KSTLE International Journal, Vol. 7, No. 2, December 2006, pp. 56-60

A Study of Thermal Behavior in Ventilated Disk Brake

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Abstract: By the increasing amount of vehicles, the increase of car accident served as a major momentum for remind the importance of braking system. The adequate design of a passenger car braking system, which is directly related to the safety of a car, is very important since the safety is an essential design parameter of a car to keep men and car from the damage. The thermal behaviors of the ventilated disk has been investigated based on the air cooling effects during repeat braking operations. In this study, the temperature and velocity fields of 3-D unsteady simulated model are obtained using a software package "FLUENT". The numerical results show that there exits a temperature nonuniformity between the disk faces contacting with pads.

Keywords: Ventilated disk brake, ventilated hole, aspect ratio, unsteady, repeated braking

1. Introduction

The vehicles has been increased rapidly by economic development and it caused high rate of vehicle accident. This fact tells us the importance of braking system for prevent accidents. According to the industrial development, the higher speed has been required for increase amount of transports and shorten of time. By this reason the better engines were mounted for the higher speed of vehicles. But the high speed requires better brake devices in worse condition than before.

The main reason of braking system is to stop the vehicles using conversion of the kinetic energy to frictional energy. Thereupon, the disk brake system had been developed in late of 1950s, and since 1975, it has been researched that the new concept "ventilated disk brake system" which make holes at the disk brake can prevent deterioration of efficiency and, rising the cooling performance [1].

Analysis of heat velocity in unsteady state was carried out through axisymmetric analysis of rotating brake, numerical analysis had carried out to the brake equipment which mounted at the front of the vehicle, and studied the cooling of the rotating disk from flowing fluid spot [2], and also, the thermal stress distribution by analyze heat transfer in disk was researched [3]. In our country, the efficiency of air cooling effect to thermal distortion was studied [4,5] and the thermal conduct caused by repeating operation of disk brake which has ventilated hole analyzed by FEM [6,7].

The braking stability in touch-braking system which is presently used, is the spread of the frictional heating from the brake disk and pad to frictional surface homogeneously. The air convection cooling characteristic through the ventilated hole have great effect on the braking performance. When the vehicle reached to stop stat with repeating of releasing and braking, the temperature nonuniformity have effect on the strain at the disk. Therefore, in this study, planning the real braking conditions from the start of braking to the end of braking for analyze the unsteady heat transfer structure, and investigate the characteristic of temperature inside of brake.

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2. Analysis Conditions and Braking Mode

The moving vehicle can stop to use the friction on disk which cause the decrease of kinetic energy. When the braking has released during the driving, there will be have space so can stop the generate heat and the heat energy which stored at disk and pad had cooled by the air. In this paper, for concerning the air convective cooling through the ventilated hole when the moving vehicle make to stop state with repeating of braking and driving in 60 mph ,used the FLUENT program within the unsteady problem.

The brake model has 32 holes which arranged counter-clockwise with same spaces for vanishing the frictional heats from the touching surface between the disk and pad.

Figure 1 is the 3-D analysis model which shows the heating

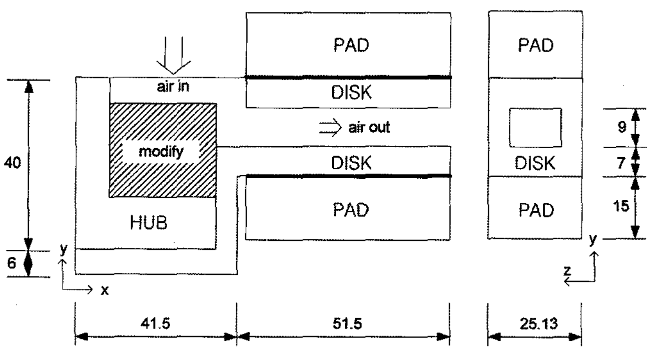
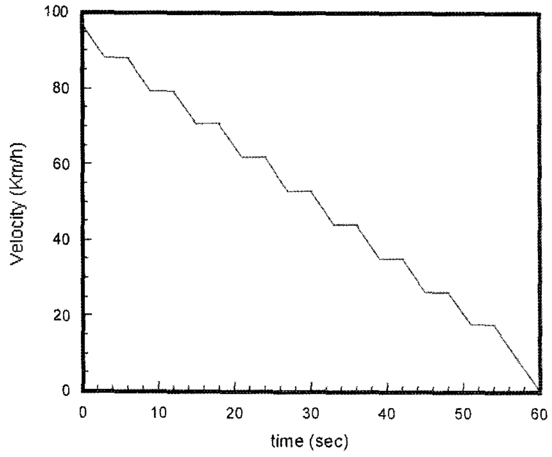
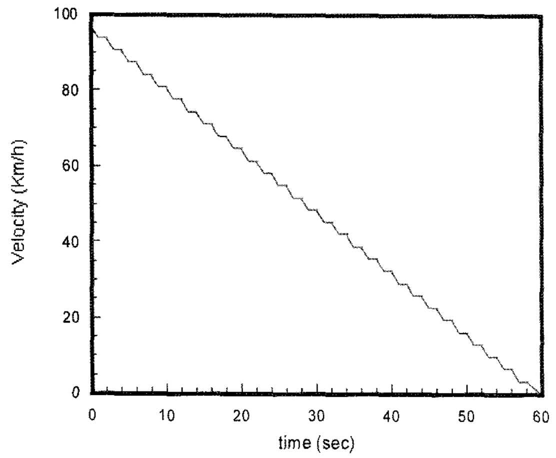


Fig. 1. Cross section of simulation model.



(a) braking 3sec



(b) braking 1sec

Fig. 2. Braking mode.

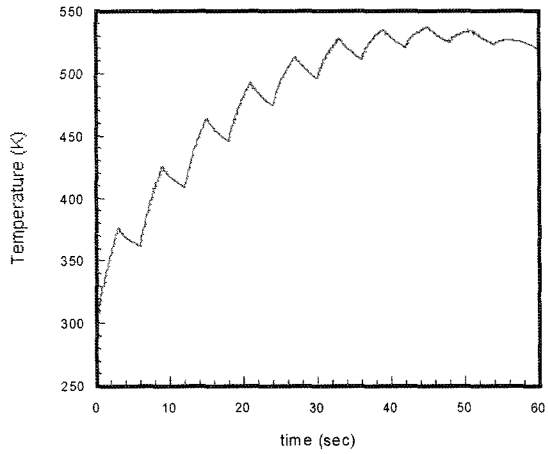


Fig. 3. Temperature distribution of friction surface.

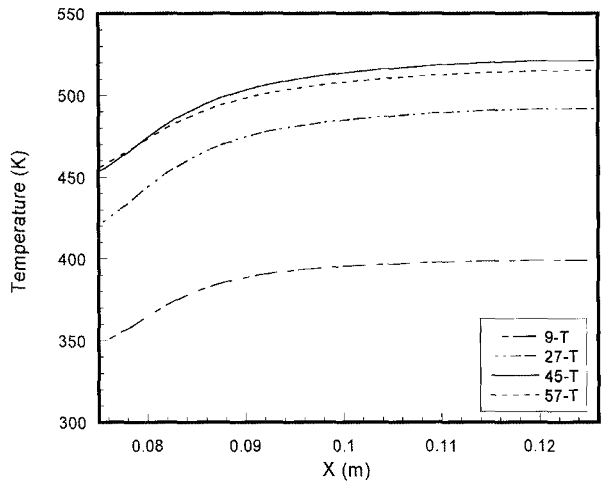


Fig. 4. Temperature distribution at y = 0.024 m.

surface between the disk and pad, the air through the hole and the hub etc.

Figure 2 show the braking mode that used in this paper. When the braking system in on, the friction had generated in 1/6 part of the disk and in rest parts of the disk had cooled by the air. It shows When the braking is over agin, the speed had decreased so that the frictional heat reduced and there are no frictional heat during the driving. In figure (a), the braking and driving are carrying in every 3 second and figure (b) are every 1 second for stop.

3. Result and Discussion

The frictional heat which caused during the repeating of braking conducted to disk and pad, and the frictional energy which conducted from disk cooled by the air through the hole. Figure 3 shows the increasing temperature distribution in frictional surface during the 10 times repeating of braking and driving. There was rapid increase of temperature when the braking is on, and during the driving ($Q = 0$), the decrease of temperature had repeated. According to repetition, the maximum temperature at the frictional surface is increased but than the generated heat value will decreased by increase the number of braking so after 30 seconds, the maximum temperature has roughly fixed to 537 K.

Figure 4 shows the temperature distributions through the flow direction at the bottom surface ($y = 0.024$ m) of ventilated hole. At the entrance, by the flow goes on, the temperature had rose smoothly and than maintained at the position of $x = 0.09$ m. When the braking time had increased, the temperature had decreased ($t = 57$ second). The rising of temperature at the entrance shows the convection cooling having occurs activity.

Figure 5 shows the temperature distributions through the flow direction at the upper surface of ventilated hole ($y = 0.033$ m). From the entrance to exit of ventilated hole, the constant temperature had increased suddenly by times of braking in the beginning but the temperature became smooth rising and decreasing at the end of braking process. According to increased braking process, the highest temperature (45 second) was 255°C higher than the beginning and the upper the temperature of upper surface ($y = 0.033$ m) was 7°C higher than the lower surface ($y = 0.024$ m) at the exit of ventilated hole. The lower surface (Fig. 4) of ventilated hole is connected to disk plate, hub, wheel axle, and the temperature can be

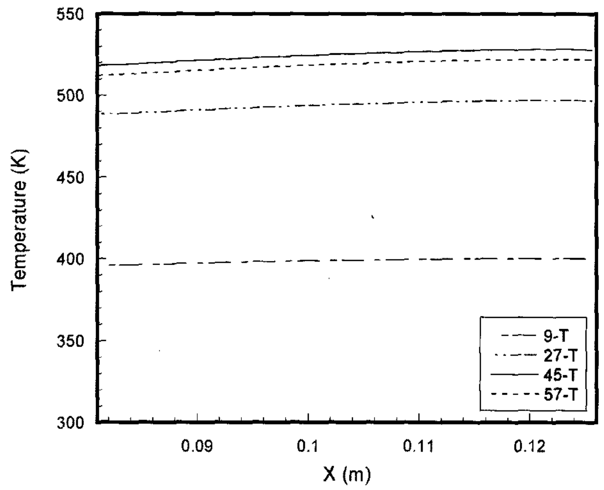


Fig. 5. Temperature distribution at y = 0.033 m.

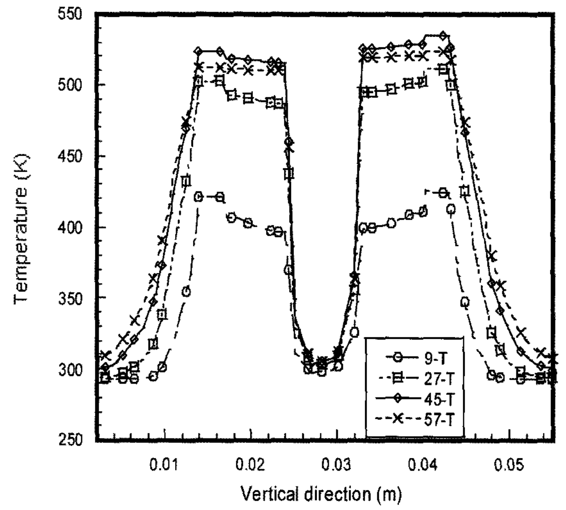


Fig. 6. Temperature distribution of the middle at ventilated region (x = 0.105 m).

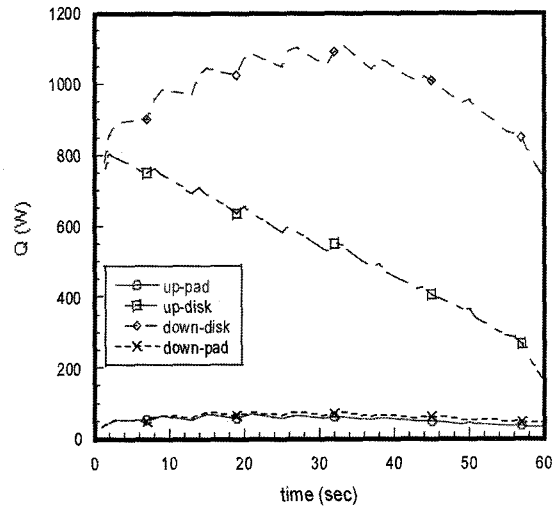


Fig. 7. Heat conduction rate of the disk and pad.

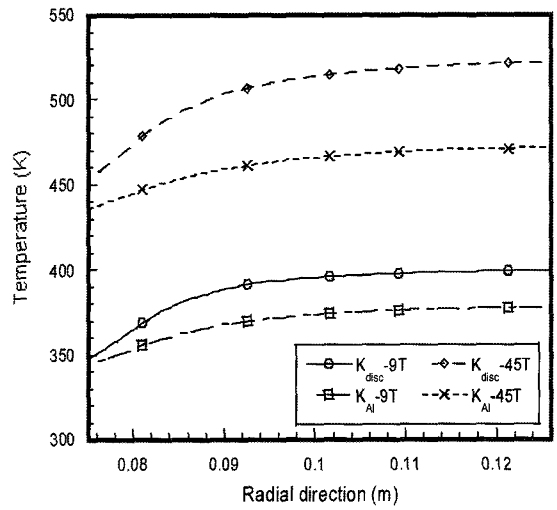


Fig. 8. Temperature distribution for radial direction of disk & aluminum.

conducted to them so the temperature from the frictional surface appeals lower relatively. And the same reason, the temperature of upper surface is higher than the lower surface.

Figure 6 shows the temperature distribution by the time of braking through the width from the center of ventilated hole (x = 0.105 m). It also shows that the maximum temperature in both sides of the disk and the touched surface of pad, and the heat conduction at the pad and inside of the disk, the variation of temperature of ventilated hole by convection. The temperature at the disk reveals remarkably higher than the pad's and the maximum temperature at the upper heat generating surface occurs after 45 seconds and it is 264°C. The fact that the temperature graph have not symmetrically with its axis tells the transfer of the generated frictional heat is conducted to upper and lower of the disk differently. The frictional heat that generated at the lower surface can transfer easier than the upper through the disk that connected to hub. The temperature difference between the upper and lower disk is 3 after 9°C seconds, and after 45 seconds it is 11°C. The result that the upper disk show higher temperature that the lower is that might causes thermal deformation of disk and it can be a factor of thermal instability of brake.

Figure 7 is result of the heat transfer shape which caused at the surface between the disk and the pad. According to the repeating of braking, the lower part of the disk has easy increasing of heat conduction at the primary stage and after 27 seconds, it has decreased because of the decreasing of frictional heat value which followed by decreasing speed. It also shows the small quantity of conduction to the pad under the influence of bad conductivity. The upper part of the disk, the heat radiation by conduction reveals small amount relatively and the heat transfer through the pad has increased somewhat. The stat of generate heat at the lower part which connected to the hub, 94.3% of the frictional heat goes to the disk and 5.7% to the pad and the upper part, 90.3% goes to the disk and 9.7% to the pad.

The conductivity of the disk has effect to heat emission. The conductivity of aluminum that concerned for its light weight is

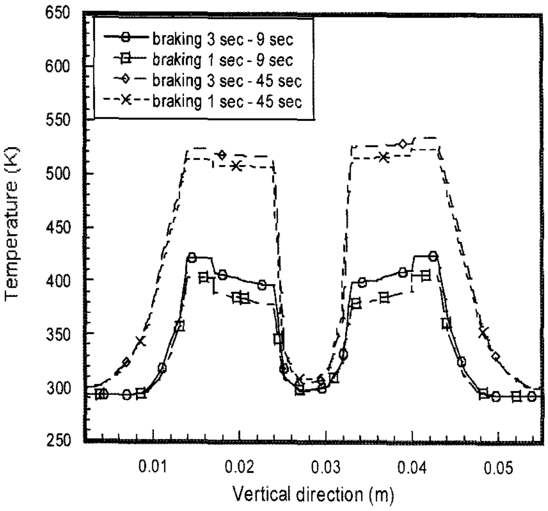


Fig. 9. Temperature distributions along the vertical direction at the middle of ventilated region (x = 0.105 m).

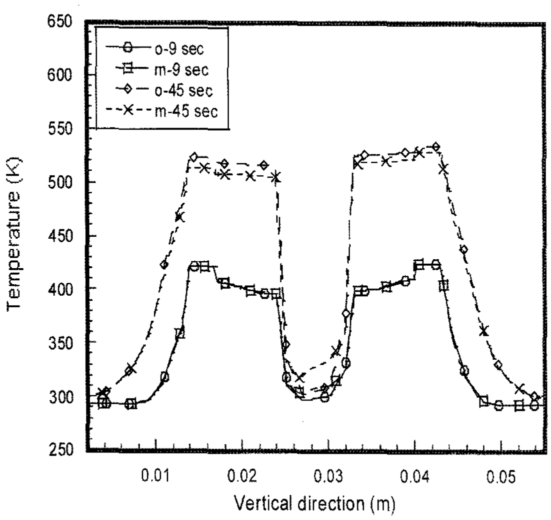


Fig. 10. Temperature distribution at the middle of ventilated region (x = 0.105 m).

4.5 times bigger than the disk. Figure 8 shows the temperature distribution at 9 and 45 seconds after generation of heat at the bottom of ventilated hole after changing the disk and the material to aluminum. The gap of temperature still big even the time had passed means the heat energy is keep transferred. We can see that the temperature inside of the disk being lower because of high conductivity of aluminum.

Figure 9 is the variative temperature distribution followed by radian direction at 9 and 45 second for each braking mode using Fig. 2b mode instead of the mode so far. Even the mode had changed, the transfer at the lower part of disk still more than the upper. The braking mode operated in every single second tells that the temperature at the upper and lower part of the disk reveals as low.

The flow structure of air coming into the inside of ventilated hole can be changed by the shapes of ventilated hole. Therefore, the temperature distributions at the ventilated hole and the flow of heat energy on the disk can be changed by changing the shape of ventilated hole like Fig. 1. Figure 10 show the temperature distribution that changing from the center of ventilated hole (x = 0.105 m) to direction of width only in case of over braking time 9 and 45 second. In the figure, the letter o means original shape and m means the changed shape. The variation of the temperature cause by changing shape at the pad and dist surface after 9 second passed was not remarkable. However, according to the changing of entrance shape, the convection had occurs activity so the air temperature show 10 higher. After 45 second passed, in case of upper disk the temperature at the changing shape is 8 lower than the original shape and in case of lower disk the difference was about 10°C. That show the variations of the shape having effect to the conduction. In addition, the air temperature shows 23 higher by the changing of velocity pattern caused by the changing of shape. According to that it is known that the convection had progressed actively.

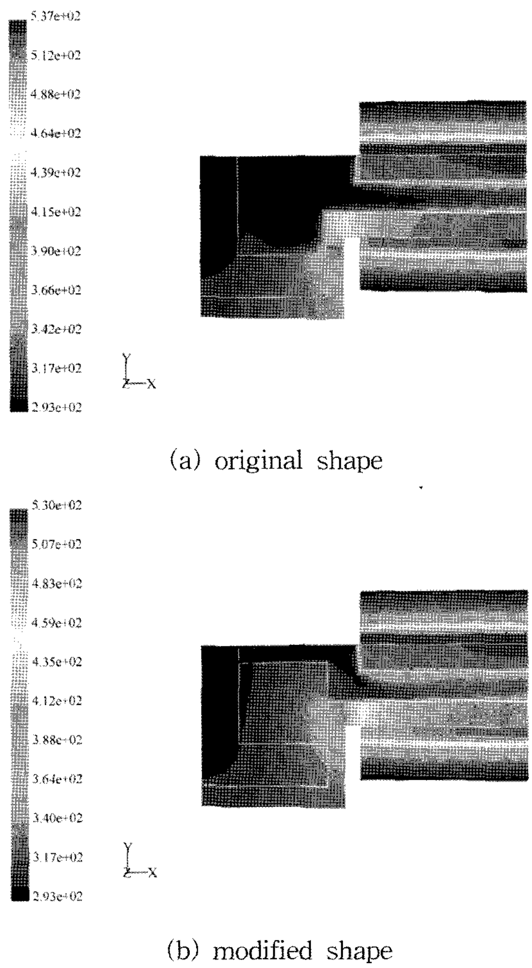


Fig. 11. Contour of temperature distribution of ventilated disk at t = 45 sec.

Figure 11 show the heat distribution that changing by the conductions to hub, axis and ventilated hole in case of original and changing shape like Fig. 1. At (a) it is found that the effect of the axis is not that great yet and the conductions to hub and the heat convection by hub and the incoming air is an important route of heat transfer. At this point, the temperature difference between upper and lower disk surface is Delta T = 21 so the cooling efficiency of upper surface has been needed. At (b) that the shape had been changed, the difference of heat transfer route is occurs. It can have stable temperature distribution through the prompt heat emission by the improved shape.

4. Conclusion

The thermal behavior of ventilated disk brake system was investigated by numerical method. The 3-D unsteady model was simulated by using a general purpose software package "FLUENT" to obtain the temperature distributions of disk and pad.

The model includes the more realistic braking method, which repeats braking and release. The effects of aspect ratio of ventilated hole on the heat dissipation was investigated.

1) The maximum temperature occurred at the sliding surface increases exponentially with repeated braking, and shows slight decreases near the end of braking. These maximum temperatures at the two sliding surfaces showed the asymmetric temperature differences, which could result in the thermal distortion.
2) The amount of 94.3% of the heat, that is generated at the sliding surface, conducted to the disk and 5.7% of heat conducted through the pad. The heat conduction rate through the pad increases from 5.7% to 9.7% at the sliding surface where is not connected directly to the axis.
3) The effect of thermal conductivity on the temperature distribution was analyzed. The temperature uniformity and the good cooling effect of the disk was obtained by using aluminum disk brake.
4) The stabilized braking performance was achieved by reducing the braking period and increasing the number of braking repetition.

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