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CFD Parameter Study on the Dry Helium Rotating Seal

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CFD has been used for a parameter study on the rotation speed of the seal runner and the groove dimensions of the helium rotating seal located between the generator and the axial Active Magnetic Bearing assembly in the vertically arranged GT-MHR rotor shaft assembly. The forces on several surfaces and the leak rate through the gap are presented. If the seal ring rotates in the intended direction, a feedback mechanism ensures a stable balance between the gap size and the pressure force acting on the seal ring. However, if the seal ring rotates in the opposite direction an unstable balance is the result. The height of the groove has a negligible influence on the mass flow rate through the gap and the forces. A longer groove results in a higher force on the seal runner at the expense of a higher leak flow rate through the gap.

1 Introduction

In a previous report [1], CFD has been used to calculate pressure distribution and flow patterns in the helium rotating seal located between the generator and the axial Active Magnetic Bearing assembly in the vertically arranged GT-MHR rotor shaft assembly. After finishing this report, a parameter study has been performed on rotation speed of the seal runner and groove dimensions. The following rotation speeds have been used in calculations with gap widths of 5 and 7 μm:

- standard speed of 3000 rpm;
- the seal runner is rotating at half speed of 1500 rpm;
- stagnant seal runner, 0 rpm;
- the seal runner is rotating in reversed direction, –3000 rpm.

The influence of the groove dimensions has been studied with a gap of 5 μm. The following groove dimensions have been used:

- the groove height has been increased from 15 μm to 30 μm;
- the angle of the groove has been increased from 6° to 9°. This implies that the angular period of the grooves is increased from 9° to 12°. As a consequence, the total number of grooves is decreased from 40 to 30.

The ten cases are summarised in table 1. The differences from the standard case are shown in bold.

table 1 Summery of cases described in this report.

case number	**case description**	**gap width** (μm)	**rotation speed** (rpm)	**groove height** (μm)	**number of grooves** (-)
5a	standard	5	3000	15	40
5b	half speed	5	**1500**	15	40
5c	stagnant	5	**0**	15	40
5d	reversed	5	**-3000**	15	40
5e	high groove	5	3000	**30**	40
5f	long groove	5	3000	15	**30**
7a	standard	7	3000	15	40
7b	half speed	7	**1500**	15	40
7c	stagnant	7	**0**	15	40
7d	reversed	7	**-3000**	15	40

2 CFD Model

2.1 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.

2.2 Geometry Modelled

The helium rotating seal located between the generator and the axial Active Magnetic Bearing assembly in the vertically arranged GT-MHR rotor shaft assembly (see [2]) consists of forty identical sections. The gas volume of this seal is shown in figure 1. It is sufficient that only one of the identical sections is modelled. The section 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.

2.3 Computational Grids

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. In the previous report [1], the mass flow through the gap and the pressure force on the walls were extrapolated to an infinitely fine grid from the results obtained from computations on several different grids. This time consuming process is not used in this report. Instead, the fine grids have been used. In these grids, the thickness of the gap has been divided into 5 cells, which results in a cell size between 1 and 1.4 µm. In the other two dimensions cells of 200 µm have been used. Four grids have been used:

- a grid for the 5 µm gap and the four different rotation speeds (case 5a, 5b, 5c and 5d);
- a grid for the 5 µm gap and the high groove (case 5e);
- a grid for the 5 µm gap and the long groove (case 5f);
- a grid for the 7 µm gap and the four different rotation speeds (case 7a, 7b, 7c and 7d).

The number of cells varies between 550,000 and 740,000.

An error is introduced because the results in this report are not extrapolated to an infinitely fine grid. On the bases of the calculations performed for the previous report [1], it can be estimated that the mass flow through the gap is overestimated by 10 to 20%. The force is underestimated by about 1%.

2.4 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 2. The influence of pressure on the properties in the pressure range used in the calculations is negligible.

table 2 Physical properties of helium at 450 K.

Physical property	Value	Unit
Atomic mass	$4.0026\cdot10^{-3}$	kg/mol
Viscosity	$26.5\cdot10^{-6}$	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.

2.5 Boundary Conditions

The boundary conditions are summarised in table 3. The colours in this table refer to the colours used in figures 1 through 5.

table 3 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, depending on the case
Stagnant walls	grey	no slip walls
Periodic boundaries	yellow	periodic boundaries

3 Results

The mass flow rate through the gap, the maximum pressure in the groove and the total force on the seal runner are given in table 4. The forces on the surfaces of the seal ring are given in table 5. The values in these tables refer to the total seal ring. The names of the surfaces are shown in figure 5, for one section.

In section 2.3, it is estimated that the mass flow through the gap is overestimated by 10 to 20% and the force is underestimated by about 1%.

If the seal ring rotates in the intended direction (cases 5a, 5b, 7a and 7c), the pressure force on the seal ring increases if the gap between the stagnant and rotating parts becomes smaller. Eventually the resultant force acting on the seal ring becomes upwardly directed, which results in a gap widening and a decrease of the pressure force acting on the seal ring. This feedback mechanism results in a stable balance between the gap size and pressure force. However, if the seal ring rotates in the opposite direction (case 5d and 7d), the pressure force on the seal ring decreases if the gap between the stagnant and rotating parts becomes smaller. This implies that reversed rotation results in an unstable balance.

The height of the groove (compare cases 5a and 5e) has a negligible influence on the mass flow rate through the gap and the forces. A longer groove (compare cases 5a and 5f) result in a higher force on the seal runner. A disadvantage of a longer groove is the higher leak flow rate through the gap.

table 4 The mass flow through the gap, maximum pressure and the force on the seal runner for all cases. The values are for the total seal ring.

case number	**case description**	**mass flow** (kg/s)	**maximum pressure** (Mpa)	**force on seal runner** (kN)
5a	standard	1.52E-04	3.35	246
5b	half speed	1.37E-04	3.01	234
5c	stagnant	1.26E-04	2.70	224
5d	reversed	1.01E-04	2.72	202
5e	high groove	1.38E-04	2.99	234
5f	long groove	1.61E-04	3.56	253
7a	standard	3.74E-04	3.11	236
7b	half speed	3.48E-04	2.88	228
7c	stagnant	3.27E-04	2.70	222
7d	reversed	2.83E-04	2.72	207

table 5 Forces on the surfaces for all cases. The surfaces of one section are shown in figure 5. The forces are for the total seal ring.

case number	**case description**	**total** (kN)	**top** (kN)	**mid** (kN)	**surface 1** (kN)	**surface 2** (kN)	**surface 3** (kN)	**surface 4** (kN)	**surface 5** (kN)
5a	standard	246	16	91	18	6	31	19	65
5b	half speed	234	16	86	18	6	29	18	62
5c	stagnant	224	16	81	17	6	27	17	60
5d	reversed	202	16	71	16	6	25	15	53
5e	high groove	234	16	86	18	6	29	18	62
5f	long groove	253	12	105	21	5	24	15	71
7a	standard	236	16	87	18	6	29	18	62
7b	half speed	228	16	84	17	6	28	17	60
7c	stagnant	222	16	81	17	6	27	17	58
7d	reversed	207	16	74	16	6	25	16	54

4 Conclusions

CFD has been used for a parameter study on the rotation speed of the seal runner and the groove dimensions of the helium rotating seal located between the generator and the axial Active Magnetic Bearing assembly in the vertically arranged GT-MHR rotor shaft assembly. The forces on several surfaces and the leak rate through the gap are presented. If the seal ring rotates in the intended direction, a feedback mechanism ensures a stable balance between the gap size and the pressure force. If the gap between the stagnant and rotating parts become smaller, the pressure force on the steal ring increases. Eventually, the resultant force acting on the seal ring becomes upwardly directed, which results in a gap widening and thus a decreasing pressure force. However, if the seal ring rotates in the opposite direction, the force on the seal ring decreases if the gap between the stagnant and rotating parts becomes smaller. This implies that reversed rotation results in an unstable balance. The height of the groove has a negligible influence on the mass flow rate through the gap and the forces. A longer groove result in a higher force on the seal runner at the expense of a higher leak flow rate through the gap.

References

[1] N.B. Siccama, CFD Calculations on the Dry Helium Rotating Seal. NRG report, 20793/03.54363/C Petten, 19 November 2003.

[2] P. Parent, HTR E – WP 4 Helium rotating seal, Dimensional data proposition for NRG calculations. 03 CER 038 C, Framatome, July 3, 2003.

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

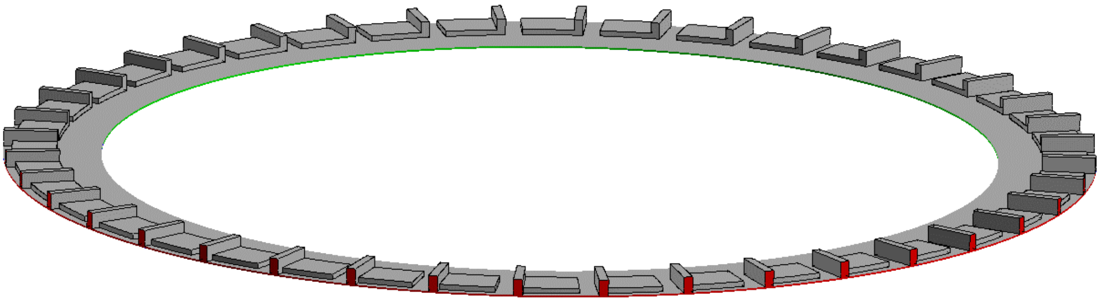

figure 1 The gas volume of the seal ring. The colours are explained in table 3.

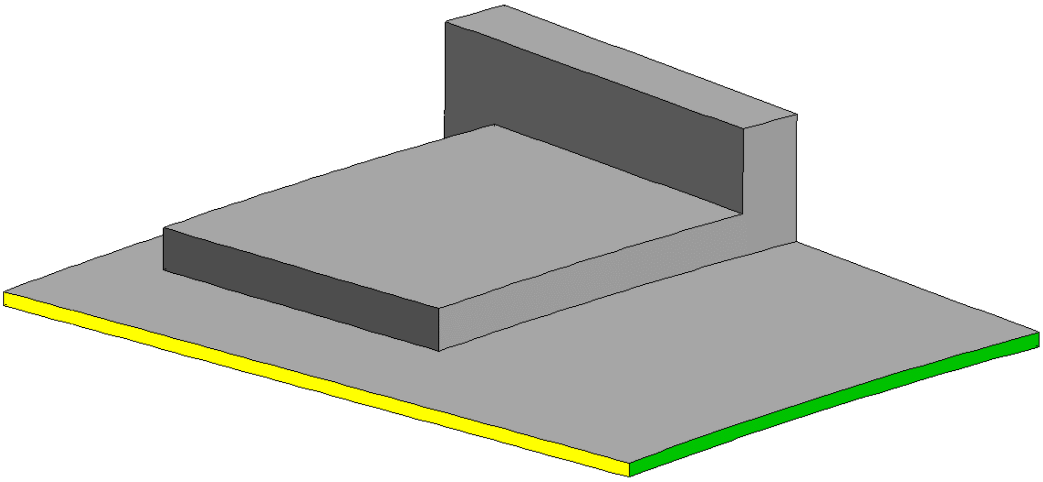

figure 2 The modelled section of the seal. View from the low-pressure side. The colours are explained in table 3.

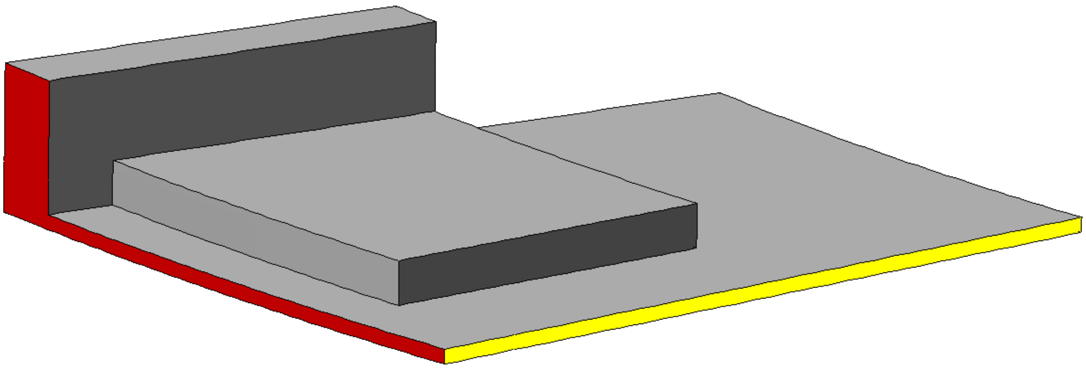

figure 3 View from the high-pressure side. The colours are explained in table 3.

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

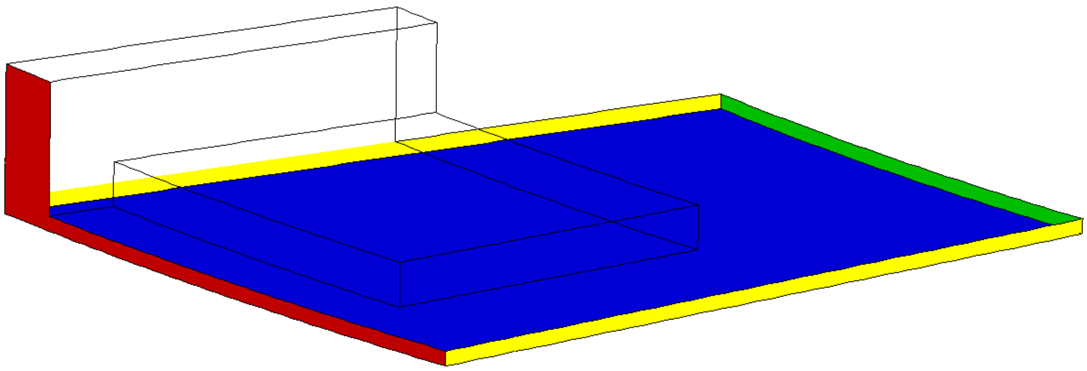

figure 4	View from the high-pressure side. The steady walls are removed. The colours are explained in table 3.

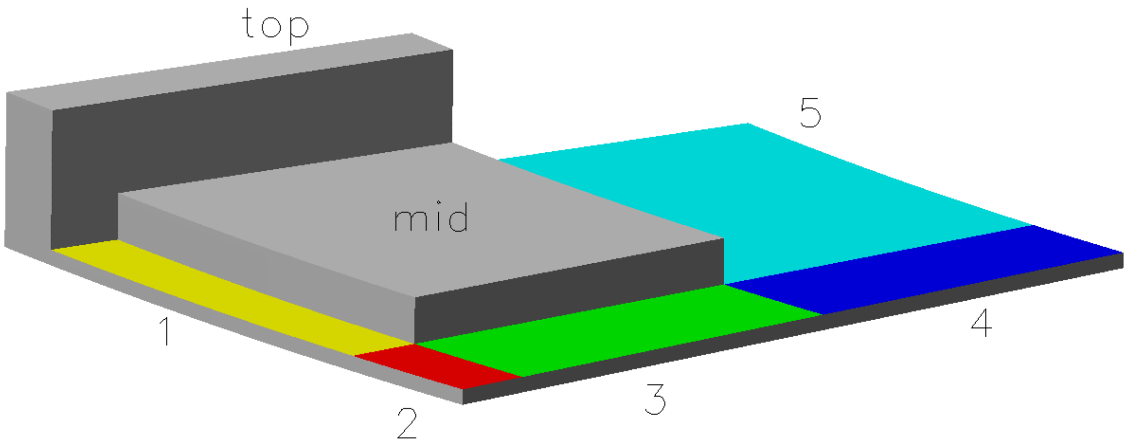

figure 5	Areas used for table 5.

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