Conditions Affecting the Propeller-Engine Dynamics of a Marine Vessel

Ronak Prasad Dhongde[1], **Anuj Ambrish Shahade**[2]

[1]Mechanical Engineering, SmtKashibaiNavale College of Engineering

[2]Mechanical Engineering, PVG's College of Engineering and Technology

rounakdhongde@yahoo.com, shahade.anuj@gmail.com

ABSTRACT

Ship structure vibrations are caused by a complex combination of different hydro dynamical and mechanical effects. The main source of the hydrodynamic ally excited vibrations is propeller. Determination of loads on marine propeller is one of the important and challenging problems for the prediction of hull structure and propulsion shafting vibration. The main source of the propeller excited vibrations is the unsteady loading, which results from the rotation of the propeller through non stationary and non-uniform wake. The non-uniformity of the wake is the dominant effect for the vast majority of ships. Classical engineering methods of the marine propeller forces calculation are based on this effect, approximately assuming the velocity field to be stationary.Cavitation has posed limits in propeller performance ever since sufficient power was available at the shaft. It started out with severe loss of thrust, due to the formation of large pockets of water vapour, where the local pressure dropped below the vapour pressure. Due to extensive research and practical experience this can be avoided by careful propeller design. The demand for efficient propulsion has led to the acceptance of moderate forms of cavitation on propellers. This requires detailed understanding of the limiting effects of cavitation nuisance. Erosion can occur when vapour volumes violently implode on a propeller or hull surface. This is addressed by altering the overall propeller geometry, as seen on most modern propellers. As the leading edge of the propeller is swept back in the rotation direction, the sheet cavity is transported into the tip vortex, away from the propeller surface.

Keywords***: Propeller power fluctuations, turbo-lag, cavitation, tip-vortex cavitation.***

---

1. EFFECT OF WAVES ON ENGINE PROPELLER DYNAMICS

If the wake is steady the variations of forces and moments are strictly periodical. In mechanics, such processes are referred to as periodic rather than unsteady. The non-stationarity of the wake plays more important role for ships with large block coefficients (the full-bottomed ships) and is far less studied. The wake of full-bottomed ships contains complicated vortex structures which amplify the unsteady effects in wakes. The existing engineering methods do not take the non- stationarity of the wake into account due to the difficulties connected with its determination. From the measurement point of view it is a big challenge to measure the unsteady velocities in the wake using traditional techniques like the Pitot tube.

Wake field is one of the important inputs required for the propeller design and performance estimation. Therefore, to study the effect of waves on propeller performance, it is essential to know the wake field in waves.The data for wake in waves is obtained from particle image velocimetry (PIV) which is validated with the CFD simulations (CFD and PIV are available only for head sea conditions).

1.1 Engine considerations and analysis

The purpose of the engine system model here is: (1) to provide dynamic shaft torque and (2) to predict the cycle efficiency of the engine under transient conditions. The transient load from the propeller tends to change both torque and speed, causing highly nonlinear behaviour of the system. Therefore, the engine system model should include the physical process of the essential components of the engine system, namely turbo charger, air coolers, air/exhaust receiver volumes and engine cylinder blocks in order to predict nonlinear and transient aspects of engine operation. The physical interface of the system is through the mechanical shaft where rotational speed is input to the engine model and torque is output. In addition, the engine model takes inputs from the engine controller, which is fuel rack position, valve timing, and injection timing. The engine system model was then validated against the steady state performance data provided by the engine manufacturer. From numerous simulations, we found that brake specific fuel consumption (BSFC) is well-correlated with maximum cylinder pressure. As the combustion profile described by the Wiebe function is fixed, we could control the maximum cylinder pressure by changing exhaust valve close (EVC) timing and fuel injection timing. Quick exhaust valve closing will result in apparent compression ratio high and vice versa. Also retarded fuel injection may be enabled keeping high compression ratio without exceeding permissible maximum cylinder pressure. Here, a controller was devised to get a reference maximum cylinder pressure from comparison of measured BSFC and the reference value. While the firing pressure, which is the pressure differential between maximum cylinder pressure and compression, was kept constant by maintaining the fuel injection timing, the compression pressure was maintained at the reference value by regulating exhaust valve timing. The turbo charger shaft inertia has significant influence in case of a large step change in speed command because of the smoke limiter. This additional controller limits the fuel rack position depending on the charge air available in the cylinder. The amount of charge air available is predicted from the scavenge air receiver pressure and the volumetric efficiency of gas exchange process. As the rate of pressure development for load increases delayed due to inertia of the turbocharger and filling the receiver volume, the fuel rack position from the governor saturates by this limit. This phenomenon is commonly referred as “turbo-lag”.

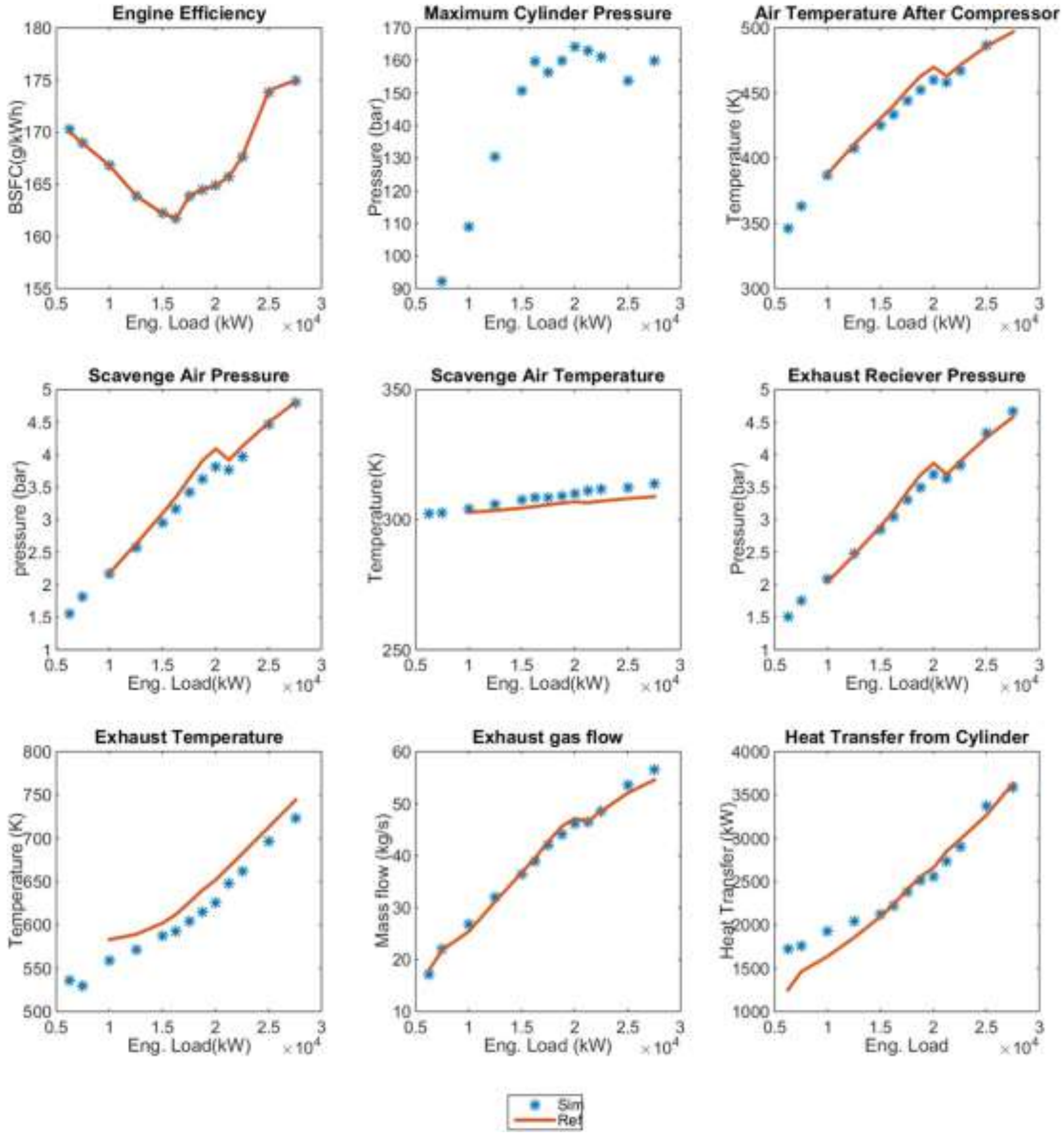

Fig-1 Steady state simulation of Diesel engine

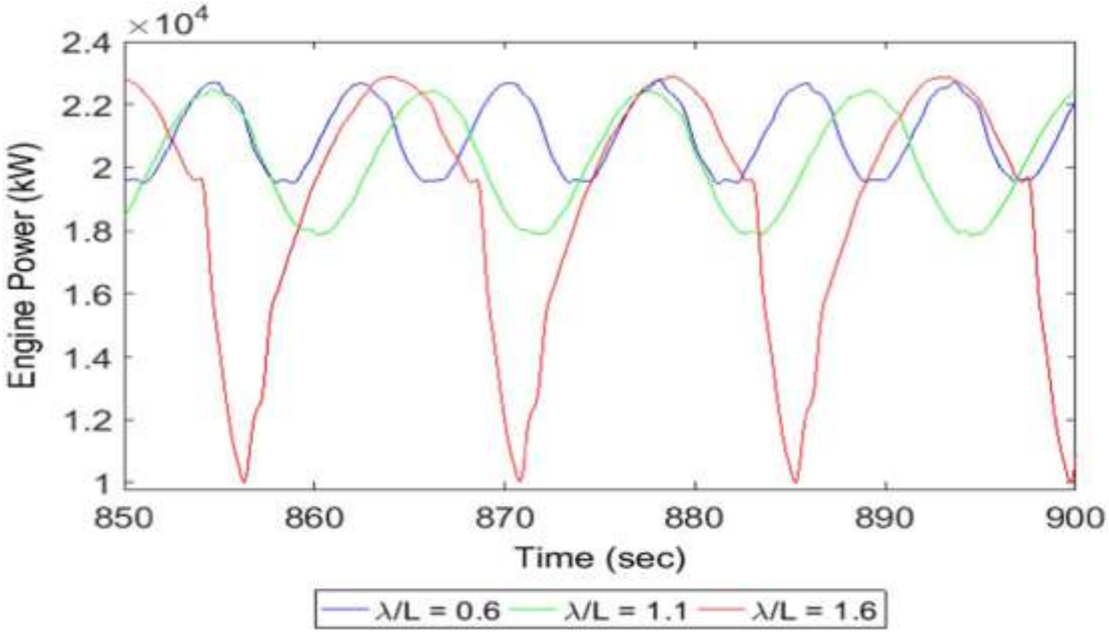

Fig-2 Low frequency engine power fluctuations in presence of three different head waves of 5m wave amplitude.

Power variation sinwave λ/L¼1.1arelarger as compared to those in λ/L¼0.6. This can be explained by the fact that larger wave sreach the propeller without much decrease in amplitude as compared to smaller waves. In case of λ/L¼1.6, distinct sharp peaks in shaft speed are caused by propeller emergence, causing sharp drops in torque.

1.2BSFC change as per conditions

Variation in BSFC in different conditions as a result of load fluctuations due to waves can be observed in Fig-3. In all the cases, change in BSFC is relatively small. As mentioned in the control part of the diesel engine, the cycle efficiency of the engine highly depends on the timing of the exhaust valve or, in other word, apparent compression ratio. Since the speed is controlled at a single reference value and the speed variations are relatively low, we could not observe meaningful deviation of the average cycle efficiency.

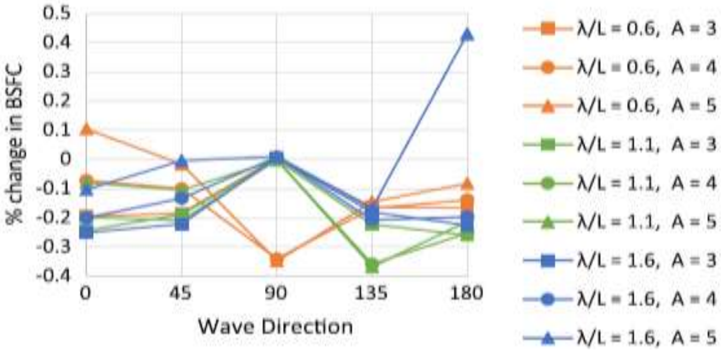

Fig-3Increase in engine BSFC due to time varying propeller torque in different waves.

2. CAVITATION

Large variations in sheet cavity volume are existing sources of high-amplitude pressure-fluctuations related to the blade passage frequency. Although quantitative estimation of the amplitude is still a challenge, there is a clear physical understanding of the mechanisms of this sound source. The shift of vapour from the propeller surface into the tip vortex has a significant side effect in the frequency content of the pressure fluctuations. The vapour volume oscillation is no longer solely related to the blade passage frequency,various studies have tried to model this problem experimentally with a fixed wing model in a cavitation tunnel. These experiments involved the measurement of sound from a steady tip vortex cavity. The scope of the present study excluded cavitation inception. Sound production mechanisms at inception are different from steady vortex cavity oscillations, and the interest is mainly limited to naval applications.

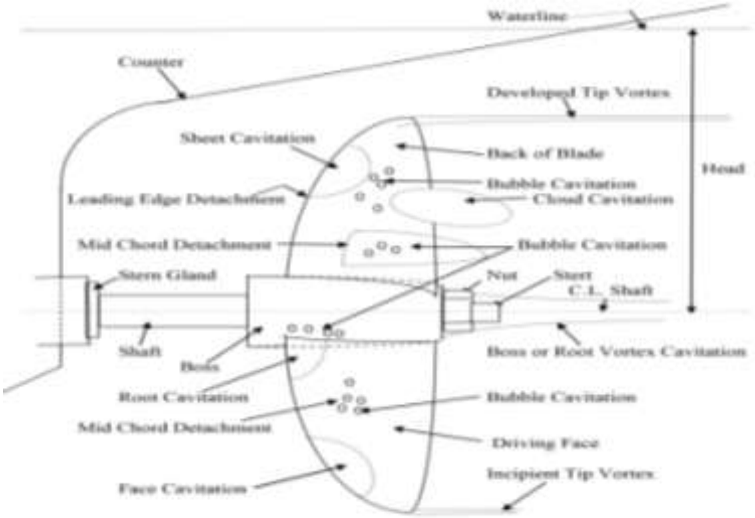

Fig-4 Propeller cavitation and its types.

In the preliminary stages the parameter space of the cavitation tunnel was explored. The first criterion that had to be met was to arrive at a moderate propeller Reynolds number. Full-scale propellers operate at significantly higher Reynolds numbers. Maximum propeller diameter and revolution rate were used to limit the scale effects of large chord-wise laminar boundary. This resulted in a limitation of the minimum advance ratio due to the maximum motor torque. The second criterion was a sufficient cavitation sound production. Only for the minimum advance ratio was sufficiently large range of cavitation numbers available for studying cavitation related sound. The tunnel pressure could only be reduced, and not increased, relative to atmospheric pressure. Therefore, at the chosen condition a steady tip-vortex cavity was always present at the highest cavitation number. This prevented a comparison to a sound spectrum of fully wet- ted flow. From steady tipvortex cavitation there was no significant sound production above the tunnel background. For study of tip vortex cavitation related sound a strong excitation is necessary. This was realized by a non-uniform inflow into the propeller, caused by a narrow wake.

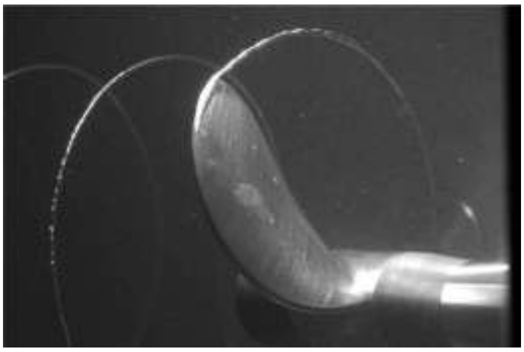

Fig-5 Image of cavitation on the propeller in uniform inflow. Conditions: $J = 0.56$, $K_T = 0.18$, $10\,K_Q = 0.27$, $Re = 6.6 \times 10^5$, $\sigma_n = 5.5$ and $DO = 2.3$ mg/l.

2.1 Methods of reducing cavitation

2.1.1 Nozzle system

As the name suggests, this system uses a set of nozzles to help reduce and prevent the possibility of cavitation in marine propellers. This system was developed by Samsung Shipping which is based in South Korea. To reduce the possibility of cavitation occurring in marine propellers, a set of nozzles are placed on the hull of the ship directly in front of the propeller. These nozzles spray out compressed air over the propeller that creates “a macro bubble”. This bubble completely surrounds the propeller that is in operation. With the differing characteristics of the seawater outside of the bubble and the air inside, a zone develops that has the ability to reduce the “resonance frequency”. Due to this reduction in resonance frequency, cavitation is less likely to occur during operation of a marine propeller.

2.1.2 Air filled rubber membrane

The Air-Filled Rubber Membrane works on the same principles as the Nozzle System to reduce cavitation in marine propellers. Since the Nozzle System requires a large source of energy to operate, here the system that has the same results but is cheaper to operate. The membrane is developedbased on the drawbacks observed during designing the Nozzle System and uses an envelope of air to prevent cavitation but does not require nozzles or compressors to do so. While at the same time as limiting the cost of operation, this membrane provides almost equivalent protection against cavitation as the nozzles do.

2.1.3 Materials used for Propellers

This solution focuses on the materials that marine propellers are created from which is a major factor in cavitation. The most common material marine propellers are created from is blend of nickel aluminum bronze. This blend can resist erosion but cannot properly handle cavitation.

However, this is beginning to change. The Royal Netherlands Navy is conducting experiments with composite materials like resins or carbon fiber. These materials, when formed into a propeller, are flexible enough under pressure to deflect which can help reduce cavitation. Materials like carbon fiber, epoxy resin, or even glass, are able to produce a hydro elastic effect. Since these new propellers can flex and are not rigid under pressure, the risk of cavitation is reduced.

3. CONCLUSION

Here, an effective method for modelling wake in waves has been demonstrated which enables us to study different aspects of the propulsion system in time varying wake in waves of different wavelength, wave height and wave direction. It has been shown that engine propeller response i.e. power fluctuations, propeller speed fluctuations and torque fluctuations can be obtained through coupled simulations by using actual scale engine and propeller models. Therefore, the frame work of coupled system described here can be used to investigate engine load variations, propeller loads in waves, shaft vibration and engine control system. It is capable of analysing the performance as well as safety of a control system used for controlling the engine.

Also to enhance the efficiency of propulsion along with proper design of propeller the material of the same must be taken into consideration, Emergence of propeller, low resistance to cavitation, high acoustic print of propeller in the ocean, diameter of cavitation cavity, etc. are the all factors that vary the effect of cavitation. The tip vortex formation in various wake regions like wake inflow and uniform wake also affects the cavitation number thus ultimately affecting the cavitation experienced by the marine vessel.

REFERENCES

[1] Bhushan Taskar, KevinKoosupYum, SverreSteen, Eilif Pedersen (2016) The effect of waves on engine-propeller dynamics and propulsion performance of ships, 2016ElsevierLtd. Department of Marine Technology, Norwegian University of Science and Technology (NTNU), Trondheim, Norway. Journal homepage : www.elsevier.com/locate/oceaneng. B.Taskar etal./OceanEngineering 122 (2016) 262–277. Pg no.: 263, 268, 269, 270, 271, 273, 275.

[2] Pepijn Pennings, Jerry Westerweel , Tom van Terwisga (2016) Cavitation tunnel analysis of radiated sound from the resonance of a propeller tip vortex cavity. Delft University of Technology, Department of Mechanical, Maritime and Materials Engineering, Mekelweg 2, Delft 2628 CD, The Netherlands. journal homepage: www.elsevier.com/locate/ijmultiphaseflow. Page no.: 1, 3, 4, 7, 8, 10

[3] N.Abbas, N.Korneva, I.Shevchuka, P.Anschau (2015)CFD prediction of unsteady forces on marine propellers caused by the wake non uniformity and non stationarity.