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Alternate Approach to Redundant Propulsion as a Result of a Risk Management Policy

Professional paper

Propulsion reliability, vessel and environment safety are significant reasons for redundant propulsion demand. Costs involved in the class notation Redundant Propulsion (RP)¹ 2x50% make this application costly and less attractive. Searching for technically and commercially viable solutions while Classification Societies have not yet unified the rule requirements is a challenge for ship owners and shipyards. This paper considers the limits in Power Take In (PTI) application in slow speed propulsion plants and related potential difficulties. In addition, the example of lower sized PTI application in practice, without assigned notation, is reported.

Keywords: *redundant propulsion (RP), slow speed engine, propulsion reliability, Power Take In (PTI)*

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Alternativni pristup redundatnoj propulziji kao rezultat smjernice upravljanja rizikom

Stručni rad

Pouzdanost pogona, sigurnost broda i okoliša, značajan je razlog zbog kojeg tržište sve više traži redundatnu propulziju. Troškovi koje notacija klase RP¹ 2x50% donosi čine primjenu kontraproduktivnom ili manje atraktivnom. Traženje tehničko-komercijalno održivih rješenja, u situaciji dok klasifikacijska društva nisu ujednačila pravila, stvarni je izazov za brodovlasnike i brodogradilišta. Ovaj se rad bavi prvenstveno sporokretnom propulzijom uz naglasak na ograničenjima primjene prigona (PTI – *Power Take In*) i mogućim kritičnim točkama. Izložen je i primjer primjene u praksi PTI manje snage, bez dodijeljene RP (*Redudant Propulsion*) notacije za redundatnu propulziju.

Ključne riječi: *redundantna propulzija (RP), sporokretni motor, pouzdanost propulzije, prigona snage osnovnoj propulziji (PTI)*

1 Introduction - Objectives, means and merits

Over the centuries and millennia of its existence, shipping has been primarily a trade of experience gained, more often than not, by trial and error method.

In order to speed up the process of such lengthy and expensive learning procedure seafarers and shipbuilders, had from time to time, accepted innovations proposed largely by inventors who tended to look over the horizon, and were as a rule always ahead of their time. This was a troublesome process accompanied by scepticism. Conservative by nature, seamen had embraced by

instinct proven and tested measures and only if forced, either by forces of nature but more by forces of trade, sailed into uncharted waters of new design.

Since sea trade involves risks that are of such proportions that could not be covered by single operator, or its vessel, or its trade i.e. cargo, it had to resort to the insurance as the only reasonable means of spreading the risk and henceforth making it palatable to the very essence of trade itself, to carry and bring safely goods over vast distances to their destination, ultimate end user.

The very essence and soul of insurance, besides the already mentioned spread risk, was the assessment of safety of the transport itself, in this case the vessel. Independent and trustworthy societies were established in order to assess and ascertain the safety of the vessel. Rules that were gradually improved and refined, also largely by trial and error or even instigated by major disasters, reflected the tendency to solidify the regulative procedures which are, as in law in general, and even much more in shipping, the very foundation of orderly manner in which such operations have to be carried out.

¹ The term redundant propulsion (RP) is being used when a ship is equipped with the system that either allows the ship to reach the first suitable port or place of refuge, or to escape from severe environment, allowing minimum services for navigation. Another definition would be that the alternative propulsion system is an arrangement of machinery suitable to maintain the ship in operating condition in case of loss of the part of propulsion system.

Hence the continuous improvement of rules and even the unification in order to close the loopholes is however small. Conservatism as a direct consequence of ever-increased costs involving necessary changes in vessels construction led to constant lag in introduction of new rules and regulations. Exemptions and exceptions are often justified by practical measures.

Safety and reliability has its price but it also has its merits. That distinguishes the operators by class and charterers tend to honour it. Remuneration is there as an incentive to go forward, even if not forced by regulative bodies, whatever they are, higher profits and secured trade in troubled times or waters is the driving force behind the new initiatives.

Such a try is in front of us and it represents a risk management policy as a constant effort to improve the shipping safety itself to the predefined level. Whether it should be recognized in time by regulators, Classification Societies, time will show. If the vessel so construed receives the premium on the market, then the market, as *ultima ratio*, shall judge.

2 Redundant propulsion as result of compatibility in shipping

General maritime safety and lowering the risk of possible delays in cargo transportation are good reasons for implantation of RP arrangement onboard ships.

Tankers with RP especially would benefit due to possibility to maintain and overhaul main engine during cargo handling at terminal by keeping ship ready to sail at any moment. Once redundant propulsion is applied, main engine overhaul is possible independent of vessels employment. Thus, increased number of effective working days would result in significant commercial effect.

Sensitive public opinion on environment safety entitled all participants in shipping to make improvements. Forthcoming and existing regulations are the first step but not the final step of introducing of RP as significant safety improvement.

Increasing of safety and reliability is quite a huge task. It asks for a number of tests of ship's performances, as well as propulsion and other appertaining systems. This evaluation process would recognise compatibility with market demand and guarantee safety of ship and her cargo.

Benefit of RP was reason for additional class requirements dealing with subject matter resulting in stringent rules where performance of RP accepts only solutions with 50% power, leaving solution with less power practically neglected without assignment.

Examining rules requirements, ship owners can possibly consider two different strategies. The first strategy considers application of equipment recognised by class society as fully redundant (and separate) propulsion. The second strategy offers RP possibilities but not necessary within class notation yet having additional safety for ship i.e. take-me-home device.

Therefore future rules requirements should consider the benefit of RP with less than 50% power.

Above-mentioned is contained in the concept of compatibility [1] that relates to or contains information or knowledge of shipping, so the concept of compatibility is a framework aiming at better elaborating the way a shipping practitioner conducts his daily tasks.

Considering this concept, shipowners were looking forward to the solution which would give better chances for employment of their vessel and which, with additional equipment or other better performances, would result in:

- long term charter contract (regularly eliminating risk of un-employment when general demand for cargo transportation is lower),
- continuous employment at spot market (taking the benefits of high daily earnings in high market period),
- trading within designated areas (where compatible ship is preferred or rules ask for her special performance).

3 Overview of existing rules of some class societies with consequences

Det Norske Veritas (DNV) [2] foresees RP notation for ships designed with concept of 2x50% of independent propulsion power and steering but excluding fire class and flooding division (RPS notation requires both divisions). Equivalent to this are *Germanischer Lloyd* (GL) [3] notations RP 2 (RP 3) and *Lloyd's Register of Shipping* (LR) [4] notations PSMR (PSMR*) with slightly different steering abilities. *Bureau Veritas* rules [5] lately consider the criteria b) by class notation AVM-APS that more realistically accepts our solution of take-me-home device.

The above mentioned is valid provided that the rest of propulsion (or additional propulsion capability) can be activated prior to course keeping is lost (30 minutes or less) and enables upstream sailing i.e. vessels certain speed within weather conditions. The basic sea and weather criteria for fulfilling class notation are:

- a) 6 knots with 8 BF wind,
- b) 7 knots with 5 BF wind and
- c) 9 knots with 2 BF wind.

Rough estimation of necessary power to fulfil these criteria for the *panamax* ship size with 15 knots service speed at abt. 85-90% MCR [7] is as follows:

- for fulfilment of criteria under a) about 50% MCR is needed,
- for fulfilment of criteria under b) and c) about 20% MCR is needed.

Presuming that the required power estimation is enough accurate, there is a large disproportion between criteria a) and others where one can conclude that b) and c) criteria are less stringent.

GL solely also foresees notation RP 1 x% for ships that have additional engine with x% power of the main propulsion, without the need for redundant steering and shafting, by keeping same principle of RP notable for the following:

1. alternative a) two medium speed engines coupled to the common shafting,
2. alternative b) single slow speed engine with PTI arrangement.

Considering criteria a) both alternatives are applicable as exception only and especially alternative b) suggests strange technical solutions if the RP rules requirements are strictly followed. Common practice is to apply one slow speed propulsion plant on ocean going vessels since it has low maintenance costs, and compared to one medium speed plant it is more reliable.

4 RP related to weather condition

Starting from [6] NOAA/NCEP reports regarding significant wave height and distribution on a global scale, it is possible to

evaluate roughly the amount of additional safety and reliability given by the RP of certain power for ships with unrestricted service.

Basic observations are:

- significant wave height $H_{1/3} = 18$ ft i.e. 8 BF and above can be simultaneously observed only at 5% of the area of all seas and oceans, and $H_{1/3} = 9$ ft i.e. 5 BF and above only at 25% of the area,
- if few spots are excluded, high and potentially dangerous waves are distributed mainly (over expected average value) outside sailing routes of merchant fleet,
- it should be stressed that weather forecasting on global level has significantly improved enabling rather good and reliable prediction, which amounts to maritime transportation safety when properly used, all being of utmost relevance to the above mentioned.

Comparison with report [6] gives following reliability of redundancy propulsion (referring to sea and weather criteria) without changing the route:

- a) in 98% cases with the propulsion RP 50% MCR and
- b) close to 90 % cases for the propulsion needed under criteria
- c) with Take Me Home (TMH) 20% MCR.

The comparison of these data with the existing rules is done without any intention to analyse manoeuvrability and performances of vessel, only as a benchmark for possible and predictable development of rules for the subject matter. The main question, still waiting for a proper answer, is: why additional safety of 90% or less given to the ship by TMH device applied is not recognized by the rules?

In that respect, regulatory bodies have already implemented new requirements for passenger vessels i.e. "Safe Return to Port" where safety criteria closely follow criteria for cargo vessels ad b) and/or c) as given in para. 3.

Rather conservative approach of class societies and quite stringent rules requirements when dealing with the subject matter are not the result of limited knowledge. Quite the contrary, these societies only have substantial statistical data (reliable and classified feedback from seas) and knowledge to make criteria what reliable propulsion should be. Once made, these criteria will ease quantification of risks involved i.e. enable «risk management» for all parties involved.

Considering the knowledge of IACS members and their feedback from ships in service as well as real situations that could happen, our opinion is that they should propose realistic criteria acceptable to the shipowners while still staying on the safe side.

5 Starting and speeding up of redundancy propulsion

The below formulae present characteristics needed to derive the necessary power for redundancy propulsion.

By knowing full torque curve of power source when PTI is applied in the period of starting shafting, as well as checking of heat load in the transient period, the following can be derived.

The equation below is the basis for this analysis.

Abbreviations:

- I (kgm²) - moment of inertia of shafting
 ω (s⁻¹) - rotating speed

- M_{ACTIVE} (kNm) - engine torque, active torque
 $M_{REACTIVE}$ (kNm) - resistance torque, reactive torque
 M_P (kNm) - propeller resistance torque
 M_{FR} (kNm) - friction torque
 μ - friction coefficient
 G (kN) - weight of shafting
 D (m) - shafting diameter
 t (s) - time

Basic equation for starting of shafting:

$$I \cdot 10^{-3} d\omega/dt = M_{ACTIVE} - M_{REACTIVE} \quad (1)$$

$$M_{REACTIVE} = M_P + M_{FR} \quad (2)$$

$$M_P = \text{konst} \cdot \omega^2 \quad (3)$$

$$M_{FR} = \mu \cdot G \cdot D/2 \quad (4)$$

Equation (4) is usually enough accurate, but in the case that we want exact value that strictly follows bearings load as derived from shafting alignment calculation, then the following should be replaced $G \cdot D = G_1 \cdot D_1 + G_2 \cdot D_2 + \dots$

Friction coefficient for sliding bearings, with sufficient margin included, is

$$\mu = 0.21 - 0.1 \cdot \omega \quad \text{for } \omega (0 - 2) \text{ s}^{-1} \quad (5a)$$

$$\mu = 0.015 \quad \text{for } \omega (2 - 7) \text{ s}^{-1} \quad (5b)$$

M_{ACTIVE} in equation (1) is dependent on the type of prime mover applied. For instance, in case of starting by hydraulic motor or electric motor with frequency converter/inverter it is practically constant. In other cases at least parabolic law should be enough accurate.

Generally, equation (1) should be transformed into

$$I \cdot 10^{-3} d\omega/dt = P(\omega) = A_0 + A_1 \cdot \omega + A_2 \cdot \omega^2 \quad (6)$$

giving time elapsed for each speeding up interval (ω_i to ω_{i+1})

$$t_i = \ln(F(\omega_{i+1})) - \ln(F(\omega_i)) \quad (7)$$

In practice, the derived equation is sufficient for controllable pitch propeller plants analyses. On the contrary, fixed pitch propeller plants analyses ask for more sophisticated approach, taking into consideration also transient period during slowing down and reverting, where handling the energy load is the basic problem and priority.

6 Difference in PTO/PTI application for slow and medium speed propulsion plants

Given the fact that in medium speed propulsion plants the reduction gear with the thrust bearing is already incorporated, this results in somewhat smaller sized additional parts necessary for PTO and consequently PTI. Since dimensions of shafting and its arrangement are related to the power/rpm ratio, these elements are of smaller size. Also, part of the possible problems that may be caused due to torsional vibrations is much easier to solve than

on low speed propulsion where additional elastic coupling that connects tunnel shaft and reduction gearbox is necessary.

Disconnection of the main engine obtained by coupling within the gearbox (Figure 1) is simpler than the combination of coupling and thrust bearing given in Figure 2. The solution presented in Figure 2 was preliminary considered for RP but it was rejected in favour of innovation given in Figure 3.

Due to the above mentioned, the cases with medium speed propulsion on the market have long lasting experience compared to only a limited number of cases with low speed propulsion.

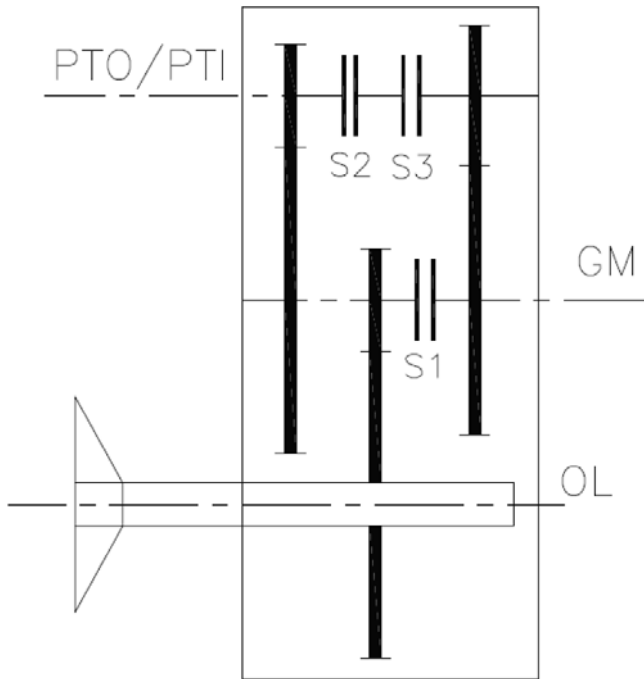


Figure 1 Typical solution used for PTO/PTI for medium speed engine
Slika 1 Uobičajeno rješenje koje se koristi za PTO/PTI za srednjokretni motor

The common feature for both cases is that the use of controllable pitch propeller (CPP) provides much better efficiency and more flexible adjustment to any weather condition that may be encountered.

Figure 3 Alternate approach to RP - chain drive instead of gearbox
Slika 3 Alternativni pristup redundantnoj propulziji - lančanik umjesto reduktora

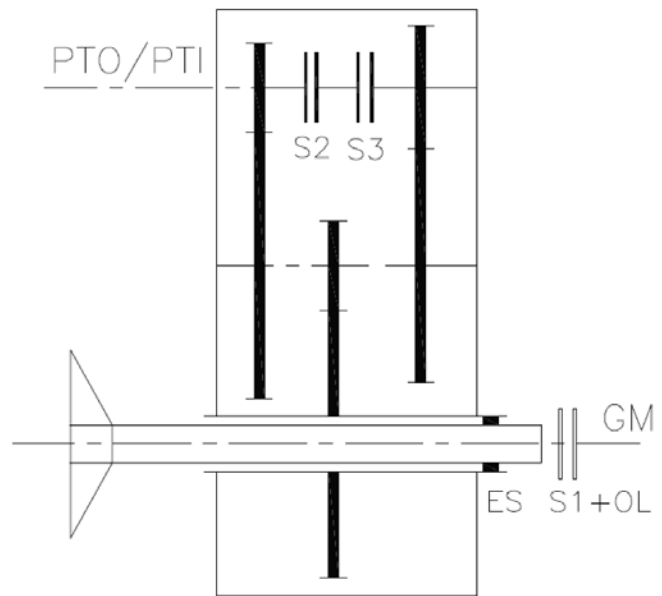
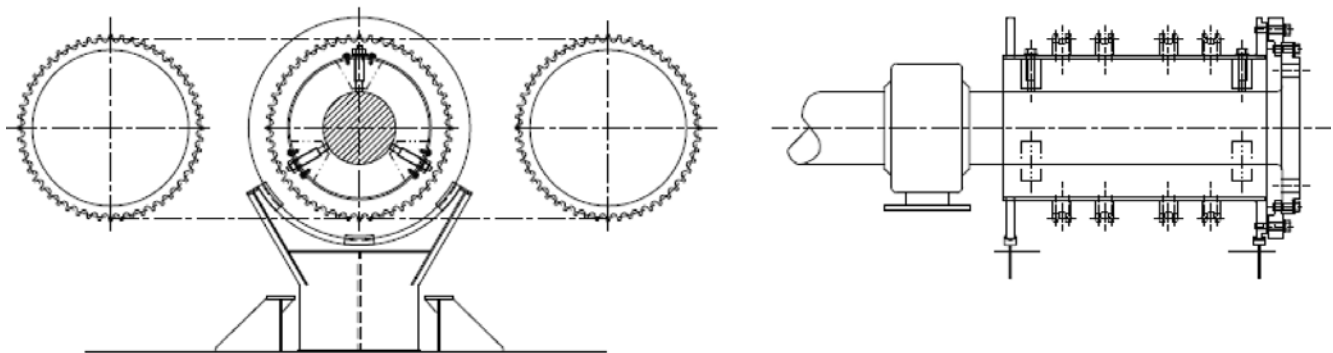


Figure 2 PTO/PTI for slow speed engine
Slika 2 PTO/PTI za sporokretni motor

In addition, a different transmitting ratio needed for PTO and PTI is obtained in the same way for both cases, i.e. by using two clutches S1 and/or S2.

7 Prototype PTI solution for low speed propulsion

In spite of common opinion, the cost/benefit study of electric generator application in PTO [8] shows that the overall benefits of this mode are doubtful. Regarding this, the ship owner jointly with the shipyard developed only PTI solution without PTO mode by optimizing benefits of energy sources onboard ship, thus eliminating all other functions that were deemed as not necessary for the given purpose:

- PTO elimination (hence, angular displacement caused by torsional vibrations of the main engine and multiplied by step-up gear ratio avoided, consequently voltage distortion eliminated and elastic coupling avoided as well),

- use of hydropower pack (installed for the purpose of submerged cargo pumps drive) is offering 2 MW of available power,
- tunnel shaft arrangement as per Figure 3 used enabling power transmission by chain drive instead of gearbox (all parts related to PTI are moving in PTI mode only, thus wear and tear is practically negligible).

There is also a possibility to achieve PTI by disconnecter.

The basic function of the combined coupling and thrust bearing (S1 in Figure 2) is transmission of the main torque to the propeller when engaged and releasing torque moment, but still taking the propeller thrust towards the main engine, when disengaged in PTI mode. In standard coupling, conical bolts with integrated sliding thrust bearings have to be sealed with oil, which can cause lower reliability owing to related different engaged/disengaged shafting alignment conditions.

Coupling used, with roller bearings instead of sliding thrust bearings designed on the basis of dowels for torsional torque load instead of standard coupling with conical bolts, resulting in more reliable thrust power transmission (in both, PTI mode and main propulsion mode).

A simple and effective solution.

Energy is supplied to the propulsion system of relief by the hydraulic system of cargo pumps delivering approximately 2400 kW. Four hydraulic motors, high torque, lead a drum on the shaft by means of channels at a speed of 65 rpm. Normally, the drum is separated from the tree, but the propulsion relief drum is connected to the shaft through friction bolts allowing coupling in all angular positions.

The main engine has to be disconnected from the tree, which is achieved through a decoupling system located on a flange of the intermediate shaft. The decoupling system is relatively small, and the propeller thrust is transmitted to the main thrust by two spherical roller bearings. Between the decoupling and the flange of the shaft there is a space of 5 mm. In normal operation, the torque of the shaft is passed behind the space with 10 pins mounted radially in cylindrical grooves of each of the flanges.

The crew can switch to the machine propulsion relief under 20 minutes using only standard tools, even with a 500 mm shaft

diameter. The sea trials on new ships confirmed a speed propulsion relief over 10 knots at design draught and calm seas.

This system would cost less than half the usual solutions and thus greatly interested builders and owners.

Although a transmission chain has been chosen to get power at the shaft, other solutions may be used as well. Hydraulic power has been chosen because there was a large hydraulic power available on board. In other cases, electrical power may be used.

8 Conclusion

Redundant propulsion most certainly forms group of measures that contribute to maritime safety in general and it is expected that in such sense demand for such propulsion will be in future clearly defined. The example presented in paragraph 7 is only a guideline how PTI application for low speed propulsion may be solved and is not intended to form general approach.

Additional effort of all sides mentioned in this article will be necessary to reach an optimal solution that may be used worldwide.

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