FLOW ANALYSIS OF THE PRESSURE DISTRIBUTION IN THE EXPERIMENTAL CHAMBER OF THE DIFFERENTIAL PUMPING

PAVLA HLAVATÁ[1], JIŘÍ MAXA[2]

Abstract: The paper deals with the effect of the critical flow, which is reached during pumping of the differential pumping chamber of the Environmental Scanning Electron Microscope (ESEM). The study compares the state of the flow in the area of pumped chamber at pressure ratio on the apertures when the critical flow occurs and its advantages in design of the chambers versus the flow without the clogging the nozzle. The problem was solved using the finite volume method by the Ansys Fluent system.

Keywords: Differentially pumped chamber; ESEM; Ansys Fluent; The finite volume method; SolidWorks

1. INTRODUCTION

The article is based on a study of Dr. Danilatos, 2012, which deals with the pumping of the differential pumped chamber in the environmental scanning electron microscope using the Monte Carlo statistic method. Based on these articles, a comparative study by Maxa, 2016 was produced, where comparable results were obtained by mechanism of continuum using the Ansys Fluent system which use the finite volume method, see Fig 1. and Maxa 2011 and 2012.

On this type of differentially pumped chamber, the analysis was made which monitor the impact of the shape of differentially pumped chamber on the flow path behind the aperture PLA 1 see Neděla 2010. This flow is interesting because of the critical flow created behind the aperture PLA 1, see Vyroubal 2013.

[1] *Brno University of Technology*
[2] *Brno University of Technology, maxa@feec.vutbr.cz*

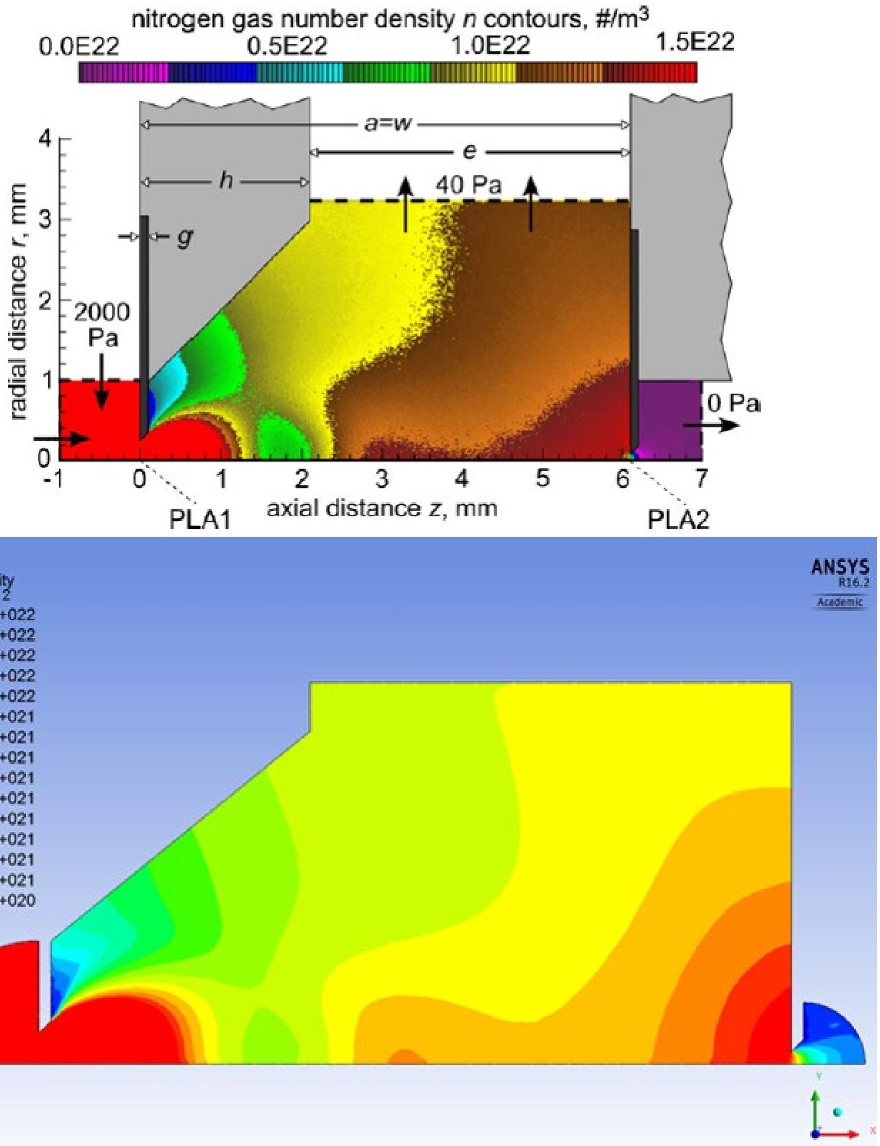

Fig. 1. Comparation of the analysis results obtained using Monte Carlo method and mechanism of continuum

On Institute of Scientific Instruments of Czech Academy of Sciences and Faculty of Electrical Engineering and Communication Technologies is preparing to base the theoretical studies with the experimental measurement of given physical conditions: supersonic flow in low pressures in the borderland of mechanism of continuum as a part of the Environmental scanning electron microscope parts development, see Neděla 2015, 2016, 2018.

2. EXPERIMENTAL CHAMBER

Prepared experimental chamber is constructed as a multicellular for the full scale of physical measurements. For example:

- Flow velocity above the aperture
- Pressure running in the flow axis above the aperture
- Pressure on the nozzle walls
- Pressure and temperature on chamber walls
- Optical method uses
- And etc.

The picture of the preparing experimental chamber is in the Fig.2

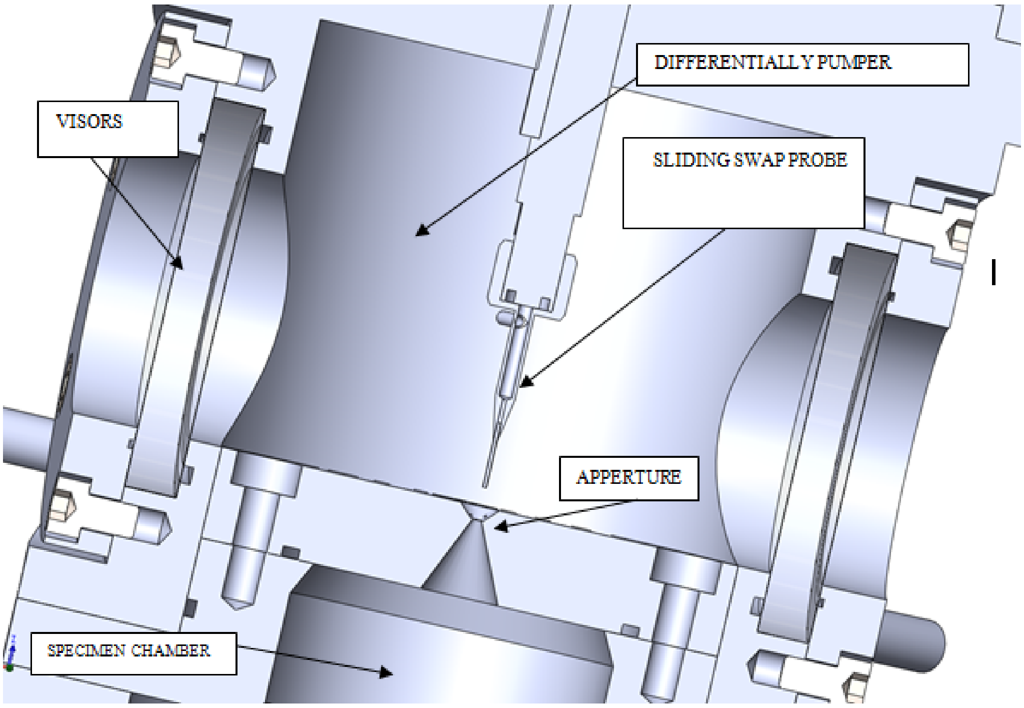

Fig. 2. Experimental chamber

Before the construction of given chamber took place many types of simulations to obtain presumed physics results, which will be compared with next experimental measurement. The construction of the chamber also came out from the series of mathematical- physics analysis.

In the Fig. 3 is pictured the 2D axisymmetric model of given chamber for the analysis in the Ansys Fluent system with the boundary conditions: in the specimen chamber is the area of 2000 Pa. The pressure is pumped through the aperture with the diameter of 0.5 mm to differentially pumped chamber and from here with appropriate feat to have 40 Pa in the differentially pumped chamber. It is about usual conditions in the environmental electron microscope.

Due to markedly different pressures in both sides of the aperture, the critical flow creates behind the aperture.

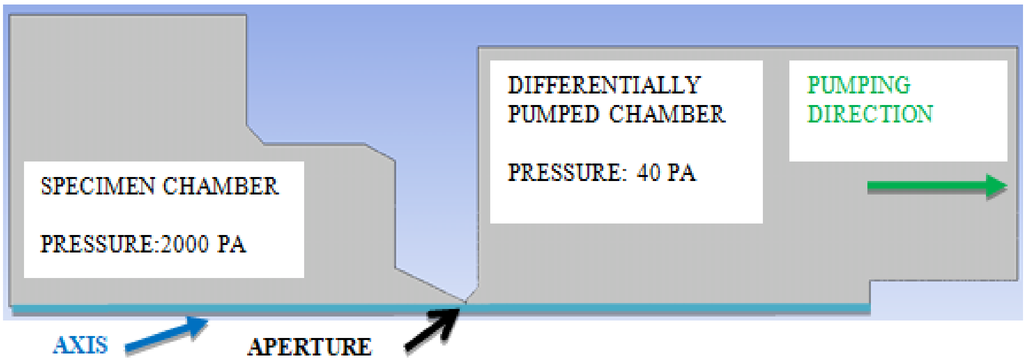

Fig. 3. Axisymmetric shape of the experimental chamber for simulations

3. ANSYS FLUENT SYSTEM

To solve this problem, the Ansys Fluent was used, which uses the mechanism of continuum solving the equations b finite volume method. Due to the supersonic flow, the solver setting was chosen as Density based with the second order discretization. Density - Based solver solves the equations for momentum, continuum and energy at the same time, equations for other scalar quantities are solved separated after that. Also, in this case is the condition to do determine number of iteration cycles to meet the convergence requirement. The Density – Based method solver offers two types of equation linearization method, explicit and implicit method [12]. In explicit method are the unknown values, in every cell, calculated using relationships which contain just existed values, known from the previous iteration. In this method can occur problems with numerical stability. In implicit method are the unknown values determined from existed and unknown values in near cells [12]. In our case, due to the difficulty of convergence, the implicit method was used.

4. RESULTS

We evaluated the running of velocity, pressure and temperature in chosen lines see fig. 4 and also it was evaluated the total layout of given quantities in the chamber.

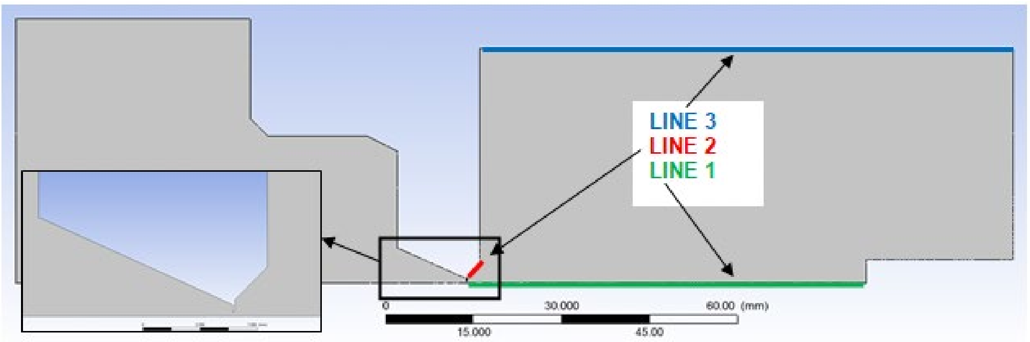

Fig. 4. Monitored paths

From the results comes out that above the aperture according to the pressure gradient occur the supersonic flow, when the velocity in the distance of 1.2 mm achieves almost values of 2 Mach. In this area the big pressure gradient occurs up to value of 16 Pa, see Fig.5 and 6. In the area, where the flow velocity drops below the velocity of 1 Mach, the pressure raises, and the shock wave is created, as is obvious in Fig 5 b.

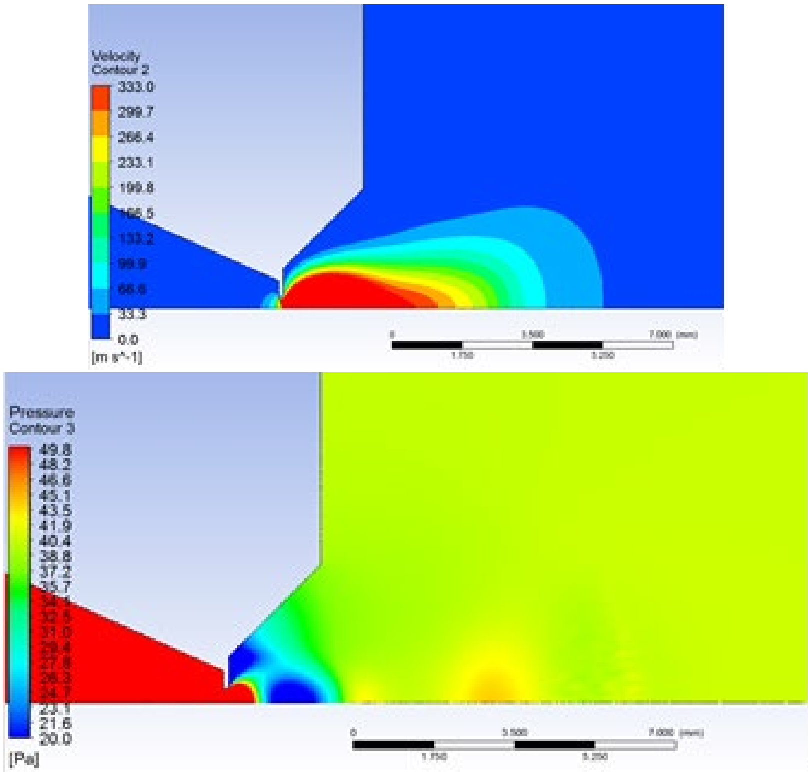

Fig. 5.
(a) Velocity layout above the aperture – line 1; **(b)** Pressure layout above the aperture – line 1

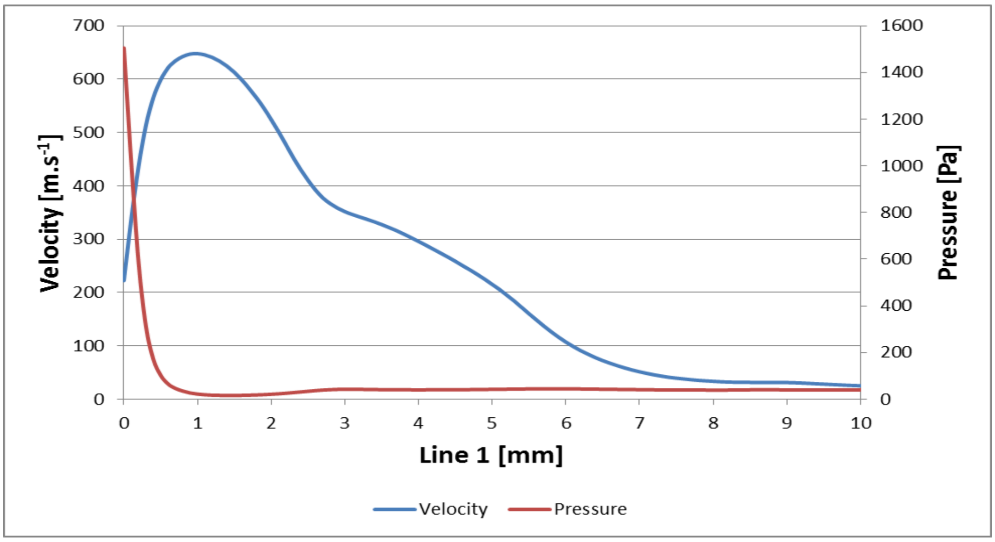

Fig. 6. Velocity and pressure running on line 1.

In the Fig. 7 is pictured the temperature running with the dependence on the distance from the aperture on the line 1. The temperature behind the aperture drops up to value of – 183 °C. The reason of the quick temperature drop of the gas is supersonic flow state. After the minimum achievement because of the velocity drop below the value of 1 Mach, the temperature starts to rise and stabilize on the temperature of the differentially pumped chamber. The temperature will be scanned also from the walls of the differentially pumped chamber for the evaluation of the temperature layout in given chamber during its pumping- see line 3. The temperature running is evaluated in Fig. 8.

Another criterion will be pressure scanning using differentially pressure probes from the aperture walls – see line 2. Its running according to the mathematical – physics analysis is pictured in Fig. 9.

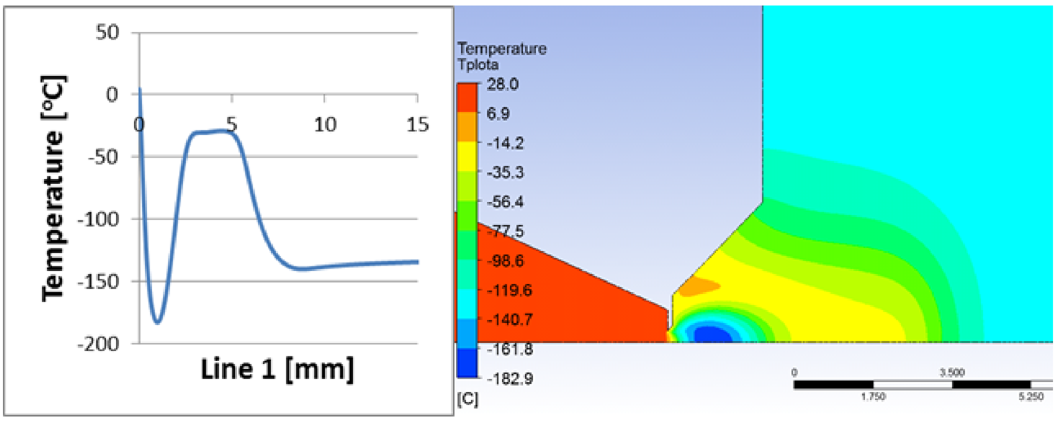

Fig. 7. Temperature layout above the aperture – line 1

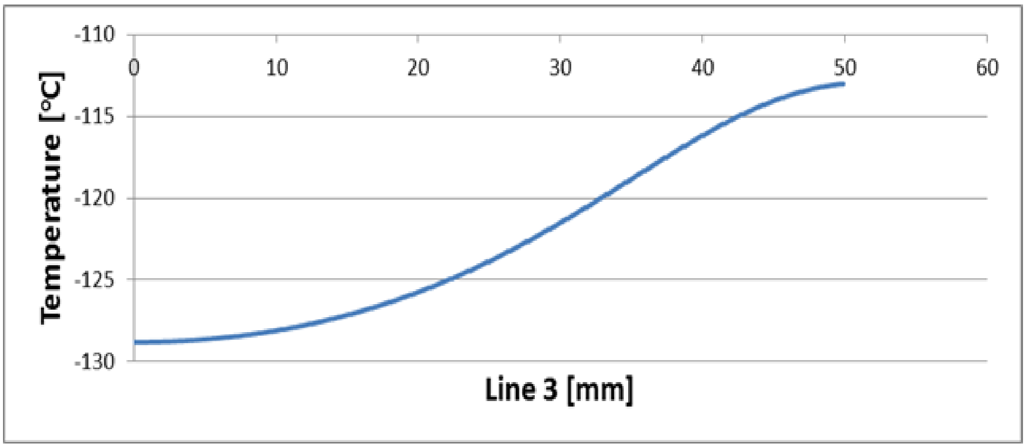

Fig. 8. Temperature layout on the chamber walls – line 3

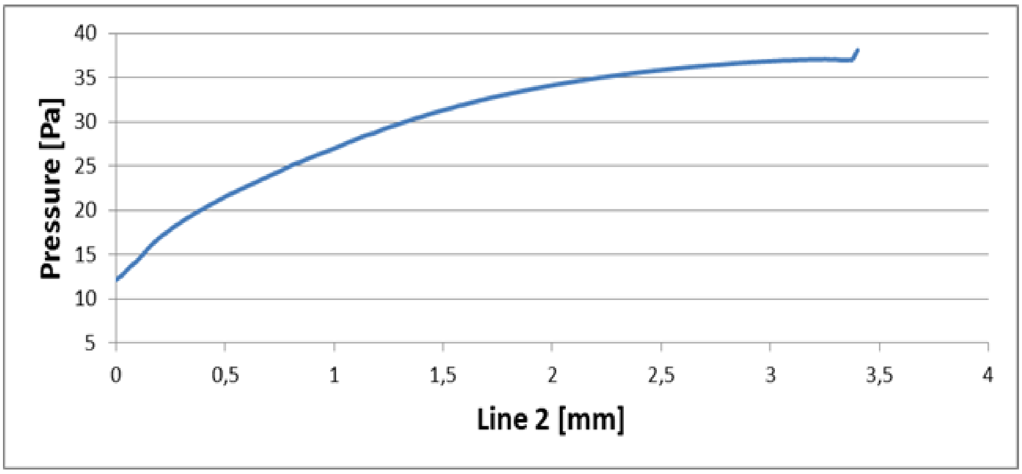

Fig. 9. Pressure layout on oblique aperture wall – line 2

4. CONCLUSIONS

It was made mathematical – physics analysis of the suggested experimental chamber. From the results comes out that for corresponding measurement is necessary to provide temperature probes able to capture the temperature up to – 183 ^{o}C, also the pressure probe used for capturing of the total and static pressure on the line 1 able to work in cryogen regime, where the very low temperatures are expected.

For pressure capturing from the conic aperture walls – see line 2 and Fig. 9 – is necessary for corresponding measurement to provide probes with the measurement error up to 1 Pa, because on this path will be expected, according to the analysis, the difference between the measured places approx. 5 Pa.

5. ACKNOWLEDGEMENT

This research has been carried out in the Centre for Research and Utilization of Renewable Energy (CVVOZE). Authors gratefully acknowledge the financial support from the Ministry of Education, Youth and Sports of the Czech Republic under NPU I programme (project No. LO1210) and BUT specific research programme (project No. FEKT-S-17-4595).

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