DIESEL ELECTRIC PROPULSION

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ABSTRACT

Conventional merchant ships, for most of their serving life, run at more-or-less their design speed, delivering cargo from one port to another. Manoeuvrability is of little importance, and the low-speed direct-drive diesel engine is the most favoured means of propulsion. The engine is matched to drive the ship, at its service speed, with maximum fuel economy and efficiency, together with long life and reliable operation, with the minimum of maintenance. This, however, is not the case with all ships. The operating profile of some vessels is very divergent from that of conventional cargo ships, and hence the design features also differ. For instance, large deck space aft is required by seismic survey vessels, AHTSVs, PSVs and OSVs, for different reasons. Therefore the engine room and accommodation are shifted right forward, but this can only be done at the expense of long shaft lines. In the case of the AHTSVs, a large power is required for towing, but only a fraction of it is used for supply duties. Seismic survey vessels, geo-technical research vessels and oceanographic research vessels are required to have minimal vibration and propeller-induced noise. Excellent manoeuvrability is required in ferries, OSVs, PSVs and MSVs, while dynamic positioning is also essential for MSVs. In passenger ships, the hotel load is even greater than the propulsion load, while redundancy of even the main propulsion machinery is necessary, on account of passenger safety. For ice breakers, the propulsion system should have a very high dynamic performance. These aforementioned vessels are a small part of a large group for which the direct-drive low-speed engine may not be the soundest choice for propulsion.

Some of the alternative means considered in this paper are:

-One medium-speed diesel per shaft, driving a FPP through reverse reduction gears, together with a separate electric generating plant for other services.

-The same arrangement with a CPP instead of an FPP.

-The same arrangement but with two medium-speed engines per shaft.

-One or two medium-speed diesels per side, driving azimuthing thrusters instead of the conventional shaft lines.

-Diesel-electric power generation, supplying both propulsion and power for other services, a choice of several different schemes being possible.

Each of these alternatives has its own advantages, weighed down by certain disadvantages. The paper draws a comparison based on various factors eg. the ship's role, it's operating profile, layout of machinery, fuel consumption and limitations of manoeuvrability; leading to the conclusion that the diesel-electric propulsion is very well suited for each of the above-named vessel types.

It's various advantages like flexibility, lower fuel consumption, higher efficiency, good dynamic performance and additional benefits which include the ability to consider new and unique forms of propeller drive like the pod propulsion and CRP are discussed further.

Finally, the various future developments possible with diesel electric propulsion are also discussed briefly.

KEYWORDS

1. Diesel Electric Propulsion
2. Manoeuvrability
3. Flexibility
4. Station Keeping
5. Fuel Efficiency

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MAIN TEXT

Conventional merchant ships are more than often propelled by low speed diesel engines directly coupled to a propeller. The reasons for this choice are not very difficult to comprehend. This means of propulsion has numerous advantages and excellent suitability to the conventional merchant ships. To begin with the arrangement is very simple. There are no gears and clutches involved since the engine is directly coupled to the propeller. This enables us to save on some engine room space. The amount of transmission losses is also reduced, because these losses have a direct relation with the number of components between the prime mover and the propeller and direct drive implies that there are no such components. In addition to this, even the maintenance work reduces. The prime mover in this case, i.e. the diesel engine has an excellent thermal efficiency. It is around 50% which is way above any of the other prime movers like steam turbines etc.. This results in efficient fuel utilization and with the increasing fuel prices, this is not something that can be ignored. These engines being low speed allow a greater time for the fuel to burn. This means that such engines are more tolerable to even the lower grades of fuel with proper pre treatment resulting in cost savings up to a large extent. Another important advantage of this arrangement is its reliability and long life. The piston speeds are low as it's a low speed engine. This reduces the inertia force and also the wear of the components. The mean effective pressures are also lower reducing the stresses acting on the various components.

On the other hand, it is to be kept in mind that this assembly is very tall. The ship is a large mass and propelling it requires a very powerful engine. Since the power that these engines are required to produce is huge, the size of the engine also increases. They are so tall that they govern the engine room dimensions and location. The exhaust arrangement is such that there can be no cargo placed over the engine room. However the presence of the accommodation in conventional merchant ships at this place solves this problem. Since it is a direct drive arrangement, the propeller shaft and the engine crankshaft has to be in line for proper transmission. This again poses certain restrictions on the engine placement. In all, we cannot exercise much flexibility while arranging the propulsion equipment. The engine weighs a lot which is not surprising considering its huge dimensions and the material of the components. The initial cost of the machinery is very high because the components should be able to withstand the huge stresses and pressures that they're bound to be subjected to. This means that the quality of the materials used should be good and so the cost increases. The entire assembly is done on site because it wouldn't be possible to later on install such a huge engine. This again results in an increase in the initial cost. The manoeuvrability provided by these engines is very less. Due to the large mass of the components and the resulting high inertia forces the response of the engine to any required change is low. There will also be a need to stop the engine and start it again in the reverse direction to move the ship astern because of the direct line arrangement. This is not an easy task. As the engine is a very large mass, rigidly mounting it to the foundation is the only way to hold it securely. This however means that the noise and vibrations produced are directly transmitted to the hull without attenuation. There is no shock absorbing medium in between which can only be placed in smaller weighing engines. The noise levels on the other hand are not so small that they can be neglected.

In the case of bulk carriers, tankers, container ships and general cargo ships, the advantages outweigh the disadvantages. Most of the service life is spent in long voyages at more or less their service speed delivering cargo from one port to another. Manoeuvrability is of little importance and even when it's required, tugs are available for assistance. More important considerations in such cases are efficient fuel economy. This can be achieved by burning lower grades of fuel and also lower quantities for the same amount of power. Owing high thermal efficiency and ability to burn lower grades of fuel after suitable pre treatment, both the specified conditions are very adequately met by the low speed direct drive diesel propulsion. Even though the initial costs were high, because of high reliability and long life of components, the saving in the running costs more than compensates for the initial costs. As discussed previously, the space above the engine room which can't be used for placing cargo wouldn't have been used anyway because of the presence of the accommodation. In other words the arrangement of cargo spaces is such that the place under the superstructure wouldn't have been used for cargo anyway and so the engine room can be accommodated easily here. The huge weight can be tolerated keeping the simplicity of the assembly and the high fuel efficiency in mind.

There are however many other different types of ships for which there are many other requirements to be met for instance high manoeuvrability is required by certain vessels.

Cruise ships move at high speeds from home port to cruising area. These speeds can be around

28 to 30 knots. Then they make short trips at lower speeds which can be around 12 to 13 knots and anchor at night. This means that the propulsion power requirement keeps varying and there isn't any fixed service speed. Therefore a low speed diesel engine which is designed to work with

maximum efficiency at the service point will not be effective here. In such ships because of the type of cargo being carried, the hotel load is very high. It forms a larger proportion of the total load, even more than the propulsion load. It is therefore not very thoughtful to have one low speed diesel engine occupying so much space and also so many generators that will meet the hotel load which will be much more than the propulsion load. Next, to maximize the cargo space, to minimize the noise low speed diesel engine been present, because of the height the decks can't be continuous. This type of arrangement offers such little flexibility that the engine room location and dimensions are fixed and any other alternate arrangement is also not possible. Another requirement of such vessels is to minimize noise and vibration for passenger comfort. As discussed earlier, this is not possible with low speed diesel engines because of the mounting arrangement. The noise and vibration is directly transmitted to the hull in such cases. In the case of passenger vessels, redundancy of the machinery is very important. We cannot afford to have a machinery breakdown and the vessel stranded with passengers onboard mid way. With low speed diesel engine being used as the propulsion machinery, meeting this requirement is unimaginable. Also in case of this engine because of its great height, the centre of the machinery space is raised. Now ideally we would want the centre of gravity of the machinery space to be as low as possible to compensate for the many decks that are situated at greater heights in such vessels. In case of a direct drive arrangement, the propellers are generally equal to the number of shafts. This means that with low speed diesel engine we are limited to just one propeller. For a large power requirement as is the case generally with such vessels, the propeller will have to be of larger dimensions. Had more than one propeller been present, the dimensions could have been smaller. With a propeller of such large dimensions, there are bound to arise situations where the propeller is not completely immersed because of the draft limitations in certain cruising areas.

In the case of car/passenger ferries also, some requirements are same as those for cruise ships. Here too we require as many uninterrupted decks as possible to maximize cargo carrying capacity. This also enables faster and easier loading and unloading which in turn minimizes the turn-around time. These vessels are also required to have redundant machinery to be able to continue programme even in case of machinery breakdown. As above, at certain terminal ports the permissible draft is limited and it may not be possible to immerse a large dimensioned propeller. These vessels make comparatively shorter voyages and therefore spend a larger proportion of their service life maneouvring at both ends. Now, if the use of tugs can be minimized the cost will be drastically improved. This can be easily achieved if the vessel's propulsion machinery inherently offers high manoeuvrability which is certainly not offered by low speed diesel engine.

Offshore/platform supply vessels/AHTSV's transit from supply base to oilfield at moderate speeds which are around 10 to 14 knots. They then proceed from platform to platform/rig at lower speeds with frequent stops to discharge/load cargo. At night they may anchor or drift. AHTSV's also have to tow rigs and platforms to the desired locations. Once this is done they lay out anchors and chains at much lower speeds. This means that the propulsion power requirement keeps varying and like cruise ships they do not have a service speed. Here again, low speed diesel engine will not function efficiently. These vessels need to hold position close to the rig or platform despite total exposure to winds etc. For such station keeping abilities, very high manoeuvrability is required. Dynamic positioning is often used. The auxiliary power requirement in such ships is very high. This is due to the cargo pumps/compressors, hydraulic pumps that are required for anchor handling winch in case of AHTSV's, or external fire fighting pumps which may be present in case the vessel also fights fire. As in both the above cases, the permissible draft can be limited at different bases, and for proper immersion of propeller, this imposes restrictions on the dimensions of the propeller. Most of the cargo in such vessels is placed on the deck itself to ensure easy discharging. The accommodation is thus right at the fore end of the vessel and we can now no longer have the funnel for the exhaust there as it will simply render that much deck area useless. To also not adversely affect the stability, the main deck is kept at a low height and now to protect this cargo, the forecastle and the forward superstructure is raised. This means we can't have the low speed diesel again.

There is yet another category of vessels. This comprises of diving support vessels, multi support vessels, construction vessels, pipe laying vessels, drill ships, geo technical research vessels and oceanographic vessels. They generally transit at moderate speeds of around 10 to 14 knots, but while carrying out their assigned task, they need to maintain position with extreme accuracy. For this very high manoeuvrability is required, and this can by no means be provided by a low speed direct drive diesel propulsion. In the case of diving support vessels, multi support vessels, and geo technical vessels the mid ship area is occupied by a moon pool. In drill ships it's occupied by the drill rig and heavy lift cranes occupy it in case of construction vessels. Aft deck space is also required for different reasons in these vessels. Therefore the accommodation along with the main propulsion machinery is shifted right at the front. With a low speed diesel engine this would mean long shaft lines which would be very inconvenient. Geo technical research vessels, oceanographic vessels, and fishing vessels have very strict underwater noise requirements. In the case of ice breakers, the load variations are significant and to prevent tripping due to over speed or overloading of components, the propulsion system should have a very high dynamic performance and this is again one area where the low speed diesel engine doesn’t fit in well.

In all the aforementioned cases, manoeuvrability is essential. In some cases even station keeping abilities are required. Twin screw propulsion along with thrusters placed at the fore and aft end are essential. Because of the space constraints and limited headroom available low speed diesel engines usually cannot be used for propulsion. Often medium or high speed engines are used. Another additional advantage that they offer is the low sound and vibration as some attenuation takes place in the mounting.

THE VARIOUS OTHER POSSIBLE ALTERNATIVES ARE DISCUSSED BELOW:

-One engine per shaft, driving a fixed pitch propeller through reverse-reduction gearing. This arrangement is very simple but it has certain limitations. When the speed is reduced, the engines tend to operate at speeds touching their fouling limit. At such low speeds efficiency also reduces. We could counter this situation by just running one engine but that makes manoeuvrability very difficult. The ship tends to experience one sided thrust. Full power is not available while towing. In this arrangement also, we have rotating parts and thus the propulsion system responds very slowly to any change because of the large inertia of the rotating parts. In these medium and high speed engines the transmitted power is limited by the clutch size which is about 5000HP per clutch. Therefore for a larger power more shaft lines will have to be present.

-One engine per shaft driving a controllable pitch propeller through reduction gearing. This arrangement is similar to the one above. The only difference here is that the pitch can be varied. This means that when towing we can reduce the pitch to shift the operating point closer to the MCR point and have better fuel consumption. We will also be using the installed power more efficiently. Since the pitch of the propeller can be varied, to reduce or increase the speed we will simply have to vary the pitch and the speed of the engine can be kept constant. So the propulsion system responds faster. Even for the astern-ahead and vice versa manoeuvers the direction of the engine does not have to be changed, simply varying the pitch serves the purpose. Unlike above here there isn't any limit on the amount of power that can be transmitted. However, with this type of propeller we get a slightly lower efficiency at operating points far away from the design point. In this arrangement as well there can be occasions when the engine might have to run at lower speeds as the ship is required to move slowly, and at such times the engine is likely to touch its fouling limit. This arrangement is not very simple as compared to the one with the fixed pitch propeller. Even the dry dock maintenance required in this case is more frequent.

-Two engines per shaft, driving a fixed pitch propeller through reverse reduction gearing. The two engines can be of equal capacity or we can have a father and son arrangement. Now here we have the liberty to simply run one engine when one lesser power is required and this means that the engines can run at their maximum efficiency points for longer periods. This in turn reduces the fuel efficiency. When higher power is required we can run both the engines. As the number of engines has increased, so has the redundancy of the propulsion machinery. Now a single breakdown will not reduce the available power to 50% but to 75% (if the engines are of equal power). These engines are bound to be comparatively smaller in size as compared to two engines delivering the same amount of power. Therefore it's easier to install them. The installed power can be doubled if we consider the same limit of clutch size. The various limitations of this arrangement are that a two speed gearing will be required for better loading in single engine operation condition. This increases the mechanical complexity as more number of clutches has to be included and the controls also become more complex. Here too as above the propulsion system tends to respond slowly because of the large inertia of the rotating parts.

-Two engines per shaft, driving a controllable pitch propeller through reduction gearing. This arrangement will have the same advantages and limitations as above except for slight differences. With a CPP the complexity increases along with the frequency of the dry dock maintenance. However the propulsion system will be able to respond to any change more quickly as simply varying the pitch of the propeller will serve the purpose. Ability to adjust the pitch also means that in single engine operation the engine may be loaded nearer to the design point enabling us to make better use of the installed power.

-One or two engines per side driving an azimuthing thruster instead of conventional shaft lines. This arrangement is very advantageous if the engines can be located close to the thrusters as shaft lines will be eliminated. This arrangement also eliminates the rudders. These thrusters offer higher manoeuvrability. Depending on the design of the aft end overhaul of the thrusters may even be possible without dry docking.

In all these cases we will also have to provide power for the auxiliary machineries. Power will be required for steering, navigation, cooling, ballast, fire fighting etc. Electric power will be required for hotel services. Bow and stern thrusters, hydraulic winches for anchor handling, towing, etc. all require power. To meet this diesel alternators have to be installed. As the load increases either the number of generators installed is increased in number or the capacity of the ones already installed is increased. We can also have a shaft generator installed to meet the power demand when the engine is running. It would however not be suitable to use the shaft generator to provide power for the hydraulic winches for anchor handling etc. as the engine will already be loaded at such times. We can also use power take offs from main engine for thrusters, cargo handling pumps, compressors, cranes, hydraulic winches for anchor handling, towing and external fire fighting pumps, together with mechanical power take offs from diesel alternator for hydraulic winches for anchor handling. The disadvantage is that along with the propulsion machinery these will also occupy some space. These alternators are costly and they will not be loaded up to their design point during normal running. In case of a shaft generator we will also have clutches, frequency convertors, complex controls, gearing arrangements which will add to the mechanical complexity.

-another alternative is diesel electric power station supplying needs of propulsion, auxiliary and hotel loads, under all circumstances. It comprises of diesel alternators which can be located at any convenient place on the ship. This is possible because of the very high flexibility that this arrangement offers as all transmission takes place via cables. There will be present switchboards and distribution network. This system supplies the converters and motors for propulsion, as well as motors and consumers for other purposes. The disadvantages of this system are that the transmission losses are increased because of the increase in the number of components between the prime mover and the propeller. The transmission efficiency is lower than both, the direct drive and geared transmission. Total space occupied is more as the number of components is more and so is the total weight. Even the installation cost is higher because the many additional components in between. There are however many advantages that justify the use of this arrangement in spite of these disadvantages. Though the total weight and space used is more, the flexibility of the system enables us to make better utilization of the space. With the use of power electronics we can control the shaft speed keeping the frequency constant. Therefore with the same power generated we can propel the ship and also cater to the hotel load and other auxiliary services. When the total power required reduces we can simply stop a generator and the others can keep running at their maximum efficiency points. The manoeuvrability is increased as crash stop regenerative braking is possible and highest speeds are possible with limited engines running. The noise and vibrations are also reduced alone with the length and space occupied by the exhaust piping. The various aspects of diesel electric propulsion and its associated components will be discussed hereafter.

POWER SUPPLY NETWORK:

As the demand for electrical power increases on ships the supply current rating becomes too high at 440V. To reduce the size of both steady and fault currents, we increase the system voltage. Therefore most diesel electric propelled ships are high voltage ships. The component parts are HV diesel generators sets that feed HV main switchboards. We have a choice when it comes to deciding the type of motor to be used. DC motors can provide a very high torque with a very precise speed control. They are mostly used by traction devices. Their drawback is that switching of armature current is achieved by mechanical commutators and carbon brushes which increases the maintenance required. There is also a limitation on the maximum voltage that can be applied to the armature and this is about 750V only. Beyond this if more power is required, we will have to install two motors in series.

In case of AC motors, we can either have induction motors or the synchronous motors. The induction motors have a simple and robust construction. They are also comparatively less costly. However, these motors run at almost constant speed when voltage and frequency of the input is fixed. Also, the current required for starting is very high.

The synchronous motors are most commonly used. In such motors, the shaft always runs at the synchronous speed set by the supply frequency.

For the general control of such motors, in case of a DC motor, we can achieve control by varying the resistance in armature of field circuits. This will however increase the losses. For an AC induction motor or synchronous motor running on a fixed voltage or frequency the resistance will only affect the size of operating current but speed is constant due to fixed supply frequency. This can only be overcome by changing the frequency of stator current. For precise control we use convertors. The most commonly used motor drives are:

-voltage source inverter (VSI) type converters for AC motors.

-current source inverter type converters for AC motors, normally synchronous motors.

-cycloconverters for AC motors, normally for synchronous motors.

-DC converters, or SCR (silicon controlled rectifier) for DC motors.

REFERENCES

1] Basic Principles of ship Propulsion – MAN Diesel and Turbo – No

2] Electrical System – Propulsion System Evaluation [A Design Guide] – DC Maritime Technologies inc.(publication date :5-DEC 2000)

3] Marine Electrical Installations and Diesel Electric propulsion by Alf Kare Adnanes (ABB technical paper [2003- 04-22])

4] Naval Architecture for Marine Engineers : W. Muckle : Publication date 1975

5] medium and high speed diesel engines for marine use _ S.H. Henshall-(Publication date:1972)

6] GAS Turbine Theory by Cohen and Rogers : (Publication date: 1951)

7] Offshore support vessels – A practical guide by G.Ritchie (published in 2008)

8] Electrical Machinery – Fitzgerald, Kingsley, Kusko(published in 1952)

9] Practical Marine Electrical knowledge – Dennis T-Hall (published in1984)

10] Applied Naval Architecture by A.Zubaly

11] electrical Power and Propulsion- LPDs for RN by KJ street and NS Smith(technical paper 1998)