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INVESTIGATION ON TEMPERATURE PROFILES OF PISTON USING LOW COST BURNER RIG

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ABSTRACT

Engines like a compressed natural gas with direct injection system (CNGDI) and diesel engine (heavy duty and marine transportation) have a tendency to produce extreme temperature level which may lead to high thermal stress. Inappropriate heat transfer will cause the pistons fail to operate effectively. In order to imitate the condition of high temperature like in a combustion chamber, burner rig is developed to obtain the steady-state temperature profiles. In this work, a low-cost burner rig is developed as preparation to determine the heat transfer mechanism of piston instead of using real engine. The function ability of the end-product burner rig will be evaluated to ensure its quality. Piston samples were tested using the rig and shows different temperature at various region of piston compared to the steady-state temperature on the piston crown.

Keywords: burner rig; low cost; temperature difference; piston; heat transfer.

INTRODUCTION

The generation of extremely high temperature and pressure from an engine such as CNGDI and diesel engine with high compression ratio will lead to high thermal stress. This may contribute to piston failure. Previous researches have proved that the temperature plays a significant effect on the piston. Heat transfer is a very important criterion as its mechanism directly affects the performance of the engine, either by increasing the consumption of fuel or the exhaust emissions. The lifespan of the main engine components which are directly operating within high temperature range is affected. If the components cannot withstand the rate of heat transfer inside the engine components especially during the high temperature process such as during the combustion process for the components like the piston and cylinder head, the components will start to fail to operate effectively and will also lead to the damage of the components themselves mainly due to the fatigue failure, the creep or the crack that will occur on the components. The thermal deformation and mechanical deformation will cause piston cracks and fatigue. Therefore, it is essential to reduce the stress field, temperature field, heat transfer, thermal load and mechanical load coupling of piston in order to lower the heat load and improve the thermal stress distribution and also improve its working reliability during the piston designed (Silva, 2004; Jankowski, 2010; D'Silva *et al.*, 2013; Kuppast *et al.*, 2013).

The ongoing exposure of heat onto the piston crown, will resulted in piston failure. The high stress as the effect of the exposure to high temperatures of the combustion resulted in the melting of the piston crown and the ring zone. The piston crown melted as the glow ignition on pistons with mostly flat crowns and larger quenching area. The piston crown heated up significantly due to the glow ignition. The temperature reached the values which made the pistons went soft. So, by developing this burner rig, the temperature of the combustion process could be controlled in order to test the thermal properties of the piston.

Burner rig is used to force hot spots, and can avoid edge effect damages. It also can allow internal cooling. It may also expose specimens to relatively high gas velocity, which may be important when volatility is an issue and to inject salt contaminants. Other else, the heat specimens relatively rapidly so that short-duration cycle durability representative of subsonic engine take off and climb can be investigated. Somehow, this burner rig has higher heating and cooling rates than the furnaces, but they are significantly less than in the engine. Commonly, the most problems in the burner rig include in difficulties to measure the temperature (Miller 1997).

In the same year, Yonushonis applied heat to the panels through the use of small propane torches mounted on a ring that surrounded the base flat-plate substrates. At the backsides of the substrates, a thermocouple was placed provided the processing temperature and allowed for manual adjustment of the propane to maintain desired pre-stress temperature through the spray run. The rig thermal cycle was targeted to achieve a maximum surface temperature of approximately 675 to 730°C, and the maximum thermal gradient across the substrates is 480 to 537°C at a 7s time point into the cycle.

ARPN Journal of Engineering and Applied Sciences

Another research was done where a thermal shock rig was used to choose the best top coat material consists the rotating wheel with eight positions which are four are heated with a burner flame and the other four cooled with compressed air on the back side. The wheel is recorded to achieve 75s on the hot station and 75s on the cold position. With a proper burner gas flow adjustment within the time, the surface temperature may achieve 1100°C on the hot side. The backside was kept 450°C by cold air coolers. (Tricoire *et al*., 2009).

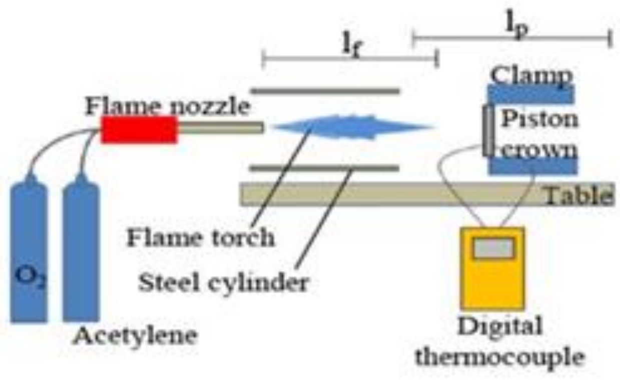

Figure-1. Experimental apparatus of horizontal burner rig (Helmisyah *et al*., 2011).

Meanwhile, a simple horizontal burner rig was developed by Helmisyah *et al*. (2011) to test the function of piston crown samples with and without coating as in Figure-1. The top part of the piston crown was heated and burnt by oxy-acetylene flame at a range of temperature up to 900℃. The temperature that was heated by the flame may be imitating the real temperature that was produced in the engine during combustion process.

The temperature was controlled by adjusting the distance of the flame source with the piston. The farther the distance of the flame from the piston, the lower the temperature produced on the piston crown surface. According to this experiment, the flame source was positioned in front of the piston crown so that the heat was directly targeted towards the piston crown. A steel cylinder is positioned around the flame produced to prevent flame disturbance from other source such as the wind; which might disturb the direction and the flow of the flame. As a result, the flame would not produce the desired temperature on the piston surface and the temperature produced is not stable. Next to the piston is hold by a set of clamp to make sure that it is not moving and no vibration during the combustion process. Any unnecessary movement might disturb the temperature reading of the piston for thermal distribution profile. The piston crown sample was also positioned where it just had minimal contact with the flame. Thermocouple was used to measure and record the surface temperature of the piston crown. The probe with K-type (chromel-alumel) was attached on the piston crown surface and the backside of the piston crown.

METHODOLOGY

Burner Rig Design

The burner rig is able to imitate the condition required for piston testing which in this case the temperature of the piston, especially the piston crown part during combustion process. In this research, a low-cost burner rig is developed to determine the optimum position of thermocouple in order to obtain localized temperature and heat transfer mechanism. As for the final outcome, the burner rig is tested for its function ability.

The material for building the case of the rig consists of mostly mild steel. This is because mild steel is well known to be weld-able and it can withstand a very high temperature without melting. As for the system inside the burner rig, they are mainly consist of heating system, cooling system and data acquisition system to measure the temperature on the piston surface during the combustion process. As a heating system, the source of heat from the oxy-acetylene is used. In oxy acetylene, pure oxygen is used, instead of air to increase the flame temperature. So, in this system, acetylene acts as the fuel whereby the oxygen is chemically combined with acetylene as the fuel source to produce the heat. The piston is heated by the flame to a desired temperature which is a condition to imitate the temperature of real combustion process inside the combustion chamber.

Cooling system is very much important as to control and maintain the temperature so that the desired temperature will be stable and maintained so that the temperature will be in the desired range. There are two main components in the cooling system for the engine piston which is the oil cooling system and the water cooling system. The oil cooling system is the one that is directly in contact with the piston surface while for the water cooling system; a medium of heat transfer that is in contact or being subjected to the outer wall of the cylinder which holds the piston. For this burner rig, the water system consists of the pump which pumps the water to the box where the piston is situated during the heating process. Lastly, for the temperature measurement system for the burner rig, thermocouples are used in order to record the temperature measurement obtained as the result of the heating process. Specifically, K-type thermocouple is used to measure the temperature. A K-type thermocouple is able to withstand the temperature up to 1300°C which is very suitable to be used with the desired temperature for the piston.

As to determine the optimum position of the thermocouple, up to 10 K-type wired thermocouples are attached to several hot spots positions on the piston surface. The results obtained from the temperature reading are the factors to determine which position is the most and

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least important. The position of placement which is near to each other will be avoided and only the part with different part on the surface of the piston, such as the piston crown, side of the piston, and the inner side of piston skirt.

Experimental Setup

In this experiment, a similar setup of the burner rig was developed but with several improvements. The setup of the burner rig was determined in either horizontal or vertical position. For a horizontal position, the direction of the flame was horizontal with the position of the piston crown. As for the vertical position, the flame was vertically positioned above the piston sample. This setup was done to test its effectiveness whether the flame directed to the piston could distribute heat more uniformly either in a horizontal or in a vertical position. Finally the vertical position was chosen as to make sure that the flame is facing downwards directed towards the top of the piston.

As for the piston, the improvement for the imitation of the real engine during the combustion inside the burner rig, a cooling system was introduced to the burner rig. A combination of oil and water jacket or any one of the fluid was introduced to be the cooling agent for the piston during the burning process. By the implementation of the cooling system inside the burner rig, it might improve the efficiency of the experiment that was to be conducted by using that burner rig. There were three main systems that were used in this burner rig which were heating system, cooling system and temperature measurement system.

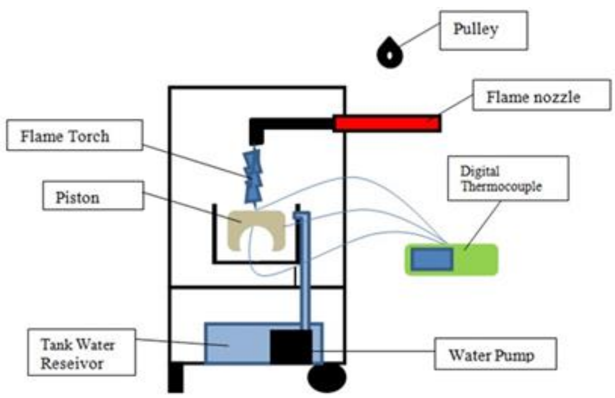

Figure-2. Experimental setup of rig test.

The heat supply was the most important part in developing this low-cost burner rig. This was because; the heat supply was needed to increase the temperature of the sample up at the range of 400-700°C to imitate the combustion process in the real engine. So, proper selection of the source of heat to be supplied was compulsory. Several ideas were proposed to be used as the source of the heat such as Bunsen burner, cooking stove, camping stove, oxy-acetylene and lastly by using electrical circuit with lemon to produce heat. The oxy-acetylene was chosen as the heat source. The piston head were compulsory to be positioned facing the flame as the heat source because in real working engines during combustion process, the combustion happened on the top of the piston head surface, which produced the highest temperature on the surface of the piston crown.

Figure-2 shows the set up for the burner rig in this research. First of all, the burner rig consisted of two main casings which were the upper casing and the lower casing. The upper casing was where the heating process took place and to cover from wind disturbance. The piston was placed inside a box at the bottom side. On the other hand, the lower part placed the tank water reservoir which acted as the storage area of the water that was pumped as water jacket around the piston and as storage for the water that was transferred from the water jacket.

The flame from the torch acted as the heating medium. The flame caused the increase in temperature. To get the desired temperature, the distance of the flame was adjusted from the piston surface. Theoretically, the nearer the distance the higher the temperature produced. To adjust the distance, the height of the flame nozzle was set of by a chain attached to the pulley which was pulled or released to get the desired height. Simultaneously, the water jacket cooling system was operated together with the heating process. As the piston was being heated, the water was pumped to the box which contained the piston. The water flew inside the box and, theoretically it would be discharged at the other side of the box. The discharged water flew back into the tank water reservoir and the process operated continuously during the heating process.

Next, for the temperature measurement system, several thermocouples integrated with data logger were used to measure the temperature on the piston surface as shown in Figure-3. The thermocouple used was from K-type thermocouple. This K-type consisted of Chromel (90% nickel and 10% chromium) and Alumel (95% nickel, 2% manganese, 2% aluminium and 1% silicon). K-type thermocouples are capable to record the temperature up to 1300°C. The thermocouples were assembled at several critical points on the piston surfaces which were at the top center of the piston crown, (1) the edge of piston crown, (2) the piston skirts and (3) the wall inside the piston behind the piston skirts, and (4) the surface under the piston crown,. The water for the cooling system was pumped by the Astro Liquid Filter from the water container that was situated under the casing of the burner rig.

ARPN Journal of Engineering and Applied Sciences

Figure-3. Thermocouple attached to the piston surface using steel epoxy.

As a comparison, the value of temperature difference between the piston crown and the underside of piston crown namely Piston A were evaluated with data from experimental works by Helmisyah *et al*. (2011) for its uncoated piston as Piston B. For reference, both pistons have different thicknesses which are approximately 8.5 mm and 11.0 mm respectively.

RESULTS AND DISCUSSIONS

Modification and improvement of the current design were very important to ensure that the fabricated design was able to function and operated according to the better and more reliable operating condition. For this development of burner rig for engine piston, several major modifications had been done in order to produce a better design.

The first fabricated design for the attachment and placement of the oxy-acetylene torch were set to control the height whether or not to increase or decrease by inserting the torch in a plate that was connected with the two vertical cylindrical hollow rods that were situated in the inner of both left and right side inside the casing of the burner rig. Later, the design was rejected as it was observed that during the heating process, the temperature produced was very high and the casing as well as the cylindrical rod was affected by the high temperature and as a result, the rod itself was very hot. It was impossible to manage and adjust the height of the torch from the piston during the heating process due to the high temperature produced. Re-adjustment was done and the lifting system for the casing of had been introduced by using the pulley system. In this pulley system, the oxy-acetylene torch was placed inside a casing of length 30cm with width of 8cm. The casing was lifted using a rope that was attached to the pulley. So, from this design, the torch was able to move by pulling or releasing the pulley until it was positioned on the desired height.

Next, during the testing process, it was observed that the height of the casing and the distance of the nozzle of the torch did not have significant role in determining the temperature of the flame produced to heat the piston surface. The temperature was still increasing and reaching the desired value, but it was only a matter of time for the heat to achieve the desired temperature. The lower the flame near to the piston surface, the faster the temperature increased and obtained the desired temperature in a shorter time compared to the flame with farther distance to the piston surface. In this case, the pressure level of oxy-acetylene is required in order to obtain desired surface temperature on piston crown as an imitation during combustion process. The time needed to heat the piston was not a major determinant in this study, so the concept of lifting and adjusting the height of the casing of the torch was not very reasonable. So, the current design for the casing was readjusted to stay fix at a certain level. The casing stayed permanently at a selected height and for the testing purposes, the torch produced flame and the selected position and by far, the result of temperature reading was obtained through time. Figure-4 below shows the design and position of the casing after the final modification process on that part.

For the third major modifications that was applied onto this fabrication of the burner rig was to adjust the method of attaching the thermocouple probe onto the piston surface. Initially, the probe was installed on the selected positions on the surface by using steel epoxy. This steel epoxy was able to combine and bind two steel surfaces together. Unfortunately, the limitations of the epoxy were needed to spend about 5 hours to cure before it reached its optimum potential. Otherwise, the binder would not be able to withstand the components and will induce to fail. So, as a solution, to produce a better solution so that the probe bound better on the piston surface, small holes were made at the selected positions of the thermocouples. The probe was inserted into the holes and the end was attached by the steel epoxy mixture.

Finally, the fabricated burner rig was tested for its function ability. Several conventional aluminium alloy pistons which attached with five thermocouples was placed in the stage box inside the rig case. The piston was heated using the flame form the oxy-acetylene torch. At first, the pressure from the oxygen and acetylene was kept constant with the same pressure at 1:1 ratio during the heating process. Any excess ratio of the oxygen caused the flame to change its properties and changed to cutting mode. So, if there was more amount of oxygen compared to the amount of acetylene used, the flame would not only heat the piston but also cut the piston.

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Figure-4. Final setup of rig test.

The piston was placed inside the box of 10cm x 10cm. From the figure, the position of the piston was at the end of the flame. The flame came only from the acetylene. No oxygen was still released in that form of flame. When the valve for the oxygen was released slowly, the flame turned into blue and it was the result of the amount of acetylene released correlated with the amount of the oxygen released.

The torch needed to be set to be directing towards the center of the piston crown so that the temperature profile distributions recorded on the piston surface were uniformed.

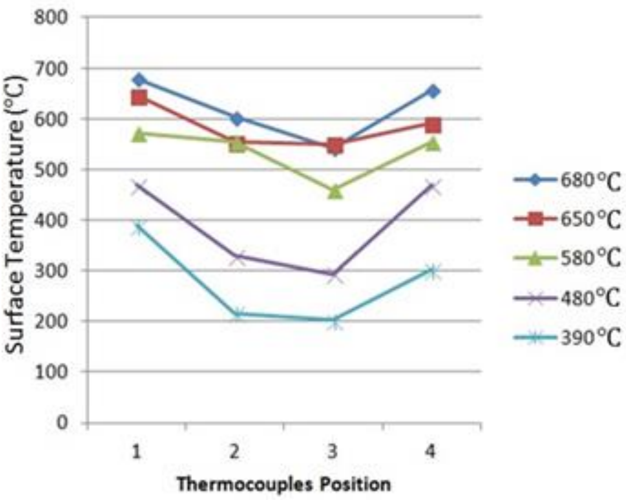

Figure-5. Surface temperatures on different thermocouple positions.

Figure-5 shows the surface temperatures of four different positions of the thermocouples on the piston surface during five readings of the temperature of piston crown surface. The highest temperature of piston crown recorded by the thermocouple during the heating process was at 680°C. From the temperature of 680°C onwards, the piston started to melt and the heating process were stopped.

Several positions of thermocouple were attached on the piston surfaces which were on the piston crown surface, surface at the edge of the piston crown, piston skirts, and surface behind the pistons skirts, and surface under the piston crown. Other positions such as at the ring grooves were also important but only a minor temperature difference was observed at a position nearby, particularly at the piston skirts. After confirming the selected positions for the placement of the thermocouples, the next process was installing the thermocouple probe onto the selected surface.

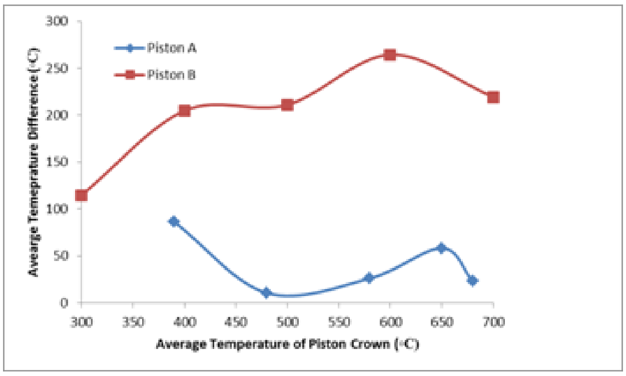

Figure-6. Average temperature differences of two types of piston types of piston

The melting piston did not prevent the K-type thermocouple from continuing recording the temperature on the selected position of the piston surfaces, but it was not reasonable to continue the process as the melting piston was considered failed. Obviously, position 1 which is at the edge of piston crown, contributes to the highest surface temperature for every crown temperature since it is the nearest region to the heat source. While position 3 which is the region of behind piston skirt gets the lowest value of surface temperature because of far distance region and assisted the most by cooling system.

Figure-6 shows the plotted average temperature differences of two types of piston (for comparison purpose). An experiment of the different types of piston crowns showed an increasing temperature trend was different especially during the early temperature. This is due to the thickness of the piston which is Piston B is thicker than Piston A about 15.9%. Heat can spread uniformly through the piston B while piston A showed the great resistance to transfer the heat.

CONCLUSIONS

This study is conducted to develop a low cost burner rig for engine piston. This end product of this study which is the burner rig might be able to be used in evaluating the effect of steady-state temperature specifically on a piston during the combustion process in an engine. From the results, the fabricated burner rig is able to measure the temperature on several critical region of the piston. As comparison to combustion process, the burner rig system's heating process may replace the combustion process. Both combustion and heating process in burner rig produce heat source that increases the heat of the piston surface. This could be a great contribution in obtaining temperature difference profile for heat transfer rate calculation using low cost equipment.

As to determine the optimum position of the thermocouple in order to measure and obtain the localized temperature and the heat transfer mechanism, the thermocouple probes itself are placed in several critical positions on the piston surface. As such, the positions include the top of the piston crown surface, the edge of the piston crown, piston skirts, surface behind piston skirts, and underside the piston crown.

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