A Fundamentally New Approach to Air Cooled Heat Exchangers

LABORATORY DIRECTED RESEARCH & DEVELOPMENT

Sandia National Laboratories

Dr. Jeff Koplow (8365)

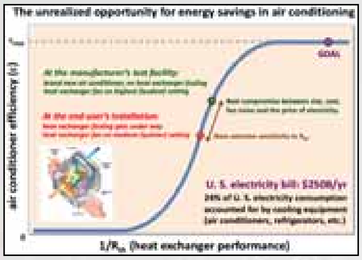
Problem

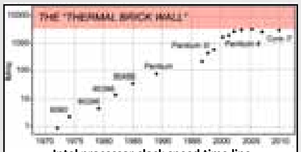
Air-cooled heat exchanger technology is of tremendous importance to both the information technology (IT) and the energy sectors. The conventional "fan-plus-finned-heat-sink" device architecture suffers from:

- **low cooling capacity per unit volume (because of heat-sink boundary-layer effects)**
- **limitations imposed on cooling capacity by fan noise**
- **heat sink fouling (clogging of the heat exchanger by dust and other foreign matter)**

In recent years, there has been a great deal of progress in *heat extraction* technology (e.g., devices heat pipes and micro-channel coolers). But the subsequent step of *heat rejection* remains the technology bottleneck; no significant advances have been made in air-cooled heat exchanger technology during the past several decades. For example, it's long been known that the bottleneck to heat transfer is the layer of "dead air" that envelops and strongly adheres to the heat sink fins. But no one has devised a practical solution to the boundary layer problem.

Technology grid lock with serious consequences...





Intel processor clock speed time line

"Over the past 40 years the technologies, designs and performance of air-cooled heat exchangers have remained unchanged. The performance data for today's state-of-the-art heat exchangers and blowers is, in many cases, based on measurements performed in the 1960s". (DARPA BAA 08-15, January 2008)

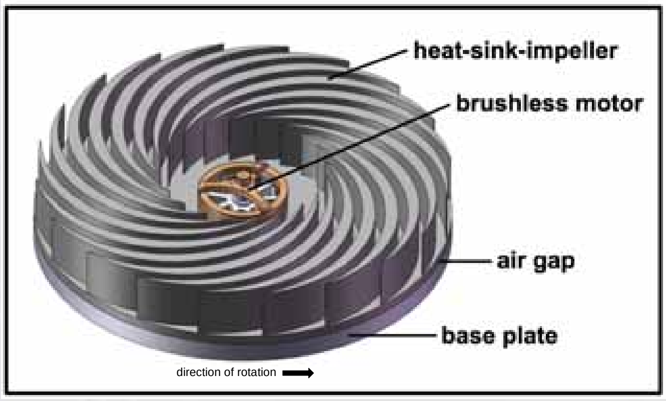
Approach

The Air Bearing Heat Exchanger (rethinking the problem of heat transfer)

In the *Air Bearing Heat Exchanger*, heat is transferred across a narrow air gap from a stationary heat spreader to a rotating structure that is a hybrid of a finned heat sink and an impeller. This places the heat sink boundary layer in an accelerating frame of reference, which at several thousand rpm, reduces the thickness of the boundary layer by up to 10X, thereby providing greatly enhanced heat transfer.

The device's "direct drive" architecture generates relative motion between the finned heat sink and surrounding air by simply rotating the heat-sink-impeller through the air. This provides a drastic improvement in efficiency and greatly reduces fan noise.

Another unique property of this rotating finned structure is that it provides the first air-cooled heat exchanger device architecture with intrinsic immunity to heat sink fouling. Because it rotates at high speed, dust and other particulate matter do not adhere to the surface of the heat exchanger.



stationary base plate → heat → 0.001" gap air bearing → heat → rotating (5000 rpm) heat-sink-impeller → heat → ambient air reservoir

- heat is transferred to a rotating frame of reference
- thermal resistance of air gap region is very low (0.02 C W^{-1} for 10-cm-diameter device)
- hydrodynamic air bearing: self-pressurized, self-regulated gap distance, extremely stiff
- numerous other geometric configurations possible

Results

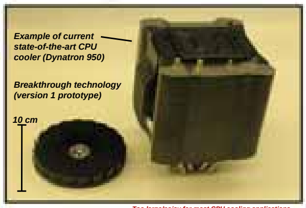
In our version 1 prototype device, we have demonstrated a factor of 30 improvement in heat transfer per unit heat exchanger surface area (see below). This confirms that the proposed new mechanism for heat transfer at the solid-gas interface, which entails placement of the heat exchanger boundary layer in an accelerating frame of reference, does indeed provide a fundamental breakthrough in heat exchanger performance. We have also confirmed predictions regarding low-noise operation and immunity to heat sink fouling. We anticipate as much of a factor of 4 further improvement in cooling performance in an optimized device.

Far more efficient use of heat exchanger surface area

The **boundary layer thinning effect** and the **direct drive advantage** make up for the fact that the version 1.0 air bearing cooler has a **factor of 30 less surface area** than the G950 CPU cooler.

Version 2 device: push thermal resistance to **≤ 0.10 C/W** by increasing surface area heat-sink-impeller fins to ~1000 cm^2.

Version 3 device: **computational fluid dynamic optimization of heat-sink-impeller** geometry.



Too large/noisy for most CPU cooling applications
No further scaling of cooling performance possible

Specification	Prototype v. 1.0	Dynatron G950
cooling performance (thermal resistance)	0.20 C W^{-1}	0.20 C W^{-1}
electrical power consumption	6.8 W	5.4 W
acoustical noise	"very quiet"	26.0 dBA
device size (total volume)	170 cm^3	2200 cm^3
heat exchanger fouling (e.g. dust)	eliminated	inevitable
heat exchanger surface area	400 cm^2	12000 cm^2
h (heat transfer coefficient, area-averaged value)	120 W m^{-2} K^{-1}	4.1 W m^{-2} K^{-1}

Intrinsic immunity to heat sink fouling

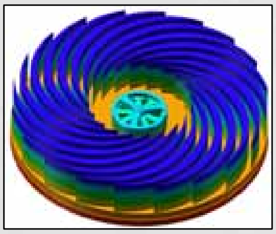
<u>**Inherent design conflict:**</u> In a conventional air-cooled heat exchanger, to facilitate heat transfer the the finned heat sink must comprise a structure having very high surface-area-to-volume ratio. Such a structure efficiently collects dust. But to achieve low thermal resistance, such a device must ingest large quantities of ambient air on a continuous basis.

Referring to the conventional CPU cooler shown on the right, the finned heat sink, which is stationary, cannot be seen because it is completely covered in dust. On the other hand, the fan blades of this CPU cooler operate in the same environment but do not become coated in dust.

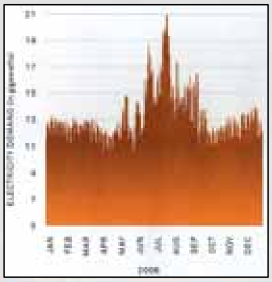
Similarly, when rotating at several thousand rpm, the fins of the air bearing heat exchanger also remain pristine.

Significance

In the IT sector, a breakthrough in air-cooled heat exchanger technology could immediately provide a factor of 2 increase in CPU clock speed, and eventually allow processors with clock speeds in excess of 10 GHz. The air bearing heat exchanger may also be well suited to reducing electrical power consumption in data centers and servers farms; the annual energy usage of the IT sector recently surpassed that of the aviation industry.



In the energy sector, air conditioners, heat pumps, and refrigeration equipment account for 24% of electricity usage in the U.S. The electrical energy sector depends critically on the scaling laws that govern device operation. The most significant achievement of the work described here is experimental confirmation of a new and potentially very powerful approach to thermal management in numerous potential applications. Power consumption of these devices could be reduced by ~30% with a breakthrough in air-cooled heat exchanger technology. Such cooling loads are also the primary source of heat-wave driven load spikes, and thus have a direct bearing on electrical grid stability and operating margin.



Successful application of air bearing heat exchanger technology in the energy sector depends critically on the scaling laws that govern device operation. The most significant achievement of this work is experimental confirmation of a new and potentially very powerful approach to thermal management in numerous potential applications

It should therefore be understood that we have merely scratched the surface of this new and fascinating subject in heat transfer technology. Future programs entailing comprehensive fluid dynamic modeling, laboratory flow imaging, and device optimization must be carried out to realize the benefits of this apparent technology breakthrough.

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