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Research Paper

Effect of Drag Stages Surface Roughness on the Compression Ratio of a TMDP

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Abstract The rotor of a turbomolecular drag pump is generally made of an aluminum alloy. Its surface finish is affected by various processes that the rotor itself undergoes during the manufacturing phase. The impact of different surface finishes on the pumping performances of a turbomolecular pump has been mainly investigated by Sawada et al [1]. The present work aims to broaden the previous bibliographic study to the drag stages of a turbomolecular pump by testing the impact of different surface finishes on the compression ratio of the pump. Experimental tests have been made focusing on two processes: the corundum sandblasting and the glass microspheres shot-peening. Both the processes flatten and/or physically remove EDM melted spheres; in particular, blasted surfaces obtained by glass shot-peening are generally smoother than surfaces obtained by corundum sandblasting. In order to characterize the surface texture left by such processes, preliminary surface roughness measurements have been made on the drag rotor disks of several pumps. The experimental tests conducted on both sandblasted and shot-peened rotors confirms previous results obtained on the turbo stages by Sawada et al. [1], showing that the average roughness of the surface has an impact on the compression ratio of the pump; in particular, an increment in the surface roughness causes a corresponding increment in the compression ratio of the pump and vice versa. For the tested pumps, the higher surface roughness gives a factor of increment of about 2 on the measured hydrogen maximum compression ratio of the pump.

Keywords: Surface roughness, Compression ratio, Turbomolecular drag pump, Shot-peening, Sandblasting

I. Introduction

Commercially available turbomolecular drag pumps (TMDP) consist of several turbo stages in series with a number of molecular drag pump (MDP) stages that depends on the desired compression ratio. The MDP stages are used at the foreline side of the turbo stages in order to extend the discharge pressure at which the pump can keep its maximum compression ratio (foreline tolerance) from the 10^{-1} mbar range up to the 10 mbar range [2]. Moreover, the addition of these stages causes a strong increase in the compression ratio of light gases. Three molecular drag concepts are known: Gaede [3], Holweck [4,5] and Siegbahn [6]. In particular, the TwisTorr technology developed by Varian Inc. ([7,8,9]) is based on the Siegbahn MDP concept and exploits a smooth disk rotor and a number of spiral grooves machined on the stator pumping in parallel (channels). Each stage can be composed by a half section pumping in centripetal direction in series with another half section pumping in centrifugal direction.

The rotor of a turbomolecular drag pump is generally made of an aluminum alloy. Its surface finish is affected by various processes that the rotor itself undergoes during the manufacturing phase (i.e. turning, electrical discharge machining/milling and blasting/shot peening). In particular, the average roughness R_a of the surface could increase due to the turning phase, to the electrical discharge machining/milling and or to blasting processes. The final surface finish of the material is measurable after all these processes are completed. The impact of different surface finishes on the pumping performances of a turbomolecular pump has been mainly investigated by Sawada et al [1]. Sawada et al. studied experimentally and theoretically the effect of the surface roughness of the blades on the pumping performance of the TMP comparing results obtained with and without a SiO_2 coating. Their experimental results for TMP with two rotor disks and one stator disk showed that the TMP coated with SiO_2 gave about 11% to 13% higher maximum compression ratio per disk than the noncoated one when the blade speed ratio c is 0.47 [1]. However, it has to be noted that the work by Sawada et al. only focused on the turbo stages of the TMP while the drag stages were not taken into account. From this point of view, the present work aims to broaden the previous bibliographic study by investigating the effect of different drag stages surface roughness on the hydrogen compression ratio of the TMDP.

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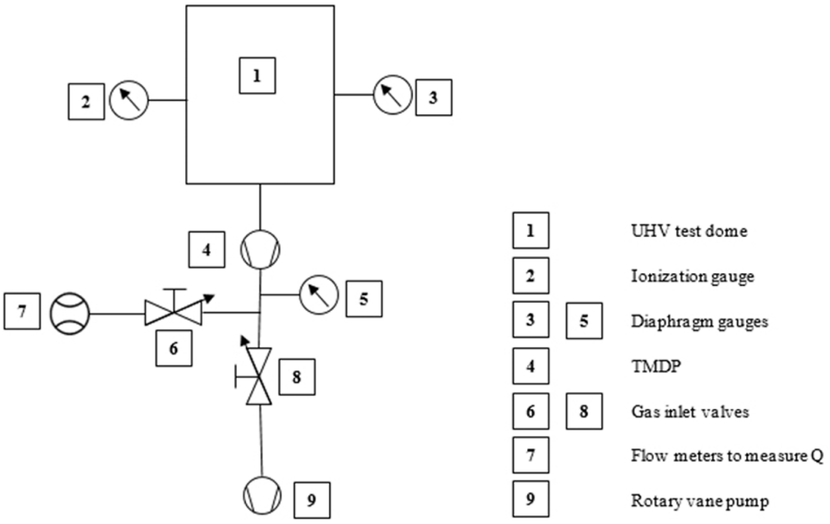

Figure 1. Experimental setup.

II. Materials and Methods

1. Experimental setup

Figure 1 shows the experimental setup. It has to be noted that both the experimental setup and the measurements were made in accordance with the ISO 5302 norm [10]. Referring to Figure 1, the backing pump is a rotary vane pump that reaches a base pressure in the low 10^{-3} mbar. An ionization gauge (type UHV-24 manufactured by Agilent Technologies, Lexington, MA) and different diaphragm gauges (type 627D Baratron® manufactured by MKS Inc., Andover, MA) have been mounted on the test dome and on the foreline side of the tested TMDPs, respectively. In particular, two different diaphragm gauges have been mounted on the test dome, reading a maximum pressure of 0.1 mbar and 1 mbar, respectively; while on the foreline side of the TMDP three different diaphragm gauges have been used ranging within 1 mbar and 100 mbar. The ionization gauge has been previously calibrated using a spinning rotor gauge in the range between 10^{-5} and 10^{-2} mbar (type VM211 manufactured by Leybold) and a stabil-ion gauge (model 360 manufactured by MKS, Granville-Phillips division, Longmont, CO, USA) in the range 10^{-6}-10^{-5} mbar. The diaphragm gauges have been also previously calibrated using a reference diaphragm gauge (type 390HA manufactured by MKS Inc., Andover, MA). Finally, four different flow meters (type 179B manufactured by MKS Inc., Andover, MA) ranging from 10 sccm to 10000 sccm have been used in order to measure the gas throughput Q given at the foreline side of the TMDP.

The considered turbomolecular drag stages are based on the TwisTorr technology ([7,8,9]). Its main geometrical parameters are reported in [7] and are shown in Figure 2. Each stage is composed by a half section pumping in centripetal direction (CP) in series with another half section pumping in centrifugal direction (CF) as described in Figure 2. In particular, the tested TMDP has a total of six TwisTorr stages, including three centripetal and three centrifugal half stages.

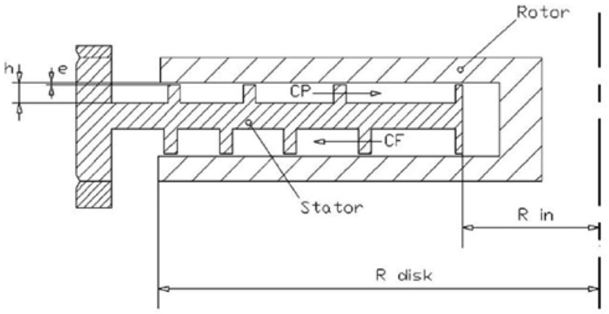

Figure 2. Typical SMDP cross section as reported in [2].

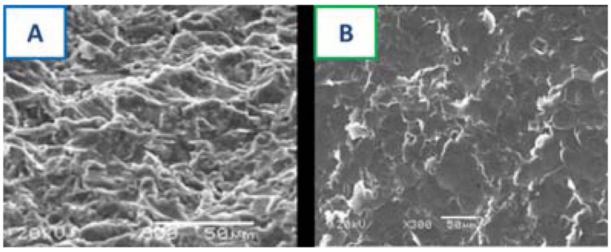

Figure 3. SEM rotor surface analysis; A: corundum blasted drag stages; B: glass peened drag stages.

The surface roughness of the rotor disks is measured using a surface roughness tester (type SURFTEST SJ-210 manufactured by Mitutoyo Ltd, UK) on all tested TMDPs according to the ISO1997 roughness standard [11]. In order to flatten and/or physically remove EDM melted spheres, the tested TMDPs have undergone a sandblasting or a shot-peening process. Figure 3-A shows the typical surface of a corundum sandblasted rotor while in Figure 3-B the picture of a glass microspheres shot-peened rotor is visible. According to Figure 2, the measured average roughness referred to the rotor disks which overlook the CF mode of the static parts, while the rotor disks corresponding to the CP mode of the static parts have a constant average roughness of approximately 1 μm for all the disks.

2. Experimental procedure

Before starting each test, the test dome has been evacuated by operating the TMDP so as to reach an ultimate pressure usually ranged between high 10^{-8} and low 10^{-7} mbar. All the tests have been performed in the pressure range that is at least 5 times as high as the ultimate pressure. It has to be noted that an ultimate pressure in the order of 10^{-10} mbar has been reached after heating the test dome. With the TMDP running, a test gas is admitted into its foreline side. Since the goal of the test is to accurately measure the maximum compression ratio of the TMDP, the chosen test gas is hydrogen. After a desired pressure has been attained in the test dome, the inlet and foreline pressures are measured using the ionization gauge and the diaphragm vacuum gauges. The pressures are recorded simultaneously when both of them are stable to within ±5% over 5 minutes as reported in [10]. At the inlet side of the TMDP, the ionization gauge is used to measure the test dome pressure when it decreases below the 10^{-4} mbar, while the diaphragm gauges are used in the pressure range 10^{-4} mbar-0.1 mbar. Finally, the foreline diaphragm gauges are used to measure the foreline pressure in all the experiments.

These measurements are performed considering a sample of seven TMDPs having R_a values comprised between 1.5 and 5 microns and obtained either by corundum sandblasting or glass microspheres shot-peening.

III. Results and Discussion

The compression ratio (K) is defined as the ratio of the foreline pressure to the inlet pressure when gas is not admitted into the inlet side of the TMP [10]. Figure 4 shows the correlation between the maximum compression ratio (K_{max}) measured for the considered sample of TMDPs and the average roughness R_a measured on the drag stages rotor disks of the corresponding pumps. As can be seen from the figure, by increasing the roughness we found a corresponding increase in the maximum compression ratio of the pump. In particular, increasing the R_a of a factor of about 3, we obtain a maximum compression ratio which is about two times higher. For more details, numerical data has been reported in Table 1.

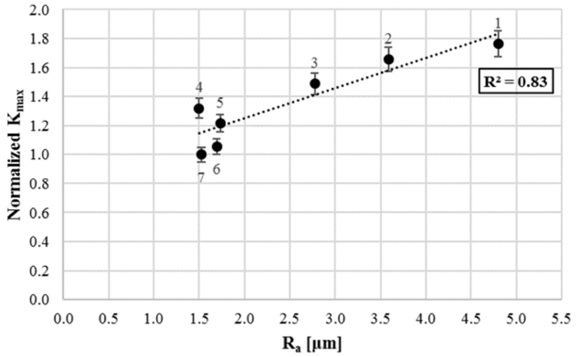

Figure 4. Relationship between the maximum compression ratio and the average roughness of the rotor drag stages Ra.

Table 1. Maximum compression ratio and corresponding average roughness.

Pump #	Average Roughness R_a [µm]	Maximum Normalized K
1	4.8	1.8
2	3.6	1.7
3	2.8	1.5
4	1.5	1.3
5	1.7	1.2
6	1.7	1.1
7	1.5	1.0

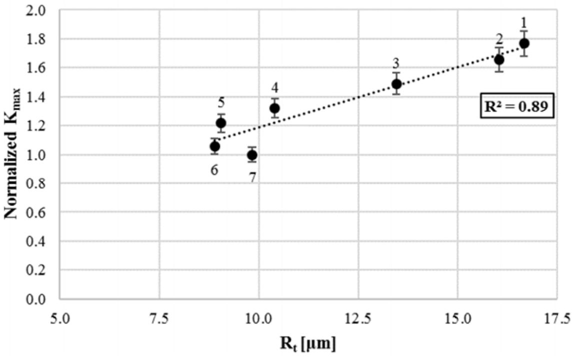

Figure 5. Relationship between the maximum compression ratio and maximum roughness of the rotor drag stages Rt.

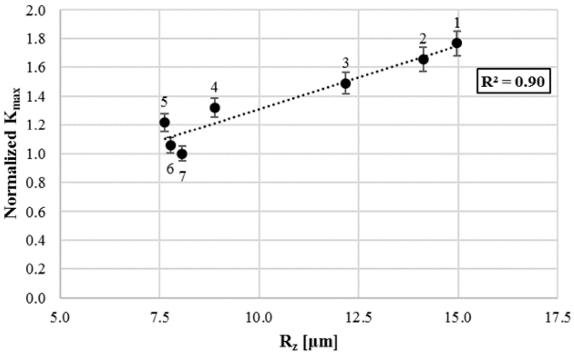

Figure 6. Relationship between the maximum compression ratio and roughness of the rotor drag stages Rz.

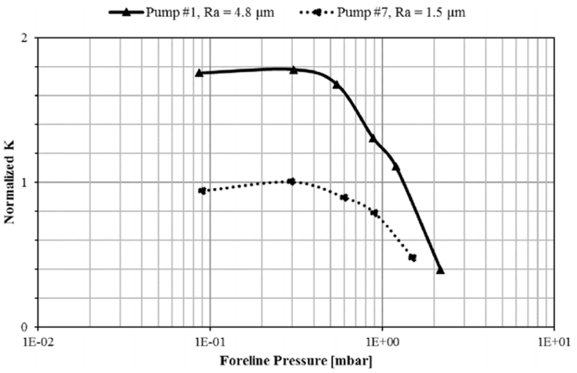

Figure 7. Compression ratio for H2. Comparison among two samples having different average roughness.

It has to be noted that the R_a parameter does not discriminate between peaks and valleys thus, in order to fully characterize the surface profile, R_t and R_z have also been considered. These parameters allowed us to estimate the order of magnitude of the maximum height of the peaks and the minimum depth of the valleys found along the evaluation length of the profile. The trends K_{max}-R_t and K_{max}-R_z are visible in Figure 5 and Figure 6, respectively. Also in this case we can observe a good correlation of both these parameters with the maximum compression ratio of the pump.

Figure 7 shows the experimental H_2 compression ratio measured for the two pumps having the highest and the lowest surface roughness, identified by number # 1and # 7, respectively. The maximum compression ratios K_{max} are clearly visible in Figure 7 as the average values of the flat zone of the curves, corresponding to foreline pressures below 0.6 mbar.

IV. Conclusions

The present work aimed at investigating the impact of different surface finishes of the drag stages on the compression ratio of the pump. In order to do this, a sample consisting of seven different TMDPs has been created. In particular, the sample gathered pumps having different surface roughness (1.5 μm to 5 μm) obtained subjecting the rotor to the sandblasting or the shot peening process. After preliminary surface roughness measurements, the standard compression ratio [10] test has been performed on all the seven pumps. Results showed a good correlation between the maximum compression ratio K_{max} of the pump and its average roughness R_a, confirming previous results obtained by Sawada on turbo stages [1]. In particular, K_{max} increases by a factor of 2 tripling the average roughness R_a. Moreover, similar correlations have been obtained by considering parameters R_t and R_z that give an estimation of the maximum roughness of the rotor and the maximum height of the surface profile. Finally, the comparison of compression ratios shows a corresponding increase in the pumps having higher R_a. We suppose that the increase in the maximum compression ratio of the TMDP estimated for the hydrogen is related to a variation in the viscous slip-flow conditions near the rotating disk [12]. However, it has to be noted that the theoretical modeling of the physical phenomena is beyond the purpose of this article and it will require further investigation.

Next step should be to investigate the influence of different surface finishes on the static parts of the TMDPs with particular reference to the drag static parts.

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