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SIEMENS - SCHOTTEL Propulsor

The Energy Saving Propulsion Concept

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0 Summary

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have developed a new propulsion system within the power range of 5 MW to 30 MW per unit. This propulsion system is proven to give a better efficiency than conventional propellers, and in addition improved manoeuvrability with increased safety and easier handling is achieved. The propulsion system **SIEMENS SCHOTTEL PROPULSOR** (SSP) (s. Figure 1) is specially suitable for cruise vessels, large ferries and passenger vessels, cargo vessels like e.g. chemical tankers, ice going vessels, large offshore structures and Navy vessels.

With this new propulsion system, energy savings of more than 10 % are possible due to the efficiency improvements of the combination of SCHOTTEL Twin Propeller and the newly developed Siemens permanent excited synchonous Motor, allowing maximum efficiency in transmission of electrical energy at minimum installation space.

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2 Background

Energy savings as well as a lower noise and vibration level on board of ships are and have always been tasks for designers, propulsion specialists, and machinery developers. Therefore hull forms of ships have been improved by many means in order to reduce the resistance of a vessel, and improved propulsors have been designed to gain efficiency, moreover machinery developments were made to reduce transmission losses and to achieve lower losses in energy.

SCHOTTEL have contributed to this by developing the Tip Vortex Vane Propeller (TVV), the Hub Vortex Vane Propeller (HVV), and the SCHOTTEL Twin Propeller (STP), offering energy savings of up to 20 % in comparison to conventional propellers.

Siemens have contributed to this by improving the total efficiency of the propulsion motor by about 2 %.

A consequential step into the future therefore is a joint development of SCHOTTEL and SIEMENS, the SCHOTTEL-SIEMENS-Propulsor (SSP), extending the power range of highly efficient propulsion systems to 30 MW per unit.

3 Siemens - Schottel Propulsor (SSP)

3.1 Comparison between SSP and Standard Rudderpropellers

The benefits from steerable right-angle drives (Rudderpropellers) for the motorization of vessels requiring up to 6MW engine power per shaft are well known. This concept is known worldwide, and SCHOTTEL as major supplier of these units is having more than 23.000 units in service.

The advantages of the system are:

- The unit replaces steering and propulsion systems of vessels.
- It guarantees optimum manoeuvrability without additional stern thrusters.
- It guarantees low noise and vibration by means of special supports.
- It needs less space and requires a smaller engine room.
- It can be installed later than the conventional system.

To improve the efficiency of a Rudderpropeller system SCHOTTEL has developed the SCHOTTEL Twin Propeller (STP). Here the propeller load is distributed to two propellers, one forward and one aft of the lower housing. With two airplane type fins added to the lower housing and 50 % load per propeller only, the STP can achieve up to 20 % higher efficiencies compared to standard Rudderpropellers.

Since mechanical right angle drives do have their limits at about 7 MW per shaft - and this is also the limit for the SCHOTTEL Twin Propeller - the development of the SIEMENS SCHOTTEL Propulsor (SSP) was done to utilize the advantages of the Twin Propeller also for higher powers. This utilization is only possible with the installation of powerfull electric motors directly into the lower housing of the azimuth drive (s. Figures 2 and 3).

Conventional, electrical synchronous motors of high power and low speed do however have the disadvantages of large size and heavy weight, so big propeller hubs are needed to accomodate these motors. The diameter of standard podded drives underwater bodies is about 60 % of the propeller diameter which has an influence on the overall efficiency (s. Figures 4 and 5).

To compensate this basic disadvantage of standard podded drives SIEMENS has continued successfully the developement of the permanently excited synchronous motor in longitudinal flow design for marine applications. A 1000 kW propulsion test unit is in operation already for more than 10 years on a navy vessel.

This type of motor, available in the power range of about 5 MW to 30 MW at low speed, allow to reduce the diameter of present day motors significantly, and so podded drives with optimum hub / propeller diameter ratios and optimum propulsion (Twin Propellers) can be designed. These units will be marketed under the name SIEMENS SCHOTTEL PROPULSORS (SSP).
In addition to Rudderpropeller installations with mechanical power transmission this new system

offers following advantages:

- No risk of vibration exitation through gear sets and cooling fans.
- Simple surface-cooled motor.
- Mounting of the lower housing is possible without drydocking of the vessel.

3.2 Reference Vessel

As a reference vessel, the 70.000 gt cruise vessel "CENTURY", built by Meyer Werft in 1995, was chosen. The ship has a propulsive power of 2 x 14 MW and a design speed of 22 knots. Propulsion analysis was carried out in tank tests under the research and assistance of tank test institute SVA Potsdam, Germany, and under consideration of the original conventional tank test of vessel carried out by SSPA, Gothenburg, Sweden.

The vessel has the following main dimensions:

- Length over all 248.5 m
- Length W.L. 213.93 m
- Breadth W.L. 32.2 m
- Draught, design 7.5 m
- Displacement 35.200 t

The conventional diesel mechanic propulsion system of this vessel includes two shaft lines with propellers each of a diameter of 5.8 m and powered by 14 MW per shaft at 120 rpm.. All informations on this vessel were kindly given by Meyer Werft, Papenburg.

Two standard podded drives with propeller diameters of 5.2 m and propeller speeds of 160 rpm., as well as two SIEMENS SCHOTTEL PROPULSORS with propeller diameters of 5.4 m and propeller speeds of 150 r.p.m. were analyzed by SVA Potsdam by tank tests and cavitation tank results. The results are laid down in Figure 6.

These results show that the SIEMENS SCHOTTEL PROPULSORS will reduce the power consumption of a propulsion plant by 10 %, so that either a higher speed of 0.5 knots or alternatively a lower fuel consumption of 10% at same speed is guaranteed.

Although for the standard podded drive the advantages of lower resistance due to the absence of stern thrusters and shaft brackets are considered, the speed with this propulsion concept is not better than with the conventional concept. Figure 7 shows the installation of SIEMENS SCHOTTEL PROPULSORS on a cruise vessel and proves the space savings compared to the conventional design.

3.3 Siemens - Schottel- Propulsor (SSP)

The 14 MW SIEMENS SCHOTTEL PROPULSOR consists of a stream-lined lower housing made from shipbuilding steel and cast steel. Two fins are welded to the lower housing to gain

rotational energy from the forward propeller. The lower housing of the unit is designed in such way that it allows even underwater mounting of the lower housing as an option so that no dry-docking is necessary for dismantling of the lower unit (s. Figures 2 and 3).
The upper part consists of a cone type support structure flanged to the ship's structure and made from shipbuilding steel.
Two propellers and the propeller covers are fitted to the lower housing. Following items are installed into the lower housing :

- The propeller shaft with water-lubricated sealings and pneumatic pressure safety device, well proved in Navy applications as well.
- Bearings as roller bearings with life time > 200,000 hours (LH na), which is considered as infinite lifetime.
- Brake to block the propeller.
- Propulsion Motor.
- Bilge system.
- Alarm and monitoring sensors for motor, bearings and sealing systems.

Following items are installed into the upper part:

- The cable lead allowing 410° or optional unlimited azimuth steering.
- The pneumatic compressors for sealing actuation.
- The electric / hydraulic azimuth steering system.
- The local indicators.
- The bilge pumps.

WEIGHTS

Weight comparison of SSP installation vs conventional diesel-electric propulsion system.

Conventional diesel-electric propulsion system:

Propeller motors	210 t
Motor foundations	30 t
Shaftlines	215 t
Shaft tubes and brackets	11 t
Rudders and steering gear	54 t
Castings for brackets, Shaft and rudder support	145 t
Stern thrusters	95 t
Total weight :	760 t

SIEMENS SCHOTTEL PROPULSORS

SSP units	450 t
Additional cabling	10 t
Steel support structure	50 t
Total weight :	510 t

4 Electrical System

4.1 Mechanical and electrical requirements upon the selected machine concept

As already mentioned above the hydrodynamic requirements upon an optimized SIEMENS SCHOTTEL PROPULSOR with an integrated, electrical propulsion motor demand upon the diameter of the lower housing that it should not exceed 30% to 40% of the propeller diameter.

Because of the space requirements it is not possible to use for this specific lower housing design a conventional synchronous motors in air or air to water cooled design with electrical excitation. For that reason it was necessary to find a suitable concept of an electrical machine which essentially should fulfill the follwing, beforehand defined requirements :

- maximum efficiency of the electrical machine;
- maximum force density per unit volume [kNm / m^3] in comparison to a conventional synchronus machine;
- identical design charateristics for all power output sizes in the range of 5 MW to 30 MW at possible maximum speeds of up to 200 r.p.m.;
- maximum flexibility of the aktive elements of the motor in respect to the relation of length and diameter because of the hydrodynamic requirements for the lower housing;
- Avoidance of additional auxiliaries and cooling elements as well as expensive cooling technologies with e.g. fluid cooling mediums;
- Reduction of the rotor losses to a minimum and dissipation of these losses by convection;
- Dissipation of all core losses and heat losses due to stator current by convection via the surface of the lower housing;
- Robust and electro-magnetic simple design of the motor which also will fulfill the requirements of ice-going ships and can easily be strengthened and adapted according to requirements for navy vessels;
- Low structure-borne noise level and insulated installation to minimize the transmission into the hull;
- Simplified mechanical design of the motor and minimized diversity of mechanical parts;
- Minimized and short circuit proof supply cabling inside lower housing and shaft;
- Utilization of approved converter systems;
- Economical production technologies and -procedures at contemporary realization of delivery times comparable to conventional machines;
- The selected concept of the electrical machine shall be also applicable without mayor design changes for diesel electric propulsion systems with conventional shaft systems.

Due to the especially high technical and economical demands the concept of the permanent excited synchronous motor was advisible. In this machine concept the magnetic flux is generated by high performance magnetic elements. These magnetic elements are in general arranged on the rotor of the motor and substitute the conventional excitation winding and their auxiliaries such as sliprings, rectifier, cooling-air ducts and cooling fans. With this arrangement it is possible to reduce significantly the unit volume of the motor as well as to achieve weight savings. A special advantage in this concept of the permanent excited motor however is the considerable improvement of the motor efficiency as core losses and heat losses due to excitation current of the machine will be avoided.

Due experiences lasting for years in the design of permanent excited propulsion motors for navy submarines Siemens was able to use these experiences for further consequent develepement of the permanent excited synchronous motor.

Based on the above mentioned requirements three different concepts of magnetic flux distribution in the motor have been examined with reference to their possible suitability for propulsion motors of podded drives. In this context the technical scientific literature differentiates between axial-, transversal- and longitudinal magnetic flux distribution of permanent excited synchronous motors

4.2 Results of the analysis and selection of the machine concept

The comparison of the examination results showed that the three different concepts of magnetic flux distribution do not significantly differ from each other in respect of their overall efficiencies and force densities per unit volume. This also applies in respect to the identical design charateristics for all power output sizes of the planned motor type range.

Considering the different constructive arrangements of the active parts of the respective motor concepts the results concerning

- dissipation of thermal losses,
- additional cabling inside the lower housing,
- use of already type approved converter technology

showed essential benefits of economical production technologies and -procedures for the logitudinal flux distribution concept towards modular design of axial and transversal flux distribution concepts.

Due to the integration into the hydro-dynamically optimized SCHOTTEL Twin Propeller the motor concepts with axial or transversal flux distribution would have been less suitable for this purpose because of their disc type rotor design and thus their diameters. The longitudinal flux motor offers greatest flexibilty in respect of selecting the relation between axial and radial dimensions of the active parts. Because of its simplified and clearly arranged design - which is very similar to the design of the conventional synchronous motor - and its very similar electrical characteristic there will not be any problems at the supply by conventional converters.

Considering carefully all significant influences and having in mind the economical situation in the marine business the consequnece was to decide for the permanent excited synchronous motor with longitudinal flux distribution.

Due to its continous excitation the motor - supplied by the converter - behaves as an underexcited synchronous machine. In order to optimize the drive configuration - motor and supplying converter - economically and technically it is necessary to select a self-commutated converter type. According to the load requirements this drive configuration will be preferably offered with a cyclo or PWM converter.

4.3 Principle electro-mechanical design of the active elements

The active elements of the rotor - laminated yokes and magnetic elements - are arranged on the external surface of the hub. The magnetic elements are located in the air gap. In order to guarantee the strength of this arrangement the rotor will be banded and completely impregnated.

As the magnetic working flux in this motor is constant with respect to time only during rotation small core losses will be generated in the rotor surface due to the mutual induction which is directly related to the rotor speed. Those losses will be dissipated by convection via air gap, laminated stator core and housing directly the surrounding sea water.

The entire rotor construction will be mounted directly on the propeller shaft by means of a direct concentric membrane coupling.

The active parts of the stator do not differ significantly from those of a conventional synchronous motor however in this design the stator will be reduced to the laminated stator core and the stator windings. The completely impregnated stator will be shrinked directly into the lower housing in order to allow a maximum of heat dissipation.

In comparison to conventional synchronous motors the winding overhangs of the stator windings are not banded in this construction but casted with a heat conducting casting compound such as a firm mechanical connection will be established with the lower housing resulting in a small heat transmission. It is so far guaranteed that also in this area all resulting heat losses due to current will be immediately dissipated to the surrounding sea water

According to the demands of the propulsion system the motor will be designed with one or two independent winding systems. The individual windings of a system are terminated to a star configuration. For connection of the supply cables the remaining 3 / 6 winding ends will be brought out via a gas tight cable duct into the shaft of the lower housing. It is so far guaranteed that terminals inside the lower housing will be avoided. This however would have been necessary at a modular motor design.

Due to the arrangement of the magnetic elements in the air gap it will be achieved that in case of winding short circuit the resulting short circuit current does not exceed considerably the nominal current of the motor. As a consequence of these constructive precautions a greatest possible protection for the motor is guaranteed in case of a failure.

Because of these constructive precautions it was possible to fulfill the hydro-dynamic demands by reducing the diameter of the motor. In comparison to a conventional synchronous motor the diameter of an LF motor type can be reduced by 40% without increasing the length of the active elements in axial direction. At the same time a weight reduction of presently 15% can be achieved.

In addition to the already positive characteristics of the permanent excited LF motor a considerable increase of approximately 2% efficiency - due to avoidance of the excitation and motor driven ventilation - to the overall motor efficiency of about 98% towards conventional synchronous motors can be achieved.

It was also confirmed during the examination that these LF motors can be designed without mayor changes of the active elements also in a type of construction which is required for conventional diesel electric propulsion systems. Even in this arrangement space and weight advantages (reductions inside the motor and avoidance of auxiliaries) as also the essentially improved efficiency will increase the profitability of the drive.

4.4 Electrical data

The LF motor presented in this context has been designed for a 14 MW reference drive system of a cruise vessel and was electrally dimensioned as following :

Output power	14 MW
Supply voltage	3,3 kV
Rated current	2,9 kA
Efficiency	0,98
Power factor cos φ	0,85
Max. speed	150 r.p.m.
Number of poles	18

The motor will be supplied by a directly water cooled, fuseless and short circuit proved cyclo converter. In order to reduce the total harmonic distortion (THD) in the ships´ network caused by the converter the drive system is designed as 12-pulse configuration per individual drive.

By selecting the type of converter it is also guaranteed that the motor current has a nearly sinusoidal shape which will result in a very low structure borne noise level.

4.5 Electrical interfaces

The supply cables between converter and propulsion motor will be short circuit proved and accordingly installed. Depending on request the transmission of the stator current can be carried out either by sliprings or cable loops. The transmission of the monitoring signals of the motor and of the mechanical installations takes place accordingly.

As a consequence of this elementary design of the stator winding it was possible to reduce also the monitoring of the motor according to earthfault and overheating of the windings. As already mentioned the stator windings are firmly connected in star configuration. Because of a superior protection system in the converter current transformers in the starpoint of the propulsion motor are not necessary. The thermal monitoring of the stator winding takes place by means of standard resistance temperature detectors which are located directly in the stator windings.

Additionally bearing temperatures will be also monitored with standard resistance temperature detectors in the mechanical part.

4.6 Drive concepts

Due to its similar electrical characteristics as a conventional synchronous motor the LF motor can be integrated into already well proven drive system concepts without any restrictions. The design of the motor with two independent winding systems would allow an emergency operation with half motor. The so achieved increase of the drive availabilty will result in a significant increase of security and availabilty of the entire ship.

5 Conclusion

The development of the SCHOTTEL-SIEMENS-Propulsor (SSP) is a consequential step forward in propulsion of low energy, low noise and vibration, and low emission vessels. Power savings of 10 % are proven by tank tests and further model simulation for a 70,000 gt cruise vessel. For other types of ships, power savings may be even higher, so that significant cost reductions over the lifetime of a vessel are guaranteed. The efficiency of the system is even better compared to direct conventional and mechanical diesel engine propulsion, and apart from this it offers easier installation, better utilization of the space on board, more simple and easier maintenance of equipment, as well as exceptionally high standard of manoeuvrability and comfort for passengers and the crew on board.

6 List of Drawings