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Progress of establishing a standard for measuring the performance of mechanical booster vacuum pump by ISO TC 112

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ABSTRACT

Mechanical booster vacuum pumps (MBVPs) are widely used in many industrial applications in recent decades. While the performance measurement standard for MBVPs characterizing is still inadequate due to the strong dependence on the backing pump being not always known in advance. In order to ensure that the performance measurement of MBVPs is, as far as possible, carried out by uniform procedures and under uniform conditions, special pump characteristics are discussed and analyzed including the maximum tolerable pressure difference Δp_{max}, effective compression ratio K_{eff}, compression ratio with zero throughput K_0 and by-pass valve pressure difference Δp_1. These parameters are practically proved to be sufficient and necessary to indicate the properties of MBVPs in the end. Simplified methods are introduced and discussed based on K_0 to estimate the performance of MBVPs. Based on the results of practical usage and the existing standard of different countries, a corresponding experimental system is set up and detailed experimental principle is considered. It is intent that, as a result, measurements conducted by different manufacturers or in different laboratories, and statements of performance quoted in manufacturers' literature will be on a properly comparable basis to the benefit of both users and manufacturers.

1. Introduction

A mechanical booster vacuum pump (MBVP), also known as Roots vacuum pump, is a kind of vacuum pumps based on mechanical principle and is used between the backing pump and the high vacuum pump or backing pump and the process chamber. It could either increase the throughput of the pumping system in medium or rough vacuum applications, or improve the compression within the system to reduce the volume flow rate needed for the backing pump [1]. MBVPs are nearly all Roots, although other types (screw, molecular drag and vapour boosters) have been used [2]. By increasing vacuum pumping system efficiency and cost effectiveness MBVPs have become increasingly important in industrial applications particularly for vacuum exhausting in semiconductor fabrication and new high-technology industries (like photonics, laser, vacuum heat treatment, nuclear research, precision manufacturing and national defense technology, etc.) [3,4].

Unlike backing pumps (Rotary vane pumps and Claw pumps for example) which can work alone, MBVPs are usually combined with a backing pump. Thus, the performance measurement of MBVPs is dependent on the type and actual performance of the backing pump. For instance, effective volume flow rate is one of the main performances of common vacuum pumps in general, but the manufacturers cannot provide the characteristic for MBVPs due to the backing pump being not always known in advance. According to the existing basic standard, ISO 21360-1 provided a general description about the measurement of performance data of vacuum pumps [5]. As the complement of ISO 21360-1, ISO 21360-2 specified the methods for measuring performance data of positive-

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displacement vacuum pumps [6]. These standards cover only the performance characteristics of backing pumps including pumping units where a backing pump is supplied in combination with a booster pump. This may be inadequate for all aspects of MBVP performance. In order to compare the performances of MBVPs measured by different manufacturers, laboratories, measurements should be carried out by a series of uniform procedures and conditions as far as possible [7].

From 2007 to 2015, a series of Chinese GB standards on Roots Vacuum Pumps was discussed, part of our work was revised and then agreed on in SAC/TC18, later known as GB/T25753.1–4 [8–11]. During the 15th meeting of ISO/TC112 (Technical Committee 112 on Vacuum Technology, ISO) in Tampa, USA, a new project on measuring Roots vacuum pumps was proposed by us and then accepted as ISO/NP 21360-3. It was further discussed during the 16th meeting of ISO/TC112 in 2014, Busan, Korea. Finally, the project was partly revised along with the title defined as *Vacuum technology — Standard methods for measuring vacuum-pump performance — Part 3: Specific parameters for mechanical booster vacuum pump (ISO/NP 21360-3)* aiming at covering a wider range of medium vacuum pumps. With lots of revisions and experimental works implemented, the standard proposal was then resubmitted to the committee and voted to be a new project as ISO/NP 21360-3 in the 17th meeting of ISO/TC112 in 2015 in Balzers, Liechtenstein. In the next six months, the ISO/WD 21360-3 was drafted by the project responsible person and the relevant experts. Between June and September in 2016, ISO/CD 21360-3 was successively voted. In this process, comments of the draft were taken into full account based on a large number of experiments and practical experience, which reached an eventual agreement. The updated version of ISO/DIS 21360-3 is voted through by ISO/TC112 in Berlin in 30 NOV 2017, which will be voted by ISO soon later.

In this work, special performance characteristics of MBVPs are discussed based on the results of practice use and the existing standards of different countries. We clearly specify the special characteristics including maximum the tolerable pressure difference Δp_{max}, effective compression ratio K_{eff}, compression ratio with zero throughput K_0 and by-pass valve pressure difference Δp_1. These parameters are practically proved sufficient and necessary to characterize the properties of MBVPs. The corresponding experimental system was set up to measure the performances of MBVPs and a series of standard methods have been established. The test considerations for the parameters above are proposed with detailed experimental principles and setup.

2. Performance parameters of MBVPs

2.1. Specific parameters for the measurement of MBVPs

2.1.1. Maximum tolerable pressure difference Δp_{max}

Maximum difference between the backing pressure p_3 and the inlet pressure p_1 is Δp_{max} (maximum tolerable pressure difference), when the inlet pressure is set at a certain pressure the test pump is able to withstand under continuous operation until thermal stability without any deterioration in performance or damage.

It is defined as [8,13].

$$\Delta pmax = p_3 - p_1 \quad (1)$$

2.1.2. Compression ratio with zero throughput K_0

The compression ratio with zero throughput K_0 is defined as the ratio of the backing pressure p_3 to the inlet pressure p_1, under which condition the gas inlet valve is closed (the pump with zero throughput).

It is defined as [5].

$$K_0 = p_3 / p_1 \quad (2)$$

2.1.3. Effective compression ratio

The effective compression ratio K_{eff} is defined as the ratio of the backing pressure p_3 to the inlet pressure p_1 of the mechanical booster vacuum pump, under which condition the gas inlet valve is opened.

It is defined as [5].

$$K_{eff} = p_3 / p_1 \quad (3)$$

2.1.4. By-pass valve pressure difference Δp_1

If MBVPs are equipped with a by-pass valve, Δp_1 is the pressure difference between the backing pressure p_3 and the inlet pressure p_1 when the by-pass valve is just about to open.

It is defined as [5].

$$\Delta p_1 = p_3 - p_1 \quad (4)$$

2.2. Deduced parameters for specific parameters of MBVPs

2.2.1. vol flow rate s

According to ISO 21360-1, volume flow rate is the volume of gas which, under ideal conditions, flows from the test dome through the pump inlet per time. For practical reasons, the volume flow rate of a given pump and for a given gas is conventionally considered to be equal to the quotient of the throughput of this gas and of the equilibrium pressure at a given location.

It is defined as:

$$s = dv/dt \quad (5)$$

where v is volume; t is time [5].

2.2.2. Base pressure p_b

According to ISO 21360-1, the base pressure is the value which the pressure in the test dome approaches asymptotically. It is the lowest pressure obtainable with the pump, but no practical method of measurement is specified [5].

3. Experimental

3.1. Measurement setup

All components are mounted together under clean conditions in accordance with Fig. 1.

Based on the measurement of specific parameters in practice and the existing standards in different countries, the influence of significant accessories is considered. Standard test domes are used for comparable flow/pressure measurements. Details of test dome is specified in ISO21360-1, but the test dome is specially used to minimize errors in the standardized measurement in this experimental setup. It will offer a better comparable basis. In Fig. 1, test domes are necessary to stabilize the airflow and reduce the pressure fluctuation during the measurement. A series of experiments were carried out on MBVP-600 (Swept volume $s_{th} = 814$L/s) about variation of backing pressure at different sizes of test dome (the