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Original Research Article

Design of Quartz Chemical Delivery Parts for High Temperature Vacuum Chambers Base of Simulation Results

Erdar Kaplan[1*], Faruk Unker[1], Olkan Cuvalcı[2]

[1*]Department of Mechanical Engineering, Gumushane University Gumushane, Turkey
[2]Department of Mechanical Engineering, Karadeniz Technical University, Trabzon, Turkey

Abstract

Many of today's technologies and research techniques depend on process and methods in high and ultra-high vacuum chambers. High temperature vacuum chambers require innovative concept and use of unusual materials in design to achieve quality performance. In order to obtain quality performance, the temperature and gas delivery on the vacuum chamber surface must be uniformly distributed. In this work, a new funnel for high temperature vacuum chamber was successfully designed and tested using computer-based simulation techniques. The funnel was made of quartz crystal (Grade 2) due to ability to absorb temperature, properties of low gas permeability and low temperature coefficient. In order to mitigate O-rings from high temperature failure and to reduce non-uniformity effect during temperature delivery, a new quartz funnel was developed. The simulation and experimental results show that uniformity distributions in temperature of vacuum chamber surface were obtained with new funnel design.

Keywords: Vacuum chambers, Quartz crystal, funnel, Computer-based simulations

1. Introduction

Computer-based simulations program are extensively used across all fields of science as models of real systems to evaluate output responses. It is finding ever more applications as computing power becomes cheaper and commercially available software becomes more powerful. Simulation and analysis programs are contributed to determinate of problems or parameters to be optimized in the early stage. Here we review some of the many studies of the design of funnel that have used computational modelling and particle dynamics to optimize temperature delivery. This requires the vacuum chamber designer to have knowledge of the funnel thermal performance, which shall enable him to find efficient means to eliminate the problem and also to avoid the costly post construction additions and changes. High quality vacuum chambers are very important to the equipment's performance under different vacuum condition during the process. The funnel is one of the most important parts of high vacuum chamber due to gas inflow region. Traditionally vacuum chambers and their parts are made of variety metals [1] but, high temperature vacuum chambers require use of unusual materials in design to achieve quality performance. Hence, the funnel was made of quartz crystal due to properties of ability to absorb temperature and low temperature coefficient. This paper describes a simple new design of funnel of high vacuum chamber that have used computational modeling of temperatures on

* Corresponding Author
E-mail: erdarkaplan@gumushane.edu.tr
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and around the funnel. The aim of this paper was to achieve quality performance and obtain uniformly temperature distribution of vacuum chamber with design of a new funnel including its temperature properties in the heater temperature range from 300 °C to 650 °C through simulation analysis.

2. Literature Review

Vacuum chamber are commonly used in analytical applications and manufacturing process. The design of a vacuum chamber is critical to its ability to achieve and maintain contamination-free vacuum at high vacuum levels. The criteria are generally taken into consideration for the vacuum chamber and the design is realized within this framework. In order to achieve a significant leap in vacuum performance, the design of a vacuum chamber is to clearly define what all the criteria must be account. Huntington designed an ultra-high vacuum, low-cost universal vacuum chamber suitable for a variety of research experiments including surface science. The chamber was made from stainless steel with a 14 inch nominal diameter [2]. Hauviller [3] designed an ultra-high vacuum and offered the methodology, methods and hints for designing vacuum chambers with this work. Owing to high temperature vacuum chamber the requirements; it and its components should be designed according to the several boundary conditions [4]-[6]. Materials of vacuum parts, operating pressure and temperature, environment conditions and minimize to virtual leaks criteria are important in high vacuum design. To determine the ambient pressure and temperature are clearly the first step. The sub-sections are not necessarily exhaustive, but the list of physical phenomena influencing the design of vacuum chambers is probably complete. Parts that will be inside the chamber should be made of low outgassing materials, and should be cleanable and bakeable to very high temperatures. Dimensional stability of the chamber is of fundamental importance for establishing base pressures and obtaining temperature integrity. Dimensional stability usually equates to chamber rigidity and there is a hierarchy of basic chamber shapes in terms of this rigidity. In high vacuum systems, the physical design of the interior of the vacuum chamber must also take into account the need to avoid or at least minimize the opportunity for high temperature gradient. High temperatures are sources of low temperature coefficient that are physically trapped within the vacuum chamber and hence, the funnel was made of fused quartz crystal due to properties of low gas permeability [7, 9].

3. Materials and Methods

The choice of materials takes on strategic importance in vacuum chamber design aimed at harmonizing the performance characteristics. In order to obtain quality performance, the distribution of temperature and gas on the vacuum chamber surface must be uniformly delivered. To this end, a new material was used in design. It is an interesting and a remarkable material for design in diverse fields which is called quartz crystal. The mechanical, physical and chemical properties of quartz crystal make it suitable for many uses. It is one of the common allotropes of silicon dioxide (SiO_2) and the most abundant mineral in Earth's crust. Compared to other materials, it exhibits several unusual properties; including pressure, induced amorphization, low thermal expansion, ability to absorb temperature, high pressure and temperature phase transitions, frequency stability, anomalous elastic properties and soft mode behavior [10,11]. Quartz in its various crystalline and amorphous forms finds several industrial applications including being a raw material. SiO_2 occurs naturally as sand or rock, and when melted, the resulting product is called fused quartz. Fused quartz is very pure, has a high chemical resistance, good thermal shock resistance and is very strong in compression.

According to the many opinions; quartz crystal has a very low thermal expansion coefficient and can easily withstand quick changes in temperature. On the contrary it is very stable in varying temperatures, especially at atmospheric A description of a new vacuum chamber designed for controlled studies of funnel is presented. The aim of new design is to mitigate O-rings from high temperature failure and overall improvement of the funnel design and its serviceability. The funnel was made of fussed quartz crystal due to properties of low gas permeability and absorption coefficient. Quartz funnel mounted on closed lid plate and heater blanket is used in order to control temperature distribution. Kalrez 7075 O-rings are also used between chamber bodies due to properties of improved thermal resistance that extends temperatures and pressures. The temperature coefficient is specified in units of parts per million over the operating temperature change. Hence, it can be used in design of which unwanted to get distorted by changes in temperature such as design of high vacuum chamber. In this paper, in order to mitigate O-rings failure from high temperature and to reduce non-uniformity effect during temperature delivery, the funnel was made of fused quartz crystal (Type 214) due to ability to absorb temperature, properties of low gas permeability and low temperature coefficient. Material properties for the fused quartz (SiO_2) are given as following Table 1 [12].

Table 1. Material Properties of The Fused Quartz (SiO_2)

Properties	Value
Quality Grade (Type 214)	2
Apparent porosity (%)	0
Density (gcm^{-3})	2.2
Melting point(°C)	1715
Thermal Conductivity ($W\ m^{-1}\ K^{-1}$)	1.46 @ 20°C
Coefficient of thermal expansion ($x10^{-6}\ K^{-1}$)	0.54 @20-1000°C
Coefficient of absorption(±max at2800 nm), cm^{-1}	0.045

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We simulated the temperature distribution on and around the quartz funnel when the heater is controlled at temperature range from 300 °C to 650 °C at 1 atmosphere (atm) external pressure and room temperature. Axi-symmetric model is considered and 2D axi-symmetric thermal simulations are carried out. Gas flow effects are ignore due to low heat capacity of gas and low pressure limit effects of gas flow on temperature distribution.

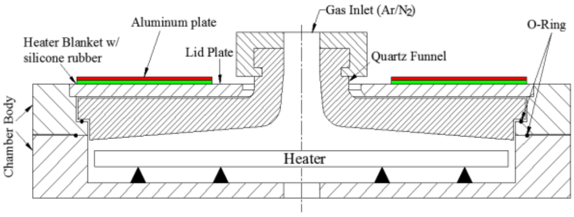

Fig. 1 Schematic representation of new high vacuum system

4. Results and Discussion

An example of vacuum chamber FE modeling with new funnel design is investigated to show the accuracy of results from ANSYS. This section focuses on analysis of temperature distributions through the funnel when the heater is controlled at temperature range from 300 °C to 650 °C. The absent O-ring has a direct impact on the uniformity of temperature into the vacuum chamber. An increase in the diameter of funnel causes a decrease in the temperature and hence enhances the uniformity of temperature generated into the vacuum chamber. The results obtained from the cross-section measurements, shape of the funnel has maximal impact on the uniformity.

The heater temperature was calibrated at 600 °C with the chamber body temperature of 135 °C, as shown Fig. 2. Furthermore, it was calibrated at room temperature. Simulation condition for quartz funnel, thermal conductivity and coefficient of absorption are chosen as about K=0.2 W/mK and 0.045 respectively.

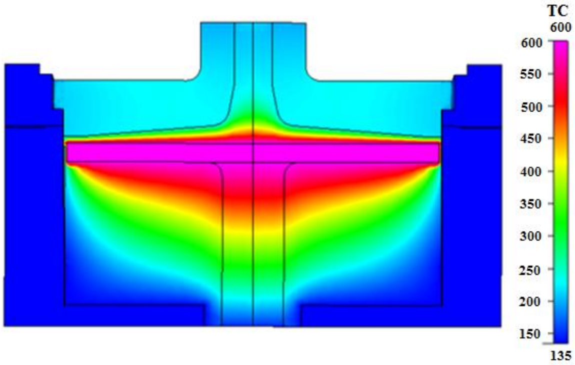

Fig. 2 Thermal simulations of calibration model

14 pieces of K type thermocouple (TC) are mounted circumferentially into vacuum chamber. Temperatures of 14 points on and around the funnel to predict temperature distribution by the simulations are taken into account as shown in Fig. 3. Furthermore, a thermocouple (8) is placed on chamber body to estimate temperature of inner surface of wall of chamber body.

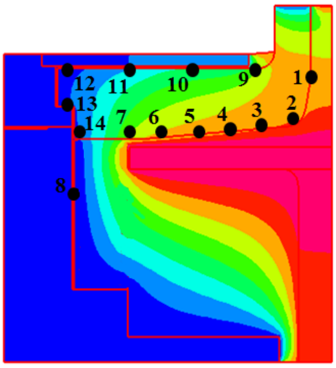

Fig. 3 Thermocouple (TC) position on and around the funnel.

With the calibration models, the temperature distributions on and around the funnel were measured at the range of 195-231 °C from thermocouples of chamber as shown in Figure 4.In the case of modified funnel, the combining of the parts to one part greatly increased the temperature drop and makes the temperature uniformity higher than old chamber. The temperature values are very close to the value read from the Fig. 4 in all points where the temperature drop equals approximately 35 °C with respect to TC points.

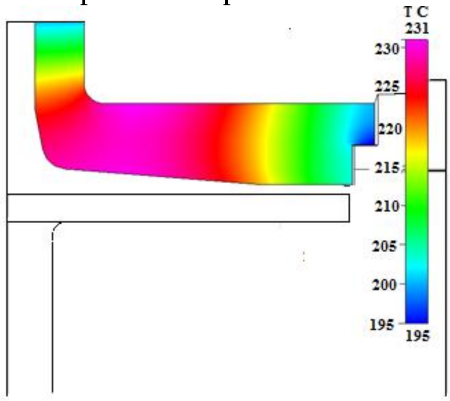

Fig. 4 Results of temperature distribution for calibration model

After the obtaining calibration results, temperatures of heater and chamber body are increased step by step to obtain temperature distribution by the simulations and experimental results. Experimental results are compared with FEM results at different vacuum condition as following Fig. 5 and Fig. 6.

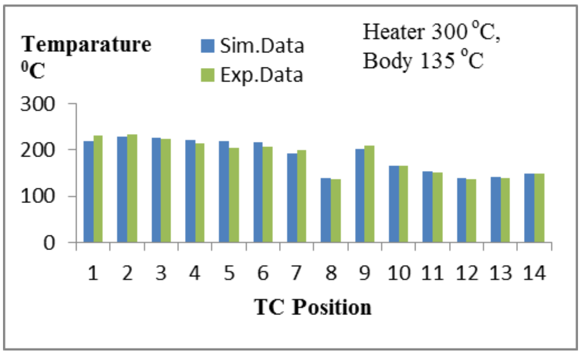

Fig. 5 Simulation and experimental results of temperature distributions

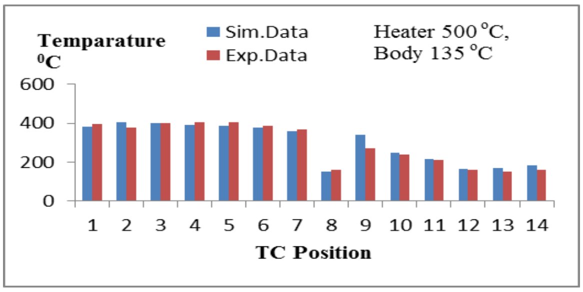

Fig. 6 Simulation and experimental results of temperature distributions

Both of the results show that good agreement between the experimental data and simulated temperatures. At higher temperatures, there is a gap between the experimental temperatures and simulated temperatures. This is may be due to the change of radiation properties of the materials. First, the temperature of chamber body was controlled by 135 °C with the heater temperature of 300 °C. The temperature distributions on and around the funnel were measured at the range of 140-230 °C from TC of chamber from simulation heater temperature of 500 °C. The temperature distributions on and around the funnel were measured at the range of 163-405 °C from simulation results as shown Fig. 6. The temperature of inner surface of chamber body was also measured at 153 °C. The results generated with the FEM simulations show very good agreement with the experimental data, which can be used for the refinement of models and modelling parameters. Temperature results obtained from 14 points are changed accordingly based on the distance along the cross-section of funnel. Fig. 5 and Fig. 6 show the comparison of temperature uniformity among different TC points from both horizontal and vertical measurements. All the temperature intensity results align well on a single trend, which indicates that there is no distinguishable difference with the heater temperatures used. The temperature inside the chamber can be considered to have reached a fully developed temperature gradient beyond the simulation of TC point 1-7. On the other hand, a comparison of the vertical temperature fields does not change as the heater temperature decreased. results. The temperature of inner wall surface of chamber body also was measured at 139 °C. The simulation and experimental results show that temperature distributions near the heater are observed uniformly as seen at TC points 1-7 which is also can be called manufacturing process region.

In the second condition, the temperature of chamber body was controlled by 150 °C with temperatures of heater and chamber body are increased step by step to estimate temperature distribution on and around the funnel at higher temperature by the simulations. When the temperature of chamber body was controlled by180 ^{0}C with the heater temperature of 600 °C, temperature distributions inside of the chamber body were measured at the range of 182-498 °C from TC points of chamber. The results show that temperature distributions closed to the heater are observed about 90 °C differences between TC points 1-7 as shown Fig. 7.

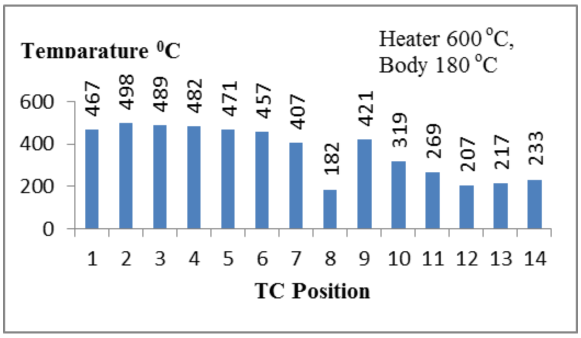

Fig. 7 Simulation results of temperature distributions

In a subsequent study, the temperature of heater was controlled by 650 °C with the chamber body temperatures of 150 and 210 °C. When the chamber body was controlled by150 °C, the temperature distributions thorough the funnel was measured between 181-538 °C. The temperature of inner surface of chamber body was also measured as 157 °C, as shown Fig. 8. On the other hand as shown Fig. 9, temperature of chamber body increased to 210 °C and temperature delivery thorough the funnel was measured at the range of 239-546 °C when heater temperature of 650 °C was fixed.

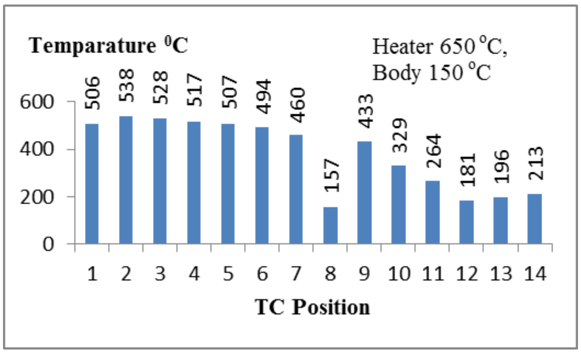

Fig. 8 Simulation results of temperature distributions

Temperature results obtained from 14 TC points are changed accordingly based on the distance along the cross-section of funnel. From figures, it can be seen that the temperature measurements decreases with the distance from center of funnel. All the temperature intensity results align well on a single trend, which indicates that there is no distinguishable difference with the heater temperatures used.

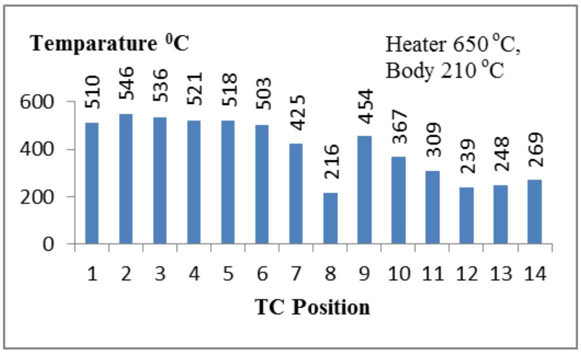

Fig. 9 Simulation results of temperature distributions

5. Conclusions

In this study, a new funnel, made of quartz crystal, for high temperature vacuum chamber was successfully designed and tested using computer-based simulation techniques. The results of this work show that the joint application of modern simulation methods such as process simulation is a powerful tool for the design and optimization of an innovative concept. Generally, these tools enable the simulation and analysis of numerous complex processes in the engineering practice in an early stage of the project. The results of the analysis of temperature distributions as well as the results generated with the simulations mostly show uniformity distributions in temperature, which can be used for the refinement of models and modeling parameters. The work reported in this paper is a complete numerical investigation of parametric study of temperature distribution through the funnel of a chamber. Basing on obtained results, the new behavioral quartz model has been developed which appears to be more efficient than old design. As a result, the simulation and experimental results show that uniformity distributions in temperature of vacuum chamber surface especially on process region, were obtained with new funnel design.

6. References

1. R.A. Campbell, and D.W. Goodman, “A new design for a multi technique ultrahigh vacuum surface analysis chamber with high pressure capabilities”, Volume 63, Issue 1, pp.172-174, Jan. 1992.
2. www.huntvac.com., 02/01/2015.
3. C. Hauviller, “Design rules for vacuum chamber”, CERN Accelerator School: Vacuum in Accelerators Proc. Cas, pp. 31-42 May. 2007.
4. U. Hahn, P. K. Hartog, J. Pfluger, M. Ruter, G. Schmidt, and E.M. Trakhtenberg, “Design and performance of the vacuum chambers for theundulator of the VUV FEL at the TESLA test facility at DES”, Nuclear Instruments and Methods Physics Research Section A, Volume 445, Issue 1-3, pp. 442-447. A 445, 2000.
5. G.D. Alexeev, L.N. Glonti, V.D. Kekelidze, and et al., “The thin-wall tube drift chamber operating in vacuum”, Proceedings of the 12th Pisa Meeting on Advanced Detectors, 20-26, Volume 718, pp.421-423, May 2012.
6. K.M. Birnbaum, and The Quantum Optics Group, “Ultra-high vacuum chambers”, California Institute of Technology, Norman Bridge Laboratory of Physics, CA 91125. Tech. Rep. 12-33, 2005.
7. V. Avagyan, H. Gagiyan, S. Nagdalyan, H. Petrosyan, “Vacuum Chamber Design Considerations for Candle Light Source” Proc. of EPAC, Paris, France, pp. 2532-2534 2002.
8. F. Burri, M. Fertl, and et al., “Copper coated carbon fiber reinforced plastics for high and ultra-high vacuum applications”, Journal of vacuum science and technology, Volume 101, pp. 212-216, 2013.
9. Y.C. Kang, D. A. Milovancev, and et al., “Ultra-high vacuum investigation of the surface chemistry of zirconium”, Journal of Nuclear Materials, Volume 281, pp. 57-64, 2000.
10. M. Goryachev, S. Galliou, J. Imbaud, and Abbe, P, “Advances in development of quartz crystal oscillators at liquid helium temperatures”, Cryogenics, Volume 57, pp. 104-112, Oct. 2013.
11. F. Balik, A. Dziedzic, and T. Swietlik, “Quartz crystal unit modeling at

cryogenic temperatures", Materials Science and Engineering, Volume 177, Issue 15, pp. 1254-1260, Sep. 2012.
12. www.quartz.com/gedata, 02/01/2015.