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Simulation of Modeling Characteristics of Pumping Design Factor on Vacuum System

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Abstract

Recently, with the development of advanced thin film devices comes the need for constant high quality vacuum as the deposition pressure is more demanding. It is for this reason our research seeks to understand how the variable design factors are employed in such vacuum systems. In this study, the effects of design factor applications on the vacuum characteristics were simulated to obtain the optimum design modeling of variable models on an ultra high vacuum system. The commercial vacuum system simulator, VacSim$^{(multi)}$, was used in our investigation. The reliability of the employed simulator was verified by the simulation of the commercially available models of ultra high vacuum system. Simulated vacuum characteristics of the proposed modeling aligned with the observed experimental behavior of real systems. Simulated behaviors showed the optimum design models for the ideal conditions to achieve optimal pressure, pumping speed, and compression ratio in these systems.

Keywords: *Vacuum system, Design factor, Pumping system, Vacuum characteristics, Vacuum simulation*

1. Introduction

Recently, the applications of vacuum technology is indispensable for the cutting edge technologies such as advanced materials engineering. Developments of high-tech products could not be accomplished without the generation of high quality vacuum system. Highly advanced techniques on the generation, measurements, maintenance of vacuum and evaluation of vacuum system had become an essential for the fabrications of electronic devices. Especially, most of the industry which brought the current mobile environments are based on the electronic chips. Applications of high performance of vacuum system are expected to be keep growing on next generation. Generally, the manufacturing costs of vacuum system are very high and performance characteristics also strongly dependent upon the design modeling of system. Therefore, simulation of vacuum systems based on the design factors is very important to predict the vacuum characteristics and reduce the manufacturing budgets considerably for the optimum system design. Among the vacuum characteristics of process equipment, the reliable sustainability should be ensured for the successful process managements. To achieve the reliable behavior in ultra high vacuum, it is essential to utilize the variable design factors on vacuum system. Applications of variable design factors on vacuum system has continued to grow with the advance of electronic devices. In this study, we investigated the effects of many design factors on vacuum characteristics of Turbo Molecular Pump(TMP) system.

The acquired simulation results of the modeled TMP system suggested the optimum pumping factors for

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variable models of vacuum system. Industrial simulator of vacuum system, VacSim$^{(multi)}$, was used on this work. Reliability of simulation program was verified by the simulation of commercially available vacuum system. Based on verifications of reliability, the effects of various design factors on pumping characteristics of TMP system were obtained.

2. Feasibility of simulation on vacuum system

A commercial vacuum system was simulated to verify the reliability of the VacSim$^{(multi)}$ simulation programs.

Table 1. Simulation parameters of TMP system

System	Volume	Time	Rotary pump
TMP	0.3 m³	25 min	Edward E1M5
TMP	0.3 m³	25 min	Edward E2M5

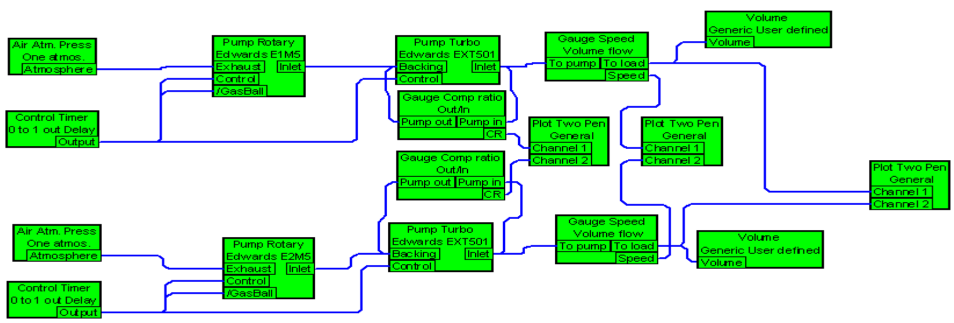

Figure 1. Modeling schematics of TMP systems by VacSim$^{(multi)}$ simulator

Table 2. Pumping parameters of employed rotary pump

Rotary pump	Ultimate pressure	Pumping time	Pumping speed(max)	Compression ratio of Ar
E1M5	1.22 X 10^{-9} torr	931 sec	206 liter/sec	4 X 10^{8}
E2M5	1.48 X 10^{-10} torr	1056 sec	181 liter/sec	3 X 10^{8}

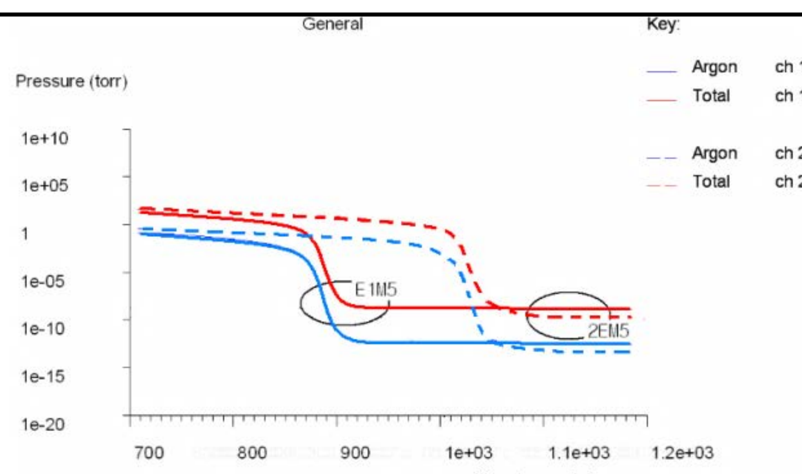

Figure 2. Pressure curves of rotary vacuum pumps : E1M5(solid line), E2M5(dotted line)

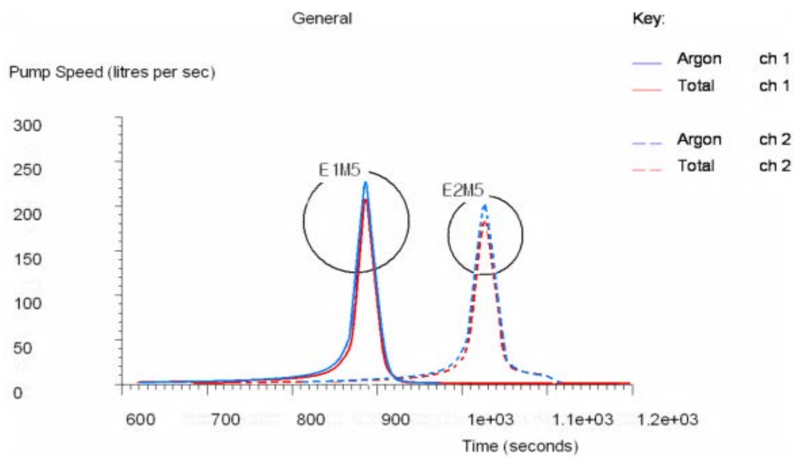

Figure 3. Pumping speeds of rotary vacuum pumps : E1M5(solid line), E2M5(dotted line)

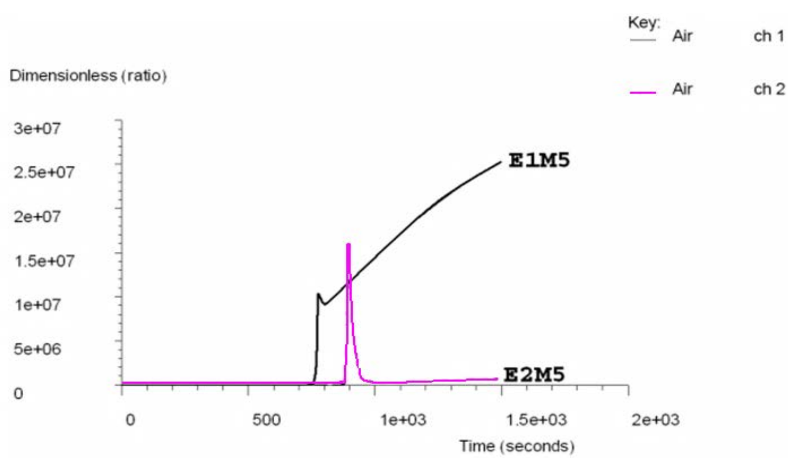

Figure 4. Compression ratio of turbo molecular pumps : E1M5(solid line) and, E2M5(dotted line)

In the TMP system, modeling schematics are showed on Fig. 1 with the different model of rotary pump as the simulation variables of design factors. It was predicted for system performance to significantly influence not only ultimate pressure but also pumping time to reach acceptable process vacuum ranges. Based on the obtained simulation results, characteristics of ultimate pressure, compression ratio, and pumping speed were agreed with the specifications of employed commercial vacuum system. Duration of simulation time was set to 25 minutes. Because the rough pumping time required to operate TMP system was taken into account to obtain the more reliable process pressure and the time to reach ultra high vacuum. It took about 931 [sec] by E1M5 pump to reach 1.69 X 10^{-9} torr and 1056 [sec] by E2M5. A ultimate pressure of E1M5 (1.22 X 10^{-9} torr) was slightly higher than that of E2M5 (8.5 X 10^{-10} torr) With this result, it was estimated that a higher pumping speed of rotary pump could provide the shorter pumping time to reach ultimate pressure. According to figure 2 and 3, it was also observed that there are specific transition zone where the pumping pressure rapidly decreased even though pumping speed and compression ratio not significantly increased. Transition time was about 754 [sec], 873 [sec] on E1M5 and E2M5 respectively. And the ultimate pressures were stabilized at 785 [sec] of E1M5 and 967 [sec] of E2M5 as the pumping speed and compression ratio decreased accordingly. Obtained simulation characteristics showed a fairly good agreements with the specification data of commercially available TMP vacuum system. Based on this agreements, a high feasibility of VacSim(multi) simulator to evaluate the pumping characteristics of TMP system was verified. Because the reliability of simulation on TMP system was obtained, simulation of pumping design factors was expected to provide the characteristics of compression ratio, pumping speed, and reachable ultimate pressures.

3. Simulation modeling

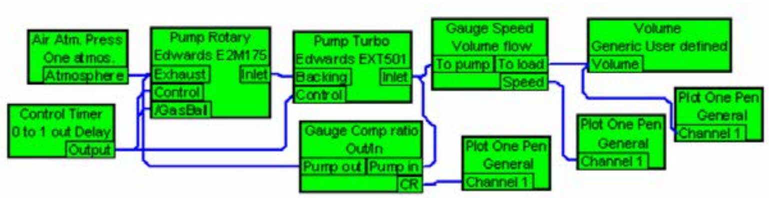

Figure 5. Modeling schematics of TMP systems with pump team-up combinations

The simulation modeling of pumping design factor was schematized on figure 5. Modeling pumping variables were selected as the different team-up models of TMP and rotary pumps. Team-up combinations of TMP and rotary pumps were comprised of three different types of TMP and four different types of rotary pump. As a result, twelve different team-up pumping models were simulated. Simulation data were obtained and estimated based on the each of pump team-up models respectively. A dimensional size of EXT TMP model is smaller than that of other TMP models which have permanent magnet for maglev operations. The STP model was designed to operate with lower amounts of energy, less vibrations and a long operation time. Simulation was performed to estimate not only the behavior of each pumping factors but also performance characteristic of system.

4. Results and conclusion

Table 3. Estimated ultimate pressures of each pump team-up models (torr)

	E2M175	E2M275	E2M40	E2M80
EXT501	9.0×10^{-11}	9.1×10^{-11}	9.0×10^{-11}	9.2×10^{-11}
STP2001	9.1×10^{-12}	9.4×10^{-12}	9.1×10^{-12}	9.0×10^{-12}
STP400	1.3×10^{-11}	1.2×10^{-11}	1.3×10^{-11}	1.3×10^{-11}

Table 4. Estimated transition duration of pressure variations (sec)

Starting	E2M175	E2M275	E2M40	E2M80
EXT501	166.431	154.724	269.546	200.56
STP2001	69.529	57.407	221.942	124.86
STP400	125.814	111.448	252.529	172,054

Ending	E2M175	E2M275	E2M40	E2M80
EXT501	177.077	163.333	284.792	215.208
STP2001	106.061	76.094	334.175	187.149
STP400	149.832	129.742	282.492	200.409

Table 5. Estimated maximum pumping speed of each pumping models (liter/sec)

	E2M175	E2M275	E2M40	E2M80
EXT501	485.714	486.952	422.85	463.143
STP2001	95.9048	123.048	51.62	64.2667
STP400	139.45	185.714	143.662	141.37

Table 6. Estimated pumping speed at transition zone (liter/sec)

Starting	E2M175	E2M275	E2M40	E2M80
EXT501	162.177	149.27	258.246	185.185
STP2001	58.589	38.047	212.121	112.186
STP400	105.724	121.437	251.964	169.473

Ending	E2M175	E2M275	E2M40	E2M80
EXT501	178.742	164.053	287.318	216.611
STP2001	111.785	81.818	341.077	197.643
STP400	151.74	132.211	285.354	202.301

Table 7. Estimated Compression Ratio (CR) of each pumping models (dimensionless)

TMP	Total CR	Rotary Pump	CR of Ar
STP2001	8.46×10^{-13}	E2M175	6.33×10^{-14}
		E2M275	6.14×10^{-14}
		E2M40	4.42×10^{-14}
		E2M80	5.38×10^{-14}
STP400	5.89×10^{-13}	E2M175	3.59×10^{-13}
		E2M275	3.80×10^{-13}
		E2M40	3.04×10^{-13}
		E2M80	3.22×10^{-13}
EXT501	8.49×10^{-12}	E2M175	5.10×10^{-14}
		E2M275	3.85×10^{-14}
		E2M40	5.57×10^{-14}
		E2M80	7.62×10^{-14}

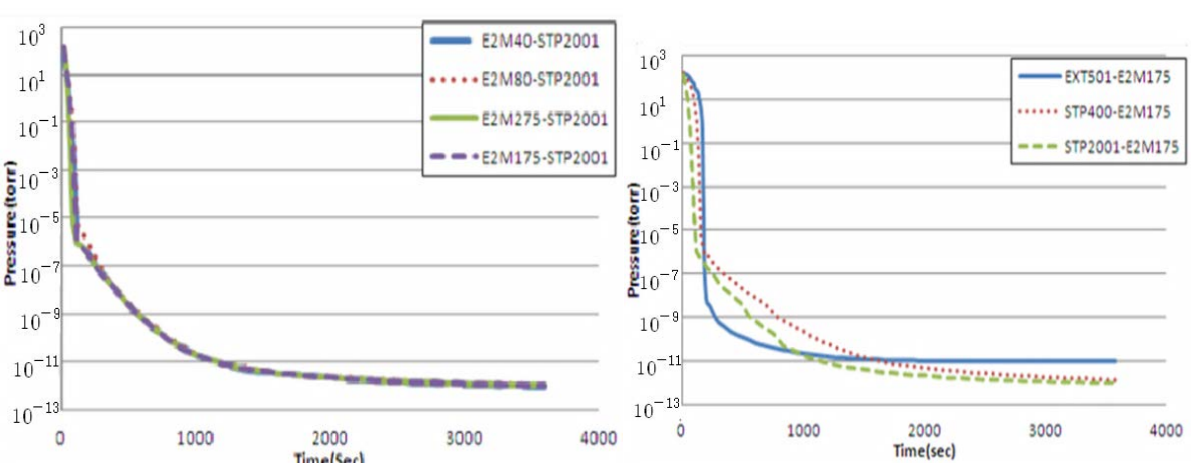

Figure 6. Simulation pressure curves of each pumping team-up models

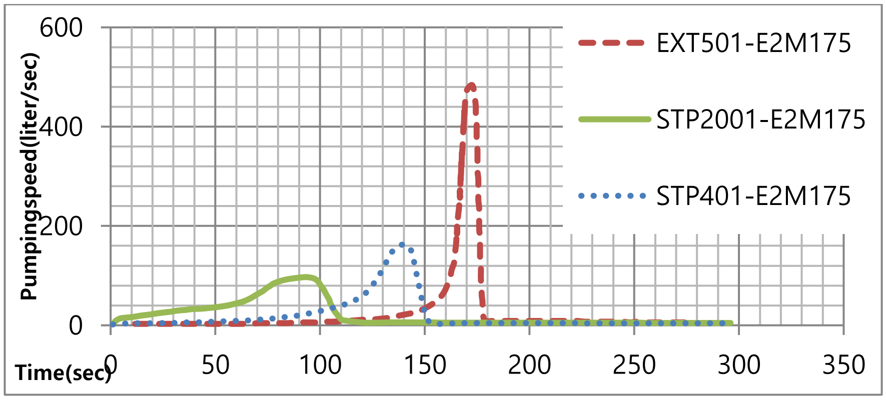

Figure 7. Comparison of pumping speed with variation of TMP model

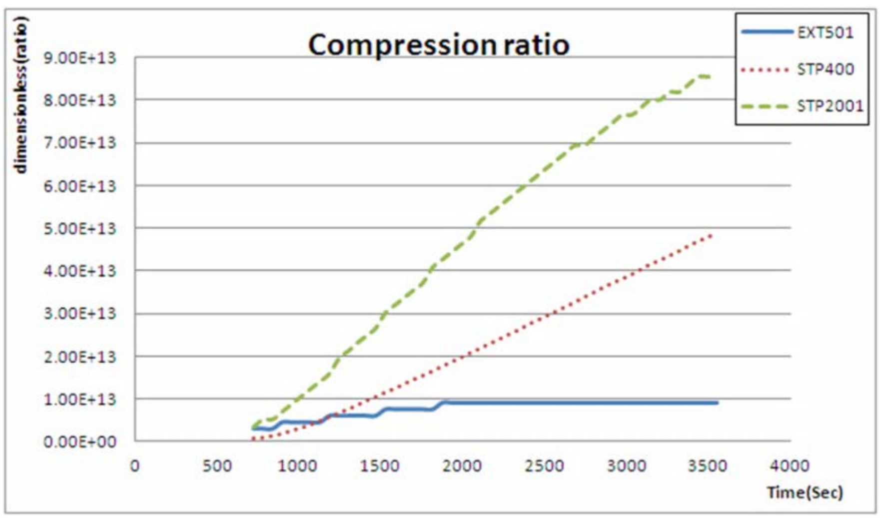

Figure 8. Comparison of compression ratio with variation of TMP model

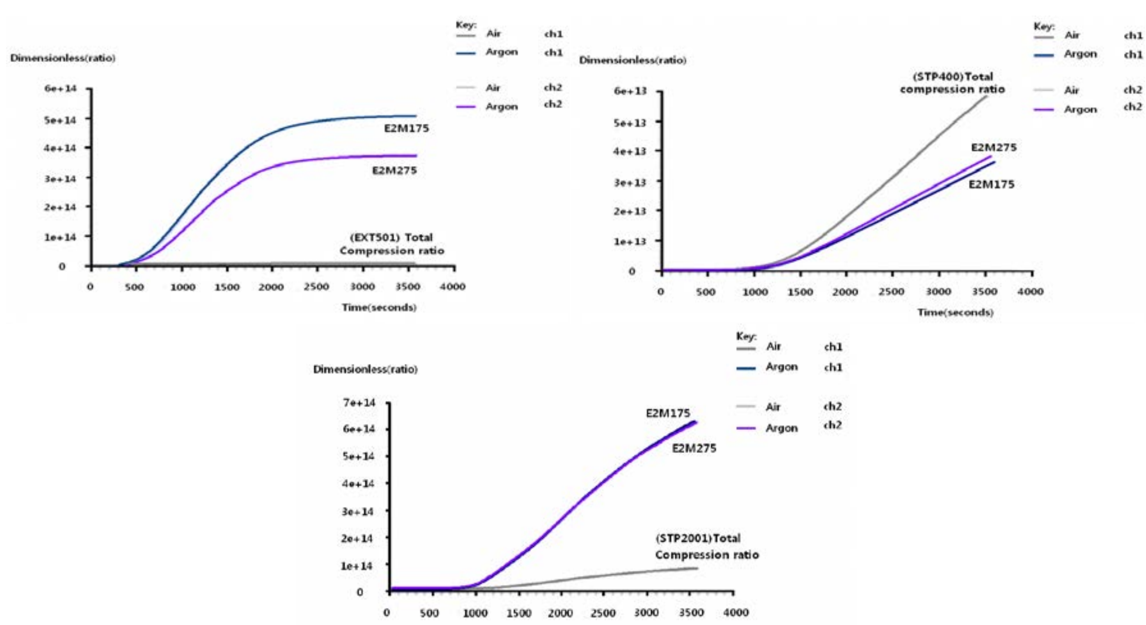

Figure 9. Simulation data of compression ratio of VacSim(multi) simulator

According to simulation results of compression ratio and ultimate pressure, it was verified that pumping behavior absolutely dependent on pumping team-up combinations. But, even though the pumping combination influenced on the range of reachable ultimate pressure, the maximum compression ratio and pumping speed were not affected significantly by the selection of TMP. Pumping combination of rotary pumps showed more effects on the overall performances of system. In other words, selection of appropriate rotary pump for team-up is more important to acquire the better pumping characteristics of system. This simulation results is slightly disagree with general understanding that overall pumping performances of vacuum system totally depend on the adopted high vacuum pump. Simulation results strongly suggested that the pumping combination should be based on the compression ratio of employed TMP. It was also observed that the compression ratio of TMP model were varied significantly with combined rotary pumps. But, there was slight variations among TMP models. Unlike the compression ratio of air, almost all pumping models tended to compress argon gas constantly. It is expected that argon gas is usually utilized as the process gas. Although the overall pumping behaviors of system depending on TMP, it was estimated that pumping factors could influence considerably on process time and yield of microelectronics. Simulation curve showed that reaching time at particular pressure could be speculated easily. In STP2001 pumping model, pumping time was estimated to be getting short as the ultimate pressure decreased. Even though maximum pumping speed was getting decreased, it was observed that pumping speed and compression ratio still have effects on the reachable ultimate pressure. A relationship between ultimate pressure and pumping speed was noticeable because the variation of pumping time depending on performance of employed rotary pump. Duration of increase in pumping speed was coincided with that of pumping time. Effects between total ratio of compression and ultimate pressure was distinguished by performance of TMP models. Concerning about pumping speed, compression ratio and overall performances of system, the STP2001, STP400 models showed the superior characteristics in process applications. However EXT501 provided good behavior on pumping time to reach ultimate 10^{-9} torr. This work was tried to indicate that simulation of pumping design models for vacuum applications could be a useful topic for further research. To simulate the overall performance of vacuum systems, it is necessary to consider the tolerance of all of the design factors. However, 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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Reference

[1] Hyung-Taek Kim. Analysis of High Vacuum System Based on the Applications of Vacuum Materials. The journal of The Transactions on electrical and electronic materials VOL.14,No.6,pp.334-338,December25,2013, DOI; http://dx.doi.org

[2] Varian Associates, Inc, “Basic Vacuum Practice 2ndEd.”,p.69,2001.

[3] James M. Lafferty, “Foundations of Vacuum Science and Technology”, John Wiley & Sons, p. 103, 1999.

[4] H.W. Kim, D.H. Park and K.J. Lim, Introduction to basic vacuum engineering for semiconductor and display processing (NaeHa, Seoul, 2007) p. 100-109.

[5] Y.S Kim, Journal of the Semiconductor & Display Equipment Technology, 8., 1., 7 (2009).

[6] M.J. Seo, Journal of the Korean Institute of Electrical and Electronic Material Engineers,