The Propulsion and Maneuvering Concept of the BCF- Super C-Class Double End Ferries

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Abstract

One important milestone of British Columbia Ferries (BC Ferries) during their Major Fleet Replacement Program was the development of a new Double Ended Ferry class to replace their existing C-Class vessels. The final design of the ships called the BCF Super Class Ferries, which are actually the world’s largest double end ferries, was finally carried out by Flensburger Schiffbau-Gesellschaft (FSG), Germany.

Some of the Design requirements put forward by BCF had been very hard to fulfill in the final concept. Most challenging was the demand for extremely low fuel consumption, low wake wash, and very good steering performance that had to be combined with the requirement for a diesel electric power plant. Furthermore, the operational profile of the vessel required a very short acceleration time of the vessel from zero up to full design speed, which is quite high with 21 knots. These requirements lead to an unconventional propulsion concept with bow and stern CPP-Propellers which are operated in constant rpm mode where the bow propeller feathers with the trailing edge. This propulsion concept is embedded into a completely new hull form that was developed on the basis of numerical flow simulations.

The concept was finally derived from the numerical and experimental evaluation of many alternative concepts.

With respect to the maneuvering demands, most challenging was the fulfillment of the Active Pass Route operation, which was demonstrated by a full mission maneuvering simulation carried out during the initial design phase. The harbor approach procedure requires a mode shift which includes the de-feathering of the bow propeller at full speed and the starting procedure of the bow drive motor into the constant shaft speed mode using a soft starter. To do so, the automation system of the propulsion plant was combined with the maneuvering model that allowed to determine all important interactions of the complex systems and finally lead to the design of the propulsion control system. The paper shows that the technological challenges of such a complex kind of ship can only be tackled in close cooperation between the owner, the shipyard, the main suppliers, and the research institutions, as many design tasks require scientific simulations on a high level.

Keywords

Double-ended ferry, Super C-Class, wake wash, diesel electric propulsion, Active Pass, product development

Introduction and Initial Considerations

Fig. 1: The BCF Super- C- Class Design Requirements
When BC-Ferries quoted for the new design of the so-called SUPER-C Class Ferries, the following main design requirements were demanded by BCF with respect to the existing C-Class vessels which are to be replaced by the new designs:

- 370 vehicles, 1500 day passengers on 2 car decks
- Dimensions and deck strake compatible with all mainland terminals
- 21 knot service speed, 20 knots w/o one prime mover, 18 knots w/o two prime movers
- Double-ended configuration based on C-class experience
- Diesel electric propulsion
- High lift rudders for optimum docking performance
- Fast acceleration to service speed
- Significant turning rate > 90 Deg/min

Based on the initial requirements, the following propulsion variants should be considered:

- Podded propulsion with either for or two prime movers
- Conventional propulsion with bow/stern propeller and power sharing
- CPP bow/stern propulsion with either trailing or leading edge feathering

BC-Ferries itself initiated a detailed model test program at the OCEANIC model basin to get a clearer picture of the most efficient propulsion configuration, where a model of the existing C-class vessels was used. To most efficiently exploit the results of these tests for our concept development, detailed numerical investigations of some double-ender hulls (see e.g. Fig. 3) were carried out prior to the experiments in order to figure out the most important design drivers of a double-ended ferry. This concern was also considered of major importance to validate our numerical codes with respect to the specific problems related to double-ended ferries and to get an initial impression of numerical problems which might become relevant later during the hot product development phase.

When the hull form of the C-class vessels was developed in 1973, it was pointed out by the model basin that the displacement should be shifted from the ends to the main frame to allow for lower entrance angles of the waterlines at the end(s). The other lesson to be learned from these experiments was that the design of the propeller for a double-ended ferry has much greater impact on the total power requirement as for single-enders due to the fact that the forward propeller may generate excessive resistance if not properly designed. To cope with this design task, basic computations were carried out to roughly estimate the effect of parasitic resistance of the bow propulsion unit and its effect on the propulsion. The calculations have shown that large excessive power demands can be generated if the whole system was not optimized in total for the following reasons:

Even for a fully optimized hull with minimum resistance, the thrust loading of the stern propeller is still quite high resulting in reduced propulsion efficiency and demanding a large propeller diameter which the hull must be capable of accommodating.

The large propeller (if acting as the forward propeller) might generate excessive additional parasitic resistance if not properly designed which generates additional thrust loading on the aft propeller, reducing its efficiency further. This coupling makes the design as well as the speed-power prognosis quite complex. In this respect, a fundamental principle was found that is generally valid for all types of double-ender propulsions:

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both minimum resistance and maximum propulsion efficiency. As the propulsion concept converged to either bow- and stern propeller or bow-and stern pod, the hull form must allow for the installation of a large propeller diameter to keep the thrust loading at an absolute minimum. In order to avoid large amplitudes of propeller induced fluctuations, it is also important to have sufficient clearance to the hull. Thus, the profile was clearly determined by the propulsion requirements. As the thrust loading is quite high due to the double-end ferry concept, the pressure pulses can hardly be reduced to extremely low levels. This concern was a further problem as BCF insisted on having ice strengthening for the propeller design to cope with objects floating in the water. Therefore, the area exposed to the pressure fluctuations must be kept at a minimum in order to keep the exciting forces low. In this case, some fluctuations bearing higher pressure measurements can be accepted.

As the resistance (mainly wave making) is influenced by the waterline shape of the end(s), slim waterlines have to be designed into the profile determined by the propulsion requirements. This feature includes dynamic effects such as trim and bow wave generation, so also the hull above the DWL also had to be designed for minimum wave making. The analysis of several hull form alternatives generated during the design process clearly indicated that MARIN’s proposal in 1973 to shift buoyancy from the ends towards the main frame during the evaluation of the C-Class is clearly beneficial for the wave making resistance.

The hull form must further generate a propeller inflow as uniform as possible to increase the propulsion efficiency and to reduce propeller fluctuations.

As the propulsion concept resulted in propellers installed at the centerline of the ship it was absolutely crucial not to have a center skeg. Because such a sharp center skeg would result in a local wake peak at the 6 o’clock position (keel) which results in a very low propulsion efficiency, as the relative rotation efficiency drops. Then, care must be taken that the hull is able to generate sufficient cross-force for good course stability. For this reason it was decided to replace the center skeg by a hydro-dynamically efficient gondola. This concept can in principle be used for both conventional and podded propulsion if designed properly.

The hull form must further have a minimum thrust deduction fraction. This action is important for the following reasons:

If podded propulsion should be favored, then the forward propeller will generate a large additional resistance if the axial clearance is not large enough. The benefit from having an additional propulsion unit at the bow is compensated to a certain degree by the amount of additional thrust deduction.

If conventional propellers are used, the forward propeller can be operated in two different modes: It can turn freely at some rpm which correspond to zero torque (or close to zero torque) or it can be turned by the engine at some revs which lead to a total propulsion optimum. (Braking the propeller is not an option, because the resistance is excessive at this point.). Alternatively, the forward propeller could be used as booster if desired. In such cases, the system will benefit from high axial clearance like the podded variant. Low thrust deduction for the stern propeller has the same effect as reducing the resistance and decreases thrust loading.

For low thrust deduction fraction a large axial clearance to the hull and small waterline angles at the gondola were realized. To minimize the wave resistance, the optimum interference between bow and stern waves is important as well as the interference between bow wave and main section (more or less the position of the shoulder). Therefore, the bow wave was shifted to a position where the wetted length leads to an optimal interference of the wave pattern components. With respect to maneuevering, especially keeping course, there is a problem from the main dimensions: a course stable ship can hardly be expected at the relatively high speed. Therefore, it is beneficial to shift as much displacement towards the main section as possible and to reduce the buoyancy at the ends. This action will lead to a longitudinal distribution of section added masses that supports course keeping ability. Besides, care has to be taken that the hull is able to produce sufficient cross force. The rudders had to be integrated into the hull without creating too much additional resistance due to the forward rudder. The head box of the forward rudder is part of the waterline and was carefully integrated into the hull. The rudder type chosen is of FSG- TWIST FLOW high lift type that is beneficial for high steering forces at low resistance. Care was further taken to fully integrate the Costa Bulb into the appendage concept to avoid additional resistance from the propeller hub. Based on these considerations, an initial hull form was designed by intense use of numerical flow computations. The results that are presented in Fig. 4 show the significant decrease of wave resistance of the new design, although the displacement is about 60 % larger than for the existing C-class vessels.

Fig. 3: Some Double-Ender Concepts and their wave patterns

Fig. 4: Wave Pattern of existing C-Class (left) and new initial design at 21 knots.
The Results of the BCF OCEANIC Model Tests

Based on the model test results performed at the OCEANIC model basin, where the original C-Class-Vessel has been thoroughly tested at a higher draft of 5.90 m, the following conclusions could be drawn for the new building project: The wave pattern (see also Fig. 4, left) is characterized by a significant bow wave which causes a large trough in its wake. Although the dynamic trim was consequently down by stern during all tests, it was found beneficial for the overall resistance if the model was pretrimmed down by stern, which increases dynamic trim. This behavior is quite unusual, because typically, a pre-trim in the opposite direction is more favorable, because the vessel is dynamically more on even keel. It can clearly be concluded that the vessel suffers from the large bow wave. Therefore, the trim by stern reduces overall resistance due to the fact that the bow wave is decreased, although the dynamic trim is so large that the stern balcony knuckle was fully wetted. These findings are in line with the conclusions that the buoyancy should have been removed from the end part of the hull and shifted into the main section.

The additional resistance of the two rudders was quite large. This resistance is due to the fact that the hollow profile type chosen with an indication of a fish-type trailing edge is not very favorable for the bow rudder in reverse flow. The rudders clearly needed to be optimized for both conditions. The results of the power sharing tests showed that there was a small benefit only when putting additional power into the forward propeller. Also, the additional power requirement of the forward propeller was quite large, although the forward propeller was running at a very favorable pitch ratio. This action was in line with our theoretical considerations: To minimize its additional resistance, the bow propeller must have a large P/D-Ratio. On the other hand, the stern propeller can benefit from a large P/D-ratio only if the thrust loading is so low that the stern propeller still runs at a favorable J-Value. In this respect, a CPP should further be considered as a useful option. In general, all numerical predictions that were performed before the model tests were conducted were validated by the OCEANIC model tests. These tests gave proof that these codes could usefully support the product development. Most important was the finding that the wave pattern could be predicted correctly, as we did not have experience in applying the code to double-ended ferries, and the interaction of the bow wave with our hull form resulted in significant numerical problems. Now we were in a position to finally optimize the hull form and the propulsion concept based fully on numerical predictions.

The advantages of CPP propulsion

The most important finding from the OCEANIC model tests with respect to the final configuration of the propulsion concept was the fact that regardless of the optimum power sharing, roughly 25% of the total propulsive power were required simply to compensate for the existence of the forward propulsor, if this unit is designed as a fixed pitch propeller (see Fig. 5, right). Therefore, it was a straightforward consequence to go for CPP propulsion and to feather the bow propeller into a position where the additional resistance of the bow propeller was a minimum. From theoretical considerations based on 2 quadrant experimental results of a CPP operating freely without torque, the optimum feathering angle of the propeller was determined to be about 88 Degrees, trailing edge forward. A special hub was considered which allowed for a blade turning range of beyond 115 degrees. It was possible to fully feather the CPP into the desired position and at the same time operate the stern propeller at a reasonable design pitch. At the same time, the CPP also offers a big economical advantage, as the design requirements put forward by BCF clearly demanded a diesel electric configuration. In case a CPP is used, this allows for constant rpm operation and there is no need for any cycle or synchro converters, which significantly reduced the initial building costs. However, this decision makes the final automation concept, especially the starting procedure of the drive motor, a little more complex with respect to the BCF acceleration and stopping requirements. The propulsion plant then consisted mainly of the four MaK 8M32 prime movers, the electric drive motors, gearbox, shaft line and the CPP. From this propulsion train design, the important feedback to the bow propeller is the fact that in case the bow propeller would not be feathered to a zero torque condition, it would have to turn the complete shaft line, gear box and drive motor, which is obviously not a zero torque condition. From initial calculations, it was suspected that the additional resistance of the bow propeller would be significant in case it was not set to a close to zero torque condition. In this respect, large care was taken to perfectly meet this condition. Based on the maximum draft of 5.75m, a propeller diameter as large as reasonably possible was selected, which resulted in a 5.00m propeller diameter. If the stern wave height and the dynamic sinkage at the A.P. were taken into account, the dynamic immersion of the propeller was large enough to fully absorb all required power without any hint on air drawing. Fig. 6 shows the aft body outline and the towing tank model of the final hull form design that was thoroughly tested in the Hamburg Model Basin (HSVA).
The HSVA resistance and propulsion tests

Systematic model tests were carried out at the Hamburg model basin. Both during resistance and propulsion tests, the bow propeller rpm as well as the bow propeller torque and thrust were measured. During the resistance tests, the model was equipped with all appendages including the bow propeller in the pre-calculated feathering position. The stern propeller was replaced with a dummy hub. Together with the measurement of the resistance, the bow propeller thrust measurements gave a clear picture of the effect of the feathered bow propeller on both the resistance and propulsion behavior. The resistance tests confirmed the pre-calculated wave pattern as well as the dynamic sinkage characteristics of the hull, which was always down by stern. The bow wave was smooth, and a little spray could be observed only at the 23 knot testing condition.

During the resistance tests, it was found that the bow propeller was slightly turning at about 0.5 rev/s, an indication for the fact that the optimum feathering condition was not fully met, which could have also been a consequence of the wake of the asymmetrically-shaped rudder. An additional run where the bow propeller was fixed confirmed the fact that the influence of the bow propeller on the performance was significant, as the required effective power increased for about 500 kW (see Fig. 8). The propulsion tests showed an extremely large propulsive efficiency that was determined to be about 0.80. This fact was mainly a result of the high propeller efficiency and the low thrust deduction fraction. In total, the power demand was more or less as expected and took the very low value of about 9200 kW for the full-scale ship. As the tests were governed by the scale effect of the appendage, a form factor evaluation was additionally performed, which resulted in a prognosis of about 500 kW less than the conventional method. Therefore, the design target was fully met, even if the standard evaluation method was used, and it can be expected from the form factor results that the full-scale vessel will perform slightly better. During all tests, there was no indication of air drawing. To check for the influence of air drawing on the station keeping, additional bollard pull tests were performed. These tests showed that without stern wave, some slight air drawing could be noted. Yet the measured power under these conditions was still larger than the maximum output of the drive motor, which resulted in more than sufficient thrust for the station keeping requirements. The wake field measurements have shown smooth gradients in the 12o’clock position. Although the hull was fully symmetric, the wake field (see Fig. 9) is slightly asymmetric, a result of the bow propeller and the twisted bow rudder.

Wake Wash Requirements

As the new SUPER C-class vessels will operate in a protected environment, special requirements put forward by the Canadian Administrations with respect to wake wash had to be fulfilled. Reference is made to the BCFERRIES report "British Columbia Corporation, Fast Ferry Program - Wake and Wash Project - Final Report, August 2000." In this report, wave heights in the near and far field of the existing C-Class which have been measured in full scale are documented, and the wave heights generated by the existing ships have been found to be to be uncritical for the environment. For the wake wash analysis, the computations were also validated against the wave patterns obtained by the model basin OCEANIC, St. John's, where model tests for the existing C-Class ships were carried out. These tests were performed at a larger draft, which was also evaluated by our CFD method, and the agreement between model experiment and calculation was found to be good. Fig. 9 gives an overview about the results, which compares the existing C-Class vessels (left) with the new design (right). The report by British Columbia Ferries states the following permissible wave heights in wave cuts perpendicular to CL of the vessel:

- 0.90 m in the range of 0.00 - 0.10 nm
- 0.72 m in the range of 0.10 - 0.25 nm
- 0.56 m in the range of 0.25 - 0.60 nm
- 0.46 m in the range of 0.50 - 1.00 nm

From the near field calculation, there is good agreement between calculation and measurement: Close to the ship in the stern wave pattern, the maximum wave height was calculated to about 1.00m, (We calculated the intended speed of 21 knots instead of 20 kn, as in the report.), and in a distance of about 0.05 nm a wave trough of about 0.80 m is found. The far field calculations show wave heights of slightly above 0.40 m. The results are roughly in line with the values stated in the BCF report. The same calculations carried out for the FSG design show that the wave heights generated are significantly lower, especially in the wake, although the local trough at L/2 is somewhat larger. In the near field, a maximum wave trough of about 0.80 m is generated very close to the hull at L/2. Due to interference effects, at a distance of about 0.05 nm from the CL of the ship, a maximum wave height of about 0.3m can be found. The far field calculations show maximum wave heights of about 0.2-0.3m. In general, the whole wave pattern is
characterized by lower wave heights compared to the existing C- Class ships. Again, this view is valid proof that the chosen concept is competitive, as the wave making is significant although the displacement is far higher.

Propeller design and pressure fluctuations

Regarding the propeller design, BCF required a very high comfort class, which resulted in low acceptable vibration levels. At the same time, the ice strengthening for the propeller was a main driver for the propeller design, because the ice strengthening resulted in thicker blades, which increases blade rate. Due to demands of the classification society, the ice class requirements restricted the skew that limited the possibilities of the propeller design. Further, the operational profile of BCF required a significant amount of time where both propellers were idling in harbor during loading/unloading, resulting in an off-design condition that had to be regarded for the propeller design with respect to erosive cavitation. This condition was considered a problem as the propellers were always operated in the constant rpm mode.

To check how these demands fitted to the hull form concept as such, fully unsteady VLM-cavitation calculation was performed to judge both upon the cavitation behavior and the propeller excited pressure fluctuations. For the calculations, the wake field measurements that were taken at HSVA were adopted to the full-scale ship applying Yazaki’s approach. Also, deformation of the wavy surface and the sinking at the A.P. were taken into account. Based on these calculations, the propeller-excited pressure fluctuations were calculated for various propeller alternatives as well as for the final propeller design prior to the cavitation tests. The clearance to the propeller is about 30% of the propeller diameter, and the area exposed to the propeller fluctuation was kept to a minimum during the design of the hull. The forced vibration analyses of the steel structure have brought the result that the BCF requirements could be fulfilled if blade rate was below 2 kPa, higher harmonics steadily decreasing. Due to the design restrictions with respect to the limited skew, the first propeller did not meet the requirements, and it was then agreed upon with ABS and the propeller maker that the propeller design should be evaluated according to acceptable blade stresses instead of simply limiting the skew. This decision allowed them to modify the propeller, and the final propeller design met the target of both according to the numerical simulations as well as during the final tests in HSVA's HYKAT. The propeller development clearly showed that without assistance by scientific numerical simulations, competitive design tasks could hardly be performed.

Maneuvering performance

The most important maneuvering criterion to be achieved was a good course keeping ability of the vessel, because sufficient turning is not a problem for this type of ship. It is extremely important for such kinds of vessels to have excellent course keeping ability, because low yaw checking ability will result in permanent rudder action resulting in higher fuel demand and larger wear of the steering components. Course keeping ability is a problem for this type of ship due to the unfavorable main dimensions (with respect to maneuvering) combined with the double-end ferry restrictions. There are only a few ways to influence the hull yawing moment due to the fact that both the fore- and aft body are the same. Furthermore, the bow rudder is problematic because it decreases course stability drastically even if fixed at the neutral rudder angle. Maneuverability was achieved by a highly efficient twist flow rudder of FSG type (see e.g. Fig. 6) that was designed for both the maximum lift and quick rudder actions due to good balancing. The rudder was designed by the application of a nonlinear panel method for rudders in the propeller slipstream. The numerical simulations of the standard IMO maneuvers, such as turning circles or zig/zags, have shown that the related maneuvering data such as turning circles and overshoots is far better than the IMO data. Even the turning rate demanded by BCF for the full rudder turning circle, which was more than 90 degree/min, could be achieved without major problems. Since the numerical prediction of the standard maneuvers by the TUHH/FSG code is sufficiently validated, there seemed to be no critical points in the standard maneuvering behavior. The challenging part of the maneuvering requirements put forward by BCF was the prescribed acceleration time and stopping distance. To obtain information on the acceleration time, a full simulation model of the vessel was required which included the dynamic behavior of the propulsion plant and the system automation. The available propeller torque during a time step of the acceleration maneuver depends on the ability of the diesel engines to increase their dynamic load, which then influences the pitch control of the CPPs. The hydraulic system of the CPPs was designed for blade turning rated of about 1.2 Deg/s, and the automation system had to be designed to cope with this high value. On the other hand, the stopping proce-
The vessel, the BCF was in the position to operate the vessel in the virtual Active Pass. In several training sessions, the virtual SUPER C-class vessels were successfully maneuvered through the virtual Active Pass, and it was found that the vessel was fully able to operate in the Active Pass even under the most critical weather condition. So the numerical simulation was again a useful tool that enabled the BCF to check their requirements long before the actual delivery of the vessel.

Conclusions

A new hull form and propulsion concept for the new BCF SUPER C-Class double-ended ferries was developed totally from scratch. As the design requirements for the new building tackled completely new design aspects such as detailed maneuvering requirements and Active Pass transit, many different design alternatives had to be systematically investigated to find the best solution that could cope with the requirements. It was found that the majority of the design tasks could only be handled with numerical simulations, where the simulation models had to be generated by either model tests or full-scale trials that had to be carefully evaluated. The simulations helped to figure out critical design drivers or design risks that could then be rationally judged. All of these investigations assisted the design process and ended in a competitive product. Finally the BCF ferries chose the FSG design for their replacement program of the existing C-Class vessels. This selection process is proof for the fact that competitive solutions must be assisted by state of the art design tools and methods, which consequently have to be applied during the product development phase.

References


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