Design of Synchronous PM Motor for Submersed Marine Propulsion Systems

Design of synchronous permanent magnet motor for two different submersed marine applications, matching all the requirements of the *podded-drive* and of the *sub-jet* propulsion systems constraints.

The high power permanent magnet (PM) motors are suitable for submersed marine propulsion systems combining the advantages of high energy density magnets and electronic drives.
In particular the electrical power management realises :

- *higher ship manoeuvrability*
- *low fuel consumption*
- *reduced maintenance costs*
- *exhaust emissions limitation*
- *adequate redundancy with less installed power*
- *noise and vibration reduction*
- *higher availability of components*

Thus the electrical propulsion system competes successfully with the traditional mechanical systems.

The commercial marine market areas emerging for importance are two. At the moment they are covered by two different propulsive solutions:

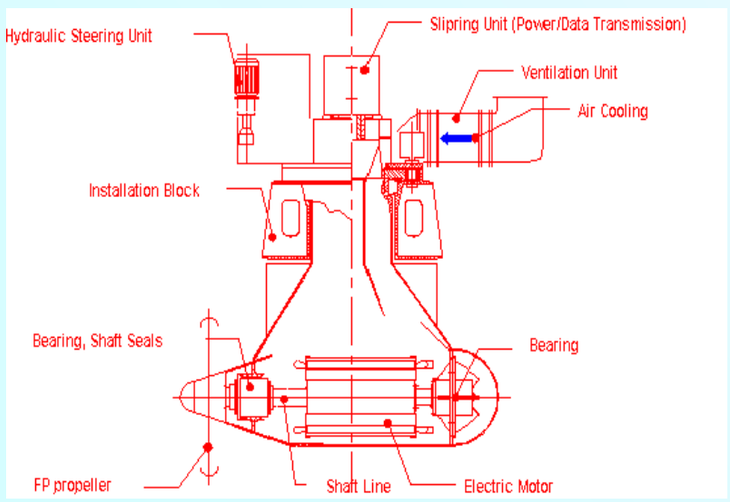
big ships [*cruise, cargo ships*] ⇩ **podded-drive systems** [*external azimuthal devices*]

high speed ships [*gliding hull vehicles, hydrofoils*] ⇩ **jet propulsion systems** [*onboard pump based*]

Two submersed PM motors fitting the different applications requirements are designed for a continuous power of 6MW.

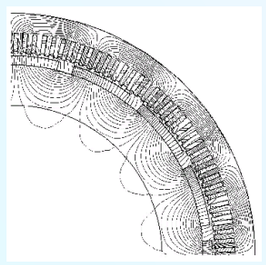
Podded - drive unit

A low speed, air cooled PM motor directly driving a fixed-pitch propeller best fit the podded-drive application:

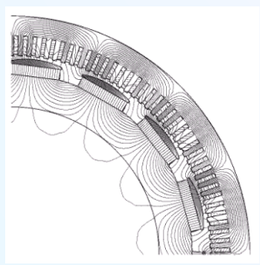


podded-drive propulsion unit

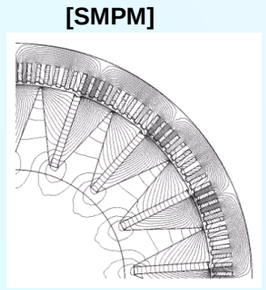
Radial-field PM motors considered:



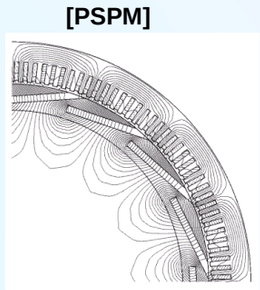
surface mounted PM **[SMPM]**



pole shoes covered PM **[PSPM]**

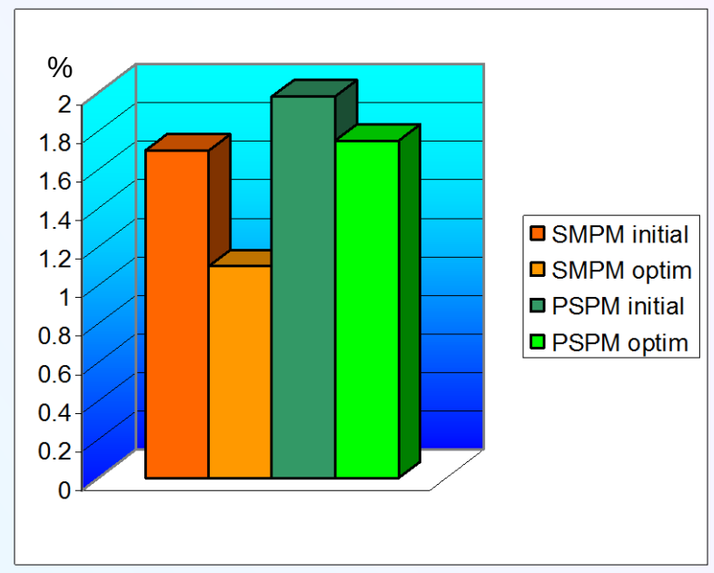


radially inserted PM



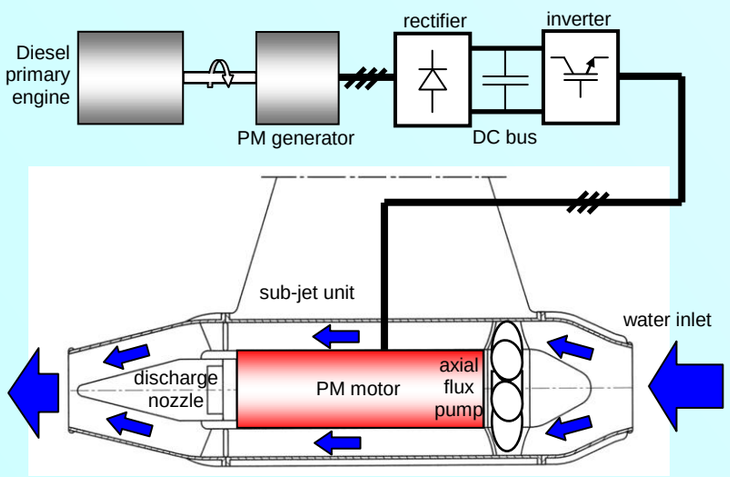
tangentially inserted PM

FEM based optimisation result: stator *winding resistive losses reduction*



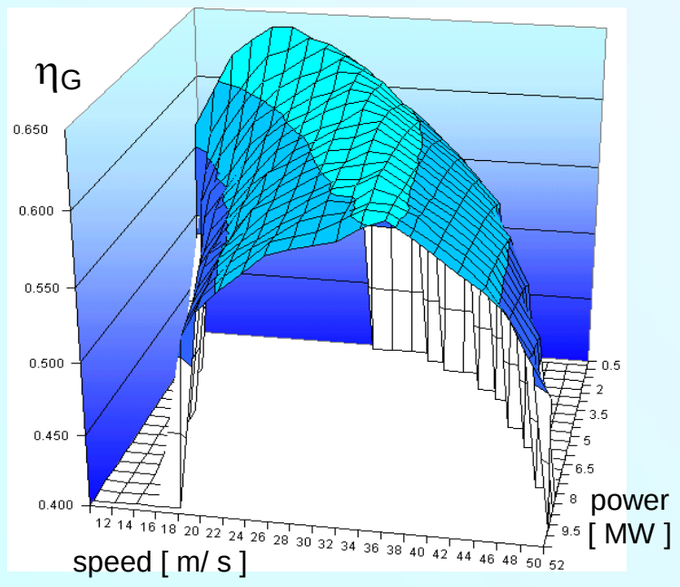
Sub-jet unit

Medium speed, water cooled lengthened PM motors driving the axial-flux pump directly in the sea water best fit the *sub-jet application:*



To evaluate the electric sub-jet overall efficiency [η_G], an existing gliding hull ship has been considered substituting its propulsive apparatus, and maintaining its original thrust and speed.

gliding hull vehicle considered



electrical sub-jet propulsion efficiency

The propulsion efficiency evaluation is very dependent on the power density achieved.
The optimum motor data are:

electric motor parameter	***value***
inner stator diameter	590mm
pole pairs number	11
PM radial thickness	10mm
PM polar pitch	75%
energy efficiency	0.96
max torque overload admitted	2.26
materials cost (L=1m)	40000€ [NdFeB @ 50€/kg]
weight (L=1m)	2695 kg

Propulsive systems final comparison:

traditional onboard jet	
global propulsion efficiency	0.48
prime required power	30 MW
electrical sub-jet	
global propulsion efficiency	0.556 ***(+16%)***
prime required power	25.2 MW ***(-16%)***

Conclusion

- The PM motors designed for low-speed and high torque operation are well fitting the podded-drive ship propulsion applications.
- The traditional radial field concept offers a good basis for further development for podded applications from the construction point of view.
- Also in the fast ship field, the design flexibility of the PM motors allow a convenient substitution of the traditional onboard jet-pump propulsion device with the sub-jet system based on a PM motor.
- A significant improvement of the global propulsion efficiency and thus a reduction of the installed power are achieved using the electrical sub-jet system.

N. Bianchi, S. Bolognani, F. Luise, Dept. of Electrical Engineering, University of Padova, Italy

A. Arkkio, T.Jokinen, M.Rosu, Dept. of Electrical Engineering, Helsinki University of Technology, Finland