Modern engineering tools for the development of new samples of vacuum process equipment

Ya O Zhelonkin, A A Biktashev, S I Salikeev, I A Sungatullin, O V Zhelonkin

FERRY VATT LLC., Kazan, Kutuya St., 159,

E-mail: zhelonkin.ya@gmail.com

Abstract. The paper presents the tools and methods used in the company for the development of new types of vacuum process equipment. A description of the design tools used and the results obtained for the examples of the development of vacuum melting radio frequency (RF) plasma and vacuum test equipment has been given.

1.Introduction

The development of new technologies requires new approaches in the development, manufacture and commissioning of non-standard samples of vacuum process equipment in a short time. Some of the modern tools for the dynamic solution of new design problems are computer development tools, such as software packages for CAD design and CAE modeling, as well as the experimental approbation of new design and technological solutions laid when creating new equipment. FERRY VATT is actively introducing the use of software packages for 3D design, physical process modeling, prototyping and modeling, as well as experimental studies at all the stages of product development in an effort to explore the markets of new equipment and technologies. Some of them have been presented in this article with the description of the targeted application projects and the results obtained.

2. Description of projects and tasks

The key project implemented by the company in 2018 is the development and manufacture of a VATT-1300VIP-S vacuum melting furnace (figure 1). The unit has been designed to produce innovative aluminum and magnesium alloys in vacuum in an induction furnace followed by casting thereof in a muffle furnace, with the possibility of adding nanomodifiers in the melt and ultrasonic melt treating both in the process of melting when alloying and before solidification when casting into molds [1]. In addition to the design solutions in the development of equipment units, some new tasks were successfully solved for the company at the design stages, such as calculating and choosing methods for vacuum pumping of the system with a metal evaporation flow, including the volatile elements of alloying additives (Zn, Mg, etc.), the strength calculations of the heat-loaded multilayer structure of the vacuum chamber; the development of a technology for preparing the input of nano-modifiers into vacuum with the uniform mixing thereof in the melt. The project has been successfully implemented and put into preliminary operation at the customer plant.

Project of studying material treatment in ICP low pressure sources. When implementing the project, the tasks of convergence of the results of modeling the gas-dynamic flows of the laminar flow regime in a vacuum chamber with the experimental ones were set. The studies were conducted jointly with the Federal State Budgetary Educational Institution of Higher Education "Kazan National Research Technological University" and PVS LLC. The cylindrical ICP source is installed on a UVN-71 vacuum chamber and is a quartz water-cooled tube with an inner diameter of 27 mm and a length of 250 mm with an inductor. The pumping means are an AVR-150 vacuum unit which consists of an AVZ-20D backing pump and a booster DVN-150; the vacuum gauge is an MKS 627B diaphragm capacitive sensor, the working gas, argon, is supplied through an RRG-10-360 mass flow regulator. The operating pressure ranges within 1-100 Pa in the experiment (figure 2).
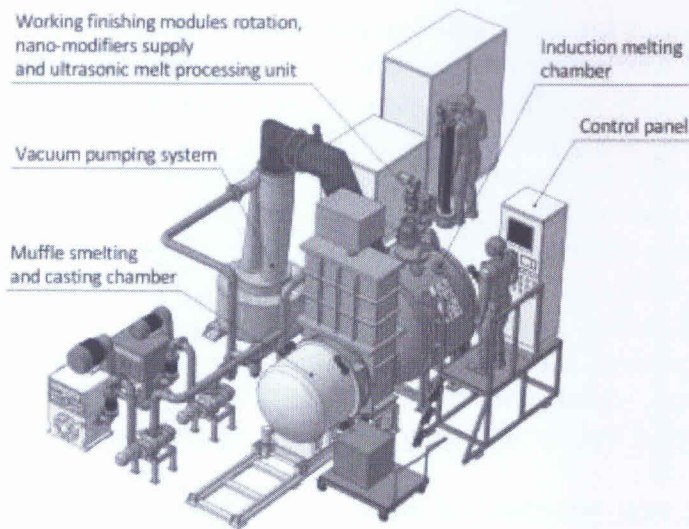
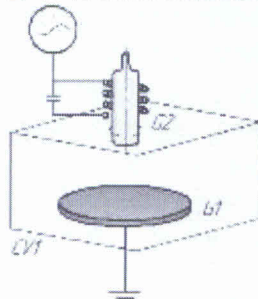**Figure 1.**VATT-1300VIP-S vacuum induction melting furnace

Figure 2. Diagram of a cylindrical ICP source. CV1 - vacuum chamber,
G1 - ground electrode / sample holder, G2 - ICP source

The project of a vacuum thermal chamber thermal protection system (figure 3), which is designed to carry out vacuum thermal tests of promising aviation complexes assumes the modernization of a unit based on a KTBV-8000 unit with additional aluminum compartments of a total volume of 25 m^3. When implementing the project, the problem of thermal non-stationary calculation of the thicknesses of thermal insulation was being solved in order to provide the established heating cycle for the tested product in the residual vapors of the gaseous medium up to 700 °C.
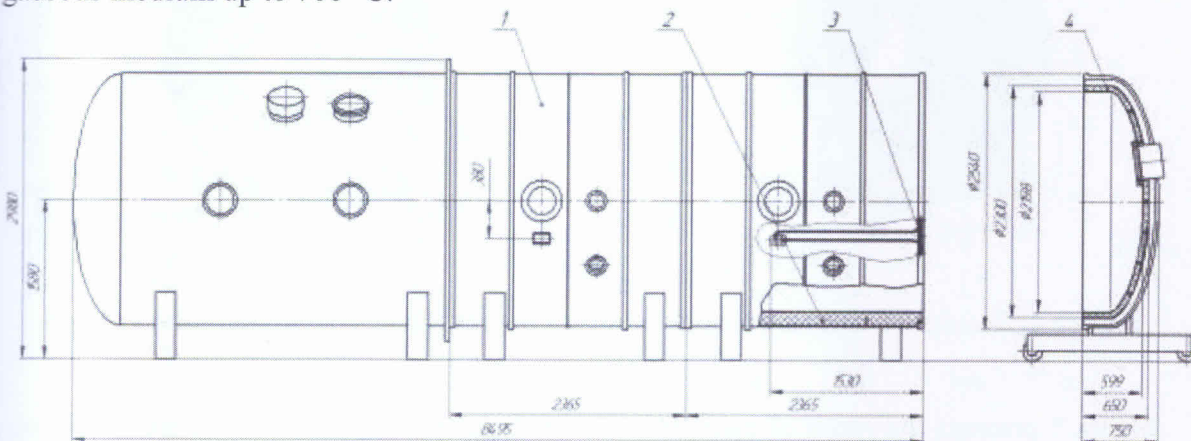

Figure 3. CTB heat insulation system. 1 – thermal testing unit, 2 – heat insulation of additional chamber compartments, 3 – flange cooling device, 4 – chamber cover heat insulation

3. Tools and techniques for solving design problems

To solve the design problems presented in the present paper, computer-aided design (CAD) systems of various levels and purposes are used. When designing the structures of parts and assemblies, a domestic CAD package Compass 3D is used. For the front end engineering of the design solutions of the equipment, design calculations are carried out, which make it possible to initially determine the shape and characteristics of parts and assemblies. As a rule, project calculations are carried out using analytical techniques or empirical recommendations, depending on the specifics of a physical process and a task. Thus, during the initial selection of vacuum pumping means, the company has developed and implemented a proven method for calculating the required values of effective pumping speed and automatic selection of the recommended pumps. After the front end engineering of the structures, calibration calculations are carried out by modeling physical processes using a multiphysical Comsol CAE package.

When designing new non-standard equipment and when developing automatic control systems, our company implemented the principle of unifying the forms of reports on equipment operation and the forms for inputting parameters for automatic control. Thus, when developing modes in manual control, reporting files are generated, which can then be the source data for the automatic repetition of the obtained reference cycle. Such an approach makes it possible to make equipment universal from the point of view of controlling various modes of processing products of various nomenclature and shorten the cycle from setting the technological modes to the target production process.

4. Results

Figures 4, 5 present the results of calculations of the mechanical strength of the VATT-1300VIP-S vacuum melting furnace chamber. Designing the structure using design-calibration calculations has made it possible to optimize the wall thickness and the final mass of the chamber. The calculated results have been confirmed by the reliability of the manufactured equipment.
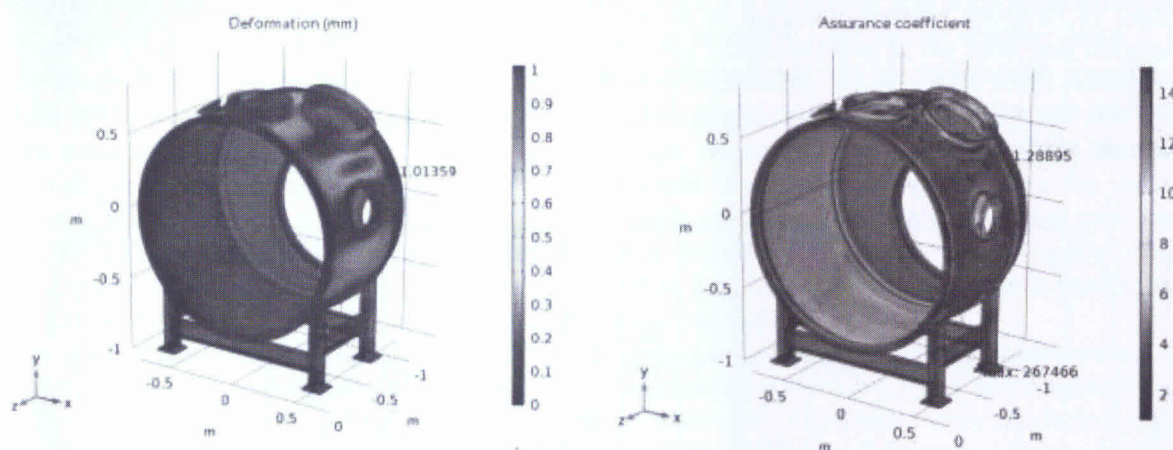

Figure 4. Results of calibration calculations of the mechanical strength of the vacuum chamber

Figure 5 presents the result of calibration calculations and modeling of the free-molecular flow regime using the example of a melting unit. When testing the equipment, the values of operating pressure are confirmed with allowance for the permissible error.
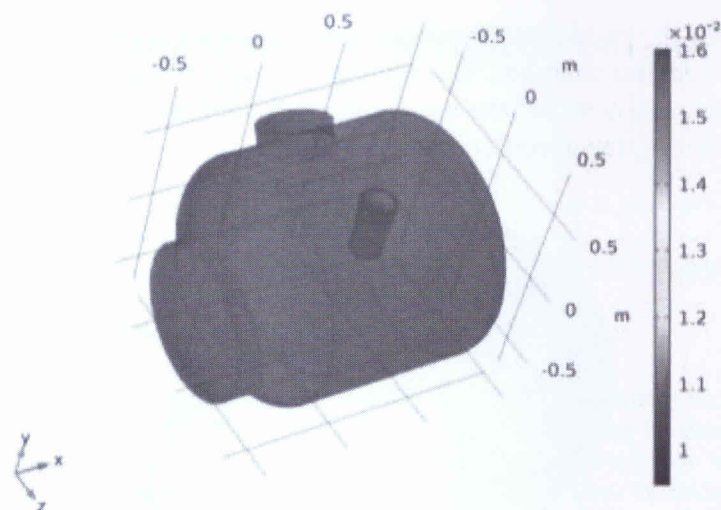
Figure 5. Result of calculating the pressure distribution (Pa) in the vacuum chamber in the dynamic mode of operation of the pumping system and the gas flow of evaporated aluminum vapors during smelting.

The results of modeling the laminar flow regime using the example of RF plasma processing units and the comparison with the experimental results presented in Figure 6 are approximated by a straight line with high accuracy. The tangent of the slope of the experimental and calculated lines is different, which causes an increase in the error with an increase in the pressure in the system, however, the calculation error within the pressure range of 1-100 Pa does not exceed 15%, which is acceptable when designing and predicting technological processes. The reasons for the discrepancies can be explained by the presence of local resistances of the line, which significantly reduce the conductivity, which depends on the diameter raised to the third power. The results of the calculation using the mathematical model of the free-molecular flow regime are given in order to visually show its inapplicability at the indicated pressures [2].
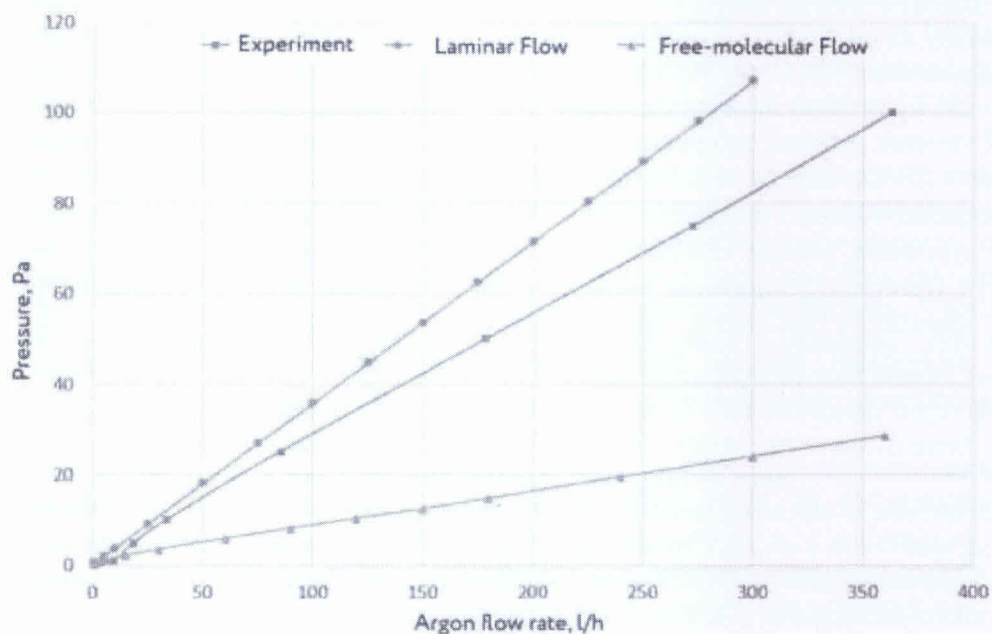

Figure 6. Pressure in the chamber versus Argon flow rate within the range of 1-100 Pa (laminar flow regime) diagram

Figure 7 presents the results of an example of calculating a non-stationary problem of heat transfer in a CTB vacuum chamber. The calculation was carried out to determine the optimal heat insulation thickness at which the temperature on the outer surface of the chamber does not exceed 80 °C during the specified test cycle time.
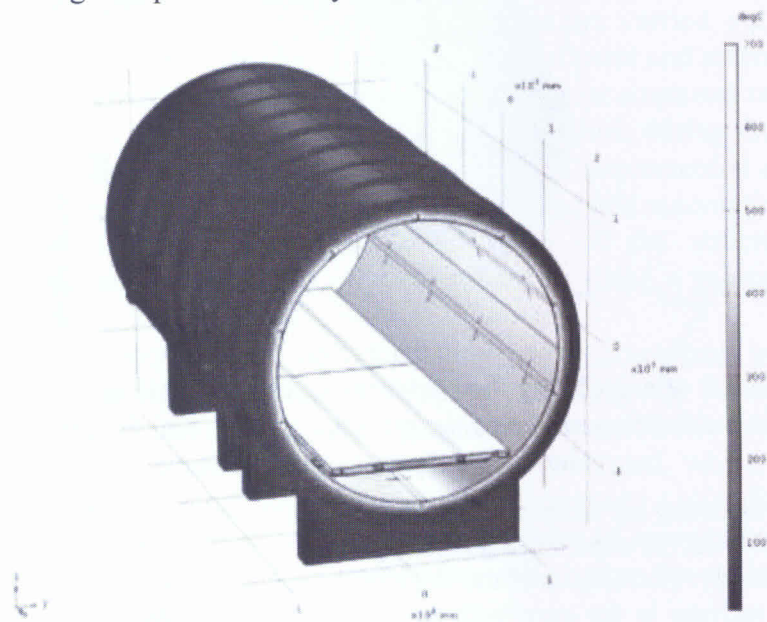

Figure 7. Temperature distribution in the structure of the CTB vacuum unit.

5. Conclusions

The presented experiment of using modern development tools when creating non-standard vacuum process equipment makes it possible to significantly reduce the output cycle time of new equipment from development to commissioning and to obtain specified functional and technological requirements with minimal production and design costs. The versatility of the presented design tools along with the rich long-term experience of the development team of FERRY VATT makes it possible to perform research and development to develop non-standard vacuum process equipment in various areas of vacuum technology, such as vacuum deposition (PVD, CVD, ALD, gas-thermal plasma deposition), RFPT (from Eng. RadioFrequencyPlasmaTreatment) technologies of processing in high-frequency plasma (etching processes, plasma chemistry and plasma physics processes), vacuum impregnation equipment (molding composites materials, the impregnation of transformers, powder and foundry metallurgy products), special melting equipment (single crystal zone melting, foundry equipment), vacuum furnaces, testing equipment (outer space imitation, testing electric propulsion), as well as other new tasks of domestic and world industry.

References

[1]   Zhelonkin Ya. O., Murtazin R. N., Salikeev S. I., Biktashev A. A., Paltsev A. V. and Sungatullin I. A. // *Proceedings of the VIII International Scientific and Technical Conference "Innovative engineering technologies, equipment and materials - 2017" (ISTC-IETEM 2017").* Part 2. - Kazan, 2017, - Pp. 31-34.

[2]   Azat R. Gizzatullin, Ya. O. Zhelonkin, E. F. Voznesenskiy and Azamat R. Gizzatullin./ *X YUbilejnaya mezhdunarodnaya nauchno-tekhnicheskaya konferentsiya* November 5-8, 2018, Kazan, collected papers.