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Analysis of Gas Flow in a Secondary Electron Scintillation Detector for ESEM with a New System of Pressure Limiting Apertures

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Abstract:

Environmental scanning electron microscopes offer wide possibilities for the exploration of various types of specimens, especially non-conductive and wet specimens containing different material phases. In this article the results of gas-pumping simulations are analyzed for the novel design of pressure limiting apertures in a secondary electron scintillation detector with usage of SolidWorks and Ansys systems.

Keywords:

ESEM, SEs Scintillation Detector, CFD, CAE, SolidWorks, Ansys.

1. Introduction

The secondary electron (SEs) scintillation detector for the environmental scanning electron microscope (ESEM) is designed for the high efficiency detection of secondary electrons at pressures ranging from 0.01 to 1000 Pa in the specimen chamber. In the detector whose cross-section is seen in Fig. 1 with a calculated static gas pressure distribution, the scintillator is placed in an individually pumped chamber, separated from the microscope specimen chamber by two pressure-limiting apertures A1 and A2. The apertures limit the gas flow through the detector and, together with efficient vacuum pumping, help to reach a pressure of 5 Pa, at the most, in the scintillator chamber at a water vapour pressure of up to 1000 Pa in the microscope specimen chamber. As the voltage on the scintillator can reach up to 10 kV, a pressure value of 5 Pa is the maximum to prevent electric discharges in the gaseous environment around

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the scintillator [1]. Voltages on apertures (in the order of hundreds of volts) create an electrostatic field enabling detected SEs to pass as far as the scintillator. The voltage at the apertures (in the order of hundreds of volts) creates an electrostatic field helping the detected SE to pass as far as the scintillator. The size of the holes in the apertures, the distance and shape of the space between apertures, as well as the pumping speed of used vacuum pumps, distinctively affect the gas flow's character and the attainable pressure decrease in the detector [2]. The present work deals with the analysis of the gas flow in the detector, where apertures A1 and A2, each with one central hole of 0.6 mm in diameter, are substituted with apertures containing a system of evenly distributed holes of 0.1 mm in diameter. The effective flow cross section of these apertures remains approximately the same. The rotary pump, with a volume flow of 0.001 m^3/s was used for pumping the space between the detector apertures A1 and A2, and the turbomolecular pump with a volume flow of 0.01 m^3/s was used for pumping the scintillator chamber [3].

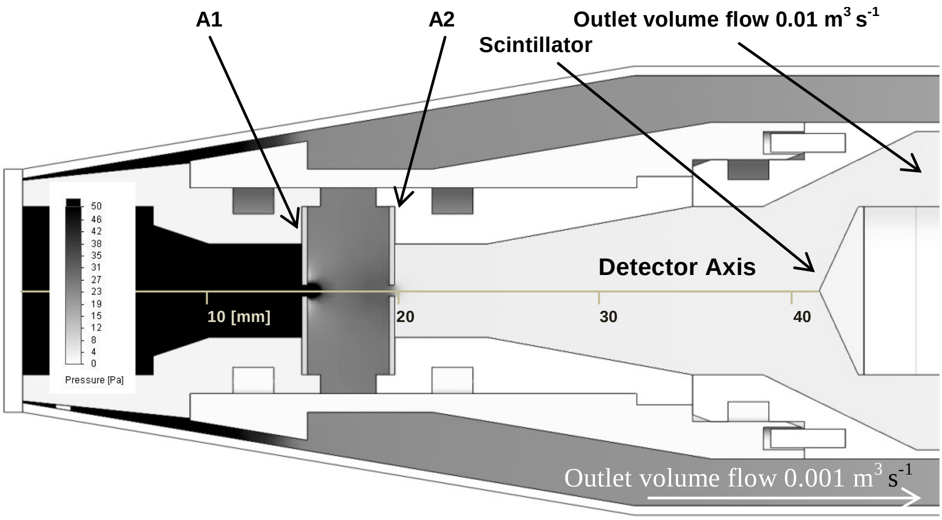

Fig. 1 Distribution of gas pressure in SEs scintillation detector for ESEM

Our aim was to evaluate the substitution of the existing apertures A1 and A2 with apertures containing small holes distributed evenly round their centre, with the anticipated impact on the pressure decrease in the critical part of the detector. On the basis of the gas flow analyses of several variants of proposed apertures performed by the method of finite volumes, a suitable shape of apertures was chosen. The apertures have 127 holes of 0.1 mm in diameter symmetrically distributed round the centre to a maximum diameter of 2.4 mm, see Fig. 2.

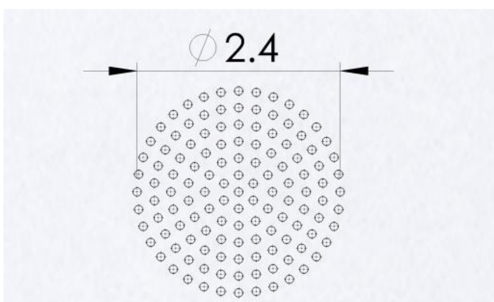

Fig. 2 Positioning of holes with diameter of 0.1 mm round the centre of apertures A1 and A2.

2. Computation Methods

The preliminary analysis of the gas flow in the new system of apertures A1 and A2 in the water vapour environment was performed using the systems SolidWorks, FlowSimulation, Ansys CFX and Ansys Fluent. For calculation of basic gas flow characteristics, where the boundary conditions of a complete 3D model were set on the basis of the gas pressure in the microscope specimen chamber and pumping speed values of particular vacuum pumps, a calculation scheme “upwind first order” in the system SolidWorks FlowSimulation was used. After the comparison of the simulation results with experimentally measured values on the designed detector, when pressure gauges (Pfeiffer CMR 362 and CMR 364) were placed on the pumping orifices of the detector, the gas flow analyses in the system Ansys were performed. Under boundary conditions in these analyses the static pressure values from the first analysis were used instead of the pumping speed values. After the convergence of results a shortened model, mainly comprising of the space between the apertures, was used and the previous calculation results were considered as boundary conditions. Thus the calculation network could be compressed at the aperture holes and in the space between apertures, and a more accurate description of the gas flow in this area was obtained. The scheme “upwind second order” used for the calculation is able to detect a discontinuous gas flow emerging in the areas where the speed of the gas flow exceeds the speed of sound. In both examples the solver algorithm “Density-Based Solver” was used where, in comparison with the “Pressure-Based Solver” regime, the equations of continuity, momentum and power are being solved using vectors, and pressure values are set on the basis of a general gas equation.

3. Results and Discussion

The conducted 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 clearer. Therefore, there is an increased possibility to separate these two spaces with high-pressure difference, see Fig. 3, as compared to the apertures with one central hole.

The gas density values calculated for water vapours by substituting in the general gas equation have a similar character, see Fig. 3.

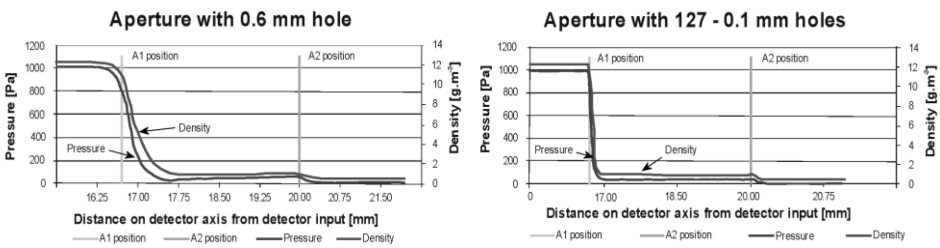

Fig.3 Gas pressure and gas density dependence along the detector axis

Distribution of the static pressure and the gas density in the space between apertures A1 and A2 is shown in Figs 4 and 5. On the left side of these pictures is always depicted the variant for the apertures with one central hole of 0.6 mm in diameter, on the right, a variant for the apertures containing 127 holes with a diameter of 0.1 mm.

With the apertures with one central hole, there is an unfavourable static pressure increase in front of aperture A2 and pressure instability between the apertures, see Fig. 4. Pressure fluctuations are due to the supersonic flow occurring behind aperture A1. Also the gas density is higher behind aperture A1 in this variant and its values are unstable, see Fig. 5.

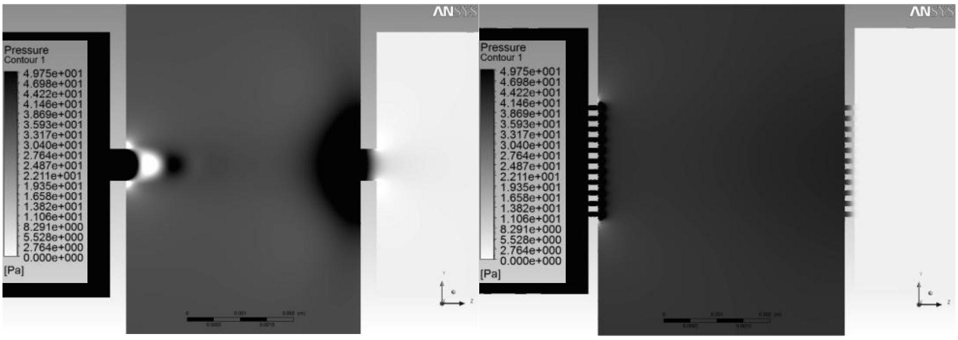

Fig. 4 Magnitude and distribution of static gas pressure in the space between apertures A1 and A2 for variant with one hole of 0.6 mm in diameter (left) and for variant with 127 holes of 0.1 mm in diameter (right).

The steeper pressure decrease behind A1 in the variant with 127 holes is confirmed by the calculated pressure gradient values in Fig. 6.

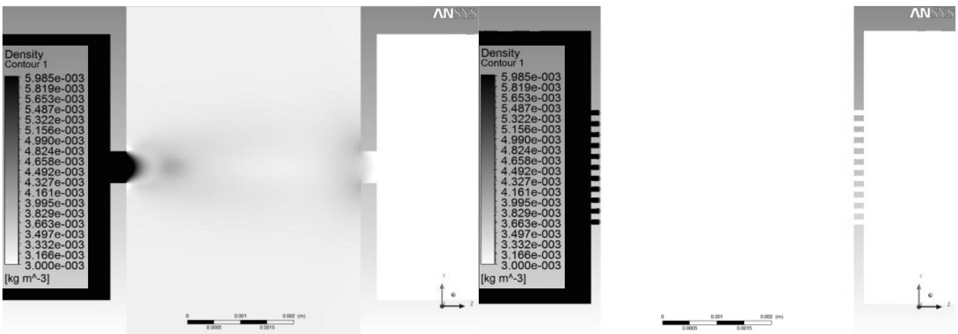

Fig. 5 Magnitude and distribution of gas density values in the space between apertures A1 and A2 for a variant with one hole of 0.6 mm in diameter (left) and for a variant with 127 holes of 0.1 mm in diameter (right).

As mentioned above, the gas flow speed is especially high in the space between the apertures. The gas flow speed distribution in the analyzed area characterized by a Mach number is shown in Fig. 7. It is apparent from the figure that the supersonic critical flow occurs behind aperture A1 in the one-hole variant only and is the cause of 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. 4 and 5. These changes are caused by the supersonic gas speed due to the critical flow behind aperture A1 in the one-hole variant.

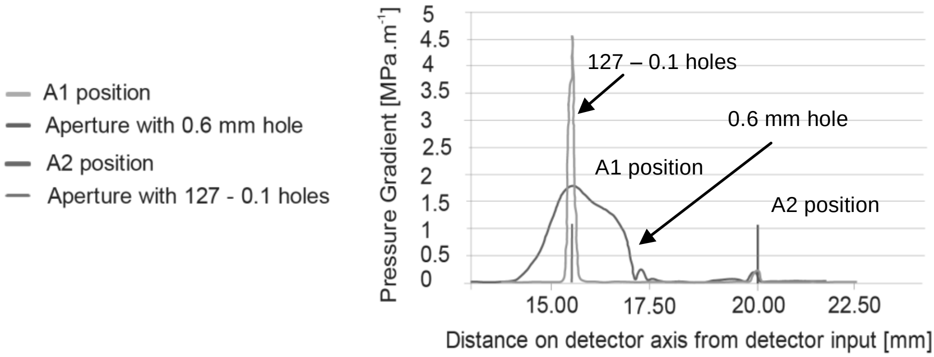

Fig. 6 Comparison of gas pressure gradient on detector axis.

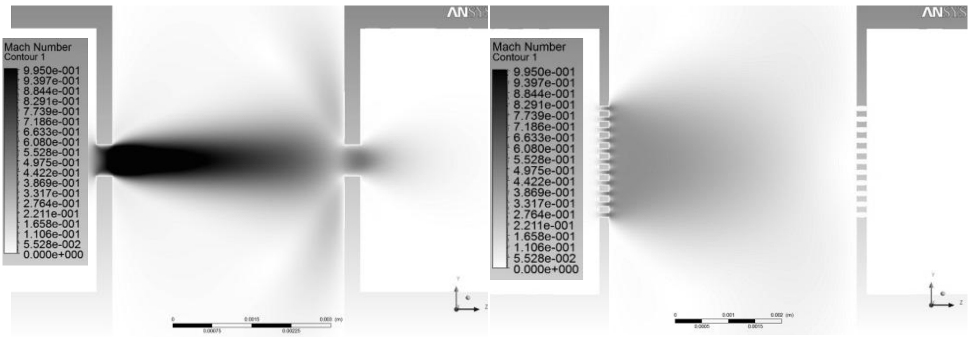

Fig. 7: Speed distribution characterized by Mach number for variant with one hole of 0.6 mm in diameter (left) and for variant with 127 holes of 0.1mm in diameter (right).

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

$$p = p_1 + p_2 \tag{1}$$

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

$$p_2 = \frac{\rho v^2}{2} \tag{2}$$

where ρ is the gas density, v the gas speed.

The total gas pressure distribution for both variants is illustrated in Fig. 8. It is apparent from Fig. 8 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. The total gas pressure distribution influences conditions in front of aperture A2 and complicates the pumping of the scintillator chamber in the one-hole variant.

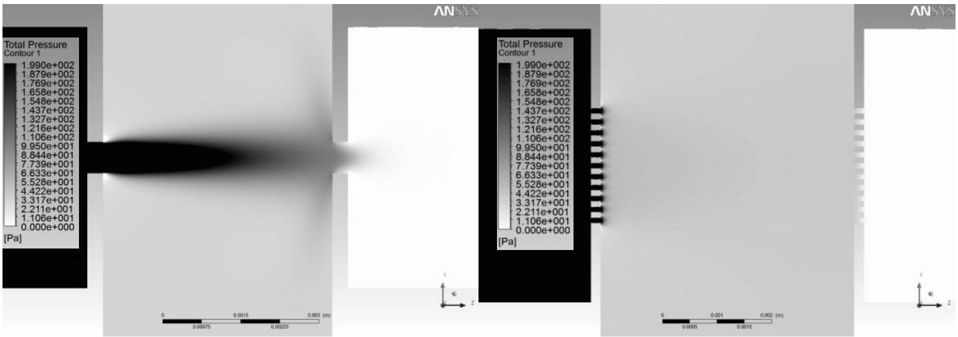

Fig. 8 Comparison of total pressure distribution for variant with one hole of 0.6 mm in diameter (left) and for variant with 127 holes of 0.1 mm in diameter

4. Conclusion

Our findings show that gas flow is more favourable in the case of the newly designed apertures with 127 holes of 0.1 mm in diameter, placed symmetrically around the aperture centre than in the apertures with one hole. Taking into account the gas density decrease in the space between the apertures at 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 electron impact on the scintillator.

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

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