HYDREX WHITE PAPER N°10

WHITE PAPER

Ship Propeller Maintenance Optimum Solutions

An easy way to save 5-15% of your ship's fuel costs without harm to the environment

The Hydrex Group
www.hydrex.be

UNDERWATER TECHNOLOGY

Part I. Introduction

The propeller is by far the most prevalent means of ship propulsion. Invented some time in the late 1700s or early 1800s (its origins are contested), nearly all modern ships rely on this handy device to make any progress through the water at all.

The propeller blade functions much like an airfoil, developing thrust as a result of the pattern of flow around the blade. As the propeller turns, the blades create a pressure differential in the water which propels the ship forwards or backwards depending on which way the propeller is turning and/or the pitch of the blades (some propellers have fixed pitch and others variable pitch).

Although the surface area of the propeller is minuscule when compared to that of the entire hull, the effects of a rough propeller on the vessel's fuel consumption is comparatively large. On the other hand, the cost of remedying a rough propeller compared to that of remedying a rough hull is very slight. Thus remedies for a rough propeller are not only simple and quick to execute, they also represent a fast, high return on investment.

Thus remedies for a rough propeller are not only simple and quick to execute, they also represent a fast, high return on investment.

Propeller blades can be rough for a number of reasons. New propellers can be relatively smooth or rough as a result of their manufacture. They invariably become rougher during service as a result of cavitation damage to the metal surface itself, calcium deposits, mechanical damage and marine fouling, including slime, algae, barnacles, tube worms and other marine organisms as with the ship's hull in general.

Propellers can be cleaned or polished in the water or in drydock. Badly done polishing with a polishing disc or grinding wheel can in itself create a rougher surface than that of the new propeller, leaving scratches which not only increase the propeller's roughness but also invite easier attachment of fouling organisms. On the other hand, well-executed cleaning or polishing can restore the propeller's smooth surface and hydrodynamic properties.

If a propeller is allowed to become fairly rough, then restoring it to its original state (or close to it) requires grinding away a considerable amount of the material itself, mostly copper but also zinc, nickel and other metals from which the propeller is made. While the amount of material removed from a single propeller may be relatively small, when this is multiplied across all the propellers used in the entire world fleet, this polishing can represent a significant emission of heavy metals and thus pollution and contamination of water column and sediment which cannot be ignored.

The rougher a propeller is allowed to become before the condition is remedied, the more rapidly further roughness will accrue. It is an accelerating downward spiral.

Caught early enough, the propeller can be buffed by divers using special tools, removing almost no metal, preventing the effects of cavitation damage from spiraling and avoiding the formation of calcium deposits. This early attention can speed up the cleaning process considerably, extending the useful life of the propeller and preventing the emission of heavy metals into the water and sediment.

Economically, the fuel saving from the more frequent cleaning of a propeller before it has become seriously fouled and rough greatly outweighs the cost of the buffing itself. This propeller buffing can be combined with a general hull inspection by divers making it even more economically viable.

While most ship propellers are bare metal, some experimentation has been carried out to try to remedy some of the propeller's inherent problems through the application of various coatings. While no universal, fully workable and tested solution has yet been placed on the market, this line of research shows promise.

This current White Paper is a practical look at ship propeller maintenance, aimed at greater fuel economy for shipowners and operators while also taking into consideration the environmental impact caused by this maintenance. The subject of propeller coating is not dealt with in this White Paper.

Part II. Propeller problems

The problem of propeller roughness has been well researched and documented, not only in its nature but also in terms of the different causes of the roughness and of the effects that varying degrees of propeller roughness have on vessel fuel efficiency.

> Ships with rough hulls often also have rough propellers, although the causes of the surface deterioration are different. Most attention has been given to the hull roughness problem however. It has often been cited that a rough hull condition is the cause of reduction in performance in ship operation. However, in practice a significant contribution to the reduction in performance may well be as a result of the propeller roughness. Alternatively, in absolute terms, propeller roughness is less important than hull roughness, but in terms of energy loss per unit area, propeller roughness is significantly more important. In economic terms, high return of a relatively cheap investment can be obtained by propeller maintenance standards.[1]

Causes of propeller roughness

There are a number of reasons why propellers can be rough and get rougher in service.

- manufacture
- marine fouling
- calcareous deposit (chalk layer)
- impingement attack
- corrosion
- cavitation erosion
- mechanical damage from impact with objects
- improper polishing or cleaning

These different causes tend to work in concert, with each source of roughness complementing the other sources and accelerating the propeller's decline in overall smoothness. Conversely, properly taking care of one source of roughness will help to diminish the effects of the others.

Manufacture

The material used to make the propeller can have a significant bearing on the propeller's smoothness or roughness when new and during service, as can the method and standard of manufacture.

Today, propellers are made from bronzes or stainless steels. Cast iron has virtually disappeared from use. For the last 20-30 years nickel-aluminum bronze has become the material of choice and now accounts for over 80% of the propellers made. High-tensile brass, also known as manganese-bronze is used for a small percentage of propellers and manganese-aluminum bronze a similar small percentage. Stainless steels are used for a very small percentage of propellers, mostly ice class propellers.[2]

Manganese bronze propellers have been found to be considerably rougher than those made of nickel-aluminum bronze.[3]

Inherent roughness is, however, far from the only characteristic used to evaluate the usefulness of an alloy for propeller manufacture since the propeller must be strong, relatively light, resistant to corrosion and cavitation erosion as well as suitable for casting and for repair.

1 Mohamed Mosaad, "Marine Propeller Roughness Penalties," PhD Thesis, University of Newcastle upon Tyne, August 1986, p 1.
2 John Carlton, Marine Propellers and Propulsion (Second Edition), Butterworth-Heinemann Elsevier, (2007), p 383.
3 Mohamed Mosaad, "Marine Propeller Roughness Penalties," PhD Thesis, University of Newcastle upon Tyne, August 1986, p 40.

Impingement attack

A ship's propeller travels at relatively high speed through the water. The tips may be traveling (in circular motion) at 100 kph or faster. Ocean water is far from pure. It contains abrasive particles. The impingement attack is by these abrasive particles as they come in contact with the leading edge region of the propeller, particularly the outer tips furthest from the hub, where the speed is greatest. [4]

Impingement attack results in general increased roughness over a fairly large area of the propeller. As with the other sources of propeller roughness, this roughness is an accelerating downward spiral. The rougher the propeller gets, the more effect the impingement attack has.

Corrosion

The propeller is subject to both chemical and electrochemical corrosion. Almost all propellers in use are uncoated, unpainted, bare metal.

The moment the propeller is immersed in water it becomes the cathode in the hull-propeller electrolytic cell.

The moment the propeller is immersed in water it becomes the cathode in the hull-propeller electrolytic cell. The electrolysis as well as the simple chemical effect of saltwater on the bronze or other alloy, form a dual corrosive source.

The electrolytic corrosion in particular ties in with the next item on the list of sources of roughness which is the calcareous deposit.

Calcareous deposits

After a while in the water, propellers develop a tenacious, hard, rough layer of calcareous chalk. This phenomenon is explained as follows by Dr. Geoffrey Swain, Professor of Oceanography and Ocean Engineering at the Florida Institute of Technology.

It is indeed calcareous chalk produced as a byproduct to the cathodic protection system. Ships usually have sacrificial zinc or impressed current anodes that generate electrons that flow to areas of paint damage on the hull and the propeller and prevent corrosion. This causes the areas of bare metal to become cathodic and in so doing reduce oxygen and water to hydroxyl ions that react with calcium, magnesium and carbon dioxide to form calcium and magnesium carbonates (chalk). The chalk deposits add protection to the

The leading edge is particularly subject to impingement attack, especially nearer the tips which travel the fastest.

4 John Carlton, Marine Propellers and Propulsion (Second Edition), Butterworth-Heinemann Elsevier, (2007), p 487.

> surface but also cause significant roughening. The amount, rate and type of deposit is dependent on cathodic current density and ambient seawater conditions. Chalks generally form faster in tropical waters.[5]

The propeller must be at rest for this deposit to form:

> The formation of a chalk film cannot occur while a propeller is rotating as it is necessary for the alkali to remain close to the cathodic propeller surface, at which it is formed, long enough to precipitate calcium and magnesium hydroxides, and for these to change to carbonates by absorption of carbon dioxide from the sea water.
>
> However, any period of inaction affords an opportunity for a chalk film to form over the whole propeller, and the waters of some harbors and docks are more conducive to film formation than others. While that on the outer parts of blades will normally be removed during the voyage and even be reformed thinly on each sojourn in port, nearer the blade roots the chalk deposit will build up, together with fixed corrosion product and is capable of increasing the corrosion rate of bare areas nearer the blade tips.[6]

In practice this layer of calcareous deposits can be quite hard and time consuming to polish off. As will be seen later in this paper, if propeller cleaning is frequent enough, the calcareous build-up is prevented or retarded and the propeller is much easier to keep clean and smooth.

Cavitation

It is beyond the scope of this White Paper to go into details on the physics of cavitation. However, a brief explanation is in order. Hydrodynamic cavitation is a phenomenon that accompanies turbulent fluids. The turbulence in the fluid, in this case caused by the propeller's motion through the water, results in areas of greatly reduced fluid pressure. Due to the low pressure, the water vaporizes. This causes small vapor-filled cavities or bubbles in the fluid up to about 3 mm in diameter. The cavities travel through the water and the pressure around them increases, causing them to collapse suddenly. The implosion of the cavities is accompanied by a complex set of physical processes. It is the collapse of the cavities which is accompanied by very high pressure pulses, speeds and temperatures in the water, that cause the damage to the metal surfaces where this collapse occurs.

The cavitation which can wear away parts of the propeller blades comes in different forms, but again, it is not necessary to understand the science behind the phenomena in order to appreciate that the damage can be extensive and expensive.

Cavitation erosion, electrolytic and chemical corrosion combine to multiply the damage to the propeller's surface and therefore the roughness of the blades.

It is not particularly useful to the ship-owner/operator or technical superintendent to be able to differentiate between roughness caused by cavitation erosion vs. chemical or electrochemical corrosion. Whatever the cause, the effects will be mitigated if the process is caught at early stages of development and addressed promptly with proper cleaning of the propeller.

It is more important for propeller de-

5 Dr. Geoffrey Swain, Professor Oceanography and Ocean Engeering, Florida Institute of Technology, personal correspondence, 16 March 2012.

6 G. T. Callis, "The Maintenance and Repair of Bronze Propellers," *The Shipbuilder and Marine Engine Builder*, March 1963, Reprinted in *Naval Engineering* Journal, August 1963, p 645

Cavitation damage affects specific parts of the propeller blades depending on where the cavitation occurs.

signers to make the distinction since all of these sources of roughness can be reduced through correct design and fabrication (and possibly coating) of the propeller in the first place.

Fouling

In the very able book, *Marine Fouling and Its Prevention* prepared in 1952 by the Woods Hole Oceanographic Institution for the Bureau of Ships, Navy Department, the problem of propeller fouling was addressed in some detail. (The numbers in parentheses refer to end notes in the book chapter but these notes have not been included here. The entire book can be found on line.)

The Effect of Fouling on Propellers

According to modern theory, the blade of a propeller may be likened to an airfoil which develops "lift" (thrust) as a result of the pattern of flow about the blade. Actually the decrease in pressure at the back of the blade can be demonstrated to be greater than the increase in pressure at its face (23). It is consequently to be expected that any condition, such as roughening of the surface by fouling, which disturbs the flow pattern will have a marked effect on the development of propulsive force.

Bengough and Shepheard (2) have described the case of the H.M.S. Fowey which failed to develop the anticipated speed on its initial trials. When subsequently docked, the propellers were found to be almost completely covered with calcareous tube worms. On the bosses the hard tubes were about 1 ¼ inches long. Toward the tips of the blades the fouling had been washed off during the trials. The condition of the bottom was good except for patches of worms about 2 inches thick where holidays had been left in the antifouling paint. (See Figure 14.) After cleaning, the trials were repeated and the anticipated speed was realized. While it is probable that the improvement was due to cleaning the propellers, the effects of the patches of fouling on the bottom can not be completely ruled out.

Speed trials of the destroyer *McCormick* indicate that about two-thirds of the increased fuel consumption due to fouling is due to its effect on the propellers. After 226 days out of dock the average fuel consumption required to maintain a given speed had increased to 115.8 per cent of the consumption with a clean bottom. After cleaning the propellers, the fuel consumption dropped to 105.5 per cent. Thus in seven months the propellers alone were responsible for a 10 per cent increase in fuel consumption (6).

…

Taylor (24) concludes that most ships operating with propellers in moderately good condition suffer an avoidable waste of power in the order of 10 per cent above that obtainable with new, accurately finished bronze propellers. It may be supposed that roughness of a grosser sort occasioned by fouling will produce much greater losses in efficiency, and will readily explain such results as those recorded for the *H.M.S. Fowey*. [7]

The following passage from the same book gives an idea of the type and extent of fouling which can occur on propellers and also of the vagaries of propeller fouling which can be attributed to the hydrodynamics of the rotation of the propeller and its shape.

Many organisms may be found fouling the propellers of active vessels. They include algae, barnacles, tubeworms, molluscs, and encrusting bryozoa (3, 22). Differences in the amount and type of fouling between the central and peripheral regions of the propeller have been noted. Sometimes only the central portion was fouled, while the outer ends of the blades were clean. In other cases serpulid tubeworms grew over all the blades, while barnacles were limited to the areas near the shaft. Sometimes only the bases of barnacles and oyster shells were present on the outer parts of the blades. One propeller was fouled by tubeworms, all of which were oriented with their mouths towards the axis (22).[8]

Mechanical damage (contact)

Due to its position and shape as well as its speed, the propeller is prone to damage from coming in contact with solid objects. Propeller blades can be bent, broken, cracked, scratched and dented and this will obviously affect the surface smoothness and the fuel efficiency of the propeller.

Improper cleaning or polishing

Whether performed in the water or in drydock, poor quality propeller polishing can result in increased roughness. When a ship is in drydock, the propeller can be subject to additional sources of roughness:

Poor quality grinding may worsen the blade roughness which will in turn cause an increase in high wavenumber rough-

7 Woods Hole Oceanographic Institution, *Marine Fouling and its Prevention*, US Naval Institute, (1952), pp 32-33

8 Ibid. p 231

ness due to scratching of the surface. At the same time, interference with the accurate dimensions of the blade leading edge form can seriously impair performance.

During hull painting, a propeller is always subject to splashes of conventional anti-corrosive or anti-fouling paints, which increase the surface roughness of the blade. Protection from grit-blasting should be given to the propeller by covering the blades with a layer of grease before the painting. This coating should be stripped off before the propeller goes into service.[9]

Summary

While there are many sources of propeller roughness many of them are difficult to separate out as they tend to work together, one source adding to the effects of another.

Some of these sources can be addressed independently. And all of them are decreased in their effect through early, frequent cleaning, as will be discussed below in this paper.

Effects of propeller roughness on ship propulsion and fuel consumption

It is rare to find fuel penalty figures for propeller roughness as distinct from hull

A lightly fouled propeller being cleaned by a diver.

9 Mohamed Mosaad, "Marine Propeller Roughness Penalties," PhD Thesis, University of Newcastle upon Tyne, August 1986, p 43-44

roughness. It is quite usual to find figures for combined hull and propeller fouling fuel penalties. Nevertheless there is data available which gives an indication of the fuel penalty associated with propeller smoothness or roughness on its own.

In the section above "Fowling" there is some indication based on actual observations of propellers in action. The destroyer *McCormick* is used as an example. In seven months out of dock the average fuel consumption to maintain a given speed was up to 115.8 per cent compared to unfouled hull and propeller. The propeller alone was cleaned and consumption dropped to 105.5 per cent, showing that the propeller fouling/ roughness alone resulted in a 10 per cent increase in fuel consumption.[10]

In his “Green ship of the Future Seminar” at Asia Pacific Maritime in Singapore in March 2010, Christian Schack of FORCE Technology presents the following statistics:

> Hull and Propeller fouling findings:
> - Annually fuel consumption of a Panmax containership is 30-40.000 mt equalling about USD 10 mill. 1% is a large number !
> - Fuel consumption due to hull fouling may increase as much as 15% at the end of a docking period
> - Additional fuel consumption due to propeller fouling may be up to 5-6%[11]

In Chapter 7 of *Advances in marine antifouling coatings and technologies*, edited by Claire Hellio and Diego Yebra, the authors, T. Munk and D. Kane of Propulsion Dynamics Inc. and D. M Yebra of Hempel, Spain, give the following estimates

> Estimates of increases in fuel consumption from biofilm attached to the hull alone range from 8% to 12%, and from normal propeller fouling range from 6% to 14% (Haslbeck, 2003).[12]

In that same chapter of *Advances in marine antifouling coatings and technologies*, the authors cite performance increases after propeller polishing on container ships

> At 24 knots, the propeller polishing at six-month intervals resulted in a fuel savings of five tons per day for each propeller polish, and the hull cleaning resulted in a fuel savings of approximately 12 tons per day. [13]

…the propeller roughness/fouling alone resulted in a 10 per cent increase in fuel consumption.

They conclude:

> Propeller polishing is a basic, low-cost strategy that saves fuel (Grigson, 1983; NEAA, 2007). [14]

The US Navy estimates that 50 per cent of fuel savings attained by full hull cleaning can be attributed to the cleaning of propulsors and shafts:

> 081-2.1.1.1 For hull cleaning and scheduling purposes, the following definitions apply:
> - FULL CLEANING: The term full cleaning refers to the removal of fouling from the entire underwater hull surface (i.e., painted surfaces), appendages, including propulsors and shafts, and openings.
> - INTERIM CLEANING: The term interim cleaning refers to the removal of fouling from propulsors, shafts, struts and rudders. Cleaning of other sub-

10 Woods Hole Oceanographic Institution, *Marine Fouling and its Prevention*, US Naval Institute, (1952), pp 32-33
11 Christian Schack, FORCE Technology (presentation) March 2010.
12 T. Munk, D. Kane, D. M. Yebra, “The effects of corrosion and fouling on the performance of ocean-going vessels: a naval architectural perspective,” Chapter 7 of *Advances in marine antifouling coatings and technologies*, edited by Claire Hellio and Diego Yebra, Woodhead Publishing in Materials, (2009) p 161
13 Ibid. p 167-169
14 Ibid.

> merged ship systems (i.e., openings, appendages) may occur during this period. Interim cleanings are normally scheduled for all ships between regular full cleanings to take advantage of the significant fuel savings benefits of operating with clean, smooth running gear, see Figure 081–2–1. Approximately 50 percent of the entire fuel savings benefit of cleaning an entire hull (that is, full cleaning) is attributable to the cleaning of propulsors and shafts. All ships, irrespective of the hull coating formulation, will benefit from routine interim cleanings and inspections.[15]

In *An Introduction to Dry Docking*, the following statement is made about propeller cleaning:

> Even a 1mm layer of accumulated fouling or calcium deposits on a propeller will significantly increase its roughness, and within 12 months or so can increase an ISO class I to an ISO class II, or a class II to a III. This causes large increases in fuel consumption. Practical figures and elaborate tests indicate a 6 to 12% gain in fuel consumption in polishing a propeller from a class III condition to a class I condition. Some propellers support marine growth up to 20 mm thick, which obviously has a major effect.[16]

This is the drydocking perspective where a vessel will not be drydocked more frequently than once a year (or less often), but experience with in-water propeller cleaning and polishing shows that the penalties mentioned accrue in much shorter periods than a year. [17]

Based on information available, it can be seen that propeller surface roughness from fouling, corrosion and erosion can cause a fuel consumption penalty of somewhere between 5 and 15 per cent.

Thus failure to maintain a ship's propeller is very expensive, especially at today's fuel costs.

15 Naval Sea Systems Command, *Naval Ships' Technical Manual* Chapter 081 "Waterborne Underwater Hull Cleaning of Navy Ships," Revision 5, 1 Oct 2006, 081-2.1.1.1

16 David Martin et al. *An Introduction to Dry Docking*, http://www.angelfire.com/rnb/drydocking/home.htm, accessed March 2012.

Part III. Current propeller maintenance practices

Shipowners/operators, technical superintendents and those responsible for keeping ships operating efficiently are aware of the fuel penalty associated with rough, fouled propellers and it is common for some maintenance measures to be in force to take care of this.

These measures consist of scheduled propeller polishing. Often this is done only when a ship goes to drydock. Since this might be every 2 ½ - 4 years, it is nowhere near frequently enough to keep a propeller operating at optimum efficiency.

Some vessel operators therefore schedule in-water propeller polishing, perhaps once or twice per year which in most cases is still not frequently enough.

The following excerpt from the Naval Ships' Technical Manual shows the approach taken by the US Navy to propeller maintenance (underlines added, not in the original)

> 081-2.1.1.2 Differences in ship employment schedules and geographic operating areas may require variations in cleaning scheduling intervals, however, full hull cleaning shall not be accomplished on intervals of less than 6 months. Under normal circumstances, cleaning shall be conducted only when the fouling reaches the thresholds established in paragraph 081-2.1.1.3. Except in extenuating circumstances, cleaning properly prepared, newly painted hull surfaces should be unnecessary during the first 12 to 18 months after undocking. Ships which remain pierside in warm waters for extended periods of time after undocking will develop fouling more quickly and may require earlier cleaning. This 12 to 18 month window does not apply to unpainted surfaces such as propellers and masker emitter belts; <u>therefore, ships should be scheduled for interim (propeller) cleanings on regular intervals immediately after undocking.</u>
>
> 081-2.1.1.3 The decision to initiate a hull cleaning operation should be based on the results of precleaning hull inspections performed on regularly scheduled intervals. A secondary indication for the need to perform an underwater hull inspection is evidenced by ship performance indicators provided in paragraphs 081-2.1.6 and 081-2.1.6.1. The fact that these changes are due to fouling must be verified by underwater inspection of the ship's hull. Full hull cleaning shall be accomplished when a fouling rating of FR-50 or higher (over 10 percent of the hull) for non-ablative paints; FR-40 or (over 20 percent of the hull) higher for ablative and self-polishing paints, exclusive of docking block areas and appendages, is observed; <u>interim cleaning when FR-30 or greater is observed on propeller surfaces.</u>
>
> ...

081-2.1.2 SCHEDULED DRYDOCKING. A ship's cleaning schedule should be adhered to until drydocking for new paint application. Deferral or cancellation of a ship's hull cleaning because of a scheduled upcoming drydocking often results in significant fuel penalties caused by dry-docking deferral. Underwater hull cleaning costs are quickly recouped by fuel savings, thereby justifying the decision to clean although a drydocking may be scheduled within 1 or 2 months. A ship's intended employment schedule must be reviewed prior to deferring cleaning for a near time scheduled drydocking for painting to determine if the fuel savings benefit recognized by cleaning can recoup the cost of cleaning. Should the drydocking schedule remain firm, once in dry dock a clean hull will reduce time and consequently dollars for the docking package.

081-2.1.3 PARTIAL VS. COMPLETE CLEANING. To ensure the greatest payoff for limited cleaning efforts, when time or other resources are limited, the priorities for underwater cleaning are:

a. Propellers
b. Forward one-third of the hull
c. After two-thirds of the hull.

081-2.1.3.1 Tests indicate that energy usage penalties caused by fouling occur in the forgoing order.[18]

[Note that FR-30 is Fouling Rating 30 which is defined in the same *Naval Ships' Technical Manual* as "Grass as filaments up to 3 inches (76 mm) in length, projections up to 1/4 inch (6.4 mm) in height; or a flat network of filaments, green, yellow, or brown in color; or soft non-calcareous fouling such as sea cucumbers, sea grapes, or sea squirts projecting up to 1/4 inch (6.4 mm) in height. The fouling can not be easily wiped off by hand."]

In the paper "Economic impact of biofouling on a naval surface ship," M. P. Schultz et al estimate the average full and interim cleaning of the navy Arleigh Burke class destroyers at one full cleaning every five years and interim cleanings (which would include propellers) at about twice per year. [19]

Measuring propeller roughness

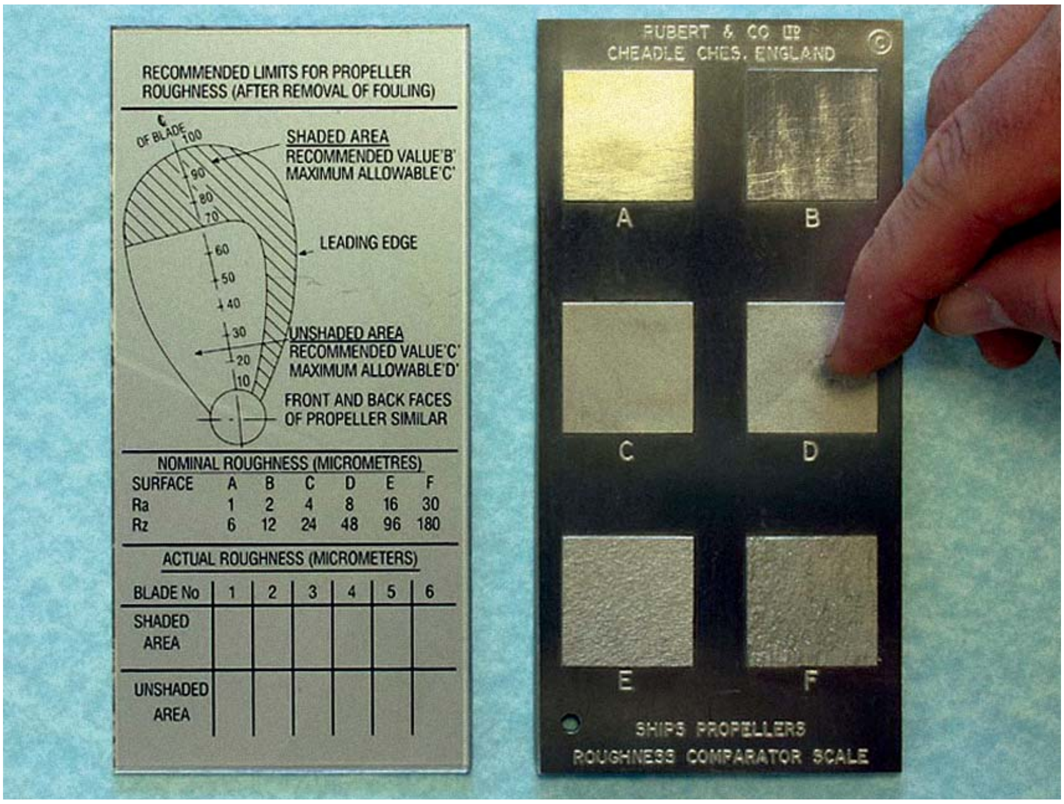
There are various methods of measuring the roughness of a propeller. Which one is used depends on the degree of accuracy required and whether the vessel is in drydock or the propeller on dry land, or whether the vessel is in the water and the propeller roughness is being gauged by a diver.

In this latter case, the Rubert comparator is most useful. (Besides the diver's version, there is a version of the comparator which is used on propellers which are not in the water.)

The Rubert comparator is based on a scale of propeller roughness ranging from A (smoothest) to F (roughest). By visual observation and touch, the diver compares various parts of the propeller blades to the samples on the comparator and the roughness of the propeller can be mapped.

When the propeller is on dry land and more accessible, stylus-based equipment can be used to precisely measure the roughness in micrometers, but from the point of view of fuel efficiency, knowing when to polish and judging the quality of the polishing, the Rubert comparator and scale are perfectly

18 Naval Sea Systems Command, *Naval Ships' Technical Manual* Chapter 081 "Waterborne Underwater Hull Cleaning of Navy Ships," Revision 5, 1 Oct 2006, 081-2.2
19 M. P. Schultz et al., "Economic impact of biofouling on a naval surface ship," *Biofouling*, 27: 1, 87-98, (14 December 2010)



The diver version of the Rubert & Co. propeller roughness comparator (© 2012, Rubert & Co. Ltd.)

adequate and very useful.

There are various methods of estimating the level of fouling on a propeller. These are the same methods used for general hull fouling.

As will be seen later in this article, many of the details of the roughness of the propeller and the fouling level of propeller and hull can be bypassed by employing a sufficiently high frequency of hull and propeller cleaning.

Summary

Current propeller maintenance practices vary greatly from fleet to fleet and ship to ship. On average, the most propeller efficiency conscious owners/operators schedule propeller polishing every six months or so; a less conscientious approach might result in propeller polishing once a year; in many cases no in-water propeller polishing is done between drydockings.

Yet the evidence is that keeping a propeller clean of anything more than a slime layer, and cleaning before a hard, calcareous layer forms, is far more fuel-efficient and economical, in addition to being safer environmentally.

Part IV. Best available propeller maintenance practices

The trick in establishing the best practices for propeller maintenance, assuming an uncoated propeller, is to work out a routine for propeller cleaning which permits rapid, easy (and therefore economical) propeller cleaning which is frequent enough to minimize the fuel penalty from propeller roughness and fouling and which results in the minimum removal of propeller material in order to achieve a smooth, fuel-efficient surface.

The following passage from *Marine Propellers and Propulsion* by John Carlton expresses this principle (underline added, not in the original):

> Finally, poor maintenance and contact damage influence the surface roughness; in the former case perhaps by the use of too coarse grinding discs and incorrect attention to the edge forms of the blade, and in the latter case, by gross deformation leading both to a propeller drag increase and also to other secondary problems; for example, cavitation damage. With regard to the frequency of propeller polishing there is a consensus of opinion between many authorities that it should be undertaken in accordance with the saying 'little and often' by experienced and specialized personnel. Furthermore, the pursuit of super-fine finishes to blades is generally not worth the expenditure, since these high polishes are often degraded significantly during transport or in contact with ambient conditions.[20]

Of course the cleaning can be overdone. Scheduling propeller cleaning once a week would not prove to be economically viable.

However, cleaning a propeller once every month or every two months would in many cases be quite advantageous. If carried out this frequently, cleaning with a relatively soft brush and abrasives in that brush is adequate to keep a well-maintained propeller at Rubert Grade A or B. It would prevent the accelerating spiral of cavitation damage plus corrosion plus fouling which, if allowed to continue uninterrupted, requires major polishing with grinding or polishing wheel and the removal of a great deal of metal into the marine environment if the polishing is carried out in the water. Cleaning propellers "little and often" would be beneficial to the environment as a minimum of bronze, copper, zinc and other heavy metals would be ground off into the water.

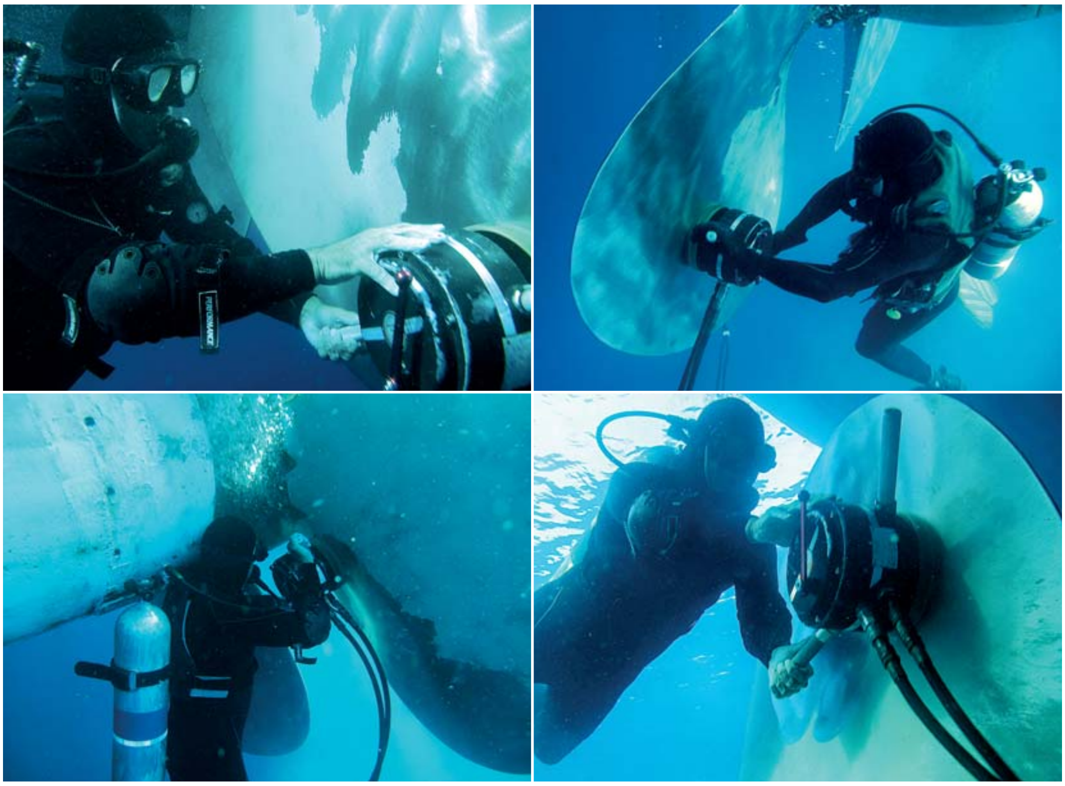
Cleaning propellers "little and often" would be beneficial to the environment as a minimum of bronze, copper, zinc and other heavy metals would be ground off into the water.

Propeller Buffing

A new technique has recently been developed for keeping a propeller ultra smooth: propeller buffing.

> According to an article on Polishing (metalworking) in Wikipedia
>
> Polishing and buffing are finishing processes for smoothing a workpiece's surface using an abrasive and a work wheel or a leather strop. Technically polishing refers to processes that use an abrasive that is glued to the work wheel,

20 John Carlton, *Marine Propellers and Propulsion*, Second Edition, Butterworth-Heinemann Elsevier, (2007) p 487



Buffing a propeller

while buffing uses a loose abrasive applied to the work wheel. Polishing is a more aggressive process while buffing is less harsh, which leads to a smoother, brighter finish.[1] A common misconception is that a polished surface has a mirror bright finish, however most mirror bright finishes are actually buffed. [21]

Case study

A recent experiment was carried out with a 134-meter cruise ship. The propellers were buffed, rather than being polished with the customary grinding or polishing disc, by one of the ship's crew who is a diver. It took one diver approximately 40 minutes to complete the buffing of the ship's two propellers. The fouling was not very heavy since the propeller is kept fairly clean. Calculations of subsequent fuel savings showed that on a 30-hour trip from Aruba to Barbados, the ship saved $2,100 compared to the same trip with a mildly fouled propeller. The ship consumes 1.6-1.7 tons/hour of fuel. The fuel saving as a result of cleaning the propeller was calculated at 6%. A 30 hour trip with the propeller before cleaning would have used 51 tons of fuel which is $35,700 at $700 per ton. 6 per cent of $35,700 is $2,142. In this case the propeller cleaning was carried out by a member of the crew. Had the propeller been cleaned by an outside company it would not have cost more than about $2,000. So the cost of cleaning, even if carried out by a contractor, would have been recouped in the first trip the ship took after cleaning. Since the propeller would not have had to be cleaned again for at least a month, the cost of the cleaning would have been regained many times over.

The following photos were taken of that specific propeller buffing.

21 Wikipedia Polishing (metalworking) accessed 25 November 2014

Advantages of frequent buffing compared to occasional polishing or no cleaning at all

A propeller maintained in this way will suffer very little cavitation or corrosion damage since the accelerating spiral is caught very early on. The multiplying effect of damage is thus prevented. The usual heavy grinding on a badly damaged propeller surface is avoided. This also means much lower emission of heavy metals into the marine environment and sediments from propeller cleaning.

When the propeller is allowed to become badly pitted, polishing with grinding wheels or polishing discs is then required to restore the propeller to a relatively smooth state. Greater skill on the part of the diver/polisher is required. The Navy's manual on the subject points out the dangers:

081-3.3.3.4 UNPAINTED PROPULSOR

CAUTION

At no time should high-pressure water jets being used on bare propulsor surfaces be allowed to operate at pressures above 10,000 pounds per square inch (psi).

CAUTION

Although approved for limited use on unpainted propulsors, wire brushes shall be used only as a last resort by a highly trained diver to remove severe fouling. Because of its configuration, wire brushes can cause scratches and gouges on the surfaces if used by an inexperienced diver. Wire brushes shall not be used to clean the outer 3-inch periphery of propulsor blades, critical areas and areas of high curvature.

NOTE

Any suspected use of wire brushes or hard tool on the outer 3-inch periphery of propulsor blades, critical areas and areas of high curvature shall be documented and reported to the Type Commander and NAVSEA Code 00C.

CAUTION

Use only the most experienced personnel when cleaning the outer 3-inch periphery of propulsor blades. These personnel shall be familiar with the critical areas and areas of high curvature geometry.

081-3.3.3.4.1 Surface ship propulsors have a range of complex geometries that will require periodic cleaning. All areas of an unpainted propulsor, except critical areas (the 3-inch area adjacent to the propulsors leading edges, trailing edges), may be cleaned with non-abrasive nylon, polypropylene, and polyester brushes, wire brushes, silicon carbide impregnated nylon brushes, abrasive discs, high-pressure water jet guns, abrasive hand pads, and hand scrapers. The critical areas shall be cleaned by abrasive hand pads, hand scrapers, nylon, polypropylene, and polyester brushes, water jet guns and abrasive discs. [22]

Not only is frequent, lighter buffing with brushes and abrasive material more economical than heavier polishing with grinding wheel or polishing disc, it requires less skill and is materially better for the marine environment.

Not only is frequent, lighter buffing with brushes and abrasive material more economical than heavier polishing with grinding wheel or polishing disc, it requires less skill and is materially better for the marine environment.

22 Naval Sea Systems Command, *Naval Ships' Technical Manual* Chapter 081 "Waterborne Underwater Hull Cleaning of Navy Ships, Revision 5, 1 Oct 2006, 081-3.3.3.4

A note on reclaim systems

It should be noted here that some underwater propeller polishing companies offer reclaim systems which are alleged to recover the material ground off in propeller polishing. However, testing of this equipment has shown that it is not satisfactory and that the material inevitably goes into the water column and from there to the sediment at the sea bottom. In practice operators using such (cumbersome) systems tend to remove the recovery system and hang it on the rudder while they do the propeller polishing, counting on the fact that they are unobserved. While this obviously does not apply to all operators, nor is it that uncommon where reclaim systems are in use.

The subject of propeller coating can still be considered to be experimental.

Cost of buffing

Obviously the cost of buffing is a factor which cannot be overlooked. If the savings in fuel costs did not substantially outweigh the cost of propeller maintenance, then one would question the value of frequent propeller buffing.

The cost varies from one location to another and from one provider to another. Cheapest is not always best. The need for skilled and competent propeller buffing and polishing has already been stressed.

Vendors usually charge per propeller size and number of blades. Polishing a 4-blade, 6-meter propeller would cost somewhere between $1,900 and $3,000. Polishing a 6-blade, 8-meter propeller might cost between $3,100 and $4,000. The costs vary by location and company.

One of the better propeller buffing vendors charges 15-20% less for propeller buffing than for full polishing with grinding or polishing discs. Which method used depends on how rough the propeller is and this is determined largely by how frequently or infrequently the propeller is polished or cleaned.

As covered in the short case study above, the cost of the propeller buffing can be recouped in the first voyage the ship makes after the cleaning.

Cleaning takes less time than polishing. The best companies offering propeller buffing and polishing can polish a large propeller in about four hours. Buffing is faster.

Part V. Conclusion

Best available practices for propeller efficiency at this time consist of the use of uncoated propellers with frequent, routine in-water buffing to prevent heavy fouling, the formation of a calcareous deposit layer and the spiraling damage of cavitation erosion and corrosion.

Further research is needed into the use of strongly adherent, highly cavitation and corrosion resistant glass or ceramic reinforced coatings which can stand up to the extremely challenging conditions in which propellers operate.

As usual, we welcome any input, experience or research information which will throw further light on this subject.

Hydrex and Ecospeed

To find out more about Ecospeed and Hydrex,
visit the following websites:

www.hydrex.be
www.hydrex.us

If you would like to be added to the mailing list for future white papers on ship hull performance and related subjects and/or copies of the *Journal of Ship Hull Performance* (all free) please go to the following link, register and state your preferences:

www.ShipHullPerformance.org

For comments, input, information about the content of this white paper or any communication relating to it, please send an email to the following email address and we will respond:

editors@shiphullperformance.org

European Headquarters

Hydrex nv
Haven 29
2030 Antwerp - Belgium
Phone: +32 3 213 53 00 (24/7)
Fax: +32 3 213 53 21
E-mail: hydrex@hydrex.be

www.hydrex.be

US Office

Hydrex LLC
604 Druid Rd E
Clearwater, FL 33756 - USA
Phone: +1 727 443 3900 (24/7)
Fax: +1 727 443 3990
E-mail: info@hydrex.us

www.hydrex.us

HYDREX® UNDERWATER TECHNOLOGY