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DIFFERENTIALLY PUMPED CHAMBER OF VP-SEM COMPUTED BY THE USE OF COSMOS FLOWORKS SOFTWARE

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Summary: *Environmental scanning electron microscope creates new possibilities in the field of examination various types of specimens and their phases. The article analyses and compares the results of air pumping measurement for selected shapes of the differentially pumped chamber to create vacuum, using the Cosmos FloWorks system.*

1. Introduction

High pressure in gases (up to 300 Pa) in the specimen chamber of the variable pressure scanning electron microscope (VP-SEM) leads to specific construction requirements for the microscope and its pumping system. Construction parts of VP-SEM, particularly of the differentially pumped chamber must be designed in such a way so that they meet the requirements for pumping their interier efficiently and the pressure in them is minimized. However, the relatively high technological requirements for the microscope are well compensated by the wide scope of applications whether in the vacuum mode or in the high pressure mode [X,X].

The high difference in pressure between the specimen chamber ($3{\cdot}10^3$Pa) and the source of electrons (10^{-3} – 10^{-9}Pa, depending on the type of cathode) in VP-SEM can be retained owing to the system of differentially pumped chambers, pressure limiting screens (PLA1 and PLA2 in Fig.2) an efficient gas pumping system. In the screens there are holes tens to hundreds of micrometers in diameter for efficient restriction of gas flow between parts of microscope and smooth flow of electrons from the source to the specimen. The system of chambers and the pressure limiting screens are usually integrated in the EREM column. As a rule, the microscope is pumped with a system of rotary, diffusion or turbomolecular vacuum pumps (the interior of the specimen chamber and adjacent differentially pumped chambers), possibly ion vacuum pumps (the source of electrons).

Due to the high pressure in gases in the EREM specimen chamber, the number of interactions of electrons with gas molecules and atoms (mainly water vapours) increases, which results in diffusion of the primary electron beam. The diffusion of primary electrons increases with increasing pressure, average atom number of gas, working distance and decreasing accelerating voltage in the beam. The diffusion results in a larger diameter of the

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primary electron beam trajectory. Consequently, the signal/noise ratio in the detected signal is less favorable, and eventually may negatively affect the microscope resolution.

2. VP-SEM AQUASEM II

Construction of the now fully operating experimental VP-SEM AQUAEM II following the previous version of the microscope, was, in cooperation with the company TESCAN s.r.o, accomplished in 2007 in the Institute of Instrument Technology, Academy of Sciences Brno [14]. The main target was testing of new detection systems operating in conditions of high pressure in gas and vacuum, study of special water containing non-conducting specimens difficult to monitor, and dynamic ´in situ´ experiments.

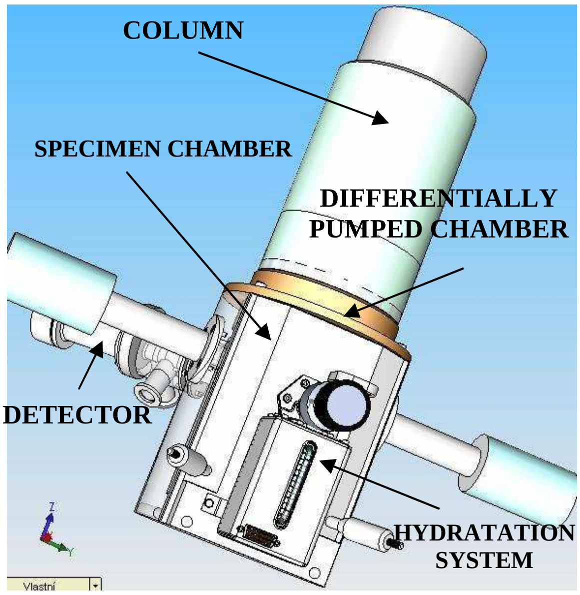


Fig. 1 Variable pressure scanning electron microscope AQUASEM II

For above reasons, an optimal variant of the shape of the differentially pumped chamber was sought as the chamber is the principal construction element for adaptation of the microscope for work in high pressure conditions. Pumping the chamber efficiently is the crucial requirement affecting the qualitative parameters of the microscope such as the maximum magnitude of gas pressure in the specimen chamber, the amount of noise in the detected signal closely associated with microscope resolution, etc. A vital parameter for the final design of the differentially pumped chamber is the minimum gas pressure in the microscope optical axis. In Fig.2, this trajectory is red. The area is the same in all variants (see Fig.4). There are differences in the shape and in the manner of pumping. On the basis of our previous experience, three preliminary shapes were proposed.

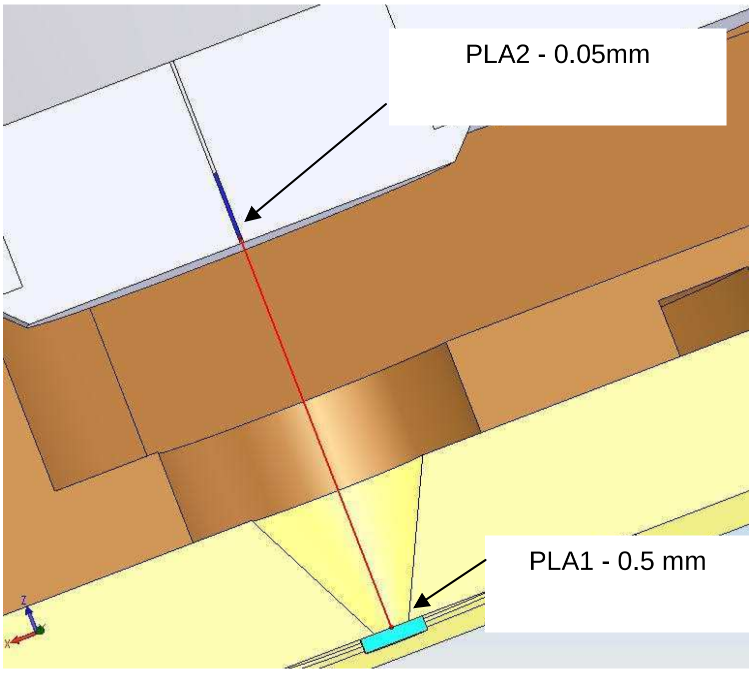


Fig. 2 Electron path length throw the high pressure environment in the differentially pumped chamber of AQUAESM II.

Variant 1 – Gas from the passage area of the primary electron beam through the differentially pumped chamber is pumped in one direction and through the area between the microscope lens and the differentially pumped chamber (Fig.4). In this variant, the delimited area for gas passage is constructed in such a way that gas can follow the shortest possible path to the rotary vacuum pump.

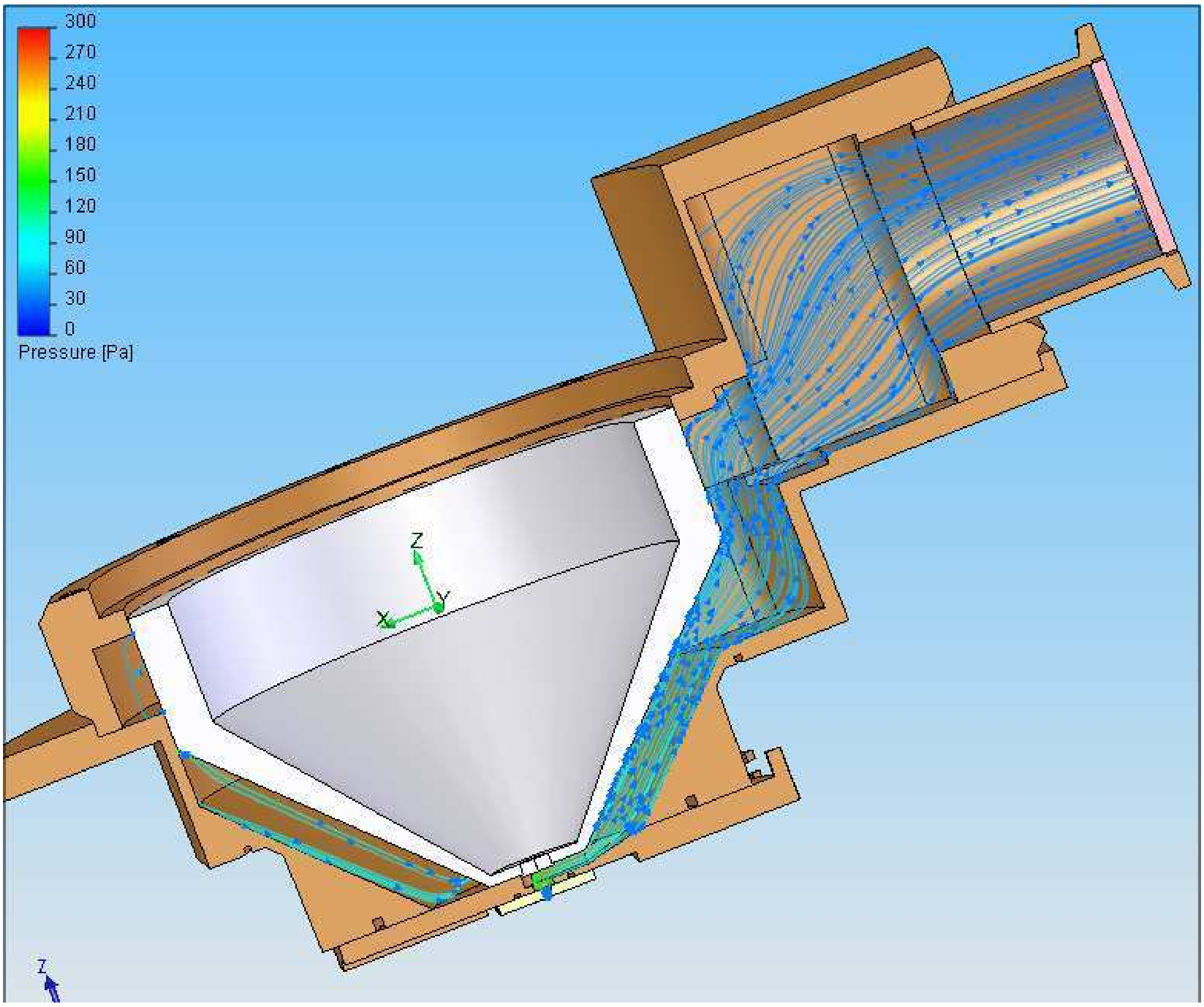


Fig. 3 Flo Trajectories in the differentially pumped chamber for Variant 2.

Variant 2 – Gas is pumped from the passage area of the primary electron beam through the differentially pumped chamber in one direction, similarly to the first variant. It passes through the entire area between the microscope lens and the differentially pumped chamber (see Fig.4).

Variant 3 – Gas is pumped in all directions through the maximum possible free area and it goes away in the same way (Fig.4). The gas offtake in this variant is identical with variant 2.

The variants were modelled using the SolidWorks system and the Cosmos FloWorks module, which enabled analysis of gas flow in seeking an optimal shape.

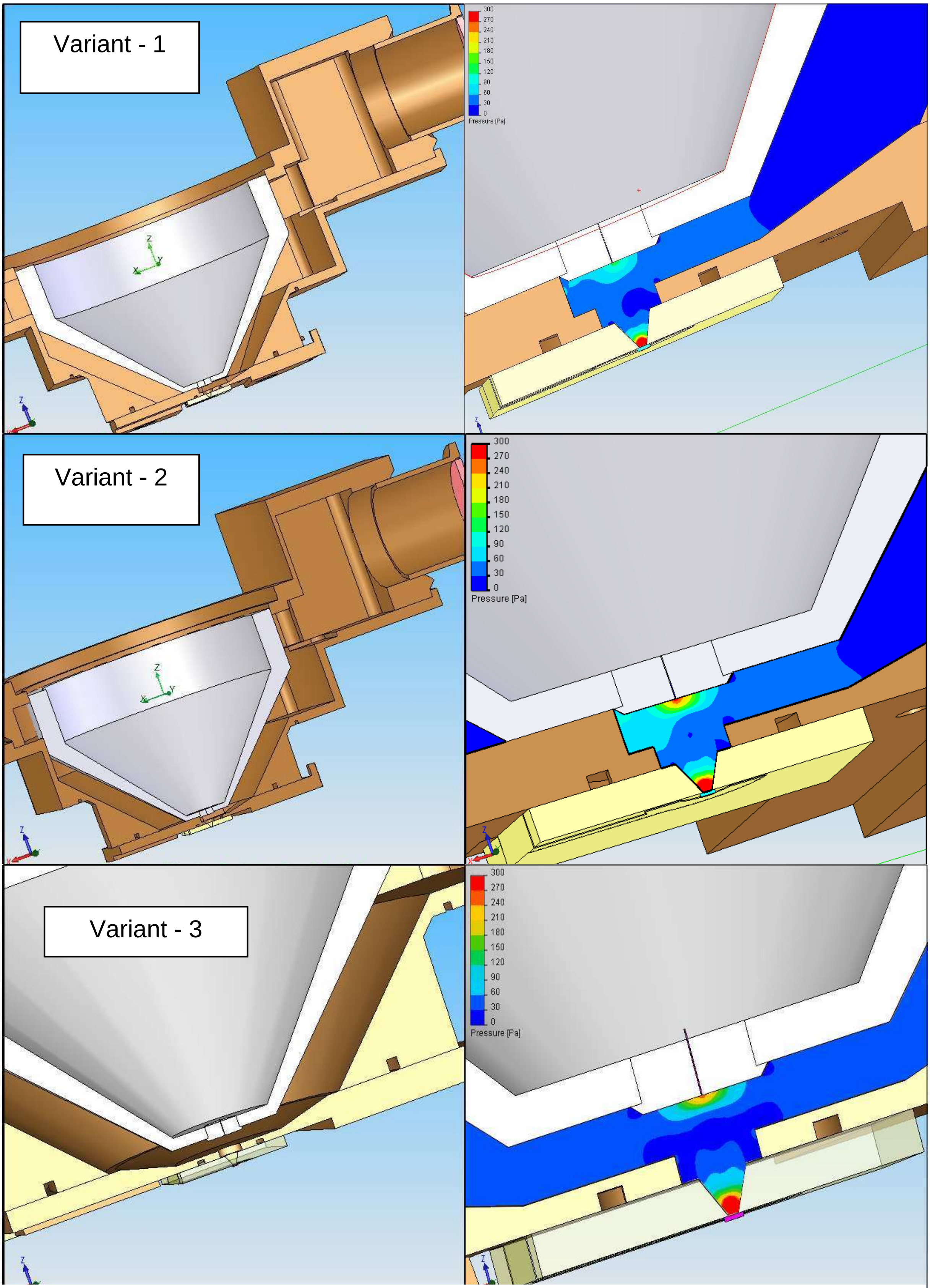


Fig.4 Variants of differentially pumped chambers.

For calculations executed using the Cosmos FloWorks the following marginal requirements were defined. On the PLA 2 screen with a hole 0,05 mm in diameter, located between the microscope column and the differentially pumped chamber, the static pressure of 0,01 Pa is required. Analogically, in the case of the PLA 1 screen with a hole 0,5 mm in diameter separating the differentially pumped chamber and the specimen chamber (Fig.2) the required pressure is 1500 Pa. This value represents the maximal pressure required for the VP-SEM specimen chamber.

For the pumping hole in the differentially pumped chamber the mass flow of the pumped gas was set to 0.00347 kg/s. in dependence on the selected rotary vacuum pump. In symmetrical objects, Cosmos FloWorks can be used to set computation for only a half of the symmetrical object and reduce the computing time. In real conditions, therefore, the mass flow value is doubled.

Using Cosmos FloWorks, results can be processed in many ways. In this case, pressure values in the trajectory of the primary electron beam passing through the differentially pumped chamber were studied.

3. Graphic output

Graphic representation of pressures in the differentially pumped chamber can be seen. In Fig.4. the distribution of pressures can be observed on the scale 0 to 300 Pa. This scope was chosen because the obtained values occur in this range. This graphic representation is the first, only rough evaluation.

Similarly represented can be the distribution of pumped gas rates in the chamber. This information is only auxiliary. It can explain the temporary pressure increase at the mouth of the microscope column (PLA2) (Fig.4) due to the high rate the molecules gain at low pressures on PLA1, and consequently they accumulate in the upper part of the differentially pumped chamber in PLA2. On the basis of achieved results it can be concluded that the higher the rate of flow in the monitored area, the higher the pressure on PLA2.

4. Pressure in the primary electron beam in monitored variants

To select the best variant it is necessary to evaluate the pressures directly in the primary beam trajectory. For this reason, a line was drawn in the trajectory (Fig.2) where the system will transform the pressure and gas density values into a table which is the basis for graphs. Figs. 5 and 6 show graphs of this dependence for all three variants. On the X axis the length of the curve representing the primary electron beam trajectory (Fig.2) through the differentially pumped chamber is plotted. On the Y axis the pressure curve is plotted.

For the sake of clarity, the primary beam trajectory 5.56 in length is divided into two graphs (Fig.5 and Fig.6).

5. First selection criterion

As there is a linear dependence between pressure and the probability number of interactions of gas molecules from the differentially pumped chamber with primary beam electrons, one criterion for selection of an optimal shape is the arithmetic mean of pressures and of the densities of the pumped medium observed on the primary beam trajectory.

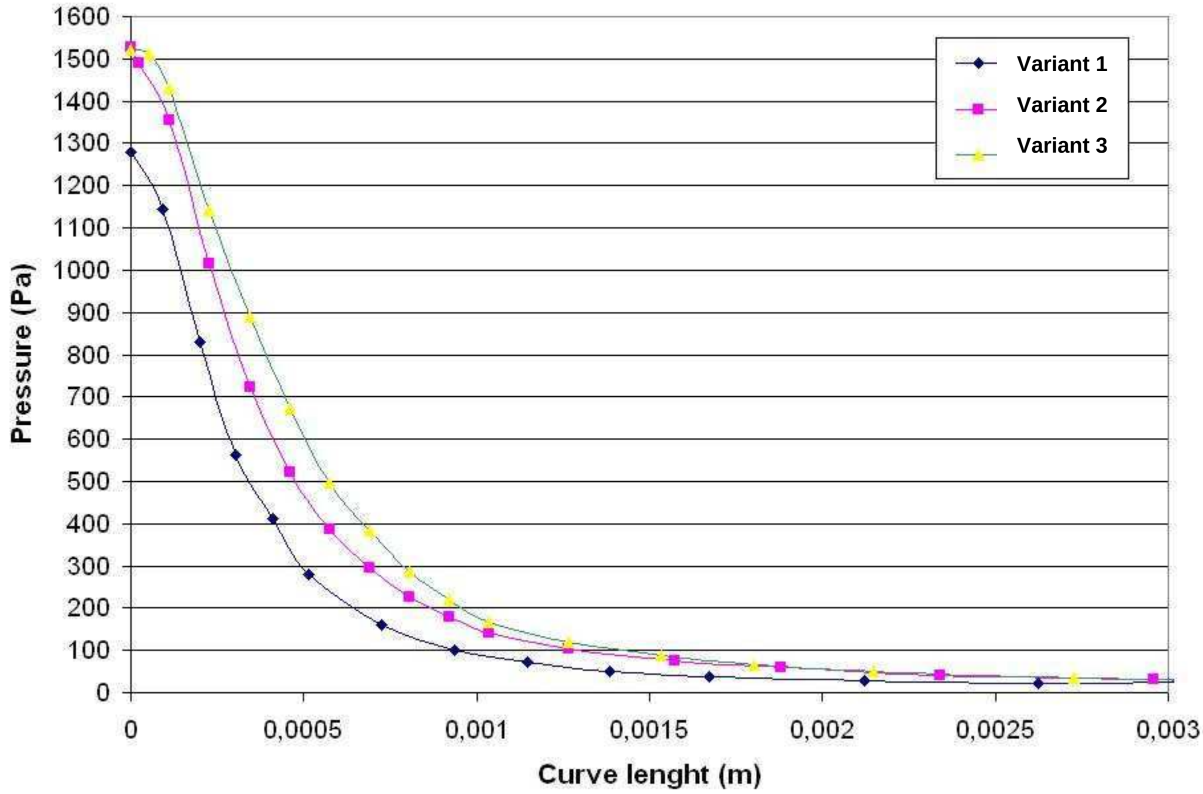


Fig.5 Pressure distribution along the curve at a distance from 0 to 3 mm.

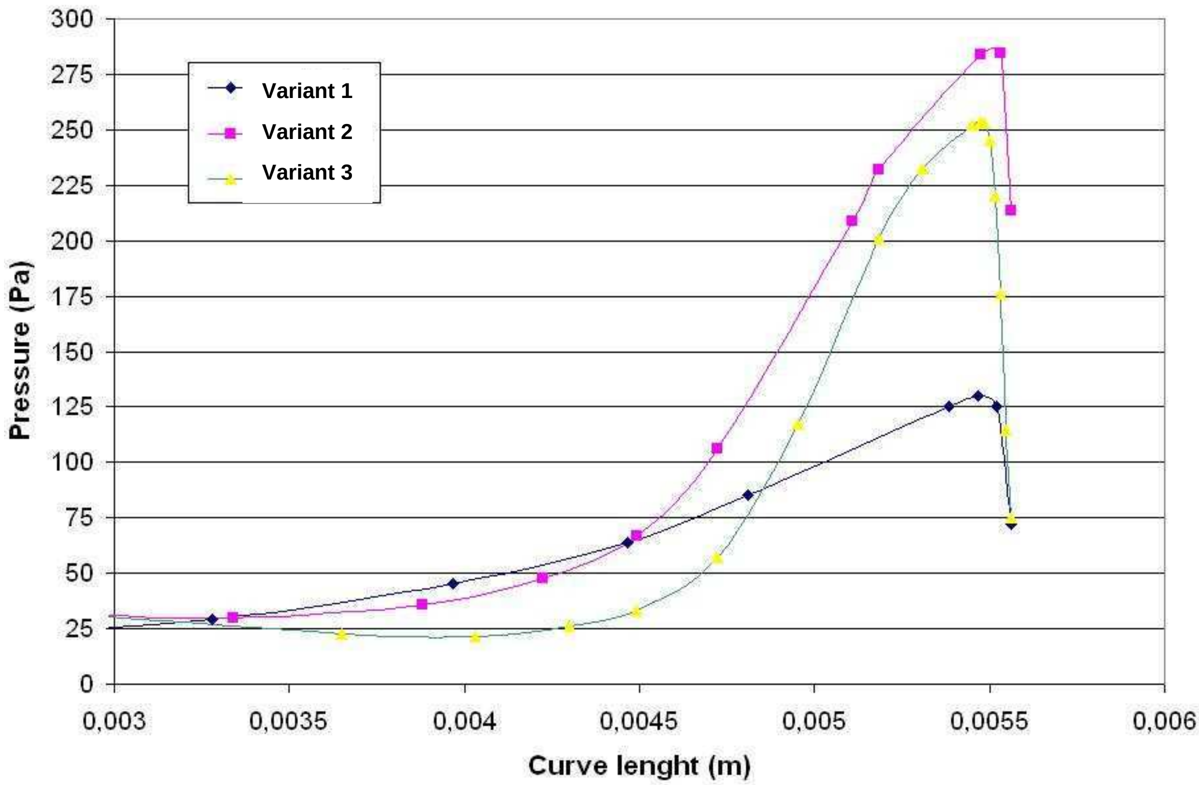


Fig.6 Pressure distribution along the curve at a distance from 3 to 6 mm.

Table 1: First variant selection criterion values

	ARITHMETIC MEAN OF PRESSURES (Pa)	ARITHMETIC MEAN OF MEDIUM DENSITIES (kg/m^3)
VARIANT 1	269,2	0.00402009545
VARIANT 2	372,5	0.004693754
VARIANT 3	335,8	0,0045173986

On the basis of above results, variant 1 seems to be the best. The primary electron beam passes through an environment with the lowest pressure and medium density.

6. Second selection criterion

To identify the second selection criterion, we have to consider some aspects of the problem.

The basic requirement for microscopes working in higher pressure conditions in the specimen chamber, as in the given case, it is necessary to create such monitoring conditions where some electrons from the beam remain, after passage through an environment of higher pressure, in the original trajectory. These electrons hit the specimen surface and bounce off. They carry information essential for microscope resolution.

In the high pressure environment, primary electrons collide with gas molecules while electrons loose a certain amount of their energy and change direction of the trajectory. This results in diffusion of the primary beam and can be compensated by increasing the flow value. Thus the noise/signal ratio can be the same as that in the vacuum.

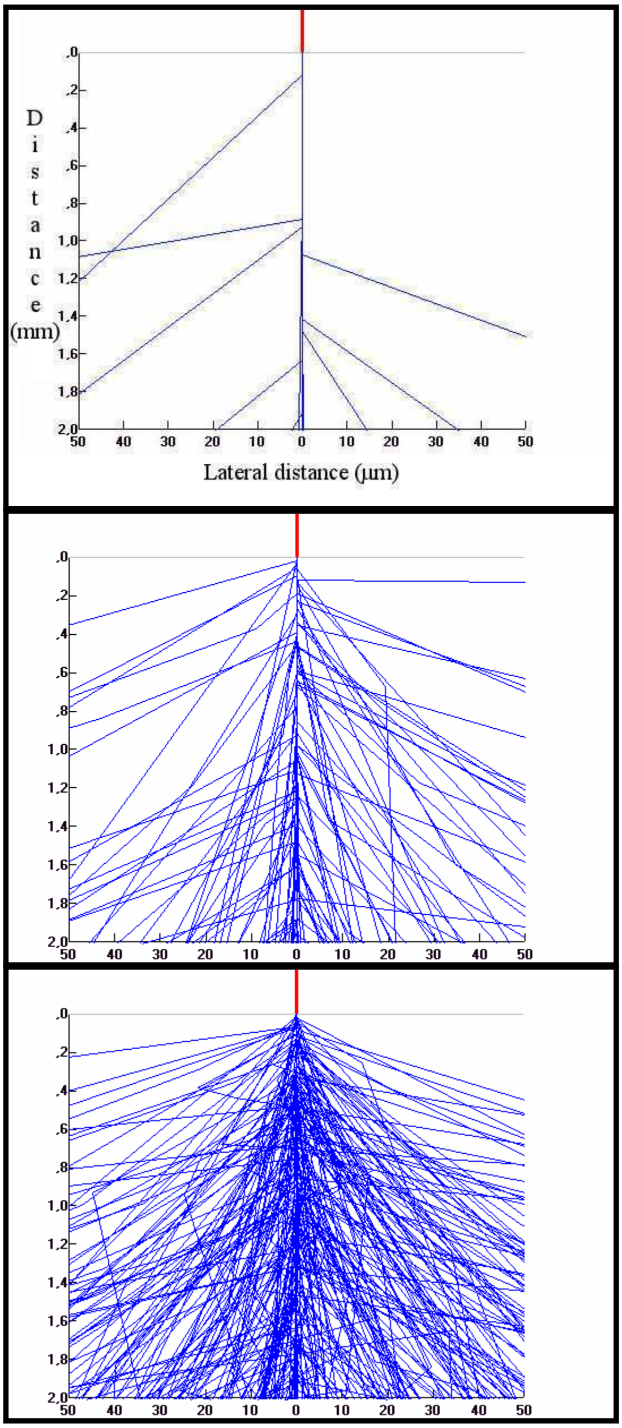
The dependence of the diffusion on the number of interactions of primary beam electrons passing through the gas environment is given by the average number of interactions of one electron, denoted m. Derived from this quantity can be three diffusion modes (Fig. 7).

The mode characterized by the magnitude of M where M reaches a value in the range 0 – 0.05 is the minimal diffusion mode. If M is 0.05, 5% of electrons interact in the passage through a higher pressure environment is used mainly in study of substances by the common REM method where M approaches 0. Effects of diffusion on the beam are minimal.

The total diffusion mode (Fig. 7) is characterized by M higher than 3. Ninety-five percent of electrons passing through a gas environment interact with atoms and molecules, which is not suitable for microscope representation.

A compromise is the partial diffusion mode in Fig. 7 with the characteristic value of m in the range 0.005-3.

From the above it follows that the second principal criterion for the best variant selection is the shortest possible primary beam trajectory in the differentially pumped chamber over the specimen chamber through a higher pressure environment.



Minimal diffusion

50 Pa

Diffusion < 5%

M < 0.05

Partial diffusion

1000 Pa

Diffusion 5% - 95%

M from 0.05 to 3

Total diffusion

3000 Pa

Diffusion > 95%

M > 3

Fig.7 Three basic modes of primary electron beam

Table 2 shows that the shortest possible trajectory of electrons in a higher pressure environment is in variant 1.

Table 2: Second variant selection criterion values

	LENGTH OF TRAJECTORY WHERE PRESSURE DROPS TO (MM)	
	100 (Pa)	**30 (Pa)**
VARIANT 1	**0.93**	**1.8**
VARIANT 2	**1.2**	**2.95**
VARIANT 3	**1.35**	**2.7**

7. Conclusions

The article discussed specific requirements for the construction of a variable pressure scanning electron microscope (VP-SEM), which works with high-pressure gas in the sample chamber. One of its key parts is a Differentially Pumped Chamber. The Cosmos FloWorks system was used to determine the optimal shape of the chamber so as to minimise the number of collisions between the primary electron beam travelling through the Differentially Pumped Chamber and molecules of the pumped gas.

Two criteria were selected to determine the best solutions. Considered there is a linear proportion between gas pressure and the probable number of collisions of molecules of the pumped gas, the first criterion was the arithmetic mean of pressure and density of the gas in the trajectory of the primary beam.

The other criterion was based on the requirement for the primary electron beam to travel through the differentially pumped chamber with minimal diffusion.

Using the Cosmos FloWorks system, Variant 1 was identified as the best one based on both criteria.

Acknowledgement

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