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The Concept of a Gravity Engine and Energy Performance for Tidal and Hydro-Power

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Abstract — This paper is to propose the concept and performance of a gravity engine which could extract energy from sea or river as a clean, renewable and sustainable power. The vertical motion of the buoyancy cylinder of the present gravity engine is converted to the mechanical work directly without any hydraulic loss. The positive net energy between the imposed and harnessed one is achieved by the specific operating procedure. The detailed derivation of the energy balance is made based on the first principle of thermodynamics The calculation demonstrates that the present gravity engine could harness more energy than the conventional turbine system in the same basin area because of the relatively high efficiency in the energy conversion system and added mass from the buoyancy cylinder.

1. Introduction

Traditionally, the mechanical energy has been extracted from water by the water mill or turbine. The sun transports water from the sea to the land through the evaporation and condensation process. The water in the high land would flow down to the sea again and its major driving cause is the potential energy. Another cyclic change has been experienced in the sea: the gravitational interaction between the earth and the moon changes the local sea water level. Turbines, a mechanical energy convertor, have been used as an effective tool for extracting work from the fluid. In terms of entropy, both hydro and tidal energy is low in entropy. Althigh it is renewable, sustainable, and clean[1][2] and Korea has a tremendous amount of tidal energy resource in the Yellow Sea, a private or government sponsorship was not forthcoming because of its high initial capital costs and the environmental consideration, Recently, the international concern on the global warming issues a concept of tax for the CO_2 production. This tax could directly affect the price of energy and change the ranking of the energy sources. The nuclear energy and other renewable energy from the sun will be in a better position. Also, in terms of the substantiality and reality for the large power, the tidal power is approaching to the real domain.

Korea has concentrated on its most favourable site at Garolim having a narrow entrance of 2 km, a reasonable depth for turbine installation, a mean tidal range of 5 m and a basin area of 100 km^2. There would be 24 power units of 20 MW each (480 MW in total), and the proposed turbines are doubly regulated and of 8m in diameter[3].

There have been many proposals for the optimal extraction of tidal energy. A fairly complex double-basin scheme with regimes involving generation on both flood and ebb tides has been proposed, aimed at significantly spreading the generation period beyond the 25~30% maximum attainable in single basin schemes[4]. A commonly proposed variation is to use the turbines as pumps at the top of the tide to add more water to that standing in the basin. The volume of the water is added at low head, and later released to generate power through the turbines at higher head. The overall effect is particularly advantageous on heap tides and can yield some 10% increase in energy production. There is small room to improve the efficiency of the conventional tidal power.

It is natural to think about a new device rather than the water mill for the tidal power. The purpose of this paper is to propose a new energy conversion mechanism, the gravity engine, for reduction of the capital cost of the tidal power and to produce the net positive energy greater than that from the conventional tidal power plant. To reduce the size of dam needed, it is the best way to develop an efficient energy conversion mechanism. The conventional turbine technology has a small room to be improved. However, the present gravity engine could dramatically increase the energy extraction in the way of the increasing the added mass of the system.

2. The Working Principles

The gravitational engine has five parts including the buoyancy tank, drain pump, latch assembly, gear box, and electric generator. These parts are working together to extract electricity from the tidal potential energy of the gravitational interaction between the earth and the moon. As shown in Fig. 1. the present gravitational engine submerges the buoyancy cylinder into the water by opening the valve at the bottom of the cylinder at the low tide. A special latch system locks the cylinder to prevent it from moving up at the high tide. The water in the cylinder is drained by the drain pump and air replaces the water volume during the ebb tide. The buoyancy force due to the empty cylinder is released when the highest tide occurs. Let us call it as "gravity engine" because it needs cyclic operation fuelled by the gravity force.

The energy from the upward motion of the buoyancy cylinder is transferred to the electric generator with the gear box assembly. The gravitational head due to tidal change could be amplified by the added mass corresponding to the amount of water inside the gravity cylinder. The driving mechanism to generate the added mass is the buoyancy force acting on the surface of the cylinder.

The vertical movement of the cylinder (A) is

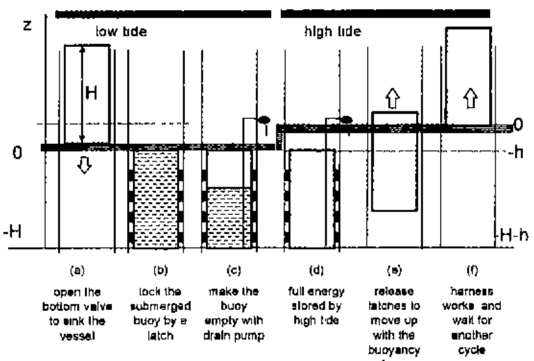

Fig. 1. The operating procedure of the gravity engine.

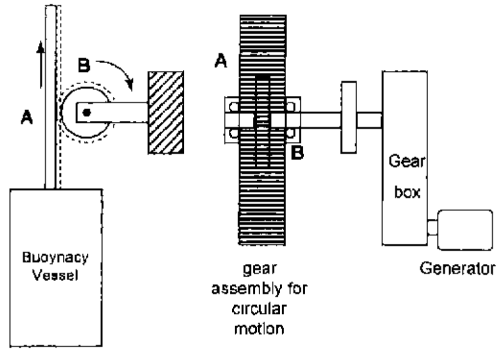

Fig. 2. The energy conversion to electric generator.

changed into the circular motion (B) by the gear assembly as shown in Fig. 2. Since the vertical velocity of the cylinder increases exponentially, a special gear assembly should be attached to get the uniform revolution of the electric generator. The adaptation of the energy storage system using the flywheel technology, compressed air, or the advanced battery technology could be an alternative mechanism.

3. Evaluation of Energy Performance of the Gravity Engine

The benefit of the present gravitational engine is the direct extraction of the mechanical energy from the vertical motion of the gravity tank. Since the friction loss of the gear assembly is less than the hydraulic loss of the turbine, the efficiency of the present gear assembly is higher than that of the turbine for the tidal power. Another strong merit is that it could extract more energy than the turbine technology from the same reservoir area because of the added mass effect of the buoyancy cylinder. In this section, the detailed energy calculation will be made on the basis of the energy conservation law.

3-1. Energy Extraction

The energy of the gravity engine is calculated to demonstrate its higher efficiency than the conventional turbine technology. Although the present engine needs energy input to drain out water from the buoyancy cylinder, the net positive energy out could be harnessed when the stored energy is bigger than the imposed one. Further, the net energy outcome is bigger than that of the conventional turbine plant. To get the net energy, at first, we calculate the maximum energy stored to the empty cylinder submerged into water at high tide, which is equal to the work produced by the vertical motion of the cylinder after releasing its latch. Once this total energy is calculated, subtracting the imposed energy to cylinder empty at low tide from the total energy gives us the net energy.

(A) Energy extraction during one cycle operation

Let us calculate the maximum energy stored in the empty buoyancy cylinder at high tide as shown in Fig. 1 (d): A buoyancy tank with the cross sectional area of A_b and the length of H is submerged under the water in depth of h which is the tidal height. If we set the origin of z axis at the water surface, the energy stored in the empty buoyancy tank could be obtained by integrating the buoyancy force from the bottom of the liner (–H–h) to the water surface (0):

$$E_{stored}=\int_{-H-h}^{0}(\rho_w-\rho_a)gA_b z\,dz \tag{1}$$

It gives the following relation:

$$E_{stored}=\frac{1}{2}(\rho_w-\rho_a)gA_b(H+h)^2 \tag{2}$$

To get the above energy at high tide, it is necessary to make the cylinder empty at low tide by operating a drain pump. The energy used to this is calculated by integrating the force for removing water from the top (0) to the bottom (–H) of the cylinder as shown in Fig. 1 (c) by dividing it with its efficiency:

$$E_{supply}|_{low\ tide}=\frac{1}{\eta_{drain}}\int_{0}^{-H}(\rho_w-\rho_a)gA_b z\,dz \tag{3}$$

This gives:

$$E_{supply}=\frac{1}{2\eta_{drain}}(\rho_w-\rho_a)gA_bH^2 \tag{4}$$

If the energy stored in the empty cylinder at high tide is greater than the energy supplied to evacuate the tank at low tide, the present system could extract net positive energy from the tidal movement. The net energy is made by subtracting Eq. (4) from Eq. (2):

$$E_{gain}=\frac{1}{2}(\rho_w-\rho_a)gA_b\left[\left(1-\frac{1}{\eta_{drain}}\right)H^2+2Hh+h^2\right] \tag{5}$$

The last term in the R.H.S is correspondent with the energy due to the tidal water level change, h. It is very similar to the the energy from the conventional tidal power plant. It is not difficult to find out the present energy, Eq. (5), is greater than the conventional one, because it has two more terms in addition to the conventional energy if its energy conversion efficiency is not so bad.

The key point is the draining time: if the draining is made at high tide, we could not produce such a large energy as Eq. (5). To check it, let us estimate the imposed energy by drain pump at a high tide to make cylinder empty:

$$E_{supply}|_{high\ tide}=\frac{1}{\eta_{drain}}\int_{-h}^{-H-h}(\rho_w-\rho_a)gA_b z\,dz$$
$$=\frac{1}{2\eta_{drain}}(\rho_w-\rho_a)gA_b(H^2+2Hh) \tag{6}$$

Then, the net energy will be

$$E_{gain}=\frac{1}{2}(\rho_w-\rho_a)gA_bh^2+\frac{1}{2}\left(1-\frac{1}{\eta_{drain}}\right)gA_b(H^2+2Hh) \tag{7}$$

The second term in Eq. (7) is negative because the drain pump efficiency is less than 100%. In the case of the draining at high tide, the net energy produced will be less than the conventional turbine tidal plant. Therefore, making cylinder empty at low tide is the key factor in this technology.

For bench marking, let us formulate the energy from the conventional tidal power plant using the turbine efficiency, η_{mill}, by integrating the static pressure force from 0 to h.:

$$E_{water\ mill}=\eta_{mill}\int_{0}^{h}\rho_w gA_b z\,dz=\frac{\eta_{mill}}{2}\rho_w A_{bay}h^2 \tag{8}$$

To compare the present system to the conventional one, let us approximate the density difference between water and air, $\rho_w-\rho_a$, to the water density, ρ_w, and consider the energy conversion efficiency η_{grv}. Then the work from the present gravity engine is derived from Eq. (5)

$$E_{work}=\frac{\eta_{grv}}{2}\rho_w gA_b\left(\left(1-\frac{1}{\eta_{drain}}\right)H^2+2Hh+h^2\right) \tag{9}$$

This system could be optimized by checking the maximum of the energy, Eq. (9):

$$\frac{\partial E_{work}}{\partial H}=0 \tag{10}$$

Equation (10) gives us an optimum length of the cylinder:

$$H=\frac{\eta_{drain}}{1-\eta_{drain}}h \tag{11}$$

Therefore, the optimum size of the buoyancy cylinder determined by the tidal height and the drain pump.

(B) Open system and closed system

The above formulation could be applied to the open system (without reservoir). which could be constructed any place where the tidal height is provided. In stead of dam, a very large buoyance cylinder should be provided to the open system. This will provide hard environments to the mechanical design of the latch system, the gear assembly and supporting structure. To resolve this problem, a closed system with the smaller buoyancy cylinder than the open system with water reservoir is proposed here also. The working principle is the same as the open system. Only the difference is the area of the buoyancy tank By the multiple operations during one tide cycle, the closed system could harness the same energy as the open system with smaller buoyancy cylinder. The hard design environment could be mitigated in this way.

The basic principle in the energy production is the same as the open system derived above. Only difference is that it needs reservoir which is smaller than the conventional one. As shown in Fig. 3, the closed gravity engine system is constructed on the dam. The water in the dam with a high tide potential flows to the outer cylinder of gravity engine to provide a high tide condition.

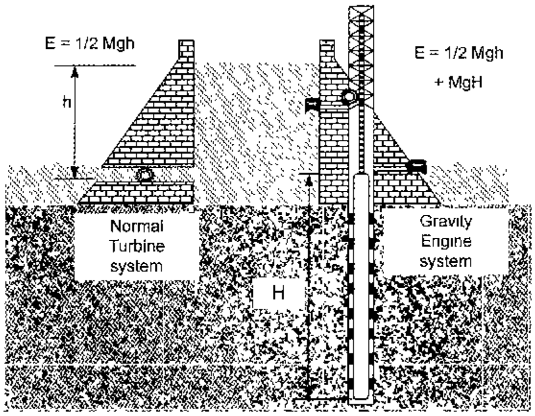

Fig. 3. The energy extraction between the conventional water mill and the present gravity engine.

The net work extracted from the present gravitational engine is made with N times operations:

$$E_{work}=\frac{\eta_{grv}N}{2}\rho_w g A_b\left(\left(1-\frac{1}{\eta_{drain}}\right)H^2+2Hh+h^2\right) \tag{12}$$

Its maximum could be made when the cross sectional area of the cylinder multiplied by the number of cyclic operations is the water surface area of the reservoir:

$$A_{reservoir}=N\times A_b \tag{13}$$

3-2. Dynamics of the Buoyancy Cylinder

The vertical motion of the buoyancy cylinder shows exponential change in velocity. In this section, the basic design principle of the gear assembly to get the uniform rotation from the nonuniform vertical motion. The relation between the angular velocity of gear and the vertical velocity of the buoyancy cylinder is as follows:

$$2\pi R\omega=v(t) \tag{14}$$

where ω is the angular speed which should be a constant to provide uniform rotation to the electric generator. Then the radius of gear is a function of the vertical velocity:

$$R=\frac{v(t)}{2\pi\omega} \tag{15}$$

Once we know the time dependency of the vertical velocity. the radius of the gear could be determined. This conversion from the time domain (vertical motion) to the geometrical domain (radius of gear) is realized by continuously connected shell type gear (like a turban shell). To determine the radius of the gear, the equation of motion of the buoyancy cylinder is modelled:

case 1) The vertical motion under the water

$$M_{buoy}\frac{dv}{dt}=(\rho_w-\rho_c)gA_bH-K, \quad -h<z<0 \tag{16}$$

case 2) The vertical motion above the surface of the water

$$M_{buoy}\frac{d^2z}{dt^2}=(\rho_w-\rho_a)gA(H-z)-K\frac{z}{H}\frac{dz}{dt} \quad 0<z \tag{17}$$

The vertical motion under the water is exponentially varying but after escaping from the water, the buoyancy force is reduced to show a damped oscillation. We leave the detail design of the gear assembly for the future study. At this moment, it can be stated that the uniform rotational motion could be achievable from the time varying vertical motion by designing a special gear based on Eq. (15).

4. Discussions

4-1. Efficiency and Added Mass Effect in Energy Production

In this section, two strong reasons why the present gravity engine could produce more energy than the conventional turbine plants are investigated: efficiency and added mass by the buoyancy cylinder. Let us compare the efficiency of the present gravity engine with the conventional turbine for the same tidal height, h: the ratio could be simply stated as follows:

$$\frac{E_{grav}}{E_{water\ mill}}=\frac{\eta_{grav}}{\eta_{mill}}\left(\frac{A_b}{A_{res}}\right)\left(\left(1-\frac{1}{\eta_{drain}}\right)\frac{H^2}{h^2}+2H+1\right) \tag{18}$$

(A) Efficiency

Many efficiency factors are presented in the above formulation, Eq. (18). Let us address their values to estimate the real merits of the present engine. The turbine efficiency of the conventional tidal power has been studied well. Normally, it depends on the water level because the water flow rate depends on the water level. The turbine with fixed blades has a high efficiency at the rated water level but poor at the low water level. Its efficiency is less than 65% by averaging the whole water level[5]. The turbine with controlled blades could maintain high efficiency with broad band of the water level whose average efficiency is less than 75%. In spite of its dependency on the water level, many factors in a marine environment including micro organisms cause degradation of its efficiency. Pessimistic estimation of the water mill efficiency reaches to 20% or less[6]. However, to the authors opinion, the reasonable value could be estimated in between 60% and 80%.

The drain pump efficiency, η_{drain}, is more easy to estimate since it works in the outside of the sea water and it has an enough time to get the best efficiency by setting the proper revolution speed. Then even for the centrifugal pump, it is not difficult to get the efficiency higher than 80%[7]. The present gravitational engine converts a vertical motion to the rotational motion with a special gear assembly. The newly introduced efficiency of the gear assembly, η_{grav}, should be checked by a sophisticate experiment. The energy loss in the gear assembly could be generated by the friction in the tooth of gears and bearings which could be partially removed by providing a proper lubrication system. Gear sets are noted for their high efficiency (up to 99%), reliability and service life as well as relatively small size and ease maintenance[8]. In addition to this, the coefficient of friction for bearing is normally in between 0.0012 and 0.008[9]. Therefore, the efficiency of the mechanical energy convertor could be 90% or more.

(B) Added mass effect

For the same basin area, the present engine could produce more energy from the amplification of the buoyancy cylinder. Let's define the normal mass of water due to tide:

$$M_{water}=\rho_w A_b h \tag{19}$$

Also, the added mass by the buoyancy cylinder with height H is defined as:

$$M_{add}=\rho_w A_b H \tag{20}$$

From Eq. (9) the energy extracted form the gravitational engine could be restated as:

$$E_{work}=\eta_{grav}\frac{1}{2}M_{water}gh+\eta_{grav}M_{add}g\left(h+\frac{1}{2}\left(1-\frac{1}{\eta_{drain}}\right)H\right) \tag{21}$$

So the present closed gravity engine could produce not only the work obtainable from the conventional turbine, the first term in R.H.S, but also the additional energy form the buoyancy cylinder, the second term in R.H.S, as shown in the second term in Eq. (21). This effect of the added mass is the key merit of the gravity engine.

4-2. Reduction of the Reservoir Area

If the objective of design is set to construct the

Table 1. The area reduction effect.

Case	Tidal height h (m)	η_{mill}	η_{grav}	η_{drain}	Buoyancy cylinder length H(m)	$\frac{A_b}{A_{res}}$
1	5	0.7	0.9	0.8	20 m (4 * h)	1/47.57
2	5	0.7	0.8	0.9	40 m (9 * h)	1/82.28
3	6	0.7	0.9	0.8	24 m (4 * h)	1/57.86
4	6	0.7	0.8	0.9	54 m (9 * h)	1/114.28

same power as the conventional tidal power plant, then the present gravity engine needs smaller reservoir area of less initial capital cost and environmental effect. The area reduction ratio could be estimated by the following relation:

$$\frac{A_b}{A_{res}}=\frac{\eta_{mill}}{\eta_{grav}}\frac{1}{\left(1-\frac{1}{\eta_{drain}}\right)\frac{H^2}{h^2}+2H+1} \tag{22}$$

We check several cases to see the sensitivity of each parameter in Eq. (22) as listed in a Table 1. Tidal height, 5 m, is selected from the data of Garolim bay[3]. The efficiencies of turbine, gear box, drain pump are addressed on the basis of the arguments in section 4.1. The height of the buoyancy cylinder, H, is determined by Eq. (11) to provide an optimum condition.

In this estimation, the turbine efficiency of 70% is used to remove special pleading to the present system, i. e. the reasonably best value to the conventional system. As shown in the table, the high efficient drain pump allows the longer buoyancy cylinder, which increases the added mass. The drain pump efficiency plays a key role in energy production.

From the above results, it was found that a large amount of energy from a smaller reservoir than the conventional plant is possible. Considering the condition of the real estate in Korea, the area reduction in the reservoir has a meaning. If we replace the conventional turbines with the present gravity engine, the hydropower in Korea increase several tens or hundreds times (in calculation) greater than now. Also, the development of the small hydropower could be reactivated. Also, the tidal energy in the Yellow Sea can plays an important role as a reliable energy resource.

5. Conclusions and Future Studies

In this study, a conceptual design of the gravitational engine is proposed and analyzed. The vertical motion of the buoyant material is converted to the mechanical work. We named it as an: "Gravity engine" which has a buoyancy cylinder, a latch assembly, and a specific hydraulic system controlling the water in and out side of the cylinder The energy calculation on the basis of the first principle of thermodynamics show that the present gravity engine could extract more energy than the conventional turbine. This is achieved not by improving the efficiency of the device but by finding additional energy. This additional energy is extracted by the added mass to the cylinder due to the buoyancy pressure. Future works to implement the present proposal are huge from design to experimental verification.

Nomenclature

A	: area
E	: energy
g	: gravitational acceleration
h	: the tidal height
H	: the length of buoyance tank
M	: mass of water
N	: the number of operations
v	: velocity

Greeks

ρ	: density
η	: efficiency
π	: 3.141592
ω	: angular velocity of gear

Subscripts

a	: air
b	: buoyancy
bay	: bay
drain	: drain
gain	: gain
grav	: gravity
mill	: mill
res	: reservoir
supply	: supply
w	: water
water mill	: water mill
work	: work

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