЛЯ СТЕЛЛАРАТОРА УРАГАН-2М

А.В. Лозин, Ю.В. Ковтун, В.Е. Моисеенко, С.М. Мазниченко, Д.И. Барон, М.М. Козуля, А.Ю. Красюк, В.М. Листопад, В.Ю. Грибанов, Ю.П. Марценюк

На установке стелларатор Ураган-2М разработана, создана и введена в эксплуатацию система создания газовых смесей (СГС). СГС основана на уже известном способе получения смеси газов – последовательном напуске. Такой напуск реализовывался при последовательном напуске в рабочий объем нескольких газов из отдельных баллонов с высоким давлением. Были проведены эксперименты по созданию газовой смеси $He+H_2$ с различными их процентными концентрациями. Результаты измерений процентного соотношенияHe+H_2 в смесительной камере и вакуумной камере У-2М находятся в хорошем согласии. Данная система позволяет изменять давление смеси в камере У-2М при постоянном процентном соотношении газов в смеси.

СИСТЕМА СТВОРЕННЯ ГАЗОВИХ СУМІШЕЙ ДЛЯ СТЕЛАРАТОРА УРАГАН-2М

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На установці стеларатор Ураган-2М розроблена, створена і введена в експлуатацію система контролю створення газових сумішей (СГС). СГС основана на вже відомому способі отримання суміші газів – послідовному напуску. Такий напуск реалізовувався при послідовному напуску в робочий об'єм декількох газів з окремих балонів з високим тиском. Було проведено ряд експериментів зі створення газової суміші $He+H_2$ з різними процентними концентраціями. Результати вимірювань процентного співвідношення $He+H_2$ у камері змішувача і вакуумній камері У-2М добре узгоджуються. Дана система дозволяє змінювати тиск суміші в камері У-2М при постійному процентному співвідношенні газів у суміші.