US 20130327505A1

(19) United States

(12) Patent Application Publication

Gonzalez et al.

(10) Pub. No.: US 2013/0327505 A1

(43) Pub. Date: Dec. 12, 2013

(54) **KINETIC HEAT SINK HAVING CONTROLLABLE THERMAL GAP**

(71) Applicant: **CoolChip Technologies, Inc.**, Boston, MA (US)

(72) Inventors: **Lino A. Gonzalez**, Somerville, MA (US); **William R. Sanchez**, Somerville, MA (US); **Steven Stoddard**, Boston, MA (US)

(21) Appl. No.: **13/911,677**

(22) Filed: **Jun. 6, 2013**

Related U.S. Application Data

(60) Provisional application No. 61/656,868, filed on Jun. 7, 2012.

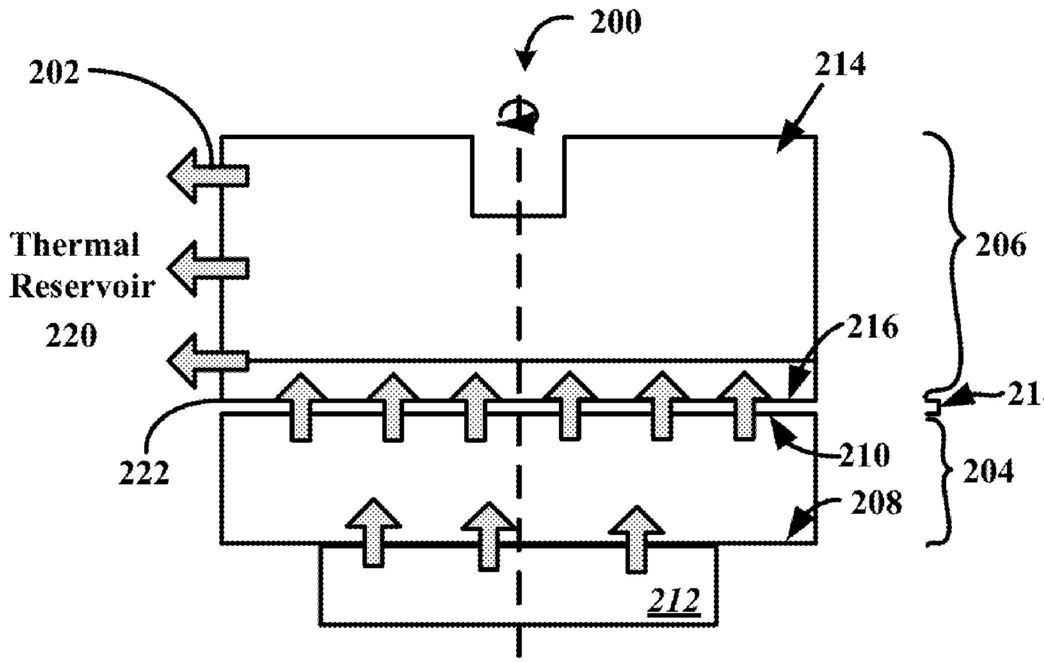
Publication Classification

(51) **Int. Cl.**
F28F 3/00 (2006.01)

(52) **U.S. Cl.**
CPC ***F28F 3/00*** (2013.01)
USPC .. **165/104.26**; 165/185; 165/104.19; 165/133

(57) **ABSTRACT**

An apparatus and method for cooling a heat-generating component includes a stationary base structure and a rotating structure. The stationary base structure is mountable at the first heat-conducting surface to or near the heat-generating component. The stationary base structure has a first and second heat-conducting surface to conduct heat therebetween. The rotating structure is rotatably coupled to the stationary base structure. The rotating structure has a heat-extraction surface facing the second heat-conducting surface across a spatial gap. As a result of the rotating structure rotatably moving, the rotating structure substantially transfers the heat from the second heat-conducting surface to a thermal reservoir communicating with the rotating structure. In addition, as a result of the rotating structure rotatably moving, at least two surfaces of the rotating structure and/or the stationary base structure generate a thrust and an opposing thrust to vary and/or maintain the spatial gap.



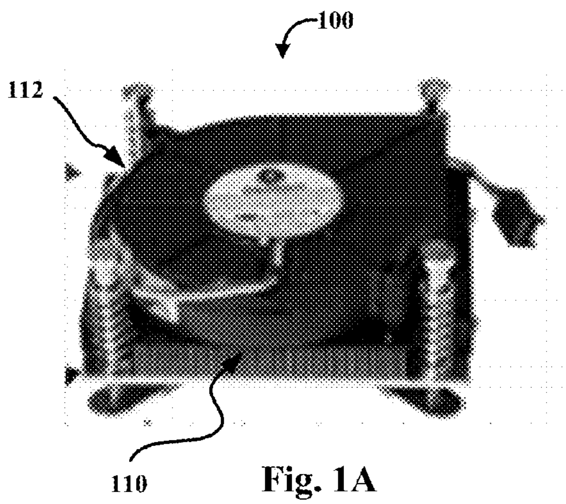


Fig. 1A

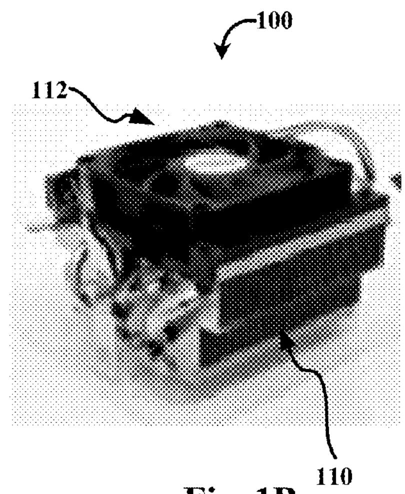


Fig. 1B

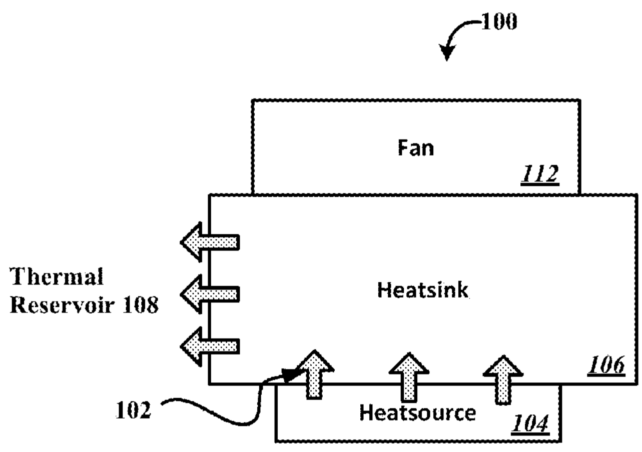


Fig. 1C

(Prior Art)

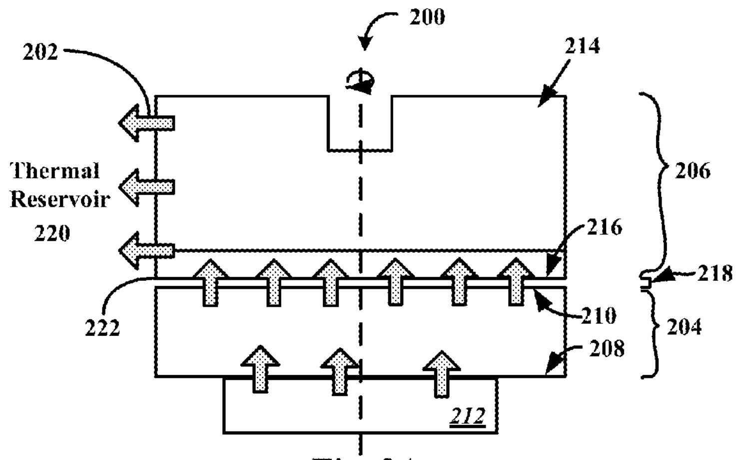


Fig. 2A

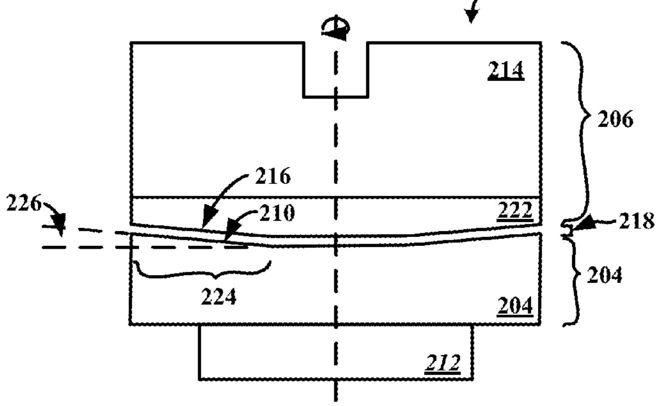


Fig. 2B

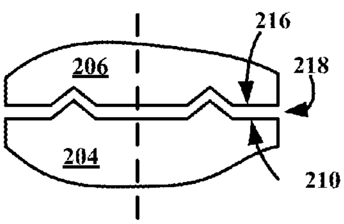


Fig. 2C

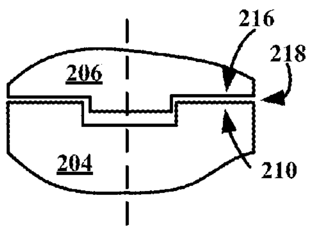


Fig. 2D

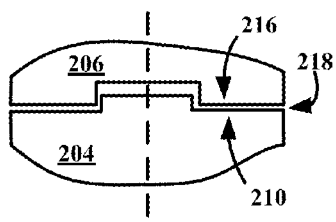


Fig. 2E

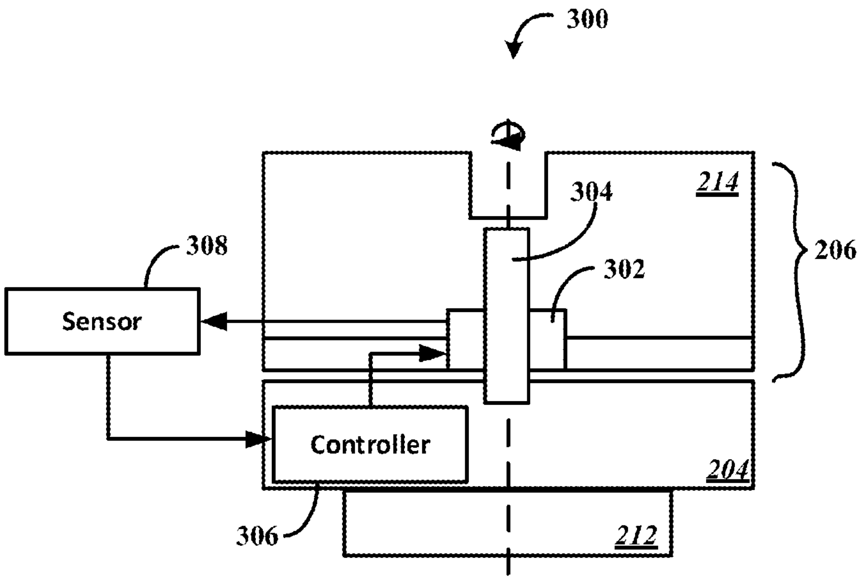

300
214
304
206
308
302
Sensor
Controller
204
306
212

Fig. 3A

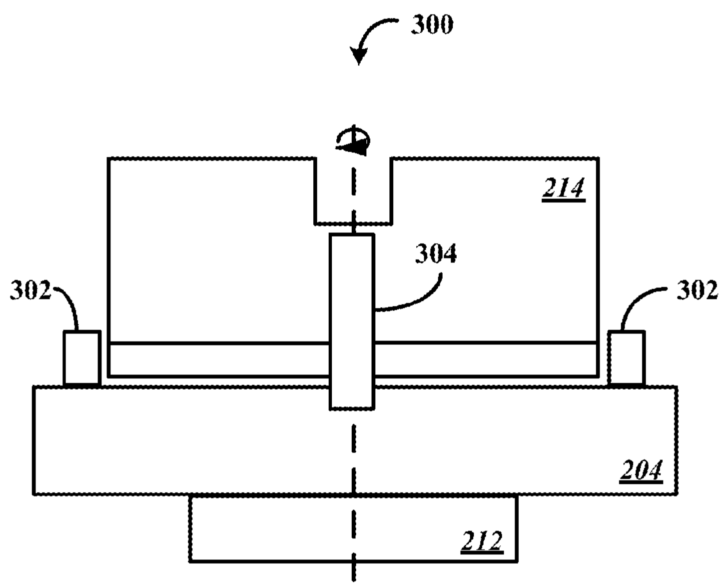

300
214
304
302
302
204
212

Fig. 3B

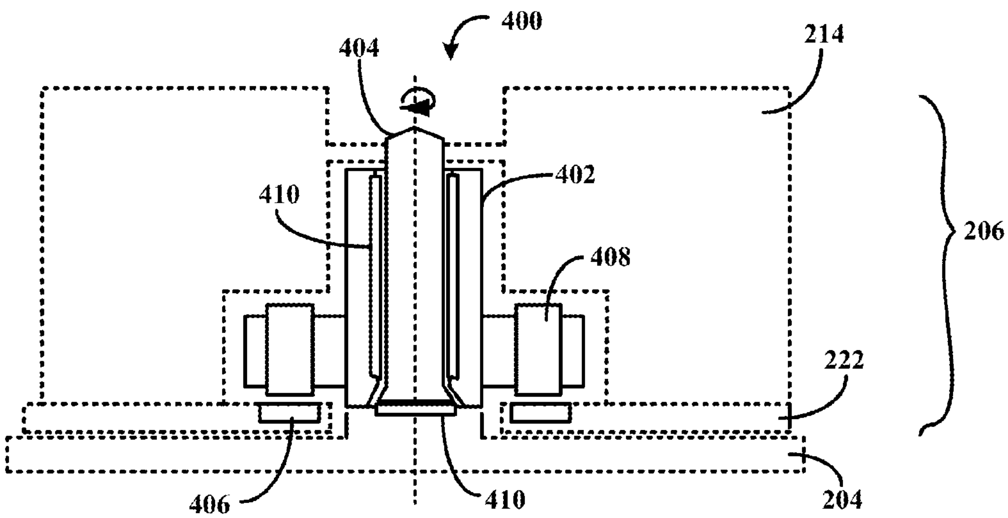


Fig. 4

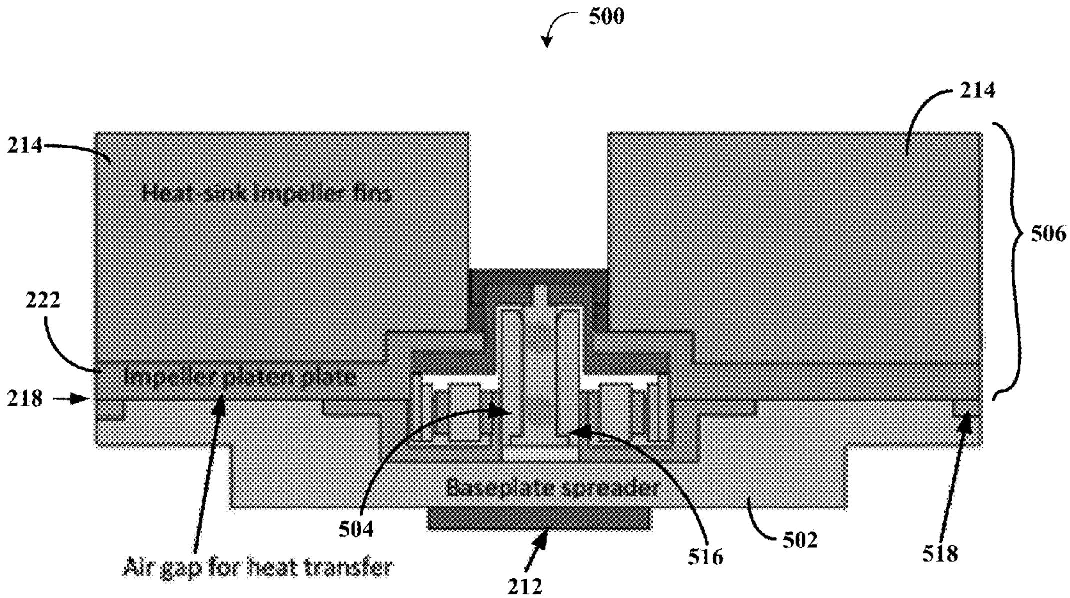

500
214
214
Heat-sink impeller fins
506
222
Impeller platen plate
218
Baseplate spreader
504
516
502
518
Air gap for heat transfer
212

Fig. 5A

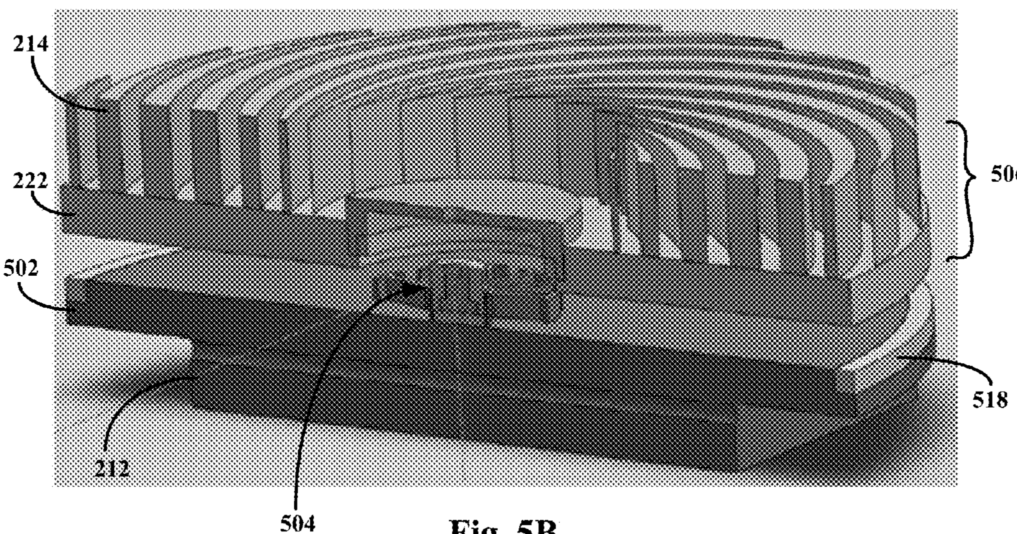

214
506
222
502
518
212
504

Fig. 5B

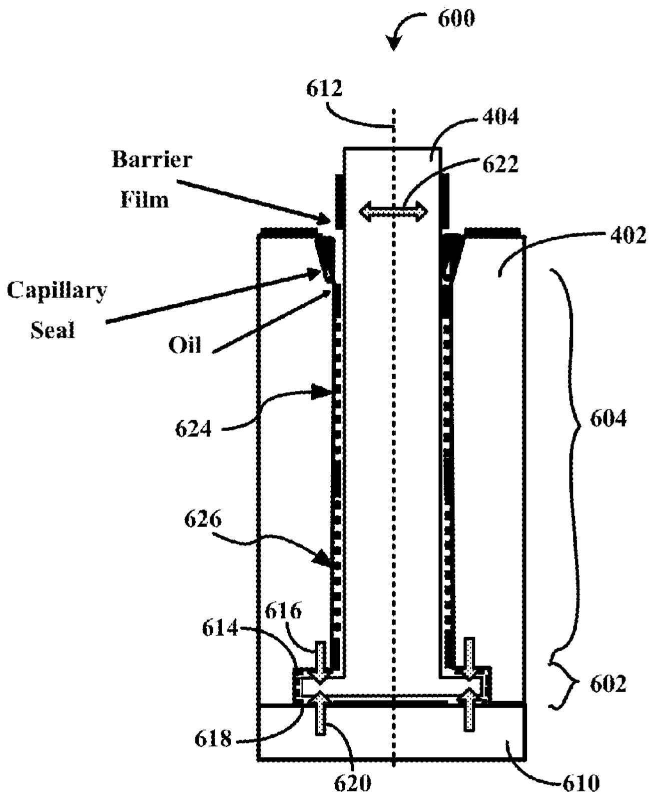


Fig. 6A

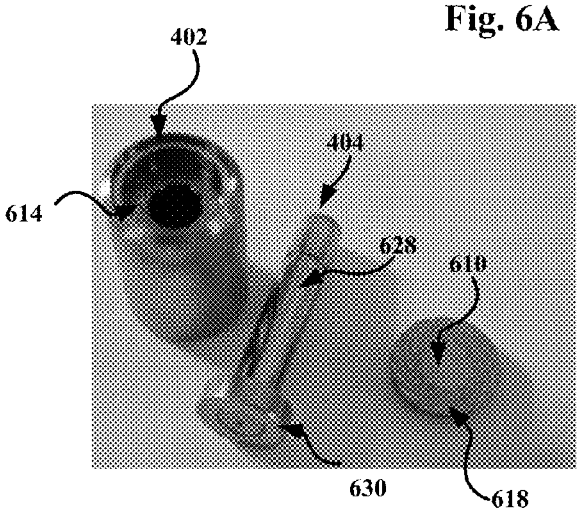


Fig. 6B

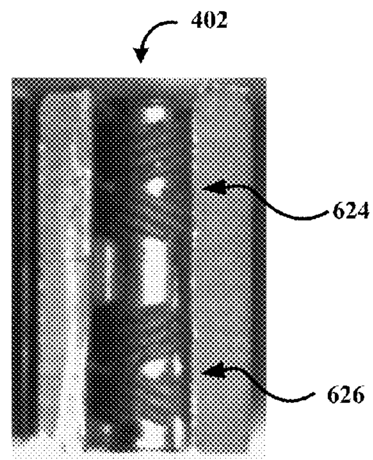


Fig. 6C

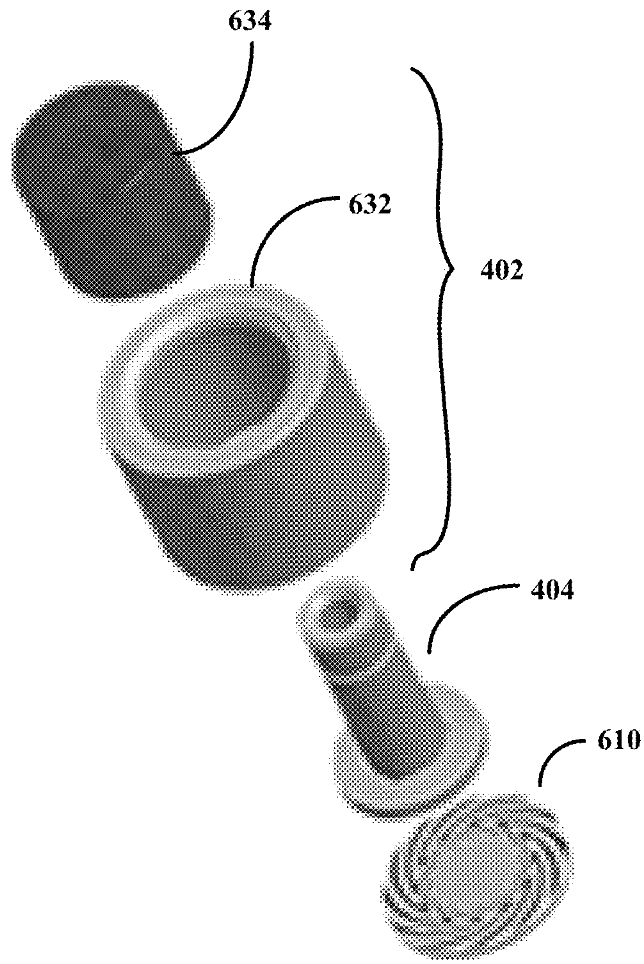


Fig. 6D

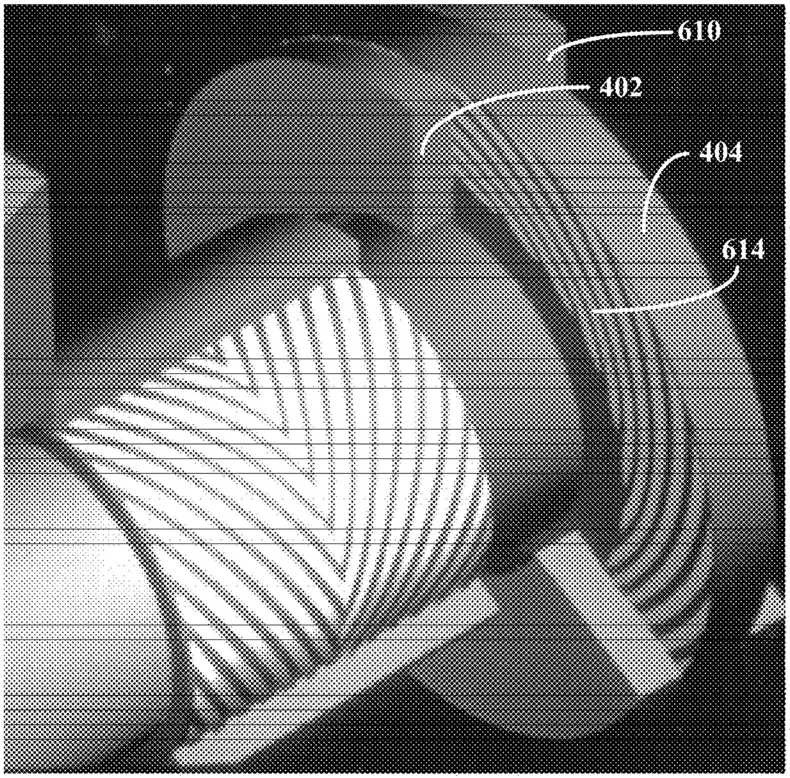


Fig. 7A

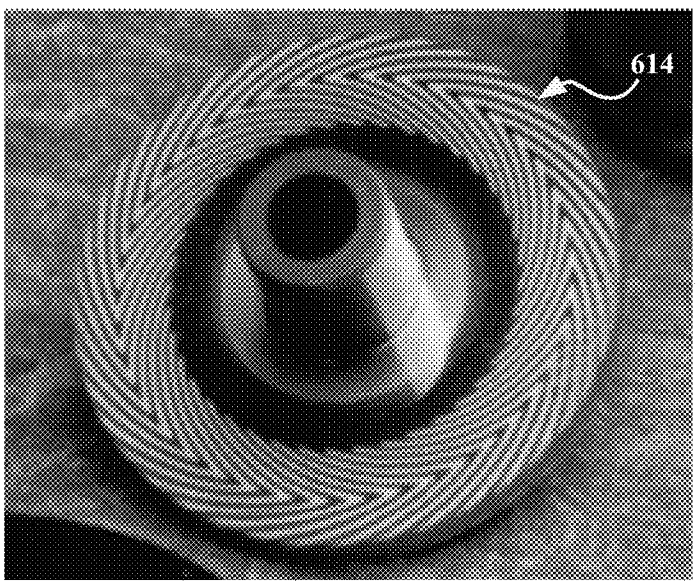


Fig. 7B

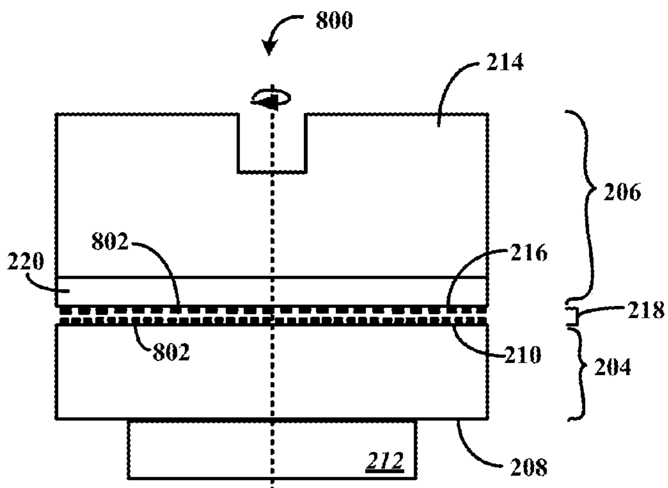
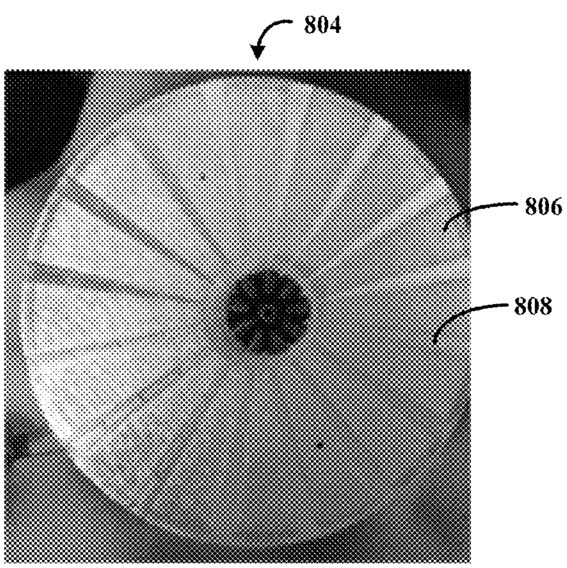

800
214
206
802
220
216
218
802
210
204
212
208

Fig. 8A


804
806
808

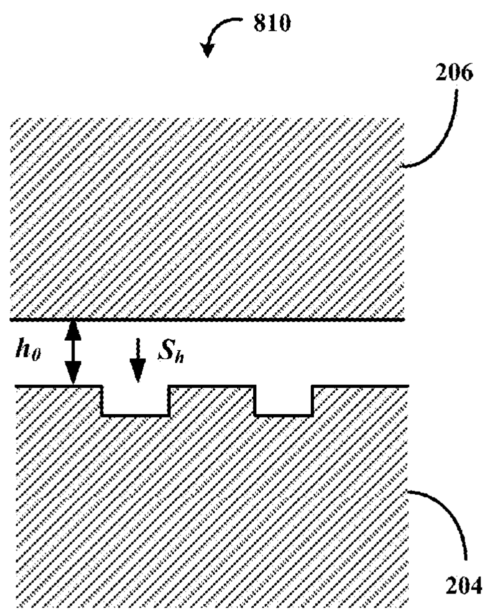

810
206
h_0
S_h
204

Fig. 8B

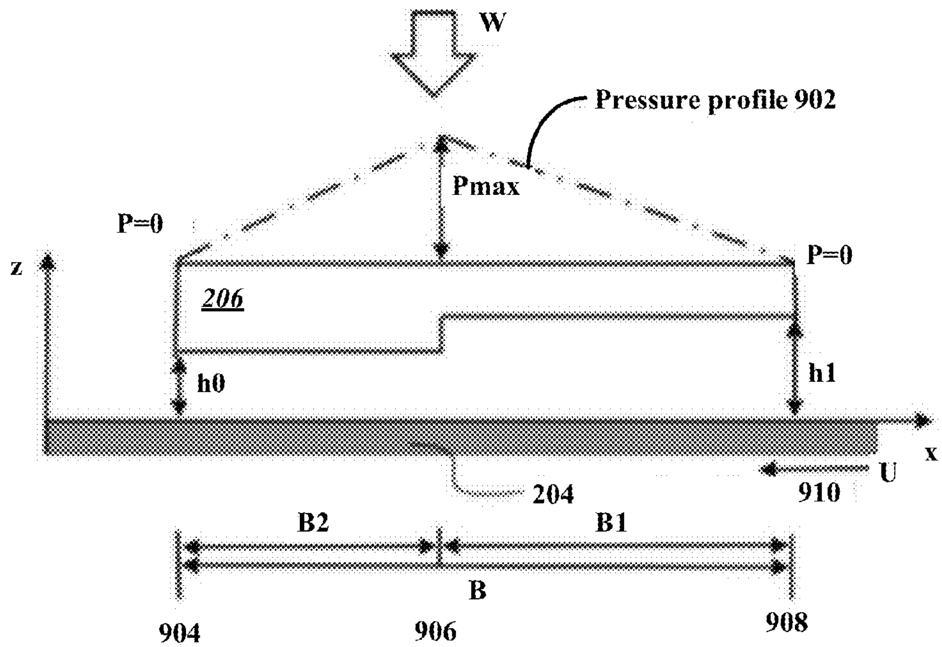

W
Pressure profile 902
Pmax
P=0
P=0
z
206
h0
h1
x
204
U
910
B2
B1
B
904
906
908

Fig. 9

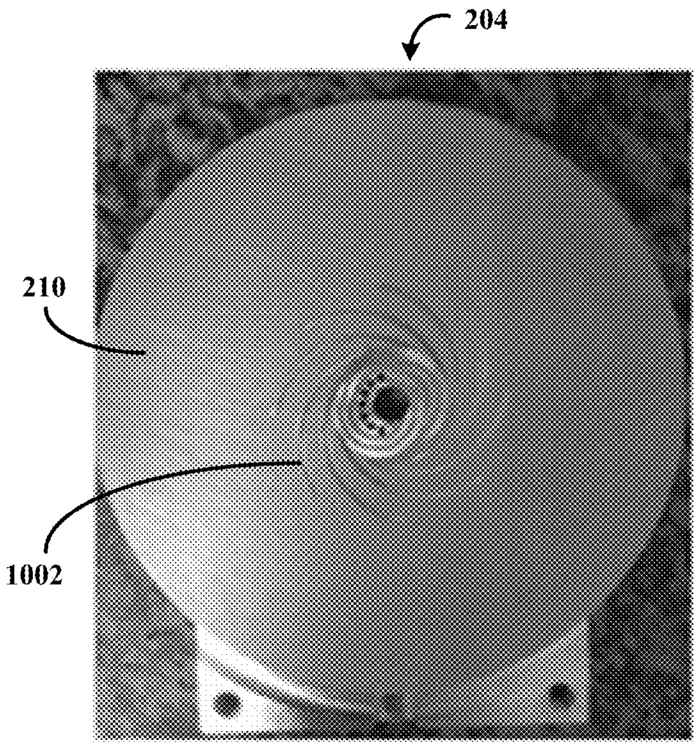


Fig. 10A

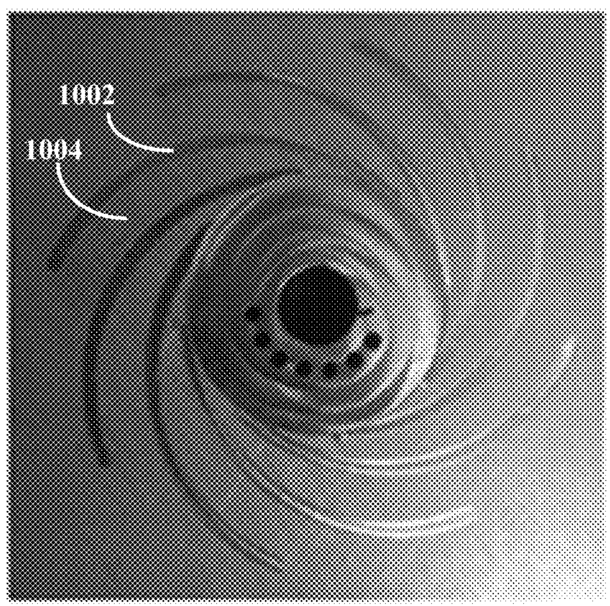


Fig. 10B

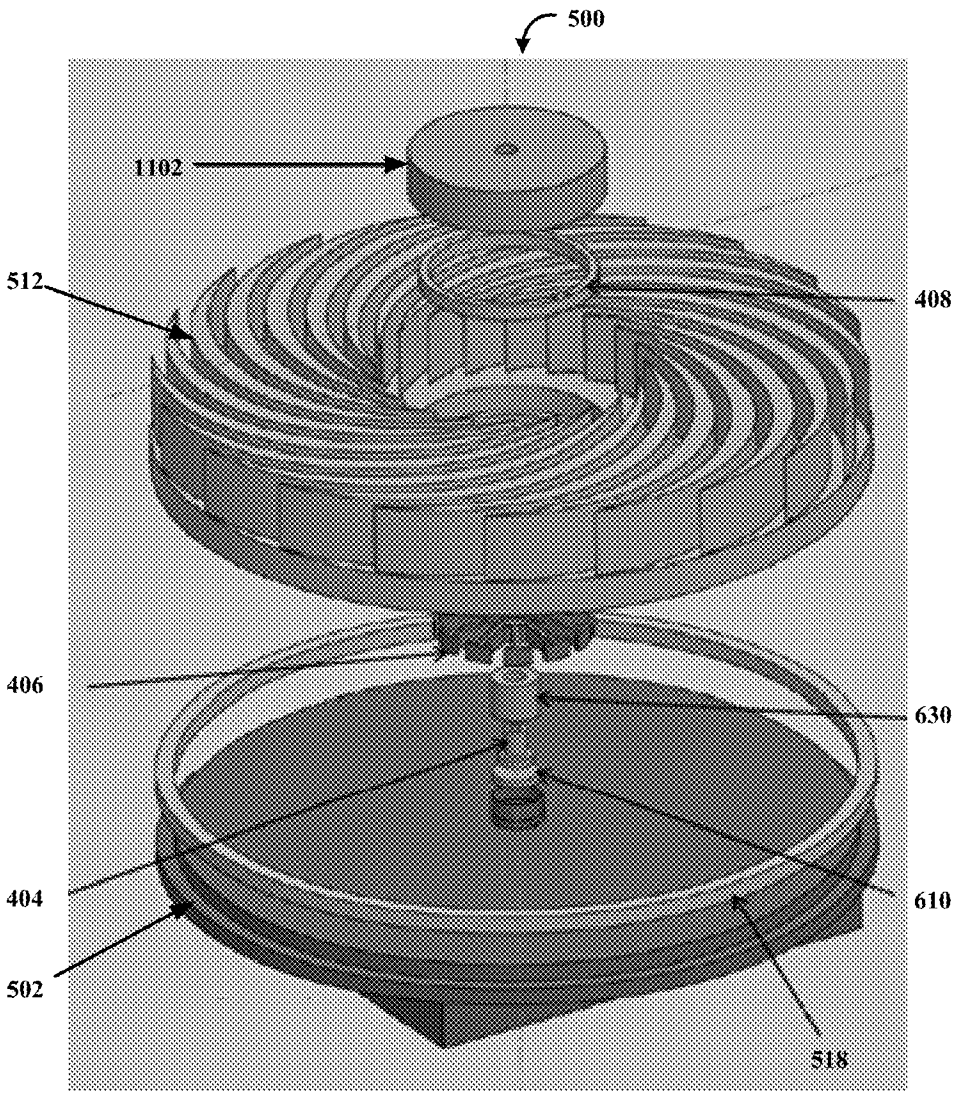


Fig. 11

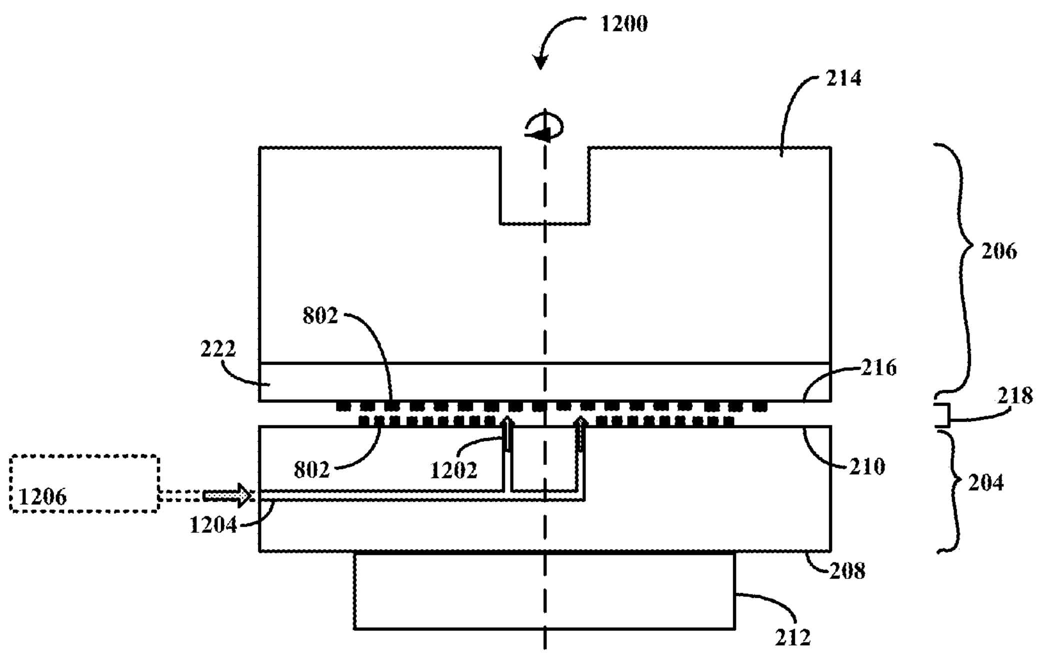


Fig. 12A

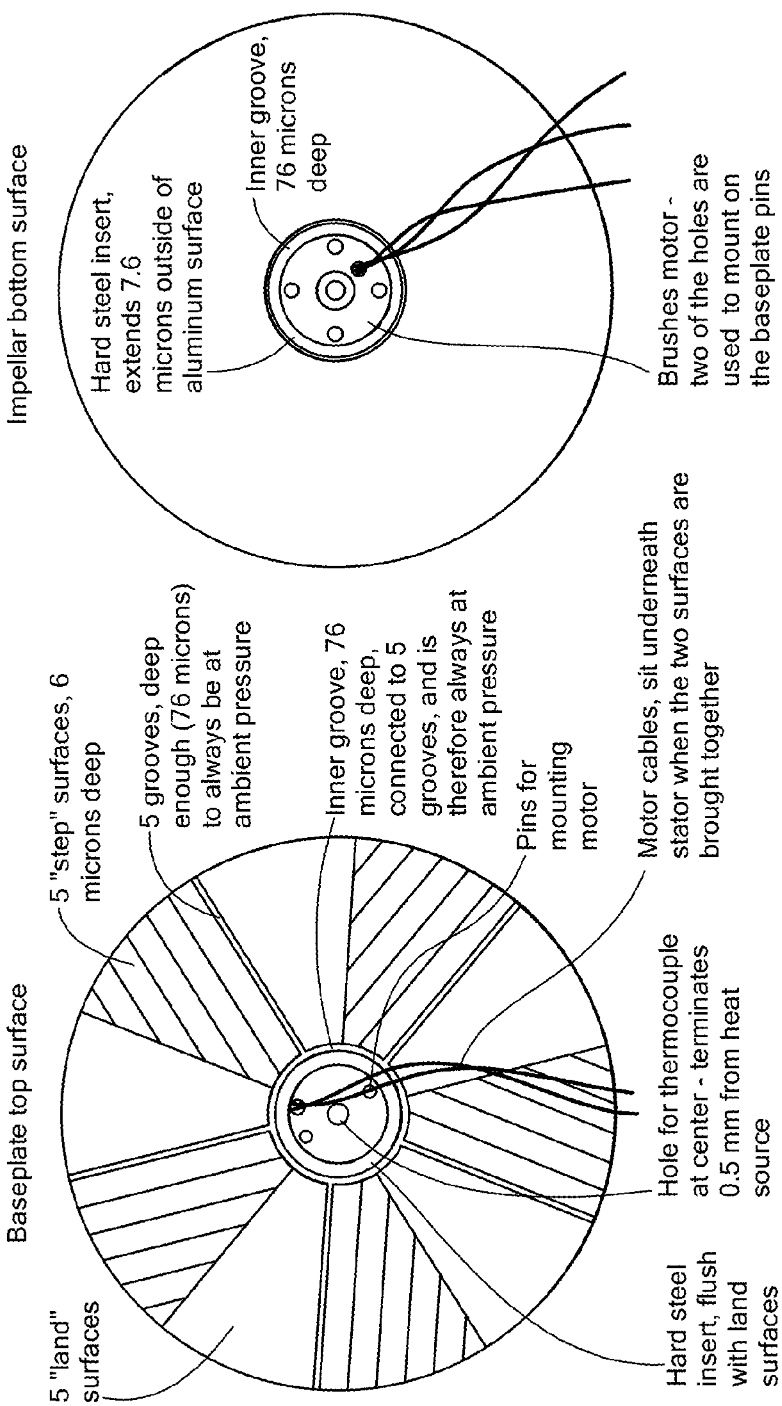

Impellar bottom surface
Hard steel insert, extends 7.6 microns outside of aluminum surface
Inner groove, 76 microns deep
Brushes motor - two of the holes are used to mount on the baseplate pins
Baseplate top surface
5 "land" surfaces
5 "step" surfaces, 6 microns deep
5 grooves, deep enough (76 microns) to always be at ambient pressure
Inner groove, 76 microns deep, connected to 5 grooves, and is therefore always at ambient pressure
Pins for mounting motor
Motor cables, sit underneath stator when the two surfaces are brought together
Hole for thermocouple at center - terminates 0.5 mm from heat source
Hard steel insert, flush with land surfaces

FIG.12B

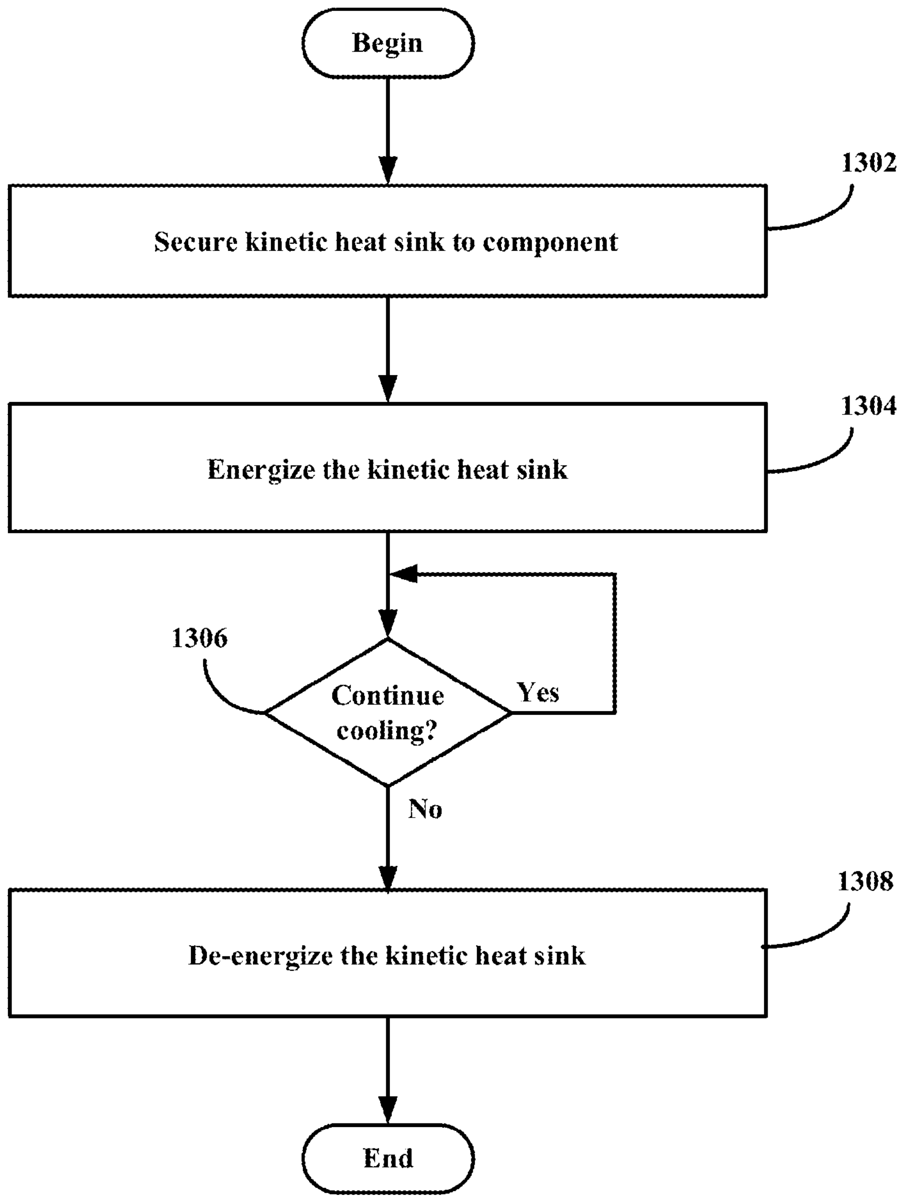
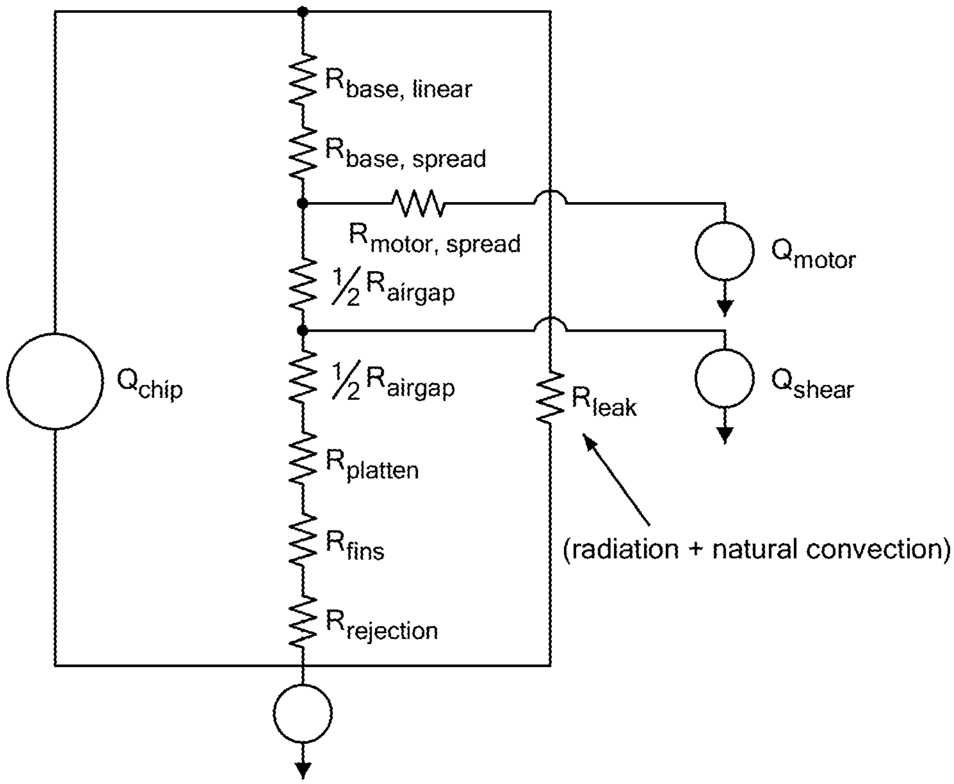

Begin
1302
Secure kinetic heat sink to component
1304
Energize the kinetic heat sink
1306
Continue cooling?
Yes
No
1308
De-energize the kinetic heat sink
End

Fig. 13



	Hybrid	Aerodynamic
Q_{chip}	46 W	46 W
Q_{motor}	5.2 W	5.0 W
Q_{shear}	3.44 W	1.86 W
$R_{base, linear}$	0.007 C/W	0.009 C/W
$R_{base, spread}$	0.143 C/W	0.071 C/W
$R_{motor, spread}$	0.07 C/W	0.07 C/W
R_{airgap}	0.074 C/W	0.151 C/W
$R_{platten}$	0.0036 C/W	0.0036 C/W
R_{fins}	0.0047 C/W	0.0047 C/W
R_{xfer}	0.175 C/W	0.175 C/W
R_{leak}	6.40 C/W	6.40 C/W
R_{total}	0.38 C/W	0.39 C/W
$R_{measured}$	0.43 C/W	0.43 C/W

FIG.14

KINETIC HEAT SINK HAVING CONTROLLABLE THERMAL GAP

RELATED APPLICATION

[0001] This patent application claims priority from Provisional Application No. 61/656,868, filed Jun. 7, 2012, titled "Kinetic Heat Sink Having Controllable Thermal Gap." The application is incorporated by reference herein in its entirety.

TECHNICAL FIELD

[0002] The present invention relates to heat-extraction and dissipation devices and methods and, more particularly, kinetic heat sinks for use with electronic components.

BACKGROUND ART

[0003] During operation, electric circuits and devices generate waste heat. To operate properly, the temperature of the electric circuits and devices has to be within a certain limit. The temperature of an electric device often is regulated using a heat sink physically mounted near or to the electric device. FIGS. **1**A, **1**B, and **1**C show several examples of conventional heat sink assemblies **100**. The heat sink assemblies **100** generally extract heat **102** (see FIG. **1**C) from the thermal source **104** (i.e., the electric circuit or device) to a heat sink **106**, and then rejects (i.e., dissipates) the heat into a thermal reservoir **108**, which is generally ambient air. To improve heat dissipation, the heat sink **106** may have fins **110** and be coupled with a fan **112** to increase the airflow across the fins **110**.

[0004] One relatively new type of heat sink assembly, known as a "kinetic heat sink," has a thermal mass with integrated fluid-directing structures (such as fins and/or fan blades) that rotates with respect to a stationary base mounted on or near the heated electric device. A fluid refers to a substance that may flow and includes a liquid, a gas, or a combination of liquid and gas. To the knowledge of the inventors, those in the art have developed several topologies for transferring the heat between the stationary base and the rotating heat sink.

[0005] A first type of kinetic heat sink design provides a thermal transfer medium, including thin films or various thermal fluids (such as oils), between the stationary base and the rotating heat sink. These designs undesirably often have problems relating to sealing, risk of leaks, or high frictional energy losses. To avoid this problem, a second type of kinetic heat sink design employs a fluid gap (e.g., air) between the rotating heat sink and the stationary base. Although air is generally considered a thermal insulator (i.e., not an efficient thermal transfer medium), when the fluid gap is made sufficiently small (i.e., in the order of tens of micrometers), the thermal resistance over the fluid gap may become negligible. Current designs of this type of kinetic heat sink known to the inventors, however, do not adequately control the noted small fluid gap. For example, the gap may not be properly regulated over a wide-range of rotational speeds or at arbitrary orientations. Moreover, kinetic heat sinks may have significant start-up resistances that impede effectiveness.

SUMMARY OF ILLUSTRATIVE EMBODIMENTS

[0006] In accordance with illustrative embodiments of the invention, a kinetic heat sink apparatus has a stationary member that includes a base structure having both a first heat-conducting surface and a second heat-conducting surface to conduct heat therebetween. The first heat-conducting surface is fixably mountable to a heat-generating component. The kinetic heat sink also has a rotating structure rotatably coupled with the base structure. This rotating structure has a movable heat-extraction surface facing the second heat-conducting surface across a spatial gap. The rotating structure is configured to transfer heat from the second heat-conducting surface to a thermal reservoir communicating with the rotating structure. The rotating structure and stationary member has at least two pairs of opposing surfaces configured to form a first thrust and second opposing thrust to maintain the spatial gap within a pre-specified range during rotation of the rotating structure. At least one surface of each of the pair of opposing surfaces may have at least one surface with hydrodynamic features thereon to generate the thrust.

[0007] Each pair of the two pairs of opposing surfaces may form a hydrodynamic bearing (e.g., a spiral groove bearing, a step bearing, a sector step bearing, a Rayleigh step bearing, a thrust inward-pumping bearing, a thrust outward-pumping bearing, and a herringbone thrust bearing).

[0008] The kinetic heat sink also may have an electric motor assembly. The stationary member may include stationary motor component fixably affixed thereto. The rotating structure may include a rotating motor component. The stationary motor component and the rotating motor component may include the pair of opposing surfaces to generate thrust.

[0009] The stationary motor component may include, or form, a heat insulating structure to thermally insulate the electric motor assembly from heat. The electric motor assembly may include cooling channels to direct fluid (air, gas, or liquid, etc.) through the assembly when the rotating motor component is rotatably moving.

[0010] The rotating structure includes a plurality of flow-directing members (e.g., fin or fan blade) to channel cooling fluid therethrough when the rotating structure is rotatably moving. The flow may exceed ten meters per second. The plurality of flow-directing members may fixably extend from a rotating base-plate. The rotating base-plate may define the heat-extraction surface, which forms the spatial gap with the stationary member. The spatial gap may vary between approximately 5 and 10 μm when the rotating structure is at rest and between 10 and 20 μm when the rotating structure is rotatably moving.

[0011] The stationary base structure and the rotating structure may be made of different thermal-conducting thermal material (e.g., copper, aluminum, silver, nickel, iron, zinc, and combinations thereof).

[0012] The kinetic heat sink apparatus may include a sensor to provide a feedback signal to a controller. The sensor may sense a distance of the spatial gap or a thermal quantity of one or more of the heat-generating component, the stationary base structure, and the rotating structure. The controller may vary the rotating speed of the electric motor assembly based upon the feedback signal.

[0013] In an alternate embodiment, the kinetic heat sink may include an active pump regulator to introduce fluid into the spatial gap. In another alternate embodiment, the kinetic heat sink may include an active spatial gap regulator. The regulator may generate thrust to maintain or assist in maintaining the spatial gap. The regulator may generate forces based on an electric field and/or magnetic field.

[0014] In accordance with another embodiment, the stationary base structure may form in part, or be part of, a vapor chamber and/or a heat pipe.

[0015] In accordance with another embodiment, a kinetic heat sink includes a base plate and an impeller. The base plate is adapted to fixably mount to a heat-generating component. The impeller is adapted to rotate in relation to the base plate across a gap of less than 20 micrometers. The impeller has an impeller plate and a plurality of fins extending therefrom. The impeller plate forms the gap with the base plate. The fins form channels therebetween.

[0016] The kinetic heat sink further includes a spindle motor adapted to cause the impeller to rotate. The spindle motor has a stationary portion affixed to the base plate and a rotating portion affixed to the impeller. Portions of the stationary portion and rotating portion form fluid-dynamic bearings. During the rotation of the impeller, the base plate conductively draws heat from the heat-generating component and transfers a substantial portion of the drawn heat across the gap to the impeller. The gap is regulated, in part, by thrusts formed in opposing direction by the fluid-dynamic bearings, and the impeller receives the transferred heat and rejects the transferred heat to ambient fluid communicating with the impeller by directing the ambient fluid through the channels.

[0017] The kinetic heat sink may be configured to operate with substantially low-friction between the heat-extraction surface and the second heat-conducting surface when at rest. In an embodiment, a portion of the heat-extraction surface may form a low-friction contact with the second heat-conducting surface via a low-friction insert disposed therebetween. The surfaces or insert may include a low-friction coating (i.e., having a friction coefficient less than 0.5). The low-friction surface may be non-abradable. Examples of coatings, includes ceramics, such as metal-doped ceramics, Teflon, and graphite (e.g., diamond like carbon (DLC)). The insert may form, or be part of, a roller bearing or a ball bearing. In another embodiment, the kinetic heat sink has a first portion of the heat-extraction surface forming the spatial gap with the second surface when at rest, while a second portion of the heat-extraction surface is in contact with the stationary base structure when at rest.

[0018] In accordance with another embodiment, a method of dissipating heat from an electronic device is described. The method includes providing a stationary structure having a first and second heat-conducting surface. The stationary structure is thermally coupled to the electronic device at the first heat-conducting surface to drawn heat from the electronic device. The stationary structure conducts the drawn heat from the first heat-conducting surface to the second heat-conducting surface. The method then includes rotating a rotating structure having a heat-extraction surface facing the second heat-conducting surface across a spatial gap. The rotation substantially transfers heat from the second heat-conducting surface to the rotating structure and rejects the transferred heat from the rotating structure to a thermal reservoir in communication with the rotating structure. The method then includes generating thrusts on the rotating structure as a result of the rotation of the rotating structure. The thrusts are in opposing direction to maintain the spatial gap within a pre-specified range.

[0019] The method may include varying the rotation of the rotating structure, including a rate of rotation, to maintain the spatial gap within a pre-specified range.

[0020] The method may also include measuring a thermal quantity associated with at least one of the stationary structure, the stationary structure, the spatial gap, and the electronic device and using the measured thermal quantity to vary the rotation of the rotating structure.

BRIEF DESCRIPTION OF THE DRAWINGS

[0021] The foregoing features of embodiments will be more readily understood by references to the following detailed description, taken with reference to the accompanying drawings, in which:

[0022] FIGS. **1**A-C show various examples of conventional heat sinks;

[0023] FIGS. **2**A-**2**E schematically show examples of a spatial gap of an apparatus for dissipating heat according to a preferred embodiment;

[0024] FIG. **3**A schematically shows the apparatus of FIGS. **2**A-**2**E with a motor assembly according to an embodiment;

[0025] FIG. **3**B schematically shows the apparatus of FIGS. **2**A-**2**E with alternate embodiments of the motor assembly;

[0026] FIG. **4** schematically shows a detailed diagram of the motor assembly and apparatus of FIG. **3**A according to an embodiment;

[0027] FIG. **5**A schematically shows a cross sectional view of a kinetic heat sink according to an embodiment.

[0028] FIG. **5**B schematically shows a perspective view of the kinetic heat sink of FIG. **5**A;

[0029] FIG. **6**A schematically shows a diagram of the fluid dynamic bearing of the kinetic heat sink of FIG. **5**A in accordance with illustrative embodiments of the invention;

[0030] FIG. **6**B schematically shows a picture of the fluid dynamic bearing of FIG. **6**A disassembled;

[0031] FIG. **6**C schematically shows a picture of a cross-sectional view of the rotor housing of FIG. **6**B;

[0032] FIG. **6**D schematically shows an exploded view of the fluid dynamic bearing of FIG. **6**A;

[0033] FIG. **7**A schematically shows cut-views of fluid dynamic bearings according to an illustrative embodiment;

[0034] FIG. **7**B schematically shows a portion of a fluid dynamic bearing according to an illustrative embodiment of the invention;

[0035] FIG. **8**A schematically shows an apparatus with hydrodynamic surfaces in the spatial gap according to another embodiment;

[0036] FIG. **8**B schematically shows a diagram of rotating structure having included a hydrodynamic step-sector bearing;

[0037] FIG. **9** is a diagram of a pressure profile for the step-sector bearing of FIG. **8**B;

[0038] FIG. **10**A illustratively shows a diagram of stationary base structure having included a spiral groove hydrodynamic bearing;

[0039] FIG. **10**B illustratively shows a zoomed-in image of FIG. **10**A;

[0040] FIG. **11** schematically shows an exploded diagram of the kinetic heat sink of various embodiments of the invention;

[0041] FIG. **12**A schematically shows an apparatus according to an alternative embodiment;

[0042] FIG. **12**B illustratively shows a picture of one implementation of the apparatus of FIG. **12**A;

[0043] FIG. **13** a method according to a preferred embodiment of the invention; and

[0044] FIG. **14** schematically shows a diagram of a resistance model of the apparatus according to the preferred embodiment of the invention.

DETAILED DESCRIPTION OF SPECIFIC EMBODIMENTS

[0045] Illustrative embodiments facilitate high-density heat transfer with a kinetic heat sink. Such embodiments provide more robust thermal control with fewer active components.

[0046] FIG. **2**A schematically shows an example of a kinetic heat sink **200** (also referred to as "apparatus **200**") for dissipating heat **202** according to various embodiments. The apparatus **200** includes a stationary member, having a base structure **204** (also referred as a "stationary base structure **204**"), and a rotating structure **206** that cooperate to transfer heat from a heat generating component. To that end, the stationary base structure **204** has a first heat-conducting surface **208** and a second heat-conducting surface **210** to conduct heat therebetween. The stationary base structure **204** may be mountable at the first heat-conducting surface **208** to a heat-generating component **212**. The first heat-conducting surface **208** and the second heat-conducting surface **210** may form the footprint of the apparatus **200**.

[0047] The rotating structure **206**, which is rotatably coupled to the stationary base structure **204**, has a heat-extraction surface **216** facing the second heat-conducting surface **210** across a spatial gap **218**. The heat-extraction surface **216** may face some or all portions of the second heat-conducting surface **210**. When moving, the rotating structure **206** rotates with respect to the stationary base structure **204** to transfer heat from the second heat-conducting surface **204** to a thermal reservoir **220** (e.g., the environment) communicating with the rotating structure **206**. The term "thermal reservoir" (or "thermal energy reservoir" and "thermal bath") refers to a fluid having a heat capacity intended for heat to flow. The rotating structure **206** may have additional flow-directing structures **214** (e.g., blades or fins) to reject the heat to the thermal reservoir **220**.

[0048] As a schematic drawing, FIG. **2**A and others simply show two planar surfaces **210** and **216**. It is contemplated, however, that various embodiments may configure those surfaces **210** and **216** with non-planar surfaces, including grooves, channels, and recesses (shown in subsequent figures). Similarly, it is contemplated that the various embodiments may configure those surfaces **210** and **216** as an angled region **224** defined by angle **226** (as shown in FIG. **2**B, for example). The angle region may be over a portion of the two planar surfaces **210** and **216** and may be located on the outer circumferential portion of the planar surfaces **210** and **216** (as shown) or, alternatively, in the inner circumferential portion. Various other planar topologies are also contemplated to be within the scope of the invention and are provided in FIGS. **2**C-**2**E for illustrative purposes.

[0049] A In accordance with illustrative embodiments of the invention, during operation, surfaces of the rotating structure **206** and the stationary base structure **204** generate a (axial) thrust and an opposing (axial) thrust to vary and/or maintain the spatial gap **218** within a prescribed distance. As known by those in the art, thrust is a tangible force resulting from fluid flowing over a tangible surface. Such surfaces may be part of the heat-extraction surface **216** and/or the second heat-conducting surface **210**. In an embodiment, the rotating structure **206** may be configured with features at differing portions that may generate different thrust vectors when the rotating structure **206** is rotatably moving. For example, a first portion of the heat-extraction surface and/or the second heat-conducting surface may generate the thrust in a first direction, while a second portion of the heat-extraction surface **216** and/or the second heat-conducting surface **210** may generate an opposing thrust in a second direction. The heat-extraction surface **216** and/or the second heat-conducting surface **210** may be configured with a dividing structure to isolate the first portion and the second portion. The rotating structure **206** and the stationary base structure **204** may include other structures, as discussed below, that include the surfaces to generate the thrust.

[0050] The rotating structure **206** transfers heat from the second heat-conducting surface **210** to the thermal reservoir **220** as a result of enhanced heat transfer properties resulting from the rotating structure **206** rotatably moving with respect to the stationary base structure **204**. A portion of the heat at the second heat-conducting surface may dissipate directly to the thermal reservoir through convection and radiation mechanisms (i.e., thermal leakage). As such, the term "substantially transfers" refers to transferring a non-negligible amount of heat that is beyond the thermal leakage mechanisms. In certain embodiments, a majority of heat is transferred from the second heat-conducting surface **210** to the thermal reservoir **220** through the rotating structure **206**. The enhanced heat transfer results, in part, due to the thermal resistance of the spatial gap **218** being reduced as a result of flow (e.g., turbulent) being developed in the spatial gap **218** from the rotating structure **206** rotatably moving. The heat transfer also depends on the size of the spatial gap **218**. The spatial gap may be configured based upon the fluid medium and the gap distance to have a thermal resistance 25 percent or less of the total thermal resistance. The heat-extraction surface **216** and/or the second heat-conducting surface **210** may be configured with surface topographic features to induce localized turbulence and mixing. The flow may be viscous-dominated to generate hydrodynamic lift.

[0051] The spatial gap **218** may include a region characterized as a fluid gap. For example, the spatial gap **218** may be approximately 10 micrometers (μm) or less when at rest. The spatial gap **218** preferably is configured to remain within a pre-specified range when operating. For example, the spatial gap **218** may vary in distance between 10 μm and 20 μm when the rotating structure **206** is rotatably moving. In some implementations, a reasonable magnitude of the thermal resistance for the spatial gap includes 0.05° Celsius/Watt or 10° Celsius·cm^2/Watt. This thermal resistance value, however, depends on the application. For example, for a small heat source (i.e., heat watt output), a higher thermal resistance value may suffice. For such small heat sources, a small kinetic heat sink may be employed. Conversely, for larger heat sources, a low thermal resistance may be preferred to prevent the temperature at the heat source from getting too hot. In general, a thermal resistance across the gap of 25 percent or less of the total thermal resistance should provide satisfactory results. The thermal resistance of the spatial gap is inversely proportional to surface area of the spatial gap.

[0052] To enhance fluid flow, the rotating structure **206** may include fluid-directing structures **214** including, for example, fins and blades, to reject heat into the thermal reservoir **220**. The rotating structure **206** may be configured as an impeller or other members that radiate heat with an enhanced surface area.

[0053] In one embodiment, the rotating structure **206** includes a fluid-directing structure to direct air. Compared to a conventional heat sink (i.e., a block of metal with or without fins and possibly coupled with a fan blowing air on it), the rotating structure **206** may have a higher fluid velocity flowing through it, thereby enhancing its heat transfer properties. Stated differently, energy may be expended directly to pump fluid for heat transfer rather than to move the fluid. From testing, it was observed that the rotating structure **206** rotatably moving at a comparable rotation speed to a fan may have up to ten times higher air velocity with respect to the fins. It should be apparent to those skilled in the art that similar advantages are contemplated when various types of fluids are employed with the various embodiments.

[0054] Accordingly, due to its increased heat-dissipation density, the kinetic heat sink may have a smaller form factor as compared to conventional blower with heat sinks. This also means that the kinetic heat sink **200** may rotate at a slower rate, thus saving energy, while providing comparable thermal dissipation performance. Moreover, in addition to requiring less energy, illustrative embodiments also reduce unintended acoustics resulting from the rotation, and should reduce the accumulation of dust that typically gathers on conventional heat sink designs.

[0055] The kinetic heat sink **200** may be used with any of a variety of different heat-generating components **212**. For example, the heat-generating component **212** may include, among other things, a circuit board having electric components generating and/or transferring heat thereon, a semiconductor device, a thermal mass (i.e., a heat sink), a power circuit including a power switch such as a IGBT, and/or an electric circuit packaging surface (ceramic or plastic).

[0056] In alternative embodiments, heat-extraction and heat-spreading devices may be employed between the first heat-conducting surface **208** and the second heat-conducting surface **210**. Heat-extraction and heat-spreading devices are generally utilized to spread/transport heat from one area to other rather than to dissipate the heat. Heat-extraction and heat-spreading devices may include, for example, heat pipes and fluid pumping systems.

[0057] FIG. **3**A shows another heat sink embodiment, this time identified by reference **300**. This figure shows more specific components of the device than those shown in FIG. **2**A, including a motor assembly **302**, **304**. The stationary base structure **204** has heat-conducting surfaces to conduct heat from the heat-generating component **212** to the rotating structure **206**. The rotating structure **206** is rotatably coupled to the stationary base structure **204** though the motor assembly. The motor assembly includes a motor-stationary component **302** and a motor-rotating component **304**. The motor-stationary component **302** may include a stator (i.e., electrical windings and armature) and a housing. The motor-rotating component **304** may include a rotor shaft and components attached thereon, including, for example, permanent magnets (in some embodiments).

[0058] The motor-stationary component **302** preferably is fixably coupled to the stationary base structure **204** and thus, may be considered part of the stationary member. The motor-rotating component **304** may be fixably coupled or coupled via a gear to the rotating structure **206**. The motor-stationary component **302** and the motor-rotating component **304** preferably are generally concentrically located between the rotating structure **206** and the stationary base structure **204**.

[0059] Any number of different motor configurations may be used. For example, the apparatus **300** may include a controller **306** to regulate the rotation speed of the rotating structure **206** by regulating the current or voltage provided to the electrical winding. In an illustrative embodiment, the electrical winding is part of the motor-stationary component **302**. However, it is noted that it should be apparent to those skilled in the art that various motor topologies may be employed, including designs having the electrical winding being part of the motor-rotating component **304**. The controller **306** may include a control circuit, a driver, and corresponding signal processing circuitries. The controller **306** may be mounted within or on the stationary base structure **204**. The control circuit may be configured to provide pulse-width modulation, frequency, phase, torque, and/or amplitude control.

[0060] The apparatus **300** may also include a sensor **308** to provide feedback signals for the controller **306**. The feedback signals may be based upon the speed, temperature, or clearance of the spatial gap. The speed may be of the rotation speed of the rotating structure **206** and/or of the motor. The temperature may be of the heat-generating component **212**, the stationary base structure **204**, the rotating structure **206**, spatial gap **218** and/or the motor. The sensor **308** may be a capacitive-based sensor, a thermocouple, and/or an infrared detector and may output an electrical signal that is un-scaled or offset and merely have some correlation to the temperature value. It should be apparent to those skilled in the art that various controllers and control schemes may be utilized to regulate the heat dissipating apparatus based upon temperature, rotation speed, and clearance gap.

[0061] It should also be apparent to those skilled in the art that a portion of the motor-stationary component **302** (e.g., the electrical winding) may be placed in various locations that are concentric the axis of rotation. For example, FIG. **3**B shows another example of an apparatus with a motor assembly according to an alternative embodiment. Rather than the motor assembly being located proximal to or near the axis of rotation, the motor-stationary component **302** (having the electrical windings) is located distally to the rotor axis. Similarly, it is contemplated that parts of the motor-stationary component **302** (e.g., electrical winding) may be located on top of the rotating structure **206** or within the stationary base structure **204**.

[0062] It should be further apparent to those skilled in the art that various direct-current and alternating-current based motor may be employed. For example, examples of direct-current (DC) based motors may include brushed DC motors, permanent-magnet electric motors, brushless DC motors, switched reluctance motors, coreless DC motors, universal motors, and examples of alternating-current (AC) based motors may include single-phase synchronous motors, polyphase synchronous motors, AC induction motors, and stepper motors. The motor assembly may include an integrated motor controller, such as a servo motor. The motor may operate based upon pulse-width modulation scheme or direct current control.

[0063] FIG. **4** schematically shows detailed diagrams of the motor assembly of FIG. **3**A (now identified by reference number **400** in this figure). The motor assembly **400** rotates the rotating structure **206** with respect to the stationary base structure **204**. In an illustrative embodiment, the motor assembly **400** includes a rotor **404** seated, via bearings **410**, in a rotor housing **402**. The rotor **404** is fixably attached to the rotating structure **206**. The attachment may be at the fluid-directing structures **214** (as shown) and/or at a rotating base **222**.

[0064] In an illustrative embodiment, the stator motor winding **406** forms a portion of the stationary base structure **204**, and the permanent magnet **408** forms a portion of the rotating structure **206**. The permanent magnet **408** may be attached at the rotating base **222** (as shown) and/or the fluid-directing structures **214**.

[0065] The bearings **410** maintain the centricity of the rotor **404** with respect to the axis of rotation of the rotating structure **206**. The bearings **410** may be mechanical-based bearings (including roller bearings or ball bearings) and hydrodynamic bearings.

[0066] Hydrodynamic bearings (i.e., self-acting bearings) provide a thin film of fluid (including gas, such as air, or liquid, such as oils and thin films) as lubrication. The thin film of fluid is created by the relative motion of two mating surfaces separated by a small distance. A subset of hydrodynamic bearings, where the thin film of fluid comprises, mainly, of gas (such as air), is referred to as an aerodynamic bearing. As the speed of the motion increases, a velocity-induced pressure gradient is generally formed across the clearance between the two mating surfaces. Hydrodynamic bearings generally include topographical features formed onto at least one of the mating surfaces. Among other things, the topographical features may be characterized as spiral grooves of a step bearing. Spiral groove bearings may be configured as a thrust inward-pumping bearing, a thrust outward-pumping bearing, and a herringbone thrust bearing.

[0067] In an illustrative embodiment, journal bearings maintain the centricity of the rotor **404**, and the thrust control the gap thickness. Among other things, thrust forces may be generated by hydrodynamic bearings of differing types. For example, the apparatus may employ one type of opposing hydrodynamic bearings to control the overall gap thickness, and employ a second type of hydrodynamic bearing features along the surface of either the stationary base structure **204** or the rotating structure **206** for additional stiffness to prevent tilting of the rotating structure **206** and/or to provide stiffening/dampening force when there is a shock.

[0068] FIGS. **5**A and **5**B show another example of a kinetic heat sink/apparatus **500** according to an illustrative embodiment of the invention. The apparatus **500** includes a base plate spreader **502** adapted to mount onto the heat-generating component **212**. A fluid-dynamic bearing spindle motor **504** is affixed to the base plate spreader **502** and a kinetic heat sink impeller **506** to rotate the kinetic heat sink impeller **506** with respect to the base plate **502**. The kinetic heat sink impeller **506** includes the rotating base **222** (referred to as an impeller plate) and a plurality of flow-directing structures **214** (referred to as impellers). The plurality of flow-directing structures **214** are configured to direct air flow through channels formed therebetween when the kinetic heat sink impeller **506** rotates to dissipate heat into ambient air.

[0069] The fluid dynamic bearing spindle motor **504** drives the kinetic heat sink impellers **506** and simultaneously controls the spatial gap **218** (also referred to as a gap thickness) between the baseplate spreader **502** and the rotating heat sink impeller **506**. The spatial gap **218** may vary to have a clearance of less than some predefined amount, such as about 20 μm, over a portion of the surfaces between the impeller plate **222** and the base plate **204** when the kinetic heat sink impeller **506** is rotating. The surfaces may be treated or configured with a low friction contact when the kinetic heat sink impeller **506** is at rest.

[0070] FIG. **6**A schematically shows a detailed diagram of the fluid-dynamic bearing **600** within the fluid dynamic bearing spindle motor **504** or within other similar embodiments. The fluid dynamic bearing **600** includes an axial control component **602** and may include a radial control component **604**. The axial control component **602** may be incorporated into the rotor **404**, the rotor housing **402**, and the rotor cap **610**.

[0071] The axial control component **602** controls the position of the rotor **404** situated on or along the direction of the axis **612**. The axial control component **602** may include a first control surface **614** to generate a thrust in a first direction **616**, and a second (opposed) control surface **618** to generate a thrust in a second direction **620**. The first control surface **614** may be a part the rotor housing **402**. The second control surface **618** may be a part of the rotor cap **610**. It should be apparent to those skilled in the art that the rotor cap **610** and the rotor housing **402** may be configured as a single unitary component. Clearance between rotor **404** and/or the rotor housing **402** and rotor cap **610** at the axial control component **602** may vary during normal operation. In an illustrative embodiment, the clearance may be about 5-10 μm or, more specifically, between about 2-4 μm. Again, the application may dictate the required clearance.

[0072] The radial control component **604** controls the clearance, and thus the position, of the rotor **404** with respect to the rotor housing **402** along the radial direction **622**. The radial control component **604** may be a fluid bearing or a mechanical-based bearing. In an illustrative embodiment, two journal bearings **624**, **626** (upper and lower) in the upper and lower regions of the rotor **404** and rotor housing **402** are employed. Clearance between rotor **404** and the rotor housing **402** may vary during normal operation. In an illustrative embodiment, the clearance may be approximately 10-20 μm or, in other embodiments, approximately 3-5 μm.

[0073] It should be apparent to those skilled in the art that the clearance values provided are merely illustrative. For example, clearance values greater than about 5-10 μm (for the axial clearances) may be used for larger scale applications where the apparatus is larger than a few inches, and for low cost cooling applications having generally high variability in tolerances.

[0074] FIG. **6**B shows a picture of the fluid dynamic bearing **600** of FIG. **6**A, including the rotor **404**, the rotor housing **402**, and the rotor cap **610**. The rotor housing **402** includes the first control surface **614** having included a fluid bearing with herringbone groove patterns. The rotor cap **610** includes the second control surface **618**, also having included a fluid bearing with herringbone groove patterns. The rotor **404**, in this embodiment, includes a shaft portion **628** embedded with a ring-shaped portion **630** at one end. The shaft portion **628** and the ring-shaped portion **630** have included the journal (i.e., portions in contact with the bearing).

[0075] In illustrative embodiments, the rotor cap **610** is assembled to be flush between the stationary base structure **204** and the rotating structure **206** (see for example, FIGS. **5**A, **5**B). The rotor cap **610** may be fixably attached to the stationary base structure **204** (such as, for example, by adhesives or by a frictional fit). The rotor cap **610** may preferably be made of a thermally conductive material to provide a parallel heat path between the stationary base structure **204** and the rotating structure **206**.

[0076] FIG. **6**C shows a photo of a cut-away of the rotor housing **402** of FIG. **6**B, specifically of the radial control component **604**. The rotor housing **402** has included the fluid bearing **624** and **626** with herringbone groove patterns.

[0077] FIG. **6**D shows an exploded view of an alternate assembly of the fluid dynamic bearing **600** of FIG. **6**A. The rotor housing **402** includes a casing component **632** and a bearing component **634**. As a result, the rotor **404** may be in direct contact only with the bearing component **634**. The bearing component **634** may be made of a different material and/or manufacturing process than the casing component **632**. For example, a lower cost manufacturing process may be employed, such as casting, to form the casing component **632**. The through-hole may be machined to achieve a defined finish and/or tolerance. In contrast, the bearing component **634** may be fabricated with high tolerance techniques. Similarly, the bearing component **634** may be made, in part, of high strength and high toughness material to minimize its wear.

[0078] In alternate embodiments, the fluid dynamic bearing **600** may be configured with a heat insulating structure embedded between the motor-stationary component and the stationary base structure, thereby insulating the electric motor assembly from the heat. The rotor cap **610** made of a thermal insulating material (i.e., a ceramic) may form the heat insulating structure. The rotor cap **610** may extend across both the motor-rotating component and the motor-stationary component, thereby providing thermal protection to the motor assembly from the heat being transferred.

[0079] Similarly, the motor assembly may be configured with cooling channels to direct air through the motor assembly when the motor-rotating component is rotatably moving.

[0080] FIG. **7**A shows cut-views of fluid dynamic bearings according to an illustrative embodiment of the invention. The fluid dynamic bearings include an axial control component and a radial control component, both of which may be incorporated into the rotor **404**, rotor housing **402**, and rotor cap **610**. The fluid bearing is shown as being a part of the rotor **404**, rather than of the rotor housing **402** and the rotor cap **610**. The first control surface **614** is configured as a spiral groove bearing.

[0081] FIG. **7**B shows a portion of a fluid dynamic bearing having a first control surface **614** according to an illustrative embodiment of the invention. The first control surface **614** is configured as a herringbone thrust bearing.

[0082] It is noted that in any of the above described embodiments, among other things, the second control surface may be configured as one of a spiral groove bearing and a herringbone thrust bearing.

[0083] Referring to FIGS. **5**A and **5**B, the fluid dynamic bearing spindle motor **504** may include thrust fluid bearings **516** to both generate the gap thickness **218** and to confine the gap thickness **218** to a finite rage (less than 20 microns) for a wide range of rotational speeds, impeller weight/shape, and orientation of the apparatus. The fluid dynamic bearings independently or in combinations with other fluid dynamic bearings may be configured to minimize the axial and radial movement of the heat-sink impeller **214**.

[0084] The lift and/or thrust force generated by a hydrodynamic bearing, including fluid bearings, may be expressed as:

$$F = K'\frac{\mu\omega(R_{outer}^4 - R_{inner}^4)}{h^2} \quad \text{(Equation 2)}$$

where K' is a dimensionless function of the bearing topology based upon the type of features, the number of features, and the thickness and depth of the features; R_{outer} and R_{inner} are the radius of the bearing features; h is the clearance gap; ω is the angular velocity; and μ is the viscosity of fluid and/or medium.

[0085] From Equation 2, it is noted that hydrodynamic bearings may form varying thrusts based on a gap h between the bearing surface and an opposing surface. Generally, the thrust (i.e., opposing pressure) increases as the gap becomes smaller due to the reverse relationship with the resulting thrust force F. As a result, hydrodynamic bearing may be characterized as having an inherent feedback control loop. When two opposing hydrodynamic bearing are employed, they may be arranged to maintain a pre-defined gap thickness.

[0086] Illustrative embodiments may use a number of different types of bearings, such as Rayleigh step thrust bearings, step-sector bearings, and spiral groove bearings (e.g., inward, outward, and/or herringbone). Hydrodynamic bearings may include Rayleigh step thrust bearing and spiral groove bearings. Rayleigh step bearings are generally angularly symmetric, and generate a repulsive force regardless of the direction of rotation. A step-sector bearing employs a non-angularly symmetric design (see, e.g., FIG. **12**B) and generally generate a repulsive force when rotating in the intended direction. Despite this, the force generated by a step-sector bearing is generally greater than that produced by a Rayleigh step bearing. Step-sector bearings generally have a deep groove right after the land section, as compared to a Rayleigh bearing, to ensure that the pressure is equalized to the surrounding fluid pressure at that location.

[0087] Spiral groove bearings may be configured as a thrust inward-pumping bearing, a thrust outward-pumping bearing, and a herringbone thrust bearing. Inward-pumping bearings are generally characterized as having fluid drawn inward from the outer perimeter. Outward-pumping bearings are generally characterized as having fluid drawn from the inner diameter. Herringbone thrust bearings are generally characterized as having both inward pumping and outward pumping actions.

[0088] The fluid dynamic bearing spindle motor **504** may rotate the heat sink impeller at high speeds. In a test setup, fluid dynamic bearing spindle motor was rotated at up to 12,000 revolutions per minutes (RPM).

[0089] The fluid dynamic bearing may be configured to provide dampening and/or stiffening effects as well as to account for thermal expansion effects. In an alternative embodiment, the fluid dynamic bearing spindle motor **504** may include mechanical bearings, such as ball bearings and/or roller bearings.

[0090] The bearings may be used for both thrust and journal bearings (i.e., for radial alignment). The fluid dynamic bearings and the mechanical bearings may be used independently or in combination for either of the axial alignment and for thrust.

[0091] The baseplate spreader **204** may be composed in part of a copper and/or aluminum disk and/or a vapor chamber. Moreover, at least two journal bearings may be used to control tilting and radial displacement of the rotor in the fluid dynamic bearing spindle motor. In addition, two opposing thrust bearings, which may be spiral, groove, or herringbone journal bearings, may be used to control the axial positioning. The operating gaps between the rotor and the rotor casing in the fluid dynamic bearing spindle motor may be 2 to 3 microns in the radial direction, and 5 to 10 microns on each side of the thrust bearings. Any number of different fluids may be used, such as oil (e.g., ester oil), thin-film, ferro-fluid, and/or air may be used as the lubricant.

[0092] When operating, the thrust bearings in the fluid dynamic bearing spindle motor may provide an additional

5-10 micron gap. The thrust generated, and thus the resulting gap thickness, may depend in part on the operating characteristics of the heat sink impeller, including its rotational speed, effective weight, and orientation.

[0093] As described, the opposing thrust bearings provide an opposing thrust to confine the gap thickness to a predetermined, preferably small range. The heat-sink impeller **214** may thus operate in arbitrary orientations over a wide range of operating speeds, as required for a robust heat-sink solution.

[0094] FIG. **8**A shows a diagram of kinetic heat sink/apparatus **800** according to another preferred embodiment of the present invention. At least one of the heat-extraction surface **216** and the second heat-conducting surface **210** are configured with a plurality of surface features **802** configured to maintain the spatial gap **218** when the rotating structure **206** is rotatably moving. The plurality of surface features may form a hydrodynamic bearing (e.g., a Rayleigh step bearing and/or a spiral groove bearing).

[0095] FIG. **8**B shows a diagram of rotating structure **206** having a hydrodynamic bearing, specifically, a Rayleigh step bearing **804**. A Rayleigh step bearing is generally characterized as having topographic surface features of alternating land regions **806** and groove regions **808**. A profile **810** of the Rayleigh step bearing is provided, where h_0 is the spatial gap **218** and S_h is the depth of the groove region.

[0096] Step bearings, such as Rayleigh step bearings, generally operate through the principle of fluid being compressed resulting from a motion between two parallel bodies. As the two parallel bodies move, the fluid is forced to move between the groove and the land regions; the forced fluid results in a force that may be configured to repel in either clockwise or counterclockwise direction of movement.

[0097] FIG. **9** is a diagram of a pressure profile **902** for the Rayleigh step bearing of FIG. **8**B. The geometry of the Rayleigh step bearing **804** is characterized by B_1 (the length of the land region), B_2 (the length of the groove region), B (the length of the each step bearing), h_0 (the spatial gap between the rotating and the stationary structure), and h_1-h_0 (the depth of the groove region). In this example, at position **904**, the pressure from the forced fluid is normalized to be zero. As the rotating structure **206** rotatably moves with respect to the stationary base structure **204** at speed U (**910**), a repulsion force is created by the compressed fluid, which linearly increases the pressure. The pressure reaches a maximum pressure, P_{max}, at the end of the groove region at position **906**. Then, the pressure profile linearly drops back to the initial starting pressure, P_0, at position **908**.

[0098] FIG. **10**A shows a picture of the stationary base structure **204** having included a hydrodynamic bearing, specifically, a spiral groove bearing **1002** on the second heat-conducting surface **210**. FIG. **10**B shows a zoomed-in image of the stationary base structure **204** of FIG. **10**A. With the rotating structure rotatably moving in a counter clockwise direction with respect to the stationary base structure **204**, the spiral groove bearings **1002** between land regions **1004** act as an outward pumping bearing. The average groove depth may vary up to 7 μm.

[0099] Referring back to FIGS. **5**A and **5**B, when at rest, the fluid dynamic bearing may be configured to provide a very small clearance between certain portions of the baseplate **204** and the impeller plate **222**. Some other portions of the opposing components **204** and **222**, however, may have no such clearance at rest. If there is no clearance, then there is some degree of friction during startup, and also during operation (e.g., if subjected to a shock). Illustrative embodiments therefore minimize the contact region of the fluid dynamic bearing to other components in the spindle motor **504**, effectively reducing start-up friction. This consequently improves the efficiency and the operating performance of the kinetic heat sink **200**.

[0100] To that end, the apparatus **500** may include a low-friction insert **518**. Although the fluid dynamic bearing spindle motor **504** may control the tilting of the heat-sink impeller **214** relative to the baseplate spreader **204** (as a baseplate spreader) during operation, the rotating and stationary surfaces of the heat sink may make contact at low rotational speed and/or when a large external shock is introduced. In addition, when the heat transfer surface area is sufficiently large, the contact may result in a high start-up power/torque in order to rotate the heat-sink impeller **214**.

[0101] The insert **518** may be configured to minimize wear or damage and may lower the high start-up power/torque. The insert **518** may be made from a variety of low friction materials, and/or may be placed closer to the axis of rotation than shown (the figure shows it at the maximum diameter), provided that the tolerances are such that the rotating and stationary surfaces do not make contact anywhere except for the region where the insert is present. FIG. **5**B shows a cross sectional view of the apparatus **500** of FIG. **5**A.

[0102] The insert **518** or the surfaces surrounding the gap thickness **218** (e.g., the surface on the baseplate **204** and the surface on the impeller plate **222**) may include a coating. The coating may be hard (i.e., non-abradable) and may provide a low-friction contact. The coating may be composed in part of at least electro-less nickel, a diamond-like coating, hardened steel, and/or dry film lubrication (e.g., tungsten disulfide, WS_2).

[0103] The low-friction insert may be placed either on the rotating surface and/or on the stationary surface such that a portion of the insert extends out with respect to either of the surfaces. When placed at a perimeter of a 4-inch diameter rotating structure, the insert may be configured to protrude up to some amount, such as about 7 μm from the underlying surface.

[0104] FIG. **11** shows an exploded diagram of the apparatus **500**. Further shown are the components of the motor assembly **504**, including the rotor **404**, rotor cap **610**, rotor housing **402**, stator windings **406**, permanent magnets **406**, and a retaining cap **1102**. In an embodiment, the retaining cap **1102** fixably retains the rotor **404** with the impellers **214**.

[0105] FIG. **12**A shows an apparatus **1200** according to an alternative embodiment. The apparatus **1200** includes the various aspects of apparatus **800** (FIG. **8**A) and further includes an active control schemes to help regulate the spatial gap distance during operation and at start-up. Specifically, the stationary base structure **204** includes an output **1202** to introduce actively pumped fluid (including, e.g., air) into the spatial gap **218**. The actively pumped fluid may be introduced at inlet **1204** and may be provided by a fluid pump **1206**.

[0106] The actively pumped fluid may have a pressure as low as 0.5 psig. FIG. **12**B shows a photo of the apparatus **1200** of FIG. **12**A. The apparatus **1200** may be configured to introduce the actively pumped fluid only at the startup to reduce the frictional contact at the spatial gap **218**. As a result, upon the heat sink impeller reaching a sufficient speed for the fluid bearings **802** to produce self-regulating thrust, the actively pumped fluid may be stopped. Similarly, the actively pumped fluid may be introduced during shutdown.

[0107] FIG. **13** shows an illustrative process of operating the kinetic heat sinks discussed above. In general, the process begins by providing the heat sources, such as a heat-generating component **212**. The kinetic heat sink is secured to the heat generating component **212** (step **1302**), which may be, for example, a package of an electronic device or a printed circuit board. Various types of securing and mounting mechanisms known in the art may be used for these purposes. Among other things, those mechanisms may include screws, clips (e.g., z-clip, clip-on), push pins, threaded standoffs, glue, thermal tapes, and thermal epoxies.

[0108] When at rest, the rotating structure **206** may be seated against the base structure **204** or on a low-friction startup surface (e.g., insert or coating). The spatial gap **218** may have a distance of 5-10 microns.

[0109] To begin cooling, the controller **306** energizes the motor assembly **302**, **304** (step **1304**) causing the motor-rotating component **304** and rotating structure **206** to rotate. The power may be in V_{DC} (e.g., 12V, 5V, etc), V_{AC}, or PWM. As the rotating structure **206** rotates, fluid in the spatial gap **218** and between the control surfaces **614**, **618** begin to move. At some rotational speed, such as over 1000 RPM, the fluid movement causes (i) the first control surface **614** (e.g., of the rotor housing **402**) to generate a first thrust thereby lifting the rotating structure **206** with respect to the base structure **204** and (ii) the second control surface **618** (e.g., of the rotor cap **610**) to generate a second thrust. The second thrust is in an opposing direction of the first thrust. This first thrust and second thrust balances the rotating structure **206** at a location along the axial axis with the spatial gap between the desired range, such as between approximately 10 and 20 microns. At such spatial gap and rotation speed, the thermal resistance characteristic of the spatial gap **218** is reduced allowing for heat to more readily transfer from the base structure **204** to the rotating structure **206**. If a change of speed or a sudden shock is introduced to the system, the opposing thrusts correspondingly increase, thereby attenuating or absorbing the shock.

[0110] While rotating, the fluid-directing structure **214** (e.g., impeller) also rotates causing the fluid in the channels between the fluid-directing structures **214** to move. As the fluid moves, heat from the fluid-directing structure **214** is rejected to the moving fluid and dispels into the thermal reservoir **108**. As a result, heat is drawn from the heat-generating component **212**, spread across the base structure **204**, transferred from the base structure **204** to the rotating structure **206** across the spatial gap **218**, and spread from the heat-extraction surface **216** to the fluid-directing structures **214**.

[0111] FIG. **14** schematically illustrates this step by showing a diagram of a heat-flow model of the apparatus according to the preferred embodiment of the invention. The heat generated by the heat-generating component **212** is characterized as Q_{chip}. As heat is spread across the base structure **204**, the resistance of the base structure **204** may be characterized as a $R_{base,\ linear}$ and $R_{base,\ spread}$. The movement of fluid from the rotation of the rotating structure **206** may be model as a sheering loss that generates heat (Q_{shear}). The motor assembly **302**, **304** also generates heat (Q_{motor}) from the rotation. The heat from the motor (Q_{motor}) is modeled to be a part of the base structure **204** to be transferred to the rotating structure **206**. Heat from the sheering loss is introduced at the spatial gap (R_{airgap}). With laminar flow formed in the small (i.e., 10-20 um) distance of the spatial gap **218**, the thermal resistance is sufficiently small allowing heat to transfer across the spatial gap **218** to the rotating structure **206**. As heat is spread across the rotating structure **206**, the resistance of the rotating structure **206** may be characterized as $P_{platten}$ and R_{fins}. The rejection of the heat from the fluid-directing structures **214** to the fluid may be characterized as $R_{rejection}$. Parasitic heat loss and leakage may be characterized as R_{leak}.

[0112] Referring back to FIG. **13**, at block **1306**, the controller **306** determines whether to continue to cool the heat-generating component **212**. This may be based on a control signal or power being applied to the kinetic heat sink. The controller **306** may vary the rotation speed of the motor-rotating component **304** or the power output thereto based on temperature (e.g., at the heat-generating component **212** or various components of the kinetic heat sink) or distance of the spatial gap **314**. Of course, various control schemes may be employed to rotatably move the rotating structure with respect to the stationary base structure. The process concludes at step **1308**, in which the kinetic heat sink is de-energized. To that end, the controller **306** may reduce power to the motor assembly **302**, **304**, or power may be removed to the controller. The rotating structure **206** slows to a stop forming a contact with a portion of the base structure **204** or de-energize to a low-friction state.

[0113] The embodiments of the invention described above are intended to be merely exemplary; numerous variations and modifications will be apparent to those skilled in the art. All such variations and modifications are intended to be within the scope of the present invention as defined in any appended claims.

What is claimed is:

1. A kinetic heat sink apparatus comprising:

a stationary member comprising a base structure having a first heat-conducting surface and a second heat-conducting surface to conduct heat therebetween, the base structure being fixably mountable at the first heat-conducting surface to a heat-generating component; and

a rotating structure rotatably coupled with the base structure, the rotating structure having a movable heat-extraction surface facing the second heat-conducting surface across a spatial gap, the rotating structure being configured to transfer heat from the second heat-conducting surface to a thermal reservoir communicating with the rotating structure,

the rotating structure and stationary member including two pairs of opposing surfaces, at least one surface of each of the two pairs of opposing surfaces having hydrodynamic features thereon, the two pairs of opposing surfaces of the rotating structure and the stationary base structure producing respective first and second thrust bearings to maintain the spatial gap within a pre-specified range during the rotation of the rotating structure.

2. The apparatus of claim **1**,

wherein the stationary member includes a stationary motor member, the rotating structure includes a rotating motor member, the stationary motor member and rotating motor member forming a motor assembly configured to rotate the rotating structure when energized,

the stationary motor component and the rotating motor component include at least one of the two pairs of opposing surfaces to generate at least one of the two thrusts in opposing direction during the rotation of the rotating structure.

3. The apparatus of claim **2**, wherein the stationary member includes a heat insulating portion between the stationary motor member and the base structure to thermally insulate the stationary motor member.

4. The apparatus of claim **2**, wherein at least one of the stationary motor member and the rotating motor member includes channels to direct cooling fluid therethrough.

5. The apparatus of claim **1**, wherein at least a portion of the heat-extraction surface and at least a portion of the second heat-conducting surface form one of the two pairs of opposing surfaces to generate one the two thrusts in opposing direction during the rotation of the rotating structure.

6. The apparatus of claim **1**, wherein the rotating structure includes a shaft portion including at least two surfaces, each of the two surfaces of the shaft portion being a part of each of the two pairs of opposing surfaces,

the stationary member including two corresponding surfaces facing the two surfaces of the shaft portion, each of the two corresponding surfaces of the stationary member being a corresponding part of each of the two pairs of opposing surfaces, the two surfaces of the shaft portion and the two corresponding surfaces of the stationary member generating the two thrust bearings during the rotation of the rotating structure.

7. The apparatus of claim **1**, wherein each pair of the at least two pairs of opposing surfaces form a hydrodynamic bearing, the hydrodynamic bearing including at least one member of the group consisting of a spiral groove bearing, a step bearing, a sector step bearing, a Rayleigh step bearing, a thrust inward-pumping bearing, a thrust outward-pumping bearing, and a herringbone thrust bearing.

8. The apparatus of claim **1**, wherein the rotating structure includes a plurality of flow-directing members to channel ambient fluid to dissipate heat from the rotating structure, the flow-directing members including at least one member of the group consisting of fins and fan blades.

9. The apparatus of claim **1**, wherein the spatial gap varies between approximately 10 and 20 micrometers during the rotation of the rotating structure.

10. The apparatus of claim **1**, wherein the base structure and the rotating structure are comprised of different thermal conducting materials.

11. The apparatus of claim **1** further comprising:

a sensor configured to generate a feedback signal associated with at least one of 1) the distance of the spatial gap and 2) a thermal quantity associated with at least one of the heat-generating component, the base structure, and the rotating structure; and

a controller configured to vary a speed of rotation of the rotating structure based on the feedback signal.

12. The apparatus of claim **1** further comprising:

an active pump regulator configured to introduce fluid into the spatial gap.

13. The apparatus of claim **1** further comprising:

a spatial gap regulator configured actively vary the spatial gap based on an electromagnetic field.

14. The apparatus of claim **1**, wherein at least one of the base structure and rotating structure includes a coating having a coefficient of friction less than 0.5, the base structure and rotating structure being in contact at the coating when the rotating structure is at rest.

15. The apparatus of claim **1**, wherein at least one of the base structure and rotating structure includes an insert that separates a portion of the heat-extraction surface from a portion of the second-heat conducting surface when the rotating structure is at rest.

16. The apparatus of claim **1**, wherein the base structure forms, in part, at least one of a vapor chamber, a motor, and a heat pipe.

17. A kinetic heat sink comprising:

a base plate adapted to fixably mount to a heat-generating component;

an impeller configured to rotate in relation to the base plate across a gap of less than 20 micrometers, the impeller having an impeller plate and a plurality of fins extending therefrom, the impeller plate forming the gap with the base plate, the fins forming channels therebetween; and

a spindle motor configured to cause the impeller to rotate, the spindle motor having a stationary portion affixed to the base plate and a rotating portion affixed to the impeller,

at least two portions of the stationary and rotating portions of the spindle motor forming fluid-dynamic bearings,

during the rotation of the impeller, the base plate conductively receiving heat from the heat-generating component and transferring at least a portion of the received heat across the gap to the impeller, the gap being regulated, at least in part, by thrusts formed in opposing directions by the fluid-dynamic bearings, the impeller receiving the transferred heat and transferring the transferred heat to ambient fluid communicating with the impeller by directing the ambient fluid through the channels.

18. A method of dissipating heat from an electronic device, the method comprising:

providing a stationary structure having a first and second heat-conducting surface, the stationary structure being thermally coupled to the electronic device at the first heat-conducting surface to draw heat from the electronic device, the stationary structure conducting the drawn heat from the first heat-conducting surface to the second heat-conducting surface;

rotating a rotating structure having a heat-extraction surface facing the second heat-conducting surface across a spatial gap, rotating transferring heat from the second heat-conducting surface to the rotating structure and rejecting the transferred heat from the rotating structure to a thermal reservoir in communication with the rotating structure; and

generating thrusts on the rotating structure as a result of the rotation of the rotating structure, at least two of the thrusts being in opposing directions to maintain the spatial gap within a pre-specified range.

19. The method of claim **18** further comprising:

varying the rotation of the rotating structure, including a rate of rotation, to maintain the spatial gap within a pre-specified range.

20. The method of claim **19** further comprising:

measuring a thermal quantity associated with at least one of the stationary structure, the stationary structure, the spatial gap, and the electronic device; and

using the measured thermal quantity to vary the rotation of the rotating structure.

* * * * *