Study of partial pressures of gases in vacuum chamber using multifunctional high-vacuum plant

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Abstract. The article studies the mass spectrum of gases inside the vacuum chamber of a multifunctional high-vacuum plant during pumping by different types of high-vacuum pumps. The most effective method to provide the high vacuum inside the cryovacuum systems is to jointly use turbomolecular and cryoadsorption pumps with the ion pump operating periodically.

Ground testing of on-board spacecraft equipment shall be carried out under conditions of appropriate operation in outer space. The space vacuum in ground conditions is simulated using vacuum pumping equipment. One of the tasks that arises when creating a vacuum in ground conditions is to maintain such operating conditions, under which process pumping equipment do not affect test results parameters of on-board equipment. It is known that gas loads generated by ground process vacuum equipment are one of the critical components in vacuum testing [1]. Therefore, this article has investigated operation of a high-vacuum pumping plant in terms of ensuring minimum pressure without additional heating of the vacuum chamber.

A multifunctional high-vacuum plant was developed for pumping cryovacuum systems for space applications during ground-based experimental testing of on-board equipment. The general view of the plant is given in figure 1.

Unlike ground-based pumping equipment, the space vacuum pumps out all the gases. The technical literature describes mass spectra for different types of vacuum pumps [1]. The study [2] determined the mass spectra of gases for oil-free scroll vacuum pumps. In this paper, the mass spectra of gases were determined during a joint vacuum pumping of the vacuum pipe (vacuum chamber) of the multifunctional high-vacuum plant by means of several high-vacuum pumps.

Multifunctional high-vacuum plant [3] includes three high-vacuum pumps: a ion pump, a cryoadsorption pump, and a turbomolecular pump, which are mounted on a vacuum pipe, as well as two initial pumping pumps mounted on the plant's load frame.

Turbomolecular pump STP-iX455 with integrated controller has the following characteristics: 67 Pa maximum allowable backing pressure, and 55000 rpm rated speed. Pumping speed comprises 300 l/s for nitrogen and 300 l/s for hydrogen. Maximum operating pressure comprises $1.3 \cdot 10^{-1}$ Pa. Ultimate vacuum comprises $10^{-8}$ Pa.
Oil-free scroll pump nXDS10i of 3.2 l/s output with KF25 inlet flange and 7·10⁻³ mbar ultimate vacuum is used as an auxiliary pump for the turbomolecular pump. Oil-free scroll pump nXDS35i of 44 m³/h output with KF40 inlet flange and 10⁻² mbar ultimate vacuum is used for pumping the vacuum chamber.

The cryoadsorption pump with medium speed after regeneration with heating up to 100°C within 1.33·10⁻¹ – 1.33·10⁻³ Pa pressure range, at least 177 l/s, 1.33 – 1.33·10⁻³ Pa operating pressure range.

Titan 200L CV ion pump bears the following characteristics: 200 l/s pumping speed, at least 10⁻⁴ mbar starting pressure and 10⁻¹¹ mbar ultimate pressure.

The vacuum pipe is a hollow stainless steel cylinder with 95.6 mm inner diameter and 1 m length. CC-10 wide range gauges with 1000 to 10⁻⁹ torr measuring range are used to inspect vacuum in the multifunctional high-vacuum plant.

During pumping of the vacuum pipe in the multifunctional high-vacuum plant by means of high-vacuum pipes, gases have been inspected by Extorr100M mass spectrometer. Extorr 100M Mass Spectrometer is a quadrupole residual gas analyser, which has: built-in electronic multiplier; integrated hardware and software complex; partial pressure sensor: Faraday cup; Pirani gauge; ion gauge; ion source, open ion source, electron impact ionization; double iridium cathode. Extorr 100M analyzes masses in 1-100 range AMU with an error within 15%. The minimum partial pressure to be measure by this mass spectrometer is 10⁻¹¹ torr.

The object of our study was to determine the optimal operating mode of the multifunctional high-vacuum plant and the partial pressures of main gases inside the vacuum pipe when various high-vacuum pumps work together. The optimal operating mode of multifunctional high-vacuum plant in our study is regarded as when operation of high-vacuum pumps inside the vacuum pipe of the multifunctional high-vacuum plant will ensure minimum pressure.

The test sequence is as follows:
1) Initial pumping of the vacuum chamber of the plant;
2) High vacuum pumping of the vacuum chamber by the turbomolecular pump down to the minimum pressure.
3) Study of one or several high-pressure pumps running together.

Test results are shown in figures 2–8, which show partial gas pressures for different cases of high-vacuum pumps running.

Study results of main partial pressures of gases inside the vacuum chamber of the multifunctional high-vacuum plant are given in table 1. The following maximum peaks can be distinguished among the main masses: 1, 18, 28, 42, 44, 55 AMU.
Figure 2. Gas mass spectrum at pumping by turbomolecular pump.

Figure 3. Gas mass spectrum at pumping by cryoadsorption Pump.

Figure 4. Gas mass spectrum at pumping by ion pump.
Figure 5. Gas mass spectrum at pumping by turbomolecular and ion pumps.

Figure 6. Gas mass spectrum at pumping by cryoadsorption and ion pumps.

Figure 7. Gas mass spectrum at pumping by cryoadsorption and turbomolecular pumps.
Figure 8. Gas mass spectrum at pumping by cryoadsorption, ion and turbomolecular pumps.

Table 1. Gas mass maximum peaks at various pumping.

| Mass, AMU | Partial pressure, torr |
|-----------|------------------------|
|           | T          | K          | M          | T&M       | M&K       | T&K       | T&M&K     |
| 1         | 1.1·10^{-7} | 7.5·10^{-8} | 1.2·10^{-7} | 3.7·10^{-8} | 7.2·10^{-8} | 1.05·10^{-8} | 2.5·10^{-8} |
| 18        | 9.5·10^{-9} | 5.0·10^{-9} | 6.0·10^{-9} | 7.10^{-9} | 1.8·10^{-9} | 4.2·10^{-9} | 3.5·10^{-9} |
| 28        | 1.5·10^{-8} | 1.5·10^{-8} | 3.2·10^{-8} | 9·10^{-9} | 1.0·10^{-8} | 2.2·10^{-9} | 4.2·10^{-9} |
| 40        | 1.5·10^{-9} | 5.0·10^{-10} | 2.5·10^{-9} | 1.0·10^{-9} | 1.0·10^{-9} | 5.0·10^{-10} | 5.0·10^{-10} |
| 42        | 1.1·10^{-8} | 5.0·10^{-9} | 8.0·10^{-9} | 3.0·10^{-9} | 2.0·10^{-9} | 1.0·10^{-9} | 1.0·10^{-9} |
| 44        | 1.0·10^{-9} | 3.0·10^{-9} | 3.0·10^{-9} | 1.3·10^{-9} | 1.0·10^{-9} | 5.1·10^{-10} | 5.1·10^{-10} |
| 55        | 5.0·10^{-9} | 3.0·10^{-9} | 4.0·10^{-9} | 1.5·10^{-9} | 1.0·10^{-9} | 5.0·10^{-10} | 5.0·10^{-10} |

Legend: T – pumping by turbomolecular pump, K – pumping by cryoadsorption pump, M – pumping by ion pump, & - joint pumping.

Experiment results are as follows:

1. Pressure inside the multifunctional high-vacuum plant vacuum pipe at high vacuum, regardless of the pump type in operation, is determined by the hydrogen ion partial pressure, which makes the main contribution during pumping. Moreover, one may note that in all cases, regardless of the high-pressure pump type in operation, the total pressure in the vacuum chamber of the plant is determined by the partial pressure of three components: 1, 18, 28. The partial pressures above 55 AMU make an insignificant contribution to the total pressure inside the vacuum chamber of the plant.

2. When pumping by a turbomolecular pump, the partial pressures of hydrogen ion (1 AMU) and water vapour (18 AMU) have the greatest impact on the total pressure inside the vacuum chamber of the plant. As can be seen from the diagrams, the water vapours are effectively pumping by the cryoadsorption pump. At the same time, the hydrogen ion partial pressure is the determining factor for the total pressure inside the vacuum chamber when pumping by the cryoadsorption pump. As for the ion pump after pumping water vapours by the cryoadsorption pump, the hydrogen ion partial pressure is also a determining factor in the total pressure inside the vacuum chamber of the plant.

3. Turbomolecular and cryoadsorption pumps together provided 1.1·10^{-8} torr minimum pressure inside the plant's vacuum pipe, although prior to research it was assumed that three high-vacuum pumps would provide the best vacuum.
Thus, during ground testing of on-board equipment, the most effective method to provide the high vacuum inside the cryovacuum systems is to jointly use turbomolecular and cryoadsorption pumps with the ion pump operating periodically.

References
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