

Simulations of the Performance Factors on Vacuum System

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Abstract

In this work, the effects of fairly influential factors on performance of vacuum system, such as constant pressure and outgassing effect were simulated to propose the optimum design factors. Outgassing effects of selected vacuum materials on the vacuum characteristics were simulated by the VacSim^{Multi} simulation tool. This investigation examined the feasibility of reliably simulating the outgassing characteristics of common vacuum chamber materials (aluminum, copper, stainless steel, nickel plated steel, Viton A). The optimum design factors for vacuum systems were suggested based on the simulation results. And, the effects of throttle valve applications on vacuum characteristics were also simulated to obtain the optimum design model of variable conductance on high vacuum system. Simulated vacuum characteristics of the proposed modelling were agreed with the observed experimental behaviour of real systems. Pressure limit valve and normally on-off control valve were schematized as the modelling of throttle valve for the constant process-pressure. Simulation results were plotted as pump-down curve of chamber and variable conductance of throttle valve. Simulated behaviors showed the applications of throttle valve sustained the process-pressure constantly, stably, and reliably.

Keywords: Vacuum system, Performance factor, Constant pressure, Outgassing, Vacuum characteristics.

1. Introduction

The importance of vacuum techniques has continued to grow with the development of advanced technology. Even greater demands and more stringent conditions are expected to be imposed on vacuum techniques requiring high vacuum qualities. Highly advanced techniques on the generation, measurements, maintenance of vacuum and evaluation of vacuum system had become an essential for the fabrications of mobile device. Generally, the manufacturing costs of vacuum system are very high and performance characteristics also strongly dependent upon the design of system. Therefore, simulation of vacuum systems based on the design factors is very important to predict the vacuum characteristics and reduce the manufacturing expenses considerably for the optimum system design. Among the highly influential factors on performance of vacuum system, the sustainability of constant process-pressure should be ensured for the

successful process managements [1, 2]. And to achieve pressures in the ultrahigh vacuum (UHV), it is essential to minimize the outgassing from the chamber materials [3, 4]. In this work, we simulated the effects of fairly influential factors on performance of vacuum system, such as constant pressures and outgassing effects of modelled system. Effects of throttle valve applications on vacuum characteristics were investigated. The acquired simulation results of the modelled throttle valves suggested the optimum design factors for variable conductance system. The feasibility of reliably simulating the outgassing characteristics of common vacuum chamber materials was also examined. Three different UHV systems based on the pumping combinations were modeled by the VacSim^{Multi} simulation tool [5, 6]. The outgassing characteristics of stainless steel, anodized aluminum, polished copper, nickel plated steel, and Viton A in the proposed simulation models were examined. Each of the modeled vacuum systems was simulated separately for each of the selected materials with and without the outgassing. The acquired simulation results of the modeled systems and of the probed vacuum materials are plotted in the form of the dynamic pump-down curves.

2. Simulations

2.1. Simulation model

Modeling was performed on the commercial specifications of vacuum systems used in experimental applications. Three different UHV pumping combinations were employed in this modeling with fixed design factors for the chamber, exhaust pipelines, and valves. The simulation design factors of the modeled UHV systems were fixed; the same parameters were used except for the pumping combinations in each simulation. Three different combinations of pumping systems were employed in this modeling, viz. turbomolecular-rotary, diffusion-rotary, and diffusion-booster-rotary pumps. The proposed UHV systems have a straight pipelines with a length of 0.3 m and a diameter of 0.0254 m. The valves which were employed had internal aperture areas of $5 \times 10^{-4} \text{ m}^2$ and $5 \times 10^{-3} \text{ m}^2$ for rough and high vacuum pumping, respectively, and were normally closed in the absence of a signal. The chamber volume of the modeled UHV systems was fixed at 15 liters. The commercial specifications of the employed pump models are summarized in Table 1.

Table 1. Commercial specifications of employed turbomolecular pump (Edwards Ltd.).

model name	EXT70-DN63CF
compression ratio	$\text{N}_2 > 1 \times 10^8$ He 6000 H_2 500
nominal rotational speed	90000 rpm
standby rotational speed	63000 rpm
cooling method	free convection or forced air or water
quiescent electrical power	10 W

pumping speed	N ₂ 65 L/s He 60 L/s H ₂ 50 L/s
ultimate pressure	$< 3.8 \times 10^{-10}$ Torr
weight	3.4 Kg

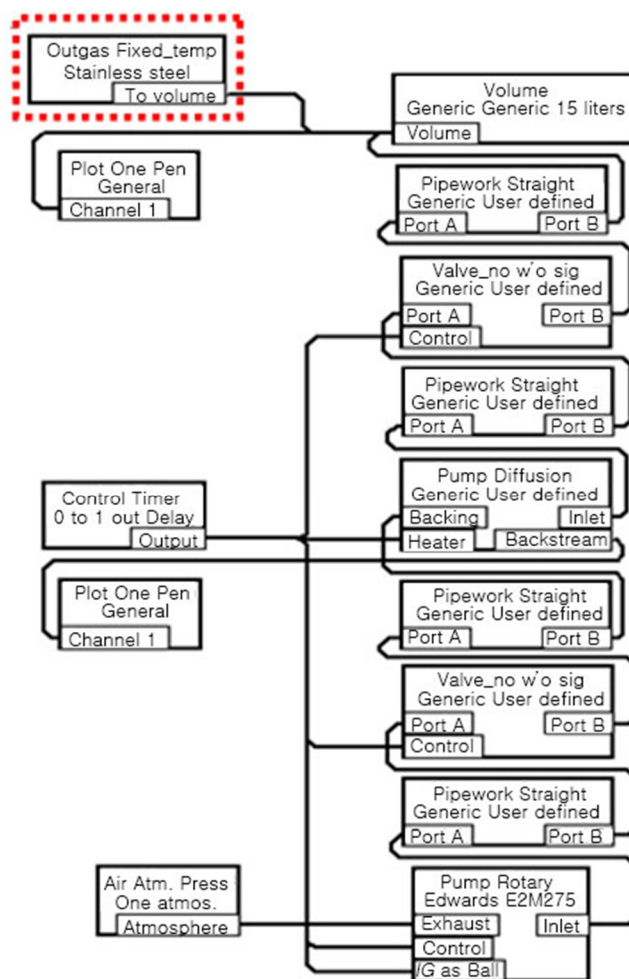


Figure 1. Simulation schematic of diffusion pump system with outgassing

2.2. Simulation of UHV system with and without outgassing

The simulation schematic with outgassing effects of the diffusion pump (DP) system is illustrated in Fig. 1. All of the models with outgassing were also simulated to compare the outgassing behaviors of the systems. The outgassing characteristics obtained in situ are plotted in the form of the pump-down curves in Fig. 2. The dynamic pump-down curves with and without the outgassing effects are indicated by the dotted and solid lines, respectively. The simulation results indicated that the overall outgassing effects are more significant in the TMP system than in the DP systems. The ultimate stabilized pressure of the TMP system with outgassing effects was 7.5006×10^{-7} Torr (Fig. 2-(a)), which is approximately three orders of magnitude

higher than that of the TMP model without outgassing effects (7.5006×10^{-10} Torr). No outgassing effect was observed within the initial evacuation time of 40 seconds. In addition, the pumping pressure was rapidly stabilized within one minute after the outgassing effects noticed. DP systems with outgassing effects, the ultimate stabilized pressure was almost 7.5006×10^{-8} Torr (Fig. 2-(b)). The employment of a booster pump had a greater effect on the evacuation time than on the ultimate pressure. The initial outgassing effects of both DP systems were reflected in their evacuation times of about 510 seconds without a booster pump and 73 seconds with a booster pump. The simulation results of the outgassing effects confirmed the feasibility of utilizing simulation modeling in design applications.

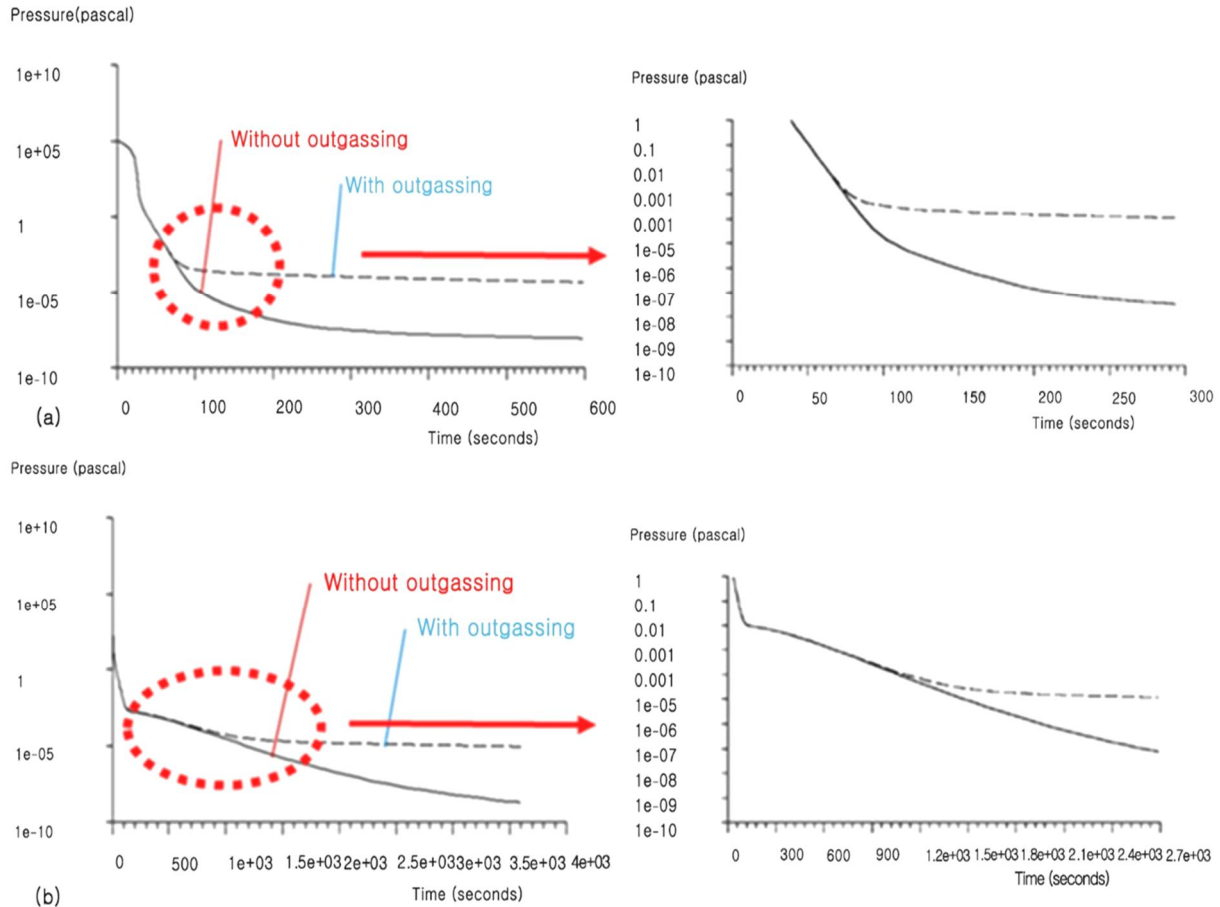


Figure 2. Comparison of simulation results with and without outgassing effects of modeled systems [(a) TMP-MP system (b) DP-MP system without booster pump]

2.3. Simulation of diffusion pump system with and without baffle

Both of models with and without baffle were simulated to compare the effects of baffle employment on vacuum characteristics. Achieved in situ characteristics are plotted in the pump-down curves in Fig. 3. The dynamic characteristic curves with and without the baffle effects are indicated by the dotted and solid lines, respectively. The simulation results showed that the baffle effects are significant to the overall performance of system. The ultimate pressure of the DP system with baffle was reached almost at 10^{-7} Torr which was approximately same as the without baffle model. Effects of baffle employment were not observed within the initial evacuation time of 32 minutes. In addition, the pumping down curve with baffle system was gradually

stabilized compared to the abrupt behavior of without baffle. The employment of a baffle had a greater effect on the evacuation time and the degree of backstream than on the ultimate pressure. The initial baffle effects of both DP systems were reflected in their pumping times to the ultimate pressure of about 43 minutes without a baffle and 26 minutes with a baffle.

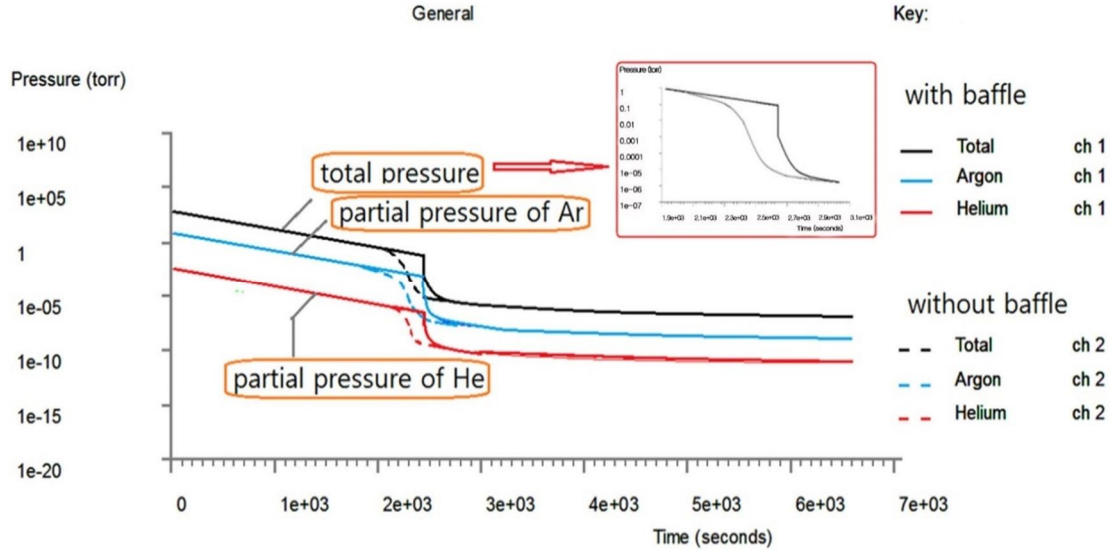


Figure 3. Comparison of pumping curve with and without baffle on DP system

2.4. Simulation of outgassing characteristics of vacuum materials

The outgassing of the chamber materials places a limitation on attaining very low pressures in UHV systems [7, 8]. The simulation results of the outgassing characteristics of the selected vacuum materials are illustrated in Fig. 4. The VacSim^{Multi} simulator supports the five different materials which are commonly used as vacuum materials in the outgassing model. In the TMP system, an ultimate stabilized pressure in the UHV range (7.5006×10^{-8} Torr $\sim 7.5006 \times 10^{-9}$ Torr) was observed only in the case of polished copper and nickel plated steel among the studied materials. Polished copper showed the lowest pressure of 9.676×10^{-9} Torr during the simulation. An appreciable amount of outgassing, which was larger than expected, was noticed in the case of anodized aluminum. The lowest pressure obtained in the case of aluminum (7.801×10^{-7} Torr) was approximately two orders of magnitude higher than that obtained in the case of polished copper. Almost no variation in pumping behavior due to outgassing effects was observed within the initial evacuation time of 80 seconds in the case of the probed materials, except for Viton A. Achieved in situ simulation data of vacuum materials plotted as pump-down curves in Fig. 4 summarized in Table 2.

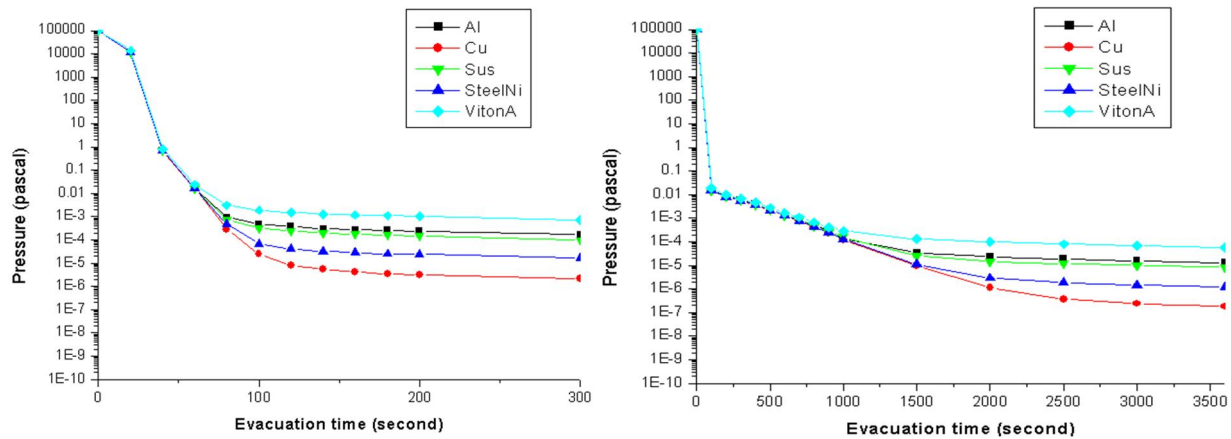


Figure 4. Outgassing characteristics of vacuum materials
[(a)TMP-MP system (b)DP-MP system without booster pump]

Table 2. In-situ simulation data of vacuum materials plotted as pump-down curves in Fig.4.

(a) TMP-MP system

materials \ evacuation time	Al-andoized	Cu-polished	Stainless steel	Steel-Ni plated	Viton A
111 sec	3.188×10^{-6} Torr	9.376×10^{-8} Torr	2.055×10^{-6} Torr	3.750×10^{-7} Torr	1.35×10^{-5} Torr
300 sec	1.268×10^{-6} Torr	1.62×10^{-8} Torr	8.251×10^{-7} Torr	1.29×10^{-7} Torr	5.761×10^{-6} Torr
483 sec	7.801×10^{-7} Torr	9.676×10^{-9} Torr	4.853×10^{-7} Torr	7.576×10^{-8} Torr	3.188×10^{-6} Torr

(b) DP-MP system without booster pump

materials \ evacuation time	Al-anodized	Cu-polished	Stainless steel	Steel-Ni plated	Viton A
1493 sec	2.985×10^{-7} Torr	6.841×10^{-8} Torr	1.965×10^{-7} Torr	9.076×10^{-8} Torr	9.751×10^{-6} Torr
2500 sec	1.5×10^{-7} Torr	2.805×10^{-9} Torr	9.376×10^{-10} Torr	1.455×10^{-8} Torr	6.151×10^{-7} Torr
3129 sec	1.215×10^{-7} Torr	1.665×10^{-9} Torr	7.576×10^{-8} Torr	1.163×10^{-8} Torr	4.853×10^{-7} Torr

2.5 Simulation of variable conductance system

VacSim^(multi) provide two different modelling components, pressure limit valve and controlled valve, for the simulation of variance conductance throttle valve system. The valve components were modelled as circular apertures with the size of which is zero when closed. Modelling of the throttle valve by controlled valves was consisted of the control trip and normally open/close valve with signals modules. The control trip component behaves like pressure-sensor which send control signal “1” if the chamber pressure is lower than the preset pressure. Control signal “1” is fed to the normally open valve which is open when the controlled signal is less than 0.5. Purpose of throttle valve is to sustain the chamber pressure constantly, reliably during the process. The preset pressure was set to 10^{-3} Torr as the constant process-pressure. Therefore, the modelling of controlled valve provided variable conductance characteristics by closing the normally open valve unless the chamber pressure is higher than 10^{-3} Torr. To sustain the variable conductance accurately, the controlled valves are fully open and close according to the pressure of chamber. If the chamber pressure down to below

10^{-3} Torr, the control valve is closed to keep chamber pressure constant. The closed indicator is 1 when the valve is closed. Simulation scheme of the controlled valve system was represented in Fig. 5.

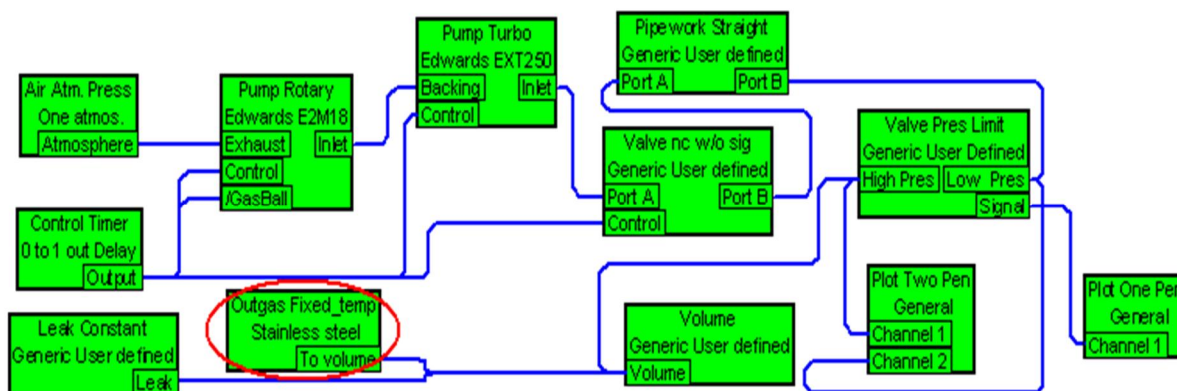


Figure 5. Simulation schematic of pressure limit valve system with outgassing effect

Simulation results of the pressure limit valve was plotted on Fig. 6. Comparison of outgassing effects to the variable conductance characteristics was represented on each plot. Pumping curve showed the in-situ variation of pressure at chamber and at exhaust line as the solid and dotted lines respectively. Chamber pressures were stabilized constant to 10^{-3} Torr at the around 965 sec on both model. It was estimated that the maximum conductance of pressure limit valve was at around 965 sec. It was indicated that the values on both initial point of stabilized chamber pressure and on maximum conductance of valve was agreed with each other. As expected, the more gradual behavior of pumping down was observed with outgassing model.

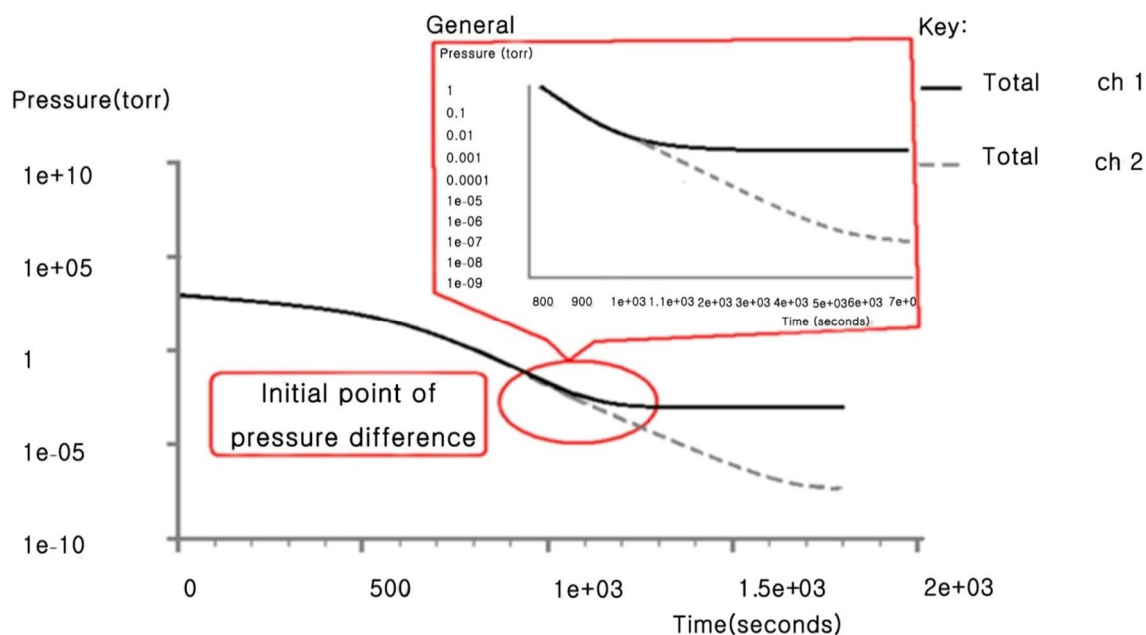


Figure 6. Pumping characteristics of pressure limit valve system with and without outgassing

3. Results and conclusion

To study the reliability and feasibility of using simulation, three different UHV systems were modeled. Also, in order to confirm the consistency of the simulation results, each of the three modeled systems was simulated separately for each of the studied materials without and with outgassing effects. Only the optimum simulation results, which were obtained after numerous repetitive simulations, were illustrated in the figures and tables. The obtained simulation results are plotted in the form of dynamic pump-down curves for each model. The simulation predicted that the outgassing effect would be more significant in the TMP system than in the DP system. Characteristics of variable conductance for the constant chamber pressure was also obtained by the simulation of controlled valve model. There were no partial open/close states in the operation of control valve. During the duration, approximately 1653 sec, of constant chamber pressure, the virtual leakage was estimated to be negligible. Suggested modelling of controlled valve showed the possibility of simulation for variable conductance system. In addition, the achieved simulation results were consistent with the experimentally observed pumping behavior of throttle valve applications. The present preliminary study enabled us to evaluate the feasibility of using simulation for studying vacuum systems in a reliable manner.

Acknowledgement

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