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Numerical Solutions for Prediction of Nozzle Loss Factor and Flow Coefficient of 1.5 Stage Axial Gas Turbine Utilizing Waste Heat from Marine Diesel Engine

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Abstract: Main engine exhaust gas energy is by far the most appealing among the waste heat sources of marine diesel engines in ships in light of the heat flow and temperature. It is feasible to produce electrical power output using this exhaust gas energy in a waste heat recovery system containing power turbines and steam turbines (some portion of exhaust gas heat is used for creating steam). The essential wellspring of waste heat of the primary motor is the exhaust gas heat dissipation, which represents about portion of the complete waste hotness, for example around 25% of the total fuel energy. In the present study, a 1.5 stage axial turbine (with the turbine rotor interspaced between two stators) utilizing waste heat from the marine diesel engine is considered for investigating performance using ANSYS CFX. Simulations are carried out with rotor speed varying from 1000 RPM to 8000 RPM with turbine inlet pressure kept constant at 4 bar. The performance of axial gas turbine is analyzed with inlet temperatures varying from 523 K to 673 K for different mass flow rates and rotor speeds The Flow coefficient of the rotor is also found to be within the acceptable range between 0.5 to 1.1 and is observed to cut the efficiency line between 2800 RPM and 4000 RPM, corresponding to 70% to 78% efficiency. Nozzle Loss Coefficient (NLC) represents the deviation of the actual process with the isentropic process in a stator blade of the turbine.
Keywords: Marine diesel engine, Exhaust gas, Waste heat recovery, Power output, Nozzle loss coefficient, Flow coefficient.

I. INSTRUCTION

Recently waste heat recovery from engine exhaust is known as one of the most effective means of utilizing exhaust gas energy from marine diesel engines and it is drawing attention of many researchers in the research field. The maritime ships especially run with a gigantic weight at a predictable speed for the long haul contrasted with that of vehicle working conditions. The waste heat delivered from these marine diesel motors is more steady contrasted with vehicles. The fundamental benefit in ocean going ships is that the heat source can be given from the waste heat source and the cooling heat source can be taken from seawater. A motor that runs with diesel as its fuel delivers the biggest measure of waste heat to the environment. Marine diesel engine releases the maximum amount waste heat because of the different continuous cycles working in ordinary conditions, for thermodynamic heat transfer. There are a few techniques known and involved today for recuperating waste heat onboard ships. The most widely recognized of them comprises of warming the Heavy diesel fuel oil to keep up with it with a low viscosity. To this end, the vast majority of the boats have some sort of heat recuperation steam generator, often called an exhaust gas boiler (EGBO) that utilizes the heat from the exhaust. In addition, the waste heat can likewise be utilized for retention or adsorption refrigeration, which has been shown with practical use by a few investigations. In this sense, the utilization of joined cycles with a Rankine cycle for huge ships, is generally embraced in the global exchange for ships.

II. LITERATURE SURVEY

Z. Mat Nawi et al [1] prepared a definite report on using Waste Heat from Marine diesel Engine in an Organic Rankine Cycle power plant utilizing Organic working liquids dependent on microalgae. The exhaust gas, temperature, mass flow rate were viewed as subject to Engine load. Maximum & Minimum exhaust gas temperatures Maximum & Minimum exhaust gas temperatures were 573.15 K & 548.15 K with mass flow rates of 2 kg/s & 1.15 kg/s respectively. Fotis Kyriakidis et al [2] delivered definite hypothetical advancement studies on the presentation of two distinct designs of steam Rankine cycle with WHR and incorporated

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EGR to address NOx emanation from a two-stroke marine diesel motor. It was reasoned that out of the three tensions level setup (I) is Mojtaba Tahani et al [3] utilized a 12-liter six-chamber CI motor at full burden for an itemized study on waste heat resources and involved two distinctive Organic Rankine Cycle Configurations for using the waste heat. Distinctive working liquids Viz R-134a, R-123, and R-245fa were utilized in the Organic Rankine Cycle. It was seen that R123 yields the best exhibition among the three working liquids utilized in the examination. A. Giovannelli et al [4] researched mathematically the performance of a radial turbine at full & partial loads for waste heat recovery Organic Rankine Cycle power plant involving R123 as working liquid. Because of the low working temperature associated with ORC plants, the productivity would be exceptionally low, and henceforth to augment plant proficiency the turbine ought to be planned with greatest execution at full and halfway loads.Simone Lion et al [5] explored the different innovations used to recuperate the waste hotness from marine diesel motors. Furthermore presumes that the Organic Rankine cycle recuperates greatest hotness from the exhaust gases further developing the framework proficiency and furthermore very unwavering quality.

III. ANALYSIS OF TURBINE PARAMETERS

In the present study, a 1.5 stage axial turbine (with the turbine rotor interspaced between two stators) utilizing waste heat from the marine diesel engine is considered for investigating performance using ANSYS CFX. Simulations are carried out with rotor speed varying from 1000 RPM to 8000 RPM with turbine inlet pressure kept constant at 4 Bar. The inlet temperatures are varied from 673 K to 618 K at 44 Kg/Sec mass flow rate and 523 K at 26 Kg/Sec. Numerical investigation is considered for effective utilization of waste heat from exhaust gases of 2 - stroke and 4 - stroke marine diesel engines (MDE) of a container ship. The detailed specifications of the container ship MDEs are presented below.

Table 1.Container Ship Parameters

Type	Bulk carrier value
Size (at scantling draught) (m)	55,000
Length between perpendiculars (m)	185
Breadth (m) 32.0	32.0
Draught (scantling) (m) 12.5	12.5
Vessel speed (knots) 14.5	14.5

Table 2.Marine Diesel Engine Parameters

Engine Parameters	Two-Stroke Engine	Four-Stroke Engine
Bore (mm)	500	460
Stroke (mm)	2000	580
Brake power at Maximum Continuous Rating. (kW)	8815	8775
Engine speed at Maximum Continuous Rating (r/min)	122	500
Specific Fuel Oil consumption at Maximum Continuous Rating (g/kW h)	171% ± 5 %	183% ± 5%

A. *Flow Coefficient*

The flow coefficient is defined as the ratio of the actual velocity of the working fluid at the rotor inlet to the blade speed. Normally flow coefficient value varies from 0.5 to 1.1.

$$\phi = \frac{V_{f1}}{U}$$

Where,

Symbol	Parameter	Units
ϕ	Flow coefficient	Dimensionless
V_{f1}	Actual velocity at the rotor inlet	m/s
U	Rotor blade speed	m/s

The flow coefficient is calculated for the turbine speed of 1000 RPM at a mass flow rate of 44 Kg/Sec at 673 K temperature.

V_{f1}=Actual velocity at the rotor inlet= 95.3 m/s

U =Rotor blade speed = 43.9 m/s

$$\phi = \frac{V_{f1}}{U} = \frac{95.3}{43.9} = \underline{\mathbf{2.17}}$$

Table 3.Flow coefficient at 673 K and 44 Kg/Sec

Speed (RPM)	Power (MW)	Isentropic Efficiency (%)	Flow Coefficient
1000	0.729	42	2.17
2000	1.184	65	1.06
3000	1.432	75	0.74
4000	1.537	79	0.517
5000	1.498	78	0.413
6000	1.321	71	0.345
7000	1.015	57	0.298
8000	0.578	52	0.285

In the above table, the various values of flow coefficient are noted down along with the isentropic efficiency calculated at different turbine speeds but same temperature i.e at 673 K and mass flow rate of 44 Kg/Sec.

B. Nozzle Loss Factor

Nozzle loss factor (ζ_N) is characterized as the proportion of adiabatic enthalpy loss in the stator outlet to the rotor exit velocity. Nozzle efficiency in a turbine is defined as proportion of genuine enthalpy drop to isentropic enthalpy drop. Let it be taken as 'X' here to evaluate the Nozzle loss factor.

Stator -1 exit velocity = V_2 m/s

Static enthalpy at stator-1 inlet = H_{STIN}, J /Kg

Static enthalpy at stator-1 outlet = H_{STOUT}, J/Kg

Difference in enthalpy = Y = H_{STIN} - H_{STOUT}, J/Kg

Adiabatic difference in enthalpy = $\frac{Y}{X}$

Adiabatic enthalpy at stator outlet = Z = H_{STIN} - $\frac{Y}{X}$

$$\zeta_N = \frac{H_{STOUT} - Z}{(\frac{1}{2}V_2^2)}$$

For 1000 RPM, at temperature of 673 K and 44 Kg/Sec mass flow rate

Nozzle efficiency = X = 93.16 %

Stator -1 exit velocity = V_2 = 288.9 m/s

Static enthalpy at stator-1 inlet = H_{STIN} = 400986 J /Kg

Static enthalpy at stator-1 outlet = H_{STOUT} = 361253 J/Kg
Difference in enthalpy = Y = H_{STIN} - H_{STOUT} = 400986 - 361253 = 39715 J/Kg
Adiabatic difference in enthalpy = $\frac{Y}{X}$ = 39175/ 0.931 = 42704 J/Kg
Adiabatic enthalpy at stator outlet = Z = H_{STIN} - $\frac{Y}{X}$ = 400986 - 42704 =358281 J/Kg

$$\zeta_N = \frac{H_{STOUT}-Z}{(\frac{1}{2}V_2^2)} = \frac{361253-358281}{0.5*288.9^2} = \underline{\mathbf{0.0699}}$$

Table 4: Nozzle Loss Factor values at different turbine speeds, temperatures and mass flow rates

SPEED (RPM)	673 K 44 Kg/ Sec	653 K 44 Kg/ Sec	628 K 36 Kg/ Sec	618 K 44 Kg/ Sec
1000	0.0699	0.0698	0.0697	0.0696
2000	0.0686	0.0685	0.0684	0.0683
3000	0.0681	0.0680	0.0679	0.0678
4000	0.0673	0.0672	0.0670	0.0669
5000	0.0671	0.0670	0.0669	0.0668
6000	0.0675	0.0674	0.0673	0.0672
7000	0.0685	0.0684	0.0683	0.0682
8000	0.0696	0.0695	0.0694	0.0693

The above table shows the variation of the Nozzle loss factor concerning the change in temperature and mass flow rates recorded at different speeds of the turbine.

IV. RESULTS AND DISCUSSIONS

A. *Flow Coefficient Vs Rotor Speed*

In the fig.1, a red line is depicted which demonstrates the Flow coefficient conduct concerning the adjustment of speed from 1000 RPM to 8000 RPM at the temperature of 673 K and mass stream pace of 44 Kg/Sec

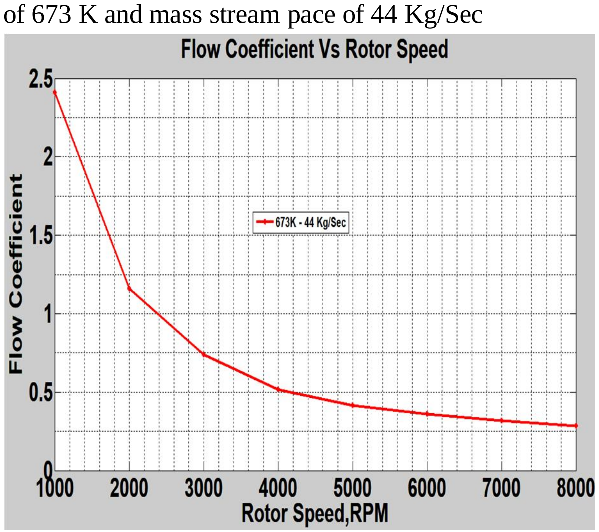

Fig.1.Flow Coefficient Vs Speed

In fig.2 similar conditions were taken, though here the red line demonstrates the isentropic productivity and the blue line showed the Flow coefficient noted at a similar mass stream pace of 44 Kg/Sec and temperature of 673 K at different turbine speeds going from 1000 RPM to 8000 RPM.

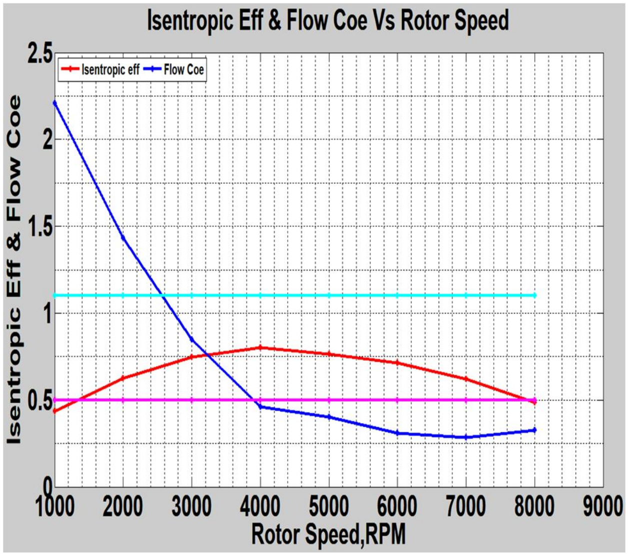

Fig.2.Isentropic Efficiency and Flow Coefficient Vs Rotor Speed

Flow coefficient is the ratio of meridional velocity of working fluid at rotor inlet to the blade speed. As blade speed increases the meridional velocity also increases in a lesser proportion. At lower blade speeds rapid decrease of flow coefficient is observed, and at speeds beyond 4000 RPM flow coefficient remains more or less constant up to 8000 RPM. The upper and lower boundaries for flow coefficient are 1.1 and 0.5 (indicated by Cyan and Magenta lines) cuts the efficiency line between 2800 RPM and 4000 RPM. Hence the useful range of flow coefficient falls between 70% to a maximum of 78% efficiency.

B. Nozzle Loss Coefficient Vs Rotor Speed

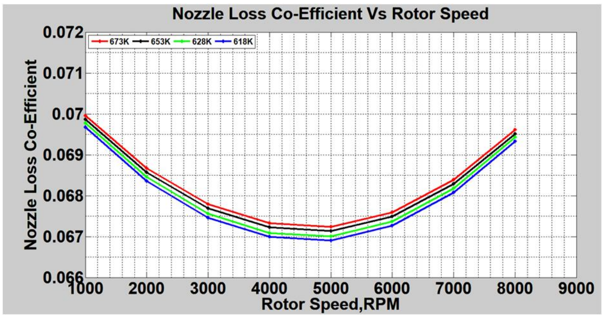

Fig.3.Nozzle Loss Coefficient Vs Rotor Speed

Nozzle Loss Coefficient (NLC) represents the deviation of the actual process with the isentropic process in a stator blade of the turbine. The NLC tends to be zero as the above deviation becomes smaller and smaller. It is seen that the variation of NLC is very small (the difference between the maximum and minimum value is only 0.003) indicating that the actual process in the stator blade is not affected by rotor speed and the inlet temperature of the exhaust gases from the marine diesel engine.

V. CONCLUSIONS

1) The Flow coefficient is observed with an acceptable range between 0.5 to 1.1 which cuts the efficiency line between 2800 RPM and 4000 RPM, corresponding to 70% to 78% efficiency. Hence it is concluded that at this particular point, the flow coefficient is maximum.
2) The NLC tends to be zero as the deviation becomes smaller and smaller. It is also observed that the variation of Nozzle Loss Coefficient is very small and the difference between the maximum and minimum value is only 0.003.
3) The numerical solutions demonstrate that the actual process in the stator blade isn't impacted by rotor speed thus it is free of the gulf temperature of the exhaust gases from the marine diesel engine.

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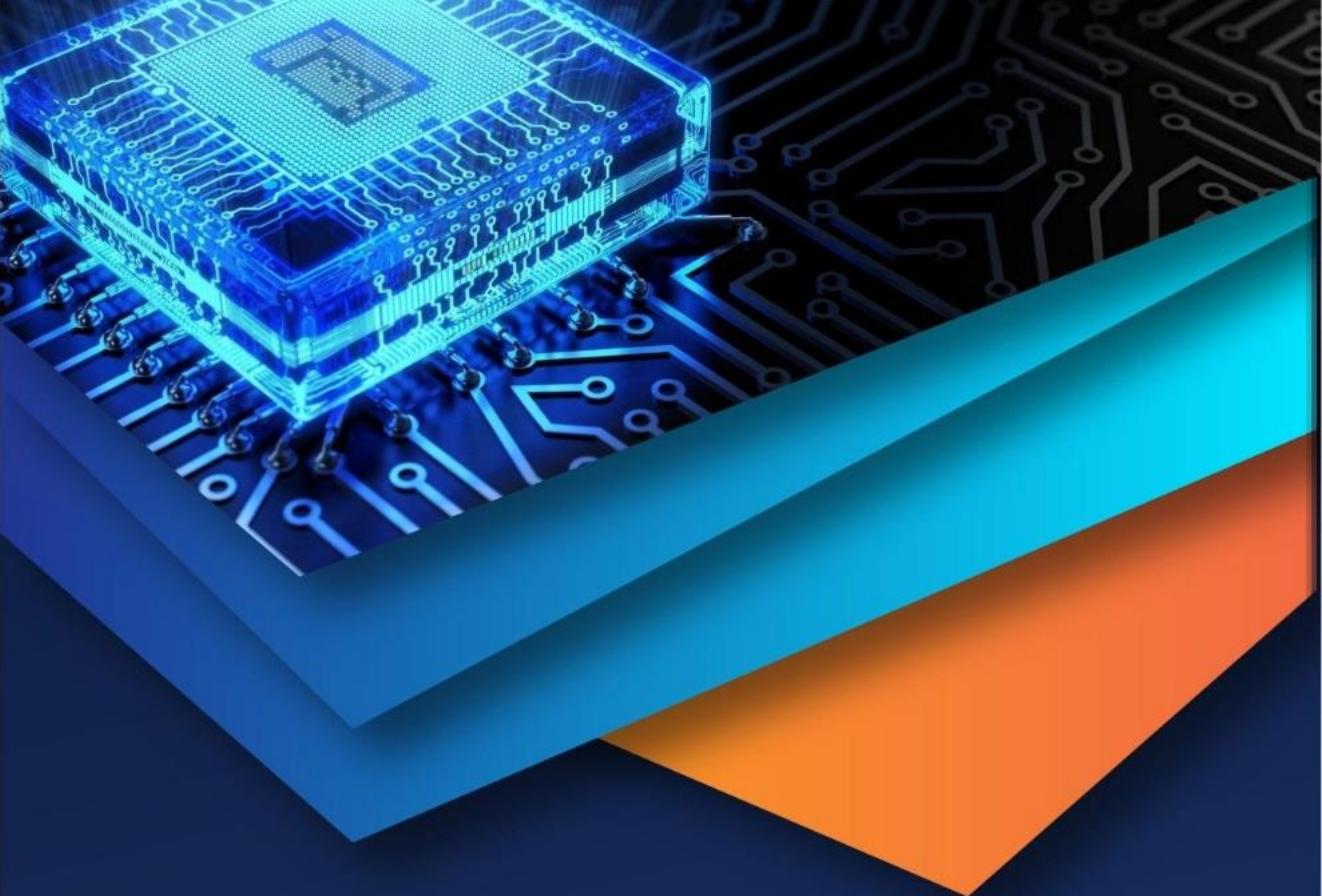

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