Piston for internal combustion engine

November 14, 2018

1 Introduction

Reciprocating pistons are at the core of the internal combustion engine technology. They need to be designed for both durability and performance. One important aspect of the design phase is to evaluate the cooling performance of the piston to avoid overheating that would lead to a degradation of the material properties. A simplified piston will be studied to understand better the challenges of the design phase. Figure 1 presents the pistons in context inside the engine.

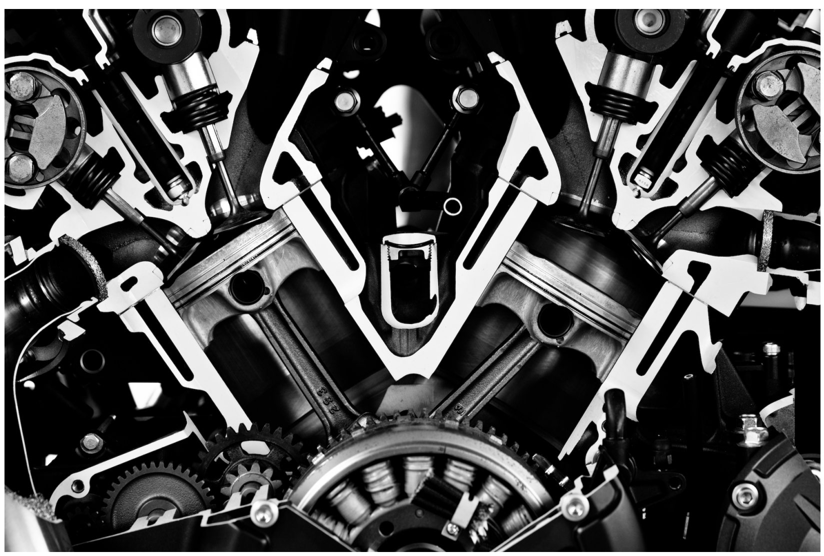

Figure 1: Cross section of an internal combustion engine.

2 Material properties

The material used to manufacture the pistons is a special aluminum alloy. The thermal diffusivity of this metal is $5.4 \times 10^{-5}\,\mathrm{m}^2/\mathrm{s}$.

3 2D piston case

The gmsh script file can be found in folder "piston-2d". Figure 2 presents the geometry together with the index of the boundaries.

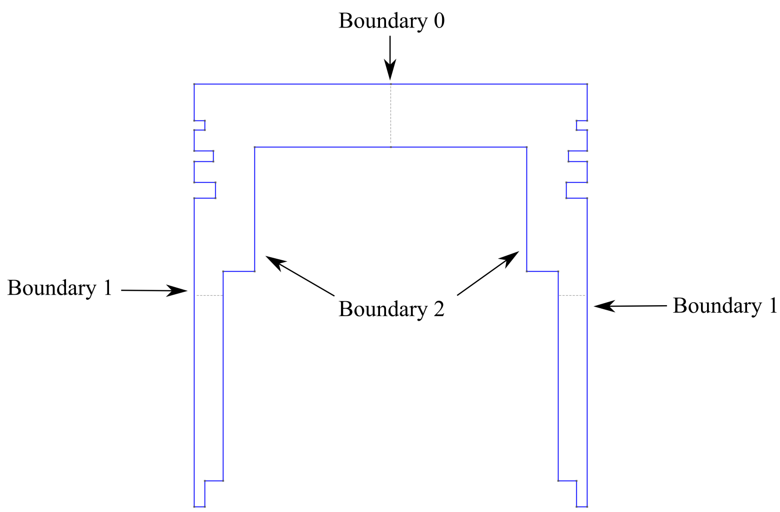

Figure 2: Piston 2D

3.1 Case 1 - Dirichlet boundary condition

For the first case only Dirichlet boundary conditions will be considered.

Boundary ID	Comment	Type	Value	Unit
0	Top	Dirichlet	300	°C
1	Liner	Dirichlet	100	°C
2	Piston underneath	Dirichlet	30	°C

Table 1: Boundary conditions case 1

3.2 Case 2 - Neumann boundary condition

The boundary condition on the top of the piston is now replaced by a Neumann boundary condition.

Boundary ID	Comment	Type	Value	Unit
0	Top	Neumann	2	$\mathrm{MW} \cdot \mathrm{m}^{-2}$
1	Liner	Dirichlet	100	°C
2	Piston underneath	Dirichlet	30	°C

Table 2: Boundary conditions case 2

3.3 Case 3 - Time-dependent Neumann boundary condition

Vehicles commonly use four-stroke engines that have four phases that are represented by the rotation of the crankshaft (more information https://en.wikipedia.org/wiki/Four-stroke_engine):

- 0° to 180°: Intake,
- 180° to 360°: Compression
- 360° to 540°: Power
- 540° to 720°: Exhaust

An engine that rotates at 4000 RPM is considered here and, at this speed, a complete cycle (720° of the crankshaft) is completed after 0.06 seconds. For our heat problems, this four-stroke cycle means that, after the ignition, a spike in the heat flux on the top surface is observed once per cycle. The following function is used to mimic this behavior:

$$\dot{q} = \frac{4 \times 10^6}{((\alpha - 550)^2 + 1 \times 10^3)^2}$$

α is the current crankshaft angle. A plot of this function over a piston cycle can be found on Figure 3.

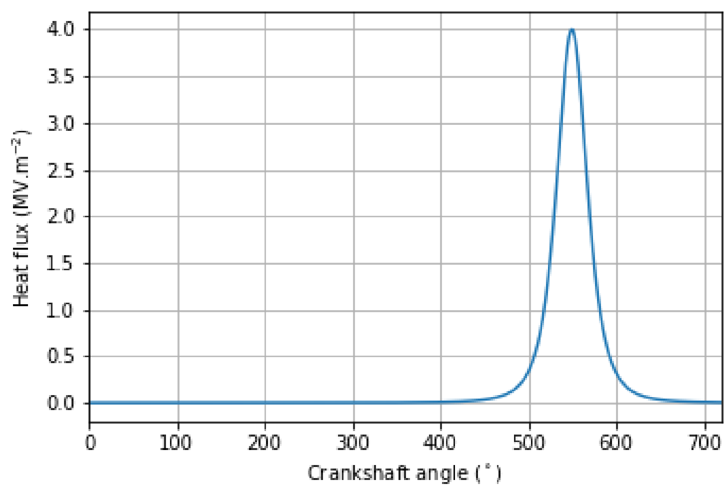

Figure 3: Heat Flux vs crankshaft angle

Boundary ID	Comment	Type	Value	Unit
0	Top	Neumann	$\dot{q}$	$\mathrm{MW} \cdot \mathrm{m}^{-2}$
1	Liner	Dirichlet	100	°C
2	Piston underneath	Dirichlet	30	°C

Table 3: Boundary conditions case 3

4 3D piston case

The gmsh script file can be found in folder "piston-3d". The 2D case is now extended to 3D by taking a 90° section of the piston (cf. Figure 4).

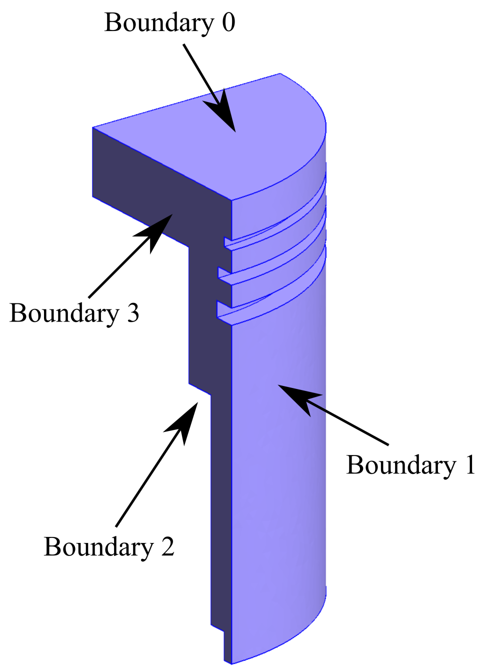

Figure 4: Piston 3D

4.1 Case 1 - Dirichlet boundary condition

For the first case only Dirichlet boundary conditions will be considered.

Boundary ID	Comment	Type	Value	Unit
0	Top	Dirichlet	300	°C
1	Liner	Dirichlet	100	°C
2	Piston underneath	Dirichlet	30	°C
3	Symmetry plane	Neumann	0	$W \cdot m^{-2}$

Table 4: Boundary conditions case 1

4.2 Case 2 - Neumann boundary condition

The boundary condition on the top of the piston is now replaced by a Neumann boundary condition.

Boundary ID	Comment	Type	Value	Unit
0	Top	Neumann	2	$\mathrm{MW \cdot m^{-2}}$
1	Liner	Dirichlet	100	°C
2	Piston underneath	Dirichlet	30	°C
3	Symmetry plane	Neumann	0	$\mathrm{W \cdot m^{-2}}$

Table 5: Boundary conditions case 2

4.3 Case 3 - Time-dependent Neumann boundary condition

For this case, the same setup as section 3.3 is used but in 3D.

Boundary ID	Comment	Type	Value	Unit
0	Top	Neumann	$\dot{q}$	$\mathrm{MW \cdot m^{-2}}$
1	Liner	Dirichlet	100	°C
2	Piston underneath	Dirichlet	30	°C
3	Symmetry plane	Neumann	0	$\mathrm{W \cdot m^{-2}}$

Table 6: Boundary conditions case 3

5 Tasks

For each case provide the following information:

- For the time dependent boundary condition, compute several cycles until a steady periodic solution is obtained.
- Save a time series of the solution and use it to generate an animation of the evolution of the temperature field.
- The maximum and average temperature for each record that you save.
- Mesh convergence study.
- Study the influence of piston thickness on the maximum and average temperature.