

Multiphysics Study into Compression Rings, Coated Against Uncoated

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Abstract: Internal combustion engine components have been a main research interest over many decades. The structural mechanics and dynamics of the piston rings has been a large focus of work in order to gain a greater understanding of the how the piston ring dynamics affect the piston ring. Piston rings are often coated to reduce the level of wear on the ring as they will suffer substantial levels of material loss during operation. To further the understanding of the ring allows for a more accurate estimate of its behaviour [1-3].

1. Introduction

This paper presents simulation results from COMSOL to show how the compression ring performs when coated and uncoated. Two piston ring materials are considered.

A thermal and dynamic analysis was carried out to enable an accurate behaviour to represent the ring during operation. By using the interpolation tool within Comsol, heat and pressure predictions have been applied. An air standard air cycle was used to generate a cycle pressure plot for the simulations. The KTM 520 engine has been used in this study as it is a high speed a four stroke internal combustion engine used in motor cycles. An engine speed of 8,000 rpm was used throughout the simulations.

2. System

As the piston rises from bottom dead centre to top dead centre the interaction on the piston ring comes from the lower contact of the groove where the ring sits and also the cylinder wall. However during operation the cylinder wall will also be lubricated allowing the ring to travel more smoothly. Also during this time the piston ring will be inclined to twist eliminating the linear continuous contact. Therefore in the simulation the pressure acting on the ring caused by the piston has been calculated and is applied as a boundary condition.

The KTM 520 engine dimensions and material features (defined as typical KTM Spec) have been reported in Table 1.

Table 1 - showing component details

Dimension [mm]	Component	Material
0.16	Coating	M _o S ²
95	Compression ring 1	EN GJL 250
95	Compression ring 2	SAE 9254
94.95	Piston	4032-T6 alloy
95	Cylinder	Nikasil

As this is a study to examine the performance of two materials for a piston ring under coated and uncoated conditions. It is important to define the material properties noted in Table 2.

Table 2 - Piston rings and coating material properties

Material	Young's Modulus	Thermal conductivity	Coe Expan
SAE 9254	200 GPa	44.5	12
M _o S ²	117 GPa	52	10.7
EN GJL 250	184 GPa	46	11

To compensate for the pressure acting on the ring during operation an air standard Otto cycle was used to generate a pressure characteristic. To calculate the displacement of the piston during one cycle equations noted by Stone were used.

$$\mathbf{x} \approx \mathbf{R} \left\{ \cos\phi + \frac{L}{R} \left[1 - \frac{1}{2} \left(\frac{R}{L} \right)^2 \left(1 - \frac{1}{2} \cos 2\phi \right) \right] \right\} \quad (1)$$

Where R , L and ϕ are the crank radius, the connecting rod length and the crank rotation respectively. To calculate velocity and acceleration the position can be numerically integrated. Force boundaries are considered as noted in previous studies.

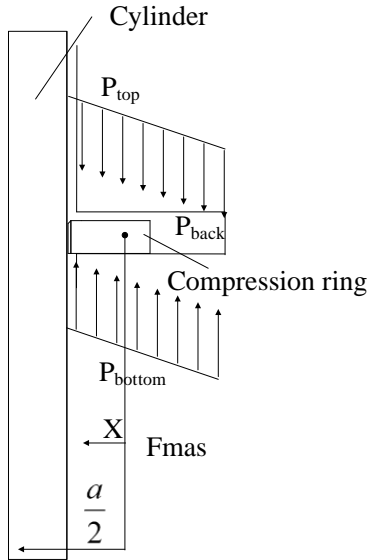


Figure 1. Piston

Figure 1 showing the method of calculating the pressures of the ring during operation. Equations 3-6 denote the methods used to calculate the pressures. Negative pressure was calculated as:

$$p(x) = \frac{1}{2}(P_{bottom} + P_{back})\frac{x}{a} + (P_{bottom} - P_{back}) \quad (2)$$

The resulting gas pressure acting on the ring contact face gap is calculated as:

$$p(x) = -\frac{1}{2}(P_{top} - P_{bottom})\frac{x}{a} - (P_{top} - P_{bottom}) \quad (3)$$

The gas force in the system can be determined from the pressure of the top and bottom, based on the circumference of the ring thickness a .

$$Gas_F = -\frac{1}{2}a(P_{top} - P_{bottom}) \quad (4)$$

The approach used by R.Mittler & al. approach [4] was been used to establish the pressure boundary conditions. In this study it is assumed that the ring is fully flooded.

The model also includes the thermal expansion of the ring is to calculate through use of the thermal strain, namely,

$$\Delta_l = \alpha \Delta T \quad (5)$$

Where Δ_l , α and c are the thermal strain, linear coefficient of thermal expansion and temperature rise respectively as illustrated by figure 2. The thermal deformation of the material have been considered in both coated and uncoated conditions.

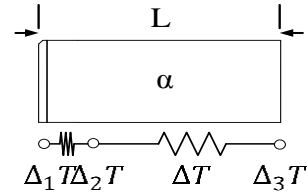


Figure 2. Thermal expansion diagram

Piston ring geometry used in this study is defined by the ISO standard [5]. In this work it is assumed that the piston is of cylindrical profile. As Comsol has the ability to allow for work with variables and parameters, the use of equations on the simulation become easily applied.

3. Results

With the use of the standard air cycle, piston inertia force and cylinder pressure output was simulated shown in Figure 3.

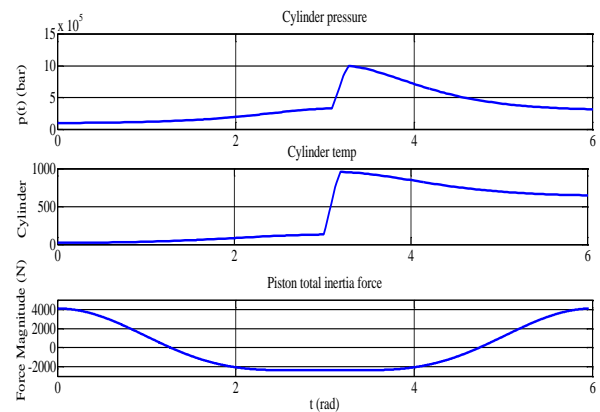


Figure 3. KTM cylinder pressure output

Two materials were used for the running-in of this compression ring. All simulations were calculated around the operational value of 8,000 RPM. All ring geometry is from the 6622 ISO standard.

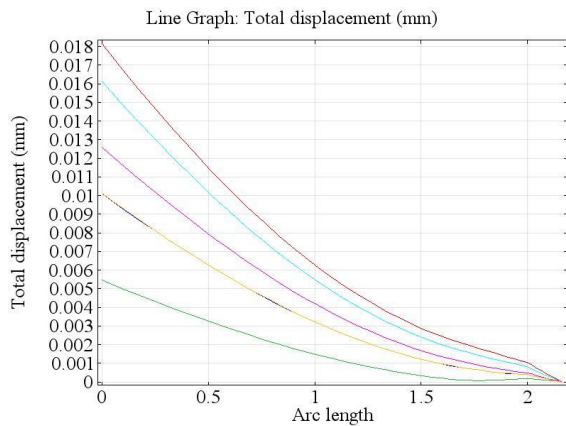


Figure 4. EN GJL 250 +MoS₂ after 30 mins running-in

During the simulation time step iterations of 0.01s were used. Figure 4 and Figure 5 illustrate the use of 5 iteration steps to represent the running-in of the ring. In these results the cross sectional distance 2.2mm of the ring is considered. Also both x and y planes were considered for deformation to also incorporate torsional twist noted by [1].

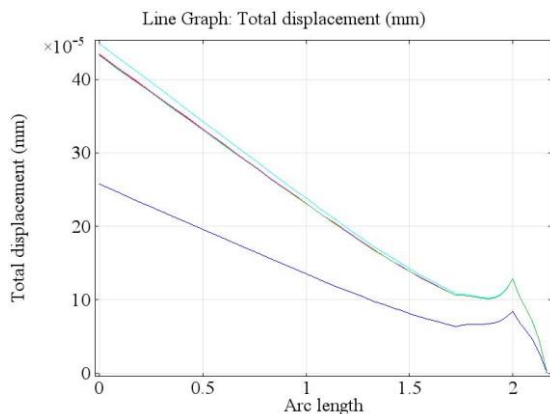


Figure 5. SAE 9254+MoS₂ after 30 mins running-in

In both sets of results the thermal deformation and applied pressure are considered defined.

4. Discussion

As the heat and pressure begin to build during operation, as to be expected the back face of the ring will deform the greatest over time. The ENGJL 250 will deform to a maximum of 0.018 mm over the 30 mins of running. As for the SAE 9254 will have minor deformation up to 50 um during the same operation time. However in both sets of results the substrate material is restricted in fully deforming by the MoS₂ coating. It has been noted by [1,3] that during the running-in it is vital to the engine performance that the ring will run-in wearing down to suit the cylinder wall.

5. Conclusion

During operation the ring temperature and pressure will increase and then decrease in the cylinder, which has effects on all components that are working around the cylinder area. The idea is to attempt to deform to a point where the ring will bed into the cylinder wall creating an almost perfect seal.

In the race car condition this seal is vital to ensure the highest level of performance as possible. As the heat increases the substrate will act against the coating attempting to deform however the coating will restrict the ring, as seen in Figure 4 and Figure 5 both substrates are interrupted when reaching the point where both coating and substrate meet. The coating will resist the ring leaving and incomplete deformation process, leave a drop in performance. Further work should examine the idea of a running-in process coating less and then coating the ring. Also as noted by [7] that the surface of the coating will have flash temperatures during this process further examination of the coating profile is needed.

6. Acknowledgements

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9. References

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