SOLVED AND UNSOLVED GAS DYNAMICS PROBLEMS FOR TURBO-MOLECULAR-DRAG PUMPS: AN INDUSTRIAL OVERVIEW

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ABSTRACT

Turbomolecular Pumps (TMP) theory in molecular regime dates back to the ‘60s, when Kruger and Shapiro performed the first 2D non-collisional Monte Carlo simulations and developed the first 2D analytical model of axial bladed stages in molecular regime [1]. At that time TMPs were prototypes manufactured in small numbers and were used almost only in ultra high vacuum systems for high energy physics experiments, where the molecular regime model was adequate for the early industrial design purposes.

In the last two decades TMP has become an industrial product manufactured in several thousands of units per year, and its technology has evolved introducing molecular drag high pressure stages, originally designed as standalone pumps by Gaede, Holweck and Siegbahn, downstream axial stages, in order to keep the maximum compression ratio at higher discharge pressures (up to 20 mbar). Besides, the operating inlet pressure range has increased up to 10^{-2} mbar, progressively replacing diffusion and cryogenic pumps in plasma processes, furnaces and in mass spectrometry differential vacuum systems. In these systems a significant part of the TMP works in transition or even viscous flow regime and power dissipation and rotor heat exchange issues must be considered during pump design and validation.

From the modeling perspective two approaches can be found in the literature, namely simplified analytical models and numerical solutions of complex 2D/3D models. The analytical models are very useful for understanding the physics of the pumps and for parametric design and optimization in the industry; unfortunately their scope is limited to a few simple geometrical cases [2] and/or to a specific pressure regime and often they don’t accurately model the leakage effects. Analytical models for molecular drag in the viscous regime normally ignore the inertia of the gas, claiming that as the mass density (i.e. the pressure) tends towards zero, the inertial force becomes zero. All articles and texts make this assumption , except for E. Moll [3], who concludes that “…the force of inertia does not disappear in high vacuum, but rather with modern, fast running TMPs may be comparable to friction.” The importance of inertial effect end centrifugal forces, in particular in Siegbahn technology molecular drag pumps and regenerative stages, is still unanswered.

Thanks to the increase in computational resources, a significant amount of numerical work was done in the last decade to address geometrically complex 3D problems and to extend their validity to the full range of Kn numbers, from molecular to viscous regime. These models are based on DSMC [4], numerical solution of model Boltzmann equation [5] or sometimes on Navier-Stokes equations for the viscous regime. The power dissipation and heat exchange problem is almost completely uncovered for TMPs: the issue is to understand the rotor heat balance, considering all the possible heat sources and heat exchange contributions, namely thermal radiation, conduction/convection in the gas and conduction in the solid parts supporting the rotor.

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