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Vibration control by propeller design

L. Bodger[a,*], S. Helma[a], N. Sasaki[b]

[a] Stone Marine Propulsion Ltd, Birkenhead, UK
[b] Newcastle University, Newcastle Upon Tyne, UK

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ABSTRACT

Propeller research has generally been focussed on improving the open water efficiency, and by considering the various energy losses associated with the marine screw propeller, it can be seen that for a design brief with given main engine power and RPM input, plus a thrust requirement defined by the specified ship speed, the most fruitful area for improvement in efficiency by propeller design is a reduction in energy losses. The simple way to increase the efficiency is reduction of blade area, increasing load near the tip and adopting a larger diameter with low RPM. However, vibration and noise will be the first issues when a designer tries to increase the efficiency of the propeller by these ways. This paper will present a simple prediction method of pressure fluctuations induced by thickness, propeller loading and unsteady cavitation taking not only propeller dimensions but also stern shape into account at the beginning of the propeller design.

1. Introduction

Energy loss of propellers can be explained as follows (Glover, 1987);

The axial kinetic loss results from the acceleration of the fluid necessary to produce the propeller thrust and is fixed for a given propeller loading condition.

The rotational kinetic loss derives from the swirl induced in the fluid by the rotation of the propeller.

The viscous loss depends upon the profile drag originating from the viscous drag of wing sections.

Viscous losses are largely associated with the surface area of the blades which is in turn associated with the need to avoid the harmful effects of cavitation. The original NPT (New Profile Type) research led to the development of an aerofoil profile type with low drag characteristics coupled with excellent cavitation properties. The superior cavitation properties permitted the adoption of lower blade surface areas than those required by traditional designs and thus reduced the frictional losses of the propeller as a whole. NPT propellers designed according to this principle have proven to be very successful in delivering high propulsive efficiencies. In the last few years orders for over 150 NPT propellers have been secured by SMP, mainly for Far Eastern shipyards, with many vessels destined for Western owners.

One interesting characteristic of the NPT design was that the adoption of the new profile family reduced the optimum diameter below that of the optimum diameter of conventional propellers designed for the same installation.

This had a number of immediate benefits: reduced propeller weight and inertia; reduced propeller cost; improved shafting dynamics; and improved clearances between the blade tips and the hull.

However, it became clear that the reduced diameter gave rise to other benefits in terms of the propeller hull interaction factors, which along with the propeller open water efficiency make up the overall propulsive efficiency as in Eq. (1).

$$\eta_D = \eta_O \frac{1-t}{1-w_T} \eta_R \tag{1}$$

where

η_0 = Propeller open water efficiency
η_R = Relative rotative efficiency
t = Thrust deduction factor
w_T = Mean wake fraction.

Associated with the reduced propeller diameter is an increased propeller pitch necessary to ensure that the propeller absorbs the main engine power at the correct RPM. The increased pitch has the effect of reducing the thrust deduction factor.

Also, the reduced propeller diameter means that the blades are operating in a region of higher wake fraction which enables increased energy recovery from the vessel's boundary layer.

From Eq. (1) it is evident that these effects further increase the overall propulsive efficiency of the vessel.

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[*] Corresponding author.
E-mail address: lb@smpropulsion.com (L. Bodger).

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It also became clear that in addition to improved overall efficiency the excellent cavitation performance and the reduced diameter of the NPT designs had further benefits in terms of a reduction in the excitation forces on the hull (Fig. 1).

2. Vibration control by propeller design

In order to fully exploit the potential for improved overall efficiency and reduced excitation forces the NPT design method was expanded into a more holistic approach where interactions with the hull and effects on the hull were taken into account at an early stage in the propeller design process – see Figs. 2 and 3.

Introducing the extended NPT propeller design process into the ship design process at an early stage enables the shipyard to take into account the enhanced overall propulsive efficiency in the selection of the main engine rating.

Furthermore, the ship designers will have a reasonable estimate of the cavitation performance of the propeller and estimates for excitation forces with their intended hull form, thus allowing potential problems and possible solutions to be investigated at an early stage. By this means the propeller design becomes fully integrated into the ship design and if necessary the propeller design may be adapted to control hull vibrations.

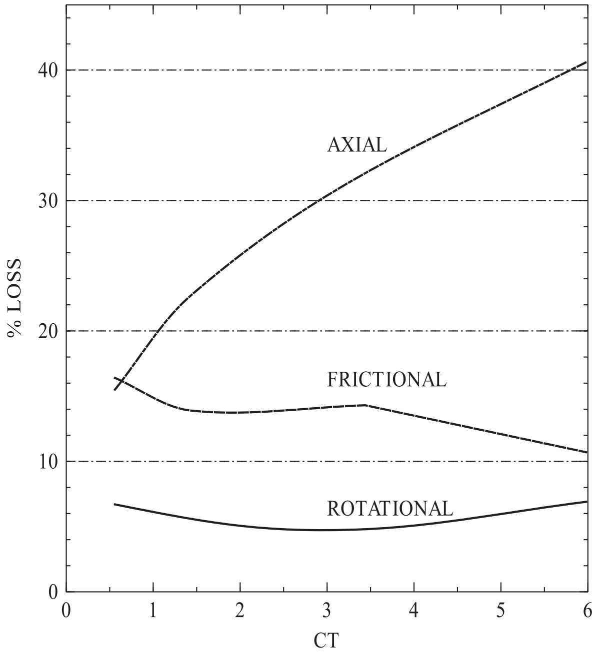

Fig. 1. Energy losses from the propeller.

In this context, the characteristics of any particular NPT propeller can be exploited in a compromise manner along a continuum, with highest efficiency at one end and best cavitation performance at the other end, depending upon the particular demands of each ship design case. The enhanced efficiency of the NPT propeller means that even in those cases where some efficiency has to be sacrificed to achieve the required vibration levels, the overall propulsive efficiency will usually be better or at least no worse than with a conventional propeller optimised in terms of efficiency.

An important part of the extended NPT design process is the ability to estimate the level of pressure impulses on the hull before finalising the design and submitting it for evaluation by model testing.

Such a procedure has been developed and the results from its application have shown very good agreement with the predictions made from model experimentation.

Eq. (2) gives an overview of the methodology.

$$K_{PZ} = \sqrt{{K_{P0}}^2 + {K_{PC}}^2 + 2K_{P0}K_{PC}\ \cos(\pi - \varphi Z)}$$
$$K_{PC} = 0 \quad if \quad \sigma \geq \sigma_{CR} \tag{2}$$

where K_{P0} is non-dimensional pressure fluctuations induced by blade thickness and blade lift force, K_{PC} is non-dimensional pressure fluctuations induced by cavitation occurrence. The angle φ is the phase difference between K_{P0} and K_{PC} , and Z is the number of blades. σ_{CR} is the critical cavitation number for the cavitation inception. Full details of the calculation procedure have previously been presented by Sasaki while a brief review is given in Appendix (Sasaki and Nagamatsu, 1984) of this paper.

2.1. *Example Case 1 (PCTC)*

A good example of its utility was provided by the case of a series of PCTCs built in a Far Eastern shipyard. Preliminary model tests with a stock propeller revealed that the achievement of the contract speed presented a significant challenge. The shipyard appreciated that the final design propeller would have to deliver a high efficiency whilst at the same time avoid exciting the aft end vibration to which this type of ship can be prone.

In order to satisfy the demanding specification the decision was made to fit an NPT propeller.

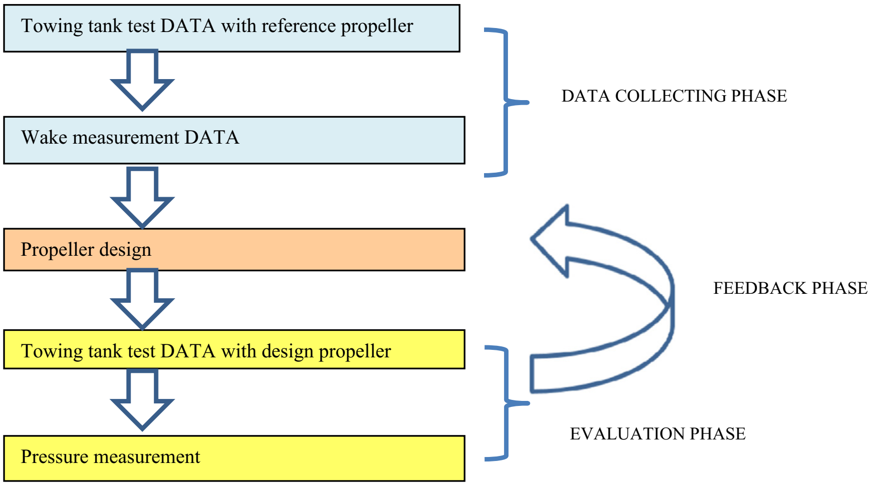

Fig. 2. Original design process for the NPT propeller.