Heat Pipe Inspection System for Thermal Management in Electronic Circuit

P. Nilas

***Abstract*--This research paper proposes the inspection system of heat pipe cooling for electronic devices, such as CPU in personal computer, laptop computer and so on. The inspection system is an essential part in production process of heat pipes CPU cooler. To ensure the high quality product, a 100% quality checking is taken into account. Generally, heat pipe inspection system is conducted by human ears that may cause errors. Therefore, this work proposes the automatic inspection system using the concept on the basis of sensing Acoustic Emission (AE) signals. In the experiment, the AE sensor was mounted on the heat pipe surface to measure the vibration degree sent to computer. The signal of acoustic vibration was analyzed by windows operating system using LABVIEW and NI USB-9233 data acquisition module. Threshold level of noise vibration shown in the program could identify quality or defect of the heat pipe cooling operation. The performances evaluation is satisfactorily achieved with the proposed system illustrated by the testing of the known condition product. This research could potentially help improving the quality assurance operation of heat pipe cooling inspection system in any industries.**

***Index Terms*—Fault diagnosis, Intelligent instruments, Information processing**

I. INTRODUCTION

Today's highest-performance computer system on advanced technology have been boosted with high power density and frequencies scale yet produce increasing rate of heat that is converted from energy consumed. No matter the design for high-speed device or development for complex performances generate temperature impact. For example, around 50W/cm2 of power density is used for high-performance microprocessors; and it might exceed 100W/cm2 at below-50nm wire size [1]. The exponentially rising of heat in the system needs a thermal management system that is more efficient to transfer large amount of heat in an architectural circuit. Solutions for heat transfer have been presented through academic studies including thermal reduction by heat sink, finning, heat pipes, cooling fan, cooling sheet, and so forth.

Kevin Skadron et al. [2] described the "HotSpot"—an accurate design yet work speedily based on heat-resistant parallel circuit and capacitances that is compatible with necessary element of the thermal case and micro-architecture block.

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In 2001, a study on dynamic thermal management [3] invested on the techniques of power dissipation limitation and major components of thermal-management technique focusing on hardware and software implementation. Although heat transfer is considered very necessary in any device with electronic circuit and is utilized with almost kinds of invention that need energy consumption, inadequacy of investigation into the area is still present. A number of academic studies on heat sink do not directly specify on methodology of heat dissipation in electronic circuit; it conducts only an open system through the field. Our paper, focusing on operation of heat pipe, is designed with functional analysis, components' characteristics, and practical experiment.

Among methods of heat dissipation in electronic circuit, heat pipes are capable of transferring a large amount heat per a given volume of working fluid with aquatic circulation in form of multiphase flow. The heat pipes are filled with liquid under low pressure (or vacuum) that boils into vapor when it absorbs heat. In multiphase flow of substances, the vapor passes to a cooler part of the heat pipe and then condenses back to liquid which can release heat curried from the circuit. Hence, the concept here is to draw the heat from the CPU to another edge of the heat pipe while liquid from the end of heat pipe contact with a larger heat sink to expel heat into air. Normally, heat pipe is a common heat dissipation method for commercial and military products. Reviewing about essential information of heat pipe, this paper covers basic mechanisms of heat pipe operation, the choices available between the design process, heat pipe reliability, and heat pipe cost. The design of an automatic inspection system is conducted through this paper by adapting sensing Acoustic Emission signal. Because the prior experimental operations were done by human ears inspection that require an experienced operator, this system is designed to solve the error that might be coursed by human nature. The AE sensor was mounted on the heat pipe surface to report the analog signal of acoustic vibration to computer through NI USB-9233 USB data acquisition module. The analyzed signals based on window operating system using LABVIEW have been present.

II. PRINCIPLE OF HEAT PIPE COOLING SYSTEM

Heat pipes are sealed and evacuated vacuum tight vessels which have been partially backfilled with a fluid. This fluid serves as the heat transfer media. The internal walls of the vessel are lined with a porous media (the wick) which acts as a passive pump, via capillary action, to circulate the condensate within the heat pipe. Fig.1. is a cut away view of a heat pipe showing the wick and the vapor and liquid flow characteristics.

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When heat is applied, the working fluid in the heat input area (the evaporator) is vaporized. This generated vapor is slightly higher in temperature and pressure than that of the vapor in other regions of the heat pipe. As a result of this pressure gradient, the vapor flows to the cooler regions of the heat pipe where it condenses. The condensate is then returned to the evaporator region via the wick structure. As a frame of reference, the temperature gradient associated with this vapor pressure gradient is typically in the order of one degree Celsius.

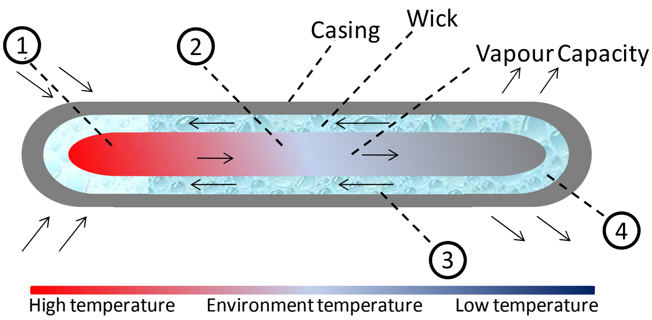

Fig. 1. A flow diagram of thernal-fluid in heat pipes

Fig.1. shows the heat pipe thermal cycle that includes the following state:

1. The working fluids evaporate to vapour absorbing thermal energy.
2. The vapour migrates along cavity to lower temperature end.
3. The vapour condenses back to fluid and is absorbed by the wick releasing thermal energy.
4. The working fluid flows back to higher temperature end.

These two phase modes of heat transfer provide the heat pipe with its high effective thermal conductivity. For example, a 3mm diameter copper rod, 20cm long heated at one end, cooled at the other and insulated in between would have an end to end AT of over 300°C at IOW. A heat pipe of the same dimensions and with the same heated and cooled areas would exhibit an end to end AT under 5 'IC. This equates to a thermal conductivity for the heat pipe of 60 times that of copper. One thing that has to be noted in the heat pipe augmented systems is that the heat pipe itself is a heat transfer device, not a heat dissipation device. The heat pipe must be coupled to other components (such as a heat sink) to accomplish the dissipation function via natural or forced convection. What the heat pipe adds is a high thermal conductivity thermal link permitting the heat sink to be located remote from the heat source. The heat pipe can also increase the effectiveness of the heat sink surface area by distributing the heat load almost isothermally over its entire surface, overcoming the material's low thermal conductivity (compared to heat pipes).

The wick structure is the pumping system which circulates the condensate from the condenser region to the evaporator region. There are three typical wick structures utilized in commercial heat pipes:

1. Swaged or extruded grooves
2. Screen mesh
3. Sintered powder metal

The performance of the wick is set by its pore radius and permeability. The smaller pore radius and the higher pump capacity, boost up the higher power throughput capability. Swaged or extruded grooves are made as an integral part of the tubing production process. Groove wicks provide a low cost fluid transporting approach; however, manufacturing limitations of the groove's size diminishes the pumping capacity of this type of wick. The limitation in pumping capacity decreases the maximum power throughput of the heat pipe as well as the ability of the heat pipe. For function in orientations, the wick is required to lift the working fluid against a gravitational head. For this instance, the heat input area of the heat pipe is placed physically above the cooled regions of the heat pipe. Screen mesh wick structures can be made with finer pores and hence offer improved performance over simple groove wick structures. Since the installation of the screen is an additional step in the production of the heat pipe and because the process can be tedious, screen mesh wick heat pipes are slightly more expensive than groove wick heat pipes. Sintered powder metal wicks are porous metal structures which are integrally formed within the heat pipe envelope. Because the size of the particles used in forming the sintered structure is various, a tailored high performance wick can be made by using this process. Sintered powder metal wick heat pipes can be used to work in any orientation, even with the vertical pipe and the top-heat source. This capability makes the sintered powder metal wick structure a very high performance system, particularly for applications such as notebook computers which their heat pipes function is uncertain. The cost of sintered powder wicks is cheaper than screen mesh wicks because of their ease of installation under the heat pipe's manufacturing process. At high volumes, cost of sintered powder wicks is close to that of groove wicks structures. Although sintered powder wicks requires an additional production step. This supplementary process is compensated by the material cost saving of thinner wall of sintered wick heat pipes.

III. Inspection and Analysis

According to the real operation in CPU cooling system, we simulate the operating condition by heat source from heater and temperature control system. The correct operation of the heat pipe cooler has to maintain the temperature at the steady state as shown in Fig.2.

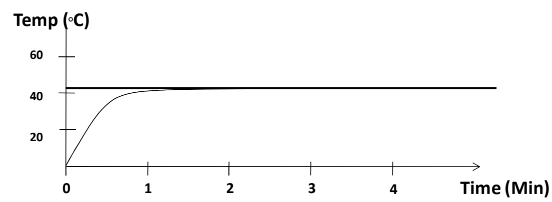

Fig. 2. Normal operating condition

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On the other hand, if the temperature cannot keep the steady state, the cooling system will have problem as illustrated in Fig.3.

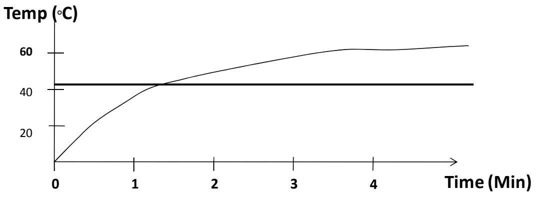

Fig. 3. Abnormal operating condition.

The reaction testing of heat pipe is to study the heat transfer properties. The quality of heat and mass transfer of the heat pipes cooling system is related to the vibration inner the pipe line. The liquid flow in the pipe line can be divided into two types as the following.

Laminar flow is particles of motion flow in parallel line with similar level. Flowing speed of level flow is almost the same yet forms a little different value. Laminar flow is a relation theory of shear stress and transformation ratio of angular deformation. It is the result of viscosity of the flow with velocity gradient that is $\tau = \mu(dv/dy)$ viscosity of laminar flow is changed to turbulent flow.

Turbulent flow is flowing particles with confusing movement. Particles speed of flow depends on differences of size and dimension. The shear stress for turbulent flow is

$$R\ \tau = (\mu + N)\frac{dv}{dy} \qquad (1)$$

where N is component show from turbulent.

Since the viscosity of flow is result reaction of loss head**,** the status of head loss in laminar flow and turbulent flow is different from experiment result by plotting on graph and scale log-log follow Fig. 4.

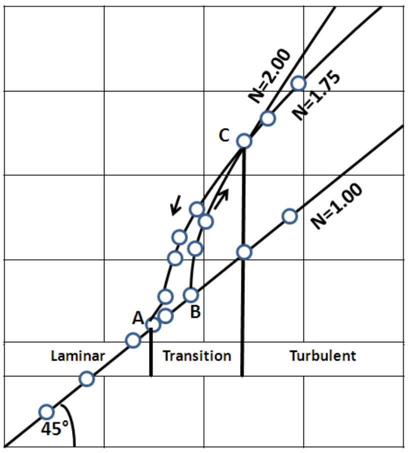

Fig. 4. Log-log graph of the flow properties

Fig.4. shows changing point from laminar flow transferring to turbulent flow. There are 2 related points: A point is a lower critical and B point is a higher critical. Speed is unavailable. It cannot be identified which laminar or turbulent flow is. But the point which is surely identified is Reynolds number that is

$$N_R = \frac{Dv\rho}{\mu} = \frac{DV}{\upsilon} \qquad (2)$$

By N_R is Reynolds Number not unit

D is diameter of pipe line m unit

V is average speed in pipe m/s

μ is viscosity of flow in pipe line Pa.s

ρ is density of flow in pipe line kg/m^3

υ is viscosity kinematic of flow in pipe line m^2/s

If the flow of pipe represents D in equation 2 by radius hydraulic

Is $$A = \frac{R}{P} \qquad (3)$$

By R is radius hydraulic m

A is area of flow pass m^2

P is wetted perimeter is long line of face area of flow

The fluid flow, specifically the flow surface area, is touching the pipe. Thus, Reynolds number in term of radius hydraulic is

$$N = \frac{V(4R)}{\upsilon} \qquad (4)$$

Critical value of Reynolds number is called that laminar flow or turbulent flow is

$$N_R = 2000 \qquad (5)$$

If N_R is less than 2000, it is laminar flow. But if it is higher than 2000, it is turbulent flow.

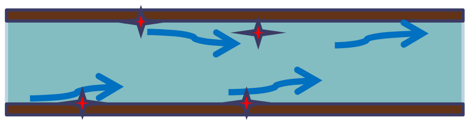

Fig. 5. Reaction friction of liquid and wall of pipe line

P = Flow of inner of liquid transfer to vibration force
T = Total temperature effect toward reaction of molecule steel of pipe line.
F = Friction from liquid perform pipe line effect to vibration force.

These parameters will be integrated to total vibration. Thus, V_t = Total vibration from any reaction.

$$V_t = P+T+F \qquad (6)$$

Our research utilizes this beginning parameter for vibration sensor selection.

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IV. INSTRUMENTATION SYSTEM DESIGN

This research proposed the instrumentation for inspection the heat pipe quality by measuring the vibration generated from liquid and vapor flowing inner the heat pipe. The Acoustic Emission (AE) sensor is selected to use as the vibration sensor which mount on the heat pipes surface. The specification of AE sensor is low impedance, fast response, and high sensitivity with 5 volts of output signal. This sensor is produced from piezoelectric with titanium case.

The data acquisition module from National Instrument model NI USB-9233 has been applied to get the analog signal from AE sensor. This module consists of 4 channel inputs of 24 bits analog to digital convertor with 102 dB of maximum signal and dynamics at 50 ks/s. As shown in Fig.6, USB2.0 is used to communicate between computer and data acquisition module. The heat source for the experiment generates by heater and temperature control system in order to simulate the heat condition as in the real operation.

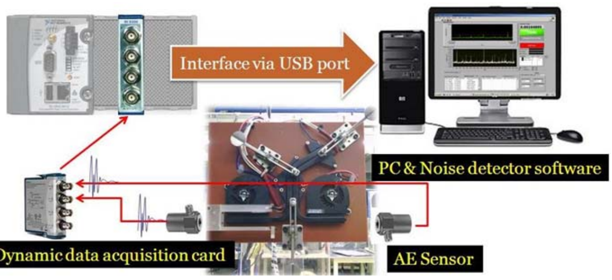

Fig. 6. System Overview Vibration Analyses Experiments

This research uses Lab view version 7.1 from National Instrument to develop the programming software for analyzing and inspecting the heat pipe cooling system. In the experiment, the 30 pieces of known condition of product were divided into 3 groups i.e., no noise, low noise, and large noise. The no noise and low noise products can be classified as the high quality products while large noise product is considered defect. The noise in this paper means the sound of vibration. The first experiment was performed the temperature measurement as shown in Table I, Table II and Table III.

TABLE I. RECORDS PIPE NO NOISE 10 PCS.

No Noise	**Time(Sec)**						***unit***
No.	***10***	***20***	***30***	***40***	***50***	***60***	
1	38	50	58	62	61.9	62	°C
2	39	51.2	58	62	61.9	62.5	°C
3	37.5	51	58.1	61.5	62.3	62.3	°C
4	38.5	51.7	58.2	62.1	62.5	62.4	°C
5	39.5	51.9	58.1	61.9	62.1	62.2	°C
6	40	51.2	58.3	61.1	62.1	62.2	°C
7	39.5	51.6	58.1	61.6	62.3	62.3	°C
8	39.7	51.8	58.3	61.8	62	62.1	°C
9	40.1	53	58.2	62	62.5	62.4	°C
10	39.5	51.7	57.9	61.5	62	61.9	°C

TABLE II. RECORDS DATA OF HEATPIPE LITTLE NOISE 10 PCS.

Little Noise	**Time(Sec)**						***unit***
No.	***10***	***20***	***30***	***40***	***50***	***60***	
1	39.8	52.2	58.1	62.3	63.1	63.1	°C
2	39.7	52.1	58.3	63.2	63.3	63.3	°C
3	39.6	52.3	58.4	63	62.9	63	°C
4	39.7	52.4	58.5	63.2	63.4	63.3	°C
5	39.5	52.5	58.3	63.2	63.3	63.4	°C
6	40.1	53.4	58.4	63	63.1	63.1	°C
7	41	52.3	58.2	63.1	63.3	63.2	°C
8	40.7	52.7	58.5	63.2	63.3	63.3	°C
9	40.4	53.1	58.6	63.2	63.2	63.2	°C
10	40.5	52.6	58.3	63.1	63.3	63.4	°C

TABLE III. RECORDS DATA OF HEATPIPE LARGE NOISE 10 PCS

Large Noise	**Time(Sec)**						***unit***
No.	***10***	***20***	***30***	***40***	***50***	***60***	
1	40.2	55.2	60.1	64.5	68.2	71.3	°C
2	40.4	55.3	61.2	64.2	68.3	71.4	°C
3	41.1	55.4	61.1	64.1	68.5	71.5	°C
4	41.9	55.3	60.9	64.2	67.4	71.6	°C
5	41.3	55.6	61.4	65	68.2	72	°C
6	40.1	54.9	61.3	64.5	68	71.8	°C
7	41	55.8	60.8	64.2	68.4	71.4	°C
8	40.7	55.1	61.3	64.3	68.2	71.2	°C
9	40.4	54.8	61.2	64.2	68.5	71.8	°C
10	40.5	55.6	61.5	65.1	69	72.1	°C

According to Fig.7., the temperature of large vibration noise are not met the steady state, therefore, the cooling system is slightly defective.

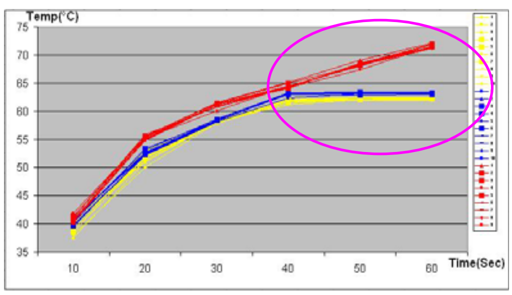

Fig. 7. Comparison temperature of known condition of product

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In the second experiment, the developed program using Labview was applied. The threshold level of vibration noise can be recognized to pass or reject of the heat pipe cooling system as shown in Fig.8. to Fig.10.

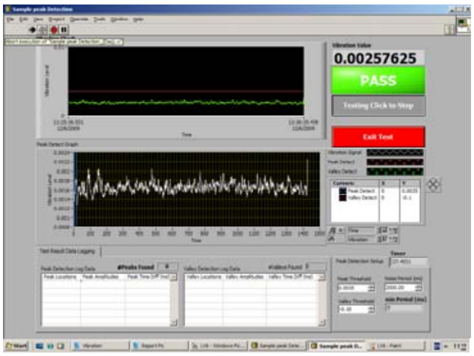

Fig. 9. No noise in heatpipe

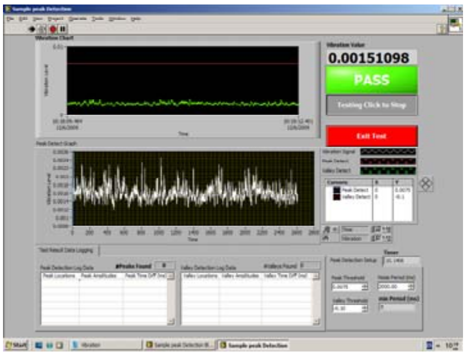

Fig. 10. Little noise in heatpipe

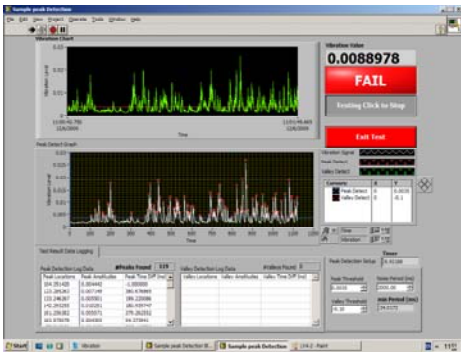

Fig. 11. Large noise in heatpipe

V. CONCLUSION

In this paper, we present the design of an automatic inspection system using the concept on the basis of sensing Acoustic Emission signals. This research can solve the problem from the previous operation that uses human ear's inspection as well. Therefore, this system is designed to solve the problem from human error inspection. From the experiment, the temperature of the large vibration noise are not met to the steady state, therefore, we can use this point to identify the defect of product. The developed program using Lab view can be effectively applied to the automatic inspection system by defined the threshold level of vibration noise in order to be recognized to pass or reject of the heat pipe cooling system. This research can be used in the real operation efficiently.

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