EAN 2018
56th conference on experimental stress analysis

Method For Vacuum Conductivity Estimation For Engineering Use

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Keywords: Vacuum, vacuum conductivity, vacuum conductance, computational model, pumping speed, effective pumping speed

Abstract. The paper focuses on the vacuum conductivity of high vacuum elements. The aim of the paper is to find a fast-use calculation method for determination of vacuum conduction in molecular flow mode for basic elements of vacuum chambers.
Work on the described computational model can be divided into two steps. The first step is to create your own computational model on the basis of literature. The second step is a series of measurements that verify the accuracy of the calculation approach and allow it to determine its error (uncertainty).
The proposed method is also tested on model examples using the Monte-Carlo method in MolFlow+ software. In addition, the verification process continues, however, for some geometries and vacuum parameters, the results are already experimentally validated and excellent conformity can be noted (deviation has not yet exceeded 10% of the measured values) allowing for seamless use of the method in engineering work.

Introduction

The paper focuses on the vacuum conductivity of high vacuum elements used in the CERN, the join institute of nuclear research JINR and other workplaces of a similar nature, because in these conditions its significance excels. Achieving the highest quality vacuum (if possible XHV) plays a major role in particle accelerators where collisions of the accelerated beam with particles of residual atmosphere occur, which has a number of adverse effects. In various methods of surface analysis, particles of residual atmosphere pollute the samples under investigation. However, the problems of various industrial plants, from relatively crude applications in the food industry, to physical vapor deposition, for example in the automotive industry, can not be overlooked. For the efficient design of the vacuum system, the knowledge of the vacuum conductivity of the elements used is of great importance and there is therefore a long-term effort to create practical background for its determination based on knowledge of the parameters of the required vacuum and geometry of the given elements of the apparatus. The aim of the paper is to find a fast-use calculation method for determination of vacuum conduction in molecular flow mode for basic elements of vacuum chambers.

Theoretical background

Vacuum (from Latin: Empty space) is defined as a state of gas whose pressure is lower than atmospheric pressure at room temperature [1]. Decreasing pressure results in significant changes in gas behavior. Therefore, three basic types of gas mode are distinguished. These are viscous flow mode, molecular flow mode and transitional area. In a molecular mode, gas changes its behavior from continuous to chaotic movement of individual atoms and molecules. A more detailed division of the vacuum is shown in Table 1.

Tab. 8 Pressure ranges in vacuum technology

Pressure range	Pressure [hPa]	Mode type
Low vacuum (LV)	300…1	viscous mode
Medium vacuum (MV)	1…10^{-3}	transitional area
High vacuum (HV)	10^{-3}…10^{-7}	molecular mode
Ultra-high vacuum (UHV)	10^{-7}…10^{-12}	molecular mode
Extremely high vacuum (XHV)	<10^{-12}	molecular mode

Achieving and maintaining a high vacuum is very economically demanding. This is the reason to deal with the details of the elements used for the construction of the vacuum chamber. One of the essential parameters is vacuum conductivity. Vacuum conductivity plays an important role in designing the vacuum pump on the apparatus as it reduces the pumping speed of used vacuum pumps.

Vacuum conductivity is characterized the flow of gas through the vacuum system [l/s, m^3/h]. With the pressure drop in the chamber and the transition between flow modes, the vacuum conductivity of the same component decreases by several orders of magnitude. This is due to the fact that in the viscous mode the vacuum conductivity is directly proportional to the fourth power of a characteristic dimension, while in the molecular mode it is only the third power. For this reason, it is much more important to study the vacuum conductivity for the molecular state.

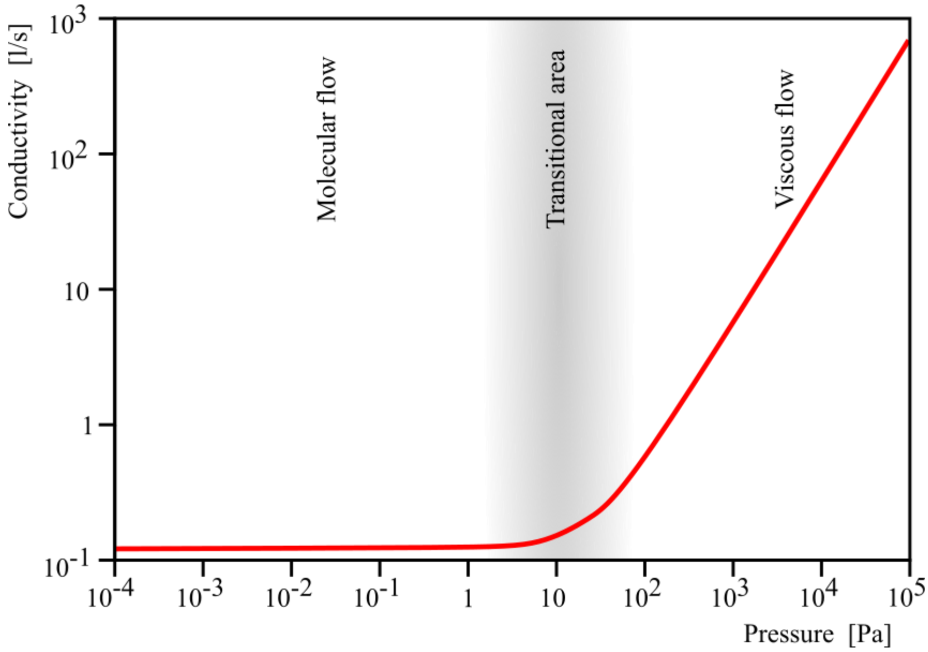


Fig. 43 Conductance of a smooth round pipe as a function of the

In addition to the characteristic dimension, the length of the tube, the mean gas pressure in the tube (viscous mode), the gas type and its temperature influence the conductivity (Eq.1, Eq.2).

$$C_{circle.lam} = C(d, l, \eta, \bar{p}) \tag{1}$$

$$C_{circle.mol} = C(d, l, \bar{c}) \tag{2}$$

C…vacuum conductance
d… tube average
l… tube length
η…viscosity (depends on temperature)
$\bar{p}$…mean pressure
$\bar{c}$…mean thermal velocity (depends on the type of gas)

The total vacuum conductivity of a system composed of individual elements can be calculated analogously to the conductivity of the electrical circuits (Eq. 3 - Parallel connection conductance, Eq. 4 - Series connection conductivities) [2].

$$C_{\Sigma} = C_1 + C_2 + \cdots + C_n \tag{3}$$

$$\frac{1}{C_{\Sigma}} = \frac{1}{C_1} + \frac{1}{C_2} + \cdots + \frac{1}{C_n} \tag{4}$$

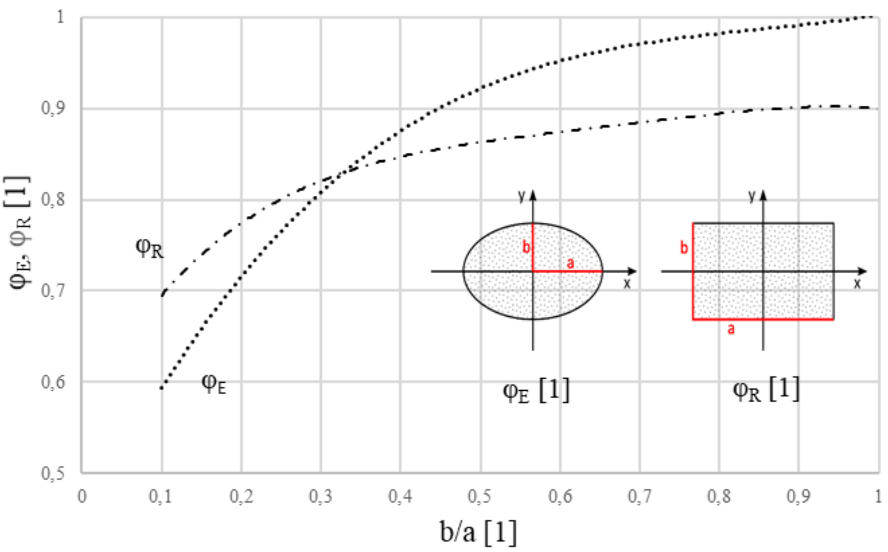
The effect of total vacuum conductivity on the final pumping speed is described in Eq. 5. It will be appreciated that the effective pumping speed of the vacuum pump connected to the vacuum chamber by the system with total vacuum conductivity is lower than the indicated pumping speed. When designing a vacuum system, it is advisable to count this phenomenon. In the extreme, there is a risk of failure to achieve the desired degree of vacuum, which brings a number of complications.

$$\frac{1}{S_E} = \frac{1}{S} + \frac{1}{C_{\Sigma}} \tag{5}$$

S_E…effective pumping speed
S… pumping speed
C_{Σ}… total vacuum conductivity

Method

Work on the described computational model can be divided into two partially parallel and partly serial steps. The first step is to create your own computational model on the basis of literature. Literature lists either data for totally specific cases or data for idealized models. Their processing creates a basis for setting the calculation using the inter and extrapolation functions.



$\varphi_E = 0{,}7653x^3 - 1{,}9598x^2 + 1{,}7615x + 0{,}4357$

$\varphi_R = -1{,}2165x^4 + 3{,}2456x^3 - 3{,}2521x^2 + 1{,}5537x + 0{,}5694$

Fig. 44 φ_E, φ_R koef

The second step is a series of measurements that verify the accuracy of the calculation approach and allow it to determine its error (uncertainty). This phase is now in co-operation with the leader in the field of development and production of ultravacuum technique, spol. VAKUUM PRAHA and it will continue to be continuously, in fact, because, given the cost of creating ultra-vacuum assemblies, assemblies that are already in use or produced and prepared for the customer are used. There is also cooperation with CERN and JINR, which can help with testing. On Fig.3 there is a pumping system for NICA booster, designed by JINR and VAKUUM PRAHA. This pumping system is manufactured and assembled in VAKUUM PRAHA. A number of measurements are being carried out on the pumping system in cooperation with JINR and an adjustment is planned for the future in order to verify the proposed computational model.

Fig. 45 Pumping system for NICA booster with control system

Conclusions

In the current state of the work, a computational model (method) is prepared for the rapid calculation of the vacuum conductivity. The proposed method is tested on model examples using the Monte-Carlo method in MolFlow+ software, which was developed in CERN and is freely available [3]. In addition, the verification process continues, however, for some geometries and vacuum parameters, the results are already experimentally validated and excellent conformity can be noted (deviation has not yet exceeded 10% of the measured values) allowing for seamless use of the method in engineering work.

Acknowledgement

The project and the paper were supported by grant no. SGS17/076/OHK2/1T/12 and SGS17/176/OHK2/3T/12.

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