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(54) **Title:** MECHANISM FOR ENHANCED ENERGY EXTRACTION AND COOLING PRESSURIZED GAS

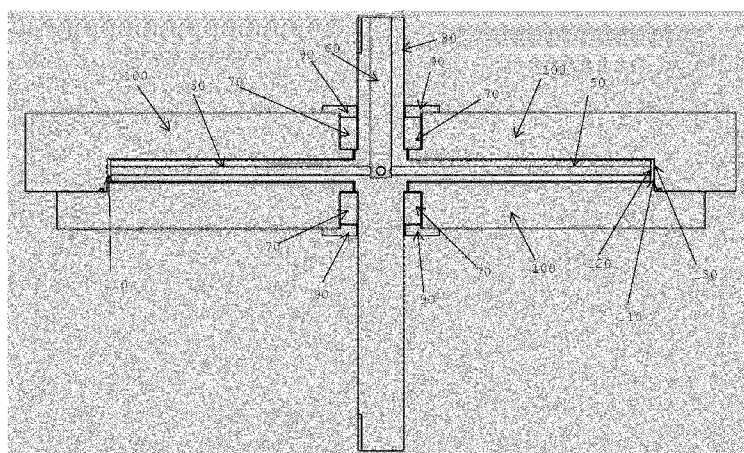


FIGURE 3

(57) **Abstract:** Systems, methods, and devices relating to a mechanism which can be used in gas cooling devices, pneumatic motors, turbines and other pressurized gas devices. A rotatable rotor is provided along with a number of hollow conduits that radially radiate from an exit port at the center of the rotor. The pressurized gas is injected into the mechanism at the inlet port(s). The gas enters the conduits and travels from the inlet port(s) to the exit port(s). In doing so, the gas causes the rotor to rotate about its central axis while the gas cools. This results in a colder gas at the exit port(s) than at the inlet port(s).



MECHANISM FOR ENHANCED ENERGY EXTRACTION AND COOLING OF PRESSURIZED GAS

TECHNICAL FIELD

[0001] The present invention relates to methods and devices relating to the vortex tube effect and its application in a mechanism that can be used in various practical applications.

BACKGROUND OF THE INVENTION

[0002] Various physical phenomena have been analyzed and their practical applications have been found over the years. This document revisits the concept of angular momentum conservation and the corresponding propulsion imparted to a reference frame by an ejected fluid. The focus is on constrained flows within moving frames, where flow confinement results in a well-defined physical problem. The thermophysics of the phenomena are examined with a particular goal in mind - namely, to predict the fluid temperature as observed in different frames of reference, to predict the angular propulsion imparted to the rotating reference frame, as well as describe the underlying physics leading to such observations. Attention is devoted to the applicability of the presented physical model to rotational flows, which exhibit radial temperature separation. A most relevant example is the vortex tube effect, discovered in 1933 by the French physicist Georges J. Ranque. The effect has now been studied for

nearly 80 years, yet while a number of models have been proposed, they remain a subject of debate. The fundamental reason for this is the complexity of vortex tube flow obscuring the underlying physics, which in its turn obfuscates any concise understanding of the effect. Notwithstanding, interest in the vortex tube phenomena remains high, as demonstrated by a present day literature search in the Google Scholar database resulting in 4240 references to published documents discussing the topic of vortex tube airflow.

SUMMARY OF INVENTION

[0003] The present invention provides systems, methods, and devices relating to a mechanism which can be used in gas cooling devices, pneumatic motors, turbines and other pressurized gas devices. A rotatable rotor is provided along with a number of hollow conduits that radially radiate from an exit port at or near the center of the rotor. The pressurized gas is provided to the mechanism at the inlet(s) of the rotor. The gas then enters the conduits and travels from the inlet(s) of the rotor to the exit port. In doing so, the gas causes the rotor to rotate about its central axis while the gas cools. This results in a colder gas at the exit port than at the outer perimeter of the rotor.

[0004] In one aspect, the present invention provides a mechanism comprising:

- a rotatable rotor having an axis of rotation;

- an exit port;
- an inlet port, said inlet port being at a periphery of said rotor, said inlet port being for receiving pressurized gas from said periphery of said rotor;
- a hollow conduit, said hollow conduit directly connecting said inlet port to said exit port;

wherein

- a radial distance between said axis of rotation and said exit port is less than a radial distance between said axis of rotation and said inlet port;
- pressurized gas received at said inlet port passes from a periphery of said rotor to said exit port through said conduit to thereby cause said rotor to rotate about said axis of rotation;
- after passing through said conduit, said pressurized gas at said exit port is colder than said pressurized gas at said periphery of said rotor.

[0005] In another aspect, the present invention provides a method for cooling a gas, the method comprising:

- a) pressurizing said gas to produce a pressurized gas;
- b) providing a mechanism comprising:
 - a rotatable rotor having an axis of rotation;
 - an inlet port at a periphery of said rotor;

- an exit port, a radial distance between said exit port and said axis of rotation being less than a radial distance between said inlet port and said axis of rotation;
 - a hollow conduit directly connecting said inlet port to said exit port;
- c) providing said pressurized gas at a periphery of said rotatable rotor to allow said pressurized gas to enter said inlet port;

wherein

- pressurized gas provided at said inlet port passes from the periphery of said rotor to said exit port through said conduit to thereby cause said rotor to rotate about said axis of rotation.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] The embodiments of the present invention will now be described by reference to the following figures, in which identical reference numerals in different figures indicate identical elements and in which:

FIGURE 1 is a schematic diagram used to explain the principles of the invention;

FIGURE 2 is a partially transparent isometric view of a mechanism according to one aspect of the invention;

FIGURE 3 is a cross-sectional view of the mechanism of Figure 2; and

FIGURE 4 is an exploded view of the mechanism illustrated in Figure 2.

DETAILED DESCRIPTION

[0007] The uniform rotation of a straight adiabatic duct about the vertical symmetry axis of its outlet produces cooling of air at the rotation center of the device. Air is supplied to the duct inlet by a pressurized gas tank at room temperature. In this simple illustration (Figure 1), the tank is mounted to the duct inlet and rotates with the duct. As air moves radially inward, it imparts its kinetic and internal energy as propulsion to the rotating system. This produces a twofold benefit: elimination of the requirement for power to sustain rotation; and cooling of air at the exit of device. Based on these findings it is concluded that the rotation of this simple device and the accompanying refrigeration of air can be utilized in providing instantaneous, on-demand refrigeration of air, and shaft work due to angular propulsion of the rotating system.

[0008] Thus in one aspect the present invention provides a rotational device, comprising:

a) a conduit D with length R and drive means connected to the conduit D to impart rotational velocity to said conduit D;

b) an air tank, which provides compressed air to the inlet of duct D

c) a cold exit vent positioned at a device centre, wherein pre-rotated air, supplied at device periphery is run through the device and undergoes a sharp temperature decrease, as this spiral motion of air leads to the exhaust of cold air via said central exit vent.

[0009] Generally speaking, the systems described herein are directed to method and device that reproduces and controls the vortex tube effect. As required, embodiments of the present invention are disclosed herein. However, the disclosed embodiments are merely exemplary, and it should be understood that the invention may be embodied in many various and alternative forms. The Figures are not to scale and some features may be exaggerated or minimized to show details of particular elements while related elements may have been eliminated to prevent obscuring novel aspects. Therefore, specific structural and functional details disclosed herein are not to be interpreted as limiting but merely as a basis for the claims and as a representative basis for teaching one skilled in the art to variously employ the present invention.

[0010] For purposes of teaching and not limitation, the illustrated embodiments are directed to the method and device that that reproduces and controls the vortex tube effect.

[0011] It should be noted that the analysis of the vortex phenomenon assumes *a priori* that a rotating flow can be discretized. Also examined is the behavior of the phenomenon's discrete element - a paradigm through which the long-standing physical phenomenon of temperature

separation unravels and becomes accessible to analysis. The main reasoning in this work follows along the lines of establishing relative contexts of a stationary and moving observer, positioned in their corresponding reference frames, followed by an examination of relative flow motion and the relevant conservation laws.

[0012] In the physics of fluids, the thermodynamic (or static) temperature T_S is that which corresponds to thermal equilibrium and is the same in all frames of reference. The total, or stagnation, temperature is an effective temperature that originates from the total (or stagnation) enthalpy

$$h = h_s + v^2/2$$

via division by the isobaric heat capacity c_p , and takes the form

$$T = T_s + \frac{v^2}{2c_p} \quad (1)$$

where v is the fluid velocity. Because the total temperature contains v , it is, consequently, frame-dependent. In a moving frame F' , this temperature becomes

$$T_{tot} \equiv T_s + \frac{v'^2}{2c_p} \quad (2)$$

where $\mathbf{v}'$ is the flow velocity relative to the frame. In adiabatic duct flow, the conservation of energy demands that the total enthalpy is conserved. Thus, utilizing the connection between total enthalpy and total temperature, energy conservation can also be expressed as

$$T = \text{const} \quad (3)$$

under adiabatic flow conditions.

[0013] Consider the reference frame F' , rotating about the z -axis with constant angular velocity $\omega = \text{const}$. Energy conservation in rotating fluid flows has the form

$$T + \frac{v'^2 - (\boldsymbol{\omega} \times \mathbf{r})^2}{2c_p} = \text{const} \quad (4)$$

under adiabatic conditions. Let the rotating frame F' be attached to a fluid flow system, comprising a tank of compressible fluid under high pressure and room temperature T_∞ , connected to the inlet of an adiabatic duct, as shown in Figure 1. The compressed fluid is allowed to flow through the duct where it gradually expands, accelerates and exits at the center of the frame. The velocity addition formula for the system is

$$\mathbf{v} = \mathbf{v}' + \boldsymbol{\omega} \times \mathbf{r} \quad (5)$$

Expressing $\mathbf{v}'$ and substituting it into the energy conservation condition (4) yields

$$T_s + \frac{v^2 - 2\mathbf{v} \cdot (\boldsymbol{\omega} \times \mathbf{r}) + (\boldsymbol{\omega} \times \mathbf{r})^2 - (\boldsymbol{\omega} \times \mathbf{r})^2}{2c_p} = \text{const} \quad (6)$$

[0014] Reworking this expression to include the total fluid temperature T seen in the stationary frame yields

$$T_s + \frac{\mathbf{v} \cdot (\boldsymbol{\omega} \times \mathbf{r})}{2c_p} = \text{const} \quad (7)$$

Therefore, the observer in the stationary frame F will report a temperature difference

$$\Delta T = T(\text{inlet}) - T(\text{outlet}) = \frac{\mathbf{v}_{\text{inlet}} \cdot (\boldsymbol{\omega} \times \mathbf{r}_{\text{inlet}})}{c_p} - \frac{\mathbf{v}_{\text{outlet}} \cdot (\boldsymbol{\omega} \times \mathbf{r}_{\text{outlet}})}{c_p} \quad (8)$$

between the high-energy peripheral flow and the low-energy flow at the rotation center. Since in this particular fluid flow system the duct is straight,

$$\mathbf{v} \parallel \boldsymbol{\omega} \times \mathbf{r}$$

everywhere, and because the flow exits at the rotation center, $\mathbf{r}_{\text{outlet}} = 0$. If we denote the peripheral tip speed of the duct

$$\boldsymbol{\omega} \times \mathbf{r}_{\text{outlet}}$$

as c , then (8) reduces to

$$\Delta T = T(inlet) - T(outlet) = \frac{c^2}{c_p} \quad (9)$$

[0015] Thermodynamics of the flow is interpreted in F and F' as follows:

[0016] According to an observer in the moving frame F' :

1. Both static and relative total temperatures in the fluid tank are equal to T_∞ ;
2. The tank fluid expands through the duct and does work to overcome the centrifugal gravitational potential $-(\omega \times r)^2/2$; the exiting fluid has lost internal energy and gained gravitational potential energy;
3. The fluid accelerates through the duct, due to expansion, and experiences the deflecting action of the Coriolis force;
4. At the outlet, the exiting fluid has a higher velocity than at the duct inlet due to expansion, but has lost internal energy and is $c^2/2c_p$ cooler than T_∞ .

[0017] According to an observer in the stationary frame F :

1. The total temperature in the pressurized fluid tank is $T = T_\infty + c^2/2c_p$ due to the motion of F' ;
2. The fluid speed at the duct inlet is equal to c and the temperature is equal to the temperature in the fluid tank $T(inlet) = T_\infty + c^2/2c_p$;

3. High-energy fluid decelerates as it approaches the outlet; that is, while the radial velocity increases, the tangential velocity goes to zero, resulting in a substantial net deceleration;

4. At the outlet, the exiting fluid has low velocity and has also lost internal energy. This conclusion contradicts the intuition of the stationary observer, since a high-energy volume of compressible fluid is expected to exhibit a static temperature rise when brought to rest adiabatically.

[0018] It is seen that the energy conservation condition (7) imposes radial dependence in the total temperature known as temperature separation. It is a physical phenomenon, in which rotating fluid flow appears heated at the periphery and cooled at the center of rotation. Therefore, in the case of rotation, cooling of the ejected fluid is due to conservation of angular momentum and the corresponding angular propulsion imparted to the rotating frame. It is this critical element that leads to a clear understanding of the temperature separation effect in fluids. Since the energy conservation requirement (4) applies under adiabatic conditions, it prohibits heat exchange through the duct walls in the system in Figure 1. Therefore the cooling of the fluid (9) is a result of adiabatic expansion, during which the fluid does work on its surroundings by propelling the moving reference frame.

[0019] Let us now begin to examine the rotating duct system with the goal of determining the propulsion energy that goes into the rotation as a result of an ejection of the

gas coming from the tank. For this purpose, consider that the rotating tank and duct assembly is a system with variable mass. This is the main physical context within which the following study will be made.

[0020] Let M be the constant composite mass of this system, moving with angular velocity $\omega = c/r$ in a circle with radius r . For generality, consider the position vector $\mathbf{R}$ and velocity vector $\mathbf{v}$ in the stationary frame of reference $\mathbf{F}$ (which reduce to r and c in the system shown in Figure 1). Consider an external torque (e.g. resistance of the medium) τ_{ext} be acting on M at time t . At some later moment $t + \Delta t$, the composite system ejects mass ΔM , which moves radially inwards on a radial constraint and thus the angular momenta $\mathbf{L}$ are

$$\begin{aligned}\mathbf{L}(t) &= \mathbf{R} \times M\mathbf{v} \\ \mathbf{L}(t + \Delta t) &= \mathbf{R} \times (M - \Delta M)(\mathbf{v} + \Delta \mathbf{v}).\end{aligned}$$

The rotational equivalent to the second law of Newton

$$\mathbf{R} \times M\dot{\mathbf{v}} = \tau_{\text{ext}} - \mathbf{R} \times \dot{M}\mathbf{v},$$

for this constant mass system in $\mathbf{F}$ is $\tau_{\text{ext}} = \Delta \mathbf{L} / \Delta t$, which leads to the equation of rotational motion as $\Delta t \rightarrow 0$ where the mass flux dM/dt is negative, since the mass of the body is decreasing in time. A tacit assumption is that mass dM , even though moving initially with velocity $\mathbf{v}$ as part of the composite mass M , reaches zero velocity at the rotation center within a time interval dt .

[0021] For rotating systems with finite size, this is still a reasonable assumption, since masses dM , each moving with their own speed within the system, form a continuous radial flow of ejected mass dM/dt .

[0022] The expression

$$\mathbf{R} \times \dot{M} \mathbf{v}$$

represents rotational thrust, which is maximum in the stationary frame $\mathbf{F}$, since the velocity of the expelled mass is zero. This expression has dimension of torque; it is to be attributed to the third law of Newton, according to which the rotating system experiences the reaction torque of the radially ejected mass flow dM/dt .

[0023] The rotational motion produced always corresponds to maximum thrust when mass is ejected at the center of rotation where its velocity is zero. Let us consider the case $\mathbf{v} = \text{const}$, where the external resistance of the environment is precisely counterbalanced by the rotational thrust. In this case, the power delivered to the rotational system by the thrust torque is

$$\tau_{ext} \cdot \omega = \dot{M} v^2$$

since

$$\tau_{ext} = \mathbf{R} \times \dot{M} \mathbf{v} \text{ and } \mathbf{R} \perp \mathbf{v}$$

which leads to

$$\tau_{ext} \cdot \omega^{12} = \tau_{ext} \omega.$$

[0024] Then, the thrust energy delivered to the system per expelled mass M is

$$E_t = M \mathbf{v}^2.$$

[0025] The equations of mechanics are sufficient to describe the concept of the propelled rotational motion. However, one is led to conclude that the most practically important variable mass systems will rely on the properties of gas: gases can form continuous flow and thus produce constant thrust; also, gases are capable of storing energy, which is reflected by their temperature. For these reasons, the thermodynamics of rotating variable mass systems is important, and will be included in this study.

[0026] As it was shown in (9) above, the exiting gas experiences a drop in total temperature $\Delta T = \mathbf{c}^2 / c_p$. It was shown, that according to an observer in $\mathbf{F}$, there is a radial gradient of the total temperature over the entire radial extent of the system. The tank at the periphery appears heated (entirely kinetic, not thermodynamic heating), while the exhaust gas at the center is cold. Since the total temperature T is defined through the total (stagnation) enthalpy of the gas, the energy transferred as propulsion to the rotating system is

$$E_t = c_p M \Delta T = M \mathbf{v}^2,$$

the same expression as the one for thrust energy delivery (with $\mathbf{v} = \mathbf{c}$ at the duct inlet), calculated above entirely with the equations of mechanics. Thus, energy was invested into the gas in a twofold process: (i) energy $M\mathbf{v}^2/2$ was invested as internal energy and (ii) kinetic energy $M\mathbf{v}^2/2$ was invested by setting the system in rotational motion with angular velocity ω . By ejecting itself from the center of mass of the rotating system, gas with mass M spends internal energy $M\mathbf{v}^2/2$ in order to decrease its kinetic energy by $M\mathbf{v}^2/2$, thus imparting rotational thrust energy $M\mathbf{v}^2$ to the system.

[0027] Thus, rotary propulsion motion producing maximum thrust is the rotational motion of a system with variable mass, exhausting at its center. The rotational system can also be characterized as an angular propulsion engine (APE) that derives thrust torque due to conservation of angular momentum, i.e. $\tau_{\text{ext}} = \Delta \mathbf{L} / \Delta t$. The maximum propulsion energy attributed to an APE having peripheral speed $\mathbf{v}$ by the ejection of gas at its center is $M\mathbf{v}^2$ - a sum of two equal energy portions, one of which is due to the deceleration of the expelled gas and the other to its cooling. The basic rotational system we studied exhibits a gradient of the total temperature over the entire radial extent of the system, as witnessed in the stationary reference frame $\mathbf{F}$. The mechanics of the rotating system has a direct and precise connection to the cooling of gas explained in the thermodynamics argument above, and thus further elucidates the concept of angular propulsion. In addition, the treatment presented herein shows that the thermophysics of the rotating system is derived based on existing laws; no

special treatment to the mass, Navier-Stokes or energy transport equations for compressible, rotating flows is implied. On this basis, it is not surprising that commercially available computational fluid dynamics solvers are already capable of predicting the observed cooling effect.

[0028] What are the conditions under which no cooling is observed? If the reference frame containing the flow is not moving, no cooling will be observed since the frame is unable to absorb the flow energy. For a duct at rest, where the exiting flow velocity has been chosen to be equal to c , no temperature decrease is observed. Cooling in the stationary frame is produced only when the duct system is moving and able to absorb the energy of the flow as thrust or propulsion. The produced temperature separation ΔT grows with the magnitude of the frame velocity c and is limited by the speed of sound in the surrounding fluid for practical reasons. ΔT is always symmetric with respect to the ambient temperature T_∞ and equal to c^2/c_p . When c is nearly equal to the speed of sound at sea level (340m/s), $\Delta T=115.2$ K. The heating of $c^2/2c_p= 57.6$ K is entirely dynamic and due to the motion of the duct periphery with velocity c ; the cooling is due to an adiabatic expansion needed to overcome the centrifugal potential barrier and has magnitude of $c^2/2c_p= 57.6$ K.

[0029] It is also important to note that compressibility of the fluid is vital for storing internal energy, which would later be imparted to the frame upon decompression as well as result in a reduction of static temperature. In

the case of incompressible fluids, energy is still transferred to the frame due to angular momentum conservation, however this cannot produce cooling as the fluid is unable to give up internal energy. The same conclusion is found in the work of R. Balmer, where water was used as the working fluid in a vortex tube. Cooling was not achieved in any of the conducted experiments by Balmer and fluid at the periphery was reported to have an elevated temperature. This result is consistent with angular propulsion imparted on the rotating fluid, resulting in high kinetic energies at the periphery consequently leading to heating through friction.

[0030] It is also worth noting that the magnitude of ΔT does not depend on the radial size of the rotating system, as long as its peripheral velocity is equal to c in the stationary frame. In addition, centrifugal and Coriolis forces alone cannot alter the total temperature of the flow, since no work is subtracted from the fluid under gravity.

[0031] Flow through the rotating duct shown in Figure 1 was also computed using the commercial computational fluid dynamics (CFD) solver FLUENT to demonstrate that the results of the presented theoretical model are also obtained by discretely solving the differential transport equations for mass, momentum and energy. Simulations were performed with air as an ideal gas using the 3-dimensional, double precision discretization model for compressible flow. The standard version of the $k-\varepsilon$ model with wall-

functions was used to characterize turbulence effects, and the second-order upwind discretization scheme was used to model advection in the transport equations. Since physical scale is not a factor in the current treatment, the duct was given a length of 15 m and rectangular cross-sectional dimensions 0.3m x 0.4m with no-slip, adiabatic walls. Smaller or larger ducts will produce the same effect provided the rotational speed is adjusted to develop the same pressure gradient across the duct. In all calculations, the mass flow rate of the air was fixed at 3 kg/s; the highest rotational speed was selected such that the peripheral velocity of the duct c remained subsonic. Energy, momentum and mass conservation were reached in all simulations, with residuals decreasing smoothly to below 10^{-13} . Table 1 compares the theoretical $\Delta T = \omega^2 r^2 / c_p$ ($r=15\text{m}$) with its corresponding total temperature difference predicted by FLUENT for different rotational speeds

ω , rad/s	0	2	5	10	15	20
ΔT , CFD [K]	0	0.89	5.53	22.08	49.68	88.3
ΔT , Eq. (9), [K]	0	0.9	5.61	22.42	50.45	89.69

Table 1: ΔT for different rotation rates

[0032] The CFD predictions approximate the theoretical result to within 1.5% in all cases. This comparison shows that the numerical values for ΔT given by Equation (9) are also obtained using another well-established method; it should be borne in mind that CFD utilizes

discretization and turbulence modeling and as such represents an approximation to the physical phenomena described above.

[0033] While the setup in Figure 1 is not identical to a vortex tube, it demonstrates the essential physical characteristics of the vortex tube flow, namely spiral flow geometry accompanied by radial pressure and temperature behavior. Therefore, a rotating duct or conduit can be considered a discrete element of the vortex tube flow field. It presents a simplification in the description of vortex tube flow, which allows for a succinct explanation of the vortex tube phenomenon. For the rotating duct, flow is driven from the periphery to the center by a pressure gradient that opposes the centrifugal gravitational field induced by rotation. Energy is imparted by the expanding fluid to propel the rotating frame via the interface between the fluid and the solid (i.e. the duct or conduit wall). In this manner, maximum energy exchange occurs and the maximum possible temperature separation is observed. In the case of a vortex tube, flow is driven from the periphery of the tube to the center by a pressure gradient that opposes the induced gravitational field, but the expanding fluid can only transfer energy to the rotating frame (the fluid itself) via fluid friction, leading to less efficient cooling than that for the confined flow.

[0034] A key difference between the rotating duct and the vortex tube is the necessity of a hot fluid outlet in the latter. The hot outlet is not required in the rotating duct because the compressed fluid source is

rotating with the duct; the only heating that occurs is due to fluid friction opposing the flow towards the duct outlet. In a vortex tube, the fluid enters the tube at the periphery to generate the swirling flow, and to set up the (centrifugal) gravitational field and the pressure gradient. Because of the high flow speeds required to set up the required gravitational field, fluid friction results in significant viscous dissipation at the periphery, which must be removed to achieve any cooling effect at the cold outlet (relative to the inlet). If the hot outlet were closed, the fluid leaving the system would simply absorb all of the viscous heat and leave the system warmer than it entered.

[0035] In terms of the magnitude of temperature separation, the control parameters in either case are the rotational speed of the fluid and the radius from the center to the periphery, since this sets up the strength of the centrifugal gravitational field, which dictates the pressure gradient from the periphery to the center. This pressure gradient dictates the maximum temperature drop that can be achieved by expansion of the fluid as it flows towards the cold outlet.

[0036] When radial flow of a compressible fluid takes place in a uniformly rotating adiabatic duct, the resulting cooling that is observed at the centre of rotation is due to adiabatic expansion of the fluid as well as conservation of angular momentum, which demands transfer of internal and rotational energy of the moving mass to the rotational energy of the system. Cooling cannot be

produced in a stationary duct by gravity, as frame motion is required for an energy transfer to occur. Compressibility is another required factor for cooling since it reflects the ability of the fluid to give away internal energy. Of key importance, is that the confined rotating fluid flow system presented in this work exhibits the essential physics of the vortex tube flow, namely radial temperature and pressure gradients as well as velocity fields and flow geometry. It is therefore plausible to consider this simplified flow system as a discrete element of vortex tube flow, which provides a concise understanding of the observed temperature separation phenomenon.

[0037] The above can be seen as the theoretical basis for one aspect of the invention. In one implementation, the present invention provides a mechanism which may be used for rotary motors, the cooling of gases, and the efficient conversion of gas pressure into mechanical work.

[0038] Referring to Figure 2, a partially transparent isometric view of the mechanism is provided. As can be seen, the partially transparent view in Figure 2 is provided to present the internal workings and components of the mechanism.

[0039] The mechanism 10 in Figure 2 has four inlet ports 20 through which a pressurized gas can be provided to the mechanism. A rotatable rotor 30 is inside the mechanism. The rotor 30 has an exit port 40 located at its center and four conduits 50 extend radially from the exit port 40 to the outer perimeter of the rotor. The

conduits 50 are hollow and provide a passageway for pressurized gas to travel from the outer perimeter of the rotor to the exit port. In this embodiment of the invention, the conduits are all straight and do not deviate from the exit port to the outer perimeter of the rotor.

[0040] Referring to Figure 3, a side cut-away view of the mechanism in Figure 2 is provided. The exit port 40 at the center of the rotor 30 leads to a gas exit shaft 60 through which the pressurized gas exits the mechanism. To facilitate the rotation of the rotor 30, the rotor 30 is sandwiched between bearings 70 which allow the rotor 30 to freely rotate. A driveshaft 80 is coupled to the rotor 30 such that rotation of the rotor 30 similarly rotates the driveshaft 80. As can be seen, the gas exit shaft 60 is inside the hollow driveshaft 80. Seals 90 adjacent the bearings 70 and the driveshaft 80 ensure that an airtight seal is maintained for the mechanism. Similarly, an enclosure 100 provides an airtight environment for the mechanism. In this configuration, the driveshaft 80 is collinear with the rotor's axis of rotation.

[0041] It should be noted that, preferably, there should be minimal space between the rotor and the upper and lower portions of the enclosure. However, there should a gap 110 between the outer perimeter or periphery 120 of the rotor 30 and the inside wall 130 of the enclosure 100. The gap 110 is there to allow the pressurized gas to travel from the inlet ports to the various conduits.

[0042] In operation, a pressurized gas is provided to the mechanism by way of the inlet ports. In figures 2-4, the said ports are oriented such that gas is injected in a direction tangential to the rotor periphery and in the direction of rotor rotation. This configuration is preferable as it provides optimal results. The pressurized gas enters the conduits and travels from the outer perimeter of the rotor to the exit port at the center of the rotor. In doing so, the pressurized gas causes the rotor to rotate about its center and thereby also causes the driveshaft to rotate. While travelling from the outer perimeter or periphery of the rotor to the exit port, the temperature of the pressurized gas drops, thereby providing a cooler gas at the exit port than at the outer perimeter of the rotor.

[0043] An exploded view of the mechanism in Figures 2-3 is illustrated in Figure 4 to provide the reader with a more detailed view of the various parts of the mechanism.

[0044] Regarding the implementation of the mechanism illustrated in Figures 2-4, the four conduits illustrated divide the rotor into four quadrants. Preferably, these quadrants are of equal size with each conduit being at 90 degrees from adjacent conduits for the purpose of mechanical balancing of the rotor.

[0045] It should be noted that while four straight conduits are shown in the drawings, other configurations are possible. As an example, a three conduit configuration is possible, with each conduit being at 120 degrees to

its adjacent conduits. Similarly, more than four conduits may be used.

[0046] Again regarding the spacing of the conduits on the rotor, it should be noted that while a regular spacing between conduits is preferable, an uneven spacing between the conduits may also be used.

[0047] It should be noted that the rotor can be extended axially to provide space such that radial conduits can be provided in layers, thereby allowing for any number and configuration of conduits. Different configurations of such an arrangement is possible. As an example, differing layers of conduits and rotors may be stacked above one another with a common exit port at the center of the driveshaft for the varying rotors.

The conduits may be formed as a tunnel in the material of a solid rotor or the conduits may be a hollow tube embedded in the structure of the rotor. Similarly, the conduits need not be located within the rotor -- placement of the rotor may be above, under, or inside the rotor as long as the rotor is coupled to the rotor such that pressurized gas travelling through the conduits will cause the rotor to rotate. The conduits may have any suitable shape but it has been found that straight conduits that directly radiate from the center of the rotor to the rotor's periphery provided the best results.

[0048] As well, while the figures illustrate straight conduits which radially radiate from the center of the rotor, straight conduits which are tangential to the central

exit port are also possible. Such a configuration would still have each conduit providing a direct passage from the outer perimeter of the rotor to the exit port. However, for this configuration, the conduits would be directing the pressurized gas in a direction tangential to the exit port instead of in a direction that is radial to the exit port.

[0049] The pressurized gas may be provided to the periphery of the rotor in any suitable manner. Preferably, if the pressurized gas is to be injected into the mechanism, the gas is to be injected in a direction that is tangential to the rotor and at right angles to the rotor's axis of rotation. Differing angles at which the pressurized gas may be provided to the mechanism may be used as long as the gas is not injected in a direction with components that are opposite to the direction of rotation of the rotor. As well, it is preferred that the direction of the pressurized gas is not parallel to the axis of rotation of the rotor.

[0050] It should be noted that the radial distance between the rotor's axis of rotation and the exit port should be less than the radial distance between the rotor's axis of rotation and the inlet port. In the configuration illustrated in Figures 2-4, the rotor's axis of rotation is at the center of the rotor such that the distance between the rotor's axis of rotation and the exit port is at a minimum. However, other configurations where the exit port is not at the center of the rotor are possible. It should further be noted that, while multiple exit ports are also possible, a single exit

port at the center of the rotor is preferable as this has been shown to provide the best results.

[0051] For configurations that have multiple exit ports, each of the various conduits connects one or more of the inlet ports to an exit port. It should be clear that the various inlet ports and their associated exit ports need not be on the same plane. It should also be clear that each inlet port is associated with an exit port with a conduit directly connecting an inlet port (or multiple inlet ports) with an exit port.

[0052] It should be noted that in the configuration illustrated in Figures 2-4, the inlet port is located at the periphery of the rotor. However, other configurations where the inlet port is not at the periphery of the rotor are possible, as long as the radial distance from the center of rotation to the inlet port is larger than the radial distance from the center of rotation to the associated exit port.

[0053] It should also be noted that not all inlet ports need be at the same radial location. Any configuration is possible provided that the radial distance from the center of rotation to the inlet port is larger than the radial distance from the center of rotation to the associated exit port.

[0054] While Figures 2-4 and the discussion above describes multiple conduits, a configuration using a single inlet port and a single conduit connecting the inlet port to a single exit port is also possible.

[0055] Regarding the pressurized gas, this may be any suitable gas such as compressed air.

[0056] Regarding the use of the mechanism, the mechanism may be used in any device, motor, engine, or system that involves a rotating rotor or the cooling of a pressurized gas. As noted above, the temperature of the pressurized gas at the periphery of the rotor is higher than the gas exiting at the exit port. Accordingly, the mechanism may be used in applications that require the cooling or the lowering of the temperature of a pressurized gas. Similarly, the rotation of the rotor may be used to turn a shaft that can be used to do work. The mechanism may therefore be used as part of a pneumatic engine, turbine or motor.

[0057] In one configuration, the rotation of the rotor may be used to pressurize gas to be used in the mechanism. As an example, gas exiting through an exit port may be recycled by being pressurized using the rotation of the rotor. Once pressurized, the pressurized gas may then be reintroduced into the system.

[0058] Once the pressurized gas has been introduced into the system, a pre-rotation may be needed to start the system. This may take the form of manually rotating the rotor. Once the rotor starts rotating, the pressurized gas in the system can continue the rotor's rotation.

[0059] To better understand the principles behind the invention, the following references are provided. These references are hereby incorporated by reference.

G. J. Ranque, "Experiments on expansion in a vortex with simultaneous exhaust of hot and cold air", J. Phys. Radium, vol. 4, p. 112S, 1933.

Y. Xue, M. Arjomandi and R. Kelso, "A critical review of temperature separation in a vortex tube", Exper. Therm. Fluid Sci., vol. 34, p. 1367, 2010.

E. A. Baskharone, "Principles of Turbomachinery in air-breathing engines", Cambridge University Press, July 31, 2006.

M. G. Rose, "From Rothalpy to Losses", Lecture Notes, Swiss Federal Institute of Technology LSM Zurich 2002.

R. Resnick and D. Halliday, "Physics I", p.307, Wiley, 1966.

R. T. Balmer, "Pressure-driven Ranque-Hilsch Temperature Separation in Liquids", J. Fluid Engn., vol. 110, p. 161, 1988.

[0060] A person understanding this invention may now conceive of alternative structures and embodiments or variations of the above all of which are intended to fall within the scope of the invention as defined in the claims that follow.

We claim :

1. A mechanism comprising:

- a rotatable rotor having an axis of rotation;
- an exit port;
- an inlet port, said inlet port being for receiving pressurized gas;
- a hollow conduit, said hollow conduit directly connecting said inlet port to said exit port;

wherein

- a radial distance between said axis of rotation and said exit port is less than a radial distance between said axis of rotation and said inlet port;
- pressurized gas received at said inlet port passes from said inlet port to said exit port through said conduit to thereby cause said rotor to rotate about said axis of rotation;
- after passing through said conduit, said pressurized gas at said exit port is colder than said pressurized gas at said inlet port.

2. A mechanism according to claim 1 wherein said conduit is part of said rotor.

3. A mechanism according to claim 1 wherein said conduit is mounted on said rotor.

4. A mechanism according to claim 1 wherein said conduit radially extends from said exit port to said inlet port.
5. A mechanism according to claim 1 wherein said mechanism is sealed within an airtight enclosure.
6. A mechanism according to claim 1 wherein said mechanism is used to decrease a temperature of said pressurized gas.
7. A mechanism according to claim 1 wherein said mechanism lowers a temperature of said pressurized gas and converts energy extracted from said pressurized gas into rotational work.
8. A mechanism according to claim 1 wherein a temperature difference between said pressurized gas at said inlet port and said pressurized gas at said exit port is up to

$$c^2/c_p$$

where c is a tangential velocity at an inlet port with a greatest radial distance from said axis of rotation of said rotor and c_p is an isobaric heat capacity of said pressurized gas.

9. A mechanism according to claim 1 wherein said pressurized gas is injected at said inlet port, said pressurized gas being injected at a direction tangential to said rotor and at right angles to said axis of rotation.
10. A mechanism according to claim 1 further comprising at least one other exit port.
11. A mechanism according to claim 10 further comprising at least one further inlet port and at least one further conduit, said at least one further conduit connecting said at least one

further inlet port to either said at least one other exit port or said exit port.

12. A mechanism according to claim 10 further comprising at least one further inlet port and at least one further conduit, said at least one further conduit connecting said at least one further inlet port to said exit port.

13. A mechanism according to claim 1 wherein a rotation of said rotor is used to pressurize a gas to result in said pressurized gas.

14. A mechanism according to claim 13 wherein said gas is derived from pressurized gas exiting through said exit port.

15. A mechanism according to claim 1 wherein a distance between said axis of rotation and said exit port is at a minimum.

16. A mechanism according to claim 1 wherein an amount of energy transferred as propulsion to said rotor is up to

$$E_t = M\mathbf{v}^2$$

where

E_t is said amount of energy transferred;

M is a mass of pressurized gas exiting at said exit port;
and

$\mathbf{v}$ is a velocity of an inlet port with a greatest radial distance from said axis of rotation of said rotor.

17. A method for cooling a gas, the method comprising:

a) providing a mechanism comprising:

- a rotatable rotor having an axis of rotation;
- an inlet port;
- an exit port, a radial distance between said exit port and said axis of rotation being less than a radial distance between said inlet port and said axis of rotation;
- a hollow conduit directly connecting said inlet port to said exit port;

b) providing said pressurized gas to allow said pressurized gas to enter said inlet port;

wherein

- pressurized gas provided at said inlet port passes from said inlet port to said exit port through said conduit to thereby cause said rotor to rotate about said axis of rotation.

18. A method according to claim 17 wherein a difference in temperature between said gas at said inlet port and said gas at said exit port is up to

$$c^2/c_p$$

where c is a tangential velocity at an inlet port with a greatest radial distance from said axis of rotation of said rotor and c_p is an isobaric heat capacity of said pressurized gas.

19. A method according to claim 17 wherein an amount of energy transferred as propulsion to said rotor is up to

$$E_t = M\mathbf{v}^2$$

where

E_t is said amount of energy transferred;

M is a mass of pressurized gas exiting at said exit port;
and

$\mathbf{v}$ is a tangential velocity at an inlet port with a greatest radial distance from said axis of rotation of said rotor.

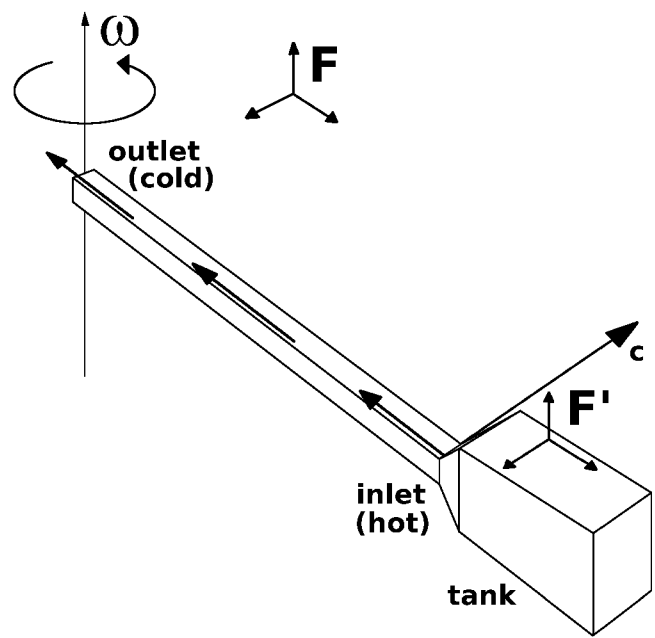


FIGURE 1

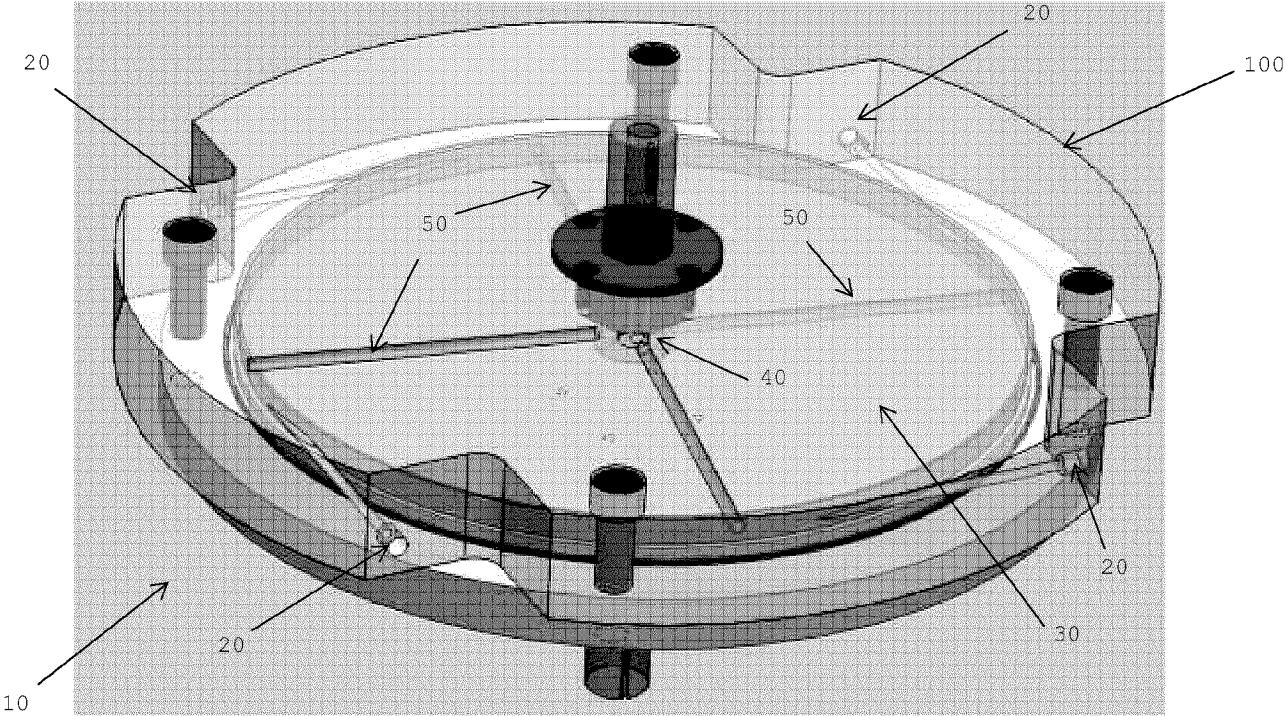


FIGURE 2

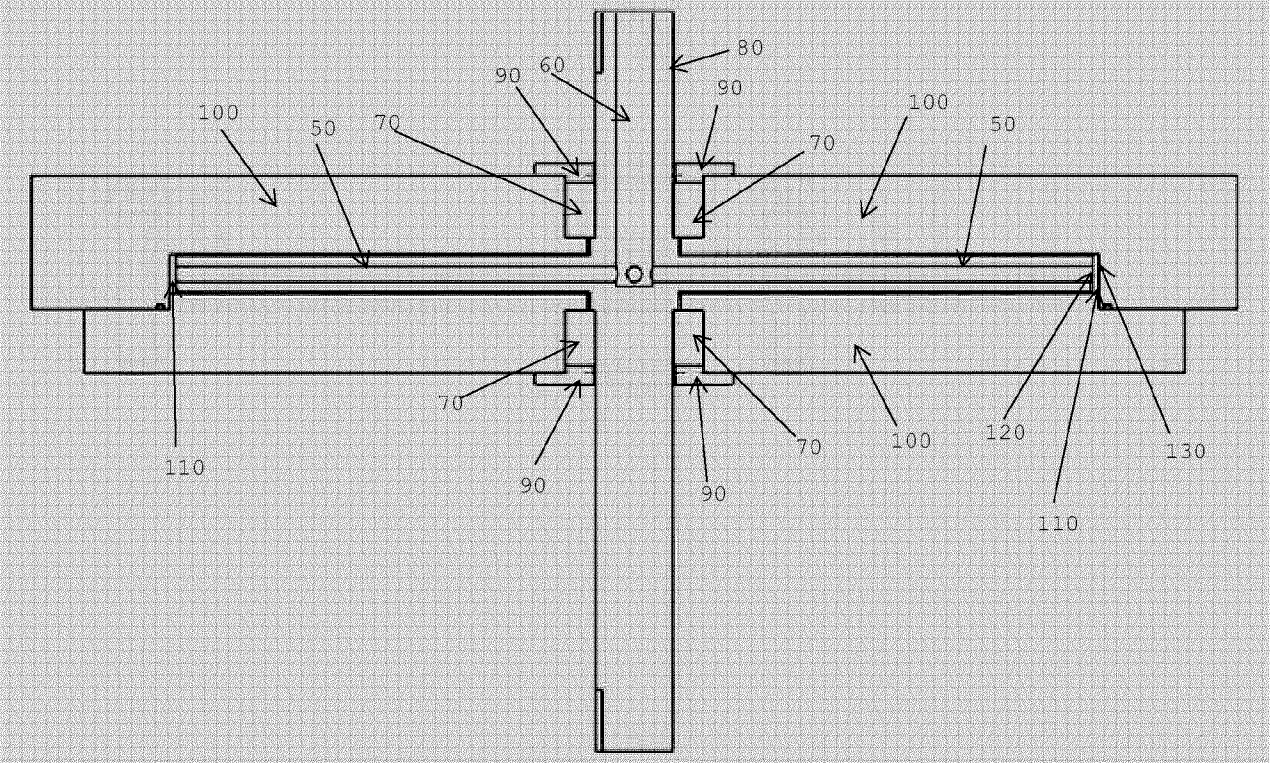


FIGURE 3

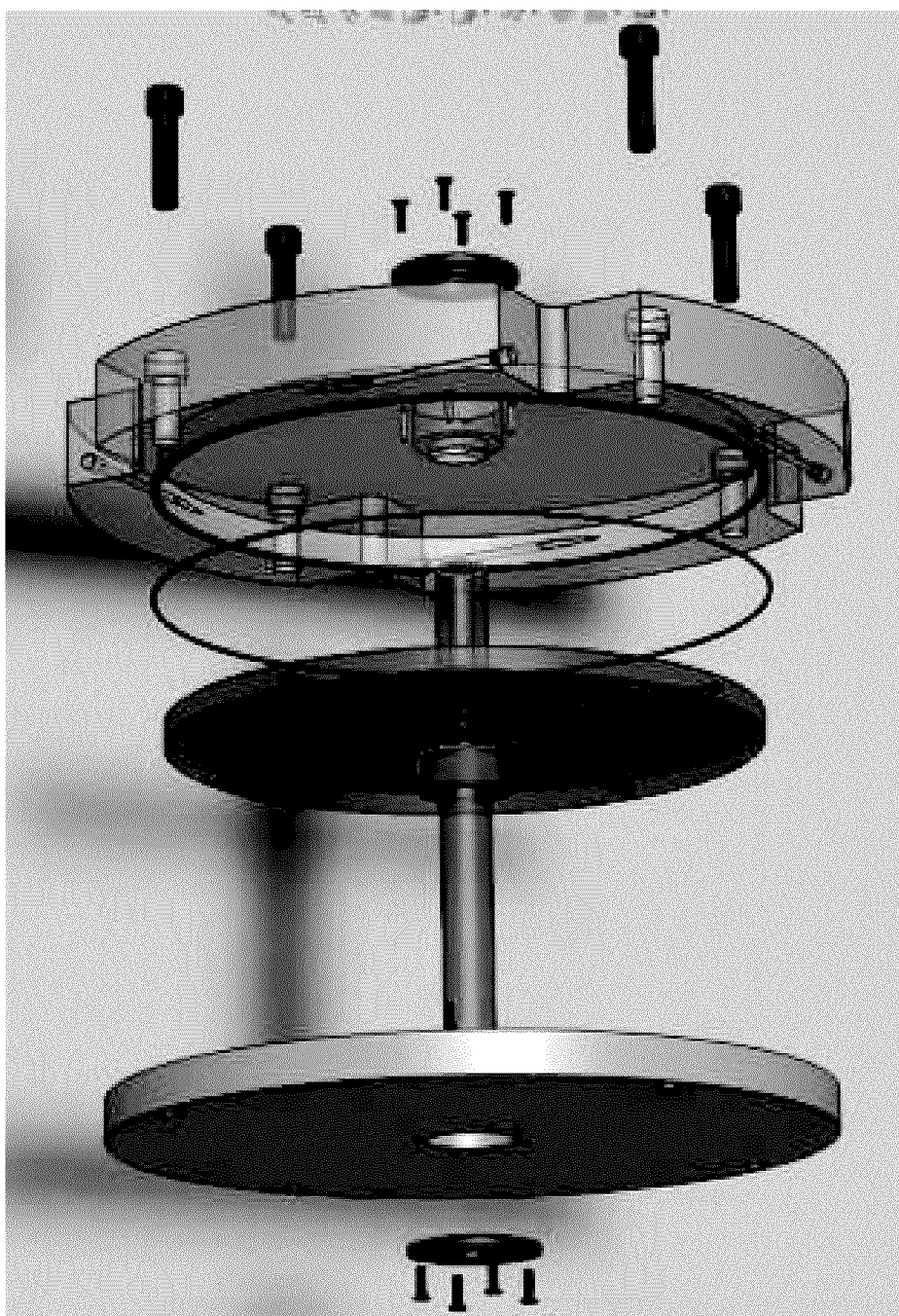


FIGURE 4

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CA2013/050411

A. CLASSIFICATION OF SUBJECT MATTER IPC: F25B 9/04 (2006.01) , F01D 1/34 (2006.01) , F01D 25/00 (2006.01) According to International Patent Classification (IPC) or to both national classification and IPC																							
B. FIELDS SEARCHED Minimum documentation searched (classification system followed by classification symbols) IPC: F25B 9/04 (2006.01) , F01D 1/34 (2006.01) , F01D 25/00 (2006.01) Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched Electronic database(s) consulted during the international search (name of database(s) and, where practicable, search terms used) Epoque (EPODOC): Keywords (Vortex+, rotor, shaft, pressur+, temp)																							
C. DOCUMENTS CONSIDERED TO BE RELEVANT <table border="1"> <thead> <tr> <th>Category*</th> <th>Citation of document, with indication, where appropriate, of the relevant passages</th> <th>Relevant to claim No.</th> </tr> </thead> <tbody> <tr> <td>X</td> <td>US2011027069A1, (Couto et al.) 03 February 2011 (03-02-2011) *whole doc*</td> <td>1-13 and 15- 19</td> </tr> <tr> <td>X</td> <td>US2005169743A1, (Hicks) 04 August 2005 (04-08-2005) *whole doc*</td> <td>1-19</td> </tr> <tr> <td>A</td> <td>US1061206A, (Tesla) 06 May 1913 (06-05-1913) *whole doc*</td> <td>1-19</td> </tr> <tr> <td>A</td> <td>US2011255979A1, (Matsushita) 20 October 2011 (20-10-2011) *whole doc*</td> <td>1-19</td> </tr> <tr> <td>A</td> <td>JP2003269189A, (Yoshinaga) 25 September 2003 (25-09-2003) *whole doc*</td> <td>1-19</td> </tr> <tr> <td>A</td> <td>JP2002174166A, (Saito) 21 June 2002 (21-06-2002) *whole doc*</td> <td>1-19</td> </tr> </tbody> </table>			Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.	X	US2011027069A1, (Couto et al.) 03 February 2011 (03-02-2011) *whole doc*	1-13 and 15- 19	X	US2005169743A1, (Hicks) 04 August 2005 (04-08-2005) *whole doc*	1-19	A	US1061206A, (Tesla) 06 May 1913 (06-05-1913) *whole doc*	1-19	A	US2011255979A1, (Matsushita) 20 October 2011 (20-10-2011) *whole doc*	1-19	A	JP2003269189A, (Yoshinaga) 25 September 2003 (25-09-2003) *whole doc*	1-19	A	JP2002174166A, (Saito) 21 June 2002 (21-06-2002) *whole doc*	1-19
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[X] Further documents are listed in the continuation of Box C. [X] See patent family annex. <table border="1"> <tbody> <tr> <td>* Special categories of cited documents :</td> <td>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</td> </tr> <tr> <td>"A" document defining the general state of the art which is not considered to be of particular relevance</td> <td>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone</td> </tr> <tr> <td>"E" earlier application or patent but published on or after the international filing date</td> <td>"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art</td> </tr> <tr> <td>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</td> <td>"&" document member of the same patent family</td> </tr> <tr> <td>"O" document referring to an oral disclosure, use, exhibition or other means</td> <td></td> </tr> <tr> <td>"P" document published prior to the international filing date but later than the priority date claimed</td> <td></td> </tr> </tbody> </table>			* Special categories of cited documents :	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention	"A" document defining the general state of the art which is not considered to be of particular relevance	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone	"E" earlier application or patent but published on or after the international filing date	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art	"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"&" document member of the same patent family	"O" document referring to an oral disclosure, use, exhibition or other means		"P" document published prior to the international filing date but later than the priority date claimed										
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Date of the actual completion of the international search 12 August 2013 (12-08-2013)		Date of mailing of the international search report 21 August 2013 (21-08-2013)																					
Name and mailing address of the ISA/CA Canadian Intellectual Property Office Place du Portage I, C114 - 1st Floor, Box PCT 50 Victoria Street Gatineau, Quebec K1A 0C9 Facsimile No.: 001-819-953-2476		Authorized officer Jarret Diggins (819) 953-1611																					

INTERNATIONAL SEARCH REPORTInternational application No.
PCT/CA2013/050411

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US2768808A, (Worre)30 October 1956 (30-10-1956) *whole doc*	1-19

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CA2013/050411

Patent Document Cited in Search Report	Publication Date	Patent Family Member(s)	Publication Date
US2011027069A1	03 February 2011 (03-02-2011)	CA2717698A1 EP2260178A1 EP2260178A4 WO2009109020A1	11 September 2009 (11-09-2009) 15 December 2010 (15-12-2010) 15 May 2013 (15-05-2013) 11 September 2009 (11-09-2009)
US2005169743A1	04 August 2005 (04-08-2005)	US2005169743A1 US6973792B2	04 August 2005 (04-08-2005) 13 December 2005 (13-12-2005)
US1061206A	06 May 1913 (06-05-1913)	US1061142A	06 May 1913 (06-05-1913)
US2011255979A1	20 October 2011 (20-10-2011)	EP2357320A1 EP2357320A4 EP2357320B1 JP4310552B1 JP2010127211A KR20110036868A KR101043350B1 WO2010061659A1	17 August 2011 (17-08-2011) 11 April 2012 (11-04-2012) 31 July 2013 (31-07-2013) 12 August 2009 (12-08-2009) 10 June 2010 (10-06-2010) 11 April 2011 (11-04-2011) 22 June 2011 (22-06-2011) 03 June 2010 (03-06-2010)
JP2003269189A	25 September 2003 (25-09-2003)	JP2003269189A JP3837601B2	25 September 2003 (25-09-2003) 25 October 2006 (25-10-2006)
JP2002174166A	21 June 2002 (21-06-2002)	None	
US2768808A	30 October 1956 (30-10-1956)	None	