Engine Performance Analysis by Studying Heat Transfer in the Valve Seat through Steady-State Thermal Simulation

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Abstract. As the engine reached high speed, the exhaust valve temperature increased exponentially due to the exhaust gas produced by the combustion process between the mixture of air and fuel within the combustion chamber of the internal combustion engine. The valve is subjected to thermal loading due to high temperature and pressure within the cylinder, which must withstand a material temperature for sustainable and optimal operation. To avoid this loss, a perfect medium must be prepared to ensure that the heat is extracted smoothly. This can be done when the valve is in contact with the seat and there is a periodic heat transfer contact. Therefore, it is imperative to research the correlation between valve and valve seat to understand the two sections' heat transfer mechanism. In this study, thermal contact analysis was used to identify heat transfer between the valve and the valve seat as both parts are interconnected. This research also has an interest in studying the two surface conduction mechanisms as the exhaust valve closed in steady-state conditions. Thus, this study portrays a significant method, particularly for determining the distribution of temperature, heat flux, and heat flux direction between the valve and its seat using ANSYS Workbench.

1. Introduction
The valve is a vital component of the valve train mechanism, ensuring that the engine maintains good dynamic performance, reliability, and durability. Failure of the valve is becoming a major issue with the engine, and thermal stress explains this. Cracks will occur when the temperature is too high \cite{1}. The substantial heat accumulated in the valve is rejected by the valve seats when the valve is reciprocated and in contact with the valve seat \cite{2}. The cooling of the valve is important because the
exhaust valve's temperature increases dramatically due to the combustion of hot exhaust gases from the burnt fuel [3]. The only way to dissipate heat from the exhaust valve is by periodic contact with the valve and its seat [4]. The heat transfer between the exhaust valve and the valve seat plays a key role in regulating the valve's temperature and maximising engine performance. Therefore, the most practical approach to solving problems is to improve the periodic heat transfer of contact [4]. The heat transfer should be carried out acceptably in the internal combustion engine. According to Cerdoun et al. [5], damaged valve and valve seats minimise engine efficiency in his experiment. Thus, the author researched the heat flow between the engine material using a mathematical model. Further experiments were undertaken by Mohsen et al.[6] have also established a method of studying the heat transfer between the valve and the seat using a thermal contact conductance. Also, the internal exhaust valve configuration using the FEM system has been refined by Soni et al. [7]. The study designs an exhaust valve that can increase the heat transfer rate to the valve seat through CFD software analysis. Analysis of the internal combustion engine in terms of unsteady heat transfer by Cerdoun et al.[8] also leads to the interpretation of similar tests of the exhaust valve. The authors have clearly stated that the engine's high temperature can cause severe damage to the valve. The research issue regarding the heat transfer of the valve and its seat is still increasing the interest among automotive research. This study aims to elucidate a steady-state thermal analysis of the valve and the valve seats in terms of thermal behavior and thermal flux characteristics.

2. Steady-state thermal methodology

This research focuses on how the material influences the valve's heat distribution in the engine. Some of the methods that previous researchers have already applied, which are likely to be identical in this research subject, will be provided as guidance. Previous studies have developed a beneficial formulation that will thoroughly help solve certain conditions or undiscovered shortcomings. This study's flow process was focused primarily on simulation. The exhaust valve material remained the same for each test done, meaning that the modifications only occur on the valve's seat. For the 3D drawing of the valve and the valve seat, the 2D drawing provided by MODENAS Research and Development team serves as a guide. Then for simulation purposes, the 3D drawing was generated by CATIA and converted to an ANSYS file. Since there was no trouble importing geometry from the external file source, the simulation process will be smooth.

After that, two simulation techniques are used to examine the specimens. A manual contact area (pinball) and a couple of temperatures between adjacent faces are two ways of describing thermal contact. The manual contact region method is used to define the sides in face-to-face contact. Then by choosing the body that has been exposed to a high heat concentration, the thermal contact area is specified to become a contact body, while the other face body becomes a target body. Finally, the last step is to determine the pinball radius to encompass the general area. In monitoring the transfer of heat through the gap, the pinball plays a significant role.

Meanwhile, the temperatures between the adjacent surfaces, contact surface, and the bodies' outer surface were established for the second technique. Plus, two faces that contact one another are combined. The data obtained by simulation was plotted and interpreted. To produce the best outcomes, the data obtained from the simulation was plotted and analyzed. For steady-state operation, the thermal equivalent circuit formulation is used. This equation is known as the thermal resistance of heat conduction.

2.1 Modeling technique

For modeling techniques, a 3D model for the exhaust valve, valve seat, and part of the engine cylinder head is constructed. Thermal analysis is conducted to achieve the temperature variations and heat transfer between the products after passing the drawing into the computational fluid software, ANSYS. In the heat transfer simulation between the valve and the valve seat, one table consists of input data for parameter data to be built for the analysis. As shown below, table 1 reflects the input data.
Table 1. Parameters for ANSYS steady-state thermal simulation.

| Parameter                  | Type/Unit                  |
|----------------------------|----------------------------|
| Type of heat analysis      | Steady-state thermal       |
| Mesh type                  | Tetrahedral element (non-uniform pattern) |
| Number of element          | 373386 unit                |
| Element size               | 1.34e003                   |
| Number of maximum iteration| 10000                      |

The existing valve and valve seat material are derived directly from the ANSYS 17.1 material database for material / thermal properties. The data for the material / thermal properties of the seat of the valve is also accurate. The ANSYS simulation sequence is begun by choosing a form of analysis, and steady-state thermal is used in this scenario. Then, the material type is specified for the valve and the seat of the valve. Following the Table 1 parameter, meshing and iteration are done after both components are identified.

2.2 Modeling work for steady-state thermal simulation

There are two ways the thermal contact between two different bodies can be calculated. One is with a manual connection that could work through a distance like the geometry provided, even if the pinball application was large enough for heat transfer. Another strategy that may be added will be to couple the temperatures between adjacent faces on the valve and valve seat, which would allow two faces to hold the same temperature values. Setup for the first and second body temperatures. Specifically, the first body is 800°C on the valve head, and the other side is from 100°C to 200°C on the outer surface of the cylinder head. This is also regarded as a boundary condition that must be established by prior study. Figure 1 adopted the first procedure, where both the exhaust valve and the valve's seat are coupled.

![Figure 1. Coupling method between contact surface.](image)

The pinball was used to define the heat transfer region around the contact surface for the bonded form. After that, the primary goal of produces a pinball around the touch surface is done. The pinball radius must be greater than the distance between two surfaces, such that the pinball can span the gap so that heat flow across the rounded region is obtained from the contact surface. The pinball example is seen in figure 2.
3. Results and discussions

This simulation is carried out only as a preliminary result. The valve seat material’s action on the engine cylinder’s heat disruption is analysed in this situation. Simulation is done on both coupling and pinball techniques, as defined in the methodology. Both strategies emphasise the relationship between the valve and the valve’s seat when the valve is closed at the exhaust port. The heat transfer analysis between two contact surfaces between the valve and the valve seat applies to this relationship.

![Figure 2. Pinball method on the contact surface.](image)

![Figure 3. Temperature distribution of sintered metal valve seat with the partial engine cylinder head.](image)
Figure 3 depicts the temperature distribution of the valve seat on sintered metal. The mean temperature is 800°C, while 108.4°C is the lowest temperature. Before the engine runs, the temperature of 22°C corresponds to the initial temperature of the outside surface of the engine. The temperature contour is marginally yellow with partly green and light blue, according to figure 3. The valve seat then offers a temperature contour that is somewhat yellow and green. Therefore, the cast iron valve seat displays a sluggish heat absorbance rate depending on the temperature contour’s outcome. For any copper-based material, good heat absorbance characteristics of the valve seat have such a contour that defines the heat conductivity. The heat flux effect in figure 4 and figure 5 shows that the heat flow from the valve seat’s surface is in the tangent direction. It also illustrates that the heat...
flows equally around the valve while some heat dissipates to its seat. As stated in the previous study, the optimum temperature must be at the combustion surface located at the valve head part.

4. Conclusions
In conclusion, using thermal analysis, heat absorption from the valve seat to the engine cylinder head can be elucidated. The research purpose was accomplished, employing steady-state thermal analysis to explain the thermal behaviour and thermal flux properties of the valve seat. The result obtained has been demonstrated to be important in deciding the heat transfer between the exhaust valve and the valve seat elements. Therefore, in future testing, the engine’s efficiency is improved by using the valve seat’s high thermal conductivity. Heat transfer research using computational fluid dynamics simulation brought importance to the thermal conductivity between the valve, the valve seat, and the engine cylinder heads. The result obtained will serve as the preliminary result due to the constraint of multiple data, which will be confirmed in future research.

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Acknowledgement
The author would like to acknowledge the support from the Fundamental Research Grant Scheme (FRGS) under a grant number of FRGS/1/2020/TK0/UNIMAP/02/97 from the Ministry of Education Malaysia. Thanks to the Research and Development team at MODENAS, who assisted the author in sharing the expertise. Under the UniMAP Motorsport Technology Research Unit (MOTECH) supervision and the university itself, Universiti Malaysia Perlis, the author would like to thank all the lecturers, postgraduate students, and team members who provided valuable advice. All your tender kindness is so appreciated.