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On possible lowering fuel oil consumption by differentiating loads on ship diesel engines running in parallel

SUMMARY

In the paper presented are possible ways of differentiating loads on individual diesel engines running in parallel by using information on their load and fuel oil consumption values, which make it possible to lower their total fuel oil consumption.

INTRODUCTION

Ship diesel engines can run in parallel in the following systems :

- the main propulsion system producing mechanical energy for ship propulsion
- as the auxiliary engines driving electric generators.

In the case of the main propulsion system the parallel run can be realized in the systems comprising multi-input mechanical, electrical (in diesel-electric systems) or hydraulical transmissions.

In the case of the auxiliary engines their parallel run is realized practically in every ship electric power plant.

OPERATION OF SHIP DIESEL ENGINES IN MULTI-ELEMENT SYSTEMS

In the case of the multi-element systems it is usually necessary to run the engines in parallel under loads substantially exceeding rated loads of individual engines.

Therefore the automation systems must ensure correct work of all cooperating engines first of all by preventing them against overloading. As a result of changing the load due to changeable operational conditions, the automation system must ensure another share of load between cooperating engines [1]. Because of the range of load changes as well as of their dynamics, the so far applied automation systems have been required to maintain the load proportional. By applying the „good seamanship" approach the engines running in parallel have been operated under the load shared proportionally to their individual rated power. Such approach has been rational in the case of the automation systems with mechanical or electromechanical control elements. Today there are at disposal electronic microprocessor systems and electronic engine's speed governors [2,3,7] which make it possible to share load among the engines running in parallel, in a programmable way. This allows to desist from the present principle of proportional load sharing.

TOTAL FUEL OIL CONSUMPTION BY SHIP DIESEL ENGINES RUNNING IN PARALLEL

The total fuel oil consumption by the engines running in parallel is an algebraic sum of the fuel oil consumptions realized by individual elements of the system in question. The so far applied way of operation in which the proportional share of load has been assumed [5,6], is correct from the point of view of minimization of the total fuel oil consumption only in the case when the fuel oil consumption characteristics of particular engines are identical or when their fuel oil consumption increments are equal. However it can be observed that fuel oil consumption characteristics of the same type engines (of given series) differ already in the instant of putting the engines into service, and that then they change and usually become even more different to each other. (Tab.1).

In such cases a minimum of the total fuel oil consumption does not happen for proportional loads. Then another load share which leads to decreasing the total fuel oil consumption, can be determined. This is possible if the fuel oil consumption characteristics determined :

- either for several or a dozen or so loads (e.g. once a year) applied when a step-by-step load change method is used [4]
- by using continuous real-time measurements, are known.

Tab.1. Specific fuel oil consumption [g/kWh] of series of 6AL25D engines (test stand data)

Engine number	Relative engine's load [%]				
	25 %	50 %	75 %	100 %	110 %
1	234	211.1	200.5	199.0	199.8
2	240.8	211.0	204.0	199.2	200.4
3	232	211.3	202.9	200.7	201.7
4	235.7	211.8	201.2	199.7	200.6
5	230.5	205.1	196.8	198.9	200.0
6	235.6	211.0	210.3	199.4	200.8
7	231.6	206.0	198.0	199.0	201.4
Mean value b_m	234.14	209.61	201.96	199.41	200.67
Relative spread $\frac{b_{max} - b_{min}}{b_m}$	4.4%	3.2%	6.68%	0.903%	0.947%

Such continuous measurement can be performed in an indirect way by measuring the set position of the fuel charging rail which controls fuel oil charge delivered by means of injectors, called the *load index*.

This way of determining the fuel oil consumption was applied for CAT3304 Caterpillar auxiliary engines installed in the tug „Heros" [4].

A fuel charging rail position transducer fitted with an ELFA precise potentiometer (of 0,5% linearity and R=10 kΩ) was fixed to the output shaft of the engine speed governor. The angle of rotation of the shaft was selected as the fuel pump setting index „w".

A PP83 active power transducer of 0.5-class, designed as the Aron's circuit, cooperating with a 200A/5A current transformer, was used for electrical power measurements.

The measurements were carried out together with simultaneous recording (on a floppy disc) readouts from four channels :

- of the fuel oil pump setting index of the auxiliary engine no.1
- of the fuel oil pump setting index of the auxiliary engine no.2
- of the active power of the electric generator of the generating set no.1
- of the active power of the electric generator of the generating set no.2.

During one measurement series 30 measurements were performed every second at steady load and its steady share between the generators. For further analysis only mean values of 30 measurements of given series were taken into account.

In Fig.1 given are the results of the fuel oil consumption measurements performed by the producer of the engines, which were used for calibration of the signals obtained from the fuel charging rail position transducers.

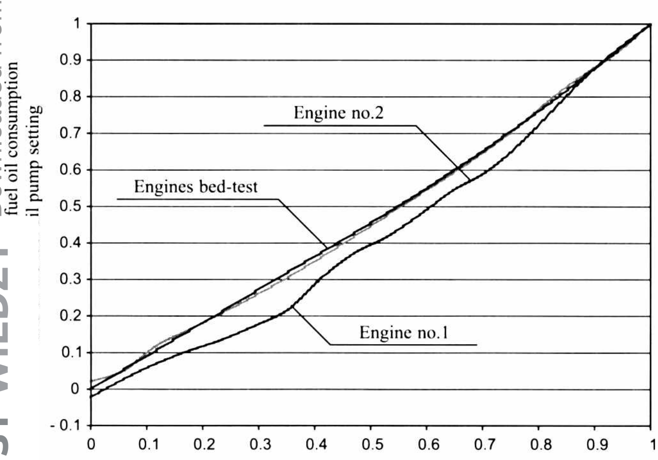

Fig.1. Relative values of the fuel oil consumption and relative settings of the fuel oil pump indices of the electric generating sets in function of the relative active power load of the electric generators

The course of the load index characteristics shown in Fig.2 corresponds with the fuel oil consumption loading characteristics. The index w_1 shows an exceptional compliance with the fuel oil consumption characteristics : their courses are practically indentical. The small deviations of the index w_2 can be compensated by scaling.

The diagrams shown in Fig.1. confirm that it is possible to use the fuel oil pump setting index (after its appropriate scaling) as an equivalent (measure) of the fuel oil consumption.

POSSIBLE DIFFERENTIATION OF LOADS ON SHIP DIESEL ENGINES RUNNING IN PARALLEL

In the cases of the different forms of the characteristics the general principle of load differentiation, in order to lower the total fuel oil consumption, consists in putting an additional load on the engine whose fuel oil consumption increase, at that load rise, is lower than the fuel oil consumption drop of the system's element unloaded by the same load value. In the analyzed cases it can be assumed that the fuel oil consumption change in the neighbourhood of the point corresponding with the load on a given system's element, is determined by the linear relationship :

$$\Delta B_i = \delta B_i / \delta N_i \times \Delta N_i \qquad (1)$$

and the total fuel oil consumption change – by the relationship :

$$\sum_{i=1}^{n} \Delta B_i = \delta B_1/\delta N_1 \times \Delta N_1 + \delta B_2/\delta N_2 \times \Delta N_2 + \\ + \ldots + \delta B_i/\delta N_i \times \Delta N_i + \ldots + \delta B_n/\delta N_n \times \Delta N_n \qquad (2)$$

where :

$$\sum_{i=1}^{n} \Delta N_i = 0 \qquad (3)$$

with the target to be obtained :

$$B = \sum_{i=1}^{n} B_i \rightarrow \min$$

As any lowering of fuel oil consumption is favourable it has been assumed that the fuel oil consumption increase has the sign (–), and its decrease the sign (+).

Hence :

$$-\sum_{i=1}^{n} \Delta B_i = \Delta B \rightarrow \max \qquad (4)$$

By applying such change of load on individual engines the total load value maintains unchanged.

In Fig.2 shown are the possibilities of lowering the total fuel oil consumption by two engines running in parallel at different fuel oil consumption characteristics. This is possible in the case of the characteristics of both convex and concave form. Moreover the lowering of the total fuel oil consumption can be obtained in some special cases i.e. when the fuel oil consumption characteristics are identical (it happens if both of them are convex or having discontinuity points).

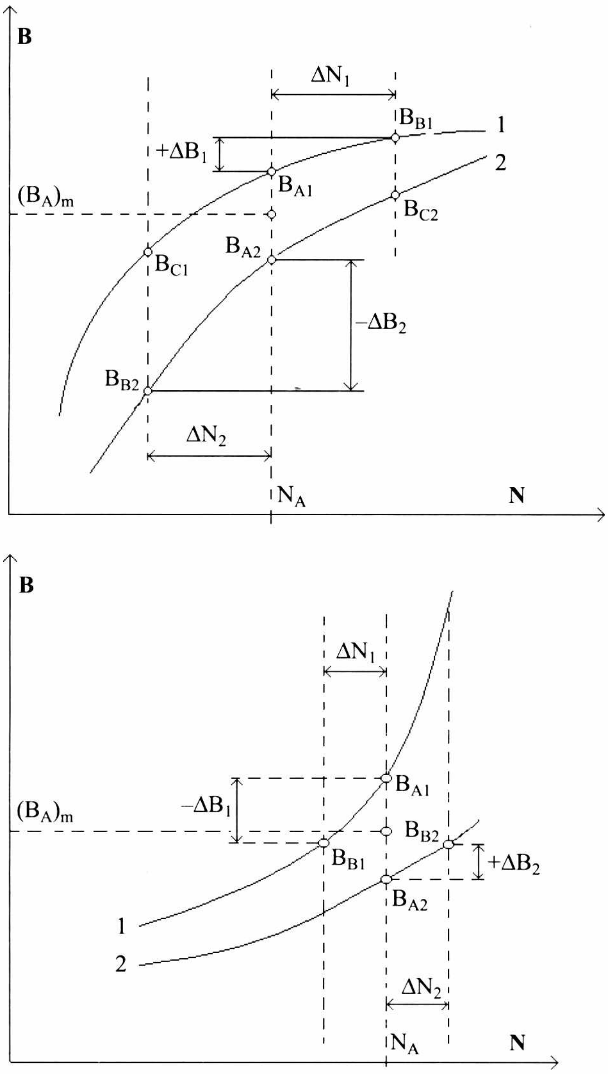

Fig.2. Schematic diagrams showing the fuel oil consumption change at differentiated loads on engines of different fuel oil consumption characteristics : convex ones (top diagram) and concave ones (bottom diagram) : 1 - fuel oil consumption characteristics of the engine no.1; 2 - fuel oil consumption characteristics of the engine no.2.

An example solution of such problem
for three engines running in parallel is presented in Fig.3.

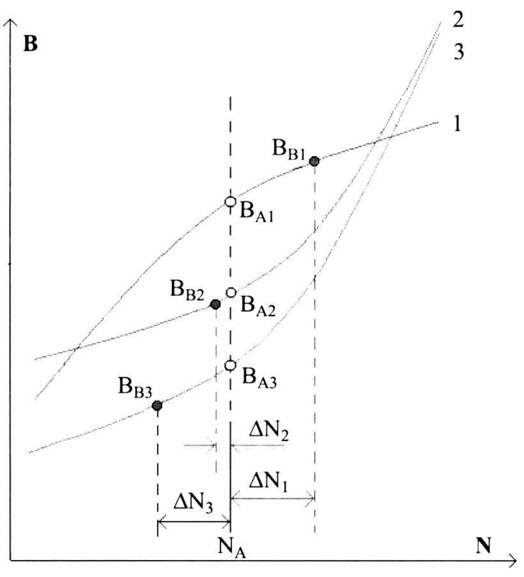

Fig.3. Schematic diagram showing the fuel oil consumption change at differentiated loads on three engines of different fuel oil consumption characteristics

Direction of load differentiation may concern a limited range whose exceedance would lead to an opposite effect (Fig.4).

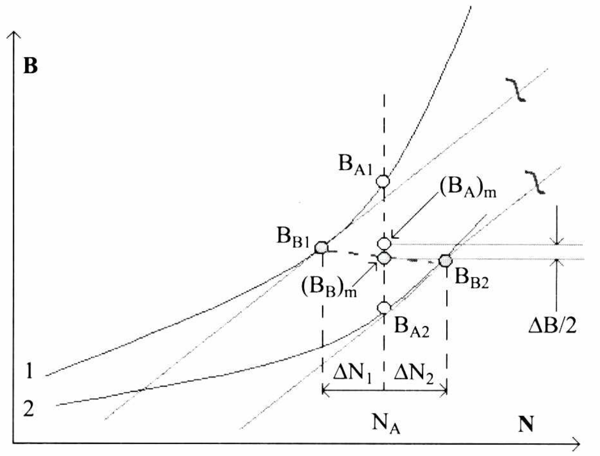

Fig.4. Schematic diagram showing the limited range of load differentiation

The programmable real-time load sharing among the engines running in parallel can be applied to modern electric power systems in which the instantaneous load and fuel oil consumption is measured continuously and automatically. This makes it possible, already in the design stage of power plant automation, to select a system allowing to make use of possible load differentiation. In order to apply this option it is necessary to elaborate a computer software able to take over the operator's function.

The block diagram of the procedures applicable to searching for a set of engines to be run in parallel, as well as to differentiating their loads, is shown in Fig.5.

In the block diagram presented are the procedures aimed at :

- choice of a number and a set of the engines to be run in parallel
- searching for such load share among the cooperating engines, which corresponds with the lowest total fuel oil consumption
- safeguarding the cooperating engines against exceedance of their service loads.

An important decision is to determine
the following threshold values :

- the waiting time Δt, under the assumption that the total load does not change during this time
- the load differentiation step dN by which the load on a selected engine has to be changed
- the change of the total load ΔN, exceedance of which will start searching for a new load share.

FINAL REMARKS

- The area of the greatest profits which would result from application of the presented method can be large power diesel-electric power plants consisted of many main electric generating sets.
- The method is also applicable to load differentiation of the fired marine boilers.

Appraised by Romuald Cwilewicz, Assoc.Prof.D.Sc.

NOMENCLATURE

b	–	specific fuel oil consumption
B	–	hourly fuel oil consumption, total fuel oil consumption
B_m	–	mean hourly fuel oil consumption
B'	–	total fuel oil consumption after load share change
ΔB_i	–	change (increment) of fuel oil consumption of i-th engine
N	–	engine power, total power of engines
N_{nom}	–	rated power of engine
dN	–	step of load differentiation
w	–	setting index of fuel pumps

$\delta B_i/\delta N_i$ – derivative of hourly fuel oil consumption against power of i-th engine
ΔN – change of total load
ΔN_i – change of i-th engine's load
Δt – waiting time.

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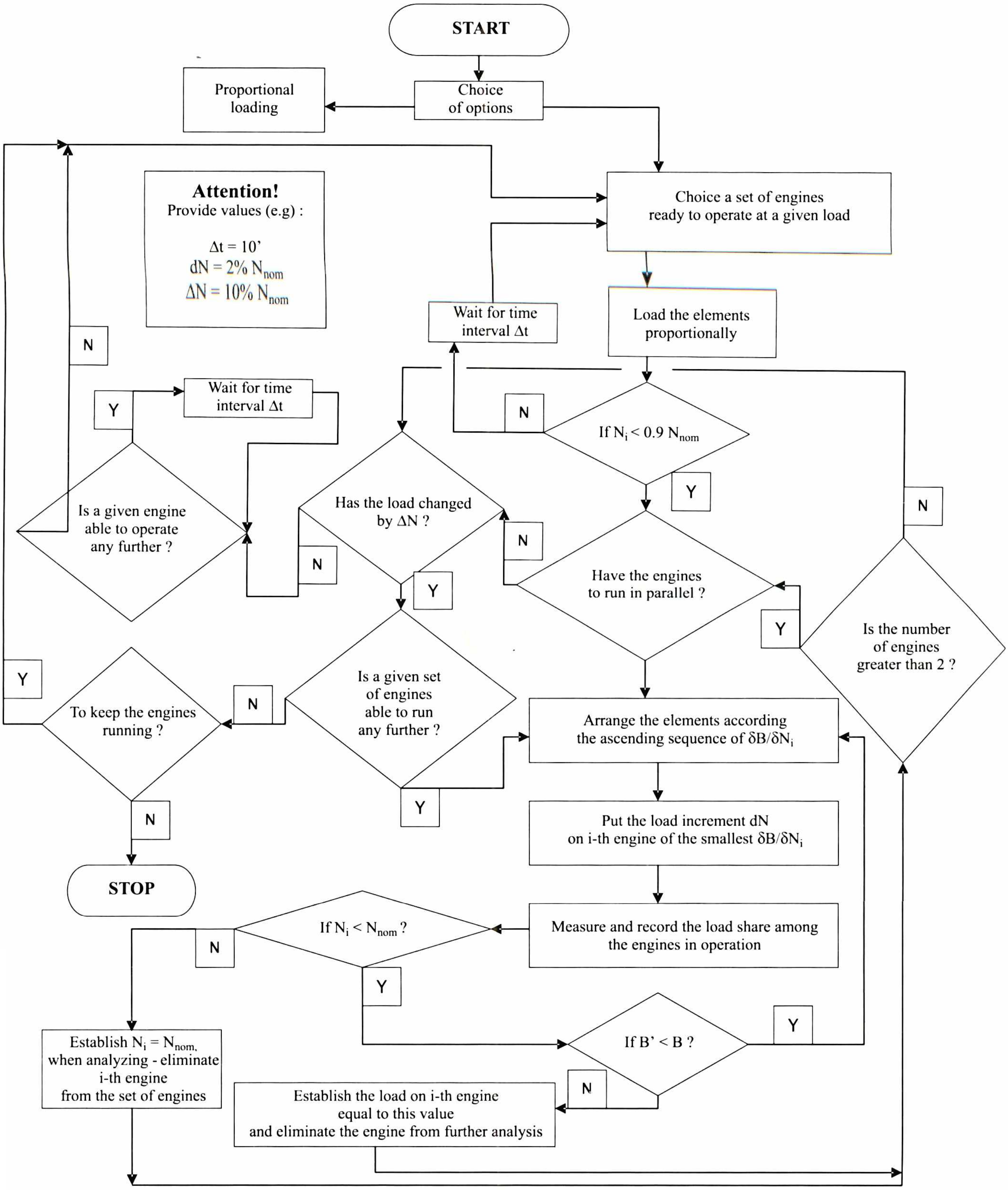

Fig.5. *The block diagram of the procedures of the method for differentiating loads among the engines by using real-time data on their fuel oil consumption*