ANALYSIS OF GAS FLOW IN NEW SYSTEM OF APERTURES OF SECONDARY ELECTRON SCINTILLATION DETECTOR FOR ESEM

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Introduction

The scintillation SE detector for the environmental scanning electron microscope (ESEM) is designed for working at pressures ranging from 10^{-2} to 10^3 Pa in the specimen chamber of ESEM [1]. Fig. 1 shows longitudinal cross-section of the detector with calculated static gas pressure distribution. In this detector, the scintillator is placed in a individually pumped chamber, separated from the specimen chamber by two pressure limiting apertures A1 and A2. The size of holes in apertures, their distance and shape of the space between them, as well as the pumping speed of used pumps decisively affect the gas flow character and attainable pressure decrease in the detector [2].

Our aim was to evaluate substitution of the existing apertures A1 and A2, each with one hole 0.6 mm in diameter, with apertures containing 127 small holes (each of 0.1 mm in diameter, see Fig. 2) placed evenly round their centre, with expected impact on pressure decrease in the critical part of the detector. The effective flow cross section of the existing and substituted apertures is approximately the same.

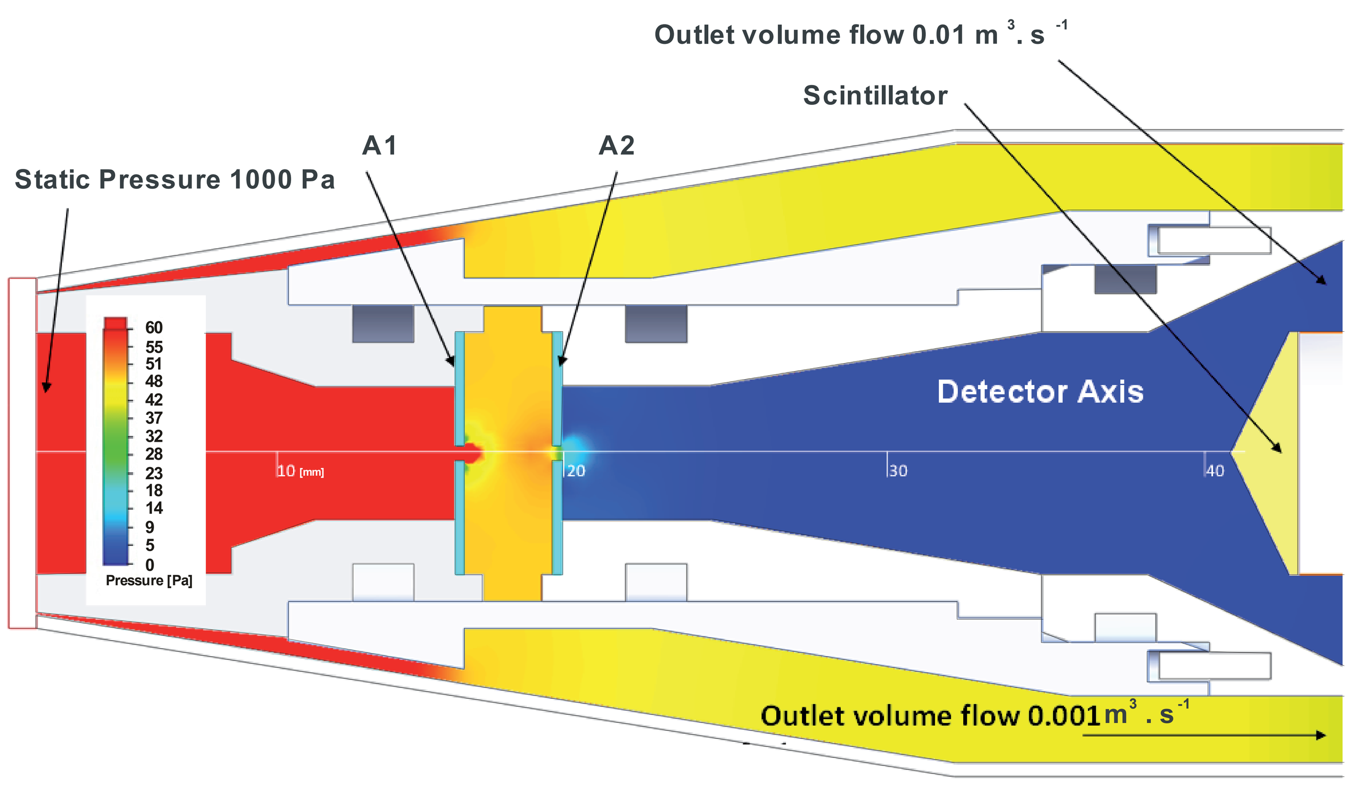

Fig. 1: Distribution of gas pressure in scintillation SE detector for ESEM (Inlet pressure 1000 Pa, pressure in scintillator chamber bellow 5 Pa, space between apertures A1 and A2 pumped by rotary pump with pumping speed of 0.001 m^3 . s^{-1} , scintilator chamber pumped by turbomolecular pump with pumping speed 0.01 m^3 .s^{-1}).

Computation Methods

A calculation scheme "upwind first order" in the system SolidWorks FlowSimulation was used for calculation of basic gas flow characteristics, where the marginal conditions of a complete 3D model of the detector were set on the basis of gas pressure in the ESEM specimen chamber and pumping speed values of particular vacuum pumps. After the comparison of simulation and experimental results, were performed gas flow analyses in the system Ansys.

After convergence a shorten model was used and the previous calculation results were considered as marginal conditions. Thus the calculation network could be compressed at aperture holes and in the space between apertures, and a more accurate description of gas flow in this area was obtained. The scheme "upwind second order" used for the calculation is able to detect discontinuous gas flow emerging in the areas where the speed of gas flow exceeds the speed of sound. In both examples the solver algorithm "Density-Based Solver" was used.

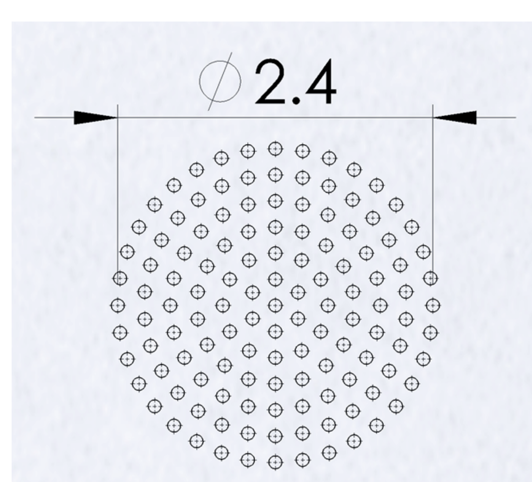

Fig. 2: Positioning of holes with diameter of 0.1 mm around centre of apertures A1 and A2.

Results and Discusion

Gas flow simulations show that if apertures A1 and A2 with 127 holes are used, the decrease of static pressure in the space between them and in the scintillator chamber is sharper. Therefore there is an increased possibility to separate the two spaces with high pressure gradient (Fig. 3) as compared to an aperture with one central hole.

The density values are of similar character, see Fig. 3 – red line, calculated by substituting in gas equation.

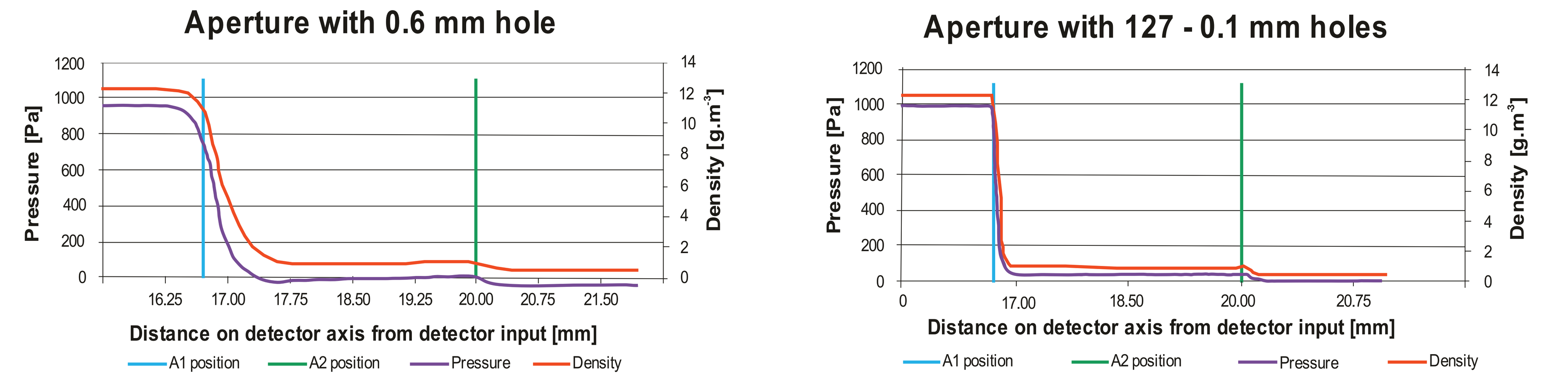

Fig. 3: Gas pressure and density dependence on detector axis for variant with one 0.6. mm diameter hole (left) and variant with 127 holes 0.1 mm in diameter (right).

At apertures with one central hole there is an unfavourable static pressure increase before aperture A2 and pressure instability between both apertures, see Fig. 4. Pressure fluctuations are caused by supersonic flow occurring behind the aperture A1. So gas density is higher behind the aperture A1 in this variant and its values are instable, see Fig. 5. The steeper pressure decrease behind A1 in the variant with 127 holes is confirmed by the gradient values in Fig. 6.

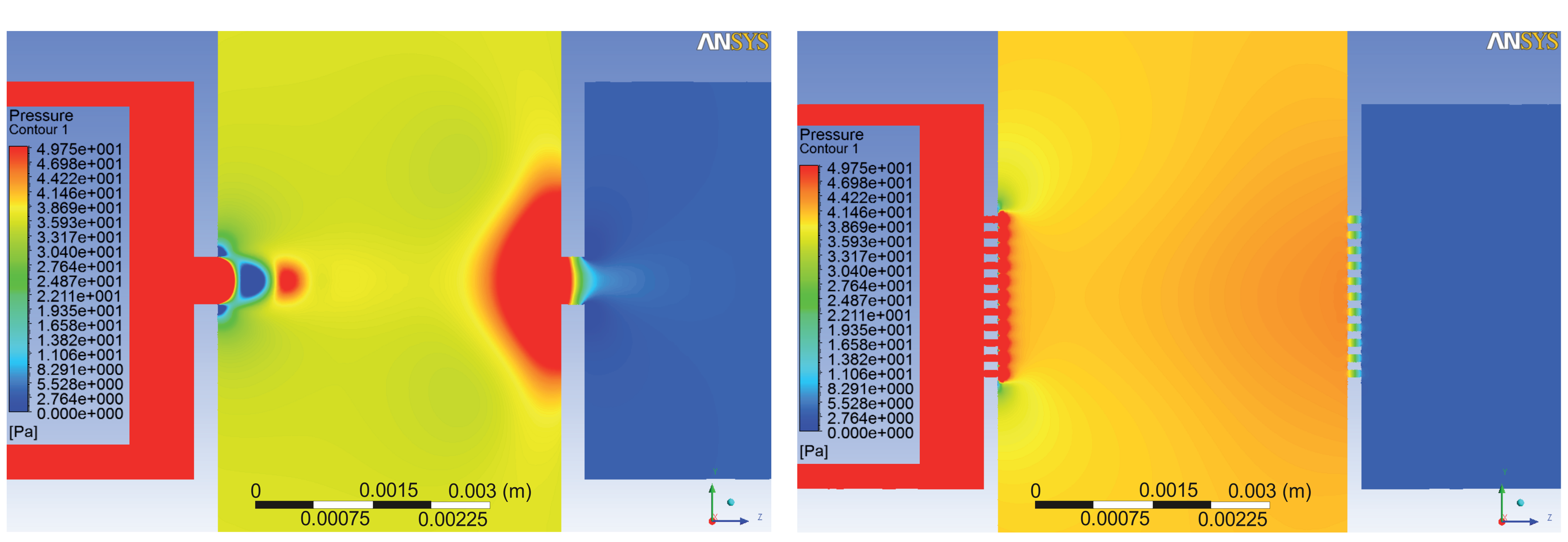

Fig. 4: Magnitude and distribution of static gas pressure in space between apertures A1 and A2. On left side is aperture with one hole (diameter of 0.6 mm) and on right side is aperture with 127 holes (diameters of 0.1 mm).

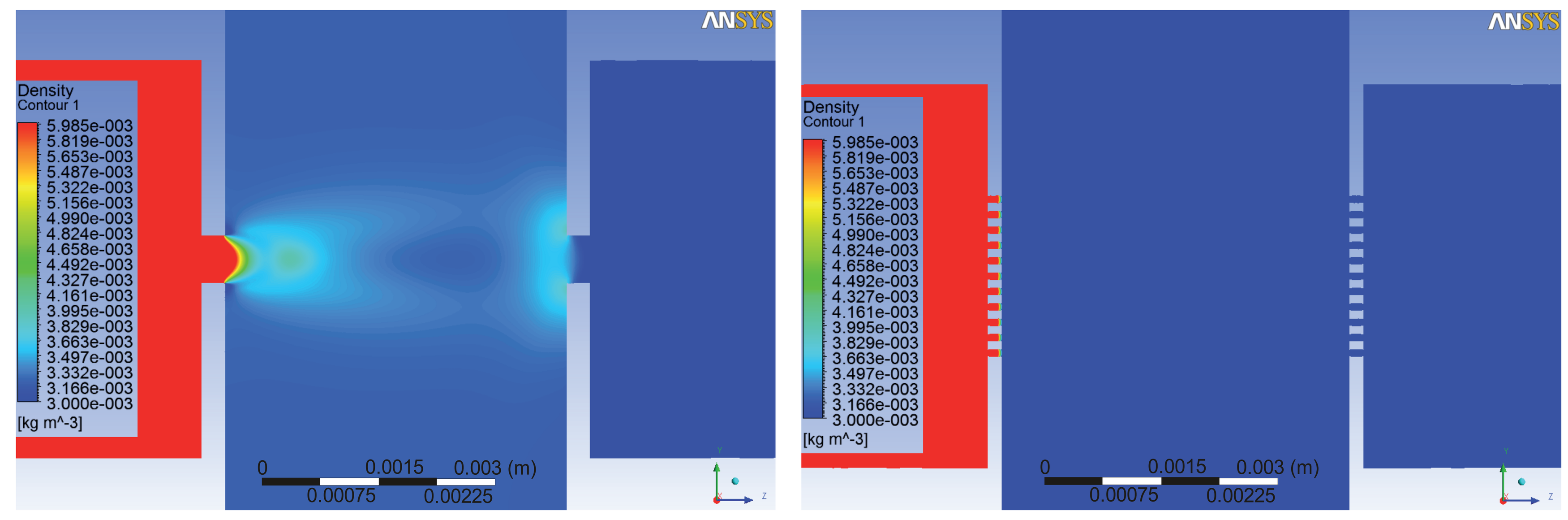

Fig. 5: Magnitude and distribution of gas density in space between apertures A1 and A2. On left side is aperture with one hole (diameter of 0.6 mm) and on right side is aperture with 127 holes (diameters of 0.1 mm).

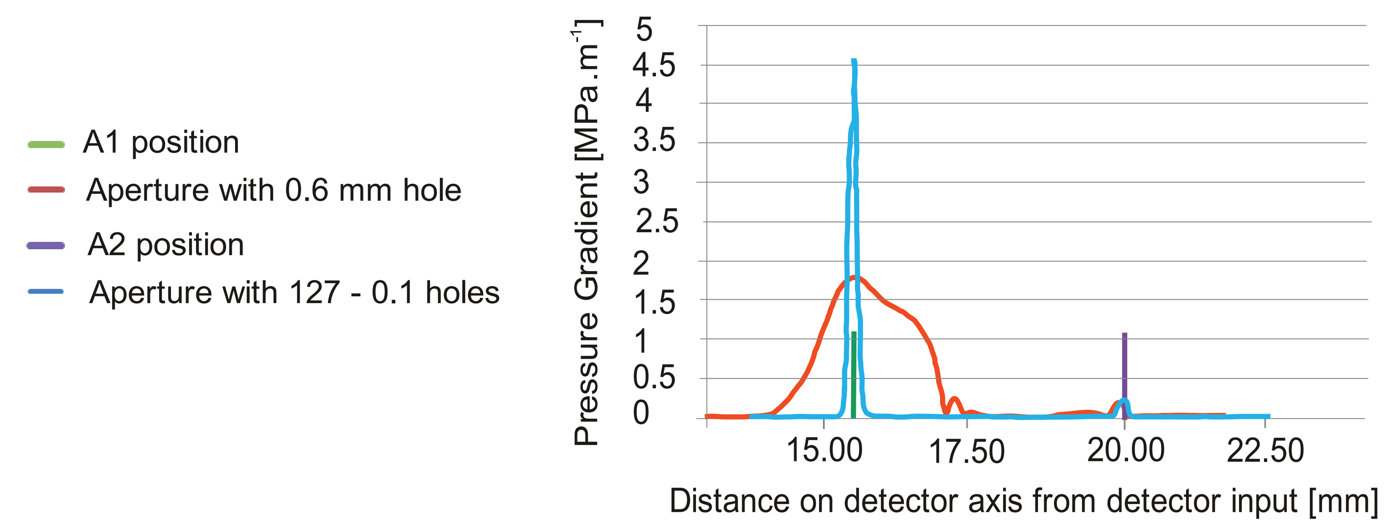

Fig. 6: Comparison of gas pressure gradient on detector axis for both aperture variants.

Gas flow speed is especially high in space between the apertures. The gas flow speed distribution in the analyzed area characterized by the Mach number is shown in Fig. 7. It is apparent from the figure that supersonic critical flow occurs behind aperture A1 in the one-hole variant only and is the reason for the gas pressure and density instability between the two apertures.

The shock wave origin has not been proved by our calculations, obviously because of the low gas pressure in the detector, however, sudden gas pressure and density changes are apparent in Figs. 5 and 5.

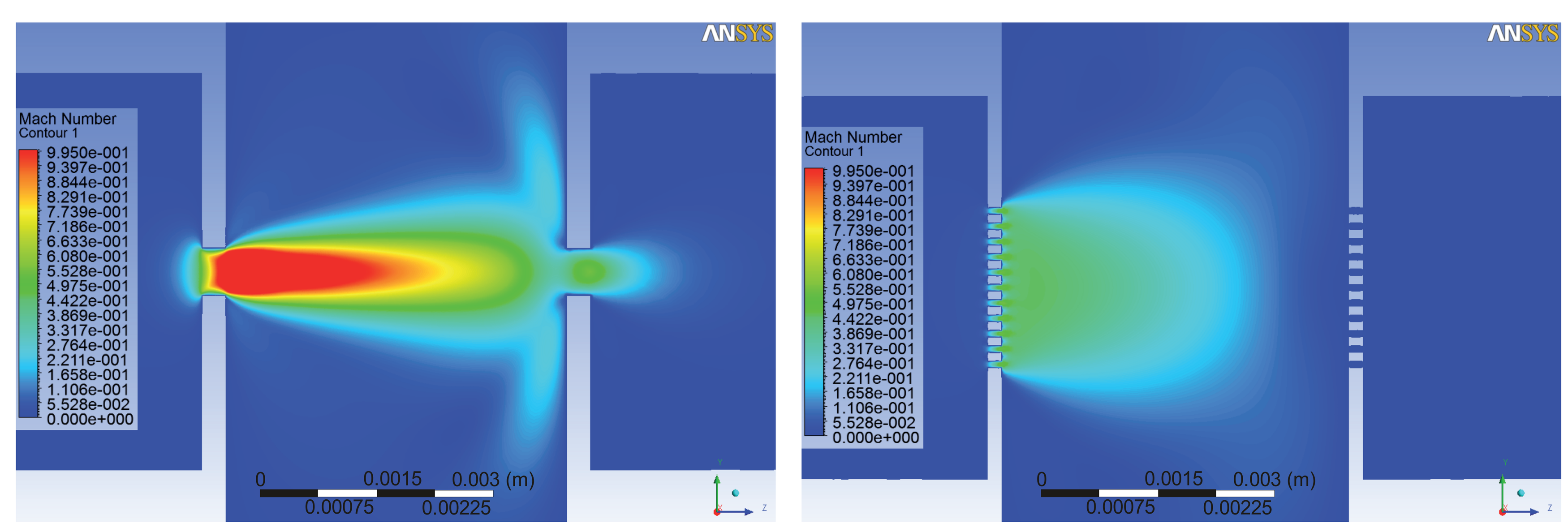

Fig. 7: Speed distribution characterized by Mach number for one 0.6 mm hole variant (left) and variant with 127 holes 0.1 mm in diameter (right).

To evaluate correctly two variants of apertures for gas pumping in the detector it is necessary to consider the total gas pressure, static and dynamic caused by fast gas flow:

$$p = p_1 + p_2$$

where p is the total gas pressure, p_1 static pressure and p_2 dynamic pressure.

The total gas pressure distribution for both variants is in Fig. 8.

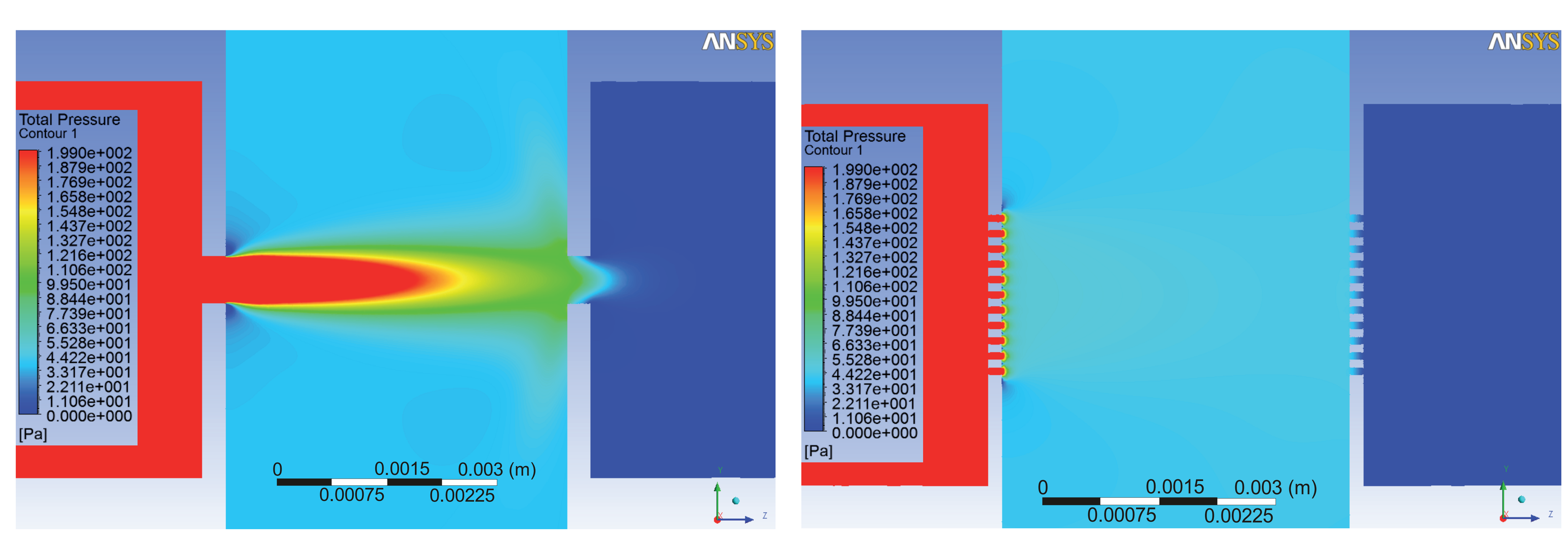

Fig. 8: Comparison of total pressure distribution for one-hole variant and for 127-hole variant.

It is apparent that total pressure values in the space between the two apertures are considerably higher in the one-hole variant than in the 127-hole variant. This effect complicates pumping of the scintillator chamber.

Conclusion

Our findings show that the gas flow is more favourable in the case of the newly designed apertures with 127 holes 0.1 mm in diameter, placed symmetrically around the aperture centre than at apertures with one hole. Taking into account the gas density decrease in the space between apertures in the novel variant, it can be presumed, that there will be fewer collisions of passing electrons with gas molecules in this space, and as a result an increased number of signal electrons incident onto the scintillator.

Simulations and experiments are aimed to construction of a novel detector with one aperture only a version that might yield even higher secondary electrons detection efficiency.

References

[1] Jirák, J. et al., J. Microsc. 239 (3), 233 (2010).

[2] Danilatos, G.D., Micron. 43, 600 (2012).

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