JERZY JAMROŻ, D.Sc.,M.E.
TADEUSZ WIESZCZECZYŃSKI, M.Sc.,M.E.
Technical University of Gdańsk
Faculty of Ocean Engineering
and Ship Technology

# Economical aspects of choice of the best propulsion plant with low-speed diesel engine

*SUMMARY*

*In the paper the effect of the operation and initial costs on choice of ship propulsion plant is analysed. Attention is paid to the optimum engine selection criteria . Two economic criteria are applied: Net Present Value (NPV) and Real Payback Time (RPT). The applied computer program and the numerical example computed with its use are based on the technical data of the MAN-B&W MC engine family.*

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## INTRODUCTION

In the 1990s substantial progress in the economy and reliability of two-stroke low-speed diesel engines applicable to ship propulsion was observed. MAN-B&W and SULZER firms offer MC and RTA engine families [1],[2] of power and speed ranges which make their application suitable to almost all types of merchant ships. The engines are universally used in ship power plants with propulsion power more than 10000 kW [3]. Their low specific fuel oil consumption and easiness of proper engine selection, viz. engine speed, number and bore of cylinders, make it possible to choose an economically justified engine for a given ship design. Propeller revolution number ,equal to engine speed in the case of direct propeller drive, requires propeller design calculations and propulsion engine choice to be carried out simultaneously. Due to the properly selected engine and propeller additional savings during ship service are available. The article is aimed at demonstrating by an example how much engine and propeller choice influences the economic indices which determine cost-effectiveness of a chosen design solution. The presented calculations were performed with the use computer programs elaborated at Ocean Engineering and Ship Technology Faculty , Technical University of Gdańsk.

## OPTIMUM ENGINE SEARCHING

When choosing engine the following should be at first determined :

- engine speed range
- number and bore of cylinders

### Engine speed range

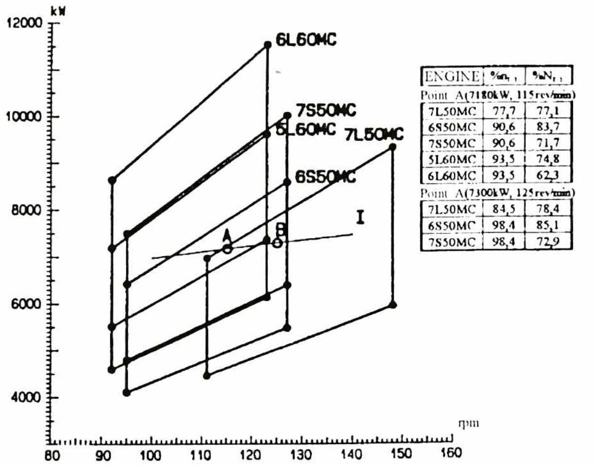
Engine speed range results from propeller calculations for a given ship and an assumed ship speed. From the propulsion economy point-of-view it is more advantageous to select an unloaded engine, of a lower speed at a given number and bore of cylinders. It is due to the fact that the gain arising from a higher propeller efficiency is greater than that of a lower specific fuel oil consumption. For each engine speed it is possible to select engines with different number of cylinders and thus with different power unloading.

### Number and bore of cylinders

In ships, low-speed engines of 6 to 8 cylinders are usually applied. A lower number of cylinders may be also found. The main advantage of application of less number of cylinders is a lower engine length at its given installed power, and that a higher cylinder bore is advantageous for fuel combustion processes and for decreasing specific fuel oil consumption. An additional advantage is a lesser amount of parts for maintenance and replacement. The trend of choosing low number of cylinders is recently being dropped, in spite of the advantages, due to vibration problems which may appear in connection with nonuniform combustion process in some cylinders. On the other hand engines with a higher number of cylinders ( 9 or more) are installed in merchant ships only when the maximum cylinder bore is already chosen and no other choice is possible. In the engines of a greater than 9 number of cylinders modification of crankshaft and bearings configuration is required which in consequence results in lower profits from application of a standard engine.

## Engine power and size

For an assumed engine power and its speed ,required to drive ship's propeller, and for a given number of cylinders : 5 to 9, it is easy to determine which engines of the actual production program can be applied for a given ship. From Fig. 1 it results that it is possible to accept MC engines of 50 and 60 cm cylinder bore and 5,6,7 or 8 cylinders for a ship of an assumed hull form and service speed, which is represented by the curve I ( power- rpm relationship for maximum efficiency propellers ) . All the engines are able to ensure the required ship speed but with different economic effects.




| ENGINE | $\%n_{r}$ | $\%N_{r}$ |
|---|---|---|
| Point A(7180kW, 115rev/min) | | |
| 7L50MC | 77,7 | 77,1 |
| 6S50MC | 90,6 | 83,7 |
| 7S50MC | 90,6 | 71,7 |
| 5L60MC | 93,5 | 74,8 |
| 6L60MC | 93,5 | 62,3 |
| Point A(7300kW, 125rev/min) | | |
| 7L50MC | 84,5 | 78,4 |
| 6S50MC | 98,4 | 85,1 |
| 7S50MC | 98,4 | 72,9 |

*Fig. 1. Contract parameters' areas for some MC-type engines*

## Other aspects of engine choice

Shipowners may prefer also other criteria e.g. ship propulsion reliability, apart from the above presented factors, which influence economic results of engine choice. However these are engine makers and ship operators who are responsible for fulfilment of reliability requirements. Ship power plant designer is able to influence operational reliability of a given type engine only by assuming a lower number of cylinders for it. But economy is always valid criterion therefore it should be at first decided upon importance of initial and operation costs for a given design.

It results from the last years experience that initial costs play now a greater role in economic analysis than before and that they can be lowered by choosing a proper engine (its type, length, mass, number of cylinders ). Operation costs can be lowered by selecting an engine with low specific fuel and lubricating oil consumption, with low rotational speed ( bound with a higher propeller efficiency ), with low repair and spare parts costs, with possible heat loss recovery and flexibility of operation in changeable conditions.

## ECONOMIC CRITERIA

The most rational design of the engine-propeller propulsion system can be chosen by comparing values of the economic indices based on the idea of investment-time-value and ship operation expenditures and incomes.

The following criteria are most often used when comparing ship propulsion systems [3]:

● Net Present Value (NPV) ● Real Payback Time (RPT).

The NPV index is the present value of all savings in fuel and lubricating oil costs, spare parts and repair costs with deduced difference between first cost of alternative and basic engines:

$$NPV = \sum_{j=1}^{N} \Delta k_j \frac{1}{(1+r)^j} - \Delta C$$

where:

$r$ - rate of discount
$N$ - assumed ship operation time
$\Delta k_j$ - annual operation cost difference
$\Delta C$ - engine investment cost difference
$j$ - current number of a year

The RPT index represents cost refund time , i.e. number of years which would pass to collect full repayment sum from annually accumulated profits. The RPT index can be derived from the NPV index by equalling it to zero. The RPT index is graphically represented in Fig. 2 by the distance between the origin of coordinate system and the intersection point of the curve NPV=f(j) and the axis of abscissae j. To calculate NPV and RPT values the data and relationships described in [4] were used.

It should be emphasized that engine prices is rather a delicate matter as they may depend on manufacturing place and time, terms of payment, as well as on maker's marketing strategy. Therefore the application of the NPV index, in which price difference of the compared engines are taken into account, is more advisable and reliable.

## ANALYSIS OF INVESTMENT AND OPERATION COSTS INFLUENCE ON CHOICE OF PROPULSION SYSTEM

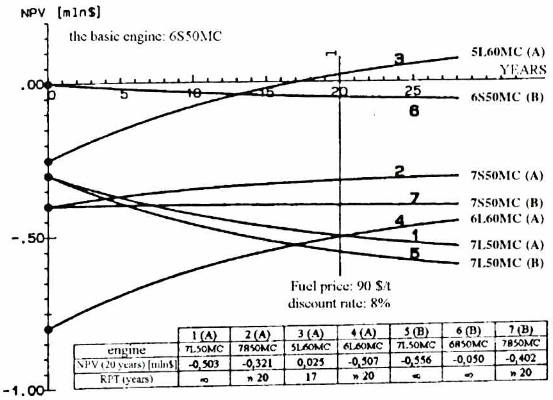
The analysis is aimed at estimation of changes in the economic indices, which are usually assumed to properly evaluate main engine choice, in function of investment and operation parameters. The parameters depend on the selected engine, market situation, but some of them - on shipowner's preferences. In economic calculations used for evaluation of such investment objects as ships are, this is determination of advantageous design range , but not searching for economic optimum, which makes it possible to choose an alternative design with other non-quantifiable factors taken also into account.

The analysis was elaborated on the basis of calculations performed for a ship with an assumed hull form and speed ( curve I in Fig. 1) and the chosen two sets of contract parameters represented by the points A ( 7180 kW, 115 rpm ) and B ( 7300 kW, 125 rpm ). The analysis was made for MAN-B&W engines, MC type of 50 and 60 cm cylinder bore, 5,6 and 7 cylinders, and engine contract speed from 92 to 148 rpm which satisfy the conditions assumed in the A and B points. In the presented diagrams the engines with less than 5 and more than 7 cylinders are omitted for the sake of clarity.

5 engines can be selected (6 and 7S50MC, 7L50MC, 5 and 6L60MC) for the point A and 3 engines (6 and 7S50MC, 7L50MC), for the point B. The following values were assumed constant in the calculations: fuel calorific value $W_{dz}$=40250 kJ/kgK, lubricating oil price of 1100 $/t, cylinder oil price of 1400 $/t, and annual ship's operation time of 260 days. Ship's useful life-time of 20 years was assumed.

### Influence of engine speed, cylinder bore and number of cylinders

In Fig. 2 the calculation results of NPV and RPT indices for 6S50MC engine , assumed as the basic one with the parameters defined in the point A , are presented. From these calculations it results that only 5L60MC engine with the largest cylinder bore would be more economical after 20 years of operation ( see the curve 3 in Fig. 2. ) than the basic one, in spite of its higher price. The gain of 25 000 $ and the investment payback time of about 17 years would be available from that choice. Higher investment expenditures of the remaining engines would not be balanced by their operation cost savings. Operation costs of 7L50MC engine incurred during 20 years ( see the curve 1 and 5 ) would be higher by more than 500 000 $ .




| engine | 1 (A) 7L50MC | 2 (A) 7S50MC | 3 (A) 5L60MC | 4 (A) 6L60MC | 5 (B) 7L50MC | 6 (B) 6S50MC | 7 (B) 7S50MC |
|---|---|---|---|---|---|---|---|
| NPV (20 years) [mln$] | -0,503 | -0,321 | 0,025 | -0,507 | -0,556 | -0,050 | -0,402 |
| RPT (years) | ∞ | » 20 | 17 | » 20 | ∞ | ∞ | » 20 |

*Fig. 2. Net Present Value (NPV) of the engines with power and speed defined in the points A and B versus running ship's operation time*

From the comparison of 6S50MC engine, chosen for the contract parameters defined in the point B, with the basic engine it results that the former one would have a higher total fuel consumption in spite of a lower specific fuel oil consumption than the basic one due to its higher rated power. Its NPV value would be decreasing with time ( see the curve 6 ) .

From Fig. 2 it reveals that 5L60MC engine with the contract parameters defined in the point A would be more economically advantageous for the considered ship and the assumed input data.

## Engine price influence

The results of NPV calculations of the engines, chosen for the contract parameters defined in the point A, performed under the assumption of ±10% possible engine price change and fuel oil price of 95 \$/t are shown in Fig. 3.

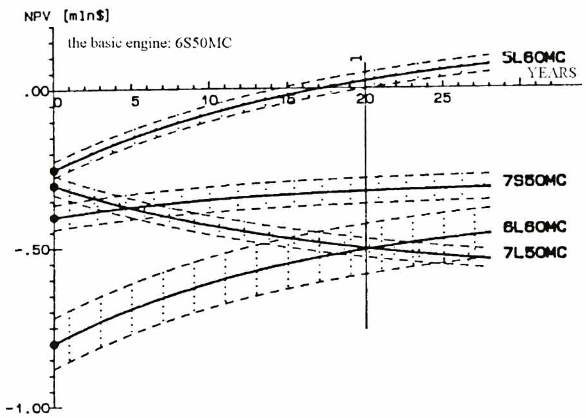



*Fig. 3. Net Present Value (NPV) of the engines with power and speed defined in the point A , calculated at engine price change within ±10%, versus running ship's operation time*

From the calculations it yields that 5L60MC engine price change within the above given range would cause the change of about ± 2,5 years in the investment RPT and the change of ±25 000 \$ in the NPV value. Changes in the NPV value of more expensive engines would be even greater. The assumed 10% engine price change does not modify substantially the qualitative results of this analysis.

## Fuel price influence

Fuel oil prices differ from port to port. Since 1991 the average prices of 180 cSt/50°C and 380 cSt/50°C heavy fuel have been changing within 60 to 120 \$/t range ( recently, viz. in 1994 , it amounts to 85 \$/t), but of diesel fuel - about 200 \$/t.

To illustrate fuel price influence on NPV and RPT values appropriate calculations at three different fuel prices: 95, 125 and 155 \$/t were performed . Their results are shown graphically in Fig. 4.

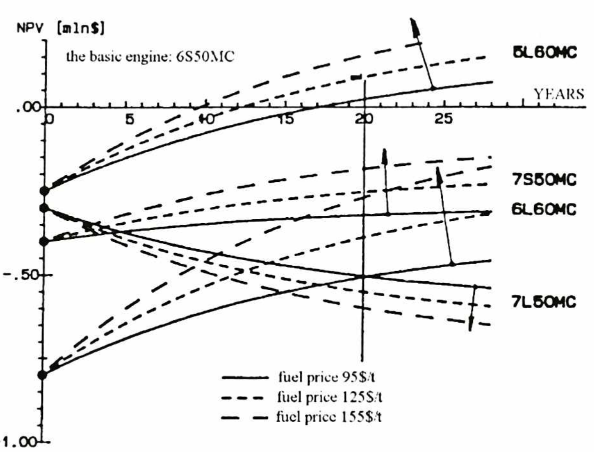



*Fig. 4. Net Present Value (NPV) of the engines with power and speed defined in the point A , calculated at different fuel prices, versus running ship's operation time*

It is obvious that RPT value decreases and NPV value increases as fuel price drops. The influence is important for the engines with much lower fuel consumption than that of the basic engine. In this case it may be more economically advantageous to apply a more expensive engine. For instance, specific fuel oil consumption of 6S50MC engine reaches 182 g/kWh, but of 6L60MC engine - 173 g/kWh. However 6L60MC engine (apart from 5L60MC) may be also more advantageous than the basic one if only price difference between 6L60MC and 6S50MC engine is lower than that and the fuel price increase in operation years to come is assumed higher.

In this paper influence of change in prices of lubricating oil, spare parts and repair works on economic indices was not considered because the share of those costs in total engine operation cost is less meaningful. The share reaches about 17%. The elaborated computer programs make it possible to carry out calculations with the above mentioned parameters accounted for.

## Discount rate influence

The discount rate influence on RPT value is opposite to that of fuel price. The higher discount rate the greater RPT value. It means that the engine with a higher discount rate is more expensive in operation. In Fig. 5. results are presented of calculations performed for two different discount rates: 8 and 12%.

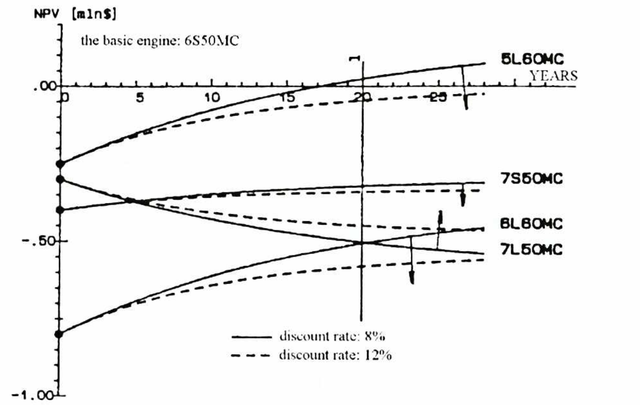



*Fig. 5. Net Present Value (NPV) of the engines with power and speed defined in the point A , calculated at different discount rates, versus running ship's operation time*

## CONCLUSIONS

The presented calculation results demonstrate how very important from economy point of view it is to choose the engine-propeller system properly and what advantages can be achieved from the properly selected design. An advantage of the presented method and computer programs is the ability of performing calculations for the existing, actually produced engines and that calculated economic effects are expressed in monetary units.

It is also vital that relationships used for calculation of engine operation parameters are based on technical specifications and data obtained from engine producers.

For large ships, propulsion of which demands higher power of installed engines, economic profits can be even greater as well as limitations arising from their large gabarites are rather unimportant.

Because of taking into account the economic criteria when selecting engine-propeller system it is possible to eliminate disadvantageous designs which are characterized by higher costs incurred in a given operation time than those of a basic engine. Specific fuel oil consumption is not a unique choice criterion of modern, low-speed main diesel engines, and screw propellers driven by them are not necessarily selected as the ones of the maximum applicable diameter. Selection of a proper engine speed and of propeller itself is the crucial issue when choosing engines of the MC and RTA types.

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**Appraised by Alfred Brandowski, Prof., D.Sc., M.E.**