

Chapter 10

Effect of Geometrical Dimension of Fins on the Cooling Performance of an Air-Cooled Engine Cylinder Block



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Abstract One of the key components vulnerable to significant thermal loads and temperature changes is the internal combustion engine cylinder and thus requires an effective method to dissipate the high amount of heat energy. In order to enhance the heat removal from the engine cylinder, it is fitted with fins or extended surfaces, with different materials, shapes, and sizes. A simulation study was carried out in this work to explore the influence of varying fin sizes on the engine cylinder block. The effect of the geometrical dimensions of fins, such as length and thickness, on the cooling performance of the engine block is investigated in this study. Using the steady-state thermal analysis of the engine block, results of the temperature drop, the heat transfer rate, and the thermal resistance were obtained. Results showed that the performance of the engine block is improved when the fin thickness is between 4 and 5 mm, the length is 30 mm and the number of fins is 7. It can be concluded that fin thickness and fin length have substantial impact on the thermal performance of the engine block.

Keywords Engine block · Compact heat exchanger · Thermal simulation · Thermal resistance

10.1 Introduction

The internal combustion engine cylinder is subjected to extreme temperature and pressure variations during operation. Heat is generated in the engine mainly due to the fuel combustion and partly due to the friction between the moving parts. The engine cylinder is usually made of material with lower melting temperature than the combustion temperature. Therefore, the moving parts in the engine cylinder are prone to melting if its temperature is not properly managed. Engine performance would be compromised by excessive engine temperature since it would diminish the

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volumetric efficiency, promote pre-ignition and detonation (Sahoo et al. 2021), and reduce the overall efficiency. Thus, to avoid thermal damage of cylinder parts and materials as well as to minimize engine performance degradation, the engines are purposefully engineered to lose around 70% of their heat through cooling systems with the remainder of the heat being transformed to useable mechanical energy (Thornhill and May 1999; Thornhill et al. 2003).

Cooling systems for an engine cylinder can be in the forms of water cooling, oil cooling, or air cooling depending on the amount of heat generated by the engine. The air-cooling method is primarily employed in small capacity motorcycle engines as they have minimal space requirements and they have a sufficient amount of air flow movement to facilitate the heat dissipation process. Fins or extended surfaces are attached to the engine cylinders have been proven to enhance the amount of heat dissipated significantly. The fins increase the surface area of the cylinder and thus provide far greater heat transfer. The fins, generally thin strips of highly conducting metals, are used on a surface where the convective heat transfer coefficient, h , is very low.

The design of the fins is very important as it can adversely affect the engine performance and longevity. Several design factors that are considered in evaluating the fins' heat transfer performance are fin shape or fin type, fin pitch, fin thickness, fin length, and fin material.

Comparison between wavy fins and annular fins was conducted by Ranjan and Das in terms of heat transfer and effectiveness indicating superior performance by wavy fins (Ranjan and Das 2014). Comparing elliptical fins and cylindrical fins experimentally, the former was found to have higher fin efficiency (Nagarani and Mayilsamy 2010). Heat transfer and pressure drop are both improved by the use of wavy fins in fin-and-tube heat exchangers, according to CFD analysis of fin-and-tube heat exchangers with plain and wavy fins (Bhuiyan et al. 2010). Louver fin surfaces have been proven to enhance the heat transfer compared to other fin types. Heat transfer enhancement of 58% was observed for louvered fins compared to flat fins in a study by Carija et al. (2014). They also suggested that caution should be exercised when choosing the optimal for louvered fins. Experimental comparative study was conducted by Okbaz et al. (2020) to study the impact of using louvered fins and wavy fins for heat exchangers. According to studies, louvered fin surfaces outperform un-interrupted fin surfaces such as plain fin and wavy fin surfaces in terms of heat transfer enhancement (Lozza and Merlo 2001; Wang et al. 2015; Tang et al. 2009).

Fin spacing or fin pitch is a measure of the gap or distance between one fin and the next fin. The relationship between fin spacing and heat transfer performance is still uncertain, as evidenced by the fact that results might be inconsistent (Awais and Bhuiyan 2018). Having higher fin pitch indicates lesser quantity of fins requirement, that consequently lowers the weight and the cost of the heat exchanger (Memon et al. 2005).

In a simulation study by Durgam et al. (2021), comparing the thermal performance of an engine cylinder block fitted with fins of different materials, it was found that aluminium alloy gives the greatest performance. In this study, they considered fin

materials such as gray cast iron, aluminum alloy, and copper alloy. Aluminum alloy was also found to be the best material for fins of an engine cylinder block in a numerical study conducted by Reddy Kummitha and Reddy (2017). Other research looking into the effect of fin materials on heat transfer came to the same conclusion: Aluminum alloy had superior heat transfer performance (Memon et al. 2005; Karthik 2018; Chaitanya et al. 2014; Madhu et al. 2015).

It is the primary objective of this study to investigate numerically the effect of the geometrical dimensions of the fins, such as length and thickness, on the thermal performance on an engine block. The impact of the number of fins on the performance is also considered in this study.

10.2 Simulation Study

10.2.1 Simulation Base Model

The schematic diagram for the engine cylinder considered for this work is shown in Fig. 10.1. The engine cylinder was fitted with 5 annular fins with uniform thickness of 6 mm. Aluminum TS-6061 was used as the material for the engine cylinder and the fins, having a thermal conductivity 180 W/m·K, specific heat 896 J/kg·K, and density 2700 kg/m³. The length of the engine cylinder is 150 mm, and the outer and inner radius of the cylinder are 25 mm and 20 mm, respectively. The length of the fins was 20 mm, and the distance between the fins are equal with each other.

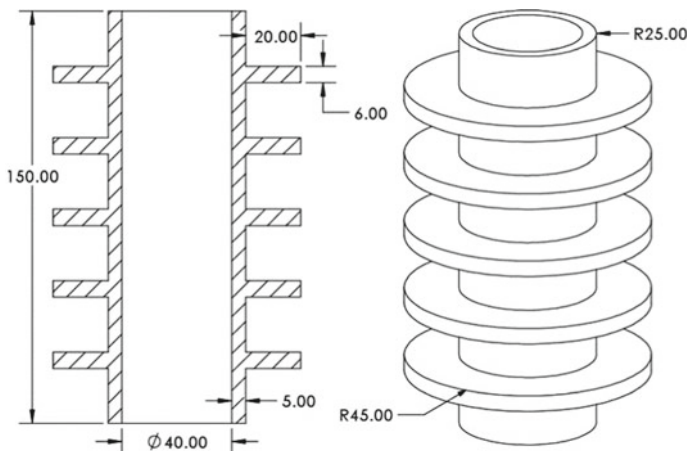


Fig. 10.1 Design of engine cylinder and fins

10.2.2 Assumptions and Boundary Conditions

A few assumptions have been made in order to conduct the thermal analysis of the engine cylinders with annular fins.

- The temperature of the inside wall of the engine cylinder is 500 K or 226.85 °C.
- The radiation heat transfer effect on the engine block is negligible.
- The thermal model of the engine block is a steady-state conduction model with a specified value of convection heat transfer coefficient, h .
- The temperature in the surrounding environment is assumed to be 300 K.

The boundary conditions for this study are inner surface temperature, ambient temperature, and coefficient of convection, h . The inner surface temperature of 500 K is assumed as this value reflects the temperature experienced by the engine cylinder during operation. The outer surface of the engine cylinder that includes the surface of the fins was subjected to convection boundary conditions, where convection heat transfer coefficient, h , is defined. Using the empirical correlation for the coefficient (Incropera et al. 2007), h is determined to be 50 W/m²·°C.

10.2.3 Independent Variables

The focus of this study is to assess the influence of different geometrical properties of the fins on the cooling performance of the engine block. Three geometrical characteristics of the fins are the focus of this study, which are the fin length, fin thickness, and the number of fins attached to the engine block. The length of the fin is varied between 5 and 30 mm, and the fin thickness varies between 2 and 10 mm. The number of fins attached to the engine block is varied between 2 and 7.

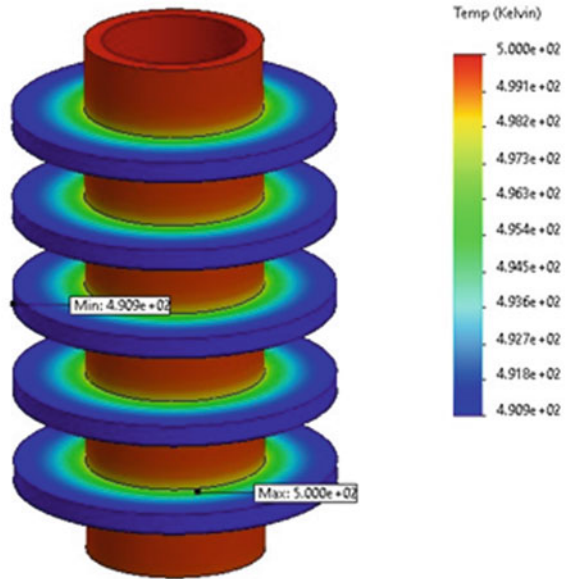
10.2.4 Response Variables

The cooling performance of the engine block is measured by the minimum temperature experienced by the engine block, the amount of heat dissipated, and the total thermal resistance. The first two parameters can easily be obtained from the simulation, while the thermal resistance, R_t , can be found by using Eq. (10.1).

$$R_t = \frac{T_{\max} - T_{\min}}{Q} \quad (10.1)$$

where T_{\max} is the maximum temperature of the engine, T_{\min} is the minimum temperature of the solid wall of the engine block, and Q is the total heat transfer rate.

Fig. 10.2 Temperature contour plot for the base model



10.3 Results and Discussion

10.3.1 Temperature Distribution of the Fin

The temperature distribution of the engine block fitted with 5 annular fins of 5 mm thickness and length of 20 mm is shown by the contour plot in Fig. 10.2. As can be seen in the figure, the wall surface of the engine block is constant at 500 K, whereas the fin experiences reduction in temperature from the inside to the fin tip. The minimum temperature of the engine block is denoted as the temperature at the fin tip, which is 490.9 °C (a reduction of 9.1 °C from the solid wall of the engine block).

10.3.2 The Effect of Fin Thickness

In this study, the fin thickness is varied from 2 to 10 mm. The effect of this variation on the temperature drop and the amount of heat transfer is shown in Fig. 10.3. The results indicate that the temperature drop reduces with the increase in the fin thickness. It is also found that the heat dissipated increases with the fin thickness. At fin thickness of 2 mm, the temperature drop is the highest at 17.7 °C but the heat transfer rate is the lowest at 665.19 W. For an engine block with fin thickness of 10 mm, the temperature drop is the lowest at 6.1 °C and the heat transfer rate is 719.75 W (similar with fin thickness of 8 mm). These results indicate that by increasing the fin thickness up to 5

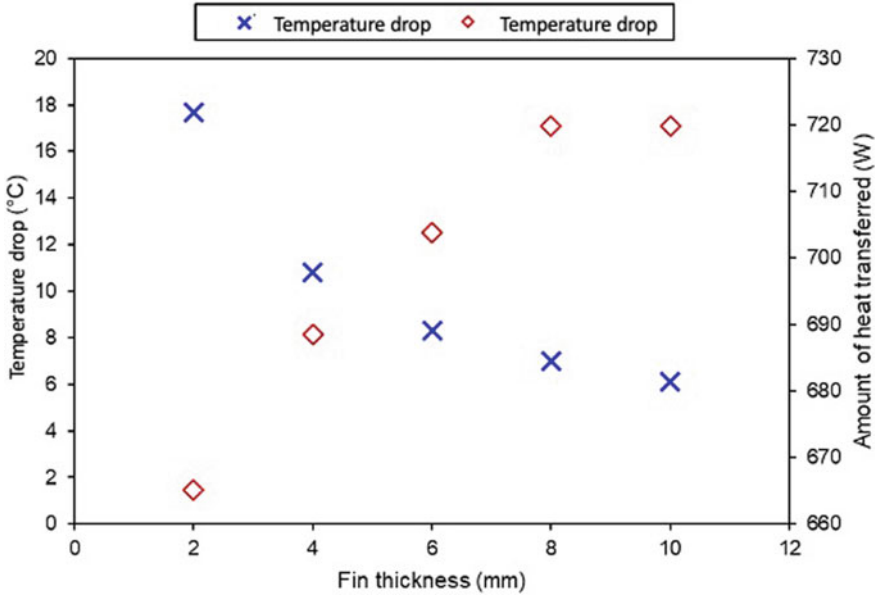


Fig. 10.3 The effect of fin thickness on the temperature drop and the amount of heat transferred from the engine block

times the original size, the heat transfer can be enhanced by 8.2% and the temperature drop reduces by 190%. By increasing the fin thickness, the available surface area for heat transfer increases, thus enhancing the amount of heat dissipation.

From Fig. 10.3, it can be observed that there is an optimum point where the amount of heat transferred and the temperature drop are desirable (both are at the highest possible values), which is occurring when the fin thickness is between 4 and 5 mm. It can also be seen that fin thickness that exceeds 8 mm does not produce significant change in the amount of heat transfer.

Figure 10.4 shows the effect of the variation in the fin thickness on the thermal resistance of the engine block. As the fin thickness increases from 2 to 10 mm, the thermal resistance decreases from 0.00266 to 0.00848 °C/W (reduction of 214%). As the main objective of fins that are attached to the engine block is to reduce the amount of heat and the temperature as much as possible, it is implied from the results that the fin thickness should be between 4 and 5 mm.

10.3.3 The Effect of Fin's Length

Studies showed that the length of fin or the radius of the annular fin produces significant effects on the thermal performance of a heat exchanger. In this study, the length of the fin is varied from 5 to 30 mm. The simulation results of the temperature drop

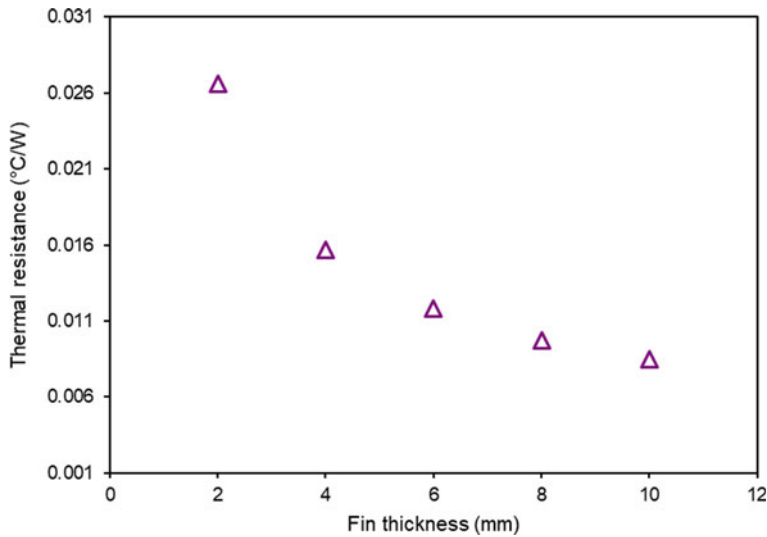


Fig. 10.4 The effect of fin thickness on the thermal resistance

and the amount of heat transferred from the engine block are shown in Fig. 10.5. It can be clearly seen that there are positive relationships between the fin's length and the temperature drop and the heat transfer rate. As the fin's length increases, the temperature drop and the heat transfer increase.

When the length is 5 mm, the temperature drop experienced by the engine block is 1.3 °C compared to 16.4 °C when the length is 30 mm, an improvement of 1162%. With the same variation in fin's length, there is an improvement of 190% in the heat transfer rate from the engine block. By increasing the fin's length, the surface area that is available for heat exchange process between the solid wall and the surrounding's air increases. Simulation results also demonstrated that the thermal resistance of the engine block increases with the fin's length of up to 214% from the lowest thermal resistance of 0.0038 °C/W (Fig. 10.6).

The results clearly showed that in order to dissipate heat and reduce the temperature of the engine block as much as possible, the length of the fins should be as large as possible, in this case, 30 mm.

10.3.4 The Effect of Number of Fins

For an engine block with annular fins with the same length and thickness, but different numbers of fins, the simulated minimum temperature of the engine block is maintained the same. Hence, only the results of heat transfer rate and thermal resistance for different number of fins are discussed (Fig. 10.7).

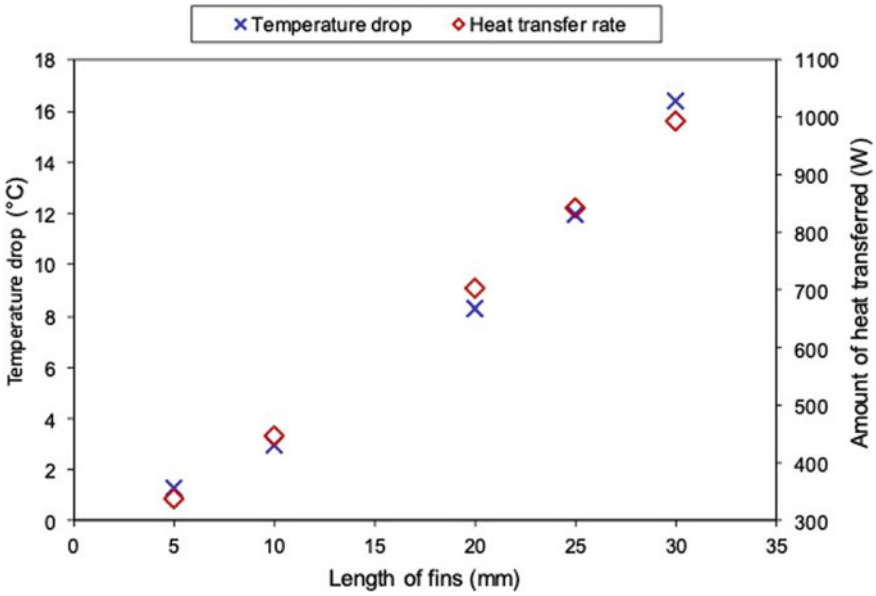


Fig. 10.5 The effect of fin's length on the temperature drop and the heat transfer rate

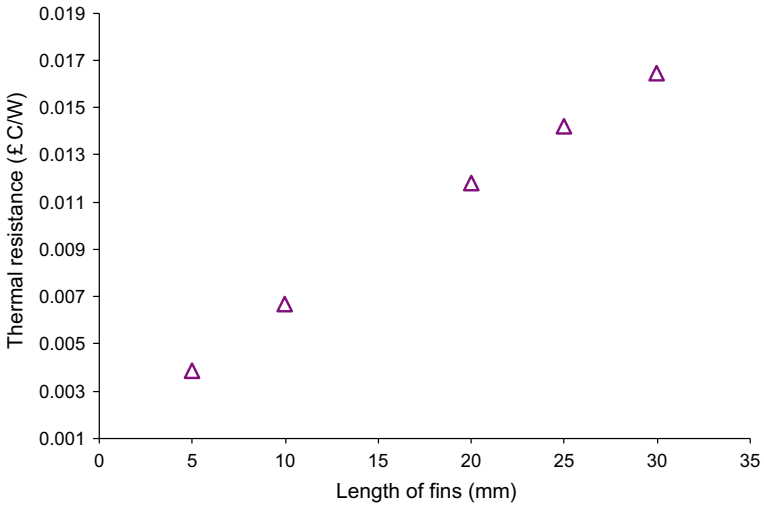


Fig. 10.6 The effect of fin's length on the thermal resistance

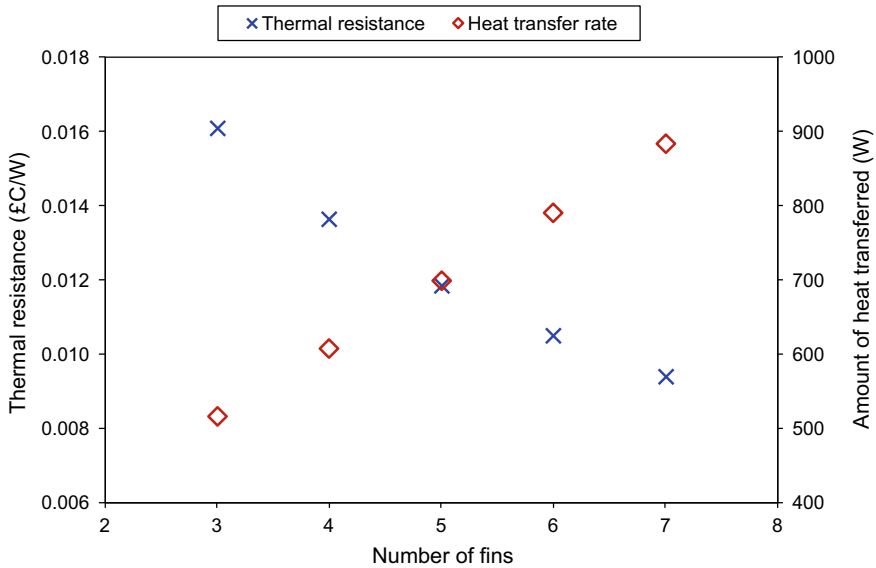


Fig. 10.7 The effect of the number of fins on the thermal resistance and the heat transfer rate

As the number of fins increases from 3 to 7 for the engine block, the amount of heat dissipated increases from 515.83 to 883.45 W (an increase of 71.3%). The thermal resistance also improved by 71.3% as well, as it is only affected by the heat transfer rate at the same minimum temperature of the block. The greater number of fins would produce greater surface area for the heat transfer process, thereby increasing the amount of heat energy that could be dissipated from the surface. Thus, the greater the number of fins attached to the engine block, the better the heat transferred.

10.4 Conclusion

This study focused on the effect of the geometrical dimensions of annular fins, such as length and thickness, on the heat transfer performance of an engine block. The effect of the number of fins on the performance is also investigated. The heat transfer performance of the engine block is characterized by the temperature drop from the inner wall of the block to the tip of the fin, the thermal resistance, and the amount of heat transferred by the block. From the study, it can be concluded that:

- The fin thickness does not significantly affect the amount of heat transfer, but the increase in thickness improves the thermal resistance tremendously.
- There exists an optimum thickness at which the heat transfer rate and the temperature drop are desirable.

- The length of the fins should be as high as possible, in this study, 30 mm as it produces the greatest enhancement in heat transfer rate, temperature drop, and the thermal resistance.
- The higher the number of fins attached to the engine block, the higher the improvement in the thermal performance of the block.

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