Utilisation of Free-Ballast Concept Ship to generate Power

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Abstract- *Free- Ballast Concept Ship though still in their conceptual stages may open up a wide range of power harnessing techniques once its feasibility is validated. The Free-Ballast Ship would primarily require Ship ballast tanks be replaced with longitudinal structural ballast trunks consisting of one centre tank, two intermediate tanks and two side tanks which surround the cargo hold below the ballast draft, a V shaped hull design to minimize resistance and optimize propulsion. Due to the pressure differential between the bow and the stern, there would be a constant flow of sea-water from the inlet and bow of the ship to the outlet at the aft of the ship. This flow of water can be potentially used to generate power. This paper investigates factors such as pressure differential, head and flow rate of water that are necessary for the production of power using a suitable hydro power turbine. The paper proposes a concept wherein the energy of the flowing water will be used to generate power. This system does require any fuel and hence is a 'sustainable technique of power generation'*

Keywords – Free - Ballast, pressure differential, head, rate of flow, turbine, power.

INTRODUCTION

Ballasting or de-ballasting is a process by which sea water is taken in and out of the ship when the ship is at the port or at the sea. The sea water carried by the ship is known as ballast water. Ballast or ballast water is sea water carried by a vessel in its ballast tanks to ensure its trim, stability and structural integrity.

When no cargo is carried by the ship, the later becomes light in weight, which can affect its stability. For this reason, ballast water is taken in dedicated tanks in the ship to stabilize it. Tanks are filled with ballast water with the help of high capacity ballast pumps and this process is known as Ballasting.

However, when the ship is filled with cargo, the stability of the ship is maintained by the weight of the cargo itself and thus there is no requirement of ballast water. The process of taking out ballast water from the ballast tanks to make them empty is known as de-ballasting.

I. Ballast water discharge and the environment

It is already known that sea water is the main source of Ballasting. Serious problems arise when the ballast water is discharged, as water-borne organisms may create havoc when deposited in new environments.

Ballast water is considered the leading vector for the unintentional transfer of non-indigenous aquatic species into sea ports.

Cruise ships, large tankers, and bulk cargo carriers use a huge amount of ballast water, which is often taken on in the coastal waters in one region after ships discharge wastewater or unload cargo, and discharged at the next port of call, wherever more cargo is loaded.

Ballast water discharge typically contains a variety of biological materials, including plants, animals, viruses, and bacteria. These materials often include non-native, nuisance, exotic species that can cause extensive ecological and economic damage to aquatic ecosystems, along with serious human health issues including death.

There are hundreds of organisms carried in ballast water that cause problematic ecological effects outside of their natural range

The ballast-free ship concept offers a promising alternative that could block hitchhiking organisms while eliminating the need for expensive sterilization equipment.

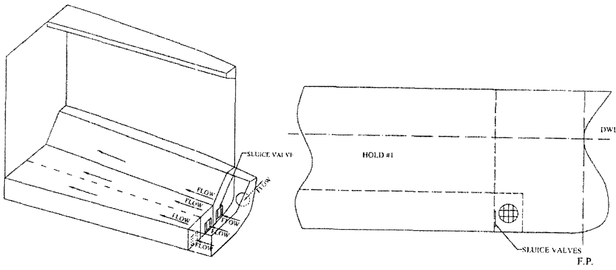
II.What is Free - Ballast ?

The Ballast-Free Ship concept involves a new paradigm that approaches ballast operation as the reduction of buoyancy rather than the addition of weight to get the vessel to its required ballast draughts.

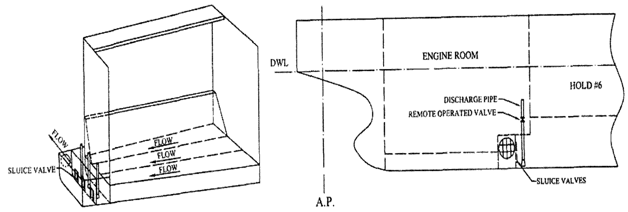
The traditional ship ballast tanks are replaced by longitudinal structural ballast trunks that surround the cargo hold below the ballast draught.

These trunks, which are connected to an intake plenum near the bow and a discharge plenum near the stern, are flooded in the ballast condition to decrease the ship's buoyancy.

V-shaped hull minimizes the resistance and optimizes the propeller conditions in fully loaded and unloaded conditions by reducing the weighted sum of the wetted surface.



Forward Plenum and Collision Bulkhead Arrangement



Aft Plenum Arrangement

The pressure differential between the bow and the stern is utilized to drive a slow flow through the ballast trunks to ensure that the trunks always contain local seawater.

This ensures that that the ballast trunks are always filled with “local seawater” and they will not transport nonindigenous aquatic species across the globe. Thus, the vessel is essentially foreign ballast free from traditional viewpoint.

When the voyage is completed, the trunks can be isolated from the sea and then pumped dry using conventional ballast pumps. The need for costly ballast water treatment equipment would be eliminated.

INVESTIGATION

This paper reports the feasibility of the ballast free ship and the potentiality of harnessing the slow flow of seawater within the ballast trunks in generation of power. Thus, recovering some amount of power that is lost in various ship operation.
Data for investigation is with reference to research done by Miltiadis Kotinis, Student Member, University of Michigan on Development and Investigation of the Ballast-Free Ship Concept. Useful parameters such as pressure differential and rate of flow have been used from the said experiment to derive other parameters such as Head Pressure, Draught, Flow Speed, Available Power, Hydro Power, etc.

About the U-M Free Ballast Experiment

The model was a scaled down version of a bulk carrier with length of water line 247.9m.
The length of the model ship was 5.2m.
The experiment was conducted in the towing tank. The tank is 109 m long with a 6.70 m by 3.05 m cross section.
All parameters were determined using Computational Fluid Dynamics (CFD) model SHIPFLOW (Flowtech 1998).

I. Estimation of Pressure Differential

The first task is to validate there would be enough pressure differential between the bow and stern of a typical ship to produce a continuous flow through the ballast trunks when they are flooded and the ship is at design speed. Experimental data for a series 60 hull can be used to establish that there is enough differential pressure needed to provide the minimum flow rate.

CHARACTERISTICS
OF A SEAWAY SIZED BULK CARRIER

L_{WL}(m)	247.9
Beam(m)	30.5
Draught(m)	9.15
C_B	0.622
C_P	0.670
LCB (m, from keel)	6.67
VCB (m, from keel)	5.05
Wetted surface (m^2)	8513

Upon experimentation, it was noted that during ballast operation, the ship draught at fore and aft perpendicular are expected to be about 60% and 80% of the design draught, respectively. This condition would result in a pressure head from bow to stern providing for the required pressure head for turbine operation.
The required pressure drop from the bow to the stern to sustain one fluid change per hour was estimated to be 0.124 psi or in terms of non-dimensional pressure coefficient ΔC_p = 0.033. The corresponding pressure coefficient for a fuller Seaway sized bulk carrier is expected to be even higher.
The Head is the distance the water will fall on its way to the generator. In this case the pressure differential will be the source of head to the generator. However, the pressure needs to be converted from psi to head (in metres).

This can be done using the equation P = 0.433 H SG where

- P= pressure in psi
- H = head in feet
- SG = Specific Gravity of seawater, 1.025 g/cm^2

The head therefore turns out to be 0.279 feet or 0.0850m

The portion of the study confirmed that adequate pressure would be available to ensure a ballast trunk volume turnover of at least once per hour, thus ensuring trunks would always contain “local seawater”.

Once it has been established that there is a minimum pressure differential across the bow and trunk, approximate head across the length of ship can be estimated.

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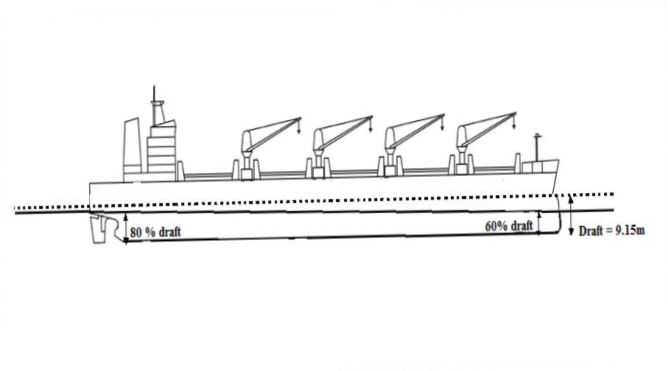


Head= (Draught at stern – Draught at bow) =7.32m-5.49m= 1.83m

design draught, respectively. From the tabulation provided in Miltiadis Kotinis's experiment, the available draught in a full-sized seaway ship is 9.15m. By using simple mathematics, it can be deduced that the head from the bow to stern would be close to 1.83m. For ease of calculation we can round off this draught to 2m.

II. Calculation of Mass Flow of Water

The impact of ballast trunk flow diversion the hydrodynamic behavior of the vessel can be a significant aspect of the Ballast Free Ship concept. The vessels resistance could be significantly modified especially the viscous drag, since the water discharged at the stern could trigger early separation and significantly modify the boundary layer.
The internal flow within the longitudinal ballast trunks was simulated by a single tube running from the bow intake position to the stern discharge position.
A model ship of scale (1:47.87) was used. The corresponding water ballast capacity was determined to be $\nabla_b = 23{,}040\ m^3$.
The mass flow rate is given by **Q = A v** where A is the tube sectional area and v is the internal flow speed. The geometrical ratio, **λ, is 47.87, so** $A = \lambda^2 A_m$.
Assuming Froude number equality and geometric similitude $(L = \lambda L_m)$, $V_s = \lambda^{1/2} V_m$ and $Q_s/Q_m = \lambda^{5/2}$.

Using the desired full -scale ballast trunk exchange time T_B, the scaled model total trunk volume floe rate is then given by,

$$Q_M = (\nabla_m / T_B)\ \lambda^{-5/2}$$

The required water exchange was varied between 60,90 and 120 min.

Full Scale Exchange Time and Model Scale Flow Characteristics

T_b	60	90	120
Q_m(GPM)	**6.4**	**4.3**	**3.2**
Flow V (m/sec)	**0.797**	**0.531**	**0.398**

*actual conditions may also use an existing bow thruster tunnel.

Hence,

$$Q_S = \lambda^{5/2} \times Q_M = 101470.20\ GPM$$

In order to calculate the corresponding velocity of flow of seawater within the trunks in a real ship we can use the equation

$$V/\sqrt{L} = v/\sqrt{l}$$

Considering complete changeover time as 60 minutes

- V is velocity of flow in a real ship (we need to find)
- v is velocity of flow of model ship = 0.797
- L is length of the real ship= 247.9m
- l is length of model ship = 5.17m

Therefore,

$$V / \sqrt{247.9} = 0.797 / \sqrt{5.17}$$

V turns out to be **5.52 m/sec**. From the data, we can conclude that

- **Q_s= 101470.20 GPM or 6401.77 Litres per Second**
- **Flow speed = 5.52 m/sec**

This confirms that there is an immense rate of slow of seawater from the bow to the stern of the ship. Also, the speed of flow is adequate to move the turbine blades**.**

III. Hydro Power Calculation

Hydro energy is available in many forms, potential energy from high heads of water retained in dams, kinetic energy from current flow in rivers and tidal barrages, and kinetic energy also from the movement of waves on relatively static water masses
The two vital factors to consider are the flow and the head of the stream or river. The flow is the volume of water which can be captured and re-directed to turn the turbine generator, and the head is the distance the water will fall on its way to the generator. The larger the flow – i.e. the more water there is, and the higher the head – i.e. the higher the distance the water falls – the more energy is available for conversion to electricity.
A low head site has a head of below 10 metres. In this case you need to have a good volume of water flow if you are to generate much electricity. The head available is 1.83m and the flow is 6401.77 l/sec. The head is considerably low but the immense rate of flow will make up for it.

Power = Head x Flow x **Gravity**

where power is measured in Watts, head in metres, flow in litres per second, and acceleration due to gravity in metres per second per second
Hence the available hydro power will approximately be

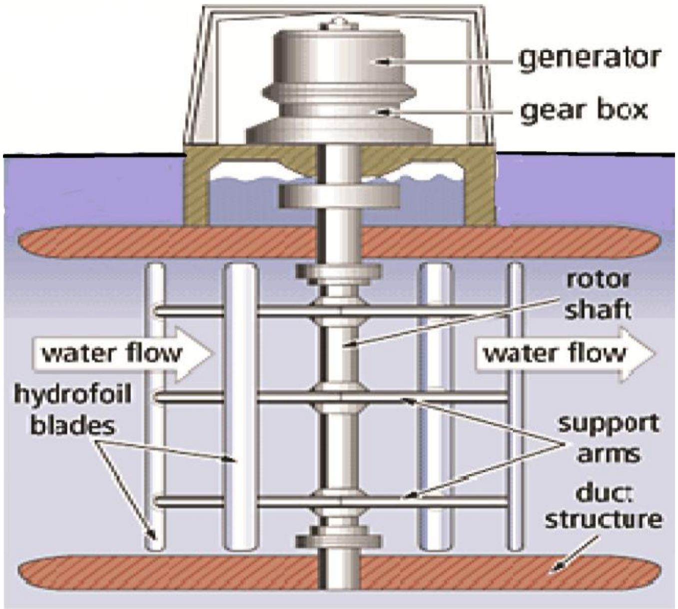
1.83 m x **6401.77 Litres per Second** x **9.81**
= 114926 Watts or 114.926 KW (115 KW)

Therefore, the power available is about 115KW. Obviously not all of it can be harnessed. The power generated by the system is dependent upon the turbine generator used.

IV. Selection of Turbine

For the given available power that we can salvage, that is 115KW, the most suitable turbine that could convert the kinetic energy of the flow of sea water to electrical energy would be a Micro hydro turbine.

Micro hydro is a type of hydroelectric power that typically produces from 5 kW to 100 kW of electricity using the natural flow of water. Installations below 5 kW are called pico hydro. As there are varying definitions of the power range of "micro" and "pico", it is advantageous to specify each project's power output in kW. The system is prevented from 100% efficiency due to the real world, such as: turbine efficiency, friction in pipe, and conversion from potential to kinetic energy. Turbine efficiency is generally between 50-80%.



Hydrofoil kinetic energy turbine

A ROR (run off river) turbine, kinetic energy turbines, also called free-flow turbines, generate electricity from the kinetic energy present in flowing water rather than the potential energy from the head. A development from the Darius wind turbine, the structure is very simple and has the minimum of components under water. Both vertical and horizontal axis versions are being developed. The vertical axis turbine can be placed in the trunk, and does not need a separate structure to control water flow. The vertical axis turbine has the advantage that the generator can be mounted above the turbine and therefore out of the water.

The turbine can be suitably placed at stern of the trunk, few metres before the sea water exits the ship. The flow of water as calculated will be sufficient to turbine blades.

The movement of the turbine blades turn the shaft which is coupled with a generator. The movement of the turbine blades however will be slow due to the slow speed of flow of sea water. The slow turning shaft is therefore connected to another shaft via a gear mechanism that produces enough rpm for the production of electricity.

Being slow moving, the turbine wouldn’t cause much turbulence to the water flow. The hydrofoil turbine should be able to harness some if not all of the power available.

CONCLUSION

The Free – Ballast Concept can prove to be a viable substitute to conventional Ballast method. Reducing the building and maintenance costs and preventing invasion of indigenous species, the free-ballast concept can also be used to produce power by using the energy of flowing water. Simple science and knowledge of naval architecture suggests that this technology may be used for production of energy. Moreover, apart from initial installation costs, this would not cost the shipowner any money and has a potential to recover some power lost.

A further thorough research is necessary for the validation of this system’s potential.

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