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DESIGN FABRICATION AND INTRODUCTION OF SEAWATER DRIVEN TURBINE TO PRODUCE AUXILIARY POWER GENERATION ON ENGINE ROOM

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ABSTRACT-*This paper presents a conceptual design for an auxiliary electrical generation system aboard marine vessels, exploiting the natural hydrostatic pressure of seawater below the ship's waterline as a primary energy source. A turbine coupled to a generator rotor is driven by seawater admitted through a sub-waterline sea chest. To overcome the inherently limited pressure differential available at typical ship drafts, a Venturi nozzle is integrated into the existing high-temperature (HT) cooling water circuit. The low-pressure region created at the Venturi throat is applied to the turbine outlet, thereby increasing the effective pressure drop across the turbine and enhancing rotor speed and electrical output. After passing through the turbine, the seawater is directed through the HT cooler as the normal cooling medium before being discharged overboard. The concept is evaluated with respect to thermodynamic feasibility, energy balance, and practical integration within conventional marine cooling architectures.*

Keywords: Marine auxiliary power, seawater turbine, hydrostatic pressure, Venturi nozzle, HT cooling system, onboard electricity generation, energy recovery, marine energy efficiency, turbine- generator system, sustainable marine.

INTRODUCTION

The maritime industry is under increasing pressure to reduce fuel consumption and auxiliary machinery losses. Ships carry large quantities of seawater for cooling purposes water that is already in motion, pressurized by the vessel's draft, and ultimately discharged overboard without energy recovery. This represents an unexploited low-grade energy stream present on virtually every ocean-going vessel. The concept explored here is to intercept this flow at the point of highest available pressure below the waterline and extract useful work from it before it serves its primary cooling function. The principal challenge is that the hydrostatic head available at normal operating drafts (typically 5 to 15 meters) is modest, and a direct-drive turbine operating on this head alone would produce insufficient shaft torque to generate meaningful electrical power.

To address this, the proposed system couples the turbine outlet to a Venturi nozzle installed in the parallel HT cooling seawater line. The pump already driving that line creates a high-velocity jet at the Venturi throat, producing a low-pressure (suction) zone. By connecting this zone to the turbine exhaust, a secondary pressure differential is imposed across the turbine rotor, augmenting the primary hydrostatic head and increasing flow velocity and turbine rotational speed.

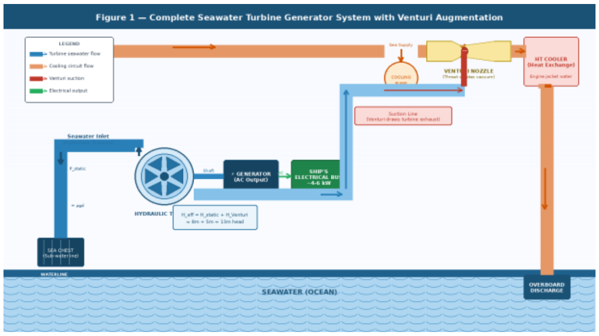

Figure 1-Complete system schematic showing sea chest inlet, turbine-generator assembly, Venturi nozzle in the HT cooling circuit, and overboard discharge path.

2. SYSTEM ARCHITECTURE AND OPERATING PRINCIPLE

2.1 PRIMARY SEAWATER INLET

Seawater is admitted through a dedicated sea chest positioned below the vessel's loaded waterline. The available hydrostatic pressure P_static at the turbine inlet is given by:

$$P\_static = \rho \times g \times d$$

where ρ is the density of seawater (approximately 1,025 kg/m^3), g is the gravitational acceleration (9.81 m/s^2), and d is the depth below the waterline at the sea chest centreline. For a typical bulk carrier at d = 8 m, this yields approximately 80.2 kPa a relatively modest differential when compared to the ambient back-pressure at the turbine outlet.

2.2 TURBINE AND GENERATOR COUPLING

The turbine is an axial or mixed-flow hydraulic turbine whose shaft is mechanically coupled to the rotor of a synchronous or permanent-magnet generator. The turbine is designed to accept the available seawater flow at the inlet pressure and convert kinetic and potential energy into rotational mechanical energy. The generator produces alternating current, which may be rectified and conditioned to supplement the vessel's electrical bus.

In the baseline configuration (without Venturi augmentation), the net head across the turbine is limited to the hydrostatic head at the sea chest minus pipeline frictional losses, yielding a low specific power output. This alone is generally insufficient for practical power generation beyond micro-watt scales without very large turbine diameters.

2.3 VENTURI-ASSISTED SUCTION AUGMENTATION

The key innovation is the application of a Venturi nozzle to increase the effective pressure drop across the turbine. The Venturi is installed in the existing HT cooling seawater delivery line, which is driven by the vessel's dedicated cooling seawater pump.

As the cooling water accelerates through the convergent section of the Venturi nozzle, static pressure drops in accordance with Bernoulli's principle:

$$P_1 + \tfrac{1}{2}\rho v_1^2 = P_2 + \tfrac{1}{2}\rho v_2^2$$

At the throat (minimum cross-section), velocity is maximised and static pressure P_throat is minimised. If P_throat is below the pressure at the turbine outlet, a net suction force draws water through the turbine circuit. The turbine outlet is connected to the Venturi throat via a dedicated suction line, effectively placing the throat pressure as the turbine back-pressure.

The total effective head driving the turbine thus becomes:

$$H_{eff} = H_{static} + H_{Venturi}$$

where H_Venturi = (P_atm − P_throat) / (ρg) represents the additional suction head created by the Venturi arrangement. This can theoretically approach the cavitation limit approximately 10.3 metres of equivalent water column at sea level though practical limits due to dissolved gas release and vapour pressure constrain it to approximately 6 to 8 metres of additional equivalent head.

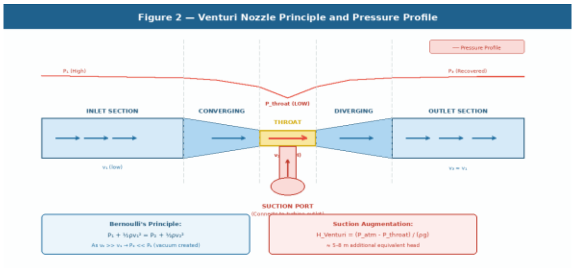

Figure 2 — Venturi nozzle cross-section showing convergent-divergent geometry, velocity and pressure profiles, and the suction port connection to the turbine outlet.

2.4 POST-TURBINE HT COOLER INTEGRATION

After passing through the turbine, the seawater still cool and pressurised by the Venturi pump's delivery enters the HT cooler as the normal cooling medium. It absorbs heat from the engine jacket water circuit and exits at elevated temperature before being discharged overboard via the ship's side valve arrangement. This dual-use of the seawater stream ensures that the turbine installation imposes no additional seawater consumption and does not disturb the cooling system's thermal performance, provided the additional flow resistance introduced by the turbine is within the pump's capacity.

3. THERMODYNAMIC AND ENERGY CONSIDERATIONS

3.1 AVAILABLE POWER

The hydraulic power available to the turbine is:

$$P_{hydraulic} = \eta_{turbine} \times \rho \times g \times Q \times H_{eff}$$

where Q is the volumetric flow rate (m^3/s) through the turbine and η_turbine is the turbine efficiency (typically 0.70 to 0.85 for well-designed hydraulic turbines). The generated electrical power P_elec is further reduced by the generator efficiency η_gen (typically 0.90 to 0.95):

$$P_{elec} = \eta_{turbine} \times \eta_{gen} \times \rho g Q H_{eff}$$

3.2 PARASITIC LOAD CONSIDERATION

It must be noted that the Venturi augmentation is not a free energy source. The Venturi nozzle introduces additional resistance into the HT cooling circuit, which increases the head against which the cooling seawater pump must operate. This increases the pump's shaft power demand, which is ultimately sourced from the main engine or auxiliary generator. A rigorous energy audit must confirm that the electrical output from the turbine generator exceeds the additional pump power demand attributable to the Venturi, accounting for all efficiencies in the chain.

The net energy gain condition is:

$$P_{elec} > \Delta P_{pump} / (\eta_{motor} \cdot \eta_{pump})$$

where ΔP_{pump} is the additional pump shaft power and η_{motor}, η_{pump} are the motor and pump efficiencies respectively. This condition represents the fundamental viability constraint for the proposed system.

3.3 INDICATIVE NUMERICAL EXAMPLE

For illustrative purposes, consider the following design parameters:

Parameter	Value
Seawater depth (d)	8 m
Static head (H_{static})	8.0 m
Venturi suction head ($H_{Venturi}$)	5.0 m
Effective total head (H_{eff})	13.0 m
Flow rate through turbine (Q)	$0.05\ m^3/s$
Turbine efficiency (η_t)	0.78
Generator efficiency (η_g)	0.93
Gross hydraulic power	6,365 W
Estimated electrical output	~4,600 W (4.6 kW)

These figures indicate a potentially useful supplementary power output, though a detailed pump energy audit is necessary to confirm net positive output for a specific vessel application.

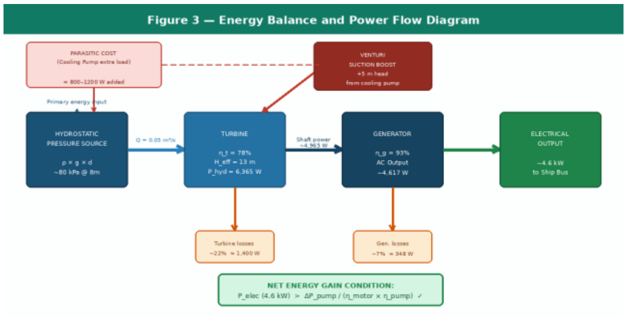

Figure 3 — Energy balance and power flow diagram showing hydraulic input, turbine and generator efficiencies, parasitic pump cost, and net electrical output.

4. PRACTICAL DESIGN AND INTEGRATION CHALLENGES

4.1 TURBINE SIZING AND SELECTION

The turbine must be designed for low-head, moderate-flow operation. Axial flow (propeller-type) or mixed-flow turbines are the most appropriate candidates at the flow rates and heads anticipated. The runner diameter, blade angle, and rotational speed must be matched to the effective head and flow rate to maximize efficiency. Variable-pitch blades may be considered to accommodate varying vessel drafts and cooling circuit conditions.

4.2 VENTURI NOZZLE DESIGN

The Venturi nozzle must be designed to achieve a throat pressure sufficiently below the turbine outlet pressure without inducing cavitation in the cooling circuit. The throat-to-pipe area ratio, convergent angle, and divergent recovery section geometry all affect the achievable suction and the pressure recovery downstream of the throat. The nozzle must be constructed from corrosion-resistant materials suitable for continuous seawater service.

4.3 COOLING SYSTEM IMPACT

The introduction of a turbine and Venturi into the HT cooling circuit will alter flow resistance and potentially reduce cooling flow rates to the HT cooler if the existing pump is operating near its duty point. A detailed hydraulic network analysis of the combined circuit is essential. It may be necessary to uprate the cooling pump or to install a dedicated pump for the Venturi line, separate from the main cooling pump.

4.4 CORROSION, FOULING, AND MAINTENANCE

All wetted components must be fabricated from or coated with seawater-resistant materials such as duplex stainless steel, naval bronze, or fibre-reinforced polymer composites. Biofouling management including cathodic protection and periodic cleaning is essential for the long-term reliability of the turbine runner and nozzle throat. Provision for isolation valves and bypass arrangements is required to enable maintenance without disrupting the vessel's cooling system.

4.5 CLASSIFICATION SOCIETY AND REGULATORY CONSIDERATIONS

Any auxiliary power generation system installed aboard a classed vessel must comply with the requirements of the relevant classification society (e.g., Lloyd's Register, DNV, Bureau Veritas). The system must demonstrate that it does not compromise the integrity of the hull, the reliability of essential cooling services, or the electrical safety of the ship. Relevant rules for sea chests, cooling systems, and auxiliary machinery will apply.

5. DISCUSSION

The proposed concept is, at its core, a low-head hydraulic turbine with Venturi-assisted back-pressure reduction. The physics are well-established, and there is no thermodynamic barrier to the concept. The critical question is whether the net electrical output justifies the additional capital cost, maintenance burden, and engineering complexity of the installation.

The Venturi augmentation is a particularly important innovation. Without it, the hydrostatic head at a sea chest is generally too small to drive a turbine at useful rotational speeds and power outputs. With Venturi augmentation, the effective head is nearly doubled, which given that power scales with the product of head and flow roughly doubles the power output potential. However, this is at the cost of additional pump work, which must be carefully quantified.

The system is most attractive on vessels with high draft (e.g., laden bulk carriers and tankers), high cooling water flow rates, and long operational periods at consistent trim. Passenger vessels and naval vessels with high continuous auxiliary power demands may also be suitable candidates. Vessels operating in warm tropical waters, where cooling demands are highest and cooling flow rates are largest, represent the most promising application environment.

A potential concern is whether the seawater drawn through the turbine undergoes sufficient treatment prior to use in the HT cooler. In standard cooling systems, seawater passes through strainers. If the turbine circuit bypasses the main strainer, additional filtration provisions will be required

6. RECOMMENDATIONS FOR FUTURE WORK

- Computational fluid dynamics (CFD) simulation of the combined turbine-Venturi circuit to optimize geometry and predict cavitation margins.
- Construction and testing of a scaled laboratory prototype to validate the effective head augmentation and turbine power output predictions.
- Full hydraulic network modelling of the ship cooling system, including the proposed circuit, to determine pump duty point changes and required pump modifications.
- Detailed energy balance analysis for at least two representative vessel types (e.g., laden VLCC and a Panamax bulk carrier) to quantify realistic net electrical output.
- Evaluation of alternative augmentation methods (e.g., ejector pump, electric motor-driven booster) as comparators to the Venturi approach.
- Assessment of classification society requirements and development of a type-approval test protocol.

7. CONCLUSION

This paper has presented a conceptual design for a seawater-driven auxiliary turbine generator system enhanced by Venturi-assisted suction. The system exploits the hydrostatic pressure of seawater below the ship's waterline and uses the low-pressure region at a Venturi throat integrated into the HT cooling circuit to augment the effective pressure drop across the turbine. The turbine outlet flow is then utilised as the HT cooler cooling medium before overboard discharge, making the arrangement dual-purpose and minimising waste.

Preliminary analysis suggests that net electrical generation in the range of several kilowatts is theoretically achievable on vessels with adequate draft and cooling water flow. The concept is physically sound and represents a novel approach to shipboard energy recovery. Significant engineering development, including prototype testing and full energy-balance verification, is required to advance the concept from feasibility to practical implementation.

If validated, the system could contribute meaningfully to reducing a vessel's auxiliary diesel generator load, thereby reducing fuel consumption and exhaust emissions aligned with the International Maritime Organization's strategy for greenhouse gas reduction in shipping.

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