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VOLUME ANALYSIS OF COOLING SYSTEMS WITH SYNTHETIC JET ACTUATOR

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Abstract: *Increasing demands on the power and efficiency of electronic devices mean that more and more efficient methods of active cooling are being sought. One of the active cooling methods is the synthetic jet. The investigations show that the synthetic jet provides higher heat transfer enhancement than a continuous jet. But, in the papers, the size of the cooling devices is usually omitted. In this paper, the size of the chosen synthetic jet cooling system was investigated and compared to the size of the fan-cooled heat sink and heat sink under natural convection. Additionally, a comparison of the performance of different cooling devices was made. Investigation showed that the size of synthetic jet actuator cooling devices used is much bigger than the size of the fan-cooled heat sink, and therefore the heat sink heat transfer rate per unit temperature difference and unit volume of the cooling device is even 12 times lower than in case of the fan-cooled heat sink. Design challenges of cooled devices, which use synthetic jet actuators were presented.*

Keywords: Performance, Forced convection, Natural convection, Fan, Heat sink, ZNMF.

1. Introduction

Increasing demands on the power and efficiency of electronic devices mean that more and more efficient methods of active cooling are being sought, and one of these methods is the synthetic jet (SJ) used for heat transfer enhancement. SJ is generated by periodic ingestion and expulsion of the worked fluid (mainly air or water) to the closed cavity by one or more orifices. This is achieved by replacing one or more of the synthetic jet actuator (SJA) walls with movable or deformable elements like a piston, loudspeaker, or piezoelectric. When this element decreased the volume of the actuator cavity, the fluid is pushed and moves away from the orifice and the vortices ring is generated on its edges. In this way is generated non-zero-net mass-flux at some distance from the orifice. When the volume of the actuator cavity increases the new volume of fluid is sucked through the orifice from the surroundings. It must be noted, that in the orifice the mass-flux is zero, therefore SJ is also called zero-net mass-flux(ZNMF).

Lasance et al. (2008) investigated the double SJA with the long orifice and showed that the SJ provides better cooling than a fan at the same power. However, they did not compare the volume of devices and it is an often-overlooked point. The size of the cooling device may decide whether this solution is applicable in practice. Additionally, authors very often skipped the size of the investigated devices, and it is impossible to estimate their size. Probably the first time the problem of the SJ cooling devices volume was discussed by Gil et al. (2021). However, Gil et al. (2021) investigated only the heat sink heat transfer rate per unit temperature difference and unit volume of the cooling device and showed that the performance of SJ cooling devices is 14 times lower than the performance of fan-cooled heat sinks. They include the volume in the performance of the devices but not showed the volume value. Additionally, SJA with an integrated heat sink was only compared in this paper.

SJ is used for the heat transfer enhancement in a laminar channel flow (Mohammadpour et al., 2022), as an impinging synthetic jet on a flat surface (Gil et al. 2020), on a heat sink (Chaudhari et al. 2012), or as an actuator with integrated the heat sink in the cavity (Gil, 2019). However, SJ is used mainly for LED cooling

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(Deng et al. 2017; Gil, 2019). The SJ can be used also to cooling of the processors during the numerical analysis (Skibicki et al. 2017; Tomaszewski et al. 2020).

In this paper, the volumes of the chosen cooling devices with SJA were compared to the volume of the heat sink under natural convection and fan-cooled heat sink. Because the volume of the cooling devices depends on the performance of the cooled area of the analyzed examples was as close as possible. However, to eliminate this dependency the heat transfer rate of the heat sink per unit temperature difference and unit volume of the cooling device was additionally analyzed.

2. Methods

In the paper, the results of the article analysis were presented. Articles have been selected that allow the calculation or evaluation of the cooling system volume. Additionally, where possible the heat transfer rate of the heat sink per unit temperature difference and unit volume of the cooling device (including the heat sink and the actuator forcing the flow) was calculated. This parameter was widely discussed by Gil et al. (2021) and can be calculated as:

$$\varepsilon = \frac{\dot{Q}_{\mathrm{HS}}}{\Delta T\ V} = \frac{1}{R \cdot V} \tag{1}$$

where $\dot{Q}_{\mathrm{HS}}$ is a thermal power dissipated by the devices [W], ΔT is the temperature difference between the air and the heat sink [K], V is the volume of the device [m^3], R is the heat sink thermal resistance [K/W].

The volume of the cooling system is calculated as the whole volume of the device including the actuator and the space between the actuator and the cooled object.

3. Results and discussion

3.1. Volume comparison

The volume of the different cooling devices was presented in Tab. 1:. The different type of cooling devices was presented for comparison: the heat sink operated under natural convection, the fan-cooled heat sink, the SJA with the heat sink in the cavity, and the impinging SJ used for the hot surface colling. It must be noted, that in the case of the heat sink used in the case of impinging jet the size of the devices increased. The cooled area is significant for the volume of the whole device and therefore the presented devices have a diameter in the range of 150 – 200 mm, except fan-cooled heat sink. But, this device was added because of ε analisis. In case of impinging synthetic jet, the devices were chosen based on the loudspeakers diameters.

Tab. 1: The volume of the cooling system

Cooling device	**Source**	**Volume, cm^2**
Heat sink under natural convection	Fischerelectronik ICK S R 140×70	1080
Heat sink under natural convection	Fischerelectronik ICK LED R 200×40	1260
Heat sink under natural convection	Yu et al. (2011)	411
Heat sink under natural convection	Gil (2019); Gil et al. (2021)	644
Fan-cooled heat sink	Fischerelectronik LA ICK PEN 38W12	122.5
Fan-cooled heat sink	Jian-Hui and Chun-Xin (2008)	381
Fan-cooled heat sink	Saini and Webb (2002)	220
Synthetic jet actuator with the heat sink in the cavity	Gil and Wilk (2021)	2444
Synthetic jet actuator with the heat sink in the cavity	Gil et al. (2021)	2300
Impinging synthetic jet (hot surface), x/D = 2; 5	Gil et al. (2020)	2936/4081
Impinging synthetic jet (hot surface), x/D = 3	Greco et al. (2014)	4825

The volume of the device in the case of impinging SJ is dependent on two parameters: the size of the actuator and the value of *x/D*. Greco et al. (2014) investigate twin and single actuators with a long orifice of 210 mm and a diameter of 21mm during an orifice used Gil et al. (2020) was 5mm long, and the diameter of 15 mm. This parameter has a significant impact on the volume of cooling devices and the SJ parameters. However, more important due to the heat transfer enchantment is the ratio *x/D*. Depending on the *x/D* the volume of the cooling devices investigated by Gil et al. (2020) has 2.9 dm^3 or 4.1 dm^3. The value of $x/D = 5$ was indicated by Gil et al. (2020) as the stagnation point heat transfer coefficient. But also higher values are indicated by some investigations(Singh, Sahu, & Upadhyay, 2022; Singh, Sahu, Upadhyay, & Jain, 2020). So it can be assumed that the device using impinging SJ by the highest heat transfer parameters will be greater than it was presented in Tab. 1:. The use of the SJA with the heat sink in the cavity (Gil, 2019; Gil et al., 2021; Gil & Wilk, 2021) decreases the volume of the devices even by half. But, still need more space than the heat sink under natural convection and the device proposed by Gil et al. (2021) increased the device volume from 0.64 dm^3 (the heat sink under natural convection) to 2.3 dm^3. Of course, forced convection increases the heat transfer and therefore the ε should be analyzed.

3.2. A comparison of the performance of different cooling devices

A comparison of the heat sink heat transfer rate per unit temperature difference and unit volume of the cooling device was presented in Fig. 1:. The lowest ε is obtained by the heat sink under natural convection due to the lowest heat transfer. The use of SJA with an integrated heat sink increased the ε around 2 times compared to the heat sink under natural convection optimized by Yu et al. (2011). But still, the use of the classic fan-cooled heat sink has the highest ε, even over 10 times compared to the case of the device investigated by Saini and Webb (2002) and 3 times compared to the commercial solution. It is caused by the volume of the devices used SJA. Unfortunately, we did not find the article which would calculate ε in the case of the impinging SJ possible, but an analysis of the volume and results presented in Fig. 1: showed that the ε will be probably lower than in the case of the fan-cooled heat sink. Espessialy, that the comparision of the fan coling and impiging SJ showed that the advantage of the SJ is insignificant (Lasance et al., 2008). Therefore, one should try to optimize the size and performance of SJA if it is to replace the cooling with a fan.

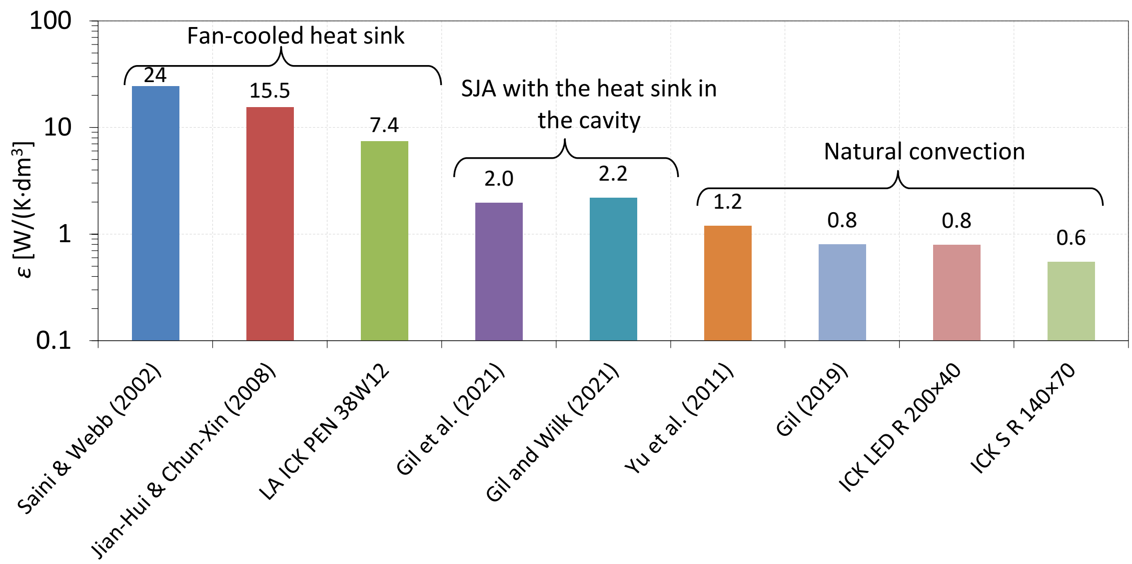

Fig. 1: Comparison of the heat sink heat transfer rate per the unit temperature difference and the unit volume of the cooling device.

4. Conclusions

In this paper, the comparison of the volume and the heat sink heat transfer rate per unit temperature difference and unit volume of the cooling device were made for the heat sink under natural and forced convection (ε). In the case of volume comparison, the devices with a similar cooled area were compared.

Analysis showed that the volume of the devices using SJ is very big, which caused their performance ε to be lower than the fan-cooled heat sink. Even in comparison to the commercial solution. The ε of the impinging SJ were not compared to the other analyzed devices, because no paper was found to calculate it. But having the volume analysis, it is to be expected to be lower than in the case of the fan-cooled heat sink. Therefore, one should try to optimize the size and performance of SJA if it is to replace the cooling with a fan. This can be achieved, for example, by designing solutions dedicated to cooling specific electronic components or devices. A the end it must be noted, that the volume analysis of the devices is insufficient but the volume of this paper it is impossible to carry out a more extensive analysis taking into account e.g. the power consumed by the devices or the noise generated. This will be taken into account in the future.

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