

ANALYSIS OF WHIRLING OF GAS FLOW WITHIN THE SPECIMEN CHAMBER OF ESEM

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Abstract: The usage of an Environmental scanning electron microscope (ESEM) brings the possibility of studying many kinds of materials and chemical reactions never studied before. In this article there are compared and analyzed several simulation results of gas flow in the specimen chamber of ESEM with high gas pressure throughout the whole volume except on its optical axis, where low gas pressure is needed.

Keywords: ANSYS Fluent, Electron microscopy, Environmental scanning electron microscope, ESEM, Gas whirling, SolidWorks, Specimen chamber, Von Karman vortex

1. INTRODUCTION

Because of high gas pressure in the specimen chamber using Environmental scanning electron microscope (ESEM) we are able to study that kind of samples, we have never been able to before. Without ESEM we had to dry up samples containing water or even air moisture by sublimation process (e.g. biological samples that of course had to be dead) to avoid the water evaporation that could damage the samples or we had to metallize their surface (e.g. insulation materials with high electrical capacity) due to its charging causing electron beam deflection. Using ESEM we are able to study samples containing water, liquid samples, dielectric materials or even chemically active samples, chemical reactions or biological processes with some modifications. [1]

Achieving and keeping such a high gas pressure within the specimen chamber (up to 3 kPa) separate from low gas pressure areas around the electron source (from 1 mPa to 1 nPa, according the electron source type) demands some specific changes in the construction of the microscope and its pumping system itself. The microscope has to be split up by at least two apertures into three or more parts with different gas pressure levels. The apertures have holes in themselves on the optical axis each ten to hundred micrometers large allowing the electron beam to pass through them and to keep high pressure differences between adjacent sections of the microscope with lowest gas pressure on its optical axis. [2]

2. SIMULATION SETTINGS

Whole model of the microscope was built in the SolidWorks program and then imported into ANSYS Fluent, which provides more accurate simulation results than SolidWorks. The block diagram of the microscope including the boundary conditions is in figure 1. In the figure 1 the DP is the diffusion pump, RP 1, RP 2 and RP 3 are rotatory pumps, V1 and V2 are common valves, NV is the needle valve and PLA 1 and PLA 2 are pressure limiting apertures delimiting the differentially pumped chamber as an area between them.

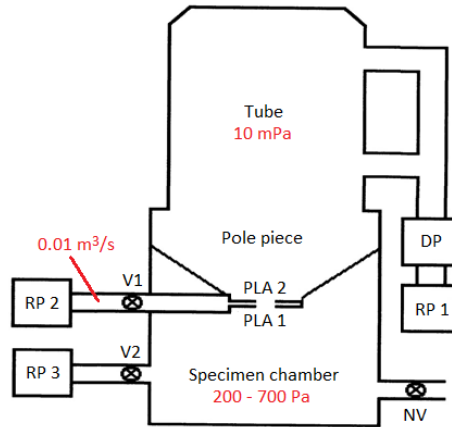


Figure 1: Block diagram of ESEM with boundary conditions [1]

2.1. SOLVER SETTINGS

All calculations were made in Density based mode, which couples the calculations for more accurate results, and with discretization of the second order due to the complexity of calculations of low pressures. The turbulent model used for the simulations was “k-omega SST”. For the calculations it was the one most suitable from all the models available in ANSYS Fluent because of its compromise between the calculation time length and its results accuracy.

2.2. BOUNDARY CONDITIONS

In all the simulations used for the analysis the gas pressure within the tube of the microscope was set to 10 mPa and the output flow rate (speed of pumping) of gas from within the differentially pumped chamber was set to 0.01 m³/s. The only boundary condition that varied in all the simulations was the pressure under which the gas flowed into the specimen chamber and it was set to 200, 300, 400, 500 and 700 Pa.

3. ANALYSIS OF GAS FLOW SIMULATIONS

To speed the simulation process up only the specimen chamber and the first differentially pumped chamber above it were used from the whole microscope model allowing to study the whirling of the gas within the specimen chamber while flowing into the differentially pumped chamber.

Figures 2 to 4 represent gas pressure distribution within the specimen chamber with gas flowing in from the bottom of the chamber under the pressure from 200 Pa to 400 Pa. With such a low entering pressure there is almost no whirling within the gas flow, so it flows around the pedestal with the specimen symmetrically.

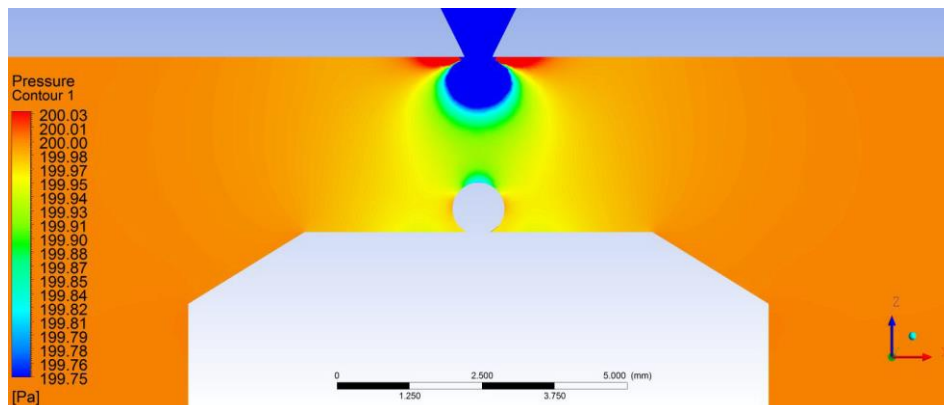


Figure 2: Gas pressure distribution within the specimen chamber at 200 Pa input

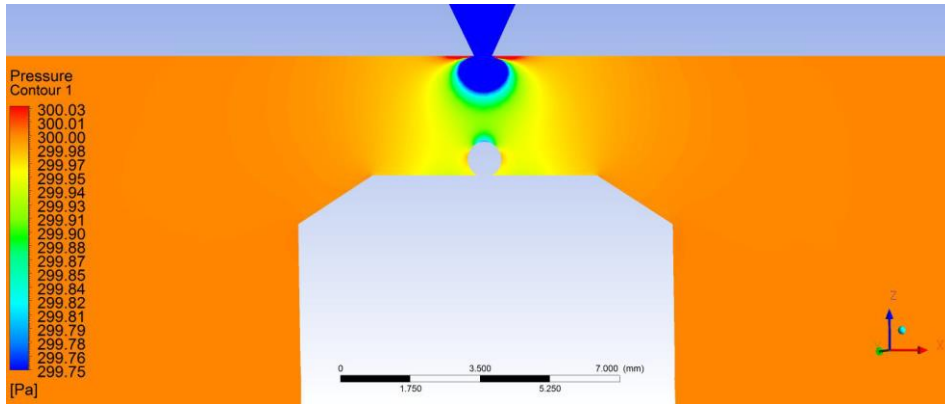


Figure 3: Gas pressure distribution within the specimen chamber at 300 Pa input

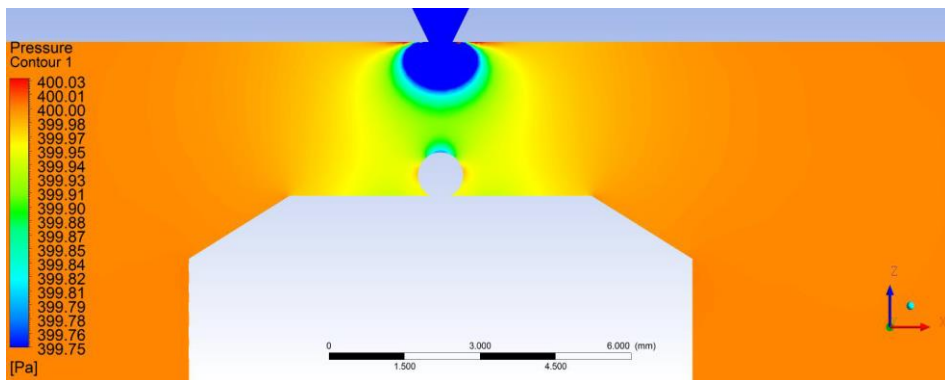


Figure 4: Gas pressure distribution within the specimen chamber at 400 Pa input

However when the pressure of the entering gas rises above 500 Pa little whirling will appear around the sample as shown on figures 5 and 6.

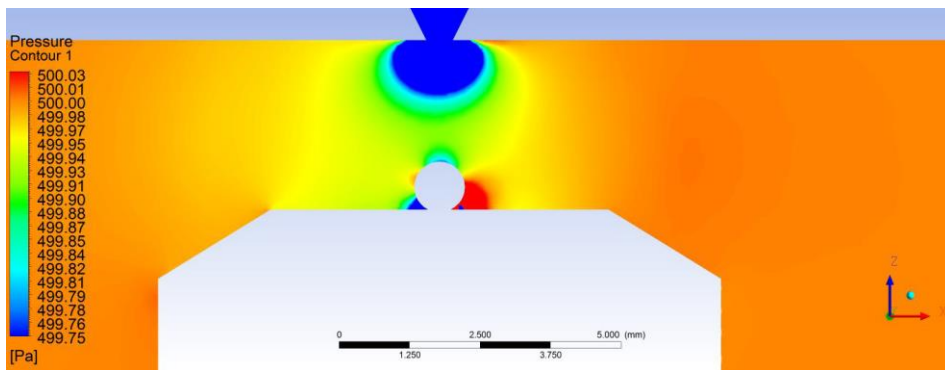


Figure 5: Gas pressure distribution within the specimen chamber at 500 Pa input

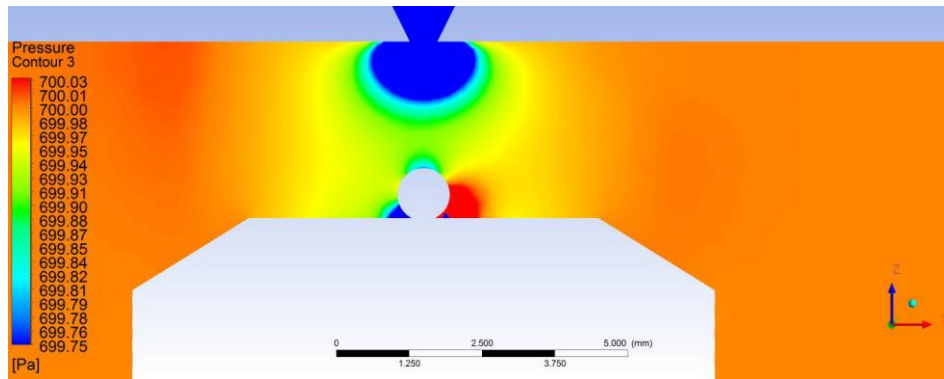


Figure 6: Gas pressure distribution within the specimen chamber at 700 Pa input

These whirling is caused by a chain reaction which starts the moment when the velocity of the gas flow above the pad near the sample rises enough to cause Von Karman vortices to appear. When these vortices appear, their path crosses the original path of the gas flow at the other side of the sample right above the edge of the sample pad, which makes a bigger vortex to appear above the pad around the whole sample as shown on figures 7 to 9.

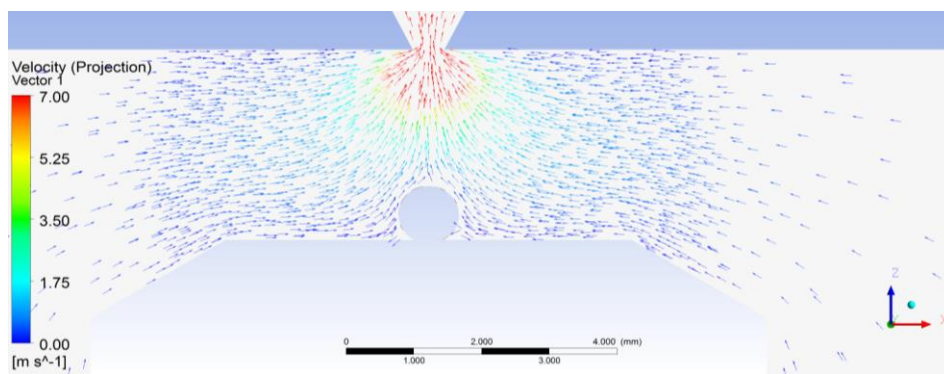


Figure 7: Velocity vectors of the gas flow at 400 Pa input

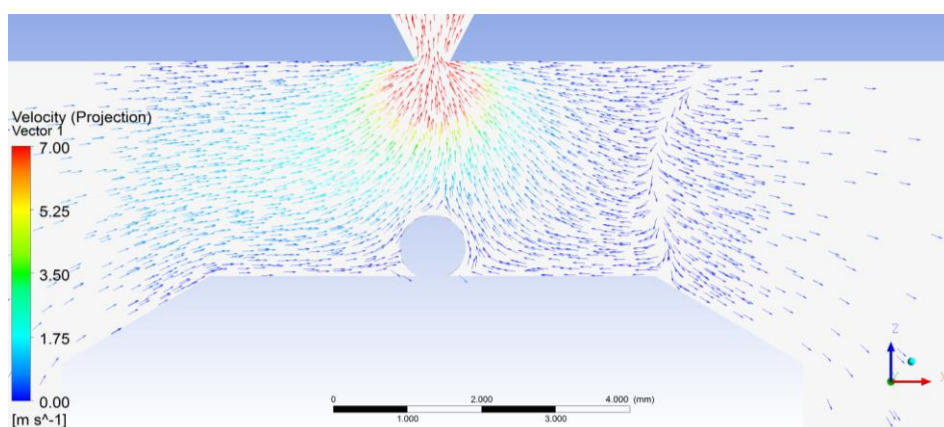


Figure 8: Velocity vectors of the gas flow at 500 Pa input

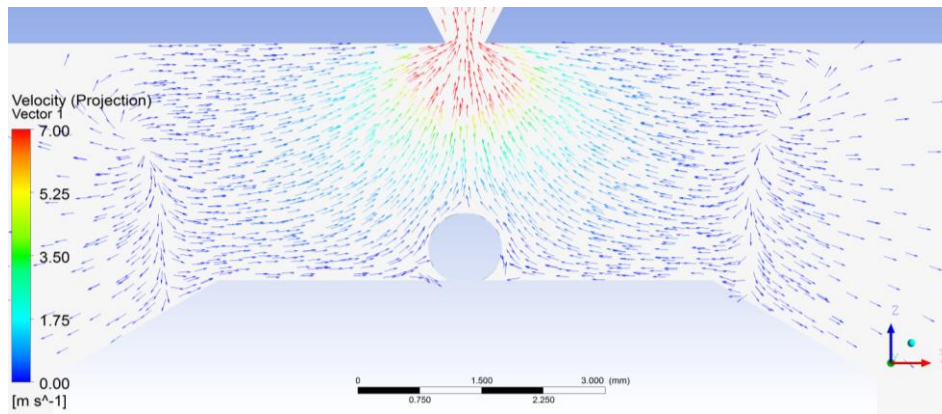


Figure 9: Velocity vectors of the gas flow at 700 Pa input

4. CONCLUSION

The Karman vortices combined with the big vortex above the pad cause small deflections of gas flow from the optical axis of the microscope that may move the sample on the pad or even to disperse it completely. They may even cause the electron beam to deflect from its original optical axis because of asymmetrical distribution of charged gas particles distorting the observation results.

The process of creation of the vortices could be suppressed by adding eligibly shaped barriers around the sample, that will give the gas flow the right direction.

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REFERENCES

- [1] Neděla, V., Autrata, R. Environmentální rastrovací elektronová mikroskopie, Československý časopis pro fyziku: Czechoslovak journal of physics. Praha: Fyzikální ústav AV ČR, 2005, 2005(3), ^{sv.} ISBN 0009-0700. ISSN československý časopis pro fyziku.
- [2] Bayer, R.; Maxa, J.; Vyroubal, P. Analýza proudění plynu v komoře vzorku EREM simulační metodou. In Elektrotechnika a informatika 2015. Plzeň, Tribun EU s.r.o. 2015. p. 3 - 264. ISBN 978-80-261-0514-5.