Cavitation EROSION Damage

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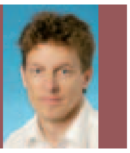

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Running the risk of costly recurrent repairs

■■ The call for increased speed for large container carriers has resulted in propellers with high power density. The downside of this trend is that rudder damage due to cavitation erosion has become an increasing problem on high speed container carriers. The necessary repairs, which can be expensive and frequently recurring if no preventive measures are taken, can reduce the ship operation economy noticeably.

It has been established that cavitation erosion problems on rudders are overrepresented for ships at speeds above about 22–23 kn with a propeller power density of the propeller exceeding about 700–800 kW/m^2, (delivered power divided by the propeller disc area).

Today SSPA uses scaled model tests in combination with CFD (Computational Fluid Dynamics) to overcome these problems. This approach gives a better design and the same method can as well be used to troubleshoot an existing poor design.

The mechanisms of cavitation damage

Cavitation may appear as several different types although the fundamental mechanism for the inception of all types is the same; when the local pressure falls far enough below the saturated vapor pressure the liquid is ruptured and a vapour filled cavity is formed at the local phase change to gas.

At some later moment, after possible reshaping and transportation by the flow the vapour cavity will collapse due to a higher ambient pressure. Complex physical processes take place during this collapse resulting in high pressure pulses, velocities, and temperatures in the fluid. This will cause highly localized transient surface stresses in the body material if the collapse occurs very close to the body surface.

Repeated collapses will ultimately cause local fatigue to the body material at which material pieces starts to flake away; a phenomenon known as cavitation erosion.

The rate of cavitation erosion can vary within wide ranges depending on the conditions in question. Observable damage can appear after only a few hours but it can also take several months or even years. The erosion rate depends among others on the:

- Violence of the collapse,
- Distance to the body of the collapse,
- Strength of the body material,
- Rate of recurrence of collapses.

The presence of cavitation does not necessarily mean that there will be erosion, but there is always a risk of erosion when the collapse occurs on the body surface. If the collapse occurs at some distance from the surface, the risk is decreased considerably or even eliminated.

The entire subsequent cause of events – the initial formation of a vapour void, its growth and possible reshaping as well as their collapse - is normally referred to as cavitation.

The loss of material caused by cavitation collapses is a result of the mechanical strains and stresses that arise due to the cavitation collapses as well as electro chemical processes, i.e. corrosion. Intensive cavitation collapses often increase the speed of corrosion. The mechanical wear due to the cavitation collapses can remove protective coatings such as paint and corrosion products e.g. the passive oxide film that otherwise would reduce the corrosion rate. Normally the entire loss of material is considered as cavitation damage even though material is wasted due to corrosion as well as mechanical strains and stresses.

The cavitation causing the damage can be generated very close to the location of the damage or much further upstream. Erosion on a rudder can therefore be caused by cavitation that is generated at the propeller and then transported by the flow to the rudder where it collapses on the rudder surface. Cavitation can also be generated on the rudder itself and collapsing on the rudder surface just slightly downstream of its inception point. For this reason it is important to consider the entire cavitation process; inception, reshaping, transportation and collapse. Preventive actions can be directed against one or more of these sub-processes.

Do it right from the beginning

When the propeller power density and the speed of the ship is high, careful attention to rudder design and its interaction with the propeller is essential to avoid cavitation erosion problems in the future.

Predicting cavitation erosion on rudders is difficult, the tools that are at hand are traditional model testing and CFD simulations. Model testing requires a reasonably correct modelling of the flow between the ship wake, propeller, and rudder, which can be difficult to obtain, mainly due to scale effects. At SSPA these difficulties are overcome by recent experience.

Neither do CFD simulations give fully reli-

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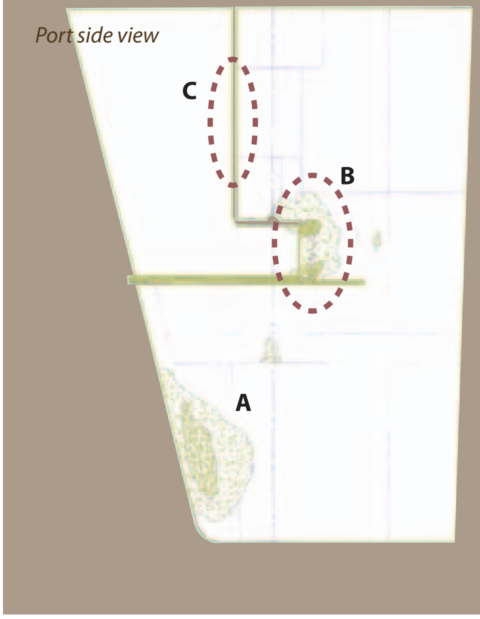


on Semi-Spade Rudders

able answers for the detailed cavitation behaviour. To get more reliable results both tools can be used combined.

CFD is used to make a first verification of new designs and design changes, possibly with several iteration loops. Model tests on the other hand, are used for verification of what is believed to be the final design. This entire process of designing and testing can also be iterated if needed.

Much of the cavitation problems related to the gap between horn and blade (B and C in Figure 1) can be avoided by the use of full-spade instead of a semi-spade type of rudder. Furthermore, by twisting the leading edge of the rudder it can be better adapted to the rotational flow from the propeller and thereby suppressing cavitation induced on the rudder (A in Figure 1).

Or solving the problems afterwards

When the design, for some reason, has turned out to be a poor solution regarding the cavitation behaviour the erosion problem can be managed, either by:

1. Increasing the cavitation erosion resistance of exposed parts on the structure.
2. Changing the cavitation behaviour by changing the flow.

The cavitation erosion resistance can be increased by cladding with stainless steel or some other high tensile material at strategic locations. High tensile stainless steel is, compared to e.g. cast iron, considerably more resistant to cavitation and if the cavitation behaviour is unchanged by the implemented cladding, the time to failure is increased.

Solving an erosion problem is most safely done by changing the cavitation behaviour to avoid collapses on the structures. However, this is for different reasons not always possible at which the efforts often are only focused on armouring the structure. Therefore, if the cause of the damage – i.e. the behaviour of the cavitation - is not changed, the surface will still be exposed to the same mechanical strain by the cavitation.

The success of armouring measures depends on the aggressiveness of the cavitation and how the reinforcement is made. Since the mechanical strain remains, this type of measures may only be partially successful, still requiring continuous maintenance or recurrent repairs although the repairs are expected to be less extensive and less frequent.

All design changes affecting the flow should be verified in some way to assure adequate results on the cavitation behaviour, otherwise the situation can easily become aggravated. Also at this stage, when a problem has to be solved afterwards, the experience of SSPA is that a combined use of CFD and model testing is preferable.

Typical locations of damage

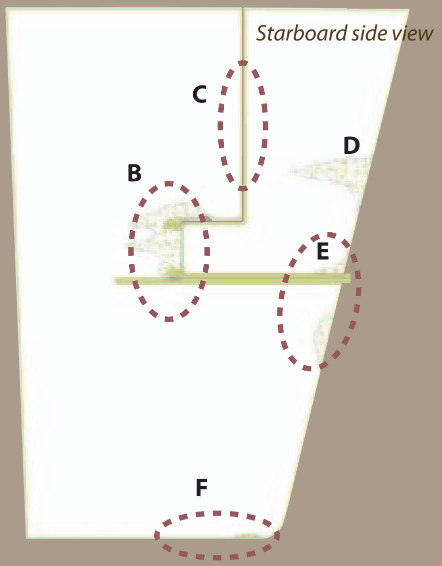
found in the areas as shown in this figure. The damage may arise due to several different underlying causes. Some of these causes are:

1. High load on the propeller tend to produce more cavitation on the propeller blades. Parts of it may collapse on the rudder and cause damage if it is frequently repeated (damage at D due to tip vortex and at E possibly due to hub vortex).

2. Particularly, if the propeller blade tip is highly loaded the tip vortex will be strong and the tip vortex cavitation, which usually persist far downstream of the propeller, is therefore difficult to avoid completely (damage typically at D and possibly also having some influence at F).

3. Unfavourable rudder tip geometry can cause vortex cavitation or flow separation of the incident flow with corresponding cavitation on the rudder sole (damage at F).

4. The rotational flow from the propeller may also induce cavitation on the rudder blade surface close to its leading edge due to a too large angle of attack (damage at A).



5. For a horn type rudder, the high flow velocity will also cause the flow around the rudder horn and rudder blade connection to cavitate more easily at the surface discontinuities that exist in the connection area (B and C).

6. For a horn type rudder, the flow through the gap between the horn and the rudder blade have a high velocity and it can therefore often cause cavitation around the pintle on the rudder horn as well as on the rudder blade (B).

7. The hub vortex may cause an induced flow, which generates cavitation. Also if the hub vortex is cavitating it can cause collapses on the rudder (E).