GENERATION OF SHOCK WAVES IN ENVIRONMENTAL SCANNING ELECTRON MICROSCOPE AND THEIR DESCRIPTION

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Abstract: Environmental scanning electron microscope (ESEM) is one of the latest trends in microscopic methods. In this microscope, we can observe various types of specimens, especially non-conductive and wet specimens. This is given by high pressure of gas in the specimen chamber. This article deals with computational modelling of pressure conditions and shock waves generation in the scintillation detector of secondary electrons for this type of microscope.

Keywords: Scintillation detector of secondary electrons, finite element method, upwind computational scheme, shock wave.

1. INTRODUCTION

Different signals are emitted from the specimen in the specimen chamber after the interaction with primary electrons. Detector is a device used for the detection of the desired signal released from the specimen. Secondary electrons bring the information about the topology of the specimen.

High pressure of gas in the specimen chamber makes impossible using the Everhart-Thornley detector, because high voltage must be placed on the scintillator. This voltage is used to acceleration secondary electrons on the scintillator. Principal scheme of scintillation detector is shown in the Figure 1.

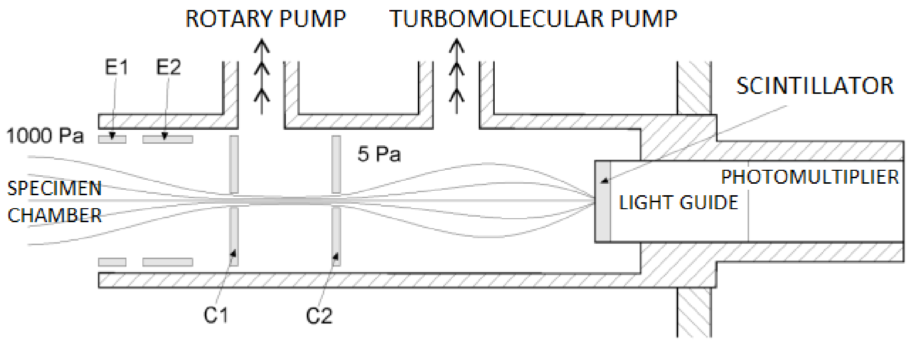


Figure 1: Principal scheme of scintillation detector of secondary electrons.

The area between specimen chamber and scintillator is separated by two apertures. Thanks to this, it is possible to create area by the scintillator with lower pressure than in the specimen chamber. Secondary electrons are accelerated by the voltage 8 kV. To avoid discharges in gas, the pressure 5 Pa must be in the area before the scintillator. Extraction and deflection electrodes E1 and E2 (voltage about hundreds volts) attract secondary electrons, which passes through to the apertures C1 and C1. Apertures C1 and C2 create electrostatic lens, because potential about hundreds volts is placed on them.

Electrodes and apertures are electrically isolated from the detector body. The area between apertures is pumped with the rotary pump, which serves to a gradual pressure reduction between the specimen chamber and the chamber with scintillator. Behind the aperture C2, the area is pumped with the turbomolecular pump [1].

Scintillation detector consists of a scintillation crystal (YAG crystal, CRY 18, etc.), light guide and photomultiplier. After the absorption in scintillator, electrons generate a large number of photons, whose number is proportional to the energy of the electron. Part of these photons is brought to the photomultiplier, where photoelectrons are released. These electrons appear at the photomultiplier anode as an electrical impulse. Scintillation crystal and light guide are covered with reflective foil (e.g. Al). Suitable lubricant ensures optical contact between the scintillator and light guide. The lubricant prevents the losses of light reflection at the interface between two environments [2].

2. MATHEMATICAL INTERPRETATION

For modelling the detector, SolidWorks software was used. The simulation of fluid flow was released by ANSYS Fluent software. ANSYS Fluent solves a system of three partial differential equations (law of conservation of mass, momentum and energy) completed with the fourth equation of state the considered fluid.

Continuity equation Eq. 1 expresses the law of conservation of mass and it takes the form:

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_i}(\rho u_i) = 0 \tag{1}$$

Navier - Stokes equations Eq. 2 express Newton's theorem applied to change of momentum in the form:

$$\frac{\partial \rho u_i}{\partial t} + \frac{\partial}{\partial x_j}(\rho u_i u_j) + \frac{\partial p}{\partial x_i} = \frac{\partial}{\partial x_j}(\tau_{ij} + \tau_{ij}^R) + S_i \tag{2}$$

Energy equation Eq. 3 expresses the law of conservation of energy for compressible fluid and it takes the form:

$$\frac{\partial \rho E}{\partial t} + \frac{\partial \rho u_i}{\partial x_i}(E + p) = \frac{\partial}{\partial x_i}(u_j(\tau_{ij} + \tau_{ij}^R) + q_i) + \tau_{ij}^R \frac{\partial u_i}{\partial x_j} + \rho\varepsilon + S_i u_i + Q_H \tag{3}$$

The equation Eq. 4 of state for the considered ideal gas, in the form:

$$\rho = \frac{p}{RT} \tag{4}$$

In the above equations u_i is fluid velocity, p fluid pressure, ρ fluid density, T temperature of the fluid, E the internal energy, S_i external mass forces acts per unit mass (gravity, centrifugal), Q_H supply and heat dissipation per unit volume, q_i flow heat, τ_{ij} viscous stress tensor and ij indexes indicate summation variables in three directions according to the coordinates (Einstein summation) [3].

2.1. FINITE VOLUME METHOD

The finite element method (FEM) (its practical application is known as finite element analysis FEA) is a numerical technique for finding approximate solutions to partial differential equations (PDE) and their systems, as well as (less often) integral equations. The method essentially consists of assuming the piecewise continuous function for the solution and obtaining the parameters of the functions in a manner that reduces the error in the solution. In simple terms, FEM is method for dividing up a very complicated problem into small elements that can be solved in relation to each other [4].

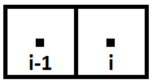
2.2. "UPWIND" COMPUTATIONAL SCHEME

In computational fluid dynamics, upwind schemes denote a class of numerical discretization methods for solving hyperbolic partial differential equations. Upwind schemes use an adaptive or solution-sensitive finite difference stencil to numerically simulate the direction of propagation of information in a flow field. The upwind schemes attempt to discretize hyperbolic partial differential equations by using differencing biased in the direction determined by the sign of the characteristic speeds [5].

Higher order upwind method captures better the areas with a higher gradient and correctly captures the strength of the shock waves. These schemes approximate solutions around the shock waves and the contact discontinuities. When the mesh is generated, the resulting flow field is not usually account. Created mesh may be not optimal (e.g. in terms of capturing the gradient values), therefore an adaptation mode uses to improve the mesh. For adaptation mode is important, the correct criterion select for detecting for example shock waves.

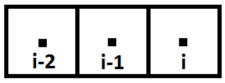
First order upwind

$$u_x^- = \frac{u_i^n - u_{i-1}^n}{\Delta x}$$



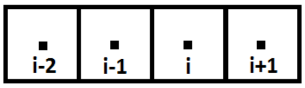
Second order upwind

$$u_x^- = \frac{3u_i^n - 4u_{i-1}^n + u_{i-2}^n}{2\Delta x}$$



Third order upwind

$$u_x^- = \frac{2u_{i+1} + 3u_i - 6u_{i-1} + u_{i-2}}{6\Delta x}$$



3. RESULTS

Geometry of the detector is shown in figure 2. Apertures C1 and C2 have 0.6 mm diameter of the orifice. The rotary pump with pumping speed 0.001 m^3s^{-1} was used for pumping the area between C1 and C2. The turbomolecular pump with the pumping speed 0.01 m^3s^{-1} was used for pumping the scintillator chamber. The pressure in specimen chamber is changed within the range from 200 to 1000 Pa.

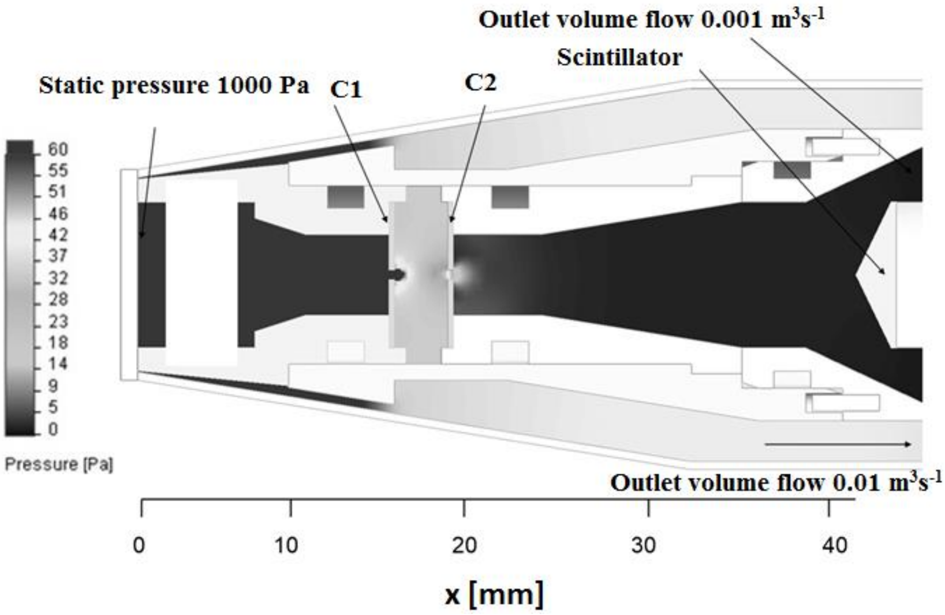


Figure 2: Model of real detector and boundary conditions settings.

A supersonic flow was created by the first aperture and it was accompanied by a local pressure reduction (Figure 3). This is advantage in regard to scatter of secondary electrons. On the first aperture edge, it was achieved a critical state of flow. Some energy is lost to the free expansion of gas around the aperture mouth due to its geometry.

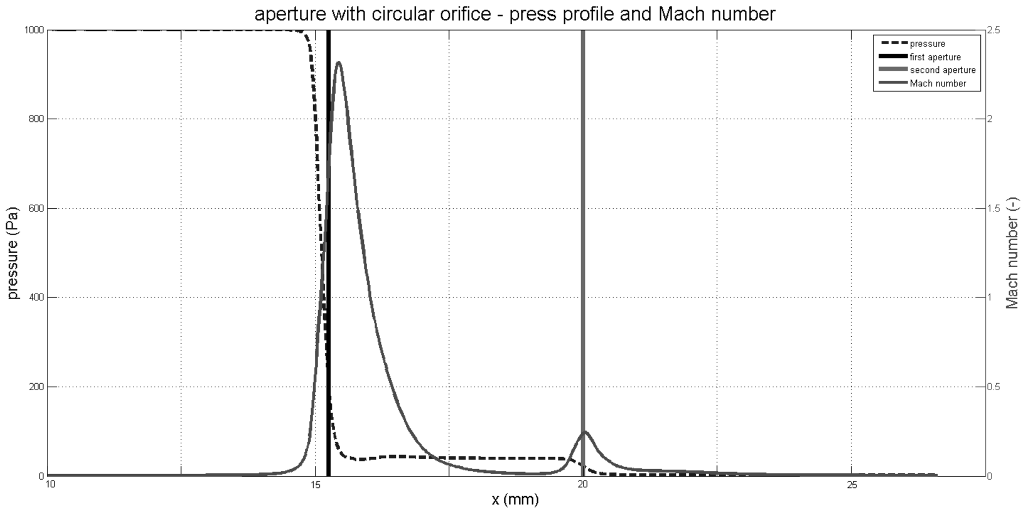


Figure 3: Press profile and Mach number in apertures with circular orifice.

The supersonic flow through the aperture can cause shock waves (Figure 4 left). This is a significant compression of gas at short distances, which may create a barrier to the passage of electrons. The shock wave is a step change value (pressure, density), and it creates a discontinuity, which cannot be described in the calculations by the finite volume method without a correct approximation type. The second order upwind method was used to investigate shock waves.

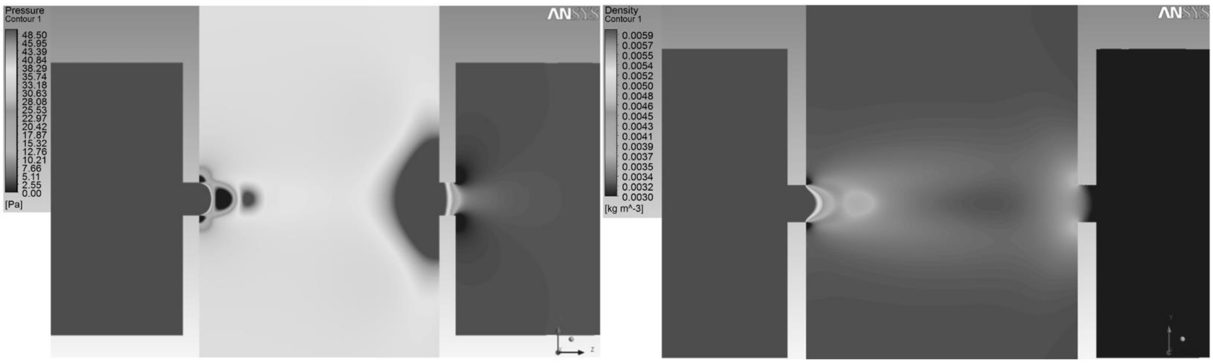


Figure 4: Pressure compression (left) and density change (right) behind the first aperture.

4. CONCLUSION

Aperture C1 determines the pressure conditions across the detector. Gas that enters into it is moving into a critical state and moves at supersonic speed. Gas entering into aperture C2 is already moving at subsonic speed, far below the Mach number. Behind the apertures, swirls form in some cases that slow the pumping the area behind apertures. In some cases, swirls are formed directly in apertures or even before the entry into the first aperture, which again affects the pressure in the detector. Although this work not demonstrated a direct shock wave formation in the detector, figure 4 show pressure compression and density change behind the first aperture. It assumes that shock waves can occur in these places.

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