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Cooling of Motorcyclist Helmet with Thermoelectric Module

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Abstract: This paper deals with the development of cooling system for motorcycle helmet using thermoelectric technology. The system consists mainly of a heat sink and thermoelectric module. When electrical voltage is applied to the thermoelectric module, it will create a temperature difference across the thermoelectric module. This phenomenon is also known as Peltier effect, is being used to utilize electricity to pump heat. The prototype had been fabricated and mounted onto a motorcycle helmet. The designed thermoelectric cooled helmet was simulated using the finite element software ANSYS as well as experimentally tested for the cooling purpose. Experiments are conducted on the prototype to analyze the performance of the cooling system. The numerical and experimental results showed a good agreement and indicated that the temperature inside the helmet was reduced from 25.5°C to 19.3°C in approximately 6 min.

Key words: Missing

INTRODUCTION

The concern over the safety of vehicle drivers has pushed for invention of new equipment that can save lives. The continuous development of the automotive industries has revolutionized new invention, not only for the safety, but also comfort has been put into the picture. Nowadays, everything is made by evaluating the comfort of the user. Motorcyclists are among the major road users. The primary safety feature used by the latters is a hard shell helmet made of hard material with a thick foam material inside it. This poly-foam liner serves as the shock absorber to support the head during collision. Unfortunately, Since the equipment has been made compulsory to be worn, the user must endure the uncomforting causes by the device. Indeed, the liner has high heat insulation properties which results in low heat transfer between the head and the outside air. This creates an uncomfortable and dangerous environment to the head, especially for long distance travel in hot conditions. Carpenter [1] observed that the temperature in the helmet during such conditions may reach 38°C. In this temperature, it is very dangerous to travel due to a decrease in the ability to concentrate. Therefore, keeping a motorcycle rider cool during transit has been at the forefront of helmet design considerations for many years.

There are several types of cooling systems applied to helmets in order to maintain a comfortable temperature. The most common and obvious solution is a system of air intakes and rear extractors that allow air flow to circulate around the rider's head based on the principal of heat transfer via forced convection. However, the meaning of ventilation is slightly insensible and the system does not provide enough circulation to the rider [2]. Tan and Fok [3] presented a helmet cooling system design using phase change material (PCM) to absorb and store the heat produced by the wearer's head so as to achieve cooling comfort for the wearer. The PCM is packed into a pouch and placed between the helmet and the wearer's head. The heat from the wearer's head is transferred to the PCM by conduction through a heat collector which is spread over the wearer's head. The cooling unit is able to provide cooling comfort for up to 2 hours when the PCM is completely melted. The stored heat from the PCM pouch would then have to be discharged by immersing it in water for about 15 minutes to solidify the PCM before re-use. As a result, this solution would be ineffective for long

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rides. Buist and Streitwieser [4] developed a thermoelectrically cooled helmet consisting of a thermoelectrically cooled liquid filled cushion, that lined the top interior of a safety helmet. They used a single, 12-volt thermoelectric module to remove heat from the liquid cushion through a flexible braided wire heat collector located within the cushion. Heat is exhausted to ambient through an outboard heat sink; a finned aluminum radiator. Movement of the helmet produces a forced convection heat dissipation effect in the radiator and effectively removes the waste heat. The biggest flaw of this design is that, in the case of a significant impact, the cushion could simply burst and the rider's head could then come into direct contact with the copper inside the helmet.

Since the designs described in the above review have failed to provide a complete solution, this study aims to design and build an air conditioned motorcycle helmet that is capable of effectively cooling the rider's head while keeping a close eye on the effectiveness, the safety and the cost of the newly developed helmet.

Background on Thermoelectricity: The thermoelectric effect is the direct conversion of temperature differences into electric voltage and vice versa. It performs the same cooling function as absorption refrigerators. In all such units, thermal energy is extracted from a region, thereby reducing its temperature and then rejected to a "heat sink" region of higher temperature.

A thermoelectric device creates a voltage when there is a different temperature on each side (Seebeck effect). Conversely, when a voltage is applied to it, it creates a temperature difference (Peltier effect). This effect can be used to generate electricity, to measure temperature, to cool objects, or to heat them or cook them. Because the direction of heating and cooling is determined by the sign of the applied voltage, thermoelectric devices make very convenient temperature controllers.

In a thermoelectric analysis the equations of heat flow

$$r\,C\,{}^{dT}\!/_{dt} + \nabla\cdot\mathbf{q} = \dot{q} \tag{1}$$

and of continuity of electric charge

$$\nabla\cdot\left(\mathbf{J} + {}^{dD}\!/_{dt}\right) = 0 \tag{2}$$

are coupled by the set of thermoelectric constitutive equations.

$$\mathbf{q} = [\Pi]\cdot\mathbf{J} - [\,l\,]\cdot\nabla T.\;\; J = [\,s\,]\cdot\left(E - [\,a\,]\cdot\nabla T\right)\cdot \tag{3}$$

and the constitutive equation for a dielectric medium

$$\mathbf{D} = [\,e\,]\cdot\mathbf{E} \tag{4}$$

where D denotes the material density, *C* the specific heat capacity, *T* the absolute temperature, q the heat flux, $\dot{q}$ the heat generation rate per unit volume, J the electric current density vector, E the electric field intensity vector, D the electric flux density, 8 the thermal conductivity, F the electrical conductivity, a the Seebeck coefficient, A the Peltier coefficient and , the dielectric permittivity. denotes a matrix.

In the absence of time-varying magnetic fields, the electric field E is irrotational $(\nabla\times\mathbf{E}=0)$ and can be derived from an electric scalar potential n:1

$$\mathbf{E} = -\nabla f \tag{5}$$

Substitution into the first two equations produces a system of coupled equations of thermoelectricity

$$r\,C\,{}^{\partial T}\!/_{\partial t} + \nabla\cdot\left([\Pi]\cdot J\right) - \nabla\cdot\left([\,l\,]\cdot\nabla T\right) = \dot{q} \tag{6}$$

$$\nabla\cdot\left([\,e\,]\cdot\nabla\,{}^{\partial T}\!/_{\partial t}\right) + \nabla\cdot\left([\,s\,]\cdot[\,a\,]\cdot\nabla T\right) + \nabla\cdot\left([\,s\,]\cdot\nabla f\right) = 0 \tag{7}$$

where the heat generation term $\dot{q}$ includes the electric power *J.E* spent on Joule heating and on work against the Seebeck field $[a]\nabla T$. Note that the displacement current ${}^{\partial D}\!/_{\partial t}$ associated with the capacitive effects has been included in the system of equations for completeness, even though it may not play a significant role in thermoelectric applications unless fast transient processes are considered.

MATERIALS AND METHODS

The major components of the air conditioned thermoelectric helmet include: aluminum pipe as outside/inside air channel, cooling chamber, electric fan as an air pump, the thermoelectric module, heat sink with built-in electric fan and lithium polymer batteries. The electrical power was supplied to the thermoelectric helmet by means of a 12 V battery. In addition, by using a chamber, the cool air can be transferred to the rider's head directly without losing the air into the surroundings (internally). The chamber is also equipped with a small fan to circulate the air in the chamber and then transfer it to the rider’s head via an aluminum pipe connecting from the chamber. The aluminum cooling pipe is similar to that used in normal air conditioning applications. The heat sink was used to enhance and increase the rate of heat transfer from the hot surface of the thermoelectric module so that the heat will be discarded outside the helmet. In order to maintain the efficiency of the thermal module, a cooling fan was used to reject the heat from the hot side of the module to ambient surroundings. The total weight of the new helmet, including the fan and heat sink, was estimated to be 1.963 kg (additional 22.7% to the original weight). Since the accepted average helmet weight for adults is 2.0 kg [5], the helmet weight is considered to be within standards.

Aluminum Pipe as Outside/inside Air Channel: The double effect pipe is used normally to force the air flow to feed in and out of the chamber directly (Figure 1). The double aluminum pipe works as a passageway for air to flow from outside, directly into the helmet. The pipe is installed at the front part of the helmet and it will directly connect to the cooling chamber, where the thermoelectric module is installed. The pipe is able to supply considerable amount of flowing air from outside the helmet during high speed travel. A high speed flowing air will enter the cooling chamber in the helmet via the pipes and help to increase the spreading of cooling air directly into the helmet. Basically, the air from the outside will push the air in the chamber into the helmet with a help of rotating fan. Thus, a higher cooling rate will be achieved.

Cooling Chamber: The cooling chamber is directly attached to aluminum pipe for direct air supply from outside (Figure 2). The chamber is built with a built-in thermoelectric cooler for cooling purpose. It acts as medium of heat transfer where outside air will be cooled and then directly transferred into the helmet. The chamber is built to provide enough space for air to be cooled and pumped-in using small electric fan. The fan will be installed on the open space of the chamber (refer fig.) thus extracted cooled air from the chamber, right into the helmet.

Electric Fan as an Air Pump: The use of the fan is very important in this design. The fan works as the pump for transferring cooled air from the cooling chamber into the helmet. The Fan also included in the design for air distribution purposes. The fan will be installed on top of

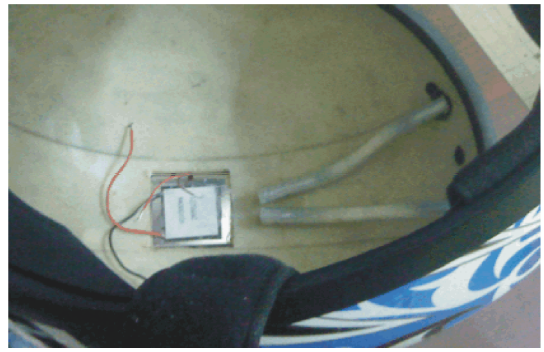


Fig. 1: Double aluminum pipe passageway

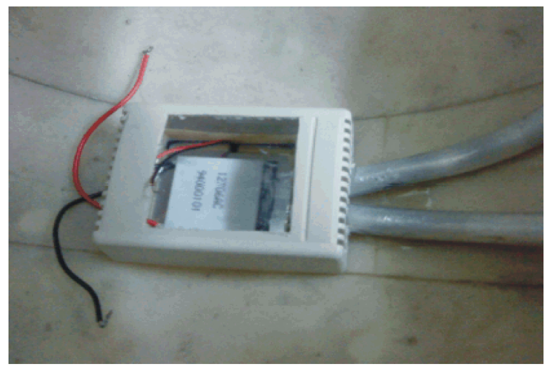


Fig. 2: Alimunum pipe and cooling chamber

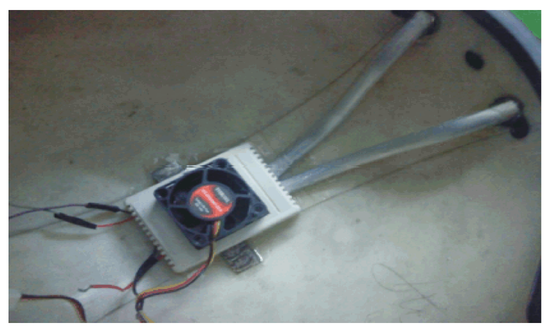
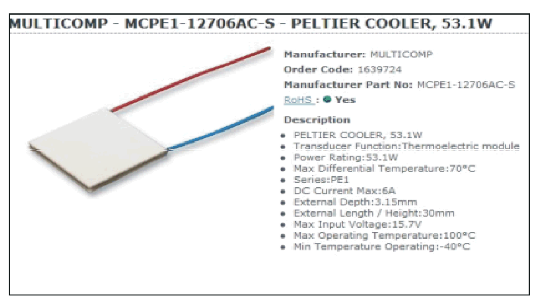


Fig. 3: Internal fan



MULTICOMP - MCPE1-12706AC-S - PELTIER COOLER, 53.1W

Manufacturer: MULTICOMP
Order Code: 1639724
Manufacturer Part No: MCPE1-12706AC-S
RoHS : Yes

Description

- PELTIER COOLER, 53.1W
- Transducer Function:Thermoelectric module
- Power Rating:53.1W
- Max Differential Temperature:70°C
- Series:PE1
- DC Current Max:6A
- External Depth:3.15mm
- External Length / Height:30mm
- Max Input Voltage:15.7V
- Max Operating Temperature:100°C
- Min Temperature Operating:-40°C

Fig. 4: Thermoelectric module

the cooling chamber and acts as an electric pump that supply cooled air (Figure 3). The fan is designed with dimension of 40mm in height. A higher dimension of fan

Fig. 5: Bottom view of helmet

Fig. 6: Battery compartment

Fig. 7: Li-po rechargable batteries

Fig. 8: Newly design helmet

is needed in order for the design to have closed space of air transfer, between the cooling chamber and protective foam of the helmet to avoid cool air leak. A square hole was made on top of the foam to accommodate the size of the fan and this hole will act as a channel to transfer the air, directly into the helmet. The 12V dc fan will have the same source of power as the thermoelectric module and is connected into a parallel circuit with the latter.

Thermoelectric Cooling Module: The installed thermoelectric has a size of 31.5mm x 30mm. Figure 4 shows the specification of the thermoelectric used in this design.

As mentioned before, both thermoelectric module and internal electric fan is powered using the same external 12-15 volt DC voltage. The power will be supplied using the power cable which is connected to the helmet by means of small hole at the back of the helmet. (Figure 5). The male/female plug and socket is connected at the back of the helmet to provide more comfort during travel.

Heat Sink with Built-in Electric Fan: The function of the heat sink is to dissipate heat generated by the thermoelectric module. The material used for this type of heat sink is aluminum having a thermal conductivity k = 170W/m, density ñ = 2707 kg/m^3 and specific heat c = 870 J/Kg.K. The size of the heat sink must be appropriate to the designed helmet.

At first, the fan is supplied with exterior source of power which uses normal 9V of dc voltage square battery. Later, it is decided that new sources of power is needed and utilization of rechargeable battery is adopted (Figure 6).

Lithium Polymer Battery: In order to cope with the relatively high power needed by the components in the helmets, two 12V lithium polymer rechargeable batteries are used (Figure 7). One battery is installed in parallel circuit with the components and is used to power both fans used in the helmet and the other one is used for powering the thermoelectric module.

Overview of Newly Designed Helmet: The new helmet is designed to operate in high speed travel of motorcycle by utilizing a high speed air flow gained by the motorcycle (Figure 8). The air will enter the helmet via the channels that made up by double aluminum pipes that act as passageway for air to flow into the helmet. The air then will be cooled by the thermoelectric module in the cooling chamber. The cooled air is then supplied or sucked into the helmet by a high speed electrical fan which is installed in the helmet. The fan will blow the cooled air into the helmet thus providing cooling effect for the rider.

RESULT AND DISCUSTION

Simulation Results: Figure 9 shows the thermoelectric module design. The original helmet design is made according to the thermal analysis and the size of the required heat sinks. Figure 10 shows the simulated heat transfer analysis in the heat sinks using ANSYS software. It shows the minimum and maximum temperatures during operation. The result clearly shows the efficiency of the heat sink used to dissipate heat.

The temperature versus time graph in Figure 11 shows the relationship between these two parameters in the heat dissipation process. The result shows the time taken to achieve the desired cooling effects.

Experimental Testing: Thermocouples are used to detect temperature changes in the helmet. Four thermocouples are placed in the helmet in different location (Figure 12). The results are shown in Figure 13.

The obtained results show that the desired cooling temperature has only been achieved up to the point where the cold air exits the chamber. So, it can be concluded that the problem lies in the pipe used to transfer the air. The experiment shows that when the cold air enters the pipe, the temperature of the pipe did not change, but rather, it remained the same. This problem might be due to an unsuitable selection of pipe material and the dimensions of the flow pipe which might have a high flow friction that prevents the transfer of cold air to the rider's head. So, modifications need to be made on the flow pipe in order for it to be perfectly insulated yet be able to provide sufficient flow for the cold air in the helmet at the same time.

Field Test: The helmet is then tested on open air by wearing it while riding the motorcycle. The parameters of the field test and the results obtained are as follows: speed of travel: 70km/h, motorcycle: Yamaha Lagenda 110cc, atmospheric temperature: 40°C, duration of test: 10 minutes and the temperature inside the helmet: 25°C and the cooling effects rate: 4 (from 1-5 where 1 is considered to be poor and 5 is the best).

This test was conducted on the heli-pad location in the International Islamic University Malaysia. The result is measured using a single thermocouple and then recorded after 10 minutes.

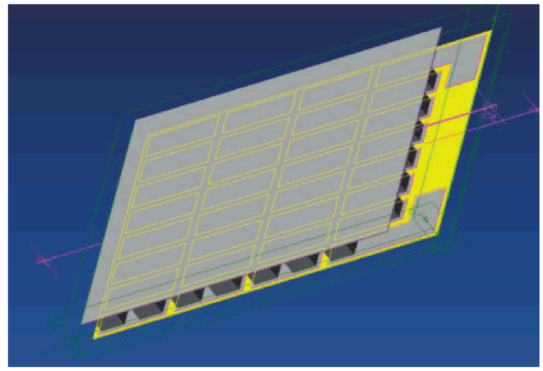


Figure 9: Thermoelectric design

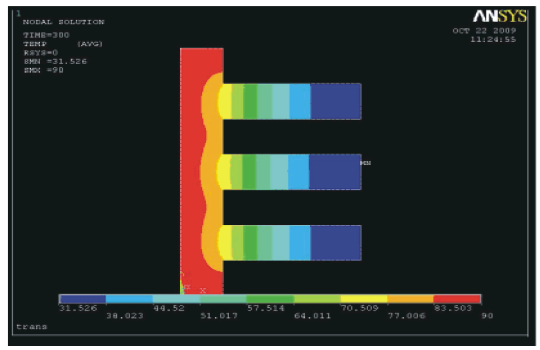


Fig. 10: Heat transient analysis of external heat sink

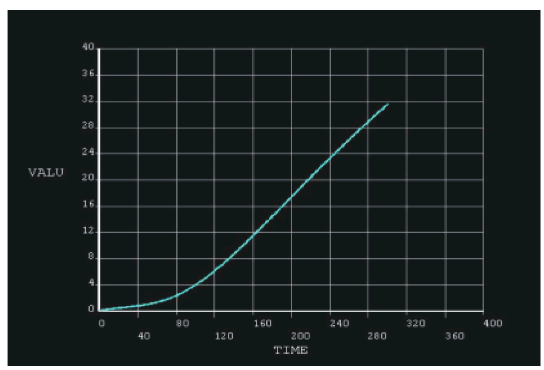


Fig. 11: Variation of external heat sink temperature (°C) vs. time (s)4

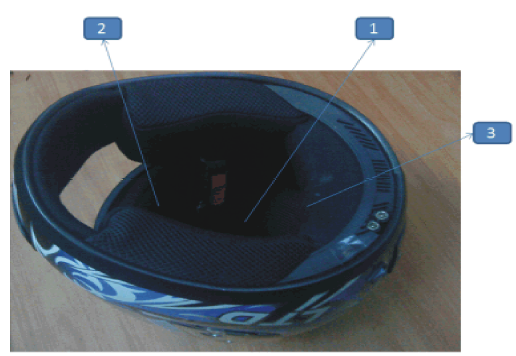


Fig. 12: Thermocouple placement point

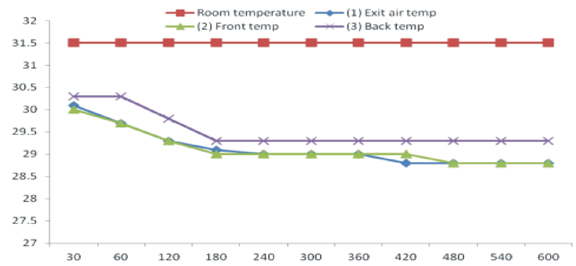


Fig. 13: Measured temperatures (°C) in the helmet as function of time (s)

DISCUSSION

From ANSYS transient thermal analysis, the results show that the thermoelectric module will be able to dissipate heat via the heat sink by achieving a cooling temperature of 25°C. This shows that the target design to cool the heat generated by thermoelectric under temperature of 30°C is successfully achieved by the heat sink. On the other hand, through experimental testing, the average temperature achieved by the heat sink surface is 27.3°C. This temperature is recorded on the outer surface of the heat sink using a thermocouple. By comparing the simulated result with the experimental one, we found that the difference is small and it can thus be concluded that the designed heat sinks are able to perform well to dissipate the heat.

After all the testing is conducted, the tabulated result shows that the helmet is able to deliver a cooling air temperature of 28°C in static condition. This result is obtained by running the helmet for 5 minutes period of time. This result is due to the static condition of the helmet and since there is no additional air flow supplied which the helmet supposedly get during traveling, the result is slightly less than expected.

The helmet is then tested by wearing it during travel. The results from field testing of the helmet show great improvements if the helmet is worn during travel. Additional mass flow rate of air from moving air is able to increase the performance of the helmet considerably. The aim to increase the mass flow rate of air by introducing aluminum pipe as air passageway or channel into the helmet is considered to be very effective and it is a good way to exploit the moving air from high speed travel of the motorcycle.

However, the new designed helmet still faced one problem which is noise from internal fan. The noise is considered not too high in volume or decibel in accordance with NVH analysis, but still for safety purpose, the noise should be eliminated for it might distract the rider.

CONCLUSION

The prototyping of a cooling system based on thermoelectricity for a motorcyclist helmet has been done. The targeted cooling performance is achieved and future improvements will be carried out to enhance the cooling performance of the design. This will include the use of a higher power thermoelectric in the future design to improve its performance. However, a problem of higher demand from the power source needs to be successfully addressed first. Furthermore, a problem of noise created by the internal fan should be addressed thoroughly and installation of a low-noise fan should be prioritized.

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