International Journal of Engineering & Technology, 7 (3.17) (2018) 90-93

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

Rapid Prototyping of a Customized Cooling System for a Novel Crank Rocker Engine

Khurram Altaf[1]*, Masri Baharom[2], A. Rashid A. Aziz[3], Junaid A. Qayyum[4] and Mirza Jahanzaib[5]

[1, 2, 3,4] *Center for Automotive Research and Electric Mobility (CAREM) Department of Mechanical Engineering, Universiti Teknologi PETRONAS, Bandar Seri Iskandar, Perak, Malaysia*

[5] *Department of Industrial & Manufacturing Engineering, University of Engineering & Technology, Taxila, Pakistan*

**Corresponding author Email: khurram.altaf@utp.edu.my*

Abstract

A novel internal combustion engine termed as Crank Rocker Engine has been developed at Universiti Teknologi PETRONAS (UTP) Malaysia. In the existing design, the engine cylinder is cooled through forced convection which is not efficient and malfunctioning of cooling system could lead to engine overheating. The objective of the current study is to develop a concept of an integrated and customized cooling system for the Crank-Rocker engine and to develop through rapid prototyping (RP). The proposed cooling system comprises of an integrated cooling water jacket around the engine cylinder, which works on the principle of forced convection. The forced convection is energy intensive and not suitable for stationary engines. Therefore, an enhanced design of the cooling system is required to improve the overall performance of the engine. Since the engine cylinder is curved, the conventional manufacturing technologies could be difficult to apply for the development of cooling system. For swift, precise and economic development as well as performance analysis of the cooling system, RP technique could be promising. In the present study, a customized and modified cooling system has been designed and developed through fused deposition modelling (FDM), an efficient RP technology. Design for additive manufacturing (DFAM) is applied to mitigate development time and support structures of the cooling system. The design is proposed by keeping in view the cooling performance and manufacturability.

Keywords: *Additive manufacturing; crank rocker engine; design for additive manufacturing; fused deposition modeling; rapid prototyping.*

1. Introduction

A typical large capacity Internal Combustion (IC) gasoline engine dissipates approximately 1200 kJ/s of heat while delivering optimum performance. Even a small 10 horse-power engine dissipates 13 kJ/s of heat while running at full load. Therefore cooling of the IC engines is an essential requirement. Forced convection could be one of the options to cool smaller engines, however for prolong running for larger IC engines, convection alone may not be sufficient. Therefore, for reliable and smooth running of an IC engine, a proper cooling mechanism is inevitable.

The idea and a fully functional prototype of the Crank Rocker Engine (CRE) was developed in Center for Automotive Research and Electric Mobility (CAREM), Universiti Teknologi PETRONAS (UTP) Malaysia. The CRE is a gasoline-port injection, four-stroke, spark-ignition, and single-curved cylinder engine. The novelty in the engine design is that it has curved cylinder due to which the swept volume has been increased while occupying the same space in the engine. This increases the power to volume ratio of the engine, when compared to conventional engine designs. Additionally, torque, power and thermal efficiency are higher than conventional slider-crank engine. The indicated torque and power are increased by about 6.28%, while the indicated specific fuel consumption is lower by 4.69% (Salah E. Mohammed et. al. 2017).

Since CRE is a novel design of engine therefore, a customized cooling system for this kind of engine is demanded. A conventional cooling systems are tailored according to crank-slider engines and therefore could not deliver best performance for CRE.

One approach to produce cooling system could be manufacturing components independently through conventional machining followed by assembly. Nevertheless, thus made prototype of the cooling system could be pricy and time consuming. Therefore additive manufacturing (AM) could potentially be a viable solution for the fabrication of such type of customized systems. Rapid prototyping (RP) is an offshoot of AM which is responsible for making prototypes by making use of AM technologies. RP is most suitable for highly customized and tailored demands. Since cooling system is customized and the design is based on true and accurate parameters of the engine, therefore it is anticipated to be more efficient. The integrated cooling system with cylinder block could directly be manufactured through RP.

ASTM (F2792 − 12a) has defined Additive Manufacturing (AM) as ‘‘a process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies”. AM has different synonyms, like freeform fabrication, additive fabrication, additive processes, layer manufacturing etc (Wohlers Associates 2010). AM could substantially reduce the time and cost of manufacturing for integrated cooling system and cylinder block and the probability of integration, compatibility could be more effective. Properly cooled engine is believed to deliver superior output power and is less pollutant (Zheng et al. 2008). Moreover, Carnot efficiency of the engine is dependent on temperature difference of source and sink. Therefore less sink temperature is more efficient during the engine operation (Yadav and Maheshwari 2016). Considering T as temperature of hot and cold reservoirs, Carnot efficiency η can be given in eq 1 (Izumida and Okuda 2016).

$$\eta = 1 - (T_H / T_C) \quad (1)$$

Leal. R. et. al. (2017) described that automotive industry faces new challenges frequently in terms of design trends and technological progress to develop new models and upgrading the existing designs. They further explained that in light of the current economic situation of the industry, it is very vital to decrease the development time for various automotive applications. Additive Manufacturing is a new manufacturing approach that can development tools and dies for the automotive industry in a short period of time and with less expenses. Ilardo & Williams (2010) presented their work on the design and manufacture of an intake system for a formula car using the Fused Deposition Modeling (FDM) 3D printing technology. The existing manufacturing process has limitations due to the inherent geometric complexities of the system. Their aim was to develop a fabrication process that by-passes these limitations. FDM was used to create an intake system that was covered in layers of carbon fiber composite. FDM technique allows for geometric design freedom, while the layup of a composite material provide the strength and heat-resistivity necessary for this application. Prada et. al. (2016) presented their work on the design, analysis and additive manufacturing (AM) of an accelerator pedal for a formula vehicle, to reduce the weight of the original pedal maintaining the level of performance. Dynamic tests showed that both pedals were able to withstand the endurance events without failure. The study suggested that AM approach is a feasible and economically affordable solution in comparison to exiting solutions with metallic alloys and composites and could be a viable option for consideration in professional competitive automobiles.

Additive Manufacturing (AM) technologies are being used by car manufacturers all over the world for their precision and ability to aid in the development of customized and complex components. Manufacturers are foreseeing AM technology making a great impact on the automotive, aerospace and many other manufacturing sectors. Automotive Industry could benefit significantly by employing AM technologies as this gives great flexibility in design. Metal 3D printing such as Selective Laser Melting (SLM) and Direct Metal Laser Sintering (DMLS) can produce customized parts that are difficult using the conventional methods. SLM of different categories of alloys are highly suitable for lightweight applications involving vehicle and engine technologies. SLM and other similar additive manufacturing techniques does not require any additional tooling. Hence expensive sand-casting and die-casting applications can be avoided. This not only shorten development times, but also considerably reduces development costs. Additionally, SLM creates parts using less energy and reducing material waste for significant cost savings and lower impact on the environment. AM provides revolutionary possibilities for the automotive industry in creating faster, safer and lighter vehicles of the future (Peycheva 2014).

An example of AM manufactured tool for an automotive application is shown in Figure 1. The application is a tire tread mold with separate segments which were produced in shorter time and with less expenses using AM technology for prototype and mass production tools using the Selective Laser Melting (SLM) technology enabling the production of the automotive applications effectively and efficiently (SLM Solutions 2016).

The rapidly changing automotive industry is adding new features in its products, by applying optimized designs, new materials, and adopting new manufacturing techniques. The demand for personalization and customization is still strong despite the globalization of automotive market that is more inclined towards shared parts and components. Additive Manufacturing (AM), more commonly known as three-dimensional printing (3DP) is an evolving area in the automotive industry has the potential to inspire the design and manufacturing of vehicles, parts, and tools which creates new prospects in the industry. For the last few decades, the automotive industry has been using AM technologies for the prototyping of components and tools during product development. The technology is helping designers to use physical models of parts without the costly and time consuming traditional methods. As the technology continues to improve and companies increase their expertise, new opportunities for AM in the automotive industry is becoming more apparent (Joshua Cregger 2015).

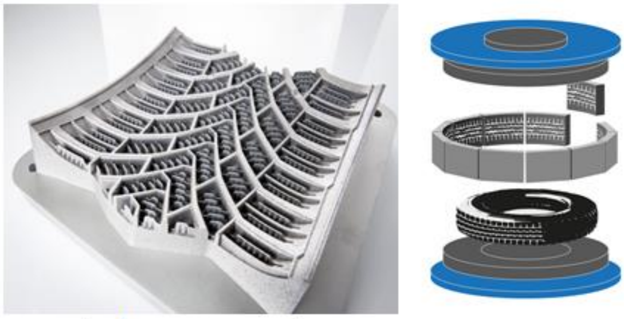

Fig. 1: A typical assembly made through RP [SLM Solutions, 2016]

All IC engines require efficient heat dissipation during combustion to regularly vent the heat of ignition and to perform better. If the temperature of engine block rises above a certain limit, then the oil lubricating the piston starts evaporating or gets ignited resulting in the damage of piston and cylinder. The high temperature developed may sometimes cause excess thermal stresses and hence cracking of the cylinder head and piston. In order to avoid any damages, the heat flowing to the cylinder walls must be carried away. In order to test and validate the performance of the proposed design, it is required that the operation of the engine over a sustained period of time is maintained without any problems.

2. Methodology

For the initial prototype, a solid cylinder block was modelled and developed so that cooling system could be designed accordingly. Figure 2 shows the 3D model and the image of CRE.

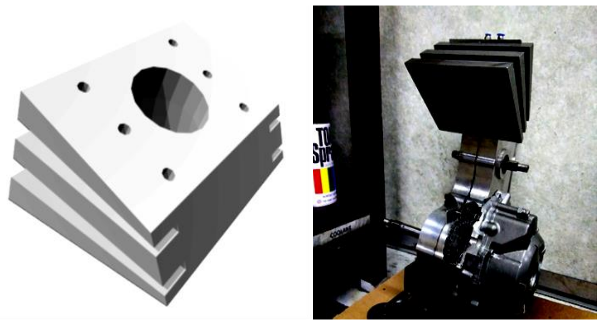

Fig. 2: Prototype of existing Crank Rocker Engine and cooling system

The proposed designs for the cooling system were subjected to DFAM and the decisions regarding the selection of the design were made according to the DFAM analyses. The designs which satisfied DFAM analyses were finalized for prototyping through fused deposition modelling (FDM). Figure 3 shows the schematic flow sheet for the prototyping steps.

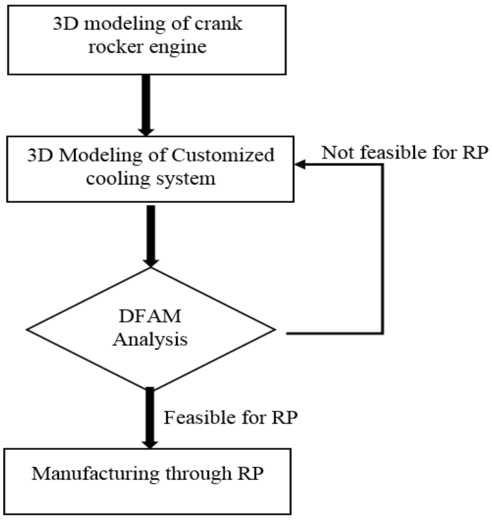

Fig. 3: Flow schematic for design of cooling system

The other proposed design improvement carries built-in ducts to circulate the cooling fluid. The air-cooled configuration could be challenging for the stationary and prolong applications. Therefore, water cooled system is proposed for relatively improved performance. The 3D modelling was performed according to the profile of the CRE engine block. The orientation and geometry of the cooling ducts were decided based on the potentially demanded areas of the engine cylinder. The proposed design provides cooling of the engine block by integrated water cooling jackets with the cylinder block. Several design iterations were done keeping in view the design constraints. One of the main constraints was the DFAM concept that has to be considered for the RT development. For the purpose of the current study, the focus is on the development of the water jacket in the main cylinder block. The first iteration was done by designing a water jacket running across the cylinder along the horizontal axis. Figure 4 shows the orientation of cooling ducts along horizontal axis.

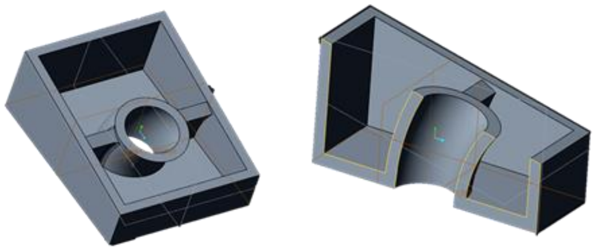

Fig. 4: Full and section view of Engine block

In another design iteration, the cooling ducts were oriented vertically along the y-axis, creating a symmetric water jackets on both sides of the cylinder and resulting in a better fluid flow, as shown in Figure 5. In the second iteration, the water jacked was designed along the vertical axis with the rectangular box. This design could be more effective as it provides a uniform volume chambers for the fluid flow creating an even flow and heat dissipation.

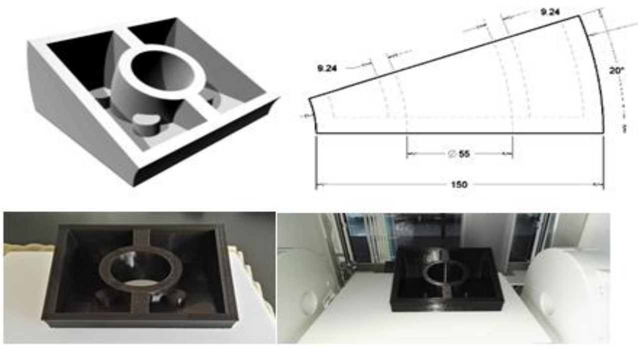

Fig. 5: Modified design with dimensions

After the initial design concepts were done, the integrated engine block was fabricated using a Fused Filament Fabrication (FFF) 3D printed with Poly Lactic Acid (PLA) material, This prototype could be used for further study and analysis and for the development of a metal part using investment casting technique. The as printed RP model part is shown in Figure 6.

Fig. 6: As printed RP block

3. Results and Discussion

The first proposed design was ruled out during DFAM analysis because of the reason that the support material could not be removed conventionally from the interior of the cooling ducts (Fig. 2).

The other design shown in fig 3 was also ruled out because the horizontal ducts are able to carry away the heat from the highly localized areas. The heat from top and bottom areas could not be dissipated efficiently. Moreover the removal of support materials from within the cooling ducts is even more challenging than the previous case in figure 2.

Figure 5 shows an improved cooling system having vertical cooling ducts and oriented according to the cylinder circumference in the close proximity of the engine cylinder. Furthermore, the design is modelled such that to minimize use of support structures as well as to facilitate removal of support structures, once manufactured. It is important to notice that the interior portion of the cooling duct is along the down facing surface. This makes the removal of support structures easy. There is an inherent downside of FDM process that the down facing surfaces are subjected to stair-case effect, due to which surface roughness becomes large. However, in the present case, the surface roughness is desirable because it facilitates the heat transfer as the contact surface area is increased. In this way, the limitation of FDM process could be manipulated to yield desired properties for some tailored demands.

4. Conclusion and Recommendations

The current study is focused on the modelling of a conceptual design and prototyping for an integrated cooling system for the Crank Rocker Engine, a novel engine developed at UTP. The design concept was based on a double chamber cooling jackets surrounding the curved cylinder. The concept prototype was fabricated using a 3D printer with PLA material. Following conclusions are drawn from the present study.

i. RP provides a swift and efficient approach to develop customized functional components economically
ii. Highly customized cooling system could be developed using FDM process
iii. DFAM could efficiently be applied to optimize build time, material consumption and the performance ability of the prototype

5. Acknowledgement

The authors acknowledge financial support from Centre for Automotive Research and Electric Mobility (CAREM) at Universiti Teknologi PETRONAS (UTP) Malaysia to conduct this research.

6. References

[1] Salah E. Mohammed, M. B. Baharom, and A. Rashid A. Aziz (2017), Performance and combustion characteristics of a novel crank-rocker engine, paper accepted in Journal of Mechanical Science and Technology.

[2] Wohler's Associates (2010). What is Additive Manufacturing. Retrieved from https://wohlersassociates.com/additive-manufacturing.html. (Accessed January 24, 2017)

[3] Zheng, M., et al. (2008), Biodiesel engine performance and emissions in low temperature combustion. Fuel, 87(6): p. 714-722.

[4] Yadav, N. and G. Maheshwari (2016), Analysis of Carnot Cycle, Based on Entropy Generation Principle, with Variable Heat Source and Heat Sink Temperature. PARIPEX-Indian Journal of Research, 4(8).

[5] Izumida, Y. and K. Okuda (2016), Molecular kinetic analysis of a local equilibrium Carnot cycle. arXiv preprint arXiv:1612.06036.

[6] Leal, R., Barreiros, F.M., Alves, L. (2017). Additive manufacturing tooling for the automotive industry. Int J Adv Manuf Technol. doi:10.1007/s00170-017-0239-8

[7] Ryan Ilardo & Christopher B. Williams, (2010). Design and manufacture of a Formula SAE intake system using fused deposition modeling and fiber-reinforced composite materials. Rapid Prototyping Journal, Vol. 16 Issue: 3, pp.174-179, doi:10.1108/13552541011034834

[8] Jorge Gonzalez Prada, Aitor Cazon, Josu Carda, Ander Aseguinolaza, (2016), Direct digital manufacturing of an accelerator pedal for a Formula Student racing car, Rapid Prototyping Journal, Vol. 22 Issue: 2, pp.311-321, doi: 10.1108/RPJ-05-2014-0065.

[9] Ralitsa Peycheva (Nov 16, 2014). Why SLM 3D Printing Has Substantial Benefits for the Automotive Industry. Retrieved from https://3dprint.com/25137/auto-industry-3d-printing/ .(Accessed February 07, 2017)

[10] SLM Solutions (2016). Tire mould segments by SLM. Retrieved from https://slm-solutions.com/industries/automotive/tire-mould-segments-slm. (Accessed February 13, 2017)

[11] Joshua Cregger (2015). Implications of Additive Manufacturing for the Auto Industry. Retrieved from http://www.areadevelopment.com/Automotive/q3-2015-auto-aero-site-guide/Implications-Additive-Manufacturing-Auto-Industry-672233.shtml.