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The numerical study of thermal flow characteristics for single and dual piezoelectric fans horizontally placed on rectangular channel

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Abstract: The purpose of this study was to use computational fluid dynamics software Fluent, the numerical simulation to discuss the impact pressure within the flow channel device for flat radiator fan heat flow characteristics. Piezoelectric fan was placed in front of the flow channel, and the cold air flow was introduced to the radiator cooling fan, and thus generated vortex fluid in the flow path around the radiator to enhance the mixing of hot and cold fluid. Numerical simulation of various parameters were including the front ends of piezoelectric fan to the front ends of radiator (L_g), the height from piezoelectric fan to the bottom of the rectangular channel (H_w), and the number of fins (n), dual-piezoelectric fans, one was in the same direction and the other was in 180◦ Phase delay. The results showed that the dual-piezoelectric fans installed in the flow channel can effectively enhance the Nusselt value of plate-type radiator. As the height (H_w) of single and dual piezoelectric fans was 15mm, and distance to the front of the radiator (L_g) was 5mm and at dual- piezoelectric fan space (a) was 20mm, the Nusselt value of this installation location had best result. And as Fin number was 10 and 14, the fin number 10 was superior to fin number 14, because thermal performance in the larger space of channel had better thermal performance.

Keywords: computational fluid dynamics, piezoelectric fans, heat sink, plate-type radiator.

1. Introduction

With advances in semiconductor process technology and development, electronic components leap slim and light design concept, the challenge of facing the overheating problem is gradually increased. At the same size, CPU (Central processing unit) internal number of transistors on an integrated circuit manufacturing process is more advanced, which represents the same size of the wafer's heat will also increase, because the wafer is easy to damage at high temperatures, so in order to maintain the operation wafer in a stable condition, and therefore electronic component cooling techniques is particularly important. Integrated circuits get smaller , making a wide range of portable consumer electronics product innovated, so that the common design philosophy of mobile phones and notebooks is to enhance user's comfort and keep in low noise level , under this situation of decreasing power consumption and extend the operating time or the life of the product , research and development of cooling devices such products as design guidelines to apply piezoelectric fans are quite applicable in portable consumer electronics products element . Piezoelectric fan is mainly composed of a piezoelectric ceramic wafer and covered by a flexible plastic sheet, when input AC voltage, the reverse voltage effect of piezoelectric material makes the piezoelectric wafer deformation, causes high-frequency oscillations, and causes the thin plate vibrating up and down, and therefore the fluid around the plate has flow convection effect, and thus achieve cooling effect purpose. Due to Piezoelectric fan has low power consumption, so it can be made into less dimension and low noise, etc. The miniaturized electronic products meets the cooling device requirements, this study applied Piezoelectric fan components as simulation object to explore heat dissipation and cooling effect of the flat-type radiator .

Acikalin and Garimella [5] used three different forms of piezoelectric fan at the top of the heat source, which were changed amplitude of piezoelectric fan, changed the distance between piezoelectric fans to the heat source, and changed the length of piezoelectric fan in the offset of resonance frequency. The offset of the resonant frequency of piezoelectric fan and the heat center were applied as parameters of heat transfer effect. In this study, a two-dimensional computational fluid dynamics model was applied, and the results were compared to the experimental results, and could find that the resonance frequency of the operating frequency was the biggest factor for the heat transfer effect. So the amplitude piezoelectric fan blades became smaller, airflow becomes weaker, that the overall heat transfer performance became degraded. Acikalin et al. [6] Analyzed and Forecasted piezoelectric fan cooling performance , the piezoelectric fan was placed in front of the heating of stainless steel sheet, used infrared thermal imaging measurement techniques to do the experiment, and the piezoelectric fan which was placed in the acrylic plate container, and then particle image velocimetry (PIV) was applied for flow visualization, and moreover simulated and studied the space relationship from amplitude to the wall of piezoelectric fan for flow analysis and thermal effects. Applied the pre-treatment aspects to establish the grid mesh, and used computational fluid dynamics simulation software CFD-ACE -dimensional numerical model to compare with the experimental results, and the amplitude of each of four parameters were 6.35, 7.5, 8.5, 12mm. The space between the piezoelectric fans was 0.5, 1, 2.5, 10mm, and in the same amplitude took four different matching sets to simulate the data. The results showed the effect of heat transfer will increase as the amplitude of piezoelectric fan became larger, the best of the wall space of piezoelectric fan was 2.5mm. While compared the simulation and experiment results, the error was around 17% for these two results.

Acikalin et al. [7] applied the piezoelectric fan in electronic components, and the fan had small size, low noise and low power consumption and other advantages, but the piezoelectric fan is not purposely used to replace the current axis rotary fan. As in the regional and local hyperthermia rotating fan couldn't meet the cooling effect requirements, so the piezoelectric fan could be used to provide effective cooling effects. Experimental results showed that the piezoelectric fan placed vertically at central position in the mobile phone had a better heat transfer coefficient than that was placed in the horizontal position. Kimber et al. [8] applied the piezoelectric fan and placed in front of the stainless steel sheet. Changed the space of the piezoelectric fan amplitude and used infrared thermal imaging technology for laboratory tests, and the results showed the distance between piezoelectric fan and heated stainless steel sheet , While the distance was from far to near, infrared thermal imagers showed that the temperature distribution changed the shape from round to oval, the experiments showed that piezoelectric fan and the heated stainless steel sheet space will be varied as the amplitude was changed, as the amplitude was larger, and the space between piezoelectric fan to the stainless steel was smaller. The heat dissipation became better, and fixed the distance would have the better heat transfer effects, and in the meantime obtained the Nusselt number, Reynolds number of a stagnation region as well as empirical formula for the relationship between gap and the proportion of cooling area, which could be applied and described characteristics of thermal properties of piezoelectric fan. Kimber and Garumella [9] measured a vibrating piezoelectric fan and applied cooling characteristics of the piezoelectric material in order to drive and place in the heat fluxes of fixed surface, and in the meantime applied infrared cameras to capture the temperature profile of fluid flow. Six sets of piezoelectric fan was used in this experiment, and the operating frequency was from 60 to 250Hz, which showed the closer distance from the tip of the piezoelectric fan to the heat source had better heat cooling effect.

Compared the frequency and vibration changes, the results showed the frequency changes for maximum heat transfer rate were varied, and slightly larger than the vibration changes. Kimber and Garimella [10] put 2 sets of piezoelectric fan vertically and in the front of heat source, and changed the amplitude of the piezoelectric fan from 7.5 to 10mm. The amplitude of the heating plate to that of piezoelectric fan amplitude was under the ratio from 0.01~2 times, and therefore set piezoelectric fan to another fan space and amplitude ratio was from 0.5 to 4 times in order to achieve the cooling effects. The infrared thermal image was applied in this experiment, and the results showed two vertically placed piezoelectric fans had better heat dissipation effects than a single fan. The main reason for causing the better heat dissipation effects was depending on the vibration amplitude and pitch change between the two vertical piezoelectric fans, and under the condition of two piezoelectric fan placed vertically as well as the distance was 1.5 times of the amplitude of the swing would produce the best thermal performance, and under such circumstance the overall thermal performance could be increased by 15 %. Kimber et al. [11] used two different materials in piezoelectric fans. The first one was Mylar material, and the overall length was 69mm. The second one was Steel material, and the overall length was 47mm. And the device was in three different acrylic outer box, which dimensions were E1 (40 × 80mm), E2 (25 × 50mm) and E3 (15 × 30mm) to measure the pressure and plot the flow rate performance graph, and under different amplitudes, the experimental load was on the frequency of 60Hz, As frequency was at 113Hz, and the maximum flow rate was approaching 30l / min and the maximum static pressure (Static pressure) reached to 6 Pa. In this study the overall performance was based on the amplitude and frequency trends and the sensitivity of changes in hydrostatic pressure convection rate, and therefore could be obtained the following conclusions:

(1) The standard form of piezoelectric swing pressure and flow rate was 10 times higher than those produced from the axial fan.
(2) Could be taken the speed of tip of piezoelectric fan as the flow rate.
(3) The vibration frequency could change pressure and flow.

Liu et al. [12] studied the horizontal and vertical placement piezoelectric fan thermal effects on the surface of the heat source, and applied experimental methods in six different geometries piezoelectric fans, the results showed that the increased heat transfer was generated by each cycle injection gas flow and entrained flow from both sides of the fan blade tip. The optimum vertically heat- transfer position was in the center of the symmetrical distribution (Symmetrical distribution), and the optimum horizontally heat- transfer position was in asymmetric distribution, and in the meantime we could find that as the blade tip was placed at the position above the plane of heat source, and as the piezoelectric fan was placed in horizontal position, the degradation of heat transfer was quite large, that was because flow field was blocked by the entrained air flow. And the results also showed the heat transfer performance of the horizontally placed piezoelectric fan was not always worse than that at the vertical place, and dimensionless analysis showed six different geometries piezoelectric fan in vertical placement, the average deviation was 4.8%.

Zaitsev et al. [13] applied the numerical simulation to study the Vortex-induced effects of surrounding objects and investigated the forced vibration which was caused by three-dimensional turbulent flows. The forced vibration was applied the parallel computing fluid dynamics techniques in fluid coupling problems, and flexible cylindrical was applied to produce vortex vibration. The three-dimensional turbulent flows were generated by the piezoelectric vibration, and flexible cylindrical was applied to produce vortex vibration. The piezoelectric materials was used to stimulate the formation of a thin flexible blade to produce vibration, and the vibration results were displayed in the direction of the jet air flow cross-section diagram, and a stagnant zone could be seen, which was formed by the temporarily reversed current, and then continued to the downstream area and mixed with the turbulent flow which would make the reversed current completely disappeared.

Wait et al. [14] used three different lengths of the piezoelectric fan to conduct numerical simulation and flow visualization experiments, the study mentioned the different resonant influence on flow field and fan energy consumption of the piezoelectric fan. The results showed that higher resonance frequency could provide complex flow field, and increased the cooling fluid as well as mixed with hot swap, but would also brought about higher relative power. The energy consumption concepts were great important in the portable electronic devices, and therefore obviously selected the appropriate resonance frequency became more important. The study discussed the previous four modes of resonance effects and also showed the largest vortex was happened in the first resonant mode of the blades end, and the flow direction was the most consistent at there, so the first resonant mode of the heat flow field was the most helpful in this study. The study also investigated that the fourth resonant mode flow field was the least significant, because the range of gas flow was shortest, and the air flow at tip of piezoelectric fan was not obvious, so the heat radiation was the least efficiency at the fourth mode.

Tseng et al. [15] studied piezoelectric fan in heat sink of cooling plate, and furthermore applied that in LED as well as CPU heat sink. For the purpose of reducing the radiator size up to 25%. In this study the radiator was so called "tilt piezoelectric fan". And that was designed for improving the thermal performance of the surface temperature of the heat source, and the heat source was 15W and 35W. The results showed the cooling effect was obvious and the temperature could be decreased from 78℃to 57℃, and furthermore the heat resistance decreased from 4.4 ℃/ W to 2 ℃/ W.

Abdullah et al. [16] mentioned the piezoelectric fan was designed and used to remove heat from microelectronic components, and hence the the design should be considered with low power consumption, low noise, small size, etc.
In this study applied piezoelectric fan on the horizontal position for two-dimensional numerical simulation and flow visualization experiments in order to observe the phenomenon and discuss swung piezoelectric fan flow field which was formed by its heat transfer coefficient. And studied the height, which was from the heat source to the piezoelectric fan. The optimum cooling efficiency would be reduced to 68.9 ° C, and the experimental and numerical analysis results error was approximately 11%.

Ng et al [17] studied thermal performance of piezoelectric fan in a laptop computer, and selected processor thermal design power (Thermal design power, TDP) 18W and 13-inch low-power notebooks , and found that if the fan wants to get better thermal performance, the fan needs to have a higher resonance frequency and larger amplitude. The study also showed the best heat transfer performance was at the tip of piezoelectric fan, and that was also at the entrance location of the heat exchanger.

2. Geometry

2.1 Calculation region and parameter settings

In this study, the numerical simulation range was set to be 300mm × 50mm ×100mm, and the physical model was shown in Figure 1 and Figure 3. However, in order to save time on numerical simulation, this study applied the model framework to establish the number of grid division. In this study, placed single and dual-piezoelectric fan at the top of the rectangular channel, and discussed different parameters of piezoelectric fan in the rectangular channel devices and the impact on the characteristics of plate-type heat radiator. By the way in this study set the origin of the X-axis of the coordinate reference

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model in front of the radiator, and designated downstream orientation was positive direction, but with the distance from a single or dual-piezoelectric fans to the front of radiator L_g as a reference point where the upstream direction was positive, and the downstream orientation was negative direction as shown in Fig. 2 and Fig. 4, and that was not completely similar to the physical model as shown in Figure 1 and Figure

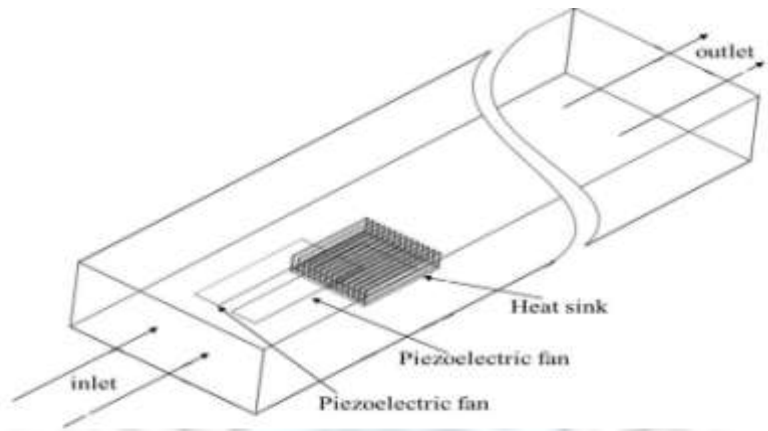

Fig. 1. Physical model of dual-piezoelectric fans.

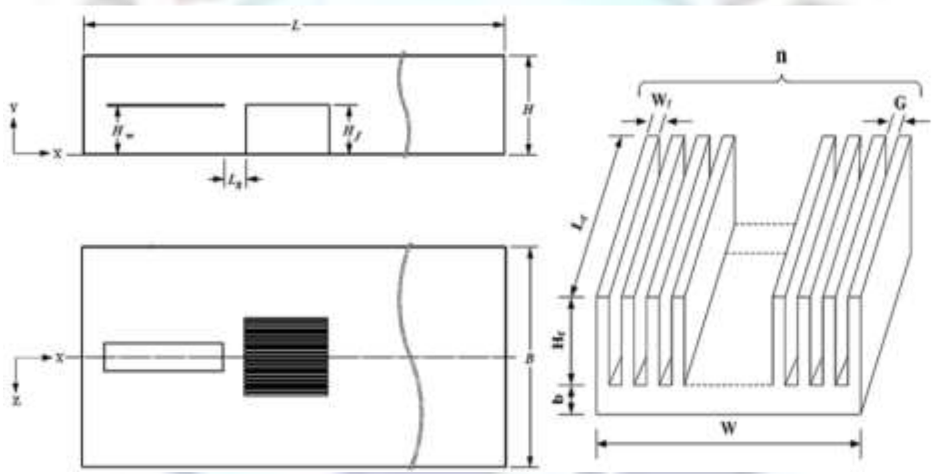

Fig. 2. Geometric model of dual-piezoelectric fans.

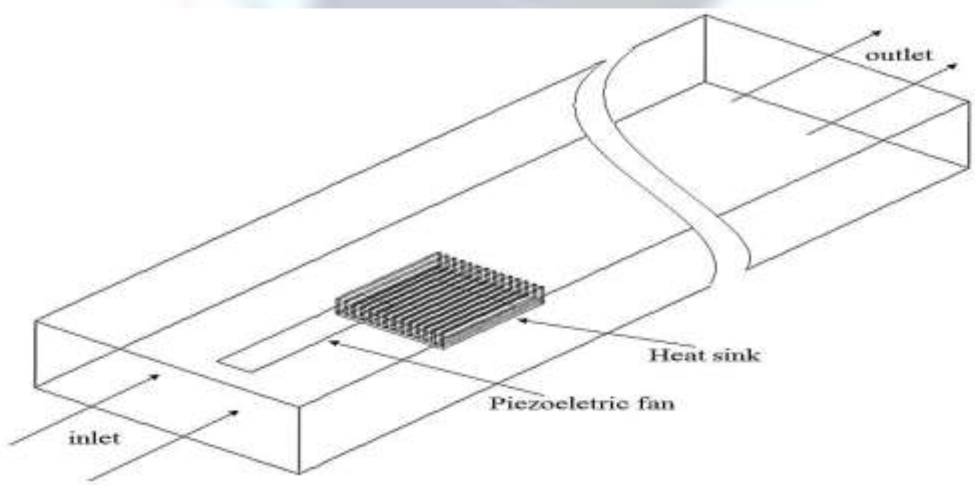

Fig. 3. Physical model of single piezoelectric fan

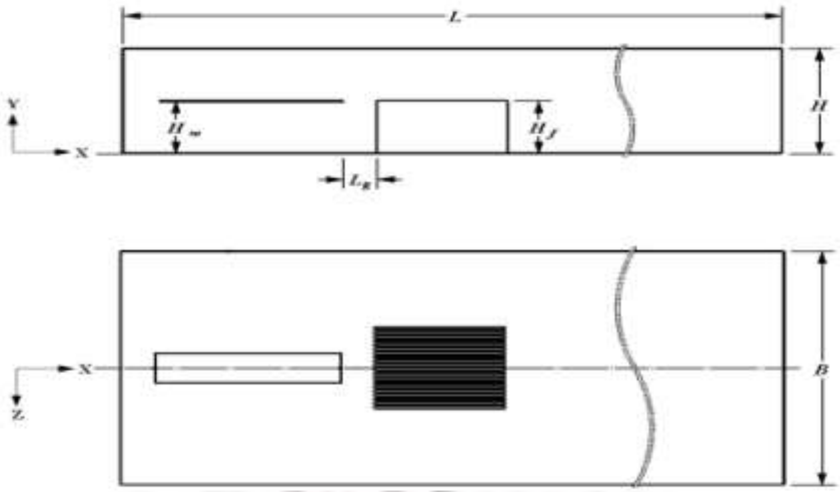

Fig. 4. Geometric model of single piezoelectric fan.

Figure 2 and Figure 4 showed a geometric model which simulated parameters of dual-piezoelectric fan, and included the shortest lateral distance of the dual- piezoelectric fans (a), the distance from the tip of piezoelectric fan to the front of heat sink was L_g, the width of fin was w_f, and the height of placed piezoelectric fan was H_w, and the fin number of heat sink was n.

2.2 The governing equations

The governing equations applied in this study could be written as:

(1) The continuity equation:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \vec{v}) = 0 \qquad (1)$$

(2) The momentum equation:

$$\rho \frac{DV}{Dt} = \rho g - \nabla p + \mu \nabla^2 V \qquad (2)$$

(3) The energy equation:

$$\rho \frac{Dh}{Dt} = \frac{Dp}{Dt} + k \nabla^2 T + \Phi \qquad (3)$$

(4) Solid-state heat conduction equation:

$$\frac{\partial}{\partial t}(\rho h) + \nabla \cdot (\vec{v} \rho h) = \nabla \cdot (k \nabla T) + S_h \qquad (4)$$

2.3 Boundary Conditions

In order to simplify the study, so set the system as a transient condition, and the fluid was incompressible, the thermal physical properties were not changed due to temperature changes and ignored gravity and thermal radiation. The boundary conditions were set as

(1) Inlet boundary:

At 1 atm, $T = T_0 = 300K$ (5)

(2) Wall boundary: $U = V = W = \frac{\partial T}{\partial n} = 0$ (6)

(3) Outlet boundary: At 1 atm (101,325 Pa)

(4) Moving boundary:

Blades amplitude equation:

$$X = -42.34 \times Y^2 + 33587 \times Y^3 - 2.732 \times 10^6 \times Y^4 + 9.053 \times 10^7 \times Y^5 - 1.265 \times 10^9 \times Y^6 + 6.34496 \times 10^9 \times Y^7 \qquad (7)$$

Piezoelectric fan equation:

$$f(t) = X \times \mathrm{Sin}(2\pi \times Fr \times t) \qquad (8)$$

(5) The heating surface and solid heat conduction boundary:

Except the heating surface of the bottom of the heat sink (31mm × 31mm), regarded base plate and took peripheral as insulated , the heating power was 35W, the thermal conductivity of the heat sink was 167 (W / mK). After heated 40 seconds, and then turned on the piezoelectric fan.

(6) The surface of fluid boundary was conjuncted with heat sink:
Set the uninsulated part of Radiator, temperature and heat flux at the conjunction area of the solid and fluid surface was continuous.

3. Numerical Methods

In this study, set the appropriate physical model, which was divided into several regions, but in the more intensive part, the density of mesh was increased in order to save the computing time, and therefore the detailed changes about the physical quantities could be easily seen. the Studies applied composite grids mesh to construct tetrahedral mesh and hexahedral meshes, that was so called Hybrid mesh, and hence the Radiator and rectangular channel part was set with hexahedral mesh, and vortex generators and its surrounding area was set with tetrahedral mesh as shown in Figure 5 . The solver was set as standard methods, and the pressure - speed linked term applied Simple rules. Momentum equations and Energy equation was applied the first-order upwind difference method (First order upwind scheme). At X, Y, Z direction, velocity and pressure was initialized. In this study, set the velocity of X, Y, Z direction, the energy equation, the continuity equation, the convergence condition, and set the average value of the monitoring outlet temperature, and then did the overall calculation. The value of Numerical simulation of the convergence condition was set less than 10^{-8} of the residual value and the rest of the equation convergence value was set to 10^{-5}.

In order to verify the accuracy of the calculation model and numerical methods, numerical simulation parameters were set as:

(1) The distance from the front end of piezoelectric fan to the front end of fins of heat sink L_g was 5mm.
(2) the lateral distance (a) of the dual- piezoelectric fans was 20mm,
(3) The length of piezoelectric fan was 65mm
(4) Fin width (W_f) of heat sink was 1mm.

And then constructed a different number of grid simulation model to verify the grid was independent. As showed in table 1, the grid Number 99,105 to 130,617 had 7% difference in the average speed, but at the grid number from 191,118 to 291,105, the average speed was 0.3% difference. So in order to simulate the results accuracy and save the computation time, this study took grid number 191,118 as the basis.

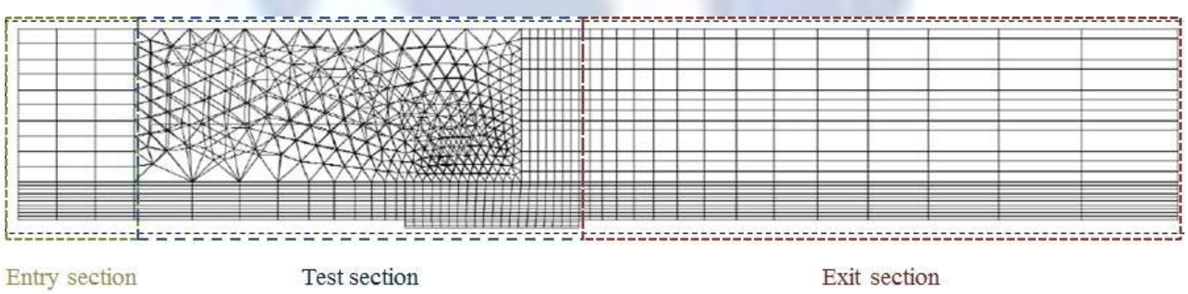

Fig. 5: Schematic diagram of constructed grids.

Table 1. The calculation speed in different grid number.

Grid number	99105	130617	191118	291105
speed (m/s)	0.55	0.572	0.482	0.496

3.1 Numerical Methods

Model of grid size was depending on the stability of its value and the selected time steps. Generally, the number (Courant number) couldn't be greater than 1. And after selecting the grid size, time steps changed to the impact of simulation would be stable, and that was shown in Figure 6.

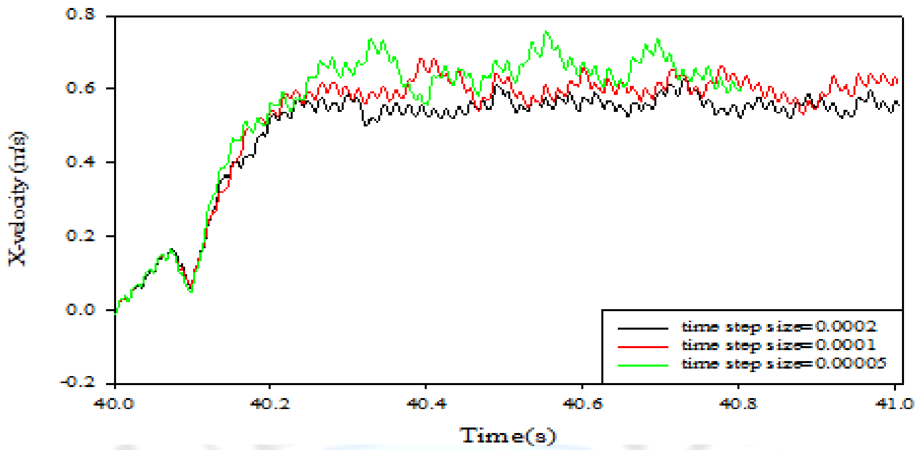

Fig. 6: The X-velocity in different time steps 0.0002, 0.0001 and 0.00005

Table 2: The comparative speed to time steps value

Time steps (second)	0.0002	0.0001	0.00005
comparative speed $C_{L(m/S)}$	0.208	0.111	0.06

Table 2 displayed the time steps, the larger value of the average speed, the smaller relative value became. As adjusted the time steps, the average speed became larger, and as adjusted the time steps to smaller value, the computation time became larger. In this study, took time steps 0.0002s as basis, and under this condition the simulation result was reliable and that the computation time would be saved.

4 Results and Discussion

In order to simplify the graphical representation, the study turned on the piezoelectric for 2 seconds. And set the front end of piezoelectric fan to the tip of heat sink Lg, height of piezoelectric fan (H_w), fin width (W_f) and the number of fins and other parameters for discussion, and investigated the heat transfer effects.

4.1 The dual-piezoelectric fans were activated in the same phase, and the distance between the front ends of dual-piezoelectric fans to the tip of heat sink was L_g At this section, chose the fin number 10 (W_f=1mm, H_f=10mm, a=20mm, H_w=25mm), and compared the simulation results, as well as discussed the impact of dual-piezoelectric fans as shown in Figure 7. That was the Lg=-11.25mm, the axial velocity distribution of x-axis, the velocity between the dual-piezoelectric fans to the center of heat sink was largest. That was for that the fluid on the top of heat sink flew down, the center position of the five flow channels speeds could reach to 1.1m/s, and in the meantime the fluid flew to the bottom would appear heat dissipation effects, so the speed would change less, and during the dual-piezoelectric fan bobbing, that would cause vortex flow at the upper part and bottom plate of the channel, and that also produced the vertical direction impact and would affect the flow channel, and entrained flow would be happened on both sides. that was happened in the center of the radiator fins, and due to the impact flow flew to the lower wall region, that caused wake flow spread to the region on both sides of the channel, and velocity diffusion range became larger, that wouldn’t be constrained by the cooling fins, and then the speed from the rear wall for the next extension. The wake region on the position of both sides of the rectangular channel would speed up and the speed presented side rolls effects, so that the higher temperature effect was appeared in figure 7. And from Figure 8. We could realize the temperature distribution of X-axis direction and the impact flow of negative y direction of dual-piezoelectric fans would immediate react with fins for heat exchange. We could observe the structure of the flow field inside the radiator, and then found the flow flew along the flow path direction, and moved toward the radiator. Due to the restriction of plate-type heat sink, so that the fluid could not flow through the z direction (Z-direction barrier). And hence most of the kinetic energy of flow region near the end of Z direction would be restricted. However the closer to the flow channel, the impact of the stream would be more easily formed a double vortex structure along the Z direction, and the center of vortex would carry the heat to the bottom of the wall, but based on the geometry of the rectangular channel, that would incite the speed traction, and therefore caused the heat flow moving along the double vortex and swirling around, and the effect was shown in figure 8. This appeared two symmetrical high temperature regions.

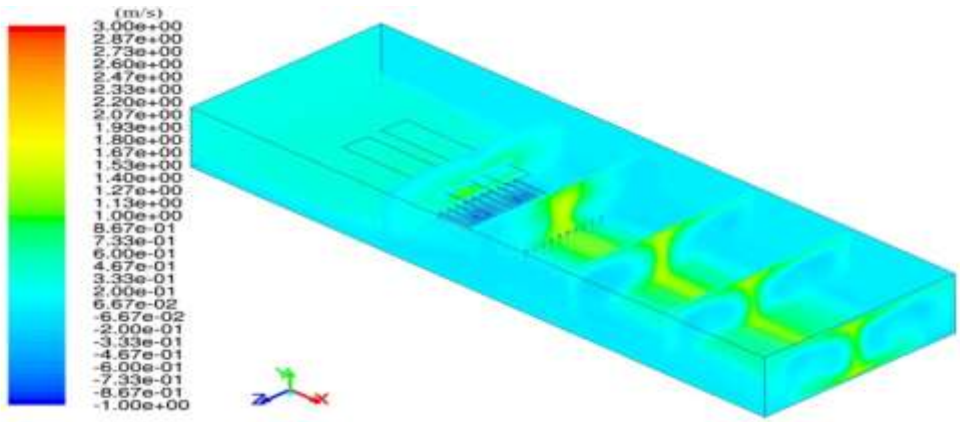

Fig. 7: At L_g =-11.25mm, the x-axial velocity distribution in the X -axis cross section.

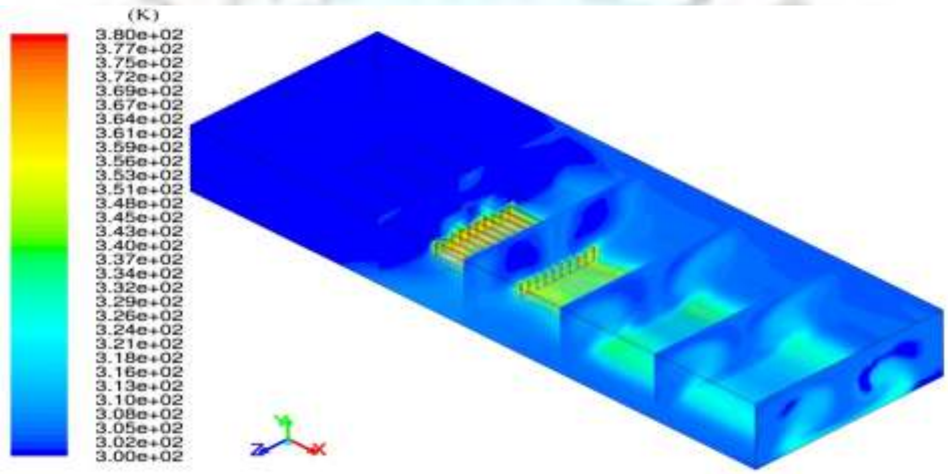

Fig. 8: At L_g =-11.25mm, the temperature distribution in the x-axial cross section.

4.2 The dual-piezoelectric fans was activated in the same phase, and the height between the front end of dual-piezoelectric fan to the tip of heat sink was Hw.
The velocity distribution of X –axis cross section in the x direction was shown in figure 9., and in this case the other condition was set as following:

(1) The piezoelectric fan was placed in the front of the heat sink, and the distance was L_g = 5mm,
(2) The height was H_w = 15mm,
(3) The fin number (n) was 14.

As dual-piezoelectric fans swung down , and during the impact flow propagated to the bottom of the radiator fins , the speed towards the direction of flow where the resistance was smaller, and therefore the flow couldn't successfully pass through the back end of radiator fins, and the speed of flow from the top to the bottom would dissipate faster, and at the back-end of radiator the speed would change smaller, that was because the dual-piezoelectric fans swung and the flow flew into the radiator channel , and therefore the speed of the bottom wall of the radiator fin would be affected, and this speed would be reflected to the less resistance direction, and then the flow flew in and bounced to the upper wall of the radiator, and led to the blocking diffusion velocity, and the directions were near both sides of the wall.

The X-axis cross-sectional temperature distribution at H_w =15mm was shown in figure 10, in this case as the dual–piezoelectric fans swung, the flow flew into the channel of radiator, and caused the impact flow bounced to the upper part of radiator, and then the accumulated heat would be quickly brought away, and this effect would also cause both sides to produce a slow heat stagnation region, and in the heat diagram presented an U- shape dissipation, and then affected the heat change in the area of wake flow and in the outlet area, And in the back end of radiator, the speed effect became smaller, and that would cause heat exchange and dissipation less, so that the heat was accumulated on the area under the wall at the rear end of the radiator. And after the heat impacted to the upper wall, the heat would diffuse on both sides of the wall, and then the wake flow would extend, which resulted in the formation of the export position looked like two heat on both sides of a central location on the export orientation, and presented no heat change.

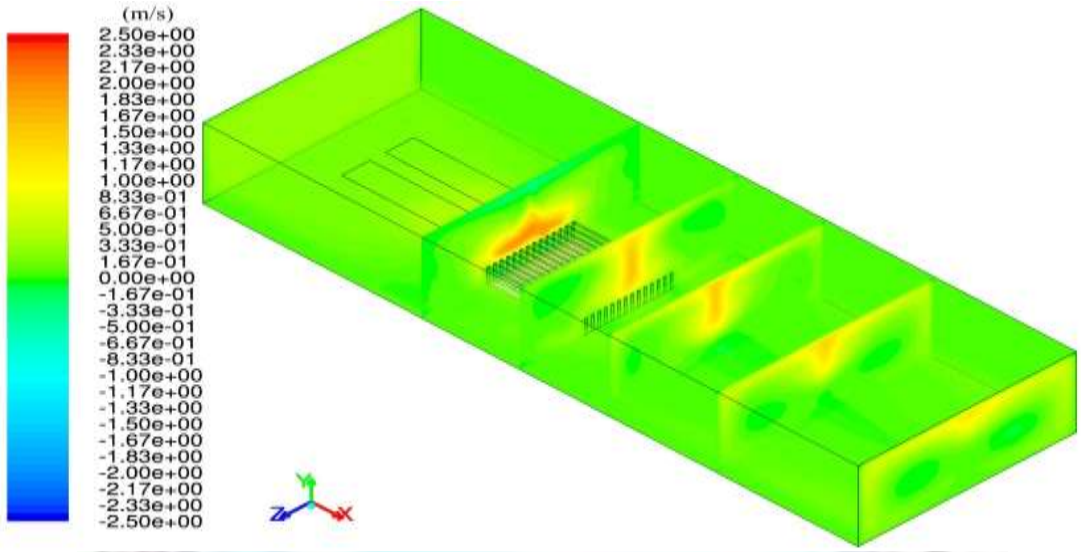

Fig. 9. At H_w = 15mm, the velocity distribution of X –axis cross section in the x direction.

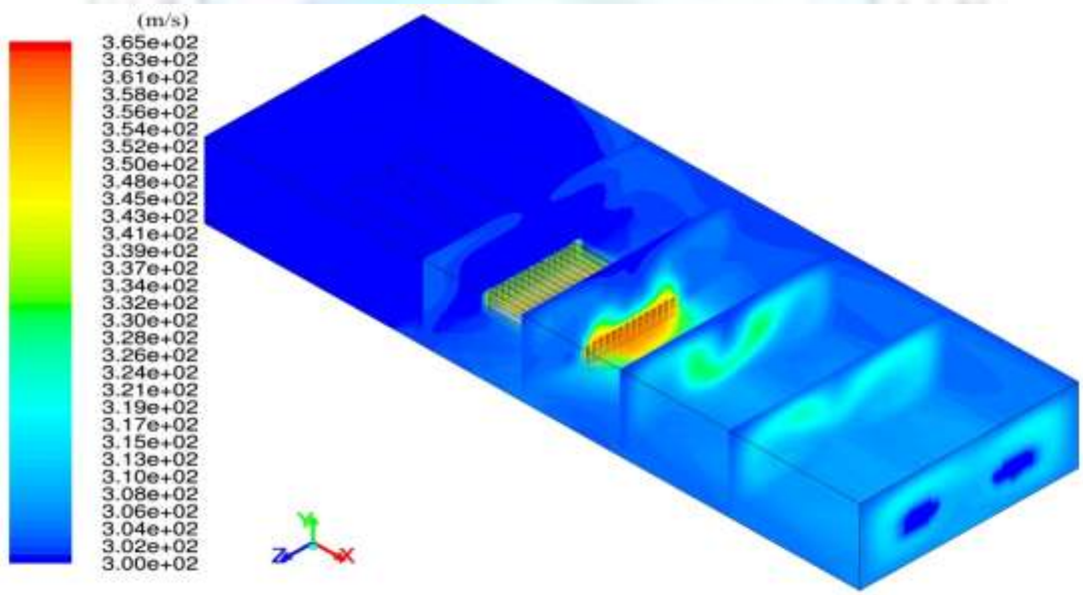

Fig. 10. At Hw = 15mm, the temperature distribution of x axial cross section.

4.3 The dual-piezoelectric fans was activated in the different phase , and the distance between the front end of dual-piezoelectric fan to the tip of heat sink was L_g The dual-piezoelectric fans were activated in different phases on both fans had 180° difference in each phase, and the placement was at the above of fins which number was n=14, and the lateral position changed would cause the impact of cooling effects, and because the relationships of the distance of the fins was closer to heat sink, that resulting in flow flew into the radiator, and during the flow flew the channel which was restricted by the adjacent fins, and hence the largest velocity of flow would concentrate in the both sides of radiator, so that the velocity of the flow passed through the channel was not the same, and at the back end of both sides had larger velocity, and the velocity at the center of wake flow region became smaller, and therefore the flow would impact up and down the wall, and sticked as well as diffused on both sides of the wall. The heat change of thermal field in different directions as the dual-piezoelectric fans in the swinging process was shown in figure 12. From the study we knew the speed of flow affected the heat exchange in the wake flow region which was totally different. The velocity on the area of right and left sides at the center of dual-piezoelectric fans became larger, and during speed delivery process and at the radiator central position, the velocity became smaller, and that cause heat at the center of back end of the radiator became larger. We could find from the back end of radiator to the wake flow region, the heat was accumulated there. And during the fans swung, both sides would swing faster, and that would cause rapid heat exchange and presented in the airflow path, and on downward of the wall had heat shock effect. The impact of the heat would bounce to the wall, and then flew away with open sides. This effects would lead to the heat would shock to the wall, and in the meantime that the heat would cause the tail to the outlet flow area presenting rolled up effects.

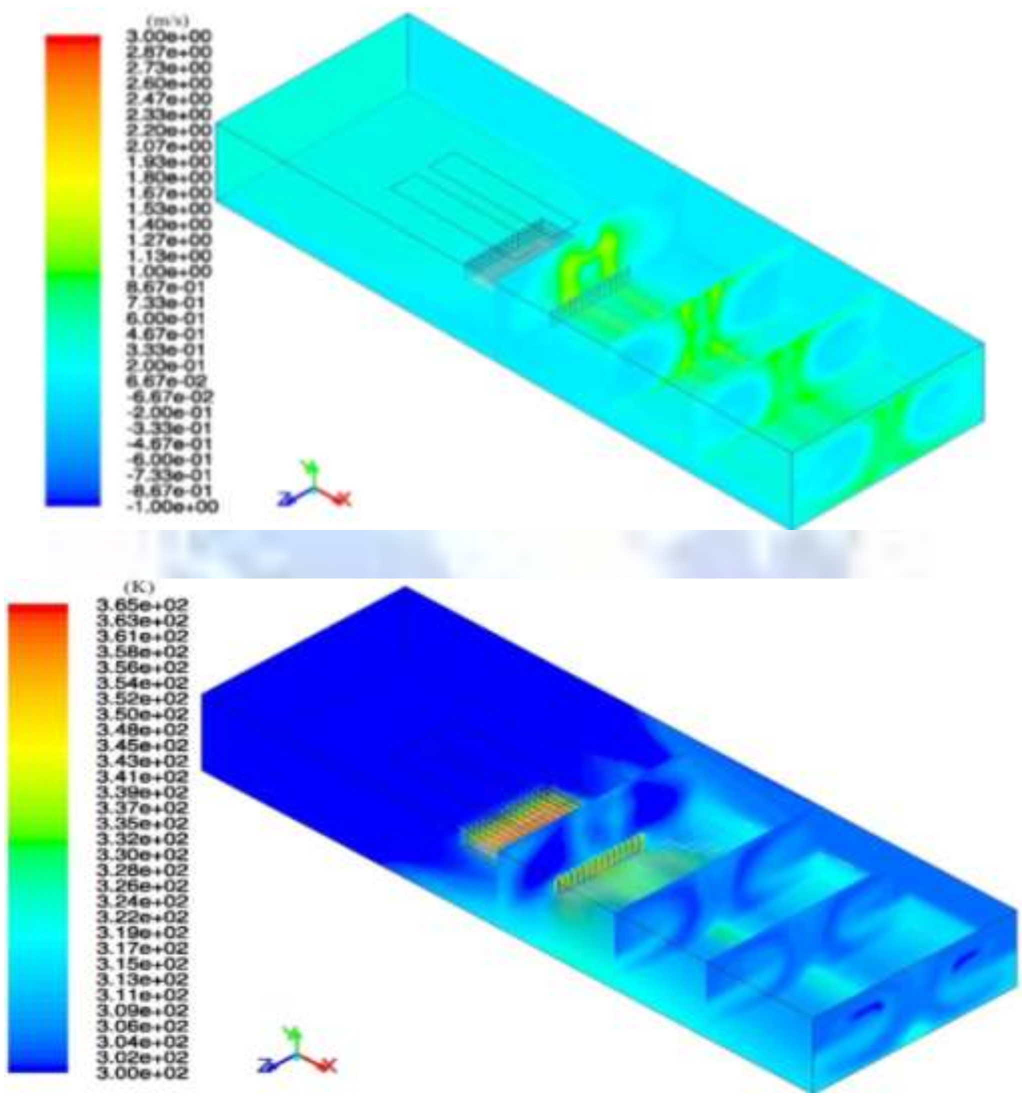

Fig. 12. At L_g =-22.5mm, the temperature distribution of x-axial cross section.

4.4 The height H_w was in different phases of dual-piezoelectric fans to the front of the radiator

At H_{w} =15mm, and the fin number was n= 10, during the fans swung, and due to the space of the radiator channel became lager, so that the flow would effectively flow into the radiator channel, which could be shown in the velocity at the back end of the radiator, and the velocity at the center part of the radiator was slower, and therefore this flow could be effectively get into the radiator, and the most velocity would concentrate in the both sides of back end of the radiator., and because of the different directions of fins blocked off, that led to the velocity of the flow at the center part of the radiator became slower, and then flow flew into the area of wake flow which was at the back end of the radiator, the velocity of flow became smaller, and beyond the outlet the speed would evenly spread. The effect of thermal field and the velocity at both sides of radiator became larger which could be shown in figure 14, that would cause the energy of the radiator effective spread away, so that the heat was not accumulated at the back end of the radiator, and therefore the heat dissipation effect was better there.

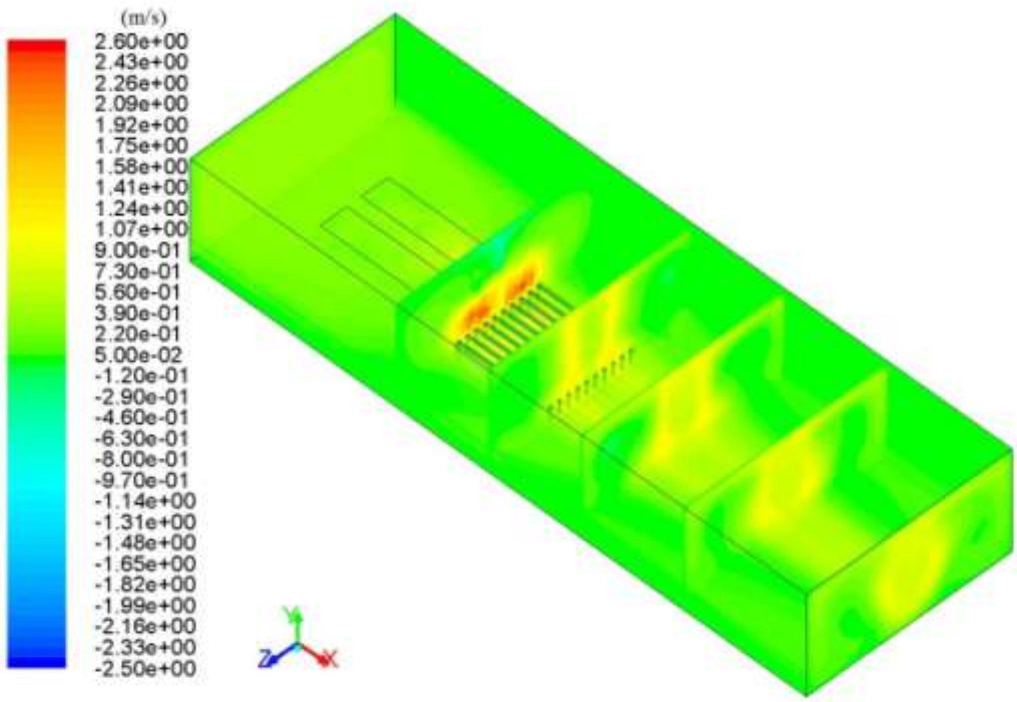

Fig. 13. AT H_w = 15mm, the X-axial velocity distribution in the X-axial cross section.

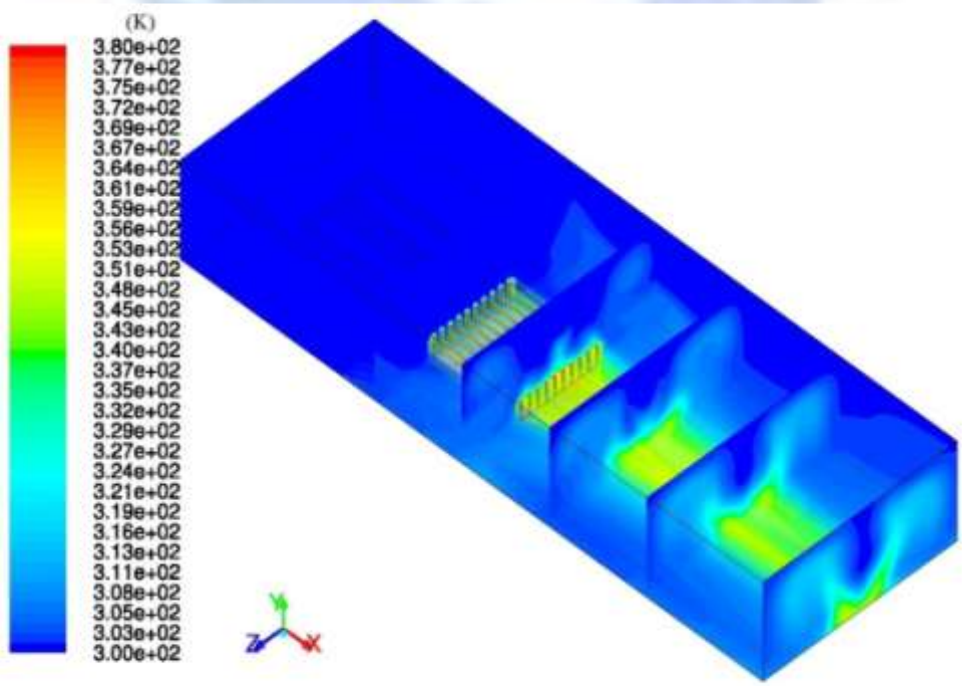

Figure 14. At H_w = 15mm, the temperature distribution of X-axial cross section.

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4.5 The distance between the single-piezoelectric fan to the front of the radiator was L_g.

The velocity of fin was 2.1 m/s, and the velocity change at one cycle of single- piezoelectric fan was shown in figure 15. We took position vector changes instead of velocity vector changes, that was because the vector of velocity could not capture and plot in the velocity diagram, and we could not clear see the vector changes in the radiator, so we took the position changes of the single-piezoelectric fan swung in the radiator, and applied the vector changes for analysis, and during the fan swung from center to the upper position, the vortex would be happened beneath the fan, and from the vector diagram we could easily understand that the vortex move toward the clockwise direction, and during the fan swung down, the vortex in the upper part of the fan would turn in counter clock wise direction and the velocity vector would appear negative value, that was because of vortex effects, so that the velocity vector appeared negative value.

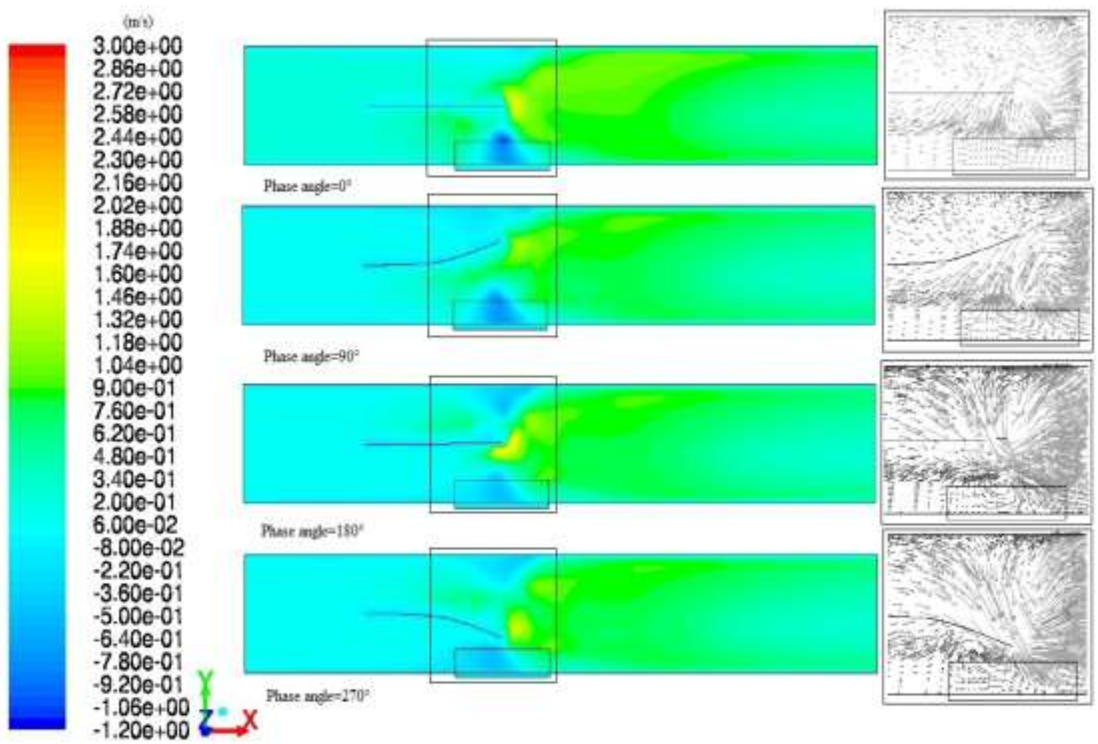

Fig. 15. AT L_g =-22.5mm, the local velocity vector distribution of x-axial direction in the Z cross-section.

4.6 The effects of changing the height H_w of single-piezoelectric fan to the front of radiator.

The fin number was n=10, and the height of single-piezoelctric fan to the front of radiator H_w was 15mm, and the position of the fan was placed 5mm in front of the radiator. The single-piezoelectric fan would induce the air into the center part of radiator, and due to the channel of radiator became larger, so that the air flow flew into the radiator became faster, but based on the blockage effects of radiator fins, the velocity of the air flow at the upper part of the back end of the radiator could be up to 1.2 m/s, and the velocity at the center part of back end of the radiator decayed less, and therefore the heat dissipation effect became better. During the air flow flew into the radiator, that would cause the flow pass through the less resistance area, so that the flow would move to the upper part of the radiator, and then impacted to the upper wall of the radiator, and diffused to both sides of the wall.

The diagram of heat dissipation and heat spreading away was shown in figure 17. And from the figure, we could see the heat effect in the wake flow area was larger, so that the flow field would affect the thermal field, the only different in the field was the place at the lower wall of wake flow area, where the heat changes were different, and at there flow could effectively flow into the radiator, so that the heat could be effectively brought away, and therefore the heat changes in the wake flow area would vary lager, and that would cause heat change at both sides of radiator became larger, and then the heat would impact to the upper wall and diffused to both sides of radiator, and the effects could be seen as at the outlet of the radiator had two non- heat change effect.

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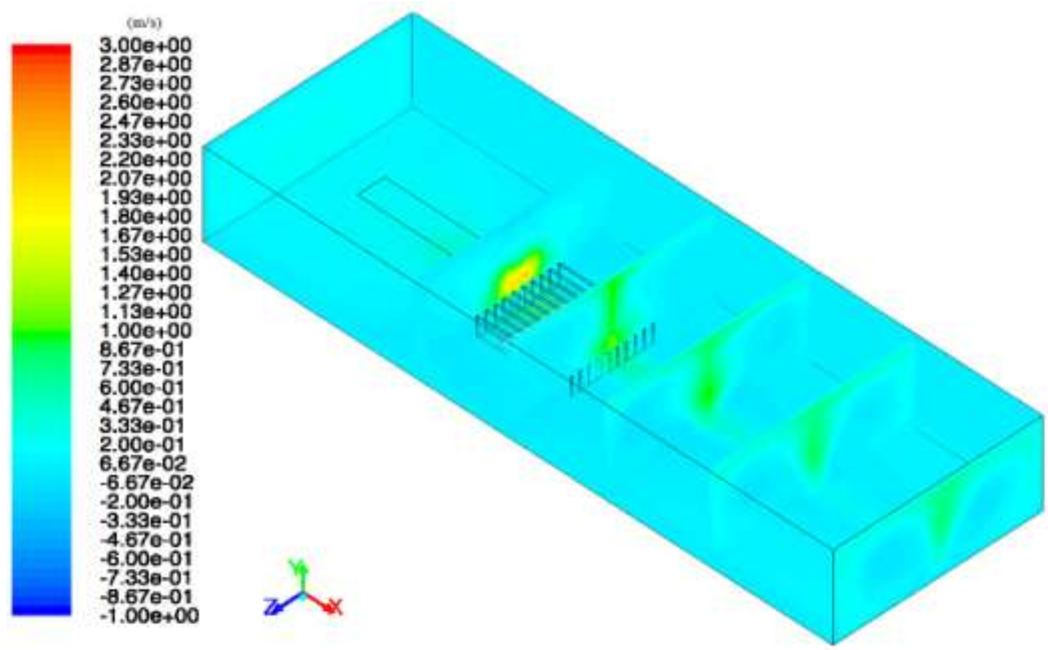

Fig. 16. At H $_w$ = 15mm, the axial velocity of the x-axis cross section in x direction.

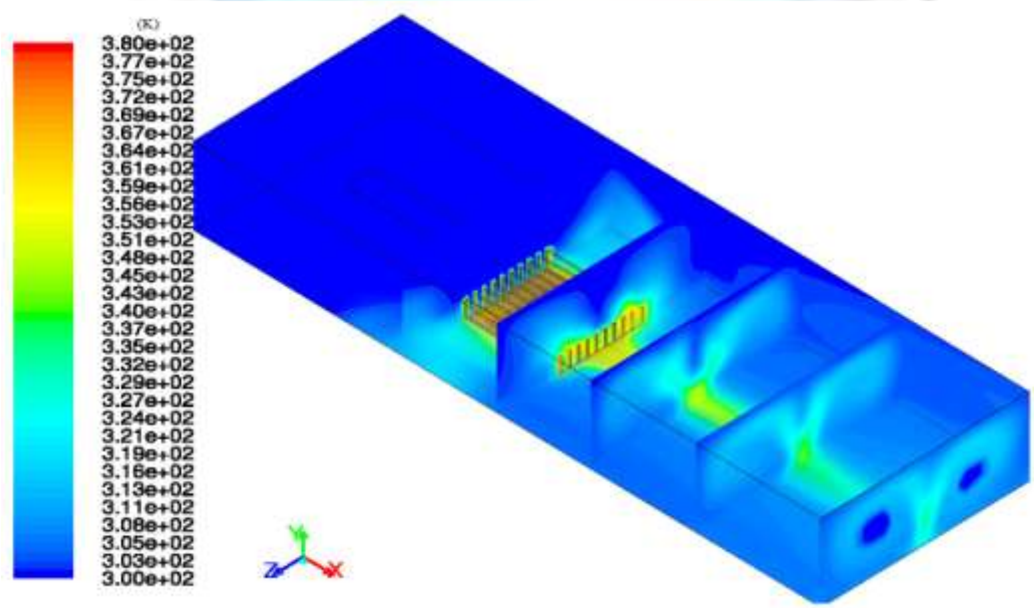

Fig. 17. At H $_w$ = 15mm, X -axis cross-sectional temperature distribution.

4.7 Overall performance

The single- piezoelectric fan and dual-0piezoelectric fans were in the same phases and different phases, whose fin number was n=10 as shown in figure 18. At these conditions, the space of the radiator channel became larger, the flow flew into the radiator became easier, so that the heat dissipation effect became obvious would be happened as the fin number was n=14, and the piezoelectric fan would be placed in front of the radiator, the position was at L $_{g=}$5mm and the height was H $_w$=25mm, because the space of the radiator channel became larger, the flow flew into the radiator became easier, so that the heat dissipation effect became obvious, but as the fan was placed in the front of the radiator, and at the position was L $_{g=}$5mm, that would stock the air flow and the flow was uneasily passed through the radiator, so the heat dissipation effects wouldn't be better, and at the position was L $_{g=}$-11.25mm, the piezoelectric fan would disturb the heat and brought the heat away by the impact flow, so that the heat dissipation effects would be better than that at L $_{g=}$0mm.

The Nusselt number effect as single or dual-piezoelectric fans placed in front of the radiator at different height (L $_g$) were shown in the figure 19. And from the results of simulation, the best heat transfer effect was the place at H_w=15mm, and as the fan was placed closer to the radiator, the space of the flow channel became larger, so that during the fan swung, the air flow would impact the radiator and Accelerate heat exchange in order to achieve the best heat dissipation effects, however at the position of the piezoelectric fan was H_w=30mm, the velocity of the air flow became smaller, and that would cause the speed of air flow in the radiator channel became smaller, and the heat transfer effect became worse.

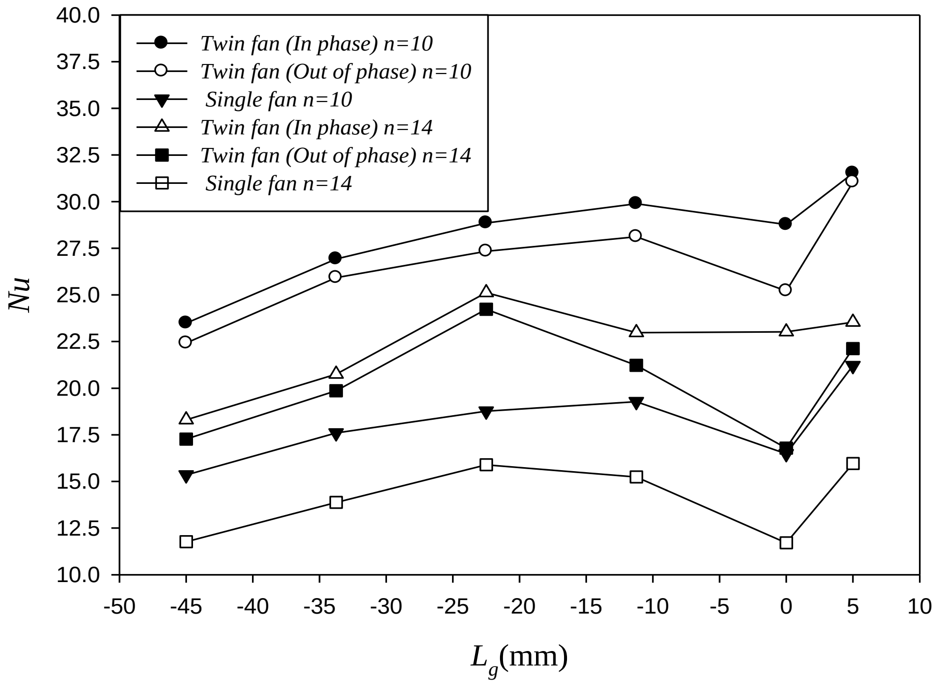

Fig. 18. The effect of Nusselt Number as the distance of front end of Single and dual- piezoelectric fans to front end of the radiator L_g was changed.

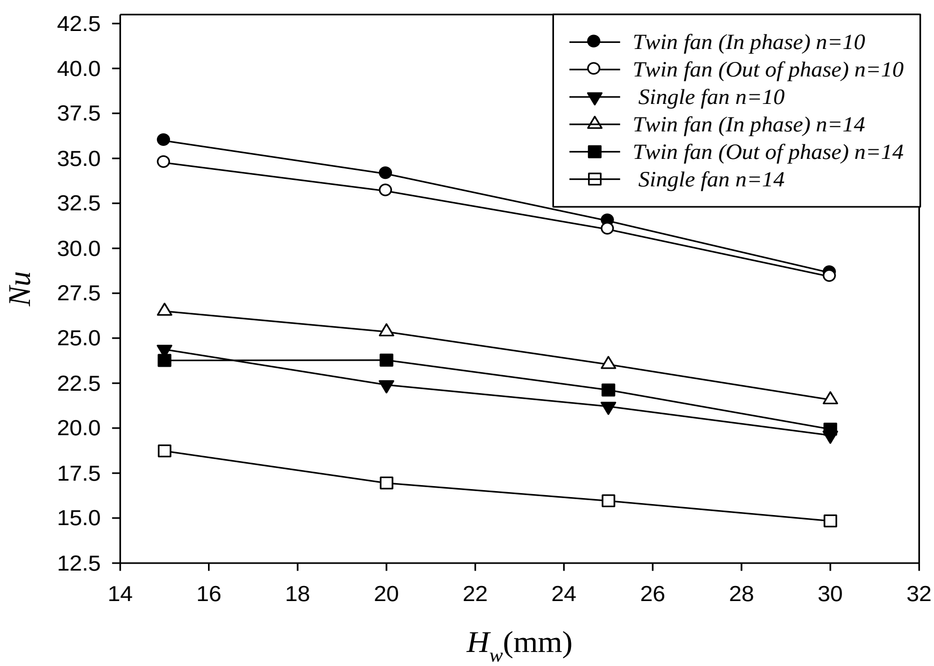

Fig. 19. The effect of Nusselt Number as the height of fan H_w to the radiator was changed.

5. Conclusion

For the dual –piezoelectric fans placed in top of heat sink, and during the fan swung that produced flow would destroy boundary layer of flow channel inside the radiator. And the produced speed could flow into the channel of radiator effectively. In the heat dissipation, both fans swung up and down which would cause the heat flow bobbing dramatically and took the heat away efficiently, and at the fin number was n = 14, the effect was the most obvious, the mainly caused this effect was because the space of adjacent fins was smaller, and the impact downstream flow was greater impacts on the speed of the radiator, so the flow speed in downstream of the radiator was increased, and that would accelerate and enhance the mix efficiency to increase the heat transfer phenomenon.

Because velocity field would be confined by the range of fins, and during the piezoelectric fan swung, the speed on the center part of radiator became smaller, and therefore the heat of radiator became larger, and that would cause the heat accumulating at the center part of radiator. During piezoelectric fan was in the swing conditions, based on the impact flow effects, the speed beside the radiator would be stirred up, and the impact downstream was more affected at the upper part of the radiator, so the speed at the upper part was greater than that at the bottom area of the radiator. From this study, we could easily find at the fin number n=10, the space of the cannel became larger, and that caused enough and greater speed of flow could flow into the flow channel, and the greater speed of flow would accelerate the heat exchange, and the accumulation of the heat in the radiator would be brought away. This Phenomenon was happened most obviously at n = 10 of the fins. During the single piezoelectric fan swung, the speed of air flow was confined by the range of the radiator fins, and the heat would be stocked in the center part of the radiator, and the heat could not be brought away, so that the heat dissipation effect was not as good as that in the dual-piezoelectric fans.

The Overall performance Conclusion could be made as:

1. Installed piezoelectric fan and changed the height placement in front of the radiator would reduce the Nusselt value of plate-type heat sink , the piezoelectric fan placed in front of the radiator height Hw = 15mm would have best performance .
2. Installed piezoelectric fan and changed the position of the horizontal displacement would damage the flow field of end side of the radiator, so that the heat accumulation in the wake flow would dissipate and the mixed flow would increase the phenomena, and therefore could enhance the heat transfer effecst.
3. Dual-piezoelectric fans placed in the center position of radiator, that would cause the vortex phenomena, and the flow in the two sides of the radiator channel would raise speed, and that caused the flow exchange in the radiator increased rapidly.
4. Piezoelectric fan placed in front of the radiator, the Nusselt value was highest than other places, and then would affect the structure of wake flow, and that would reduce the wake flow's speed change.
5. Fixed the height of piezoelectric fan as H_w =25mm, and changed the distance from the tip of piezoelectric fan to the front of heat sink L_g, and set the fin number n=14. From the study could find at the position of L_g =-22.5 mm, the heat transfer effect would be the best, and as the fin number n=10, the space of fins was larger, the flow in the radiator would flow more smoothly(Less resistance), so that at the position of L_g =-5 mm would have the best transfer effect.
6. As the fin number n=10, the height of dual-piezoelectric fans H_w=15mm, and the Nusselt value could reach to 36, and Contrary then that as the fin number n=14, and the height of dual-piezoelectric fans was placed at the same position, the Nusselt value was 26.5, It meant that the less fin number had better heat transfer effect.

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