The Combi Drive –
An innovative propulsion system for electric ships

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This paper describes a relatively new and innovative azimuthing thruster system called Combi Drive, which is a symbiosis of a full electric pod and a standard azimuthing thruster. It will show which idea lead to this system and describe it in detail. The paper furthermore highlights the advantages of this new thruster type over the existing ones and will clearly point out single benefits for operators/owners and builders, followed by a brief field report of the first units in service.

INTRODUCTION

Diesel-electric powered offshore vessels are becoming more and more common, and most of them use azimuthing thrusters either for main or auxiliary propulsion during dynamic positioning.

Even anchor handlers with a rather high power demand are nowadays fitted with diesel-electric azimuthing thrusters.

The thrusters in use are in general “conventional” mechanical geared thruster with horizontal power input so called “Z-Drives” and in some cases electric pod systems.

Both systems have their pros and cons in respect of size, space requirements, initial and operational costs. Although, if one comparing both systems clinical, there are major advantages for the electric pod system. Thus some years ago it really seemed that the electric pod system was on its way to get the upper hand in the market of azimuthing propulsion systems for full electric vessels.

But nowadays the mechanical thruster has still an overwhelming market share in the diesel electric offshore market and the full electric pod does nearly not exist in this market and is only used for special applications.

The question was raised what is the reason for that and could that be changed. The answer to this question was a little bit deflating as it seems to be quite difficult to gain a bigger market share for full electric pods. Hence the question was raised, how the offshore market could benefit from the advantages of the pod system, even if it is not used itself.

Based on this question the idea came about to develop a symbiosis out of a mechanical azimuthing thruster and the basic design features of a pod system in order to gain the advantages of both systems and combine them in one new system using well known reliable techniques.

The outcome is the so called “Combi Drive”; a combination of geared propeller shaft and vertically arranged water cooled electric motor partly integrated inside of the thruster. Basically consisting of parts of the mechanical azimuthing thrusters but offering the same compactness as a full electric pod.

THE COMBI DRIVE

The Combi Drive consist of two major parts the upper one with the integrated electric motor and the lower part with the mechanical gearbox. Both parts connected via an azimuthing steering module.

Figure 1 Lower part of a twin propeller Combi Drive

Upper part of the Combi Drive

Instead of the upper gear of a mechanical thruster with horizontal power input a vertical arranged e-motor tops the lower part and forms the upper part of the Combi Drive.

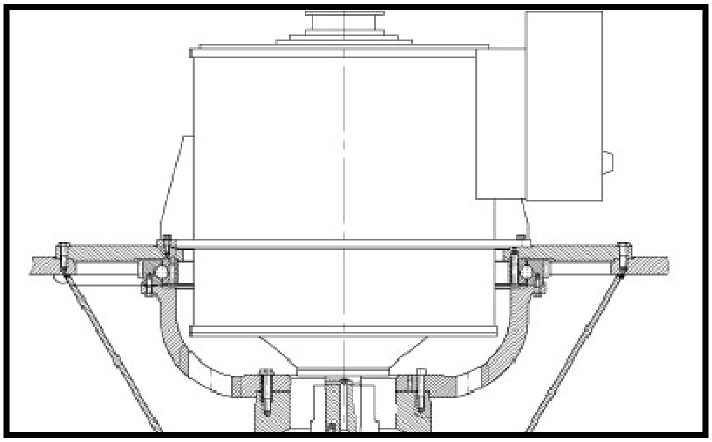

Figure 2 Upper part of the Combi Drive

One could say now we have a simple mechanical thruster with vertical power input, a so called L-Drive (see figure 3), what is so innovative about that?

But this is not correct, different from the L-Drive the Combi Drive motor sits partly integrated inside the thruster, thus only two third of the motor sticking out of the thruster (see figure 2). Hence there is a significant height advantage over the L-Drive, which needs a motor foundation and has the complete vertical motor above the top plate.

One significant thing is equal to an L-Drive, this is the fact that you have only one gear step inside the thruster which is situated in the lower part. The similarity forces you to slow down the speed of the e-motor compared to a thruster with horizontal power input with two gear steps inside.

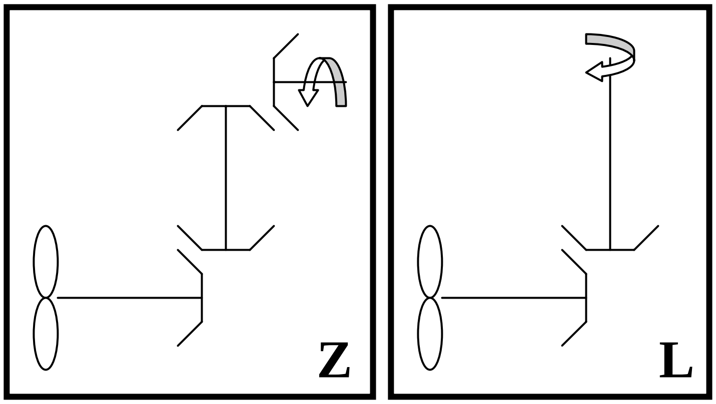

Figure 3: Principle of an Z-Drive and L-Drive

This is due to the fact that the reduction ratio of the single step gear set is smaller than the reduction ratio of the double step gear set.

One could now argue to increase the reduction ratio of the single step gear set, but this would lead to a larger bevel gear which on the other hand would lead to a larger housing which since this gears forms the lower part of the thruster would extremely worsen the hydrodynamic efficiency of the system and is therefore out of question.

What happens now is, due to slow speed and constant power you need a motor with a rather high torque compared to a motor for an azimuthing thruster with horizontal power input, so called Z-Drive (see figure 3).

$$M(n) = \frac{P(n)}{2\pi \cdot n}$$

Eq1: Motor torque

$$15.9kNM = \frac{2000kW \cdot 60\,{}^{\sec}\!/_{\min}}{2\pi \cdot 1200rpm}$$

Eq 2: Z-Drive input torque

$$25.5kNM = \frac{2000kW \cdot 60\,{}^{\sec}\!/_{\min}}{2\pi \cdot 750rpm}$$

Eq 3: Combi Drive input torque

Eq2 shows the motor torque of a Z-Drive which due to its larger reduction ratio has a higher input speed compared to the input speed of a Combi Drive. The Combi drive input torque (Eq3)in this example is abt. 60% higher.

The higher torque leads consequently to a physically larger motor.

This created one of the main challenges during the development of the Combi Drive, how can the quite big e-motor be accommodated inside the upper part of a standard mechanical thruster with a rather narrow azimuthing steering module (A-Module). The answer was quite easy, let us use the A-module of the next bigger thruster.

The A-module, especially the slewing bearing and the steering gear, of the next bigger thruster model is in general wider than the one of the model below.

On the one hand this solved the problem, but on the other hand set the lower power limit for the Combi Drive. Means beyond a certain thruster size it is neither physically possible nor economical feasible to build a Combi Drive.

Thus the Combi Drive is now available in three different sizes as you can see in below table.

	SCD 1515	SCD 2020	SCD 3030
Twin Propeller	2100 kW *	2700 kW	3800 kW *
Single propeller	1900 kW *	2500 kW	3300 kW

Table 1: Available SCD models (Actual maximum power depends on application and class rules/*currently under development)

Azimuthing steering system

What forms the middle section of an azimuthing thruster is the azimuthing steering system.

Since the Combi Drive is dedicated to be installed on full electric vessels it was just logical to install a full electric azimuthing steering system. This makes the system even more compact as there is no need for any additional hydraulic piping as it is know from simple standard Z-Drives. Even that nowadays also for this system full electric steering is available.

Connection between upper and lower part

A vertical power transmission shaft connects the vertical installed E-motor with the lower gearbox.

The lower bearing of the e-motor is used as the upper bearing of the power transmission shaft thus there is no additional upper support bearing in the thruster needed.

The elastic coupling between motor and power transmission shaft is made in such a way that it is self aligning.

That means in case the motor has to be exchanged the coupling between power transmission shaft and motor has not to be realigned manually.

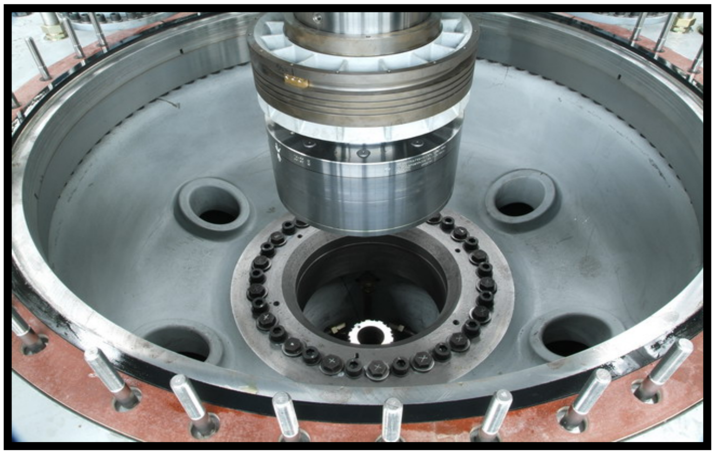

Figure 4: Elastic coupling between motor and power transmission shaft

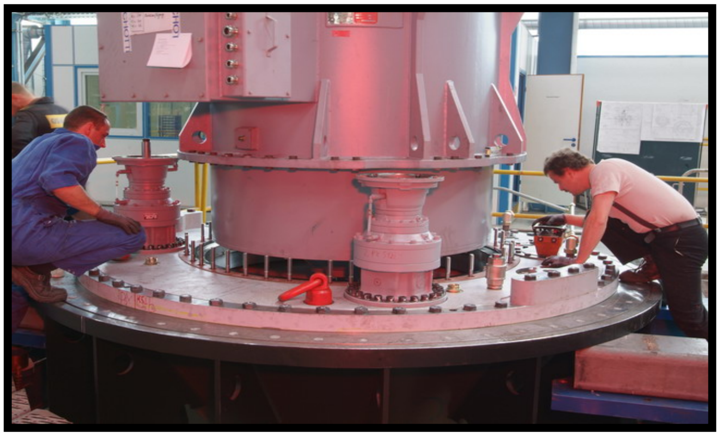

Figure 5: E-Motor is mounted to a Combi Drive

Lower part

A standard lower gearbox and stem section from the mechanical Z-Drive series forms the lower part of the Combi Drive. In each Combi Drive range are three different lower sections available as shown in Fig.

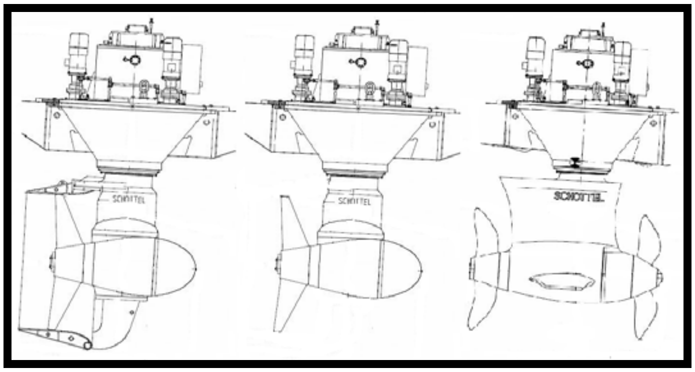

Figure 6: Three different Combi Drive types

Number one is the standard lower housing with single propeller and nozzle. This type is mainly used for anchor handlers, tugs or other vessels with a rather high thrust demand at low speeds.

The second type is as well a standard mechanical z-drive lower housing with single propeller but without a nozzle, for vessels with low thrust demand at low speeds.

The third one is a twin propeller housing which is designed for rather high speeds of abt. 21 – 22 knots. This housing is also taken from the standard thruster series but has a special hydrodynamic design which avoids separation of the water flow from the housing at high speeds.

The system furthermore has two propellers one push and one pull propeller which are both situated on the same propeller shaft. Hence you have only one gear set, which allows you to use the same gear reduction as in the single propeller type versions. A further advantage of the twin propeller housing is the high ruder effect which is based on the lager lateral area and gives further course stability to the ship.

Max. Power of the single and twin propeller version

As you certainly noticed from table 1, the single propeller Combi Drive has less maximum power than the corresponding twin propeller model.

One of the major advantages of the twin propeller version is that you share the propeller load between two propellers which on the other hand allows a smaller propeller diameter. A smaller propeller diameter again allows a higher propeller or input speed, which, provided the input power is constant, corresponds to a lower torque (see Eq1).

But the gear of the Twin propeller is the same as it is for the single propeller and has therefore the same torque limit, which consequential means you can increase the input power for the twin until you reach the torque limit of the gear. This is the explanation why we have different power limits for the twin and the single propeller version in the same model series.

COMPARISON – MECHANICAL Z-DRIVE VERSUS COMBI DRIVE

The E-Motor driven mechanical Z-Drive

The mechanical Z-Drive basically consists of an upper and a lower bevel gear set (see figure 3) with an azimuthing steering module in between. Vice versa form the Combi Drive the Z-Drive has a horizontal power input.

Driven by an electric motor, the connection between prime mover and Z-Drive is in general made by a so called flexible shaft with elastic elements or via a universal joint shaft with an elastic coupling. Pending whether prime mover and Z-Drive power input are on the same level or not.

This arrangement requires beside a foundation for the Z-Drive and the E-Motor also the alignment of the shaft line, which as well creates labour costs.

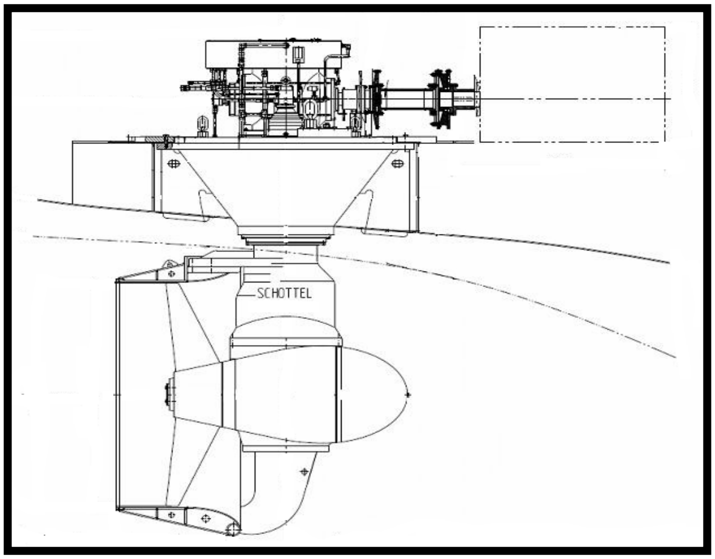

Figure 7: mechanical Z-drive

Advantages of the Combi Drive over a mechanical Z-Drive

The obvious differences between the Combi Drive and the mechanical Z-drive provide advantages of the Combi over the mechanical Z-drive for the operator as well as for the shipyard which has to install the propulsion system.

Before we come to the single benefits for operators and yards lets have a brief look to a general comparison of both systems, shown in table 2.

	Mech-Z Drive	Combi Drive
Initial cost	100%	110%
Required space	100%	80%
Mechanical efficiency	95%	97%
Electrical efficiency	96%	96%

Table 2: General comparison Z-Drive versus Combi Drive

What stands out beside all the efficiency and space saving benefits of the Combi Drive are the 10% higher costs. These costs are basically generated by the wider A-module of the Combi Drive and the more expensive prime mover based on the higher input torque. But beside that the Combi Drive offers less mechincal losses and hugh space savings over a mechanical Z-Drive.

Benefits for an Operator

Firstly I’d like to come to the benefits an operator can gain from the Combi Drive in comparison to a mechanical Z-Drive.

The most obvious advantage for an operator is the missing upper gear set of the Combi Drive, since due to that, the mechanical efficiency of the Combi is about 2% higher than the one of the Z-Drive.

Less mechanical losses can either mean that you can install less power and gain some fuel savings or that you reach a higher thrust value with the same power and may get a slightly higher speed. This on the other hand can be a marketing advantage for the vessel.

The second major advantage for the operator is the space savings you get from the Combi Drive due to the missing shaft line and the partly integrated E-motor. Space savings mean that the thruster room can be smaller and the cargo area can be extended which provides a higher profitability of the vessel.

The third big benefit is the service and maintenance costs. Due to the missing upper gearbox the Combi Drive has less mechanical parts which could fail or needed to be serviced. And due to the partly integrated e-motor the oil volume of the Combi Drive is smaller than that of the mechanical Z-Drive. Thus all over all the lifecycle costs of the Combi Drive are assumed to be at least 5% lower than the lifecycle costs of a mechanical Z-Drive.

Benefits for a shipyard

The Combi Drive offers also benefits to a shipyard. The missing shaft line not only gives space savings but also means savings in the installation, because the shaft line neither has to be installed nor aligned by the yard, which provides savings in labour. The integrated E-motor offers as well some cost savings, not only in labour but also in material. This is due to the fact that the shipyard has not to provide an E-Motor foundation and similar to the missing shaft line neither to install the E-Motor nor to align it.

To complete the simplicity of the system the Combi Drive comes with full electric steering which as well saves some costs for a shipyard as no expensive hydraulic piping is necessary.

THE COMBI DRVE STILL NOTHING ELSE AS AN L-DRIVE?

One can now argue all above mentioned benefits I can get from a simple mechanical azimuthing thruster with a vertical power input (L-Drive) as well, but an L-Drive has a significant and considerable disadvantage compared to a Combi Drive or even a mechanical Z-Drive and this is the overall height.

Due to the fact that with an L-Drive the complete E-motor sits, outside the thruster, on top of the drive the L-Drive is much higher than a Combi Drive or a mechanical Z-drive which is a no go criteria for most of the supply vessels, anchor handlers and similar ships which in general have a very flat aft ship and a very narrow thruster room height.

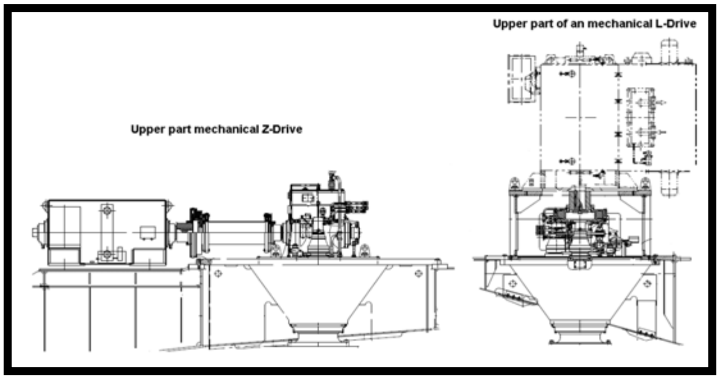

Figure 8: Dimensional comparison mechanical Z-Drive versus L-Drive

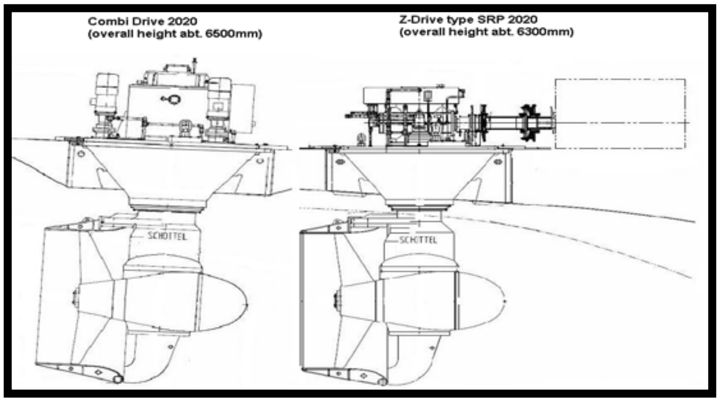

Figure 9: Dimensional comparison Z-Drive versus Combi Drive

Figure 8 shows the extreme height difference between an mechanical Z-Drive and an L-Drive inside the vessel whereas figure 9 shows how close the Combi Drives comes to the all overall heights of a mechanical Z-Drive

Due to its partly integrated E-motor the Combi Drive is as compact as a mechanical Z-Drive and has nearly the same overall height which on the other hand means it fits as well in a supply vessel as a mechanical Z-Drive.

The overall height difference between a mechanical Z-Drive type SRP 2020 and an SCD 2020 is only abt. 200mm. (see figure 9). Whereas the height difference between a mechanical Z-Drive and an L-Drive is at least the length of the e-motor (see figure 8).

COMPARISON – POD DRIVE VERSUS COMBI DRIVE

The Pod Drive

The Pod Drive has no gears and consists basically of an 360° steerable electric motor which is directly coupled to the propeller, thus the rotor shaft of the e-motor forms at the same time the propeller shaft. In terms of mechanical efficiency the Pod Drive is of course the optimum since it has only 1% mechanical losses. Beside that it has a further advantage over mechanical azimuthing propulsion systems which is that it uses nearly no lube oil.

Figure 10: 2000kW Pod Drive Type SEP 2

That becomes nowadays more and more important considering the increasing requirements concerning avoidance of environmental pollution. And a no lube oil propulsion system consequently reduces the risk of environmental pollution tremendously.

Advantages of the Combi Drive over a Pod Drive

There are some obvious differences between the Combi Drive and the Pod Drive which at the first look might give some advantages for the Pod Drive but at the end will be clear advantages for the Combi Drive.

The following table gives a first general comparison between both systems. As the mechanical Z-Drive forms the basis for both it is as well mentioned in the table.

	Mech-Z Drive	Combi Drive	Pod Drive
Initial cost	100%	110%	150%
Required space	100%	80%	80%
Mechanical efficiency	95%	97%	99%
Electrical efficiency	96%	96%	97%

Table 3: General comparison Pod Drive versus - Z-Drive and Combi Drive

What stands are the high initial costs of the Pod Drive over a Combi Drive, which is mainly driven by the much more expensive prime mover and the more extensive system.

But the question is, is that justified, are you getting a much better system for this price, if you compare the efficiency plus to the Combi Drive we would clearly say no.

Benefits for an Operator

Where are now the benefits for an operator comparing a Combi Drive and a Pod Drive. What is obvious are the lower initial costs of the Combi Drive whereas you gain the same space savings from the Combi Drive as from the Pod Drive.

But the real advantage is the simplicity of the Combi Drive. The Combi Drive uses a standard water jacket cooled asynchronous motor which sits inside the vessel and not below waterline. Anything below the waterline is from a reliable hundred of times proven simple mechanical system.

A Combi Drive is much easier to service and maintain. In case of a failure of a drive motor it can easily be exchanged without going to dry dock. If a spare motor is available it can be exchanged in one or two days, even with the vessel afloat.

A further advantage is the propeller shaft seal, the Combi Drive can use the same standard propeller shaft seal which is already in service on hundreds of mechanical Z-Drives. A Pod Drive has a much bigger propeller shaft diameter and needs consequently a special propeller shaft seal as the circumferential speed of the shaft is higher and generates more frictional heat in the sealings.

Considering all above said we can say that the Combi Drive and the Pod Drive offer the same space savings advantages and nearly the same efficiency benefits to an operator, but doing so the Combi Drive is less complex. Less complexity is of course the basis for high reliability.

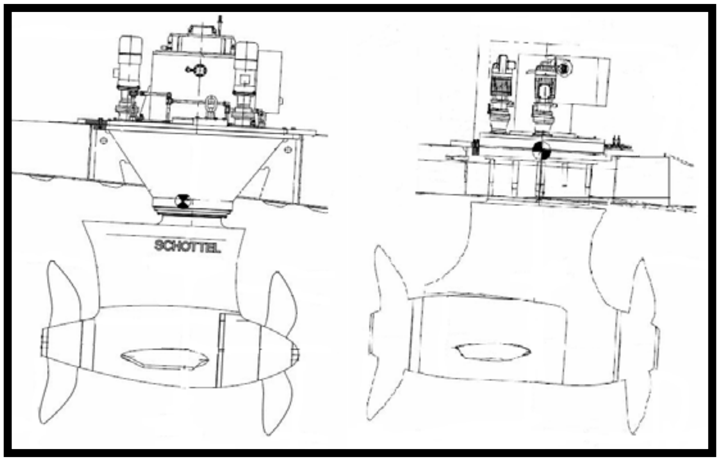

Figure 11: 2750kW SCD2020 in comparison to an 2000kW SEP 2 Pod Drive

Benefits for a shipyard

The Pod Drive and Combi Drive offer exactly the same advantages over a mechanical Z-Drive as already described above. But doing so, the Combi Drive is less complex in the installation and minimise the risk of interface failures. On top of that it has lower initial costs.

COMBI DRIVE FIELD REPORT

The first vessel in service with a Combi Drive was a doubled ended ferry in Norway which is fitted with four SCD 2020 TWIN, two in the bow and two in the aft. With this propulsion system the ferry is able to reach a speed of 21 knots.

This application was a really good basis for the first field test of the Combi Drive.

With the relatively high speed of the ferry the system was taken to the design limits and could show how reliable it performs. Some of the measurements taken during the first sea trials are explained in the following.

Figure 12: The first vessel in service with the SCD 2020

Steering torque zigzag test at 21 knots

One of the most critical services of an azimuthing drive is the zigzag test were the vessel permanently changes course from +35° to -35° steering angle of the drive. Under these conditions the steering torque can climb up to its max. The torque limit for the steering gear was abt. 485 kNm and for the zigzag test a max torque of 355kNm was calculated.

The steering torque during the sea trials was just below what was calculated and stayed absolutely in the limits.

An even more difficult/dangerous manoeuvre is the crash stop test where the ship is stopped in the shortest possible distance from full speed ahead.

This is a quite normal manoeuvre for a tug boat which operates at max 12 or 13 knots, but for the ferries with 21 knots trial speed the thing looks different. During this manoeuvre the units are turned by 180° from full ahead to full astern in about 12 to 15 sec. (standard steering time of such a system is abt 2-2,5rpm) Which brings the steering torque even closer to the limit. Nevertheless even this test showed that there is still a safety margin. This basically means although the unit performs at its limits it is still a reliable system.

Damping between E-motor and ship structure

To damp the vibrations initialised by the frequency converter, the electric motor is elastically mounted. This connection is marked in figure 13 by the third arrow from the left side.

The second measurement point was the thruster flange it self marked by the centre arrow. The first arrow on the left marks the connection between ship structure and SCD flange. On all three points measurements were taken during the first sea trials to show the damping effect of the elastic elements.

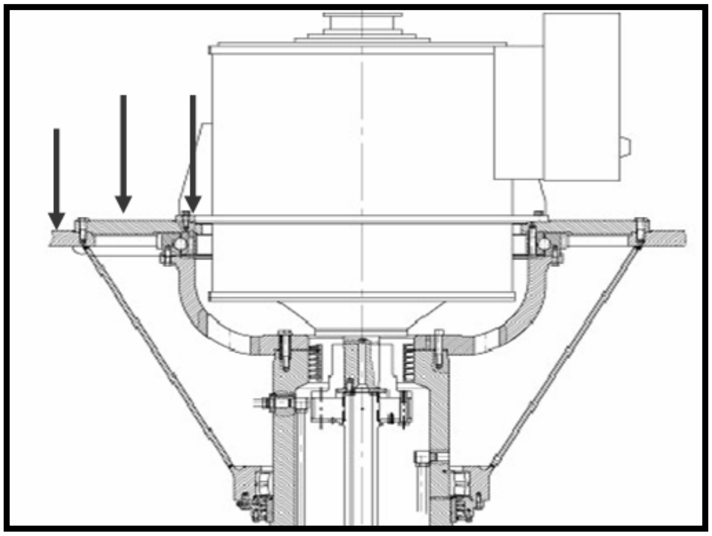

Figure 13: Measuring points at the SCD 2020 Twin

The results of these measurements are displayed in figure 14.

What you can see in the upper part of the diagram is the difference between the E-motor and the SCD flange, the lower diagram shows the damping effect between SCD flange and ship structure.

The damping between motor and SCD flange is already about 10DB above 1000Hz and gets a further improvement when you look to the connection to the ship structure. The result of these measurements confirmed further calculations and topped them in some areas.

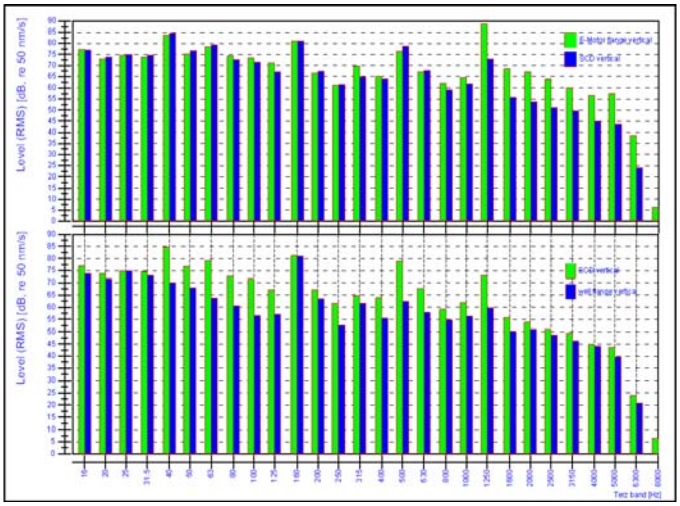

Figure 14 : Damping between E-Motor and ship structure

CONCLUSION

The Combi Drive, a new member of the azimuthing thruster family, is born.

It clearly shows a lot of advantages over the already existing systems as it is the perfect symbiosis of simplicity and compactness, the basis for high reliability.

Simplicity is taken from the mechanical Z-Drive and compactness from the Pod Drive combining both, a system was developed which exactly reflects the market needs.

A simple, compact and highly reliable electric azimuthing propulsion system, offering its benefits to operators and shipyards in equal shares.

We think the Combi Drive fills a long existing gap in the market and justly has an entitlement to be the future leader in this market.

When our engineers designed this system they always kept one quote from Albert Einstein in mind

“Make everything as simple as possible. But not simpler”.

This philosophy is fully reflected in the Combi Drive and is the soul of the system

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