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INFLUENCE OF ICE LOADS ON PROPELLER ON THE ENGINE'S BRAKING PARAMETERS AND ICE – GOING QUALITIES OF THE VESSEL

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ABSTRACT

In connection with the process on harmonization of requirements to specify the propeller blades' strong dimensions the different approaches to evaluating the influence of propeller RPM on the ice loads level were exposed. The method of solving this problem and the results of computer calculations are presented in the paper allowing us to specify the approaches to solving these problems.

1. INTRODUCTION

At the moment the classification societies is actively working towards the harmonization of regulatory requirements for the strength of propellers and propulsive systems of ice-going vessels. The governing loads for such propulsors are those applied to their blades due to interactions with the rubble ice broken by the hull.

Full-scale data (Alekseev at al, 1980; Jussila ,1983; Kannari, 1988) and computations (Veitch, 1995; Soininen, 1998) indicate that the highest loads are generated on blades when they have to mill sufficiently huge ice fragments. They turn out to be random functions which may be described through the load, its amplitude and duration. As long as we can specify certain geometric and kinematic conditions of the interaction history, it is possible to describe all ice load components with the help of computer programs based on some available method (Veitch, 1995; Soininen, 1998; Belyashov,1983,1993) However, results computed with these methods do not allow to get the value which should be regulated: the maximum ice load for a particular ship propulsor. This happens because of uncertainties associated with interaction kinematic parameters which dictate critical loads and are themselves described through the attack angle, i.e. advance J and pitch P/D ratios of the propeller. These values are available for so-called "ice-open water" conditions, i.e. in ice but without any interactions. However, it would be not correct to use such data for the subject task.

2. COMPREHENSIVE APPROACH TO TASK SOLUTION

In order to establish the above-named parameters, it is necessary to know responses of the propulsive train and of the whole ship to propeller-ice interactions. On a realistic ship, when the propeller starts milling huge ice masses the shaft speed n reduces due to the resulting additional resistance acting together with the hydrodynamic moment. Depending on the supplied power N and its available margins, on inertia parameters of the "propeller + shaft + engine" train, on output characteristics of the engine and on parameters of its automatic control system, the result is a reduction in either revolutions n or in the CPP pitch. The thrust and the propulsion of the system drop proportionally with either n^2 or P/D reductions. This leads to a reduction in the speed of the ship which also depends on the inertia mass of the ship and on the ice resistance. Both events are dynamic and time-dependent. Therefore, they as well depend on both the value and the duration t_i of the ice moment M_x applied to the propeller. As soon as the interaction event finishes, first the propulsive train and then the ship regain their initial parameters unless the propeller comes in contact with a new block of ice in a time t_f. Thus, the task of identifying the most critical conditions associated with ice milling for a particular vessel strictly speaking boils down to a series of calculations when the optimum ship configuration is chosen from a number of options with known hull, propeller and main engine parameters. There are two ways to deal with this task. The first approach is to carry out self-propelled model tests in an ice basin. However, that means the need to simultaneously model:

- ice conditions;
- ice properties;
- ship model inertia parameters (mass, metacentric height);
- characteristics of the engine (N = constant, or n = constant) and CPP pitch controls.

At the same time, all aspects of ship hull and propulsor geometry have to be known and properly modelled. Today such exercises are impossible due to complications involved in simultaneous modelling of all above-listed parameters. Ice laboratories so far resort to partial modelling parameters , but that is not enough to achieve the goal. Therefore, it is suggested to apply a combined procedure for establishing critical ice milling conditions which cause greatest loads on propeller blades. First it is necessary to carry out self-propelled model tests at n = constant in order to obtain information on propeller-ice interactions:

- the M_x^{max} probability distribution;
- the M_x^{mean} probability distribution;
- the t_i probability distribution;
- the t_f probability distribution.

Then, with the help of results of separate ice milling tests at different cut depths l_c made using a propeller model with a geometry close to that of the subject design, we can find an equivalent cut depth l_c^{eq} which corresponds to M_x of a specified probability. The subsequent analysis is performed numerically with the thus established l_c^{eq} value. It should be noted that from model experiment data is used only sufficiently reliable information on the duration of interaction process depending on the blocks dimensions of ice broken by ship hull. Beside this the ice torque value is actually used only for estimatoin at equivalent blade cut depth value. Further steps then are performed by means of computation methods.

The method suggested in (Belyashov, 1993) is applied to find realistic propeller ice moments $M_x=f(J,l_c^{eq})$ and equivalent blade cut depths l_c^{eq} for $J=J_k=$ constant. Ship motion parameters are found numerically with the below-described software package varying ship engine types, power outputs and propeller options (CPP, FPP) and geometries. The outcome of these numerical exercises enables to establish what kind of propulsive system is optimum

for specified conditions and what is the range of design advance ratios J for which it is necessary to find critical and realistically possible ice load levels to be used for blade strength analysis. This procedure also enables to find the least power level sufficient to move the ship under specified ice conditions without the risk that the propeller would be blocked (completely stopped) by the ice.
The flow chart of this software package is schematically shown in Fig.1.

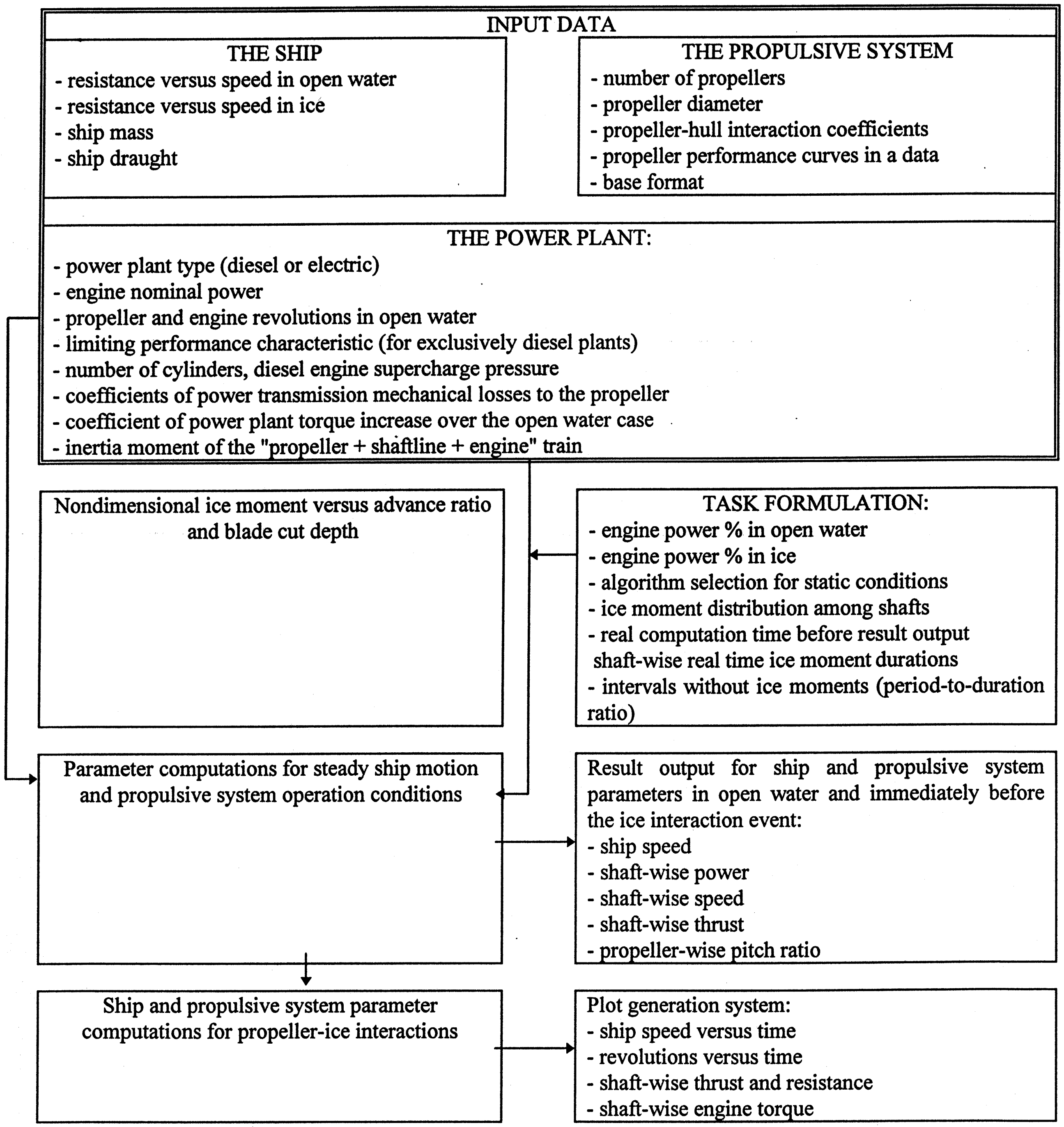

Fig.1 Ship and propulsive system parameter computation flow chart for propeller-ice interactions

Its input data include parameters of the ship, of her propulsive system and of the power plant. In order to specify ship ice resistance, it is necessary to have either model test results or relevant design prediction procedures and computer programs.

Propulsive system parameters are described by choosing a propeller from the integral data base of propeller hydrodynamic characteristics and specifying propeller-hull interaction coefficients. There is also a provision for fixing these input coefficients for open water and ice conditions. Mean, maximum and minimum values of the nondimensional ice moment are set as functions of the propeller advance ratio J at different blade cut depths l_C. Fig.2 offers a plot of such a function for an icebreaker propeller penetrating into the ice to 60% of the blade length.

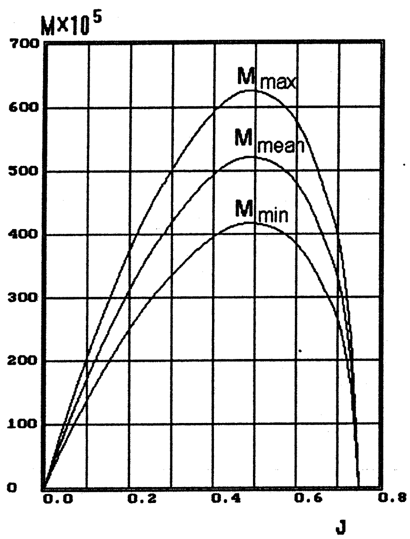

Fig.2 Nondimensional ice moments versus advance ratios

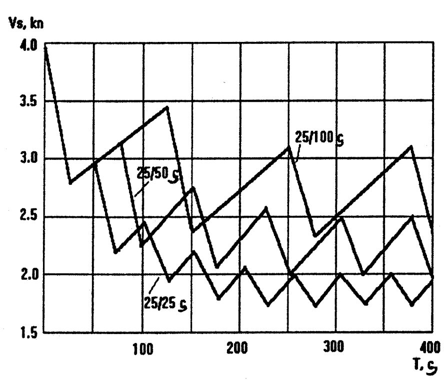

Fig.3 Effects of the period to duration ratio of the propeller/ice interaction cycle upon ship speed.

An important factor which affects thrust and torque characteristics of the whole propulsive system is the type of power plant. There are provisions for modeling propeller-ice interactions as applicable to different exclusively diesel engine options (direct power transmission, geared transmissions with fixed- and controllable-pitch propellers), as well as to electric propulsion systems. In the first case it is necessary to input the limiting performance characteristic of the diesel engine, the number of its cylinders and its supercharge pressure. That allows to model both torque and inertia parameters. In the second case a key role belongs to the maximum torque generated by the electric motor and the time during which this torque can be maintained.

While formulating the task, it is necessary to specify the percent of engine power available when sailing in ice. For triple-shaft vessels it is also required to input power distribution among the shafts. Prior to the dynamic analysis, the programme computes steady parameters of the subject ship sailing in ice without propeller-ice interactions. Under these conditions the ship speed and the ice component of the resistance reach their highest values.

Steady case parameter computations basically consist of numerical solutions of nonlinear equation sets for the resistance-thrust balance, as well as engine torques M_e and hydrodynamic resistance moments Q. There are several options of the steady parameter procedure associated with different algorithms for pitch ratio input and automatic selection. It is possible to specify fixed values for the pitch ratio, the maximum ship speed, the revolutions or to input a particular engine performance characteristic.

Propeller-ice interaction analysis consists of numerical solutions of ship motion equations and equations for the "engine + shaftline + propeller" train in terms of tail shafts. At each time integration step the program finds thrust, resistance, engine torque, hydrodynamic and ice moments. The ice moment is found taking into account its modulations with revolutions.

Figs.3 to 9 present results of modeling a series of ice interactions for "Kapitan Sorokin" icebreaker side propellers. The exercise was started with a steady run in ice at about 4kn under about 90% of the power plant rating without propeller-ice interactions. The interaction duration t_i was assumed to be 25s, intervals between consequent interaction events t_f were varied within 25 to 100s. As may be noticed from Fig.3, the ship speed drop-rise cycle in all cases stabilizes after 300s.

With the 25/100s event period-to-duration ratio the maximum steady speed is 3.2kn and the minimum speed is 2.4kn. With the 25/25s period-to-duration ratio the maximum steady speed constitutes 2kn while the minimum one is about 1.6kn which is close to the least steady speed.

Fig.4 Ship speed variations due to propeller-ice interactions
--- at the beginning of the interaction series
-•- under steady conditions (by the end of the series)

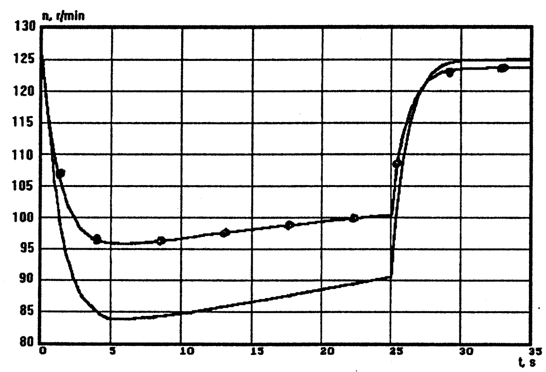

Fig.5 Propeller speed variations due to ice milling
--- at the beginning of the interaction series
-•- by the end of the interaction series

Figs.4 to 9 are plots of propulsive complex parameter functions for the interaction histories with 25/50s period-to-duration ratios. Plots in Figs.4 to 7 describe the beginning of interaction series as against steady conditions by the end of these series(dashed lines). In the first case the ice moment M_x is over 500 kNm, i.e. 160% of the nominal torque. The drop in revolutions is 34%. In the second case the ice moment decreases down to 330 kNm thanks to the speed reduction while the decrease in revolutions is 22%.

Figs.8 and 9 show propulsive system parameter functions for propeller-ice interactions of the same ship but assuming her diesel-electric plant is substituted by an exclusively diesel CPP installation with a geared or a direct transmission. It was additionally assumed that propeller revolutions in ice were maintained at the nominal level by pitch reductions. Pitch variation effects upon the ice moment were for the sake of this particular exercise ignored. It is possible to take it into consideration in computation of ice loads.

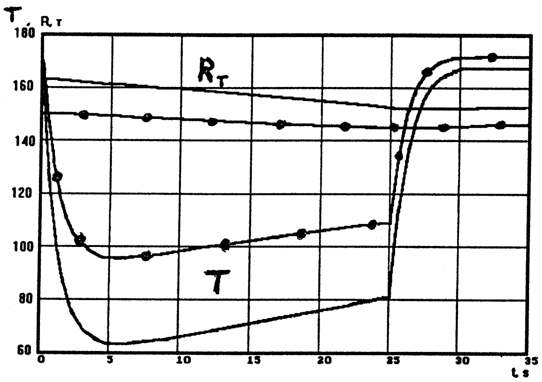

Fig.6 Thrust and ship resistance variations during propeller-ice interactions
--- at the beginning of the interaction series
-•- by the end of the interaction series

Taking into account the decrease in CPP blade pitch settings at *J*= constant leads to an additional ice resistance moment for the propeller. However, even without this effect Figs.8 and 9 clearly show that within 8s revolutions drop below the minimum steady limit. This means that the main engine stops and the ice moment peaks beyond 600 kNm in 7s. The torque at the beginning of this transient history grows to a value corresponding to fuel pump supply limits but even such an increase fails to compensate the ice moment rise.

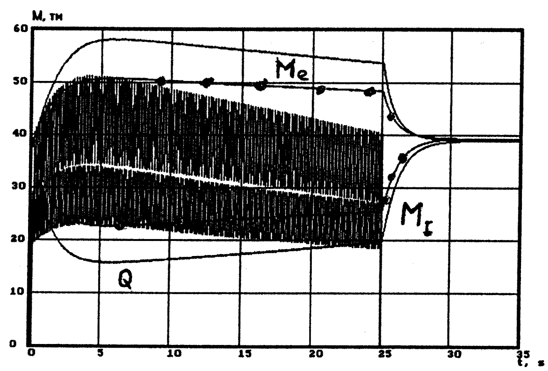

Fig.7 Engine torque, ice and hydrodynamic resistance moment variations
during propeller-ice interactions

3. CONCLUSIONS

The main goal of the reported project was to develop a closed software package which would describe the behavior of an icebreaking ship and of her propulsive system when sailing in ice taking into account propeller-ice interactions. This software package may serve as a basis for developing computer simulators to train ice ship operators. It is also necessary for better justified design of icebreakers and other ice-capable vessels. It help to substantiate the choice of the propulsive system and its individual components, propellers including.

The developed method makes it possible to clarify certain aspects relevant for scantling regulations for "propeller + shaft + engine" systems and for prescribing ice ship power levels depending on their classes and service conditions.

For example like may be observed from the presented sample predictions, the choice of kinematic conditions for propeller blade ice interactions which govern critical load levels should be made taking into consideration the involved type of the propulsive system, its parameters and propeller power levels. Fig.8 demonstrates that in case there is a sizeable margin in the available power, the highest load is generated by the end of the first significant interaction event when the ship speed is still rather high but the propeller speed has already markedly reduced. This is explained by the fact that propeller revolutions decrease faster than the ship speed but afterwards they are regained quite quickly. Later, during subsequent interaction events, the reduced ship speed can restrict propeller blade load levels.

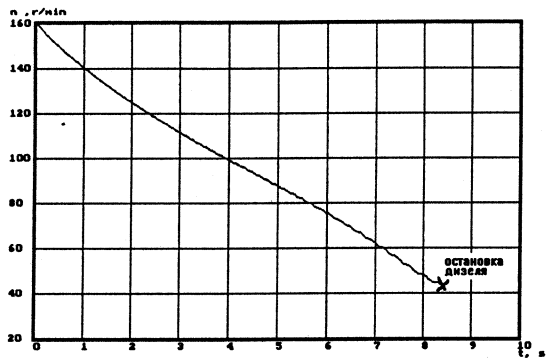

Fig.8 Revolutions versus time for an exclusively diesel power plant

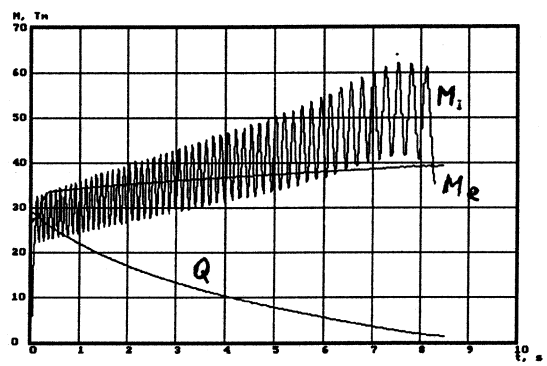

Fig.9 Ice moment, torque and hydrodynamic resistance moments for an exclusively diesel power plant

A reverse situation is observed when the propeller power is insufficient or in case of a loss in engine parameters (from the point of view of the ability to cope with overloads). Every interaction event which exceeds limiting parameters of the engine may completely stop the propeller and create extreme conditions when attack angles become negative and cause a drastic jump in ice loads which eventually break the blade. This situation is considered as irrelevant to the design standards as the stopping of screw in heavy ice conditions meanwhile the ship speed remains sufficiently high may result in a breakage of all propeller blades. On this reason the reversing regime for screw is considered as the most cjmplicated operation which is regulated by special instructions for navigators.

The described software package also offers an opportunity to get numerical evaluations of "CPP + shaft + flywheel + diesel engine" system behavior under ice conditions. An excessively fast blade pitch reduction may make ice interaction conditions more difficult and result in unnecessary increases in ice loads on blades.

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