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CFD Calculations on the Dry Helium Rotating Seal

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Summary

CFD has been used to calculate pressure distribution and flow patterns in the helium rotating seal. The pressure builds up in the seal, due to drag of the rotating plate. The pressure build up due to the drag is higher if the gap is smaller. As a consequence, the pressure force on the seal ring increases if the gap between the stagnant and rotating parts become smaller. With the geometry considered in this report, a feedback mechanism is obtained.

1 CFD Model

1.1 CFD

Computational Fluid Dynamics (CFD) is a numerical method for solving the Navier-Stokes equations of flows of liquids and gases. CFD software is based on finite volume techniques. The strength of CFD is:

- full three-dimensional modelling of the object in a 1:1 scale
- full information of gas velocity distribution and pressure distribution in the system.

In order to compute a flow problem, the geometry of the system is modelled and divided into a large number of cells. In each cell, the relations for the conservation of mass, impulse and energy are solved. The total solution of the entire calculational domain gives the pressure and the velocities in three dimensions. In the post-processing phase, variables can be plotted on every cross-section and every surface. Several options can be used, like contour plots and vector plots.

1.2 Geometry Modelled

The helium rotating seal (see [1]) consists of forty identical parts. The gas volume of this seal is shown in figure 1. It is sufficient that only one of the identical parts is modelled. The part that is modelled is shown in figure 2 from the low-pressure side and in figure 3 from the high-pressure side. The stagnant walls are removed in figure 4. The height in these figures is scaled by a factor of 200, in order to give a better view on the construction of the seal ring. The colours in these figures show the boundaries of the geometry. The colours mean:

- red: the high-pressure side of the seal ring
- green: the low-pressure side of the seal ring
- grey: stagnant walls
- blue: rotating part of the seal ring
- yellow: so-called ‘periodic boundaries’. Periodic boundary conditions are used when the physical geometry of interest and the expected pattern of the flow solution have a periodically repeating nature.

1.3 Computational Grid

Several computational grids have been used, in which the cell size has been varied. The thickness of the gap has been divided into 2, 3 or 5 parts, which results in a cell size between 1 and 2.5 µm. In the other two dimensions cells of 1000, 500 or 200 µm have been used. The coarsest grid has 9700 cells and the finest grid has 550 000 cells. An example of one of the grids used is shown in figure 5.

In the modelled geometry, one dimension is much smaller than the other two dimensions. Within the current computer capacity, this results in cells with a high aspect ratio (very slender cells). As a consequence of the shape of the cells, a grid-independent solution cannot be reached. However, the mass flow through the gap and the pressure force on the walls can be extrapolated from the results obtained from computations on several different grids. The extrapolation is undertaken by the Richardson extrapolation, also known as ‘Richardson’s deferred approach to the limit’, see also [2].

1.4 CFD Model

The CFX5 computer code developed by AEA Technology has been used for the calculations described in this report. The following models and assumptions have been used:

- The flow is laminar. The Reynolds number in the gap is in the order of 10.
- Helium is a compressible gas. The ideal gas law is used.

The physical properties of helium at 450 K are used. These properties are taken from [3] and are summarised in table 1. The influence of pressure on the properties in the pressure range used in the calculations is negligible.

table 1 Physical properties of helium at 450 K.

Physical property	Value	Unit
Atomic mass	$4.0026 \cdot 10^{-3}$	kg/mol
Viscosity	$26.5 \cdot 10^{-6}$	Pa·s
Heat capacity	5193	J/kg·K
Heat conductivity	0.208	W/m·K

CFD codes assume the continuum approach of the gas. This approach may not be valid in the entire geometry, since the mean free path length of helium atoms is 0.5 μm at 1 bar. This length is only one order of magnitude smaller than the gap height. However, the mean free path length decreases rapidly if the pressure is higher: at 27 bar it is 0.02 μm. The conclusion is that the possible non-continuum behaviour occurs only at low pressures. It may introduce a small error in the CFD results.

1.5 Boundary Conditions

The boundary conditions are summarised in table 2. The colours in this table refer to the colours used in figures 1 through 5.

table 2 Boundary conditions.

Boundary name	Colour in figures	Boundary conditions
Inlet	red	absolute pressure 27 bar
Outlet	green	absolute pressure 1 bar
Rotating wall	blue	angular velocity 314 rad/s
Stagnant walls	grey	no slip walls
Periodic boundaries	yellow	periodic boundaries

2 Results

The height in the figures in this section is scaled by a factor of 200 in order to give a better view on the geometry of the seal ring.

2.1 Temperature

The temperature variation in the seal is very small and the gas temperature is very close to the temperature of the solid structures. The heat transfer in the gap is very good due to the small gap height. The temperature difference is less than 1 K in the computations.

2.2 Pressure

The pressure distribution on the boundaries is shown in several figures: figure 6 and figure 7 give the pressures for a gap of 5 and 7 μm respectively. Figure 8 and figure 9 show the same figures with a different pressure scale. Especially the last two figures show that the rotation of the lower plate drags helium in the square grooves. The pressure build up due to the drag is lower if the gap is bigger.

2.3 Gas Velocity

The gas velocity distribution is shown as a vector plot for a gap of 5 μm in figure 10 and for a gap of 7 μm in figure 11. The planes in these figures are the mid planes of the gap: respectively 2.5 and 3.5 μm from the rotating wall. In both figures, the gas flow in the area of the grooves is in the direction of the rotation of the rotating wall. There is a small gas flow from the groove to the high-pressure side of the seal ring, which is induced by the higher pressure in the groove. Further towards the low-pressure side, the gas expands and the gas flow turns towards the low-pressure side.

2.4 Flow Rate and Pressure Force

The mass flow rate through the gap and the pressure force on the seal ring is calculated using the Richardson extrapolation mentioned earlier. The results are given in table 3. If the gap size increases, the flow rate increases and the pressure force on the seal ring decreases.

table 3 Flow rates and pressure forces in two gap heights.

Gap height (μm)	Mass flow rate (kg/s)	Volume flow rate (Nm^3/hr)	Pressure force in seal ring (N)
5	$1.27 \cdot 10^{-4}$	2.87	247000
7	$3.26 \cdot 10^{-4}$	7.33	235000

3 Conclusions

CFD has been used to calculate pressure distribution and flow patterns in the helium rotating seal. The pressure builds up in the seal, due to drag of the rotating plate. The pressure build up due to the drag is higher if the gap is smaller. As a consequence, the pressure force on the seal ring increases if the gap between the stagnant and rotating parts become smaller. With the geometry considered in this report, a feedback mechanism is obtained.

References

[1] P. Parent: *HTR E – WP4 Helium rotating seal, Dimensional data proposition for NRG calculations*. 03 CER 038 C, Framatome, July 3, 2003.

[2] W.H. Press, B.P. Flannery, S.A. Teukolsky, W.T. Vetterling: *Numerical Recipes. The Art of Scientific Computing*. Cambridge University Press, 1989.

[3] N.B. Vergaftik, Y.K. Vinogradov, V.S. Yargin: *Handbook of Physical Properties of Liquids and Gases*. Begell House, 1996.

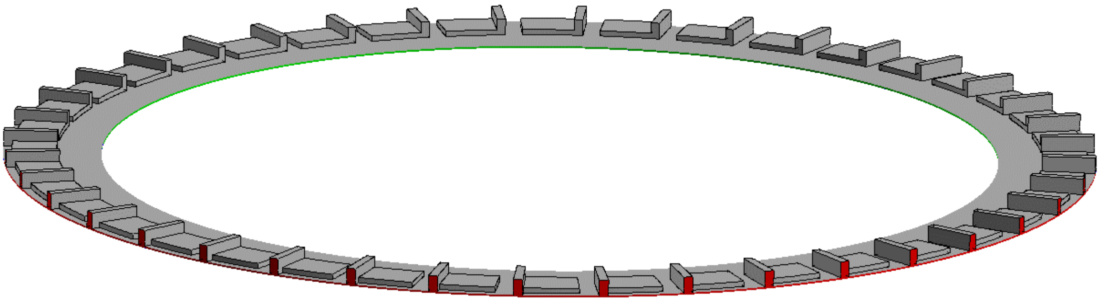

figure 1 The gas volume of the seal ring.

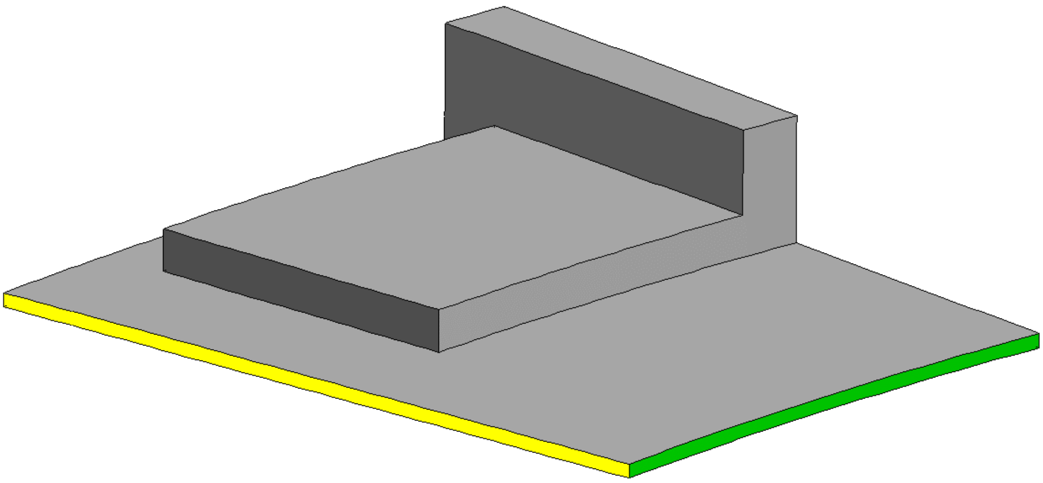

figure 2 The modelled part of the seal. View from the low-pressure side.

Note: the height in all figures is magnified by a factor of 200.

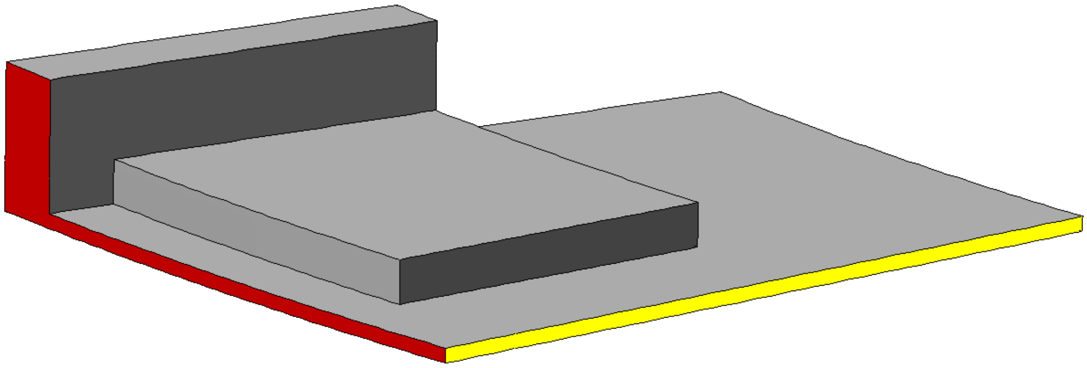

figure 3 View from the high-pressure side.

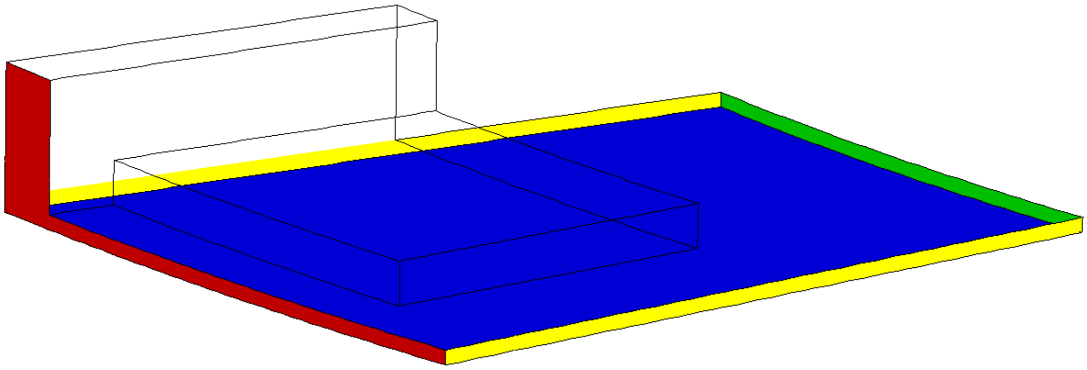

figure 4 View from the high-pressure side. The steady walls are removed.

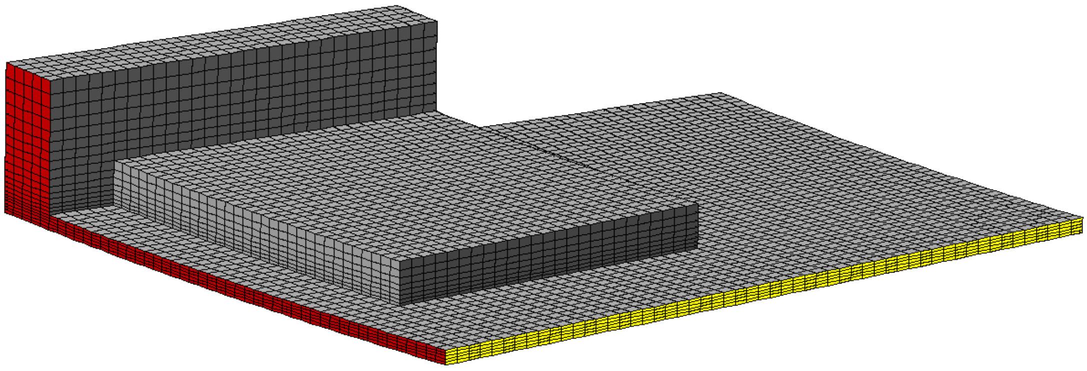

figure 5 An example of the calculation grid.

Note: the height in all figures is magnified by a factor of 200.

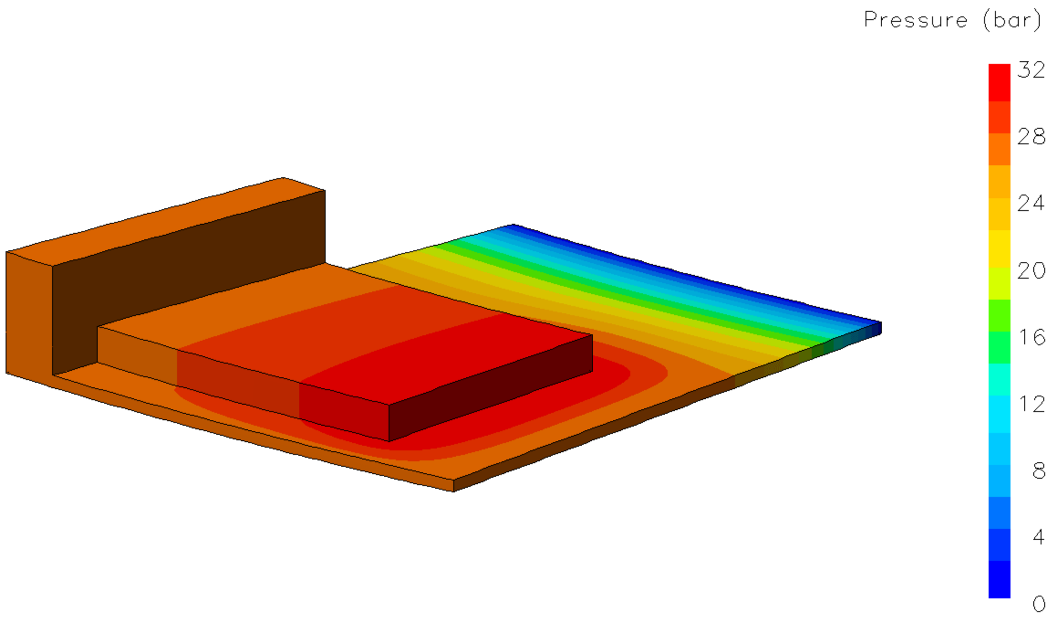

figure 6 Pressure distribution on the seal ring with a gap of 5 µm.

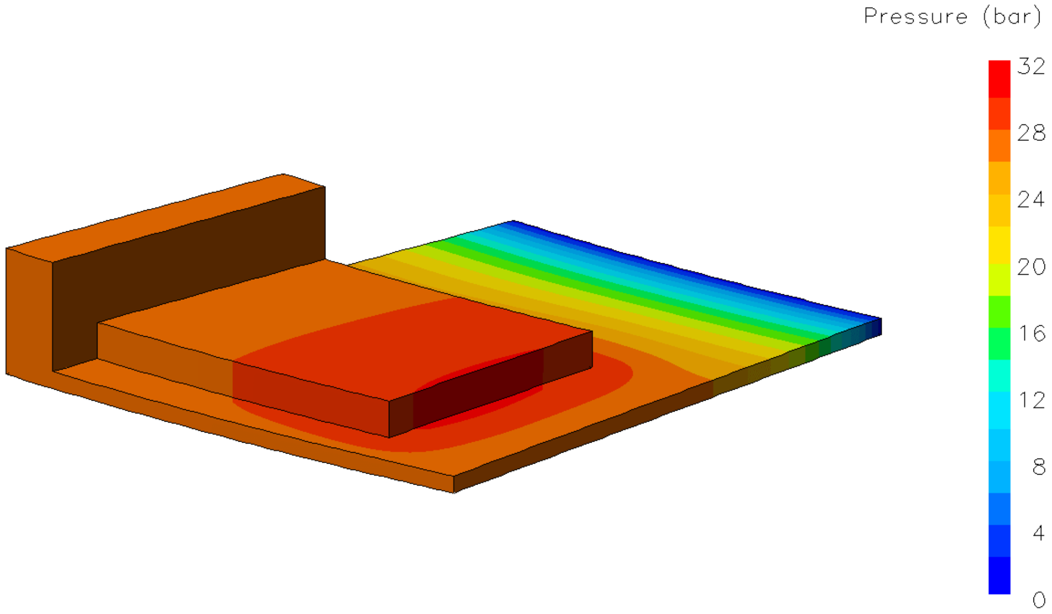

figure 7 Pressure distribution on the seal ring with a gap of 7 µm.

Note: the height in all figures is magnified by a factor of 200.

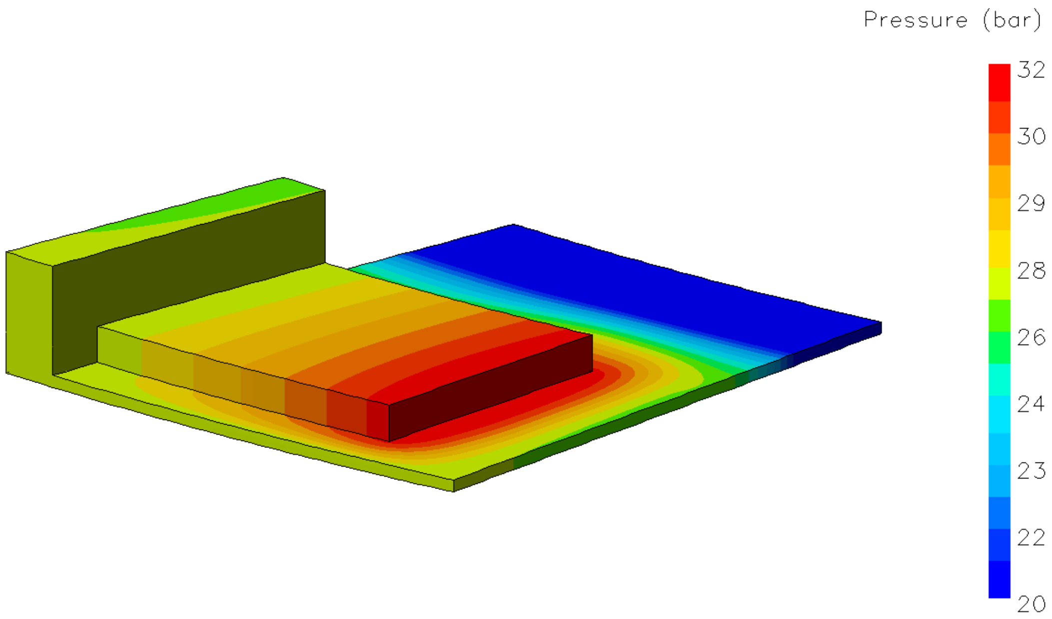

figure 8 Pressure distribution on the seal ring with a gap of 5 µm.

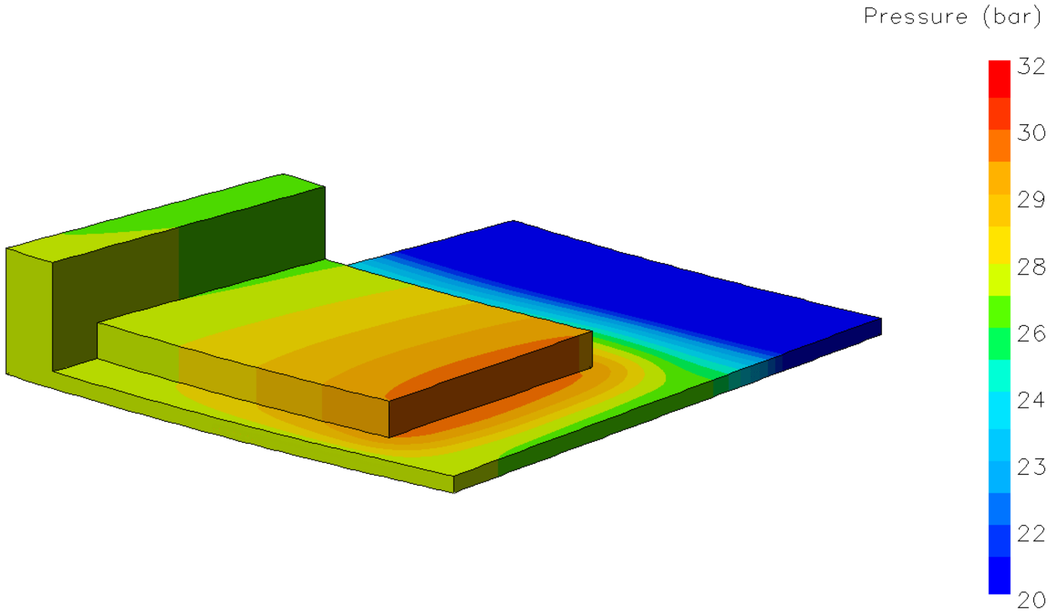

figure 9 Pressure distribution on the seal ring with a gap of 7 µm.

Note: the height in all figures is magnified by a factor of 200.

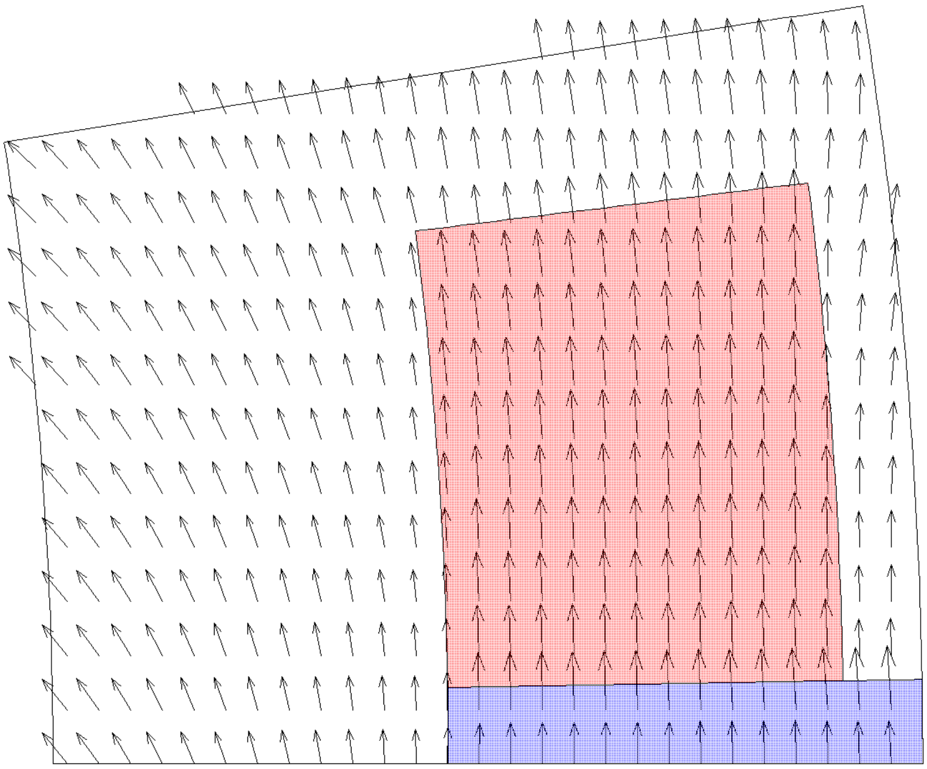

figure 10 Vector plot on the mid plane of a gap of 5 μm.

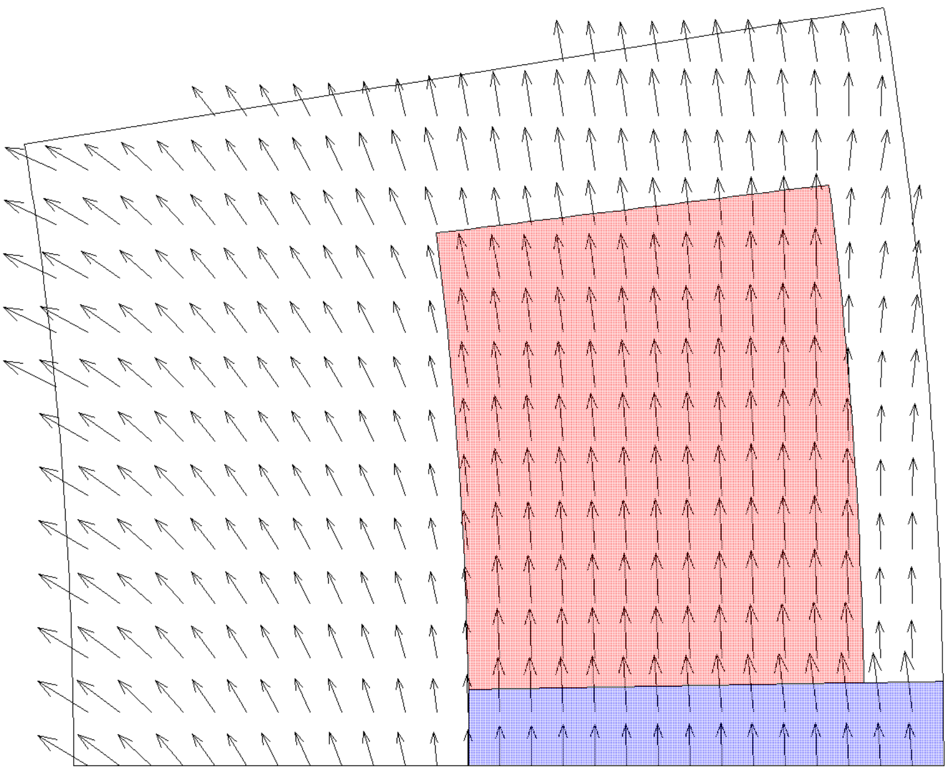

figure 11 Vector plot on the mid plane of a gap of 7 μm.