Development of a calculation method of the main parameters of the multistage turbomolecular pump

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Abstract: We developed a calculation method of the pumping parameters of the molecular stage of the turbomolecular vacuum pump (TMP) operating in the molecular flow region. Also, the authors developed the calculation method of the main parameters of the multistage TMP for the providing the main pumping parameters including ultimate pressure, pumping speed, compression ratio. As a result of calculation, the we got the performance curve of the multistage TMP.

1. Introduction

Turbomolecular vacuum pumps (TMP) are widely used in R&D and industry applications. According with the high requirements for vacuum systems, the problem of their layout to ensure the technological process is relevant. Turbomolecular vacuum pumps have a number of advantages compared to other mechanical vacuum pumps, namely they do not pollute the pumped volume, provide a low ultimate residual pressure without the pumping selectivity [1-4]. Molecular vacuum pumps are currently rarely used separately, due to the relatively low pumping speed. To increase the pumping efficiency, the molecular stage is combined with the turbomolecular stage of TMP [5-8]. There are three most common design groups of flow channels: TMP and a cylindrical stage with annular channels on the rotor (Gaede model Fig. 1a), TMP and a cylindrical stage with spiral channels along the rotor surface (Holweck model Fig. 1b), TMP and a disk stage with spiral channel from the outer diameter to the centre of the disk (Siegbahn model Fig. 1c) [9,10]. The review of references showed that in the presence of various structural configuration of multistage flow channels of the TMP, no single method for calculating such structures was revealed, which determines the relevance of the study.
2. Calculation method of the main parameters of the multistage turbomolecular pump

The structure of the flow channel of the considered TMP is determined by rotor with two stages such as turbomolecular and molecular.

In turn turbo stage is consist of the number of blades packages which provides the pumping speed required [11].

The modelling assumptions are the following:

1. The velocity distribution of the molecules is in accordance with the Maxwell distribution law in the inlet and forevacuum sections;
2. Molecular flow regime in the channel;
3. The process of gas molecules transfer is considered quasi-steady-state.

To determine the impeller geometry, theoretical models of the transition of gas molecules through the wheel are used taking into account the interaction with the walls of the blades channel. To determine the coefficient of probability of gas molecules transition through the impeller ($K_{max}$), it is necessary to determine the permissible peripheral speeds of the wheel ($u_2$), the arithmetic average velocity of the thermal motion of the molecules of the pumped gas ($v_{ave}$), and also the geometry of the operating channel [12].

To determine the pumping parameters of the wheel, it is necessary to determine the actual maximum pumping speed of the wheel ($S_{max,act}$), taking into account the obtained geometric parameters. To calculate a pumping curve of the wheels, it is necessary to determine the compression ratio of the wheels for each of the packages ($\tau_{max}$) [13].

$$
\tau_{max} = \frac{\int_{0}^{F} \frac{r k_{ab} + h_1 (1 - \lambda \psi) |r - \lambda|}{H_1 |1 - \lambda|} \frac{y + \beta_y}{\pi F} dx dr}{\int_{0}^{F} \frac{r k_{ab} + h_1 (1 - \lambda \psi) |r - \lambda|}{H_1 |1 - \lambda|} \frac{y - \beta_y}{\pi F} dx dr}
$$

(1)

where $\psi$ is blade thickness ratio,  
$k_{ab}$ is channel width ratio,  
$h_1$ is blade thickness,  
$H_1$ is width of the operating channel,  
$\lambda$ is relative diameter of the wheel,  
$r$ is relative radius,  
$y, \beta_y$ is probability of transition of gas molecules through the blade channels.

In multistage TMP the molecular drag stages operate in molecular and viscous flows. W. Gaede model is used to obtain the calculations formulas of the molecular drag stage [14,15].
To obtain the main parameters of the stage pumping curve it is necessary to determine maximum pressure drop in the channel \((p_1 - p_2)_{\text{max}}\).

\[
(p_1 - p_2)_{\text{max}} = \frac{6 \eta L u}{h^2}
\]

where \(\eta\) is dynamic viscosity,
\(L\) is channel length,
\(u\) is rotary rotations per minute,
\(h\) is channel height.

Next, it is necessary to determine the maximum pumping speed of the channel \((p_1 - p_2)_{\text{max}}\).

\[
S_{\text{max}} = \frac{mRT}{M p_2}
\]

where \(m\) is the maximum gas amount pumped by the channel at equal pressures;
\(R\) is universal gas constant;
\(T\) is temperature of the gas pumped;
\(M\) is molecular mass of the gas pumped.

To determine the pumping speed of molecular part, it is necessary to interconnect the geometric, speed and pumping parameters of the molecular part of channel [16,17].

\[
x_1 - x_2 = \frac{h^2}{6 \eta \left| u_1 + u_2 \right|} (p_1 - p_2) + \left[ \frac{h}{\Theta \left| u_1 + u_2 \right|} + \frac{mRTh}{Mb 3 \eta \left| u_1 + u_2 \right|^2} \right] \ln \frac{p_1 - 2mRT}{Mb |u_1 + u_2|} - \frac{2mRT}{Mb |u_1 + u_2|} \]

where \(x_1 - x_2\) is channel length;
\(u_1, u_2\) is speed of the walls;
\(\Theta\) is coefficient of external friction;
\(b\) is breadth of the channel.

It is also necessary to determine the maximum pressure ratio \(\tau_{\text{max}}\).

\[
A \left( \tau_{\text{max}} + \frac{1}{\tau_{\text{max}}} - 2 \right) + B \left| \tau_{\text{max}} - 1 \right| - C \ln \tau_{\text{max}} + \lg^2 \tau_{\text{max}} = 0
\]

where \(A = \frac{(2 \pi r h)^3}{Lb(2,303 h)^2};\)
\(B = \frac{Su h \Theta (2 \pi r)^3}{b(2,303 h)^2};\)
\(C = \frac{|u_1 + u_2| 2 \pi r \Theta}{2,303 h}.\)
To calculate the pumping curve of the pump, the pumping speed of the multistage flow channel is determined $S_N$ [18-20].

$$S_N = S_{pmb} + \frac{Q_{gas,bc} \cdot p}{p_1}$$  \hspace{1cm} (6)

where $Q_{gas,bc}$ is gassing in the inlet suction.

3. Results and discussions

The developed calculation method was used to obtain the pumping curve of the multistage TMP. The pumping curve is shown in Fig. 2.

4. Conclusion

Due to the fact that TMP are most often used in industrial and research practice, increasing of the pumping speed and the maximum ultimate pressure are the most important problems. TMPs with multistage flow channel have the greatest potential for the effective implementation of tasks.

The developed calculation method allows determining the main parameters of the TMP with a multistage flow channel such as: compression ratio of each stage, the pressure drop, the pumping speed of the pump.

As a result of the calculations, the pumping curve of a multistage TMP was obtained.

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