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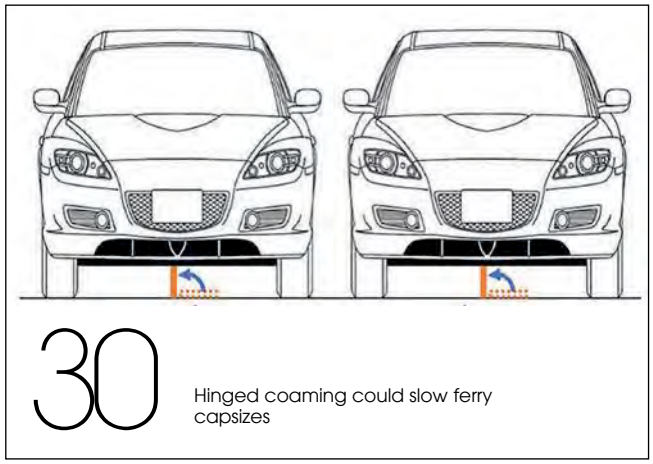

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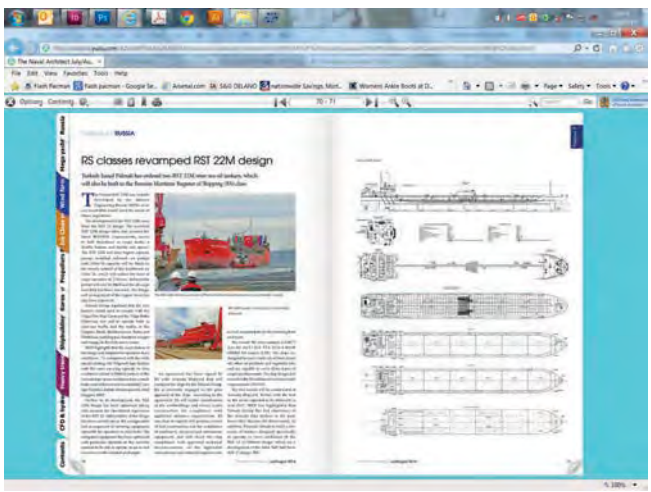

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Korean shipbuilding buys itself time - but at what price?

HHI shipyard in Ulsan

The expression may be Chinese, but South Korea is living in interesting times. At the time of writing an unprecedented summit has just taken place with its estranged neighbours in the North, paving the way – supposedly – for denuclearisation of the whole Korean peninsular. Whether this newfound desire for reconciliation has more to do with the pressure of US sanctions and fear of military action is outside of this journal's remit to speculate but it does raise the question of whether, someday, the two countries might be reunified.

It's worth remembering that at the end of armistice in 1953, and Korea's formal division the following year, both were among the world's poorest countries, with South Korean GDP being less than that of some sub-Saharan countries. It wasn't until more than a decade later that the administration led by President Park Chung-hee took the audacious decision (particularly given the country had no iron ore resources of its own) to build a steelworks, leading to the formation of the Pohang Iron and Steel Company (POSCO). Steel production became the backbone of South Korea's rapid growth, nowhere more so than in ship construction.

But the salad days of the 1970's and 80's have seemed a long way off for Korean shipbuilding in recent years, which has struggled to regain its footing since the economic crisis of 2008-09 and continues to lag behind China. The difficulties of the 'Big Three' Korean shipbuilders – Hyundai Heavy Industries (HHI), Samsung Heavy Industries (SHI), and Daewoo Shipbuilding & Marine Engineering (DSME) – have been well documented, with all undergoing significant restructuring and the inevitable confrontation with the labour unions that this has brought.

The options have been limited. Attempts to diversify into the offshore market several years ago were largely thwarted by that sector's collapse, while the economies of scale, not to mention the surplus of tonnage, have meant bulk carriers ceased to be viable some time ago (with the exception of some very large ore carriers). Nonetheless, the rhetoric from the Korean yards has been bullish this year, with all the Big Three raising their orderbook expectations, with the LNG sector in particular becoming a source of new contracts. DSME, which returned to profit in 2017 for the first time in six years, now has eight LNG carriers booked, although it is now majority owned by the Korean government. HHI, which is targeting an orderbook value of US$13.2 billion for 2018 (up from US$ 9.9 billion last year), accounts for more than 40% of current global LNG carrier orders by itself.

But is this really papering over the cracks? As reported in last month's Naval Architect, the South Korean government recently announced its Ministry of Fisheries and Oceans would prop up its shipbuilding industry by underwriting 200 ship orders, as well as an additional investment in naval and patrol vessels. It's prompted cries of foul play by the Japanese government, which argues the subsidies are distorting the market and is said to taking its case to the World Trade Organisation with the support of Japanese shipbuilders. One has to suspect the historic rivalry between the two nations has something to do with it, given that Japan would be unlikely to pick a fight with China, which continues to build the most competitively priced ships of them all.

Moreover, in the drive to improve the efficiency of the Korean shipyards one of the compromises being made is in slashing the investment in R&D. Recent reports suggest that HHI spent less than half (Kwon90.7 billion (US$85.74 million)) in 2017 than it had the previous year (Kwon203.4billion (US$192.89 million)) with equivalent declines at DSME and SHI. If Korea has previously leveraged some advantage over the Chinese by being able to offer a superior product, there's no longer the same commitment to new technologies and innovation in its vessels.

I'm reminded of a visit I made with a colleague to the stand of one of the Korean shipbuilders at Nor-Shipping in Oslo last year. Granted, there was a certain language barrier, but far from being enthusiastic to tell us about its latest designs, orders and deliveries, the shipyard's representative was more interested in asking us what we thought about the state on the maritime industry and what was likely to change in the coming years. Perhaps survival is of paramount importance right now, and nobody can reliably predict what's likely to change in the next few years, but there is now the real danger that Korea may lose ground that it can never recover. *NA*

Class societies

IACS outlines future strategy

The chairman of the International Association of Classification Societies (IACS), DNV GL's CEO Knut Ørbeck-Nilssen, stressed the organisation's commitment to quality, modernisation and transparency following publication of its 2017 Annual Review.

Speaking at a press briefing in London, Ørbeck-Nilssen said that digital transformation and enhanced connectivity will dominate over the next decade, which in turn will enhance the environmental and safety performance of vessels. By way of example he noted the growing use of drones for surveying and noted that 2017 had been a "breakthrough year for electronic certification" with something like 70,000 e-certificates issued to 7,500 vessels.

He added that while some technologies, such as additive manufacturing, are still at the "starting blocks", the next decade will see increased use of sensor technology in newbuildings and with it expanded use of Big Data. The role of IACS, he believes, is to be "a beacon of light setting the course ahead – with modern requirements, transparent processes and the highest quality of service."

Amongst its recent work, IACS formed a working group to address Unified Requirements (including Common Structural Rules (CSR)) which will need to be amended to facilitate the technical development of autonomous ships. It has also established a Cyber Panel to develop a cybersecurity risk model which is expected to publish a list of 12 recommended practices later this year.

As part of IACS' commitment to transparency, for the first time the annual report includes separate data summaries for each of the 12 current IACS members, detailing their fleets (including vessel numbers by type), tonnage and total number of surveyors.

Knut Ørbeck-Nilssen, CEO, DNV GL said 2017 was a year in which maritime players had grappled with "tectonic changes in markets, regulations and technology"

The report also looks at the work of the IACS dedicated Project Team into re-examining the parameters and values for wave-induced ship responses, or Equivalent Design Waves, to bring them in line with the extreme wave loads definitions in the CSR rules.

DNV GL's chairing of IACS will end at the close of the usual one-year tenure on 30 June. Ørbeck-Nilssen be succeeded by the Korean Register's Jeong-kie Lee.

LNG

Advanced hybrid LNG carrier christened in Nagasaki

Diamond Gas Orchid, a state-of-the-art LNG carrier owned by Nippon Yusen Kabushiki Kaisha (NYK Line) and constructed by Mitsubishi Heavy Industries, was christened last month at the group's Nagasaki Shipyard & Machinery Works.

The 73,800dwt LNG carrier measures 293.5m in length and 48.94m in width, with a depth of 27.0m and draft of 11.05m. *Diamond Gas Orchid*'s overall holding capacity of 165,000m^3 is greater than that of its predecessor, *Sayaendo*, because of the apple-shaped design of its LNG tanks, replacing *Sayaendo*'s Moss-type spherical tanks.

Significantly, the vessel is the first of the 'Sayaringo STaGE' type designed to improve capacity and fuel performance. These goals are achieved through an optimised hull structure, as well as with the use of STaGE (Steam Turbine and Gas Engines) hybrid propulsion, in which waste heat from the steam turbine is used to deliver considerable improvements in plant efficiency across the full range of speeds.

Diamond Gas Orchid was launched in March last year, and is scheduled for completion in late June. The vessel will be utilised as part of the Cameron LNG project in Louisiana, USA, of which Mitsubishi Corporation and NYK Line are partners.

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Tankers

Keppel wins order for dual-fuel bunker tanker

Following a finance agreement with Mitsui AP, Sinanju Tankers Holdings have ordered Singapore's first dual-fuel bunker tanker from Keppel Singmarine, with the option to order a second similar tanker within six months of the contract's effective date.

Weighing in at 7,990dwt, the BV-classed vessel will be fuelled by LNG and deliver fuels to other vessel within local port limits. Sinanju is set to benefit from Sing$2million of available co-funding from the Maritime and Port Authority of Singapore's LNG bunkering pilot programme (LBPP), established to develop the LNG bunkering capacities the world's largest bunkering port.

Commenting on the ship's bunkering role, managing director of Sinanju Tankers Ju Kai Meng said: "Sinanju aims to kick start a green initiative for bunker tankers operating in Singapore; for our vessels to emit less air pollutants while boosting the local use of LNG as a bunker fuel. We will be in good stead when embarking in ship-to-ship LNG bunkering as our next milestone."

Keppel O&M, the owner of Keppel Singmarine, is experienced in the LNG market having delivered the first-ever converted FLNG vessel, *Hilli Episeyo*, in October last year. The company is also building two dual-fuel LNG carriers and two dual-fuel containerships for Stolt-Nielsen Gas and Pasha Hawaii respectively, and is part of the joint FueLNG venture with Shell Eastern Petroleum.

The dual-fuel bunker tanker will be the third vessel to be built by Keppel Singmarine under the MPA LBPP and the seventh dual-fuel vessel built by Keppel O&M. It is scheduled for a 2H 2019 delivery.

Tankers

Eco-friendly VLCC delivered to Almi Tankers

Greek tanker operators Almi Tankers S.A took delivery of the first of two VLCC newbuildings, the M/T *Almi Atlas*, at Mokpo shipyard last month. The vessel is classed by DNV-GL, and flies the Liberian flag.

Weighing in at 315,221dwt, the Hyundai Samho Heavy Industries-built VLCC is 'among the most eco-friendly ships worldwide', according to Almi Tankers. This accolade is largely achieved through the choice of a Hyundai-B&W 7G80ME-C9.5-EGRTC (Tier-III) Green-type engine, which features an ultra-long stroke and a propeller with a larger-than-usual diameter, reducing emissions as compared against other engines with the same output. *Almi Atlas* is one of just a handful of vessels of VLCC proportions fitted with a Tier III engine, a designation made possible by the installation of an exhaust gas recirculation system (signified by the EGRTC designation) which reduces the NOx emissions of the vessel's heavy fuel oil.

Almi Atlas

Further technology on board the vessel designed to reduce environmental impact includes a Hyundai HiBallast HiB 6000ex Ballast Water Treatment System and SOx scrubbers, future-proofing *Almi Atlas* against the 2020 sulphur cap.

Singapore

Finland and Singapore forge new partnerships

Two Finnish companies used Singapore Maritime Week in April to announce their involvement with new projects in the Asian city state as it seeks to further its development as a marine technology hub.

Wärtsilä is to partner with the Maritime and Port Authority of Singapore (MPA) to develop and field test smart ship technologies with local operators – including autonomous ship research and secure data exchange between ports and vessels – through co-creation and mentorship of start-up firms. The organisations will also educate and showcase maritime technologies at the MPA's Living Lab and a new Singapore iteration of Wärtsilä's Digital Acceleration Centre (DAC).

Meanwhile,cargo-handling machinery specialists MacGregor, part of Cargotec, is to join the Finland-Singapore Maritime Innovation camp, taking place later this year. The collaboration between the University of Turku, Singapore Maritime Institute, MacGregor and Singapore's PSA Corporation will see participating students presented with a challenge designed to generate innovative ideas which will then be pitched to a judging panel.

"In our daily operations we tend to be focused on technical details, while students can consider a wider, more general, cross-industrial view without limitations in their ideas. The benefit for universities and students is the possibility to test theories on real life challenges," said Janne Suominen, Manager, Offering Development, MacGregor Cargo Handling. *NA*

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MEPC 72 sets out new roadmap for GHG

IMO's CO_2 pledge captured the attention of the mainstream media but questions remain, writes Malcolm Latarche

Although shipping's environmental credentials often come under attack it is rare for the musings of the IMO's committees to get a wider airing than in the marine press. So the fact that the results of MEPC 72 were reported on TV and radio stations around the globe underlines that something regarded as of great public interest was being determined.

In fact, very little was decided at the meeting beyond a compromise agreement on a strategy that has some ambitions but as yet very little in the way of substantive detailing. What generated all the comment was that shipping has appeared to have adopted a roadmap to reduced dependence on fuels that produce greenhouse gases (GHG) with an aim to eventually phasing them out by the end of this century. The strategy includes a specific reference to "a pathway of CO_2 emissions reduction consistent with the Paris Agreement temperature goals".

Before the MEPC meeting an Intersessional Working Group had been exploring the possibilities of reducing shipping's GHG contribution but it appeared that no compromise was possible between two extreme options. In the event, the protestations of the US and Saudi Arabia meant that the agreement at MEPC was not unanimous. Other countries including Brazil and Argentina had also appeared to be prepared to oppose the measure but did not vote against it.

It should not be forgotten that shipping already has an earlier roadmap to GHG reduction, adopted at MEPC 70 in October 2016, which runs until 2023 and under which the IMO has put in train its own gathering of data on GHG emissions. At MEPC 72 this was taken a little further with the declared ambition to reduce the total annual GHG emissions from shipping by at least 50% by 2050 compared to 2008 levels.

Part of this will likely be achieved by adding a fourth phase to the EEDI requirements which oblige most newbuildings to be 30% more efficient after 2025 compared to a 2012 baseline. If this idea is adopted, then the most likely result would be a further 10% efficiency saving with effect from 2030.

The means by which these efficiency savings are to be achieved is the area most lacking in detail. The IMO and most shipping bodies, although welcoming the ambition, recognise that there will need to be some major technological developments if it is to be realised but have yet to identify what these developments might be and if in fact they are achievable at all. The general perception is that fuels such as LNG will provide the largest contribution.

Notably, the EEDI rules do not regulate all GHGs but concentrate only on CO_2. As presently formulated, the 30% reduction of CO_2 under EEDI rules could almost be achieved by a wholesale switch to LNG which produces about 25% less than HFO, but the additional 10% needed for a fourth phase would need to come from other efficiency savings or a change to fuels with lower CO_2 levels still. It is interesting to note that the IMO itself in setting out targets refers to carbon emissions through to 2030 but to GHGs thereafter. Arguably, that could be seen as recognition that LNG reduces carbon but methane itself is a potent GHG.

Continuing the momentum of work on this issue, MEPC agreed to hold the fourth Intersessional meeting of the Working Group later in the year. This working group will be tasked with developing a programme of follow-up actions to the initial strategy; further considering how to progress reduction of GHG emissions from ships in order to advise the committee; and reporting to MEPC 73 in October.

Shipping's new GHG strategy may have been the main talking point but other topics were on the agenda at MEPC 72. Another fuel related matter that had received a lot of attention in the weeks preceding the meeting was the view by some sections of the industry that there may be wholesale cheating once the 2020 global cap reduction on sulphur levels is in force.

Several shipping bodies had called for a ban on the carriage of non-compliant fuels on any ship not fitted with a scrubber or other approved means onboard. The call was well received and amendments to regulation 14 of MARPOL Annex VI were approved with planned adoption at MEPC 73 in October. If adopted, the amendment would mean carriage of non-compliant fuel for use on board would be prohibited. This should not affect the exemption permitted to vessels if compliant fuel is unavailable but some believe clarification on the amount of fuel that can be taken under such circumstances is needed.

Ballast water was also on the agenda, with the finishing touches put to allowing delayed installation of systems on existing ships agreed at MEPC 71. A new Code for approval of systems was adopted. Effectively this makes the 2016 revised G8 type approval guidelines mandatory. Systems approved under the original G8 rules can continue to be installed until 28 October 2020 after which only type-approvals under the new rules will be acceptable. *NA*

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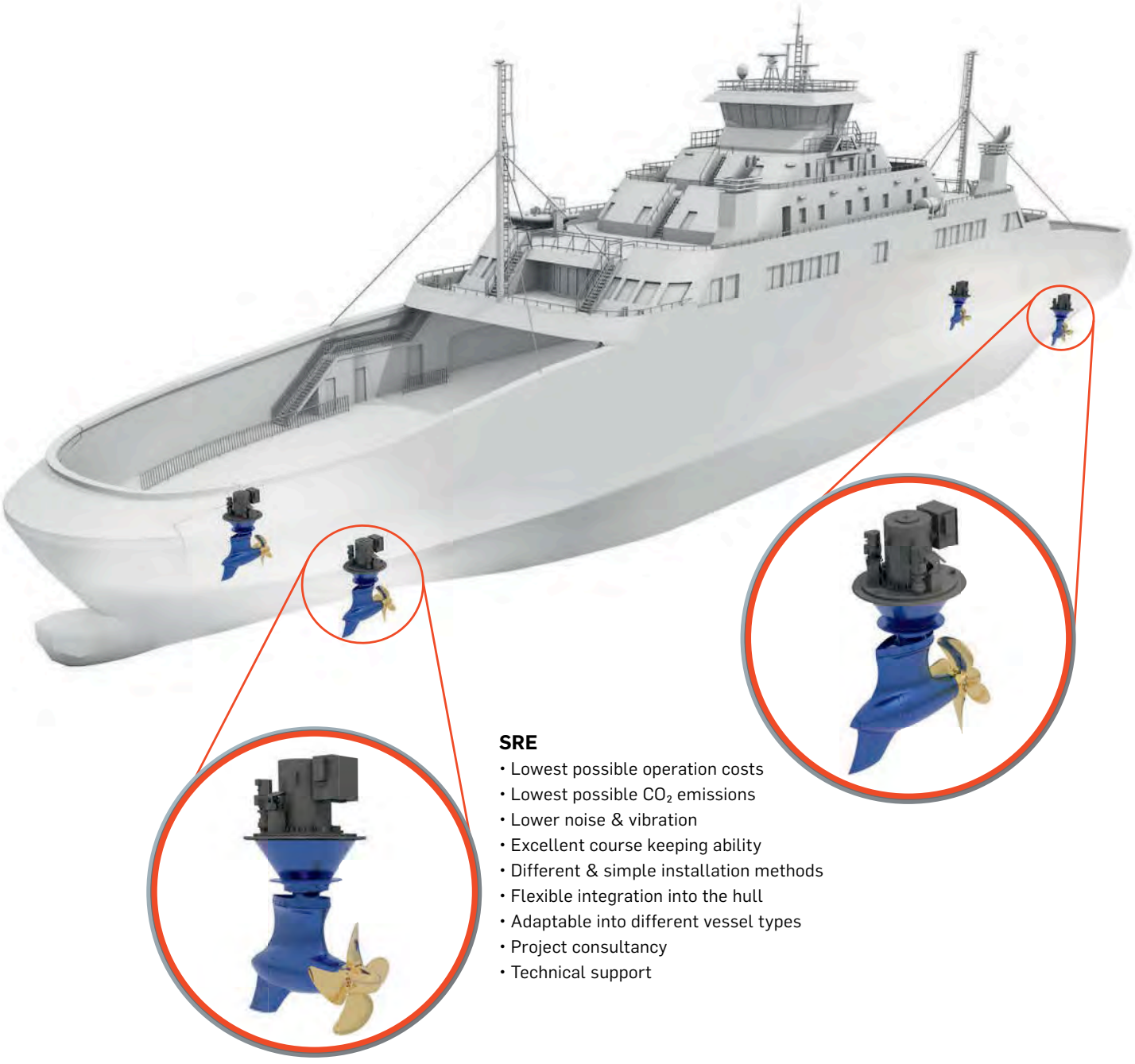

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Navigation

Rolls-Royce and Fjord1 sign autocrossing deal

Norway's largest ferry operator, Fjord1, has signed a deal with Rolls-Royce Marine for installation of the technology company's autocrossing systems, plus two azipull propellers and propeller control systems, on 13 new eco-friendly ferries.

The autocrossing system, which Rolls-Royce states is the first of its kind, will control the vessels' acceleration, deceleration, speed, and track on their regular back-and-forth voyages, providing 'safe, predictable and energy-efficient transit.' A captain will remain present on vessels fitted with the system, supervising its operation and intervening if necessary by taking manual control. In the event that the captain cannot do so, an override causes the vessel to stop before reaching the quayside.

Available as a retrofit, the system is able to work in conjunction with any standard Rolls-Royce azimuthing thruster. On the new vessels, it will work in an optimal capacity, as the azipull propellers are able to respond adaptively to environmental conditions.

Two Norwegian shipyards – Havyard Ship Technology and Fjellstrand – are due to build five ferries and one ferry respectively, whilst three Turkish yards – Tersan, Cemre, and Sefine – will take two, two, and three each. Fjord1 has already taken delivery of three ferries with auotcrossing capabilities from Tersan. This takes the operator's total number of vessels with the autocrossing system up to 16.

Fjord1's CEO, Dagfinn Neteland, stated: "Our passengers will be part of the most environmentally friendly and modern transportation concept ever seen in Norwegian fjords."

A smaller Norwegian ferry operator, FosenNamsos Sjø, has also ordered two ferries with the system, which are under construction at Kleven's Myklebust shipyard.

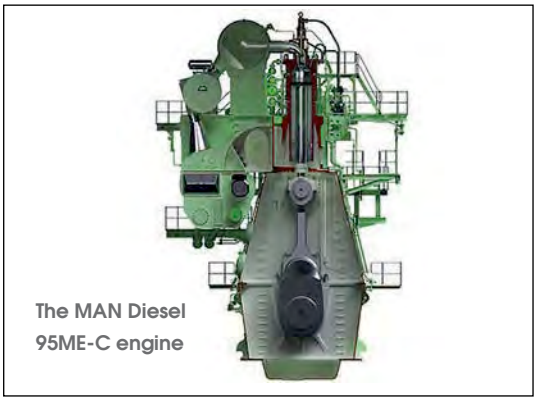
www.rolls-royce.com

Engines

MSC opts for MAN engines across 11 newbuildings

Mediterranean Shipping Company (MSC) has placed an order with Samsung Heavy Industries (SHI) and Daewoo Shipping Marine Engineering (DSME) for 11 23,000 TEU container vessels – of which the yards will construct 6 and 5 respectively – and has selected MAN B&W 11G95ME-C9.5 engines across the entire series.

The 103,000hp G-type engine features an ultra-long stroke which outputs a low rpm, generating a lower optimum engine speed. This enables the use of a large propeller rendering the G-type an efficient propulsion choice that offers reduced fuel consumption and CO_2 emissions.



The MAN Diesel 95ME-C engine

The engines bound for Samsung Heavy Industries are to be constructed by Hyundai Heavy Industries, whilst those set for Daewoo Shipping Marine Engineering are the responsibility of Doosan engine. MAN Diesel & Turbo state that they currently have 71 G95 engines on order, noting that 23 are already in service.

As well as supplying the prime movers, MAN is also set to deliver GenSets for the 11 vessels, which will be built by Korean company STX Engine. Each vessel will receive three MAN 9L32/40 units and two MAN 6L32/40 units, which output 500 kW per cylinder and feature twin camshafts, stated to provide a high level of fuel ratio flexibility.

MAN's Bjarne Foldager, VP of sales and promotion, two-stroke business, said: "It's a significant order that cements our strong position within the large containership segment where the G-type is the market's preferred engine."

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Ballast water treatment

Ballast makers announce trade association

The inaugural meeting of the Ballast water Equipment Manufacturers' Association (BEMA), a collective of manufacturers and stakeholders in the market, took place in New York in April. BEMA, which is registered as a trade association in the United States, aims to provide co-ordinated, technical and non-commercial guidance to the maritime industry and regulatory authorities.

BEMA's first elected president, Mark Riggio, of ballast treatment manufacturers Hyde Marine, said that the organisation's formation was borne of "the realisation that we needed to have a unified voice in the conversation," following the implementation of the Ballast Water Convention (BWC) at MEPC 71 last September.

The organisation has already discussed applying for non-governmental organisation (NGO) observer status at IMO. According to Steve Candito, CEO of Ecochlor and a member of BEMA's board of directors, it has already been approached by ICS, BIMCO and other shipowner associations, regarding the challenges of

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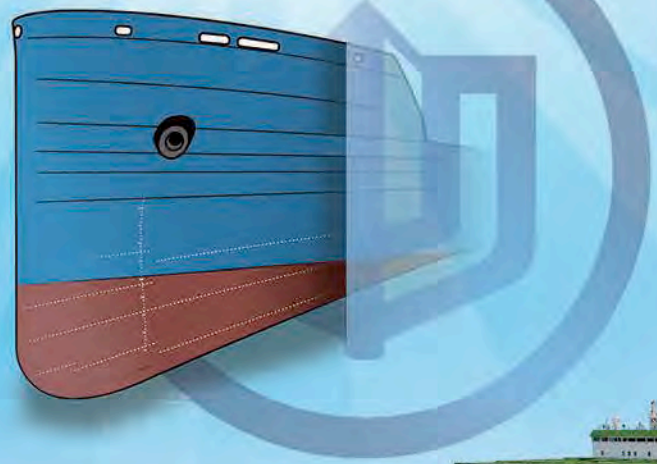

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BWC implementation. "We're ready to talk," he added.

Among its stated objectives, BEMA says that it will: "Provide and stimulate organised research, education and information exchange within the industry," as well as providing advice on design, manufacture, installation and maintenance of systems.

BEMA's board of directors also includes representatives from Cathelco, Coldharbour, DESMI, Ocean Guard, Erma First, Evoqua, Optimarin, Panasia and Wärtsilä. BEMA told *The Naval Architect* that there are currently 17 active members, 15 of whom are manufacturers of Type Approved ballast water treatment equipment and two component /service suppliers.

www.bwema.org

Fuels

DNV GL white paper assesses alternative fuel options

DNV GL has published *Alternative fuels and technologies for greener shipping*, a 40-page white paper which assesses the viability and benefits of a range of alternative fuels and technologies. A 12-page executive summary, which presents the main findings and conclusions, is also available.

The alternative fuels considered in the paper to be the most "promising" are LNG, LPG, methanol, biofuel, and hydrogen, as compared against oil fuels HFO and MGO. From an emissions perspective, the paper notes that LNG produces the lowest CO_2 emissions, but that this benefit could be comprised by methane slip. Biofuel – liquefied methane produced from biomass – is also stated to have high CO_2 reduction potential, whilst hydrogen is similarly praised provided it is produced using regenerative energy.

Different ship propulsion systems and their effect on emissions are further assessed. Diesel-cycle engines operating on HFO are shown to require scrubber installation and either exhaust gas recirculation (EGR) or selective catalytic reduction (SCR) equipment to meet Tier III requirements. When MGO is used, scrubbers are no longer required, whilst LNG only requires EGR/SCR installation. Otto-cycle engines using LNG are "future-proof" when it comes to SOx and NOx, but methane slip becomes an issue. The COGES (combined gas turbine electric and steam) propulsion concept using LNG is entirely "future-proof" if power demand exceeds 30 to 35MW.

The paper also considers fuel pricing, noting that subsidies in the form of tax breaks for using alternative fuels have no effect as ship fuels are tax free. It highlights that only LNG and LPG can currently compete economically with HFO, whilst methanol and biofuels have potential to become competitive. Hydrogen is discounted in this regard.

Alternative technologies mentioned include Fuel Cell (FC) systems, which are yet to reach maturity to substitute engines; batteries, which are becoming common, but tend to offer a supportive role; and wind-assisted propulsion, which requires development to create a business case.

Ultimately, the paper concludes that all "existing and upcoming restrictions can be met by all alternative fuels using existing technology"; for most owners, the paper suggests that LNG is the best currently viable option.

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The report is available to download from DNV GL's website

Navigation

Wärtsilä tests autodocking system

In what it claims is a 'world first', Finnish technology giants Wärtsilä says it has completed successful trials of an innovative autodocking technology.

The tests onboard the *Folgefoon*, a ferry owned by Norwegian operator Norled, took place between January and April in year. The hybrid-powered vessel, which was already equipped with a Wärtsilä wireless charging system (see November 2017's *The Naval Architect*), was manoeuvred into its berth without the need for the captain to take manual control. Instead, an automated system is activated around 2km from the docking point which performs a gradual slowing down of the speed, before lining up and docking. The system can perform the reverse procedure for departure.

Although the software takes full control human intervention is possible at any point. Wärtsilä believes the system will allow bridge officers to focus on situational awareness outside the wheelhouse and reduce the likelihood of human error. Moreover, the more efficient use of the thrusters by the automation system means there is less wear and tear.

The trials build on the same Wärtsilä's successful remote control of a Svitzer platform supply vessel in the North Sea from its office in San Diego, California, last year. There are now plans for the *Folgefoon* to be utilised for further trials of new technologies as Wärtsilä develops its 'smart marine ecosystem' vision.

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SHIP ECONOMY & TRADE

China's first scientific research icebreaker enters next phase of construction

Due for completion next year, *Snow Dragon 2* will incorporate the latest technology and work in tandem with its predecessor to significantly enhance China's polar research capabilities

Finnish firm Aker Arctic Technology provided *Snow Dragon 2*'s basic design

On 28 March, China's first scientific expedition icebreaker, *Xuelong 2* (*Snow Dragon 2*), was formally docked for equipment installation at Jiangnan Shipyard (Group) Co. Ltd, which started construction of the vessel in December 2016. It is planned for the vessel to leave its berth on August 28, 2018 and be delivered in the first half of 2019.

Snow Dragon 2 has double acting icebreaking capacity and is able to continuously break ice at a rate of 2-3knots on a 1.5metre-thick ice sheet covered with 0.2-metre-thick snow. Designed to carry both scientific expedition personnel and crew together, the vessel can complete journeys up to 20,000nm as fresh water can be produced onboard, and the self-sustaining power can last for 60 days.

Finland-based Aker Arctic Technology Co Ltd are responsible for *Snow Dragon 2*'s basic design, with China Marine Design Institute (MARIC) carrying out the detailed design work. MARIC also participated in project construction, conceptual design, extended concept design, feasibility study, preliminary design, and basic design work of the new ship.

According to Wu Gang, head of MARIC's related technology, *Snow Dragon 2* is equipped with advanced marine environmental and geophysical survey equipment, able to perform polarographical surveys. The vessel's advanced design and construction render it internationally significant. It features a cutting-edge manoeuver support system, whilst its layout and design concept are in line with international scientific standards. Higher noise reduction requirements help prevent disruptions to research as well as providing a more livable environment. A 'smart ship' network platform also ensures the coordinated management of scientific data.

Safety and efficiency are aided by an advanced communication and navigation system with excellent positioning ability. In addition, the vessel offers complete Wi-Fi coverage, features radio broadcast and satellite television receiving systems, and will have an intelligent multimedia scheduling (conference) system.

Design breakthroughs

The Antarctic region endures tough conditions including snow, ice, and some of the planet's lowest temperatures and strongest snowstorms. To satisfy the 'heavy icebreaking' requirement of the vessel, the MARIC design team made

bold innovations and achieved a number of design breakthroughs:

- The design of the ship is based on the seaworthiness of the vessel in a sea ice environment, necessitating a sturdy PC3 hull structure and advanced power system design. The performance index is one of the highest amongst current polar expedition ships.
- To compensate for the complexity of horizontal ice and ice ridge distribution in the polar region, a bi-directional icebreaking ship type was selected, representing an important precedent in the development of icebreakers in China.
- For the first time, the bottom structure of the box keel is situated at the front of the ship, allowing the important acoustic equipment at the bottom of the vessel to avoid disturbance caused by the interference of air bubbles and crushed ice.
- Full-rotary electric propulsion was chosen to optimise manoeuvrability and allow for different operating conditions, save space inside the ship, and reduce the use cost;
- A DP2 dynamic positioning system ensures that the conventional redundancy of the positioning function also improves the dynamic positioning tolerance to harsh sea conditions, and enhances the safety of the ship in the polar area where manoeuvrability may be limited by ice and during rough sea conditions.
- The use of a centralised laboratory layout, a large job shop, and a large investigation work deck design, as well as the application of the ice pool moon pool system, enables the maximum integration between the vessel's experimental functions.
- *Snow Dragon 2* meets the latest rules and regulations, such as the Polar Code, and the latest Tier III emission limit requirements. Once completed, it will achieve safety, environmental protection, and suitability for scientific research operations at an international advanced level.
- The underwater radiation noise meets the international highest standard ICES-209, and the built-up vibration noise meets the high requirements of the latest COMF (V2/N2) of CCS.
- The ship will be the world's first polar icebreaker to receive 'smart ship' notations. The i-Ship-H smart hull notation guarantees the safety of the hull structure and provides life cycle protection, while the i-Ship-M functional notation for intelligent machinery ensures the reliable operation and maintenance of the ship's infrastructure in a remote environment, providing support for fleet management, voyage management during scientific expeditions, and integrated communications.
- The vessel's long voyages were taken into consideration, reflected in a human-centred design that prioritises the safety and convenience of scientists and crew in the laboratories and during bridge and deck operations.

Foreign partners

The *Snow Dragon 2* project adopted the principle of 'co-design and domestic construction at home and abroad'. The basic design was undertaken by foreign companies. The detailed design, production design, and related plan review work were all undertaken by domestic design institutes and classification societies, and Jiangnan Shipbuilding completed the vessel.

Wu Gang emphasises that this Chinese and foreign cooperation is not simply purchasing drawings and designs from abroad – all partners were deeply integrated with one another in the project. Even at the basic design, the Chinese side focused on the long-range characteristics of the ship, contributing their technical experience. The experience of designing and building *Snow Dragon 2* has fully equipped China with the technical capabilities to design further icebreakers. The implementation of this project will play a significant role in promoting the design, construction, application and improvement of polar ships in the Chinese shipbuilding industry, and the effective implementation of the Polar Code in China.

Since the formal start of construction on 20 December 2016, the co-operation between the Polar Office of the State Oceanic Administration, China Polar Research Centre, Jiangnan Shipbuilding, China Classification Society (CCS), Lloyd's Register (LR), Shuangxi Supervision Company and domestic and external design and research institutes have maintained continuous construction progress. As such, *Snow Dragon 2* is expected to be delivered by May 2019.

Double dragon

Conducting polar studies is of great significance in addressing climate change. After *Snow Dragon 2* is put into use, it will work in tandem with its predecessor *Snow Dragon*, undertaking scientific investigations and research work. *Snow Dragon* will mainly be deployed with the task of material transportation and replenishment. This means that the Chinese polar expedition will no longer have to rely solely on *Snow Dragon*, as has been the case for many years.

Snow Dragon is China's third-generation polar icebreaker and scientific expedition ship. It is a multi-purpose transport ship in the Arctic that was constructed by the Ukrainian Kherson shipyard in 1993. After importing the vessel from Ukraine, the Chinese shipyard transformed it into a scientific vessel. In 2013 and 2015, Jiangnan Shipbuilding (Group) Co., Ltd. carried out repairs on this ship. Not only that, when '*Snow Dragon*' travelled to Antarctica for a scientific investigation, experts from Jiangnan Shipbuilding (Group) Co., Ltd. went with the ship to provide technical support. Therefore, the shipyard has a wealth of experience in scientifically based examining ship construction.

China has always attached great importance to marine development and has not only proposed to actively participate in the formulation of international rules in new areas such as deep sea and polar regions, but also listed the 'Snow Dragon Exploration' as a major project of the country's '13th Five-Year Plan'. In the future, China's growing polar scientific expedition fleet will gradually form the 'Snow Dragon' series, and lay a solid foundation for the country's responsibilities towards polar research. *NA*

IMDC 2018 highlights the latest developments in ship design

The 13th International Marine Design Conference (IMDC 2018) will be held at Aalto University in Espoo, Finland, on 10-14 June

The aim of IMDC is to promote all aspects of marine design as an engineering discipline. This year's conference focus is on the key design challenges and opportunities in today's rapidly changing maritime markets with special emphasis on: the challenges in merging ship design and marine applications of experience-based industrial design; digitalisation as a technological enabler for stronger link between efficient design, operations and future maintenance; emerging technologies and their impact on future designs; and cruise ship and icebreaker designs including fleet compositions to meet new market demands.

IMDC 2018 has received 111 articles, including three State of Art (SoA) reports related to design methodologies and cruise ship design; and seven keynote papers related to the new direction for vessel design practices and tools, digital maritime traffic, naval ship designs and new tanker design for the arctic.

The icebreaking party starts the conference, with a visit to newly renovated Aalto Ice Tank. Other excursions taking place during the week are visits to Arctech shipyard, Meyer Turku ship yard, ABB Marine and Aker Arctic.

Excursions at IMDC 2018 include a trip to Meyer Turku's shipyard, which delivered the LNG ferry *Megastar* last year

Keynote presentations

The keynote presentations will be kicked off by Jan Meyer, CEO from Meyer Turku, and Kevin Douglas, Vice President Technical Projects Newbuild, Royal Caribbean Cruises Ltd., who will share their thoughts on the main success factors behind the long-term partnership of the two companies. A passion for creative thinking, innovative engineering and design drive continuous improvement and play the key role in this unique collaboration that keeps both companies ahead of their competitors.

Per Olaf Brett, deputy managing director at Ulstein, will then describe how market conditions have directly impacted the shift in vessel buyer behaviour, knowledge and experience building in the company, and why particularly, the vessel concept design processes and analyses toolbox, have been re-furbished and design work practices executed differently than in the past.

Oskar Levander, SVP Concepts & Innovation in Digital & Systems at Rolls-Royce, will highlight the recent development of autonomous shipping and the possible effects on future ship design.

Tommi Arola, head of mobility innovations and R&D at Trafi, will discuss the maritime domain's need for specific digital architecture to increase interoperability from an administrative point of view. Arola presents a case study of domain-specific digital architecture and its application in the maritime domain, focusing on information interoperability, and the data economy.

Meanwhile, Professor David Andrews from University College London will deliver keynotes on the future role of naval architect and whether they are still best placed to lead the design of complex ships. Andrews argues that the demands on future ships to deliver 'value for money' and assumptions of increased precision in potential ship solutions will lead to increased pressure.

Finally, Markku Kajosaari, head of marketing in Arctech Helsinki shipyard, will describe the new way of designing and constructing advanced ships for the Arctic through international networking.

'State of Art' reports

Prof. Andrews will outline the history of SoA reports, which have become a unique feature of the IMDC series of conferences. First introduced at the sixth IMDC held at Newcastle in May 1997, the SoA reports are discussed in open plenary session and recorded and published along with the discussions on each of the presented papers in the main sessions of the Conference. In IMDC 2018, there will be three SoA reports: Design Methodology (Prof. Andrews), Cruise ship design (Patrik Rautaheimo, CEO, Elomatic) and Arctic ship design (Reko-Antti Suojanen, CEO, Aker Arctic).

Other highlights

In the afternoon parallel sessions, 14 topics are organised based on the papers from worldwide academia and industries. The topics can be summarised as four series:

1) State of art ship design principles, including topics on education, design methodology, structural design and hydrodynamic design.
2) Cutting-edge ship designs and operations, with topics on ship concept design, risk and safety, arctic design and autonomous ships.
3) Energy efficiency and propulsion, covering energy efficiency, hull form and propulsion equipment design.
4) Wider marine designs and practices, looking at navy ships, offshore, wind farms and production vessels. *NA*

Further information

For more details about IMDC 2018, or to register online, visit: **www.imdc.aalto.fi**

Collaboration powers Rolls-Royce's autonomous vision

In its bid to realise remote and autonomous shipping before the decade is up, Rolls-Royce is making the most of today's collaborative industry. A visit to the company's Turku-based R&D centre suggests that its strategy is working

Readers of *The Naval Architect*, and indeed most individuals in the maritime industry, will doubtless have noticed the growing hype surrounding remotely operated and autonomous ships. To the optimistic, they are a revolutionary development that will facilitate a digitally-driven and more efficient future. To the sceptical, they represent a lofty promise, buoyed by a lot of talk but little in the way of real progress. Critics say such vessels are an unnecessary development that may compromise safety, employment, and shipping's tried-and-tested business model. The pragmatists see remotely operated/autonomous vessels as a promising innovation, but know maritime well enough to warn of the roadblocks of regulation and shipowners themselves.

Rolls-Royce's Remote and Autonomous Experience Space features an example of what a remote operations centre using IA might look like, allowing captains to swap sea for shore

Despite its contentious nature, a growing number of technology firms, industry bodies, shipping companies and nations are forging ahead with realising the project, betting on their prediction that remote and autonomous vessels represent the next step in the industry's natural evolution. A risky gamble perhaps, involving significant investment, but their commitment may be more understandable when we consider that the breakout economic success stories of our age have largely been companies that have embraced digitally driven disruptive business models – for example Airbnb, Uber, and Spotify. They may have attracted consternation by tearing up the rule book, but they have remoulded the business landscape on their own terms.

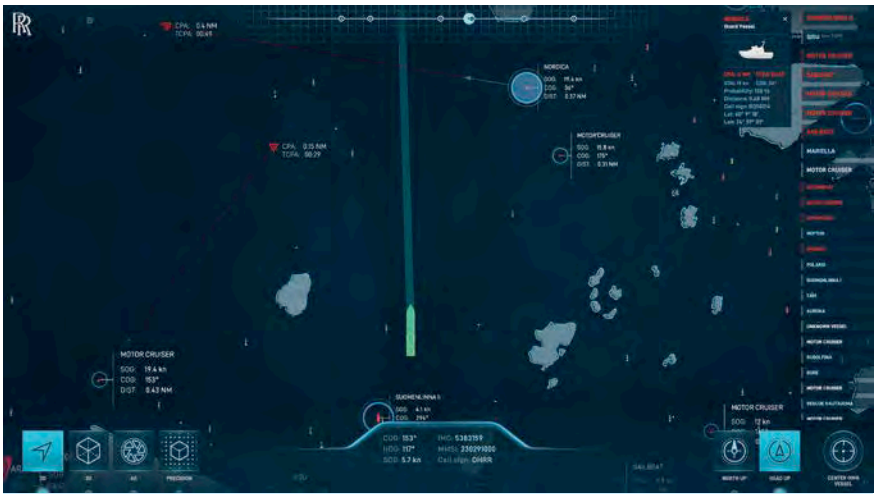
This is the goal of one of the biggest players in remote and autonomous shipping, Rolls-Royce, who set out their Unmanned Vessels Vision in 2013 and have since established a dedicated R&D centre in Turku, Finland, filed nearly 40 patents, and brought the first commercial technologies to market. For Rolls-Royce, fully autonomous vessels are a case of when, not if – and as if to prove this, they have consistently scaled back their timeline, claiming that remotely operated local vessels will be viable as early as 2020, and remotely operated and autonomous ocean-going vessels by 2025: a deliberate challenge to the technology's doubters.

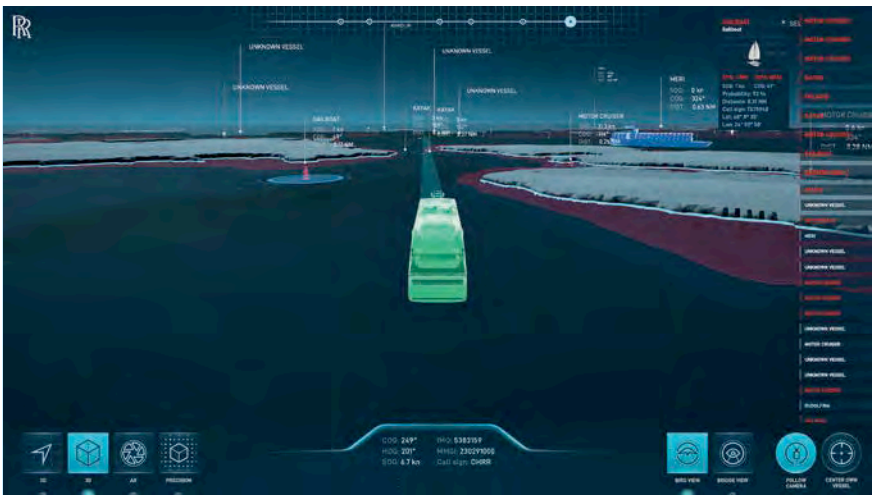
A collaborative effort

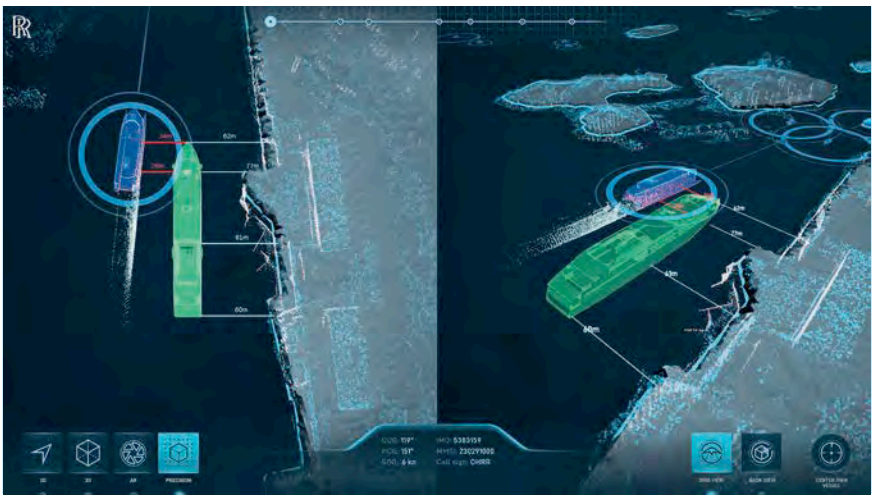
The uncertain future of Rolls-Royce's commercial marine division, which was announced as being up for sale earlier this year, doesn't appear to have diminished the company's confidence in delivering these goals. This may be due to the considerable support Rolls-Royce has attracted for the project, spanning technology powerhouses including Google (specifically Google Cloud) and the European Space Agency, national institutions including Finnish funding agency Tekes and the University of Turku, and maritime players from Inmarsat to DNV GL.

Such support has been actively sought by Rolls-Royce, which is keen to work collaboratively with partners who can bring their own expertise to the table and progress the project. This model reflects a growing tendency across maritime to work with rather than against competition in order to push forward technological development and secure mutal benefits. As Karno Tenuvuo, Rolls-Royce's SVP of Ship Intelligence, puts it: "We want to partner up with world class companies that give us credibility and allow this to scale up faster."

Besides large multinationals such as Google and ESA, support from Finnish companies and institutions has been particularly strong, as the country positions itself to become a leader in autonomous shipping and challenge its competing Scandinavian neighbours. Most reflective of this is the collaborative, Finnish-backed One Sea Autonomous Maritime Ecosystem explored in March's edition of *The Naval Architect*. Established by DIMECC in 2016, the collective body includes the likes of Meyer Turku and Wärtsilä, amongst others.







Screenshots of IA's 2D, 3D, and precision modes

It also manages the Jaakonmeri test area, a section of western Finnish coastline set aside for autonomous ship research and testing.

By basing its autonomous and remote team in Turku in particular, Rolls-Royce have availed themselves of a strong local maritime cluster supported by the University of Turku. Companies based in the west-coast city include Brighthouse Intelligence, who specialise in connectivity, security, and systems engineering, and the PBI Research Institute, a research-based management consultancy specialising in energy, transport and maritime. These smaller businesses are, in Tenuvuo's eyes, just as important as Rolls-Royce's bigger partners: "You need to work with local startups and local SMEs to get the flexibility and speed you want in development."

From a talent perspective, Tenuvuo suggests that Turku is a unique place where marine and IT expertise come together: "We have a unique combination of skills here. We have marine engineering capabilities, we have ship operations capabilities and then we have software development . . . when you put those together, you create that unique mix where you can bring these solutions to market."

An autonomous experience

Rolls-Royce's Turku R&D centre for autonomous ships, which officially opened in January, gives the company a place to focus this broad range of expertise and develop their solutions. In aid of this, the centre includes what Rolls-Royce call their 'Remote and Autonomous Experience Space', which *The Naval Architect* visited in March as part of a select media tour. Bold and cinematic, the space is designed to showcase both commercially available technologies and those still in development, to paint an exciting picture of what remote and autonomous shipping will look like. It is fitted with a number of large, fully functional table top screens which allow visitors to test demo versions of a range of systems, plus perhaps the most impressive feature: a mock-up of a remote-control ship operations centre, complete with a wraparound screen wall and captain's chair.

The space is essentially dedicated to Rolls-Royce's intelligent awareness (IA) solution. *The Naval Architect* previewed an early version of the technology in March 2017, after it was tested for six months on board Finferries' *Stella*. IA has since been refined and developed into a commercial product, which enables operators to take the first step towards remote operation by enhancing situational awareness of vessel surroundings. It uses a suite of sensors developed by Rolls-Royce: an antenna, camera unit, radar, LIDAR, and PTZ (pan-tilt-zoom) camera. The real-time data collected from these sensors is processed by the system's central unit and fed into the user interface unit. It can also be transmitted, via the cloud, to shore-side offices.

The touch-screen user interface unit visualises the sensor data across four different modes, which can be switched between instantaneously. In virtual reality 2D, the vessel follows its course through a top-down virtual copy of its environment. Other vessels in the ship's vicinity are visible, overlaid with their AIS (automatic identification system) signatures detailing their speed, course, and position. Navigational markers and shore-based landmarks are also visible. Potential hazards not transmitting an AIS signal, including small craft like kayaks and fishing boats, and environmental hazards such as logs, are also picked up by the sensors and flagged to crew to identify. Through a process of machine learning, the system builds up knowledge of such hazards. The interface also generates red 'no-go zones' that the vessel cannot enter due to their shallow depth or presence of underwater hazards.

Virtual reality 3D is much the same, albeit with a more dynamic 3D view that can be rotated and zoomed by the user. Precision mode is designed for operations in particularly restricted or busy environments, and displays more detailed information about the vessel's proximity to other craft and hazards, aiding crew with procedures such as mooring. The most advanced mode is augmented reality, which displays a 'real' video view of the vessel's surroundings, overlaid with AIS data. Again, crew can adjust their view by zooming and rotating, improving their situational awareness beyond the human eye.

IA is said to have a number of benefits, including improving short- and medium-range object detection (up to 8nm), providing better visibility in fog and stormy weather, and enhancing crews' shared situational awareness. The ability to transmit data to shore also gives fleet managers an insight into vessel operation in real time, with associated benefits for safety. As all data is stored in the cloud, too, it can be referred to in the event of an accident, or used for training purposes.

While IA is now commercially available, Rolls-Royce continues to carry out testing to improve the system, completing test trials on Stena Line's *Stena Jutlandica* and a Japanese coastal Ferry Sunflower vessel, owned by Mitsui OSK Lines (MOL). Extra features Rolls-Royce is researching include weather, audio and underwater awareness modules, plus haptic feedback, to make the experience as realistic as possible for users. Ultimately, this advanced version of the IA system will be incorporated into a shore-based remote operations centre, where it will provide captain and crew with awareness on par with – or better than – what they would traditionally have from a ship bridge. The system may ultimately enable ideas such as Rolls-Royce's modular smart-shipping concept, in which a containerised version of the bridge is located below deck.

Autonomous navigation

To achieve truly remote and eventually autonomous shipping, IA must be paired in the remote operations centre with an autonomous navigation system. This technology will arguably have the greatest impact on vessel operation – eventually removing this requirement from crew entirely – and ship design.

Up to now, Rolls-Royce have demonstrated a remotely controlled 28m commercial tug, *Svitzer Hermod*, which was taken through a number of manoeuvres in Copenhagen harbour by a captain stationed in Svitzer's headquarters. The company have also developed an automatic fjord-crossing system in partnership with Fjord1 ferries (see Equipment News, p14). Controlling the vessels' acceleration, deceleration, and route, the system optimises their repetitive operation profile, leading to energy and cost savings.

However, a commercially viable autonomous navigation system is still in development, and is likely to only be viable initially for smaller vessels such as OSVs and tugs. In order to be incorporated into larger, ocean-going commercial vessels, Rolls-Royce must first wrangle with the current lack of regulation, and consider the legalities of such a technology. In aid of this, the company is due to present their research on autonomous operation this May at MSC 99. Rolls-Royce is also working with flag states and class societies with the hope of speeding up approval once their technology becomes available.

Cyber security is a priority too, with Rolls-Royce claiming that it designs its autonomous systems to be 'inherently secure'. It is also attempting to generate an industry-standard 'autonomous framework', detailing levels of autonomy that allow vessels using autonomous systems to be more easily classified and evaluated from a safety perspective. As Juha Rokka, VP engineering in Ship Intelligence, explains: "We have our own autonomy framework. We are mapping out products and solutions to that framework, which gives you the rigour you need from a safety perspective when applying autonomy to your designs."

The business of autonomy

The ramifications of remote – and particularly autonomous – operation for ship design and shipping's business model are considerable. Freed from the necessity to install non-value adding systems for crew, including A/C, a galley, life-saving equipment, living quarters, and a bridge, a vessel can be intensely simplified and tailored to maximise energy efficiency as well as cargo capacity. Rolls-Royce predicts that average savings of US$5million can be achieved when comparing an autonomous bulker design to existing bulkers. In stark contrast to today's unique newbuildings, autonomous shipping also opens up the possibility of standardised system (and even vessel) design, as is practised in the aviation industry.

This has huge implications for the current shipping business model. For Oskar Levander, SVP of concepts & innovation, it means 'low cost smart shipping', where leasing schemes replace brokering and a digital marketplace dominates, turning shipping into an "Uber of the sea." In this marketplace, cost will be the main driver for cargo owners, with low rates made possible by highly efficient, standardised vessels operating on point-to-point routes. "Shipping will change more in the next 10 years than it has in the last 50, and it's all driven by digitilisation," Levander claims. "We will see new business models. This change will comprehend the entire maritime market."

It's difficult not to be swept up in Rolls-Royce's enthusiasm about remote and autonomous shipping, particularly given its ambitious timeline. As always in the maritime industry, however, innovators only have so much control: the fate of their technology will ultimately be decided by a plethora of different actors, including the IMO, IACS, and shipowners and operators themselves.

As we wait for the picture to become clearer (not least surrounding Rolls-Royce Marine's own future), it is worth stopping for a minute to consider: 40, 30, 20, or even 10 years ago, could we possibly have imagined that unmanned ships – something out of science fiction – might, in fact, become a reality? *NA*

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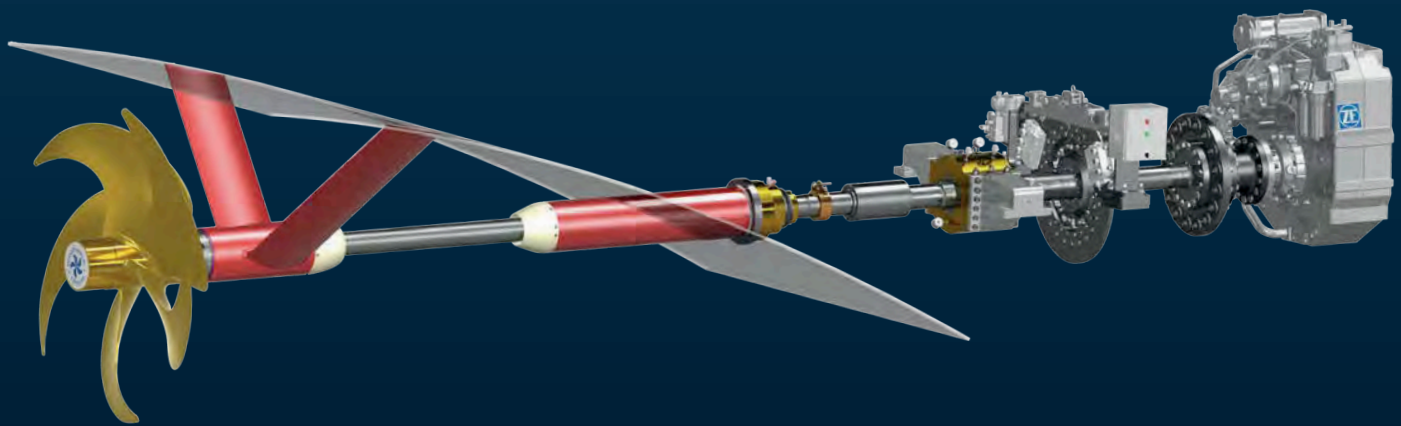
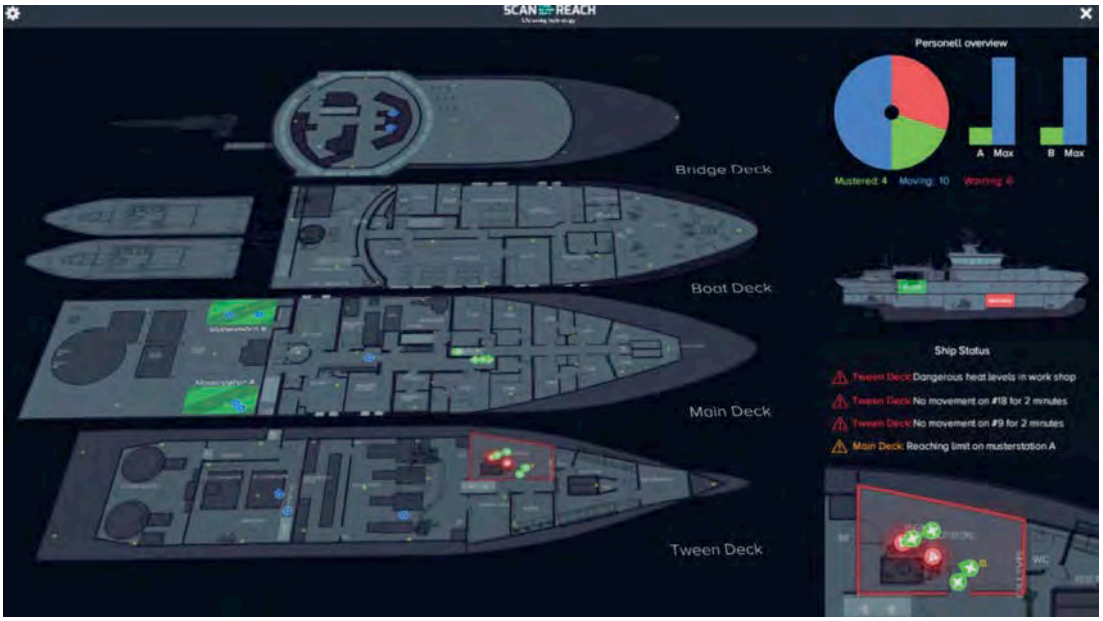


Reaching out to all crew members

Norwegian-based ScanReach has developed a wireless network that is set to change how lifesaving onboard vessels is carried out, writes Samantha Fisk



ScanReach can send and detect signals wirelessly through any structure, including steel

The latest solution from ScanReach looks at addressing one of the key issues in maritime that of lifesaving. As a company ScanReach operates as an Internet of Things (IoT) company that looks to provide solutions through this form of technology.

The wireless solution that it is bringing to the market is set to revolutionise how lifesaving operations can be carried out in emergencies onboard. Initially ScanReach is looking to the offshore market to test its product, but the company says that the system has further potential across the whole of the maritime industry.

"We took three-four years to get data floating within ships and to transfer data with the mission in order to understand where people are onboard a vessel," explains Jacob Grieg Eide, chief business development officer, ScanReach.

The In:Range solution allows for the captain of the vessel to see and locate all members of crew in an emergency situation and also act accordingly to deploy the correct life saving solutions for where the crew are situated. This is carried out using low power wireless IoT sensor technology. Each crew member is equipped with a bracelet and wireless adaptors are located all over the vessel, creating a grid where crew can be located in real time.

Eide highlights that this type of system utilising bracelets can already be found onboard cruise ships today, where there use this type of technology it is used for unlocking doors and also for passengers' accounts whilst onboard. The bracelets operate on batteries, with the In:Reach system ablt to run a health check and play an alarm when the batteries are running low.

The system also has redundancies built into it, so should a crewmember remove the bracelet or it fails, the system will still record where their last position was. Eide adds that: "you can look through the histories [data] and replay situations for training."

A major challenge in developing this system was adapting the wireless technology to be able to go through steel walls. "First thing was how to transmit data through steel as that was the barrier. Most people say that's impossible, it's not possible to transport data through steel, but no environment is perfect, a ship is not perfect. But, it's possible", Eide claims.

Initially, looking at standard 2.4GB Wi-Fi, the company found it would not be capable of penetrating the steel and radio frequencies were also a challenge due to regulations surrounding them. The company chose the option of a low power wireless solution.

Testing and installation has been carried out on the offshore supply ship *North Sea Giant*, where 100 plug sensors have been installed in various locations around the ship, except for in the cabins, to cater for the 120 crew onboard. The company states that feedback from the captain suggested that the solution has changed the safety level onboard the vessel. ScanReach is also looking to add extra sensors to its technology for gas and fire fighting in the future onboard the vessel.

Currently, ScanReach is working with Norwegian Navy who are looking to have the whole system fitted onboard all its vessels. In addition, the company notes that it is also receiving interest from the oil and gas sector for its latest life saving product.

The In:Range solution utilises an open source frequency that will allow for data storage and management. Further to having this capacity, ScanReach will also be joining forces with DNV GL's latest platform Veracity, which will be able to bundle the data, following an the agreement signed at the beginning of April. In:Reach will also be included in the Kongsberg digital platform.

ScanReach notes that the In:Range system is very easy to install. "It's just plug and play", notes Eide, with the installation price based of the complexity of the system that the operator wants to install. *NA*

Color Line goes green

Norwegian-based cruise operator Color Line is prepared to set sail with its first environmentally friendly hybrid cruise ship, writes Samantha Fisk

Color Line's first 'plug-in' ship *Color Hybrid* will be launched in 2020, signalling a new emphasis on environmentally-friendly technology and design for the cruise operator. The company noted that, with the future challenge of stricter regulation, it was imperative to take action on which way it was heading regarding future fuels.

LNG has been a firm favourite of companies utilising alternative fuels, but doubt has started to creep in to the industry regarding the fuel's ability to cut greenhouse gas (GHG) emissions, given the issue of methane slip. The current lack of infrastructure is also holding many back. "We believe in shore power and that technology. We don't believe in LNG. It is a disillusion and it's not good enough. We believe the use of LNG will be for a short period and we would find something else instead," explains Helge Otto Mathisen, EVP of Color Line.

Color Line believes that a more economical alternative to LNG would be hybrid power. In view of this, *Color Hybrid*, designed by Fosen yard and currently under construction at Ulstein, will have 5MW batteries installed and the ability to charge in one hour. The vessel's 'plug-in hybrid' system will mean that it can be recharged via a power cable from onshore facilities or onboard by the ship's generators.

Today, Color Line's ships run on three auxiliary engines when berthed. When the ships switch to shore-based electricity, the discharge of CO_2 will be reduced by 3,000tonnes per year. This is the equivalent of the annual discharge of CO_2 from 1,700 cars.

Also, the lack of nitrogen oxide (NOx) emissions while operating on battery power will greatly improve the air quality in Oslo and other ports which the vessels are operating in. Discharge of sulphur dioxide (SOx), too, will be reduced by approximately 2.5tonnes and particulate matter will be reduced by approximately 0.75tonnes.

Concept illustration for the Fosen-designed *Color Hybrid*

The main challenge with hybrid power is the development of the power grid that supplies the shore power to the vessels. "One of the challenges that we face is that the local grid needs to be strengthen to charge ships," says Mathisen.

Efficient electricity

Mathisen highlights another challenge of the varying price of electricity from port to port. Germany, for instance, imposes high taxation on electricity making it not so appealing for those that are looking to utilise electric power.

> "We don't believe in LNG. It is a disillusion and it's not good enough"

However, the company notes that power from the grid is generated in a much more efficient manner than electricity generated by auxiliary engines. The improvement in energy effect by converting to shore-based electricity is roughly 60%. Taking this into consideration, Color Line expects that it will be able to make substantial savings by utilising this latest energy source.

Color Hybrid, which will operate between Sandefjord and Strömstad, will measure 160m, with a beam of 27.10m and a design draught of 6m. It will have the capacity for 2,000 passengers and 500 cars and have a speed of 17knots. Measures have also been taken in noise reduction.

Further developments in hybrid power have already been underway at Color Line with the refitting of *Color Magic* and *Color Fantasy* to adapt them to use shore-based power. The conversion of the two vessels has been part of Color Line's exploration into the use of other fuel and energy sources.

The Norwegian government has been keen on assisting shipowners to look for greener alternatives for the future, and has been funding initiatives to promote new technologies. They have also been working in partnership with the Bellona Foundation, a sustainability non-profit which has been encouraging the development of infrastructure to support shore power.

Mathisen concludes that research is continuously ongoing as the likes of Color Line and Bellona look into the different fuel options on the market. However, the company is firmly standing by hybrid as one of the best future power options for ships needing to meet tougher regulatory targets. In light of this, a second sister ship to *Color Hybrid* expected to follow in the near future. ***NA***

Ferry car deck hinged coaming design to delay ship capsize

Naval architects are well aware that ro-ro ships experience rapid capsizing when the car deck floods, but have been reluctant to make modifications. Dr Robert Latorre, FRINA, believes foldable combing may represent a solution

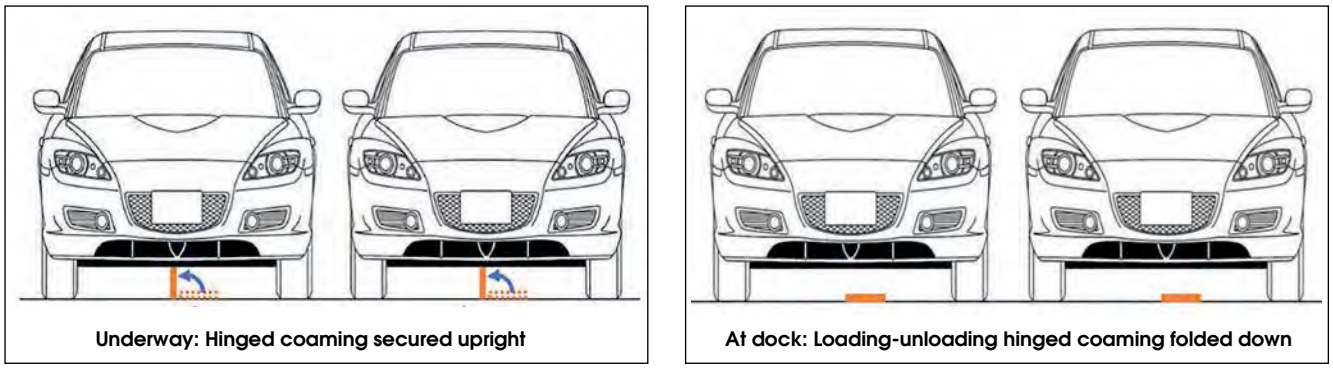


Figure 1: Arrangement of vehicle deck hinged coaming

Ro-ro ferry capsizing occurs from loss of ship metacentric height due to the free surface effect. It is also clear that this free surface effect can be reduced by adding subdivisions or partitions to the vehicle deck. But until now the operators have been reluctant to modify ro-ro car decks because of the interference this causes with vehicle loading and off-loading. The ro-ro ferry car deck hinged coaming (HC) Design was developed to end this impasse. Hinged coaming is something like a car air bag being deployed and, similar to marine aluminum structure fire protection, it provides additional time for the crew and passengers to evacuate from the damaged ferry.

The hinged coaming is designed to be installed in the vehicle deck lashing holes. It is possible to bolt the hinged coming to the car deck using these deck lashing holes (as illustrated in Figure. 2), making operation simple. In port, the hinged coaming is folded down and the vehicles can run over it during loading and unloading. Prior to getting underway, the crew ties the vehicles to the deck and raises the hinged coaming up and secures it, creating a vertical partition. The hinged deck coaming design provides a simple means to break-up the deadly free surface effect during down flooding.

Estimating ro-ro ferry capsize time

To quantify the capsize time, Latorre (2014, 2015) developed the estimated capsize time (ECT) equation:

ETC = Ship displacement, tons /FR minutes (Equation 1)

Where: FR = 327 ton water/min

For example, the MS *Estonia*, which capsized in 1994, has a displacement of 12,050 tons, so the Estimated Time to Capsize (ETC) = 37 minutes (= 12,050tons divided by 327ton water /minute). This compares well with the 35 minute capsize time noted in the official accident report. The results in Table 1 show the estimated ETC times correlate with the observed ro-ro capsize times of other incidents.

Figure 2: Photo of ro-ro car deck with vehicle lashing

Delaying ro-ro capsize

The key to delaying the ro-ro capsize is to delay/minimise the reduction in the metacentric height. Flooding causes the ferry to heel and trim, so successfully delaying the ro-ro ferry capsize involves keeping the ship within a limiting heel angle ϕ=10degrees for the passengers and crew to evacuate to the life boats (Boer 2001). The following estimate on delaying capsize uses a 10 degree heel angle.

Professor C.T. Ross (1997) performed a series of flooding tests with a 1/100 scale model of the hull of the *Herald of Free Enterprise* (Table 1). He tested the model fitted with a perforated car deck with underdeck longitudinal tanks, the results of which can be found online:

www.youtube.com/watch?v=0D7ztCzaOAE&t=25

This modified car deck significantly reduced the free surface effect. The tests showed that as more underdeck tanks flooded, the amount of water needed to reach 10 degree heel also increased.

No	Ship	Ship Type - Tonnage	Deaths/total (%)	Capesize Date Accident Type	Capesize Time	Estimated Time to Capesize: ETC @ 327ton/min
Ref	SS *Titanic*	Liner 52,3100tons 42,328 Gross tons	1514/2224 (68%)	15/4/1912 I-Iceberg	2hrs 40min	Reference 160 minutes
1	SS *Heraklion*	RO-Pax Ferry 7,447tons est	217/264 (82%)	8/12/1966 II-Side door III-34ton truck	1:10-2:00am 15-20min after door opened	22.7minutes
2	MS *Estonia*	RO-Pax Ferry 12,050tons	852/989 (86.15%)	28/9/1994 II-Bow door	1:15-1:50am 35 minutes	37minutes
3	MV *Princess of the Orient*	RO-Pax Ferry 13,935tons	150/388 (38.66%)	18/9/1998 II-typhoon	12:55 pm sank	42.51minutes
4	MS *Express Samina*	RO-Pax Ferry 5,505tons 4,455 Gross tons	82/533 (15.38%)	26/9/2000 I-Reef Aegean Sea	22:12-23:02 50min after collision	16.79minutes
5	MV *Princess of the Stars*	RO-Pax ferry 23,824tons	814/862 (94.4%)	21/6/2008 II-typhoon	11:30 life jacket 11:45 heeled	72.85minutes
6	MV *Sewol*	RO-Pax Time 6,825tons	284/459 (62%)	16/4/2014	8:48 hard turn 9:18 50deg heel (20 minutes) 2hrs roll over	20.87minutes

Key: Accident type: I- Collision and Flooding; II- Flooding from door opening; and III- Cargo shifting

Table 1: Recent Ro-Ro ferry capesizes and Estimated Time to Capesize (ETC) Ref: Latorre (2014, 2015)

Using the test results with the five underdeck bulkheads one is able to estimate the delay in capsize when the car deck is fitted with underdeck longitudinal tanks. It is possible to compare results for flooding one underdeck side tank (Qt_1) to obtain the capsize Delay Factor denoted by DF1:

$$DF1 = Qt_1/Qo \text{ at } \phi = 10 \text{ degree heel} \quad \text{(Equation 2)}$$

Introducing the delay factor it is possible to calculate the Modified Estimated Time to Capsize ETC:

$$ETC = (\text{Ship tons/FR})DF_1 \text{ minutes} \quad \text{(Equation 3)}$$

The flooding measurements were analysed using Equation 3 as follows:

Table 2: Estimate of Delay Factor DF1 from the University of Portsmouth tests (Latorre, 2015)

Ro-Ro Car Deck Design	1 underdeck tank flooded Qt_1 tons @10deg heel	Delay Factor DF_1
Original Qo tons @10deg	Qo = 140tons	NA
Deck with six underdeck tanks Marine Tech Vol 37	Qt_1 = 300tons	2.14

Step 1: The amount of flood water Qo required to achieve the 10 degree heel is Qo = 140 tons for the ferry with the original car deck.

Step 2: The amount of flood water with one underdeck longitudinal tank flooded denoted as Qt_1 was estimated for a ϕ = 10 degree heel is Qt_1 = 300 tons for the ferry with the modified deck.

Step 3: The Delay Factor DF_1 for one underdeck tank flooded is then estimated by equation 2. The results are summarized in Table 2.

The estimated ETC and capsize delay times are summarised in Table 3. These results show the perforated car deck with underdeck tanks increases the ro-ro ferry capsize time. The *MV Estonia* capsize would have been delayed by an additional 40 minutes and the *MV Sewol* capsize by 25 minutes.

No	Capesize Time	*MV Estonia* Capesize	*MV Sewol* Capesize
1	Observed	35minutes	20minutes
2	ECT Table 1, equation 1	37minutes	20.9minutes
3	ECT' with one flooded underdeck tank @10deg heel, eq. 3	79.2minutes / 40minutes delay	44.7minutes / 25minute delay

Table 3: Ro-ro ferry estimated capesize time delay – Modified Car Deck (Latorre, 2015)

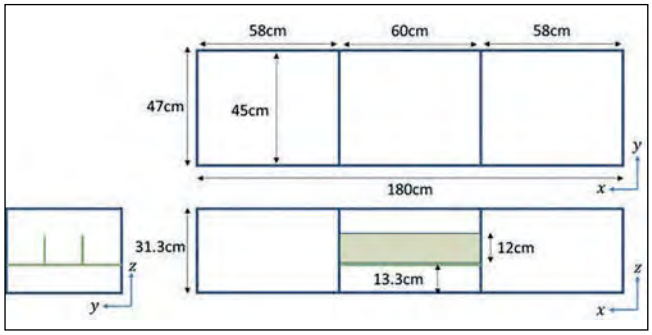


Figure 3: Box Model Arrangement with two partitions (n=3 compartments)

A second series of capsizing tests were made with a box model with vertical partitions (Mizui, Latorre, 2017) to evaluate the effectiveness of hinged coaming. The box model is fitted with multiple partitions. The test arrangement with two partitions is shown schematically in Figure 3. The ballast weights were arranged so that the transverse metacentric height GM was 0.84<GM<0.94 cm (about 5% of the model beam) similar to actual ships.

Water was added onto the deck using a set of glass beakers. The total water was divided into equal amounts for pouring into the center of each compartment. This was done simultaneously to avoid heeling. The model was left to settle for five minutes and the heel angle φ measured prior to adding additional water into each compartment. The heel angle φ for ml of water added is shown in Figure 4.

It is clear the partitions significantly increase the amount of water required to heel the model. The delay factor Df is in the range or 2<Df< 10. These results are useful in deciding the number of deck partitions. Close observation of the water after being poured into each compartment showed two distinctive patterns. The water formed either i) A wedge (viewed from end) or ii) A trapezoid rectangle + wedge (viewed from the end).

It is useful to make a brief remark on the arrangement of the partitions. The hinged coaming can be positioned between the tied down vehicles. Or they can be fitted under the vehicle as shown in Figure 1. The partition vertical height should be less than the vehicle ground clearance or as it is often termed "ride height". For a compact car this is y= 12-15 cm that corresponds to a coaming to coaming separation distance of 0.68 <x< 0.85 cm for a 10 degree water wedge. *NA*

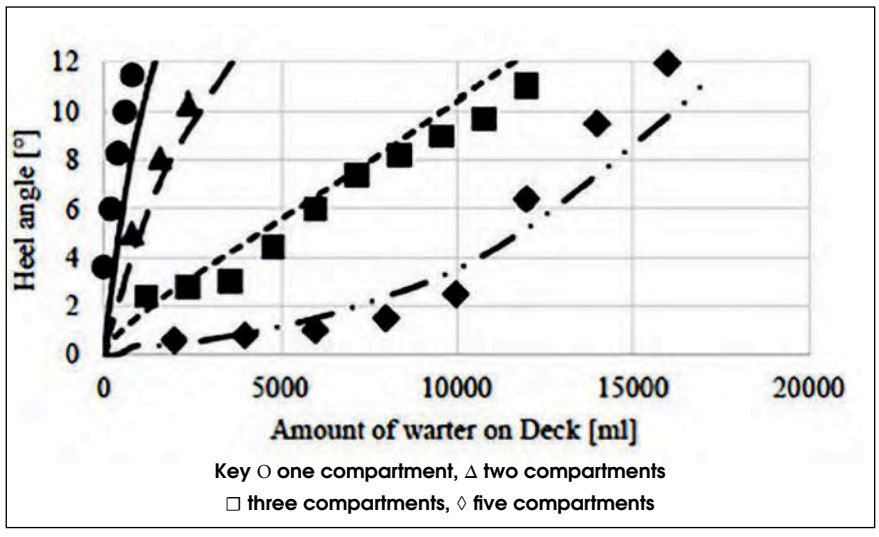


Figure 4: Measured heel angle versus water on deck (Mizui, Latorre 2017)

Further reading

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New cruise ship builders must play it safer

Inexperienced yards and owners can run in trouble with expedition cruise ship contracts, writes Kari Reinikainen

Shipbuilders with little or no experience from passenger ships have won several orders for expedition cruise ships, but booming demand for these vessels should not mean that good and safe shipbuilding practices for passenger vessels are compromised, says Markus Aarnio, chairman of the Helsinki based consultant naval architects Foreship.

Lack of consistency in the initial designs being rushed to market for vessels of around 10,000gt and over may conflict with established safety and environmental values.

"Some designs we have seen do not meet the cruise ship Safe Return to Port (SRtP) provisions that were developed for a very good reason at the International Maritime Organization (IMO)," Aarnio says.

Intended to improve safety robustness, SRtP, which became mandatory from July 2010, defines the threshold value by which larger passenger ships of 120m or over should be able to return to port following fire or flooding without the need for evacuation.

Vessels of this length are expected to have three of more vertical fire zones. In practice, some designs have two overlength main vertical zones, or three main vertical zones of which is one is 'not counted'. "This is should be allowed in principle only," cautions Aarnio, "if the Alternative Design analysis proves that two overlength main vertical zones without SRtP is at least as safe as three main vertical zones with SRtP."

"You should not play tricks with technical details. You should bear in mind where many of these ships will operate – in high latitudes north and south where little or no outside help is available in case of an emergency – and it was largely for conditions such as these that the SRtP rules were introduced in the first place," Aarnio tells *The Naval Architect*.

"Many yards new to passenger ship building are constructing these (expedition cruise) ships. Some of them are not looking for outside assistance either. They seem to think that we have built ships before, so we can handle these ships too," Aarnio continues.. "But passenger ship is a very different ship compared to, for example, an offshore supply vessel."

IMO's Polar Code was published in 2016, entering into force at the start of 2017

In some designs that Aarnio has seen, there are cabins with balconies so low in the vessel that these cannot be fitted with ordinary balconies with sliding doors. Instead, they must be equipped with a much more robust weather tight door plus a high threshold to comply with load line regulations. "This might later come as a surprise to the owner," he says.

The contents of the IMO's Polar Code, which centres on ship safety and environmental protection in polar waters, were laid out in 2015 and entered into force on 1 January 2017. The Code provides guidance to ensure that equipment operates at low temperatures, incorporates stability margins to deal with ice accretion on superstructures, and in higher categories demands additional damage stability requirements.

A boom in orders for expedition cruise ships followed publication of the Code. However, shipbuilders with strong track record in cruise ship building are also enjoying a boom in contracts for larger, mainstream cruise ships.

Expedition vessels, ranging up about 25,000gt, do not fit in the production flow of mainstream cruise ship builders, which means that yards that in the past predominantly built offshore and cargo tonnage have won many of the orders. Moreover, many of the owners that have placed expedition cruise ship orders are comparative newcomers to the deep sea passenger ship newbuilding sphere.

Aarnio suggests that more consideration should be given to the efficient use of space and energy on these smaller ships, and to meeting the new more stringent SOLAS2020 damage stability requirements in an inventive way.

Some other examples of designs that are likely to turn out problematic from a purely technical, if not safety, point of view include vessel concepts in which fuel and other tanks have been placed at ship's sides rather than close to the centerline.

This can cause problems later as tanks arranged at sides may, due to damage stability, need very large cross-flooding ducts and air pipes, which can take up space to the detriment of public spaces. It is also good to remember that all cross flooded tanks need to have same filling on both sides to comply with damage stability regulations; these requirements can make the operation of the vessel more difficult.

"There are projects where very little space has been reserved for technical areas and this can create extra cost and problems later, in operation. This might result in a ship not having an exhaust gas economiser, or not enough space for modern energy-efficient air conditioning equipment," he warns.

"Smaller expedition ships are not cargo vessels or boats; they must be designed to be fit for purpose, as passenger ships operating in remote areas. Smaller size does not mean that safety or energy efficiency should take a lower priority than is the case for bigger ships," Aarnio concludes. *NA*

Azipods to propel Lindblad's first polar voyages

The ice conditions of the polar regions require a propulsion system that is both resilient and sensitive to the environment in which it operates

The vessel's Ulstein X-Bow cuts a distinctive shape, whilst its provision of balconies and observation decks is clearly visible

The selection of twin 3.5MW ABB Azipod DO units for a 2017-ordered Lindblad Expeditions-National Geographic vessel has proved doubly pleasing for ABB. The supplier reports the contract as providing a breakthrough for its newest Azipod propulsion unit for Lindblad's first purpose-built polar vessel, while its attributes were also responsible for converting initial talks over propulsion into an ABB shipboard systems order. ABB's scope of supply includes a range of distribution transformers and switchboards, three 1MW LP motors and four tunnel thrusters.

Due delivery from Norwegian yard Ulstein in the first quarter of 2020, and with an option for two additional ships attached, the Lindblad expedition ship's profile will be distinguishable by its signature Ulstein X-Bow, designed for fuel efficiency and comfort in rough seas. It will also be marked out by the fact that 75% of its 69 cabins will feature balconies for private viewing, by multiple observation decks inside and outside, and by 'observation wings'.

Lindblad has indicated that the ice-going vessel will be the highest polar class expedition ship in service at the time of its delivery. ABB is the only thruster maker that proved able to supply the required equipment which meets strict underwater requirements; this is because, in Azipod propulsion, the electrical motor is installed directly on the propeller shaft, avoiding the need for mechanical gears like those found in Z- or L-drive azimuthing thrusters. Consequently, the Azipod shaftline is more resilient to both bending and high torque peaks under ice loading. If ice interaction is expected, the Azipod unit's electric motor and ship's power plant can be configured to provide an over-torque capability, which prevents ice blocks impacting static propeller blades when the vessel is moving forward by inertia alone.

ABB says the ability of Azipod propulsion to satisfy a variety of hull forms and ice classes will be key in building its reference list in the expedition cruise ship market in the coming years. Today, 100 cruiseships are already or due to be fitted with Azipod propulsion, including the world's largest, and these units can document over 14 million hours in service with availability of 99.8%.

According to the supplier, a twin Azipod DO installation achieves a 10% power saving compared to a twin shaftline installation with electric propulsion. The gearless construction of Azipod units also reduces the risk of environmental contamination, because the amount of oil used – just six litres – is only a fraction of the 1,000litres and above needed in traditional geared shaftline propulsion or mechanical azimuthing thruster arrangements.

Available in power ranges of 1.5-7MW, the Azipod DO propulsor also features a hybrid motor cooling solution, combining direct cooling to the surrounding sea and separate air cooling, which means 25% less power can be installed than is the case for propulsors of equivalent performance. This leads to significant fuel savings and reduced emissions. Other stand-out technical features onboard the Lindblad vessel will include its larger than average fuel and water tanks to sustain extended operations in remote areas. Lindblad has also specified zero-speed stabilisers to ensure stability, whether underway or at rest. *NA*

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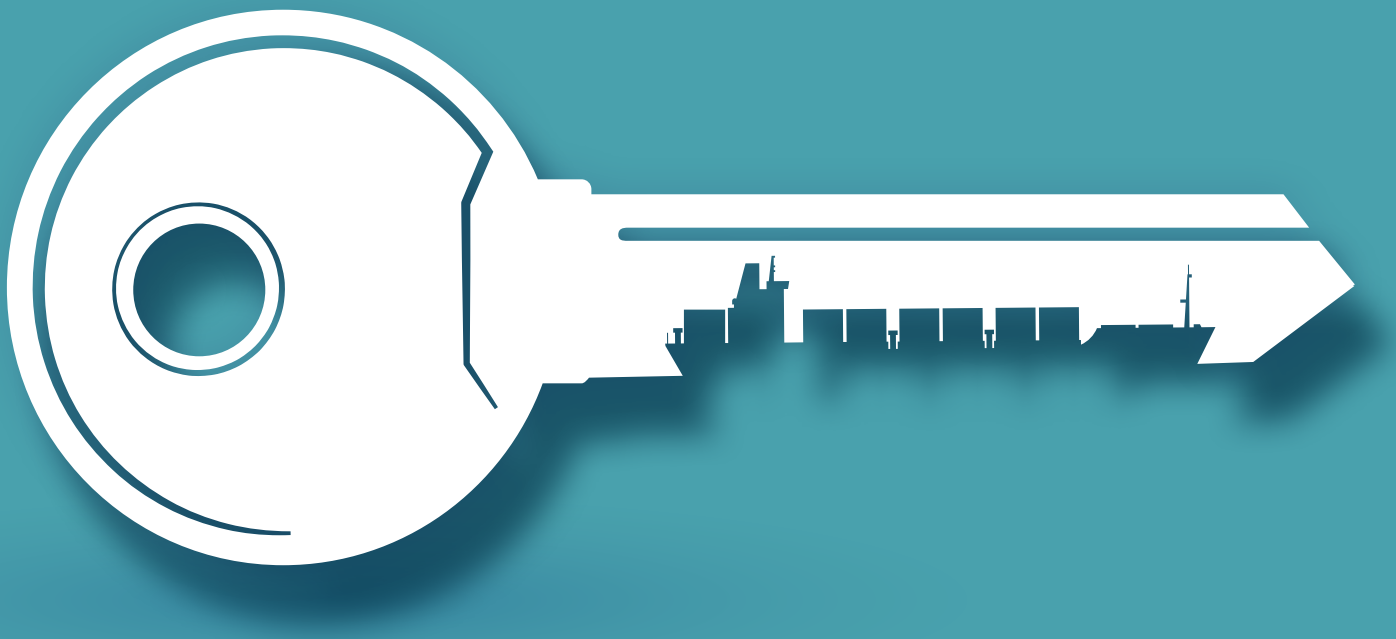

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Compac water lubricated shaft marks 20 years of cruising

May 2018 marks two decades since Thordon Bearings' water-lubricated propeller shaft bearings were first installed

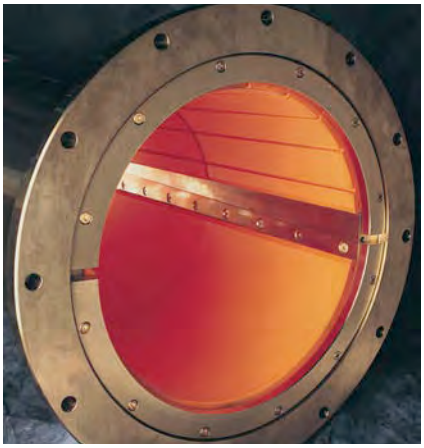
Since the very first installations onboard Princess Cruises' *Grand Princess* and Disney Cruise Line's *Disney Magic*, the cruise sector has become a major proponent of the conventional water-lubricated propeller shaft design. Thirty-two ocean-going cruiseships now operate with a Thordon arrangement and there are 11 more on order.

The reason for the wider take-up, Compac's advocates believe, is not only attributable to environmental conscientiousness: system reliability, reduced operational expenditure and maintenance are other key factors influencing the purchasing decision.

During their years of continuous service, neither *Grand Princess* nor *Disney Magic*, or any other cruiseship operating Thordon's water lubricated propeller shaft bearing systems, have experienced downtime, cancellations or changes to cruise itineraries due to propeller shaft bearing or seal failure.

"There is a raft of reasons behind the sector's adoption of the technology," says Richard Vie, a former Vice-President, Technical Development and Quality Assurance, within Carnival Corp's Corporate Shipbuilding division, who was involved in the design of the *Grand Princess* and subsequent Princess cruiseships. "Theoretically, a well-designed oil-lubricated shafting system should outlast the operational life of any vessel, but this depends on the quality and type of lubricating oil used and regular seal maintenance.

"When we built *Grand Princess* the risks we were addressing were unscheduled drydockings (there were not many drydocks that could accommodate a ship of this size at the time) and oil pollution. The cost benefit analysis included, as best we could, the expected lifetime of the bearings and I believe we assumed one replacement throughout the life of the ship. Even with this cost figured in, the benefit [of the water-lubricated conventional shaft system] was still overwhelming."



Thordon Compac bearing with single key design

Over the course of the past 20 years, Princess Cruises and Disney have closely monitored the bearing wear-down rates on these vessels. Data published shows propeller shaft bearing clearances for both ships within the classification societies' maximum allowable wear-down rates. This is how far the shaft has 'dropped' from its original build alignment condition.

"With water-lubricated systems the issue of how long it will last depends on the water quality and how many shaft revolutions there are in the ship's life. As we can see from the *Grand Princess* experience, Princess decided to replace the original bearings with new [during a major refit, rather than waiting for special survey]. It does sound as though the Inconel shaft liners performed very well," says Vie.

After 18.5 years of continuous service Princess Cruises decided to replace the bearing – again with Thordon Compac bearings – during *Grand Princess*'s scheduled drydocking, in December 2016.

Andy Wright, Fleet Operations Director, Technical Operations, Princess Cruises, says: "During the vessel's scheduled drydocking in 2013, class surveyors found the Compac bearings still fit for purpose but recommended changing them at the next drydocking in 2019. We decided to replace all four bearings in 2016 during *Grand*'s extensive refit at the Vigor floating dock in Portland, Oregon. Despite our apprehension at working on equipment that had remained untouched and under water for many years it went very smoothly indeed with no issues."

The Disney ship, meanwhile, continues to operate with the original polymer bearing. In September 2015, during the *Disney Magic*'s last shaft inspection, surveyors recorded a bearing wear down of 7mm, significantly below Lloyds Register's 10.5mm maximum allowable clearance. This was 17 years after the system was installed.

"Based on our cruise installations to date, a seawater-lubricated propeller shaft system will typically have a wear-life of 18-20 years depending on the operational profile. For all the cruiseships where Thordon Compac is installed, none have required replacement due to wear, no shafts have been withdrawn and no corrosion issues have occurred," says Thordon's Director of Marketing & Customer Service, Craig Carter.

As the design of the Compac system allows the water lubricated bearings to be removed, inspected and replaced without shaft withdrawal, the major classification societies have now introduced shaft condition monitoring notations for water lubricated shaft bearings which, provided certain conditions are met, allows extended shaft withdrawal periods of 18 years or longer, depending on the class society.

While performance of the water lubricated propeller shaft is undeniably reliable and environmentally-sound, from a cost perspective Carter admits these systems can initially cost slightly more than oil-based

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All of this is against the backdrop of rapidly advancing technologies including unmanned and autonomous systems, a changing threat environment and an insecure world; these factors require ever more adaptable ships that can fulfil a number of different roles and save money through life. Modularity may be one way to address this adaptability, however this approach has its compromises and there are other design considerations that must be in place to make a platform truly adaptable.

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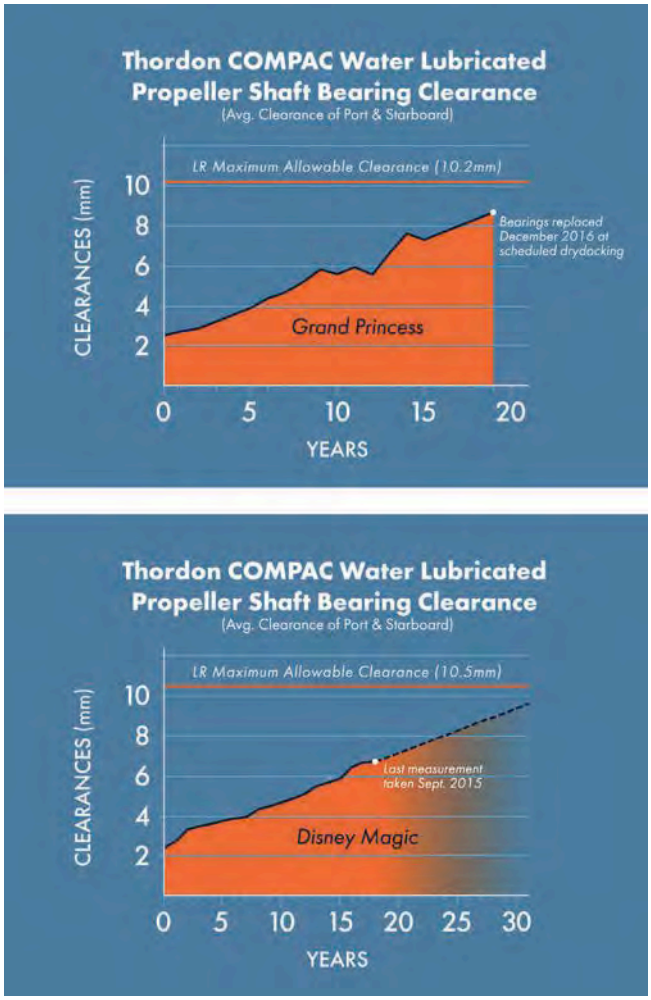


Shaft bearing clearance for *Grand Princess* nor *Disney Magic* were within the classification societies' allowable wear-down rates when surveyed

alternatives – a possible factor in some shipbuilders' reluctance to offer the solution as standard.

"Seawater-based shaft systems are less time consuming to install than an oil-lubricated system with complicated air seals. There is only one shaft seal, pipe work and wiring are minimal and there is no header tank to top up, which can reduce install and operational costs," Carter contends.

One advantage that should not be undervalued is the elimination of an aft seal, the component most susceptible to damage in an oil-lubricated propeller shaft configuration.

In a 2007 technical paper, Lloyd's Register said shaft seals for oil lubricated propeller shafts have always been a problem for shipowners, noting that "defect statistics over the last 20 years indicate that the aft stern gland (seal) and forward stern gland (seal) represent 43% and 24% of failures respectively".

Typically, aft seals require maintenance every three to five years. Even if they are not damaged, the rubber sealing elements wear down as operating hours increase and seals start to leak oil. A typical closed oil lubricated system contains 1,500 to 3,000 litres of mineral oil. And when they do leak it not only gives rise to environmental concerns, but seawater passing into the closed system can emulsify the oil, leading to shaft bearing failure.

Andy Wright agrees: "We have experienced seal problems on vessels with oil-lubricated shafts, resulting in one vessel having to emergency drydock as there was water ingress. Compared to the oil-lubricated propeller shafts of other vessels in the Princess fleet, there has been no issues with the Thordon water-lubricated configuration."

"Aside from the environmental issue of oil leaking out, water ingress can affect the viscosity of the lubricating oil," says Carter. "This means shipboard crews have to drain down the contaminated oil and top up with fresh, which can be expensive... A seawater lubricated system can eliminate this unnecessary expense, negate the regular maintenance or emergency repair of these seals, and mitigate against any off-hire time and unexpected itinerary change."

In a paper presented to the Royal Institution of Naval Architects in 2007, Fincantieri's Giampiero Lavini and Lorenzo Pedone concluded that a passenger ship with a rounded skeg hull shape, twin six-blade fixed-pitch propeller and a seawater-lubricated shaft line, with appendages optimised using computational fluid dynamics, would be comparable to a cruiseship with podded propulsion. Oil leakage is avoided, while the intermediate bracket provides a stiff shaft configuration that reduces bearing mechanical and thermal stresses, especially during manoeuvring or crash stops.

Another issue that may prompt more cruise ship owners to consider conventional seawater-lubricated shafts is the steep rise in bearing and seal failures on ships with conventional closed propeller shaft systems where environmentally acceptable lubricants (EAL) have been used.

This is such a concern that DNV-GL recently established a working group to study performance and compatibility of EALs on conventional metal bearings. The classification society also suggested that the introduction of new propulsion system designs, such as single stern tube bearing installations and larger and heavier propellers operating at lower RPM, also had a negative impact on the oil-lubricated propeller shaft bearing.

Since the first installations, Thordon has supplied water-lubricated bearing systems to 32 cruiseships with 11 more on order that have specified the arrangement. Of the 18 cruiseships in the Princess fleet, 13 operate with the Thordon system as will three newbuilds, while all the cruiseships in the Seabourn, Disney and Viking fleets benefit from the arrangement. Other operators using conventional Thordon seawater lubrciated beaing systems include MSC Cruises, P&O Cruises, Oceania, and Regent Seven Seas. *NA*

The sound of silence: permanent magnet machines for silent vessels

PM motors represent a simple and reliable mechanical solution for achieving quieter vessels, argues Jussi Puranen of Finnish technology firm The Switch

Figure 1: Generator on the left during final assembly and before painting, and the motor on the right.

A diesel-electric propulsion system, based on the power station principle and electric propulsion motors, is already the number one choice for many types of vessels, due to its benefits over diesel-mechanical propulsion. The main benefits of diesel-electric propulsion are reduced fuel costs, redundancy, excellent torque-speed characteristics (including fast dynamics), and reduced vibrations.

By using a permanent magnet (PM) machine as a propulsion motor, excellent efficiency can be achieved, resulting in fuel savings for gensets. Further benefits of PM technology are space/weight savings and increased reliability due to simple mechanical construction.

With the proper design, PM machines can also be utilised in so-called silent vessels, requiring very low structural-borne noise (SBN) levels. Typically, such vessels have used DC, induction or electrically excited synchronous motors, but low SBN levels can be also achieved with PM technology.

Reduced fuel costs

Especially with ships that do not travel at full speed most of the time, diesel-electric propulsion results in significant fuel savings, as some of the power station gensets can be shut off when operating at lower speeds, resulting in greatly reduced specific fuel-oil consumption (sfoc). Variable-speed gensets provide even more fuel savings, meaning that instead of supplying genset power directly to the grid in which only constant speed is allowed, it is supplied through the frequency converter, thus allowing variable speed for the genset, depending on power demand.

It is well known that diesel engine-driven generators operate at maximum efficiency at partial speeds. At the nominal point when a ship is moving at rated speed, the efficiency of a diesel-electric system is typically lower than that of a diesel-mechanical system. But in vessels which operate a large part of the time at reduced speeds, this is compensated by reduced fuel consumption at partial load. Vessel types benefitting the most from electric propulsion include large cruise vessels, and various kinds of vessels with dynamic positioning (DP), such as offshore supply vessels (OSV), drilling vessels, dredgers, shuttle tankers and cable-laying vessels. By using PM machines instead of conventional machine types, such as induction or electrically excited synchronous machines, fuel savings can be further increased, since losses related to magnetisation in the generators are eliminated. With direct-drive PM propulsion motors in particular, the difference compared to electrically excited synchronous machines is significant.

Increased redundancy

With diesel-electric propulsion, instead of using a single large 2-stroke main

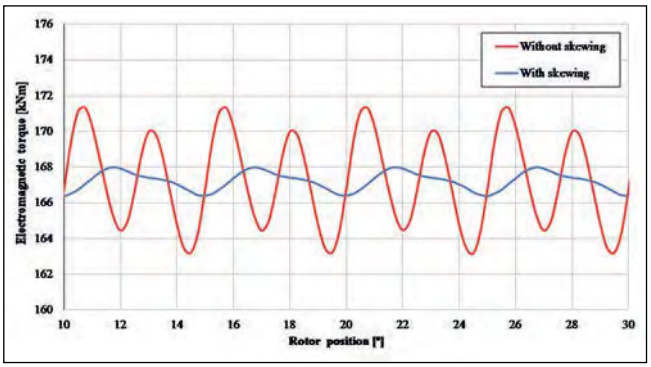


Figure 2: Torque ripple of a propulsion motor at full-load with and without skewing. As can be seen, there is a significant drop in the torque ripple when skewing is applied

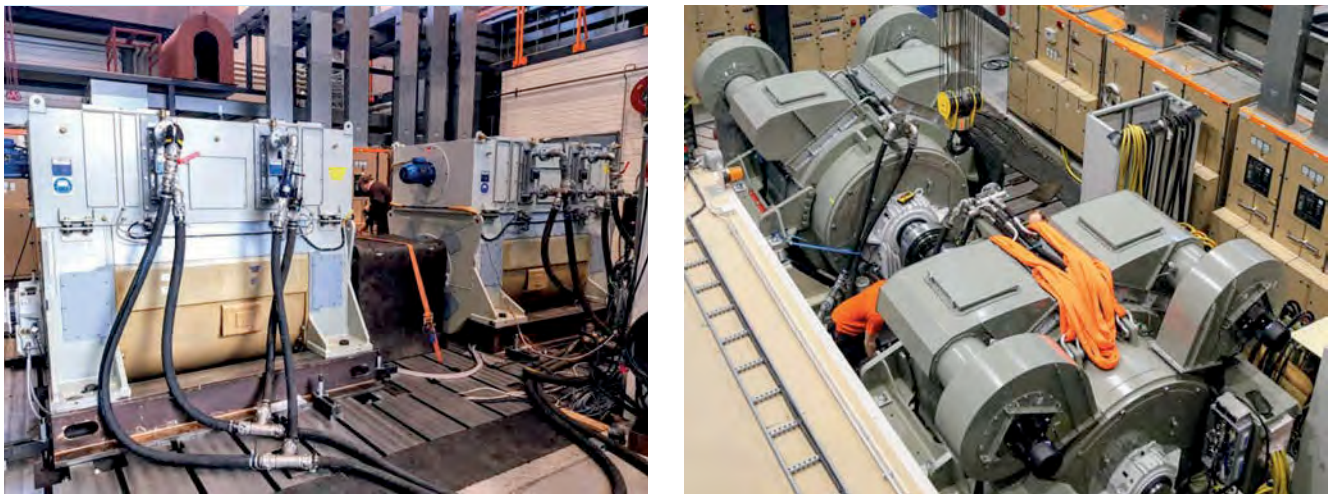


Figure 3: Machines in the full-load back-to-back test at The Switch Lappeenranta Factory. Generators on the left and motors on the right

engine as a propulsion power source, power generating sets are divided into several parallel independent units. Propulsion power can also be divided into two or three independent units, meaning that a failure in any single generator/motor will not result in total loss of power.

Often half the power, as a minimum, is left in case of a fault in one of the motor/generator units. Even if 50% of propulsion power was lost, a ship would still be able to move with around 70% of its nominal speed. Instead of just using parallel motors/generators, redundancy can be further increased by using dual-winding motors or generators.

A common practice at The Switch is to divide the stator windings into two, three, or more sub-windings that can operate independently when supplied via their own frequency converter. This means that if a frequency converter fails when it is connected to a single sub-winding, only that part need be switched off, and the PM machine can keep operating with the remaining healthy converter with reduced power. This significantly increases the redundancy of the system, and results in higher available propulsion power in case of a frequency converter failure.

Torque characteristics

The fact that conventional diesel engines produce maximum torque only in a very narrow speed range causes significant problems in vessels needing high torque at low speeds – for example in ice breakers. This is the main reason why diesel-electric propulsion is a superior choice in such applications, as electric motors can supply full torque from zero up to rated speed.

Originally DC motors were used since they were the only motor type able to produce high torque at low speeds. But their problems were huge weight and size, poor reliability due to complex mechanical construction, and their constant need for maintenance due to commutators and complexity. Nowadays they have been almost entirely replaced in propulsion drives by AC motors and frequency converters, which can produce the same excellent torque characteristics with fewer problems.

Furthermore, when direct-drive PM motors are used for propulsion, the dynamical performance of the shaft line will improve, due to the very low rotating mass and inertia of a direct-drive PM motor. The inertia of a PM motor can be a tenth of the inertia of electrically excited synchronous machines, the main alternative in direct-drive propulsion, which improves the dynamic performance significantly in a PM-motor-based system. This is important in ice breakers, as a cogent example, where it is imperative to rapidly clear the ice to avoid blocking the propellers.

Table 1: Variable speed PM genset and propulsion motor for a silent fishing vessel

	Generator	Propulsion motor
Rated power (kW)	3055	2250
Rated speed (RPM)	720	130
Rated voltage (V)	690	690
Rated current (A)	2750	2100
Rated frequency (Hz)	36	26
Measured efficiency (%)	97.7	96.6
Cooling type	IC8A6W7	IC8A6W7
Weight (t)	12	19
Bearings	Sleeve bearings	Sleeve bearings
Certification	DNV-GL (Silent F)	DNV-GL (Silent F)

Reduced installed power

Certain vessel types, such as LNG ships and floating storage regasification units (FSRU), have a very high power demand when the vessel is not moving, due to LNG loading/unloading or cooling. This means that the power plant of such ships uses high power consumption even with no propulsion power. Since propulsion power and standstill

power are not needed at the same time, using diesel-electric propulsion reduces installed power needs considerably, compared to conventional diesel-mechanic propulsion.

For example, an LNG ship with 20MW of propulsion power and 10MW of standstill power would need a total of 30MW of total power capacity – 20MW from the mechanical propulsion source and 10MW of electric power from the power plant. In the case of a diesel-electric system, total power demand from the power plant would be 20MW plus the hotel load of perhaps a few MW and margins – significantly less than a diesel-mechanical system.

Reduced vibrations

In vessels requiring a low level of underwater radiated noise, such as fishing, research and naval vessels, it is paramount to minimise the SBN of the propulsion machinery. Since diesel engines and gearboxes produce high levels of vibrations and noise, it has been common to utilise direct-drive diesel-electric propulsion in such vessels. The main reason for doing this is that the diesel engine that drives the gensets can be decoupled from the propeller, significantly reducing underwater noise.

In the past, DC motors were used exclusively, since, in addition to the good low-speed torque characteristics discussed earlier, they produced very smooth torque, causing less underwater noise than AC motors. With modern frequency converters based on insulated-gate bipolar transistor (IGBT) technology, a very low level of current ripple can be achieved.

Nowadays, when combined with properly designed AC motors, this has enabled electric drives based on AC rather than DC technology in silent vessels. Typically, AC propulsion motors have been either induction or electrically excited synchronous machines, since they are well-known technology. The drawbacks, however, are reduced efficiency and bigger size and weight.

PM generator and motor

During the spring of 2018, The Switch supplied variable-speed PM gensets and direct-drive propulsion motors for a fishing vessel having a DNV-GL Silent F notation. The main data of the machines can be seen in Table 1 and Figure 1.

In order to minimise airborne and structural-borne noise levels from these machines, the electromagnetic vibration level was reduced by optimising the rotor pole shape and by applying skewing for the magnets. The cogging torque amplitude (the tendency of the magnets to align themselves with the stator teeth, of the propulsion motor, which is more critical since it is directly coupled to the propeller) was only 0.15% of the rated torque.

At full-load, torque ripple always increases from the no-load value, or cogging. This is due to the fact that under load, stator current harmonics will cause their own torque harmonic components, causing the torque ripple to increase. Regarding the propulsion motor, torque ripple amplitude at full load was still only 0.48% of the rated torque, imparting very low torsional vibrations to the propeller and giving a low underwater radiated noise level. To illustrate the effectiveness of magnet skewing, it reduced the torque ripple from 2.5% down to 0.48%. Since skewing has a very limited downside and needs only slightly higher current, it should always be applied to any motor design. Figure 2 shows the torque ripple of

a propulsion motor at full-load, with and without skewing.

Sleeve bearings were used in both machines to keep mechanical excitations low. Low-speed cooling fans were used to limit audible noise. Resilient mountings, or 'mechanical dampers', were used for connecting the machines onto the test bed, since they were to be used in the final application as well, and typically they have the biggest impact on structural-borne noise emitted from the motor.

SBN levels were measured with and without resilient mountings, to determine their exact impact. Furthermore, measurements were repeated at various load levels. On the frequency converter side, tests were done with and without the LC-type output filter, to verify its effect.

The purpose of converter output filtering is to reduce high-frequency (typically in kHz range) current harmonics that are due to converter pulse-width modulation (PWM), and therefore to reduce both structural-borne noise and audible noise.

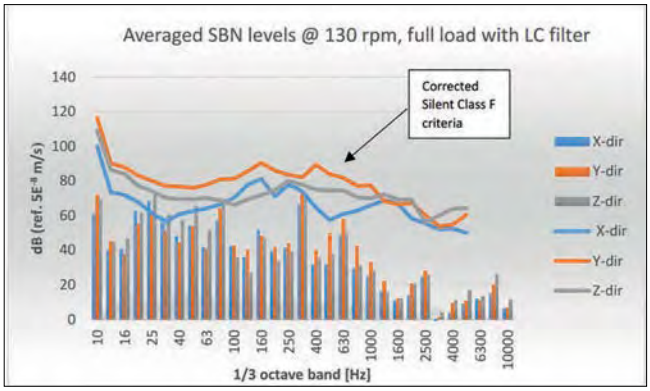


Figure 4: SBN levels for a PMM 1000 propulsion motor at full load. X=axial Y=horizontal and Z=vertical direction. DNV-GL Silent F limits were used as criteria, and corrected with the measured mobility of the test bench

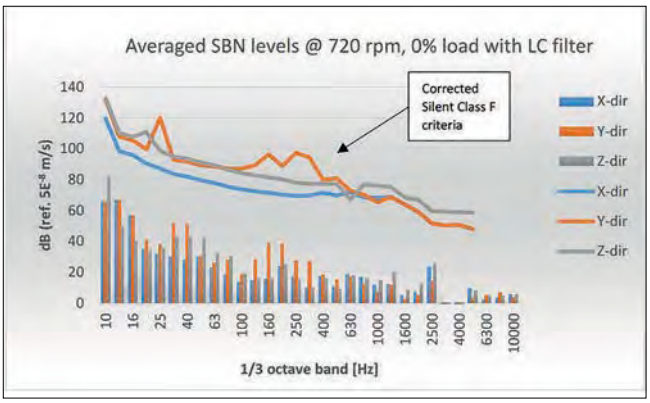


Figure 5: SBN levels for a PMM 630 generator at no-load. X=axial Y=horizontal and Z=vertical direction. DNV-GL Silent F limits were applied as above

Measurement results

Measurements were taken for all three directions – vertical, transverse and longitudinal – by using OROS OR36 8-channel signal analyzer and NVGate software. Accelerometers were glued to the foundation below the machine foot, all transducers were calibrated before the tests, and background noise was measured. The mobility of the test bedframe was measured, and results were corrected according to common practice.

Measured SBN levels are presented in Figures 4 and 5 below for both the motor and generator. Due to test-bench limitations, measurement of SBN levels at full-load was not possible for the generator (PMM 630), so it was carried out only at no-load. Still, SBN levels of the generator are not that critical, since it is coupled to a diesel engine causing far higher vibration levels. Secondly, it is not connected to the propeller shaft, and therefore structural-borne vibrations originating from the generator will not radiate into the surrounding water very well.

SBN levels were measured at various operating points for the propulsion motor (PMM 1000), and full-load results are presented in the graphs. As can be seen from Figure 5, levels are below the mobility-corrected DNV-GL Silent F criteria throughout the range, except slightly at the 25Hz frequency band in the axial direction. It was found that this was caused mainly by resonance between the two machines, the motor and braking generator, which were mechanically coupled through a stiff coupling. It must also be pointed out that, during the measurement, there were two machines, the tested motor and the braking generator, operating at full load on the same mechanical platform. This naturally increases SBN levels compared to a real situation, where only a single machine is connected per propeller.

Resilient mountings were applied in the measurements for both the generator and motor, as they both play a crucial role in achieving low SBN levels. Besides measuring SBN levels at various load points, the effect of frequency converter output filtering was verified by measuring with and without the filter. By applying LC-type machine-side filtering, high-frequency SBN levels were drastically reduced.

In addition to proper electromagnetic design and use of resilient mountings, the use of filtering on the motor/generator output seems to be one of the most effective ways to reduce SBN levels. After analysing the SBN levels of the propulsion motor, it seems likely that those levels can be further reduced from the values shown here by using resilient mountings with more flexibility.

Conclusions

Measurements presented here prove that 'silent' vessels can be designed and built using PM machines. In the past, DC motors were required, but they are physically big and heavy. They have very complex mechanical construction, causing issues with reliability and need for constant maintenance, along with having rather low efficiency.

Some of these drawbacks have been solved using either electrically excited synchronous or induction motors, but both these machine types have their own drawbacks – mainly physically large size and lower efficiency.

PM machines are very simple mechanically, therefore are reliable and need minimal maintenance, plus they run at very high efficiency due to lack of rotor winding. Proper electromechanical design, combined with the use of resilient mountings and converter-side filtering, results in very low structural-borne noise levels, which can meet even the most stringent DNV GL Silent F requirements. *NA*

International standards for ship vibration

Shinichi Hirakawa of Japan Marine United Corporation explains the background concerning the different ISO standards

The 5 February 2018 saw the publication of ISO 21984: 2018: 'Guidelines for measurement, evaluation and reporting of vibration with regard to habitability on specific ships', developed by ISO/TC8/SC8 (the Ship design sub-committee of the Ships and Marine Technology technical committee). On the final ballot, draft ISO 21984 was approved by 17 ISO members without any other ISO members with no votes cast against it.

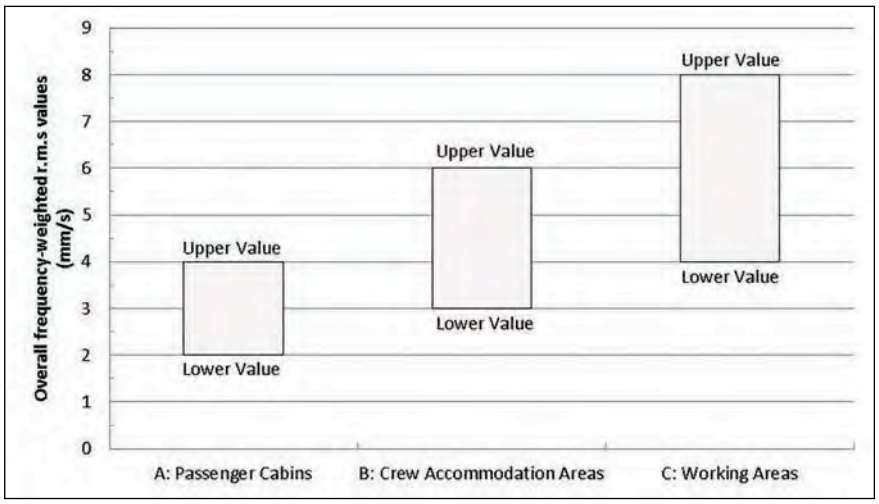
Prior to this, ISO 20283-5: 2016: 'Guidelines for measurement, evaluation and reporting of vibration with regard to habitability on passenger and merchant ships' was developed by ISO/TC108/SC2 (Measurement and evaluation of mechanical vibration and shock as applied to machines, vehicles and structures) and published on 15 December 2016, replacing ISO 6954: 2000.

Since there are now two similar international standards for ship vibration, it is necessary to understand the characteristics and background of each standard.

ISO 6954: 2000: 'Guidelines for measurement, reporting and evaluation with regard to habitability on passenger and merchant ships' has been referred to frequently in the newbuilding contract specifications for passenger ships and cargo ships without particular complaints since the earlier guidelines for vibration (ISO 6954-1984) were revised.

For each space classification, i.e., A: passenger cabins, B: crew accommodation areas and C: working areas, there are two sets of overall frequency-weighted RMS values: 'Values above which adverse comments are probable (Upper values)' and 'Values below which adverse comments are not probable (Lower values)', as shown in Figure 1. It is noted in ISO 6954: 2000 that: "The zone between Upper and Lower values reflects the shipboard vibration environment commonly experienced and accepted".

In general, Upper values have been agreed as a 'Guarantee', whereas Lower values have been agreed as a 'Non-binding target' between the interested parties (e.g., ship owner and shipbuilder) based on the common understanding of the above note.



	Area classification		
	A mm/s	B mm/s	C mm/s
Values above which adverse comments are probable (Upper Value)	4	6	8
Values below which adverse comments are not probable (Lower Value)	2	3	4

Figure 1: Vibration values specified in ISO 6954: 2000

ISO 20283-5: 2016, however, specifies a single unified limit for both passengers and crew onboard all types of ships without due consideration to technical obstacles to design for protection against vibration on numbers of, in particular, large merchant ships (as shown in Figure 2). In other words, there is no distinction between passengers onboard passenger ships and crew on board merchant ships, unlike ISO 6954: 2000, IMO SOLAS requirements and Class voluntary guidelines for 'Comfort on ships'.

At the latest ISO/TC108/SC2/WG2 meeting held in France in July 2015, in which experts from France, Germany, Japan, South Korea and the USA participated, the Japanese presented the results of statistical study based on actual ships (built in and after 2004, around 1,100 measuring points) Based on these findings, the Japanese requested to keep Upper values of ISO 6954: 2000 as one set of Guideline values in ISO/CD 20283-5, since probability of exceedance of the maximum vibration in various spaces, in particular in the crew accommodation areas and on the navigation bridge, were expected to increase significantly if the original set of Guideline values in ISO/CD 20283-5 were adopted (Figure 3). The reason these areas are vulnerable to large vibration is self-evident: they are located near the top of deck house (superstructure).

At the latest ISO/TC108/SC2/WG2 meeting, South Korea also presented the results of their statistical study based on recent ships delivered successfully and requested either to keep two sets of values (Upper and Lower) as per ISO 6954: 2000 or to raise the values specified for crew accommodation, navigation bridge and offices if one set of guideline values should be adopted for the said spaces in ISO/CD 20283-5. This would mean that all ships studied by Korea would satisfy the values, as shown in Figure 4 and Figure 5.

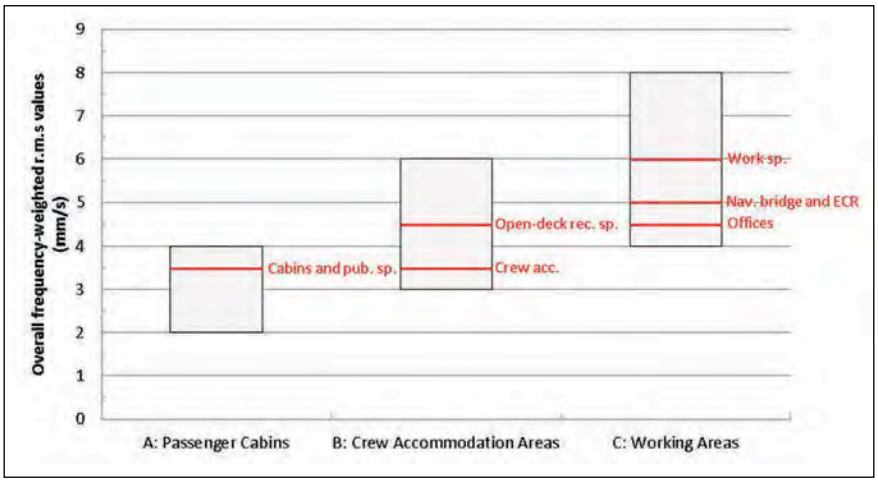
Also at the meeting, France presented the results of their own statistical study based

on actual ships (around 6,000 measuring points), and requested further to reduce the one set of Guideline values in ISO/CD 20283-5. Averages of actual vibration were incredibly low and almost equivalent to standard deviations as compared with those presented by Japan and Korea as shown in Figure 6. However, the background was that actual ships studied by France did not cover sufficient number of 'large' cargo ships and the majority were passenger ships (including cruise ships) to which the voluntary "Vibration notation" was usually granted by Bureau Veritas (BV) upon the request of ship owners. It is natural that passenger ships have numerous numbers of cabins and crew accommodations of the same types, which consequently result in numerous measuring points and therefore the averages of vibration are dominated by the measurements on passenger ships.

According to the statistics presented by Japan and Korea, the common vibration limits specified by ISO 20283-5: 2016 are quite easy to achieve for passenger ships, but hard to achieve for 20-30% of (in particular large) cargo ships because of the significant difference in design conditions.

Passenger ships (including cruise ships) have various technical advantages over cargo ships in terms of minimisation (control) of vibration:

(1) Since the superstructure (deck house) is arranged widely along the length and breadth of the ship, vibration in longitudinal and transverse directions is negligible.



Type of occupied space	Guideline value mm/s
Crew spaces	
Crew accommodation	3,5
Work spaces	6,0
Offices	4,5
Navigation bridge and engine control room	5,0
Open-deck recreation spaces	4,5
Passenger spaces	
Cabins and public spaces	3,5
Open-deck recreation spaces	4,5

Figure 2: Guideline values specified in ISO 20283-5: 2016

(2) The propulsion plant usually consists of generators driven by medium-speed diesel engines and electric motors and/or azimuth thrusters including podded thrusters for better manoeuvrability in port. Elastic mounting technique is applicable to such diesel engines, which can effectively cut off (reduce) the transmission of exciting forces into the hull structure. Medium-speed diesel engines of a large number of cylinders arranged in 'V' configuration with bank angle have less exciting forces by

Figure 3: Vibration statistics presented by Japan

Measurement location	Sample number of ship	ISO/CD 20283-5		ISO 6954: 2000	
		Limit Value mm/s	Probability of exceedance %	Limit Value mm/s	Probability of exceedance %
Crew accommodation	80	3,5	28,8	6,0	4,2
Work space	43	6,0	4,7	8,0	3,6
Office	44	4,5	3,7	6,0	0,0
Navigation bridge	83	5,0	18,1	8,0	4,5
Engine control room	36	5,0	6,1	8,0	0,0

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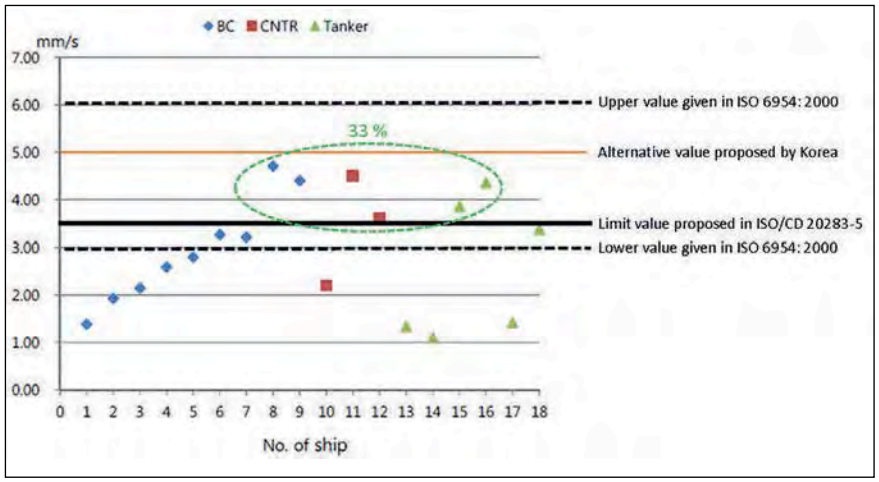


Figure 4: The maximum vibration levels at crew accommodations of recent successfully delivered 18 ships (BC: 9, CNTR: 3, Tanker: 6) – The data were given from three Korean shipbuilding companies

nature because of the self-cancelling effect. Motor rotors have no exciting forces as compared with reciprocators.

(3) The total lengths of the propeller shaft, intermediate shaft and crankshaft are relatively short, which can result in less probability of resonance because of higher natural frequencies of axial and torsional vibrations of shafting.

(4) Displacement and draft are almost unchanging, and hence have almost fixed natural frequencies and vibration modes. This makes it easier to avoid resonance.

(5) Controllable pitch propellers (CPP) are fitted in most of the cases for better manoeuvrability in port. If resonance of vibration is observed, rotational speed of propellers may be changed by adjusting pitch angles so that the resonance can be avoided.

(6) Because of business needs, higher priority is given to the minimisation (control) of vibration and better manoeuvrability by the ship owner.

On the contrary, cargo ships have various technical disadvantages over passenger ships in terms of minimisation (control) of vibration:

(1) Since length and breadth of the deck house (superstructure) are limited as compared with its height, and the deck house (superstructure) is usually arranged just above the engine room and near the propeller, vibrations in longitudinal and/or transverse directions of a cantilever mode are expected in addition to vertical direction. The vibration levels in longitudinal and transverse directions increase with the height levels.

(2) The propulsion plant usually consists of a low-speed and long-stroke diesel engine. Elastic mounting technique, which is effective to cut off (reduce) the transmission of exciting forces into the hull structure, cannot be applied to such low-speed diesel engines since movement of the diesel engine and shafting in rough seas becomes inevitably large, which leads to mechanical damage to bearings, etc. A low-speed diesel engine with a relatively small number of cylinders arranged in 'L' (upright) configuration without bank angle has large exciting forces by nature because of a smaller self-cancelling effect.

(3) Total length of the propeller shaft, intermediate shaft and crankshaft are relatively long, which can result in a greater probability of resonance because of lower natural frequencies of axial and torsional vibrations of shafting.

(4) Displacement and draft are drastically changing, and hence significant changes in natural frequencies and vibration modes. This means that avoidance of resonance is rather difficult.

(5) The fixed pitch propeller (FPP) is fitted in most cases. Even though resonance of vibration is observed under normal output of the diesel engine, the rotational speed of propellers or diesel engine is hard to change.

(6) Because of business needs, the highest priority is given by the ship owner to the fuel efficiency (EEDI/EEOI) and reduction of NOx/SOx/CO_2 emissions.

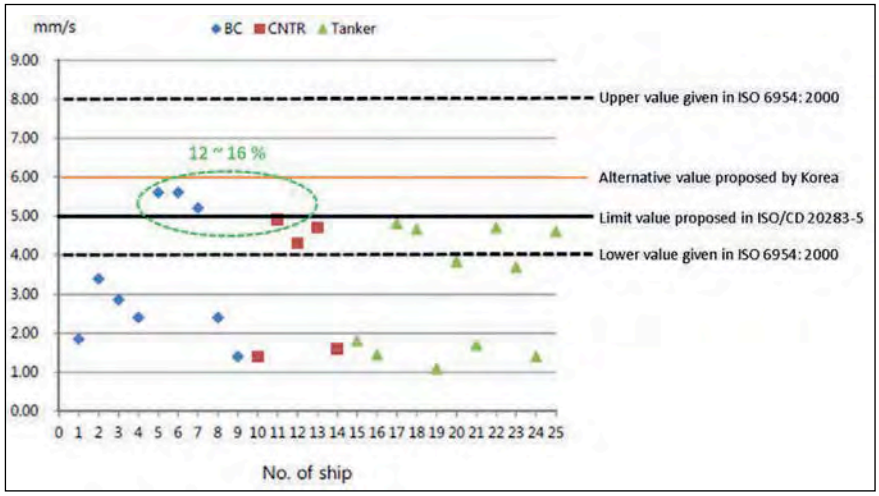


Figure 5: The maximum vibration levels at navigation bridge of recent successfully delivered 25 ships (BC: 9, CNTR: 5, Tanker: 11) – The data were given from three Korean shipbuilding companies

In consideration of IMO's Resolution A.947(23) and the International Goal-based Ship Construction Standards for Bulk Carriers and Oil Tankers (GBS), and the ILO's Maritime Labour Convention (MLC), 2006, at the end of 2013, the International Association of Classification Societies (IACS) developed Recommendation (Rec.) No. 132: 'Human Element Recommendations for structural design of lighting, ventilation, vibration, noise, access and egress arrangements', which covers all ship types. Since GBS requires

Locations	BV Rules 2014 grade 3	ISO 20283-5	Acutal measurements	
	mm/s	mm/s	average	standard deviation
Warehouse / radio rooms	3.2	5	0.4	0.3
Cabins	3.2	3.5	0.4	0.4
Offices	4	4.5	0.4	0.4
Public spaces, mess rooms	4	3.5	0.5	0.4
Hospital	3.2	3.5	0.4	0.3
ECR	6	5	0.7	0.6
Open recreation areas	-	4.5	1.1	0.4
Galleys	6	6	0.5	0.4
Workspaces	6	6	0.6	0.63
Staircase and corridor	6	-	0.36	0.4

Figure 6: Vibration statistics presented by France

'Human Element considerations' as one of its 15 functional requirements, the conformity of IACS Rec. No. 132 to GBS has been verified by an audit team established by IMO. Neither nonconformity nor observation was found by the team about values of acceptable vibration specified in Rec No. 132, which was duly authorised by IMO at MSC 96 in May 2016.

This means that for bulk carriers and oil tankers (the majority of cargo ships), IACS Rec. No. 132 has effectively mandatory status in real terms, which is stringent for shipbuilders and ship owners.

The values of acceptable vibration specified by IACS Rec. No.132 are shown in Figure 7.

The 5mm/s for Accommodation Areas and 6mm/s for Workspaces limits are in-between the two sets of values (Upper and Lower) defined by ISO 6954:2000. It is stated by IACS that these values "are generally not considered to be uncomfortable" but "should not be exceeded".

Likewise, ISO 20283-5: 2016 may also be bound to mandatory SOLAS in the future even though the ISO is of recommendatory status. If the Guideline values of acceptable vibration specified in the ISO should prove impractical for a significant number of cargo ships, that could bring serious confusion and trouble across the industry, as well as IMO.

Considering both the statistics presented by Japan and Korea and Rec. No. 132, ISO 21984: 2018 specifies slightly higher vibration limits for crew accommodation spaces and the wheel house onboard cargo ships, compared with those specified by ISO 20283-5: 2016 as shown in Figure 8. However, no complaints against such vibration limits have been made by the owners and cargo ships conforming to ISO 21984: 2018 and IACS Rec. No. 132 have satisfactorily been in operation.

As described in the scope, ISO 21984: 2018 is applicable to specific ships satisfying one or both of the following conditions:

a) A 2-stroke cycle, long-stroke, low-speed diesel engine directly coupled to the fixed-pitch propulsion propeller is installed.
b) The length of deck house (L) is limited as compared with its height (H) (i.e., deck house of around 1,0 and above in slenderness ratio of H to L).

ISO 20283-5: 2016 is generally applicable to all ships. Requirements for measurement, evaluation and reporting of vibration with regard to habitability for all persons on board of passenger and merchant ships, including specific ships to which ISO 21984: 2018 may also be applicable can be found in ISO 20283-5: 2016. ISO 21984: 2018 is neither complementary nor additional but supplementary to ISO 20283-5: 2016. The shipbuilder can select either ISO 21984: 2018 or ISO 20283-5: 2016 to apply to any specific ship upon due consideration to individual design conditions of the ship and experience, if any, in building sister or similar ships.

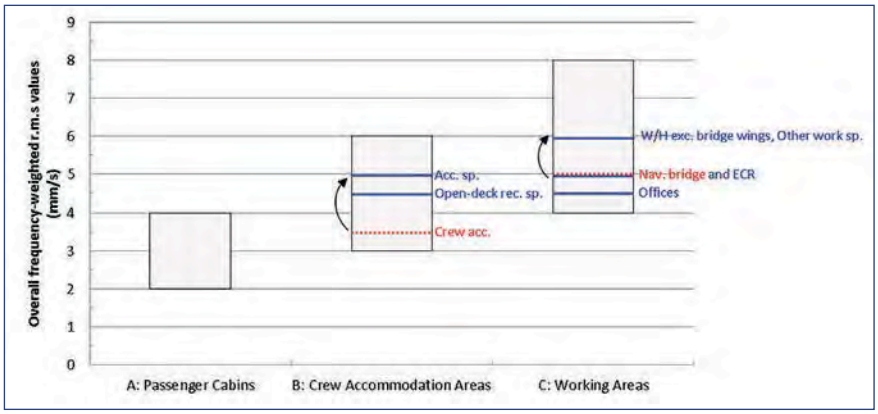
Future study on human response to vibration on cargo ships is needed to provide a more sound basis for specifying acceptable vibration limits, although this requires time and sponsorship and therefore cannot immediately solve the problem for cargo ships caused by ISO 20283-5: 2016 (the revision of ISO 6954: 1984 and ISO 6954:

Figure 7: The values of acceptable vibration specified by IACS Rec. No.132

1.4 Vibration

- Vibration comfort varies among individuals as it is determined by individual differences. Individually, perception of vibration comfort is determined by the magnitudes and frequencies of those vibrations.
- The following are recommendations aiming to control levels of whole body vibration exposure that are generally not considered to be uncomfortable, and these are based on the recommendations of ISO 6954 (2000).
- The following levels of whole body vibrations should not be exceeded when measured in three axes (x, y, and z) using the w weighting scale (whole body, as discussed in ISO 6954:2000) with a band limitation in all axes limited from 1 to 80 hz.

Maximum RMS vibration levels	
Accommodations Areas	Workspaces
180 mm/second^2 (5 mm/s)	215 mm/second^2 (6 mm/s)



Type of occupied space	Guidance value mm/s
Accommodation spaces	5,0
Open-deck recreation space	4,5
Offices	4,5
Engine control room	5,0
Wheelhouse excluding bridge wings	6,0
Other work spaces	6,0

Figure 8: Guidance values specified in ISO 21984: 2018

2000 took 16 years, respectively).

The study is needed since ISO 6954: 1984 was developed based on the vibration measurements on board cargo ships which had been built up to the late 1960s and no new data was considered additionally in the development of ISO 6954: 2000 and ISO 20283-5: 2016. Development of ISO 21984:2018 was itself based on research of the Japan Ship Technology Research Association supported by the Nippon Foundation.

The establishment of a single ISO standard for vibration, which can realistically cope with both passenger and cargo ships, is the best solution in the future, too. The acceptable vibration values for both types of ships need to be decided based on the results of the future study mentioned above. *NA*

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   - 1.3 Probabilistic concept; introduction and background (SOLAS 2020)

Wednesday, 10 October 2018

2. Probabilistic Framework of Damage Stability
   - 2.1 General Probability theory
   - 2.2 p-factor
   - 2.3 s-factor
3. Probabilistic Framework of Damage Stability
   - 3.1 Design implications
   - 3.2 Design examples

Thursday, 11 October 2018

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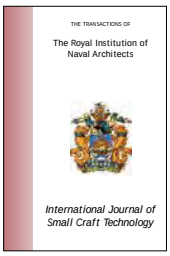

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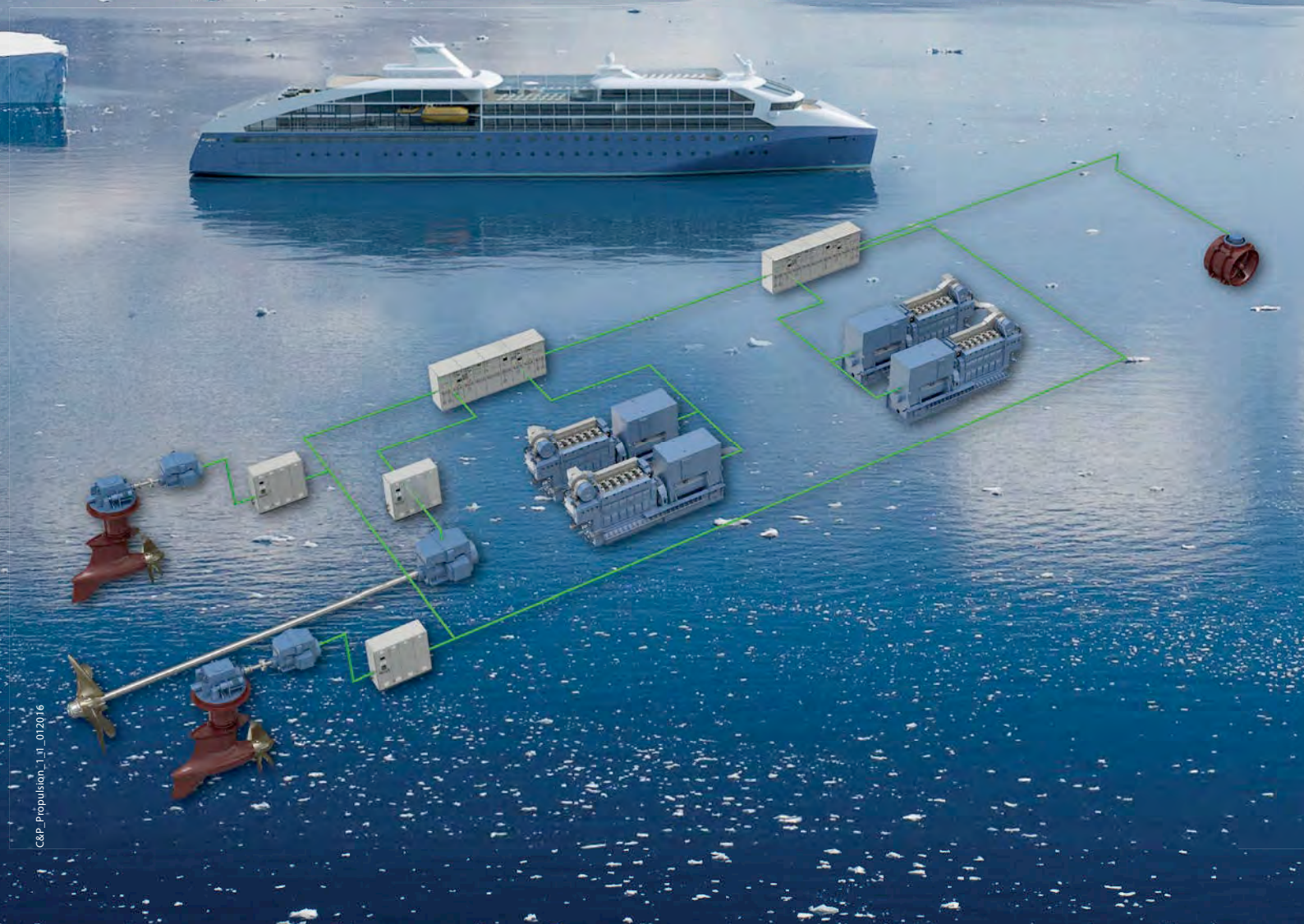

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