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CENTRIFUGAL POTENTIAL ENERGY: AN ASTOUNDING RENEWABLE ENERGY CONCEPT

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ABSTRACT It has now been discovered that an entirely new energy concept, known as the **"**Centrifugal Potential Energy" can now be used as an alternative or replacement to the conventional work and heat transfers in Engineering Systems. This new energy concept is capable of increasing the pressure, temperature and enthalpy of a fluid, without having to apply a work or heat transfer to the fluid. The operation is due to a change in the centrifugal potential energy of the flowing fluid in a Rotating Frame of Reference (Centrifugal Force Field), work is done internally by the centrifugal weight of the fluid on the fluid, thus increasing fluid pressure, temperature and enthalpy. Hence, this energy concept has led to the derivation of novel energy equations, as the Rotational Frame Bernoulli's Equation for liquids and the Rotational Frame Steady-Flow Energy Equation for gases. Some important applications of these equations are incorporated in the design of the centrifugal field pumps and compressors respectively. These devices are capable of compressing a fluid without a physical load transfer, but via the effect of centrifugal force applied to the object. When this high pressure compressed working fluid is made to expand in an expansion engine (i.e. turbines, nozzles etc), a large amount of energy is produced. Analyses conducted show that when water is used as the working fluid, it could reach renewable energy densities in the range of 25-100 kJ/kg-H_2O; and when atmospheric air is used, it could reach energy densities in the range of 500-1,500 kJ/kg-Air. Centrifugal power systems utilizing such energy density ranges would lead to a significant breakthrough in our global energy requirement for Transportation, Electricity, Agriculture, Industry and Defence.

Keywords: Centrifugal Potential Energy, Rotational Frame Bernoulli's Equation, Rotational Frame Steady-Flow Energy Equation, Centrifugal Field Pump, Centrifugal Field Compressor, Centrifugal Force Field.

INTRODUCTION

Motion of the co-ordinate frame system is now becoming an emerging science.

The rotational motion of the co-ordinate reference frame has established phenomena such as the Centrifugal, Coriolis and Azimuthal forces (Marion and Hornyak. 1984).

The behaviour of bodies in these rotational co-ordinate frame systems has led to novel conceptions as (i) The Rotational Frame Kinematics, which is the study of the motion of a body in a conservative centrifugal force field, (ii) Rotational Frame Dynamics, which deals with the forces acting on a body also in a centrifugal force field. This has led to the derivation of challenging equations in physics, such as the equation of the Centrifugal Potential Energy and the Rotational Frame Bernoulli's Equation and (iii) Rotational Frame Thermodynamics, which can be defined as the study of the thermodynamic behaviour of fluids in rotating systems, as they are influenced under a centrifugal force field. It has also led to the derivation of a very interesting equation known as the Rotational Frame Steady-Flow Energy Equation.

This approach has given rise to very unconventional sources of energy production. Hence this study would be unravelling the anonymity behind such an approach.

PHYSICS OF ROTATIONAL CO-ORDINATE FRAME

Circular motion is no exception to the general rule that forces are needed to cause acceleration of bodies having mass. Centripetal force, which causes centripetal acceleration, acts on the body in motion as is directed towards the center of the circle. The necessary centripetal force to cause the change in direction of a body moving in a circle is giving by:

$$F_c = m\omega^2 r \tag{1}$$

Where, F_c is the centrifugal force

m is the mass of the body

ω^2 is the angular velocity

and r is the radius of rotation

Marion and Hornyak (1984) stated that when an observer is moving along with a rotating body, the observer is then in an accelerated frame of reference, with the acceleration 'a' of the frame directed towards the center. In such an accelerated frame of reference an inertial force equal to – ma acts on a body of mass (m). This inertial force is directly opposite to the acceleration of the frame of reference, and for circular motion it is therefore directed away from the center. Only to an observer in the rotating frame of reference does the term centrifugal force have any significance.

A very interesting situation of an accelerated frame of reference is the rotation of an enclosed space about an axis. Oduniyi (2008) stated that any observer within this space of rotation is acted upon by a centrifugal acceleration, directed outwards and normal from the axis of rotation. This centrifugal acceleration is analogous to the acceleration due to gravity in the gravitational force field, thus creating a field of its own, referred to as the centrifugal force field.

Events taking place in a centrifugal field are quite analogous to that in a gravitational field. An example is the pressure in a static fluid.

In this analogy, the difference in pressure between two levels of fluid in both the gravitational and centrifugal force fields has been derived in Ref. (2).

In the gravitational force field, the difference in pressure p_1 and p_2 between two levels of the fluid at heights z_1 and z_2 respectively from the reference axis for incompressible fluids (i.e. liquids), where the density ρ is assumed constant, as it changes very lightly with pressure increase, is given as:

$$p_2 - p_1 = -\rho g\,(z_2 - z_1) \qquad (2)$$

Where g is the acceleration due to gravity

If the top surface of the liquid is at z_2, where the pressure has a value

$p_2 = p_0$, then the pressure $p_1 = p$ at a depth $Z = z_2 - z_1$ satisfies

$$p_0 - p = -\rho g Z \qquad \text{or } p = p_0 + \rho g Z \qquad (3)$$

Thus the pressure increases linearly with depth in an incompressible fluid.

For compressible fluids such as gases, the density changes considerately with change in pressure. For many gases, such as air, there is a relation between the pressure p and the density ρ when the temperature is constant.

(a)Using the isothermal assumption, that T (Temperature) is constant, we get:

$$p = p_0 e^{-gz/RT} \quad (4)$$

p_0 being the pressure when z = 0 and R is the specific gas constant. Hence the static pressure of the atmosphere decreases exponentially with height.

(b)Using the adiabatic assumption, that $p\nu^{\gamma} = p_0\nu_0^{\gamma}$, where γ is the specific heat ratio, we get:

$$p = p_o [\{1-(\gamma-1)/\gamma\} (zg/p_o\nu_0)]^{\gamma/(\gamma-1)} \quad (5)$$

Also in the centrifugal force field, the difference in pressure p_1 and p_2 between two levels of the fluid, at radius of rotations r_1 and r_2 respectively from the reference axis of rotation, for an incompressible fluid is given by:

$$p_2 = p_1 + ½ \rho\omega^2 (r_2^2 – r_1^2) \quad (6)$$

Therefore, the rotational speed (ω_p) of the centrifugal field pump is given as:

$$\omega_p = [2(p_2-p_1)/ \rho (r_2^2-r_1^2)]^{1/2} \quad (7)$$

For compressible fluids and using the assumptions as before,

(a) The isothermal assumption, that T is constant, we get:

$$p_2 = p_1 \mathbf{e}^{(\omega^2 /2RT)(r_2^2 – r_1^2)} \quad (8)$$

Hence for an isothermal pressure increase ($p_2 – p_1$) between radius of rotations r_1 and r_2, the rotation speed ($\omega_{isoth.}$) of the centrifugal field is given as:

$$(\omega_{isoth.}) = [\{2RT/(r_2^2-r_1^2)\}\ln (p_2/p_1)]^{1/2} \quad (9)$$

(b) Using the adiabatic assumption that $p\nu^{\gamma} = p_1\nu_1^{\gamma}$, we have

$$p_2 = p_1 [(1+ \{\gamma-1\}/ \gamma) \omega^2(r_2^2-r_1^2)/2 \nu_1p_1)]^{\gamma/(\gamma-1)} \quad (10)$$

While the adiabatic rotational speed ω of the centrifugal field is given as:

$$(\omega_{adiab.}) = [\{\gamma/(\gamma-1)\}\{2\nu_1 p_1/(r_2^2-r_1^{2)}\}\{(p_2/p_1)^{(\gamma-1)/\gamma} - 1\}]^{1/2} \quad (11)$$

Again in Ref.(2), an impeccable example of an event taking place in a centrifugal field that is quite analogous to that in the gravitational field is the phenomenon of potential energy.

The change in potential energy in the gravitational conservative force field as a particle of mass m moves from height z_1 to z_2 in the opposite direction to gravity is given by:

$$P.E = = - mg\ (z_2 - z_1) \quad (12)$$

Equation (12) is referred to as the Gravitational Potential Energy Change.

While in the centrifugal conservative force field, the change in potential energy as the particle moves from radius of rotation r_1 to r_2 in the direction of the centrifugal acceleration is given by:

$$P.E = ½\ m\omega^2\ (r_2^2 – r_1^2) \quad (13)$$

Equation (13) is referred to as the Centrifugal Potential Energy Change; this is the bedrock of this write-up.

An interesting application of the concept of the centrifugal potential energy is in the derivation in Ref. (2) of the Rotational Frame Bernoulli's Equation, which is given as

$$P + \rho gz - ½\ \omega^2 r + ½\ \rho v^2 = Constant \quad (14)$$

Where, p is the pressure term

ρgz is the gravitational pressure term

$½\ \omega^2 r$ is the centrifugal pressure term

and $½\ \rho v^2$ is the velocity pressure term

If the frame is static (i.e. $\omega = 0$), where the centrifugal effect is cancelled, then Equation (14) reduces to:

$$P + \rho gz + \frac{1}{2} \rho v^2 = \text{Constant} \quad (15)$$

Which we all know from fluid mechanics as the Bernoulli's Equation.

A very important application of the Rotational Frame Bernoulli's Equation is in the design of the centrifugal rotor field pump. This is a centrifugal rotor with the tunnels discharging the fluid into a discharge chamber at high pressure, figure 1. Here, liquid at low pressure enters the fast rotating tunnels in the disc, where it is acted on by a centrifugal field. The pressure of the liquid increases isentropically due to the centrifugal effect on it as it flows through the tunnels to attain the pressure in the discharge chamber.

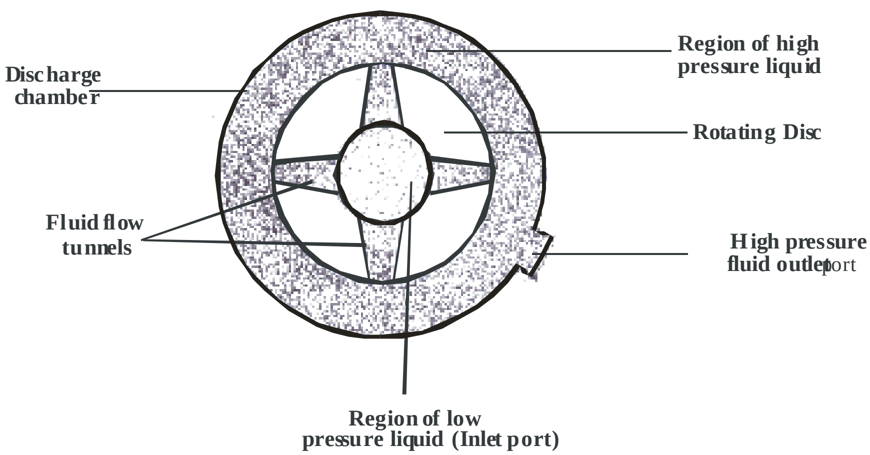

Figure 1. Showing the Plan View of a Centrifugal Rotor Field Pump

Rotational Frame Thermodynamics: The dynamics of moving fluids in an accelerated frame of reference have already been discussed earlier, as we now look into the thermodynamic behaviour of such fluids.

By simple reasoning in Ref. (2), it was deduced that the steady-flow energy equation for an open system in an accelerated co-ordinate frame of reference can be written as:

$$Q + W = (h_2-h_1) + ½(v_2^2-v_1^2) + g\,(z_2-z_1) – ½\omega^2(r_2^2-r_1^2) \quad (16)$$

Where Q and W are the heat and work transfers through the system.

(h_2-h_1), $½(v_2^2-v_1^2)$, $g\,(z_2-z_1)$ and $½\omega^2(r_2^2-r_1^2)$ are the specific changes in enthalpy, kinetic energy, gravitational potential energy and centrifugal potential energy of the system respectively. As Equation (16), expresses the relation between rates of heat and work transfers, and the properties of enthalpy, kinetic energy, gravitational potential energy and centrifugal potential energy of the fluid at inlet and outlet of an open rotating system; it is called the **"Rotational Frame Steady-Flow Energy Equation"**, and will provide the basic means for studying open rotating systems.

A very important application of the rotational frame steady – flow energy equation of Equation (16) is in the design of the centrifugal rotor field compressor, which is also a centrifugal field rotor, very similar in configuration to the centrifugal rotor field pump discussed earlier. Hence Figure 1 will also illustrate the plan view of a centrifugal field rotor compressor.

In Figure 1, the gas entering and leaving the centrifugal field compressor does so at a constant rate. The gravitational potential energy term $g(z_2–z_1)$ and the kinetic energy term $½(v_2^2-v_1^2)$ are either zero or negligible compared with the other terms. The work transfer term is W = 0, as no work transfer crosses the boundary of the control volume of the system with the surroundings.

Therefore, for an isothermal or polytropic compression process, the rotational frame steady-flow energy equation for a centrifugal field compressor in an open system thus reduces at steady state to give:

$$Q + \cancel{W} = (h_2-h_1) + \tfrac{1}{2}\cancel{(v_2^2-v_1^2)} + g\,\cancel{(z_2-z_1)} - \tfrac{1}{2}\omega^2(r_2^2-r_1^2)$$

$$\text{or} \quad Q = (h_2-h_1) - \tfrac{1}{2}\omega^2(r_2^2-r_1^2) \qquad (17)$$

Here, Q which is negative is the heat transfer from the system to the surroundings.

For a reversible adiabatic (isentropic) compression process, the heat transfer across the boundary can be neglected (Q = 0). Hence Equation (17) further reduces to:

$$\cancel{Q} = (h_2-h_1) - \tfrac{1}{2}\omega^2(r_2^2-r_1^2) \quad \text{or} \quad h_2-h_1 = \tfrac{1}{2}\omega^2(r_2^2-r_1^2) \qquad (18)$$

Where the specific enthalpy change of the system is equal to its specific centrifugal potential energy change.

It has been shown in Ref.(2), that the ideal adiabatic centrifugal potential energy change in a rotating frame of reference is an equivalent of the adiabatic compression work in an idealized open system in a static frame for either a compressor or a pump. Hence, the adiabatic centrifugal potential energy change for a compressor thus becomes:

$$P.E_{\,adiab.} = \tfrac{1}{2}\,\omega^2_{adiab.}\,(r_2^2 - r_1^2) = h_2 - h_1 \equiv w_c = c_pT_1\,[(p_2/p_1)^{(\gamma-1)/\gamma} - 1] \qquad (19)$$

Where w_c is the adiabatic compression work of a compressor in a static frame.

While the adiabatic centrifugal potential energy change for a pump is:

$$P.E_{\,adiab.} = \tfrac{1}{2}\,\omega^2_{pump}\,(r_2^2 - r_1^2) = h_2 - h_1 \equiv w_p = \nu\,(P_2 - P_1) \qquad (20)$$

Where ν is the specific volume of the liquid.

And w_p is the compression work of a pump in a static frame.

Hence the centrifugal potential energy can now be used as an alternative or replacement to the conventional work and heat transfers in engineering systems.

<u>Analyses and Results:</u> From Equations (19) and (20), we have that the centrifugal field pumps and compressors are devices capable of compressing a fluid without a work transfer, but via the effect of a centrifugal force field on it. Centrifugal power systems can now be developed by the isentropic compression of fluids in these devices, and then later, allowing them to undergo an isentropic expansion in expender engines, such as turbines, reciprocating engines, nozzles etc. Centrifugal field pumps and compressors are always

incorporated at the exit with a pressure surge chamber (at exit pressure P_2) to allow for the changing power demands of the expander engines.

In the design analysis of a centrifugal field pump that operates at steady- state; water is taken as the working fluid. Water at atmospheric pressure P_1=1.01325 bars and density ρ=1000 Kg/m^3 is taken in, at the inlet of the pump, which has radius of rotations r_1=50mm and r_2=250mm; and discharges into a pressure surge chamber at pressure P_2=300 bars. From Equation (7), the rotational speed ω_{pump} of the field pump is about 998.3 rad/s (158.89 rev/s). The increase in change of the specific centrifugal potential energy from Equation (20) would be about 29.90 kJ/kg-H_2O in an ideal isentropic process. Both the rotational speed and the centrifugal potential energy change increases with pressure P_2. It could attain ideal renewable energy densities in the range of 25-100 kJ/kg-H_2O, depending on how much fluid pressure that can be withheld.

When atmospheric air of specific gas constant (R) = 0.287 kJ/kgK, specific heat ratio (γ) = 1.40 and c_p = 1.005 kJ/kgK is used as the working fluid in a similar centrifugal field rotor configuration; it could attain a final exit temperature T_2 = 1527.37K in an isentropic compression from atmospheric pressure to a pressure of 300 bars, when ambient temperature T_1 is taken as 300K. The adiabatic rotational speed $\omega_{adiab.}$ from Equation (11) is about 6409.5 rad/s (1020.13 rev/s). The increase in change of the specific centrifugal potential energy from Equation (19) would be about 1232.45 kJ/kg-Air in an ideal isentropic process. This increase in specific potential energy, which is also an increase in the specific enthalpy of the fluid; when allowed to isentropically expand in an expander engine, a great deal of work is produced. Usually for an air power system as this, the ideal energy densities are in the range of 500-1,500 kJ/kg-Air

A centrifugal power plant adhering to this principle would have a net work W_{net} equal to the difference in expansion work $W_{expansion}$ and compression work $W_{compression}$.

i.e., $$W_{net} = W_{expansion} - W_{compression} \qquad (21)$$

But in a centrifugal field rotor, no work crosses the boundary of the control volume of the system (i.e., no work is transferred to the fluid); hence $W_{compression}$ is zero. Therefore, Equation (21) reduces to:

$$W_{net} = W_{expansion},$$ for any centrifugal power system.

If expander is a nozzle designed for complete expansion to atmosphere, it could attain an exit velocity (V_2) of about 1570 m/s. The thrust (F_N) at the exit of the nozzle is simply:

$$F_N = \dot{m} V_2 \qquad (22)$$

Where $\dot{m}$ is the mass flow rate through the nozzle. Rogers and Mayhew (1992) stated that the thrust itself is not, however, the most important criterion performance of a rocket nozzle; the thrust per unit flow really matters. This quantity, called the specific impulse (I) can be written as:

$$I = F_N / \dot{m} \qquad (23)$$

In this study, it is about 1.57 kN per kg/s, which is high enough to launch any aircraft airborne.

Centrifugal power systems utilizing the above energy density ranges would lead to a significant breakthrough in our global energy requirement for Transportation, Electricity, Agriculture, Industry and Defence.

CONCLUSION The Centrifugal Potential Energy as its counterpart, the Gravitational Potential Energy, is a free tendency energy concept; i.e., ability to freely generate itself, without a need for an energy transfer from any external source of energy (pump, natural wind or water flow etc,). This new energy source is internally generated within the control volume of a system, as compared to the work and heat transfers crossing the boundary of the control volume.

As this new alternative energy source is renewable, abundant, in-exhaustible, non-polluting, cheap and convenient, it will be highly acceptable in designing engines for the future. Hence the potential for utilizing the available energy of the centrifugal potential energy for automotive / aircraft propulsion and power generation now looks very promising.

The eventual development of these centrifugal power systems would lead to very astonishing scenarios, like cars running (fuelled) on water (hydro-cars) and aircrafts powered (fuelled) by air.

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