Multifunctional high-vacuum plant for cryovacuum systems in aerospace applications

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Abstract. The article describes a design and main features of a multifunctional high-vacuum plant. This installation provides high-vacuum pumping of cryovacuum systems for space applications during a long time with 100 liter volume, leak detection with $5 \times 10^{-13}$ m³Pa/s minimum registered helium flow and monitoring of the mass spectrum within 1...100 AMU range.

The onboard equipment of remote sensing spacecrafts widely employs cryovacuum systems designed to maintain set temperatures in photodetectors. Photodetectors are placed inside cryovacuum systems. Main components of cryovacuum systems are a vacuum chamber and a cryocooler. During ground experimental testing of on-board equipment as part of the spacecraft, it is necessary to ensure a long-time high vacuum inside the vacuum chamber of the cryovacuum system. In practice, pumping plants based on turbomolecular and mechanical pumps have been widely used in ground testing [1]. Despite their well-known advantages, such pumping plants have a number of the following drawbacks that are essential when operating highly sensitive on-board space equipment:

- necessity of power source and vibrations during operation;
- necessity of on-duty operator when operating onboard equipment at night;
- partial only pumping of gases out of the cryovacuum system.

A multifunctional plant has been developed to ensure a high vacuum during ground testing of the test object - optoelectronic devices of the on-board equipment placed inside the cryovacuum system - and to eliminate the drawbacks mentioned above.

Let us list the main requirements for modern pumping equipment during ground testing of optoelectronic devices of spacecraft placed inside the cryovacuum system:

- oil-free initial pumping and high-vacuum pumping, if possible, of the maximum spectrum of gases out of the cryovacuum system;
- monitoring of pressure and mass spectrum of gases during pumping out;
- leak detection of the cryovacuum system using oil-free pumping equipment;
- leak-in of dry inert gas into the pumped-out volume of the test object;
- minimum outgassing of the pumping unit, which shall be significantly lower than that of the test object;
- maintaining of the vacuum inside the vacuum chamber of the plant for a long time without the use of pumping equipment;
- high vacuum pumping of the test object during component tests and integrated spacecraft tests;
- ensuring the operation of the unit for at least two days (including night time) without operator's supervision;
- convenient and accessible connection of the pumping plant to the test object during spacecraft tests.

The multifunctional high-vacuum plant is a vacuum system with leakage of no more than $10^{-10}$ m$^3$·Pa/s, including high-vacuum and low-vacuum parts. The multifunctional high-vacuum plant has a mobile frame, on which pumping equipment and instrumentation are installed (figure 1). Dimensions of the multifunctional high-vacuum plant are: height 1830 mm, width 1100 mm, length 1300 mm. The height of the vacuum pipe above the ground is 1655 mm (figure 1).

![Figure 1. Appearance of multifunctional high-vacuum plant.](image)

The high-vacuum part of the multifunctional high-vacuum plant includes Conflat-type copper gaskets, while the low-vacuum part includes KF quick-connect couplings with Viton O-Rings. The main vacuum chamber of the plant is a stainless steel vacuum pipe with 95.6 mm inner diameter and 1 m length. Three high-vacuum pumps, namely - turbomolecular, cryoadsorption and ion pumps - are mounted on the vacuum pipe. Each high-vacuum pump with DN100 inlet is mounted via a gate valve with CF100 gasket, which allows pumping by one or several pumps simultaneously.

The main high-vacuum pump within the plant is STP-iX455 oil-free turbomolecular pump with natural cooling, an integrated controller, a rotor suspended by magnetic bearings, 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 $1.3\cdot10^{-1}$ Pa. Ultimate vacuum comprises $10^{-8}$ Pa.

Oil-free scroll pump nXDS10i of 3.2 l/s output with KF25 inlet flange and $7\cdot10^{-3}$ mbar ultimate vacuum is used as an auxiliary pump for the turbomolecular pump. Oil-free scroll pump nXDS35i of 44 m$^3$/h output with KF40 inlet flange and $10^{-2}$ mbar ultimate vacuum is used as the main pump for initial pumping the test object.

Cryoadsorption and ion pumps serve as additional high-vacuum pumps. The cryoadsorption pump with medium speed pumping after regeneration with heating up to 100°C within $1.33\cdot10^{-1}$ – $1.33\cdot10^{-3}$ Pa pressure range, at least 177 l/s, $1.33\cdot10^{-1}$ Pa operating pressure range.

Titan 200L CV with 200 l/s pumping speed, at least $10^{-4}$ mbar starting pressure and $10^{-11}$ mbar ultimate pressure serves as a ion pump.
In order to fill the test site with dry gas after experimental testing, a Messer Constant 2000 reducer was used in the plant, allowing dry gas to be fed directly from a high-pressure cylinder into the vacuum chamber of the cryovacuum system. During this process, the pressure is monitored using DM5002 digital pressure gauge.

Extorr100M mass spectrometer is mounted on the pipe body, measuring the mass spectrum of gases within 1 ... 100 AMU range with 15% maximum error. 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. The minimum partial pressure to be measure by this mass spectrometer is $10^{-11}$ torr.

For the purpose of leak detection of the test object, the multifunctional high-vacuum plant includes MS-4M leak detector based on a hybrid turbomolecular and oil-free initial scroll pump with $5 \times 10^{-13}$ m$^3$/s minimum registered helium flow (according to its data sheet).

CC-10 type wide range gauges with $1000 \ldots 10^9$ torr measuring range and up to 50 °C operating temperature were used to measure vacuum in the multifunctional high-vacuum plant.

Data from vacuum gauges, mass spectrometer and digital pressure gauge are transferred via RS-485 interface to PPC-4211W panel computer based on Intel 4th Generation Core I CPU i5-4300U, 2.9 GHz.

The electrical connection diagram of multifunctional high-vacuum plant instrumentation and the vacuum diagram of multifunctional high-vacuum plant are shown in figures 2 and 3, respectively.

![Electrical circuit of connections of instrumentation of multifunctional high-vacuum plant.](image_url)
microassemblies of on-board equipment. The helium leak detector, which is part of the multifunctional high-vacuum plant, allows leak tests of the cryovacuum system during ground testing without any additional mountings. The cryoadsorption pump used during high-vacuum pumping of the test object ensures that the on-board equipment is tested without additional electromagnetic interference.

![Vacuum circuit of multifunctional high-vacuum plant.](image)

Figure 3. Vacuum circuit of multifunctional high-vacuum plant.

Main advantages of the developed multifunctional high-vacuum plant are listed below:

- low outgassing due to metal sealings in the high-vacuum part.
- multifunctional high-vacuum plant vacuum pipe ensures its convenient connection to the cryovacuum system vacuum pipe within the spacecraft.
- flexibility of the multifunctional high-vacuum plant allows both gas pumping and filling operations.
- inverted magnetron vacuum gauges makes it possible to maintain average vacuum for a long period of time inside the multifunctional high-vacuum plant vacuum pipe when the pumps are not running, which does not require additional time for multifunctional high-vacuum plant pre-pumping.
- various high-vacuum pumps with different pumping speeds for different gases ensure a highest possible vacuum inside the test object.

Results of the multifunctional high-vacuum plant tests, without additional outgassing for the vacuum plant are shown in figures 4 and 5.

The pumping curve during 8 hours with high-vacuum pumps being switched on in sequence is shown in figure 4. Minimum pressure inside the vacuum chamber of the plant after 24 hours comprised $2.5 \times 10^{-8}$ torr. The mass spectrum of gases inside the vacuum pipe when three high-vacuum pumps are running is shown in figure 5. As one can see from figure 5, maximum partial pressure belongs to 1 AMU, moreover, the diagram indicates peaks at 18 AMU and 28 AMU.

The multifunctional high-vacuum plant at initial pumping down to $10^{-2}$ torr reaches its normal operation mode after less than 2 hours, and less than 5 hours at high-vacuum pumping to $1.0 \times 10^{-7}$ torr. Ultimate vacuum in the vacuum chamber of the multifunctional high-vacuum plant without heating comprises $2 \times 10^{-8}$ torr.
Thus, the article presents the requirements for the design of a multifunctional high-vacuum plant for the purpose of ground testing of on-board equipment as part of a spacecraft, and describes its design and main technical characteristics. The developed multifunctional high-vacuum pumping plant provides high-vacuum pumping of cryovacuum systems for space applications during a long time with 100 l volume, leak detection with $5 \cdot 10^{-13}$ m$^3$/Pa/s minimum registered helium flow and monitoring of the mass spectrum within 1 ... 100 AMU range.

References

[1] Rozanov L N 2012 Vacuum process equipment 4 35