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Vacuum Acceptance Tests for the UHV Room Temperature Vacuum System of the LHC during LS1

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Abstract

During the CERN Large Hadron Collider (LHC) first long shut down (LS1), a large number of vacuum tests are carried out on consolidated or newly fabricated devices. In such a way, the vacuum compatibility is assessed before installation in the UHV system of the LHC. According to the equipment's nature, the vacuum acceptance tests consist in functional checks, leak test, outgassing rate measurements, evaluation of contaminants by Residual Gas Analysis (RGA), pumping speed measurements and qualification of the H2 sticking probability of Non-Evaporable-Getter (NEG) coating. In this paper, the methods used for the tests and the acceptance criteria are described. A summary of the measured vacuum characteristics for the tested components is also given.

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VACUUM ACCEPTANCE TESTS FOR THE UHV ROOM TEMPERATURE VACUUM SYSTEM OF THE LHC DURING LS1

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Abstract

During the CERN Large Hadron Collider (LHC) first long shut down (LS1), a large number of vacuum tests are carried out on consolidated or newly fabricated devices. In such a way, the vacuum compatibility is assessed before installation in the UHV system of the LHC. According to the equipment's nature, the vacuum acceptance tests consist in functional checks, leak test, outgassing rate measurements, evaluation of contaminants by Residual Gas Analysis (RGA), pumping speed measurements and qualification of the H_2 sticking probability of Non-Evaporable-Getter (NEG) coating. In this paper, the methods used for the tests and the acceptance criteria are described. A summary of the measured vacuum characteristics for the tested components is also given.

INTRODUCTION

From January 2013 to June 2014, more than 210 vacuum acceptance tests have been carried out for the LHC, accounting to about 1100 devices. The aim of these tests is to assess the compatibility of each device with the LHC vacuum system, as described in the LHC design report [1].

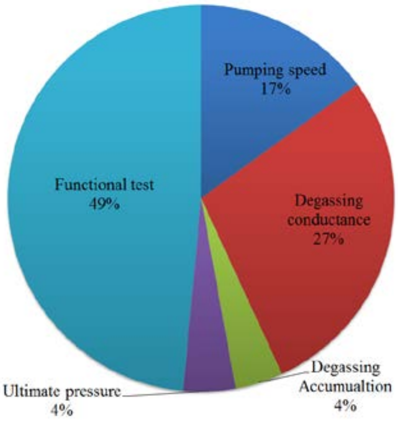


Figure 1: Tests carried out for the LHC during the LS1.

Figure 1 shows the percentage for each type of test. Two families of tested components can be distinguished. The first is represented by elementary components, which eventually integrate into equipment, such as vacuum pumps, pressure gauges or special materials like ferrite tiles. The second is composed of assemblies such as roman pot stations, collimators, and beam position monitors. In general, the testing sequence is similar and follows the same list of actions [2]: visual inspection at reception; vacuum connection to the dedicated test bench; pump down; preliminary leak detection; functional tests; bake-out cycle with adjusted temperature ramps and temperature dwell duration; ultimate pressure recording; and finally RGA scans. In the last steps, the equipment functionality and leak tightness are retested before their installation in the LHC. Specific tests like pumping speed measurements for ion pumps and qualification of H_2 sticking probability of NEG coatings are also performed by means of gas injection.

In this paper, the methods used will be presented together with the defined test criteria. In addition, a summary of the measured vacuum characteristics will be given.

TEST METHODS

Functional Check

Functional checks consist in verifying the functional working status of devices such as penning pressure gauges, ion pumps, and NEG cartridges. For this, each device is switched-on and its operational state verified under vacuum before and after the bake-out cycle.

Pumpdown Preliminary Test

For every vacuum tests performed, the pressure during pumpdown is recorded before bake-out. Pressures (P) versus time (t) curves are plotted on a double-logarithmic scale graph. In the high-vacuum region, for metallic substrates, the pressure decrease should be fitted by a 1/t equation:

$$P(t) \propto \frac{1}{t} \tag{1}$$

This equation provides information about the time needed to pump down vacuum systems before bake-out. In this condition, water vapour adsorbed onto the surfaces drives the outgassing process. This test is usually operated when successive tests of the same device are carried out; by comparing the different slopes, it could be possible to have immediate indication of possible non-conformity such as presence of contaminant and virtual leaks.

Leak Test

Global leak testing by the helium spraying method is systematically performed at reception of equipment and after the bake-out cycle to verify leak tightness integrity before and after thermal cycle.

To validate this test, the sensitivity of the measurement must remain in the 10^{-11} mbar·l/s range [3]. Helium signal increase higher than ≈ $2.0 \cdot 10^{-10}$ mbar·l/s results in non-conformity; the device is then rejected.

Outgassing Measurements

The throughput method is used to measure the total N_2 equivalent outgassing rate of nearly all tested devices. Such a method is based on the differential pressure measurement by two Bayard-Alpert ionization gauges (BA) placed on both sides of a known gas conductance. It is carried out 48 hours after the end of the bake-out cycle; a blank measurement of the system enables verifying the outgassing rate of the measuring system itself.

For devices with active pumping installed, the total ultimate pressure is recorded by a BA gauge located onto the device. At the gauge location, the effective pumping speed is calculated and the total outgassing rate is calculated.

The acceptance threshold for the outgassing rate is listed in a vacuum specification originally written for the LHC collimators [3]: the total outgassing rate must be lower than $2.0 \cdot 10^{-7}$ mbar·l/s [4]. Considering this outgassing rate and the effective pumping speed available at the location where the specific device is installed, a maximum pressure of $1 \cdot 10^{-8}$ mbar is ensured in the LHC vacuum system that correspond to the requested 100 hours of beam life time in stable operation condition [1].

Residual Gas Analysis

Residual gas analysis (RGA) is used to control the absence of contamination and air leak, and additionally to measure partial pressures after bake-out. In a baked vacuum system, H_2 is in general the dominant gas. All partial pressures of other gas species have to be lower than that of H_2. For this, a template of acceptance limits is defined and applied to RGA currents, normalised to the mass 2 amu H_2 peak. The template of acceptance limits for metallic components is illustrated in Fig. 2.

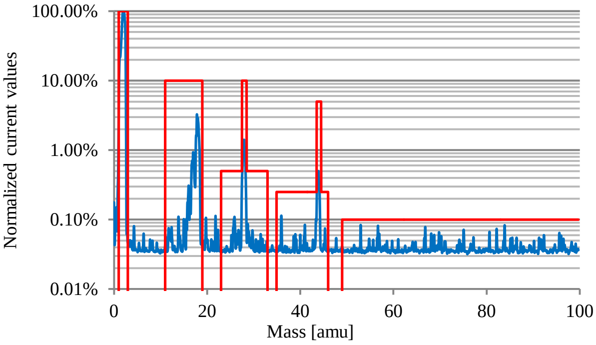


Figure 2: RGA scan normalised to mass peak 2 amu and acceptance thresholds (copper alloy sample after bake-out).

The characteristic mass peaks of CH_4, H_2O, and CO, i.e. 16, 18, and 28, respectively, have to be at least 10 times lower than the mass peak at 2 amu. Mass 44, the main peak of CO_2, has to be a factor of 20 lower than the peak at 2 amu. Finally, heavy-hydrocarbon mass peaks over 50 amu have intensities 1000 times smaller than mass peak 2.

Virtual Leaks

After bake-out, no signal of argon must be recorded by RGA. When the RGA scan shows typical air mass peaks and no external leak is detected by the helium leak detection, the virtual leak rate is measured by an accumulation test. Such a test is performed by isolating the test system from all active pumping. Pressure and RGA signals are monitored during the accumulation time as shown in Fig. 3.

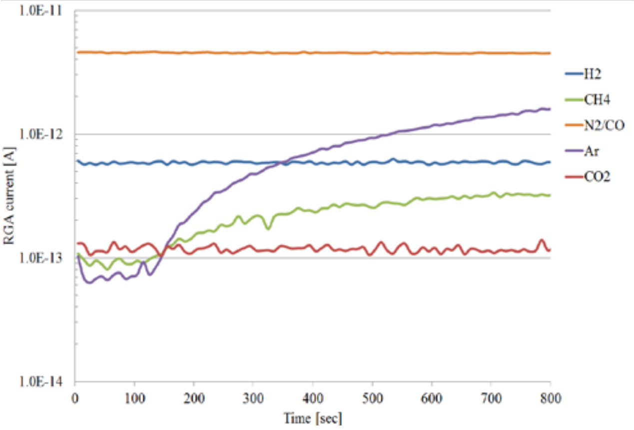


Figure 3: Accumulation test of a below-module vacuum insert after bake-out showing the increase of the main argon peak.

The virtual leak rate is estimated by calculating the increase of the Ar peak signal over a fixed period of time. The RGA calibration curves are then used to estimate the Ar partial pressure and consequently the total internal leak. The acceptance limit for a virtual air equivalent leak in the LHC UHV system is fixed to less than $5.0 \cdot 10^{-9}$ mbar·l/s. For this value, virtual leaks would produce at most the complete saturation of 1 m long, 8 cm diameter NEG coated standard beam pipe in about 150 days.

Pumping Speed Measurement

The pumping speed performance of about 140 refurbished ion pumps has been assessed. Pumping speed measurements for N_2 and CH_4 have been carried out by gas injection, after a bake-out cycle of 24 hours at 250°C. The acceptance criteria for this test are defined with respect to the nominal pumping speed of such a type of pumps (VPIA in CERN acronym). In order to be accepted, the minimum measured pumping speed at $1.0 \cdot 10^{-7}$ mbar has to be 15 l/s for N_2 and 25 l/s for CH_4.

NEG Coated Beam Pipe

The transmission method is used to determine the sticking probability of critical NEG coated beam pipes before installation in the LHC. For this, H_2 is injected in the NEG coated beam pipes, previously vacuum heated for activation at 230°C for 24 hours. During the injection, the pressure increases at both extremities of the vacuum chamber are measured by BA gauges. The sticking probability is obtained as a function of the pressure ratio by Monte-Carlo simulation (Molflow+). The acceptance threshold for H_2 sticking probabilities is $1\cdot10^{-3}$ [5].

RESULTS AND CONCLUSION

Among the 1096 tested devices, 49 (5%) were not accepted for installation in the LHC. As indicated in Fig. 4, the majority of these non-conformities were observed during functional and pumping speed measurement tests.

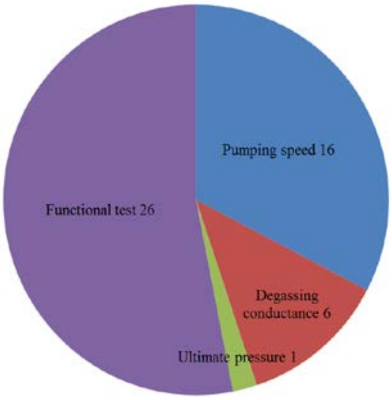


Figure 4: Distribution of non-conformities.

16 out of 140 refurbished ion pumps were rejected due to insufficient pumping performance. The average pumping speed of accepted pumps is 27 l/s for N_2 and 42 l/s for CH_4 at operating pressure of $1\cdot10^{-7}$ mbar.

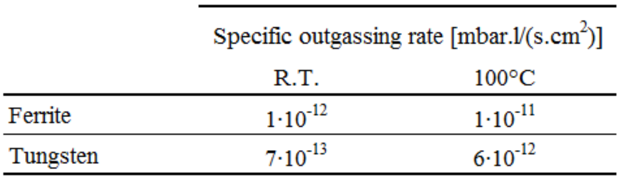
Functional-test non-conformities were found in NEG coated parts that were under development.

RGA analysis results confirmed the absence of contaminants in every tested device.

As an example, the outgassing rate measured after bake-out for a stainless steel vacuum bellow with copper RF screen ranges from $9\cdot10^{-10}$ to $5\cdot10^{-9}$ mbar·l/s, depending of its geometrical dimensions. On the other hand, a vacuum sector valve, which generally isolates the sectors at cryogenics temperature from those at room temperature, has an average measured outgassing rate of about $2\cdot10^{-8}$ mbar·l/s in open position.

Additionally, Table 1 gives specific outgassing rates measured for constitutive materials of collimators (TCTP) such as ferrite and tungsten after cleaning and bake-out, at two different temperatures.

Table 1: Specific Outgassing Rates Measured for Ferrite and Tungsten.



	Specific outgassing rate [mbar.l/(s.cm^2)]	
	R.T.	100°C
Ferrite	$1\cdot10^{-12}$	$1\cdot10^{-11}$
Tungsten	$7\cdot10^{-13}$	$6\cdot10^{-12}$

Finally, Fig. 5 shows the outgassing rate for some fully assembled LHC machine devices. Only one was rejected due to an internal leak that appears after the bake-out and presumably originating from a coaxial cable.

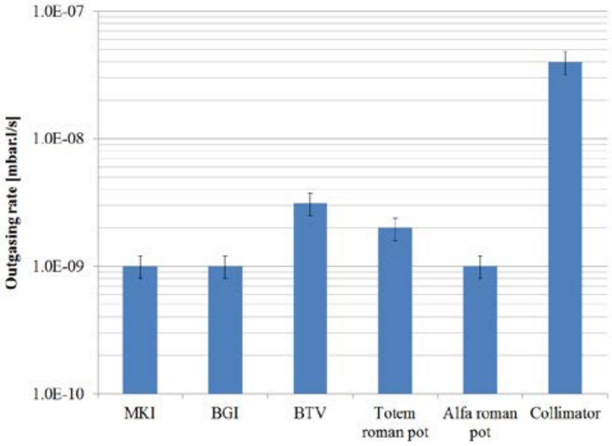


Figure 5: Outgassing rates after bake out of some LHC machine devices tested during LS1 (MKI: injection kicker; BGI and BTV: beam monitors; Totem and Alpha roman pot: detectors).

Thanks to vacuum acceptance procedures and test methods, it was possible to filter out and reject devices whose vacuum performance would not have been conforming to the stringent requirements of the LHC vacuum system.

ACKNOWLEDGMENT

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REFERENCES

[1] LHC design report, vol.1, the LHC main ring
[2] G. Cattenoz, CERN, EMDS 1312756
[3] J.M. Jimenez, CERN, EDMS 428155
[4] G. Bregliozzi, CERN, EDMS 1113402.
[5] G. Lanza et al, CERN, these proceedings.