The New MAN B&W 48/60B Engine – The Allure of Power

by

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Introduction

The current basic state-of-the-art family of MAN B&W's large medium-speed diesel engines consists of four sizes L 58/64, L/V 48/60, L 40/54 and L/V 32/40, launched between 1985 and 1995. This engine family covers an output range from 2880 kW (6L 32/40) to 18,900 kW (18V 48/60). Within the last few years, this portfolio has been supplemented by the V 40/50, the smaller engine sizes L 16/24 and L 27/38, and, finally, the new L 21/31 (2002/03). All engines are fully heavy fuel oil compatible and have been optimised for both high fuel economy and lowest exhaust gas emissions. It goes without saying that they all meet the IMO emission limits by engine-internal measures, i.e. without need to have any external equipment.

In terms of sold power, the 48/60 engine is second in the list of MAN B&W's bestsellers. Since market launch in 1989, a total of 245 engines of this size, representing 3.7 million HP, has been sold (Status: 31 January 2002). From this, 162 engines were ordered for marine applications and 83 for land-based applications. Taking the in-line versions of the 48/60, the 6L was the best selling with 51 engines, from the Vee engines it is the 18V (43 engines), closely followed by the 12V (42 engines). By the end of January 2002, the sales records list a total of 2630 cylinders. The 48/60-type engines already operating in the field have accumulated more than 3.2 million operating hours. Some of them have already clocked up around 60,000 running hours.

Fig. 1 depicts the wide variety of applications of the L/V 48/60, which was originally launched with a rating of 885 kW per cylinder at 428 and 450 rpm respectively. Since then, the cylinder output of what can be called a "workhorse" engine has been increased by more than 18% (Fig. 2).

Why 48/60B

A vast amount of service experience under a wide variety of site conditions and different applications was accumulated since market launch of the engine size 48/60 about 12-13 years ago. This combines with many design improvements and component changes that have been made during this period to make the engine even more reliable, more efficient and to improve its environmental friendliness. Such design adjustments as a consequence of changed market requirements are an ongoing process. It is not at all an exception, that, by the time a diesel power plant or a vessel with diesel engines is being officially inaugurated, customer requirements are different from the time when the engines were ordered - for instance due to more stringent emission legislation.

In addition, over the years, knowledge in diesel technology is improving, despite the fact that the old heat machine, the diesel engine, looks back on a remarkable career of approximately 105 years. Progress is made in better understanding injection, combustion and emission control, just to mention some examples. Both theoretical and experimental development work result in greater insights into the many processes involved, allow safe prediction of component loadings, safety levels and even lifetimes.

With all this experience and knowledge at hand, it is possible today to upgrade an existing proven engine in regards of output, fuel consumption, emissions, and component safety, whilst retaining proven engine sub-groups. Furthermore, customers tend to trust in an engine concept they are familiar with, and often have natural objections against a completely new prime mover.
For these reasons MAN B&W decided to retain the main dimensions, bore and stroke, of the 48/60 and with it many proven engine subgroups, whilst modifying and changing a variety of other key engine components.
In order to illustrate the relationship of the new engine to its immediate predecessor, it is named 48/60B (Fig. 3). Its rating is set at 1200 kW per cylinder at 500 and 514 rpm, respectively (Fig. 4). This is equal to an increase of 14% over the current nominal output of the 48/60 engine.

Apart from the higher cylinder output, a number of further important design targets were defined for the 48/60B, among others

- Increase in engine efficiency (corresponding to fuel savings and, correspondingly, a lower carbon dioxide emission)
- Environmental friendliness in respect of other pollutants, such as smoke and nitrogen oxides
- Reduction in engine width and, consequently, in centre-to-centre distance in order to reduce the gear size (double engine-single shaft propulsion) and/or total engine width for compact multi-engine arrangements
- Improvement of the operational and component reliability
- Increased ease of maintenance
- Improved robustness and simplicity
- Reduction in weight-to-power ratio (particular attention was given to obtaining lower weights for all engine components)
- Reduction of manufacturing costs by applying improved design features and a lower number of engine components and parts.

These are quite ambitious goals, especially considering the trade-off effects involved, for instance the trade-off between higher power density, simplicity of the engine and ease of maintenance, or the trade-off between increased thermal engine efficiency and lower NOx and smoke emissions.
The next chapter describes how this package of demanding technical goals was achieved.

Better fuel economy by a combination of different measures

With a bore of 480 mm and a stroke of 600 mm (bore-to-stroke ratio = 1.25), the 48/60B engine obviously is not a typical long-stroke engine with its options to reduce fuel consumption rates. However, even with the same bore-to-stroke ratio, the bundle of in-engine measures effected gave the same result – at a lower cost.
A package of engine-internal measures was worked out, initially confirmed to be feasible by simulation calculations and finally tested step by step on a 12V 48/60B protopype

engine (Fig. 5) in order to find the best solution between several variables, i.e. an acceptable compromise between fuel consumption, component loading, and NOx and smoke emissions.

To achieve this target, the following principal correlations, which are partly in conflict with each other, had to be considered and the work process was modified accordingly:

1. Adoption of a "slight" Miller process to lower combustion temperature levels, and, with them, NOx emission. This process, first publicly presented in 1957 during the CIMAC Congess in Zuerich, Switzerland, is based on an earlier closing of the inlet valves. The original intention of the Miller process was to limit thermal and mechanical engine loadings, which rise sharply with increasing power density of the engines. The Miller process is also a well-known tool for engine designers to reduce fuel consumption rates, provided an appropriate matching of the turbocharger is possible. Compared with the normal working process, the Miller process requires high-efficiency, high-pressure exhaust-gas turbochargers, because otherwise the effect on engine operation would be just the opposite.
2. Increase in injection intensity for lower soot production and therefore lower smoke emissions, especially at partload. Unfortunately, this measure has a negative effect on NOx emission. In order to neutralise the increase in NOx emission, the injection can be retarded, although this leads to a higher fuel consumption rate and increased particle emission. Another effect of the delayed injection is a lower firing pressure.
3. To neutralise the fuel consumption disadvantage resulting from step (2), it is necessary to take advantage of the firing pressure potential of the engine. Therefore a higher compression ratio has been chosen for the 48/60B.
4. Use of the considerably increased efficiency level of the newly designed MAN B&W TCA-type turbocharger so that the resultant fuel savings from steps (1) to (3) exceeded the fuel losses involved in (1) to (3).

By optimising the combustion space geometry (with unchanged engine stroke), which was achieved by avoiding dead volumes, edges and ribs in the combustion side of the cylinder cover, the compression ratio was increased from ε = 14.4 (48/60) to ε = 15.3 (48/60B). A possible further increase in ε would most likely result in increased smoke emission at low loads. A conventional medium-speed diesel engine with a bore-to-stroke ratio of 1.25 and a rather high compression ratio of, for instance ε = 17, would produce a pronounced dark plume - even at higher engine loads – which would be visible from far away.

The slightly increased compression ratio of the 48/60B has another beneficial effect: it improves the ignition behaviour of lowest-quality heavy fuel oils. The 48/60B can therefore safely operate with HFO up to a viscosity of 700 cSt/50°C and runs on fuels up to, and including, the CIMAC H55/K55 specifications.

The firing pressure of the 48/60B was increased to a maximum of 200 bar. This, in connection with other measures such as modified injection (the injection pressure was increased from 1300 bar for the 48/60 to 1600 bar) and a further improved gas exchange process, resulted in a process very close to the ideal constant-pressure combustion. The higher firing pressure was possible without risking the operational safety of the engine: to have the same safety margins as the 48/60 in spite of a higher mechanical loading, better materials were used and/or components strengthened.

TCA, the new turbocharger

One engine component considerably contributing to make this engine setting easier is the newly designed TCA axial-flow turbocharger from MAN B&W Diesel in Augsburg, Germany. Compared with the previous turbocharger generation (NA/S-type series), TCA turbochargers show increased airflow rates, higher compressor pressure ratios and, simultaneously, significantly higher turbocharger efficiencies across the whole load range. The most obvious benefits from this are greater flexibility in matching the turbocharger to the engine, a higher surge margin and improvements in the engine's scavenging process. The TCA turbocharger can be easily optimised for higher charge-air pressures at part load for best fuel consumption, for lower pollutant emissions and for a quick load response.

Fig. 6 compares the overall efficiencies of the earlier NA/S (lower curve) and the new TCA turbocharger series (upper curve) plotted across the compressor pressure ratio. Over the whole operating range, the (total-to-static) turbocharger efficiency level was increased by 8 - 10%. A typical service rating point (85% of MCR, propeller operation) is plotted on the efficiency line of the TCA turbocharger with the total-to-static turbocharger efficiency reaching approximately 69% (calculated from measured temperatures, pressures and mass flows for this optimisation point). Worth mentioning is the favourable efficiency increase towards lower engine part load, with a maximum efficiency of 71% at a compressor pressure ratio of 3.5.

Figs. 7 and 8 are a summary of test results recorded from MAN B&W's 12V 48/60B prototype engine. For these measurements the engine was operated at constant speed (514 rpm) and 1200 kW/cyl. NOx emission is in compliance with IMO regulations; and the given fuel consumption rates are based on ISO conditions. Although these operating results are not representative of the final engine setting, the low fuel consumption curve and the favourably low smoke emission line confirm the engine design philosophy as outlined above.
The minimum fuel consumption rate, at 85% engine load, and in constant speed application, is 173 g/kWh, which is 7 g/kWh better than that of the 48/60 Vee-type engine at the same absolute output. Simultaneously, the measured smoke Bosch index, from full load down to about 20% engine load, is below 0.3 - which means invisible soot-produced exhaust (Fig. 8).
With such favourable smoke emission figures, the new 48/60B is a genuine ***IS***-type (***IS*** = invisible smoke) engine, a result that has been achieved only with inbuilt emission-reduction technologies, omitting additional hardware such as an auxiliary air blower.

Engine design

Since bore and stroke of the 48/60B remained unchanged, the robust and stiff single-part engine block of the current 48/60-type engine, cast of grey iron or nodular iron, could be used with sufficient operational and safety reserves. The main features of the basic engine structure are the same for all MAN B&W medium-speed diesel engines: cylinder jackets separated from each other and mounted on the frame, and an underslung crankshaft. The engine cooling water is only supplied to these jackets, leaving the engine frame itself completely free from cooling water. Therefore the risk of lube oil contamination by water is avoided.

Other well-proven design features have been adopted as well; where necessary, they have been slightly improved to match the engine's higher mechanical loading. Examples include

- Changed turbocharger/charge-air cooler mounting to decrease engine width of all 48/60B Vee-type engines. As Fig. 9 shows, the centre-to-centre distance between two V48/60B-type engines was decreased by about 1 m.The total height of the engines is the same as with the current 48/60 models.
- Re-designed cylinder head without valve cages and a new valve train (Fig. 10)
- Modified valve timing
- New injection system with high injection intensity (as described above)
- Improved piston with a steel crown and a skirt cast of nodular iron or a steel skirt
- Improved material for the connecting rod, and increased shaft diameter
- New combustion chamber (as described above).

Other engine components have been newly designed in order to meet the high development targets set for the 48/60B. One example is the simplified exhaust-gas system with only one single exhaust manifold (Fig. 11) and a single (TCA) turbocharger for Vee-version engines. This concept improves access to engine components, reduces the number of component variants, and contributes to a reduction in engine mass. For instance, the dry weight of the 14.4 MW 12V 48/60B engine is 181 tons (Fig. 12) compared with 193 tons for the current 12V 48/60 that is rated at only 12.6 MW. In case of an 18V 48/60B, the weight saving is 15 tons. This makes the new engine a remarkably compact and light prime mover in its class: the weight-to-power ratio of the 18V 48/60B, for instance, is only 11.9 kg/kW (current 18V 48/60: 14.3 kg/kW).

As with all MAN B&W medium-speed engines, the axial-flow turbocharger with its inboard plain bearings allows straight exhaust-gas admission to the turbine inlet casing. This avoids flow disturbances and, consequently, efficiency losses which occur when exhaust bends have to be applied. Together with the two intercoolers, the single turbocharger is located inside a stiff frame, forming a "turbocharging module" of its own (Fig. 13). This module is integrated into the front side of the engine rather than on top of the engine.

Another example for new inventions with the 48/60B is the innovative (and patented) rocker arm concept with the modified rocker arm. As illustrated in Fig. 14, the axial bearing of the rocker arm was replaced by two spherically shaped bearings. With this solution the number of moving parts is reduced from three to two. Accordingly, the valve train assembly is less complicated than in the current 48/60.
Rocker arm housing and charge-air pipe section made of aluminium form one common casing. This allows easy dismantling, reduced maintenance work for the rocker arms and the rocker casing. Further benefits were reduced weight and reduced outer dimensions.

To meet the higher mechanical load, special attention was paid to the conrod bearing. Its big-end design was improved by

- modified bearing shell concavity
- optimized bearing clearance, and
- reduced width of the oil grooves (Fig. 15).

These design changes resulted in lower temperatures in the conrod's lower bearing shells. As Fig. 16 shows, the difference between the current 48/60 and the 48/60B at no-load and an engine speed of 514 rpm is 10 °C (zero load is the critical operational condition for conrod bearings).

The 12V 48/60B prototype engine has been fully running and undergoing tests on the Augsburg testbed since late summer 2001 (Fig. 5). Vee-form models with cylinder versions from 12 to 18 will be introduced first and become available early in 2003, covering an output bracket between 14.4 and 21.6 MW (Fig. 12). Afterwards in-line configurations with 6, 7, 8, and 9 cylinders will follow, becoming available in late summer 2003. The output range of the 48/60B therefore covers 7.2 to 21.6 MW per engine.

Prepared for possible stricter future emission regulations

All engines from MAN B&W for marine applications, of course including the 48/60B, meet the IMO NOx requirements and the World Bank guidelines on NOx and particulate emissions by employing engine-internal measures. This neither increases costs nor reduces simplicity and reliability of the engine. The IMO NOx cycle emission value for a standard 48/60B production engine is 12 g/kWh, 8% below IMO's NOx curve.

The environmental impact of a diesel engine, however, is not only determined by the NOx cycle value, because CO_2 emission and smoke emission have to be considered as well. If CO_2 (at 85% load of the 48/60B, which is equal to about 100% of the 48/60), NOx (cycle value) and smoke (at 20% load) are plotted in a 3-axis-diagramme as done in Fig. 17 for the 48/60 and 48/60B, the volume of the resulting "emission cube" is indicative of the engine's "pollution potential". The smaller the volume of this "cube" is, the better the engine is in terms of envrionmental friendliness. Clearly, the 48/60B pollutes less than the 48/60.

The combustion chamber optimisation of the 48/60B was strongly influenced by the vast experience gained on MAN B&W's single-cylinder 32/40 research engine. This diesel engine can be operated up to mean effective pressures of 30 bar and maximum injection pressures of 2000 bar. On the 1L 32/40 engine the following variations were made and analysed:

- Cylinder heads with differently designed bottom
- Different piston bowls with small and large internal diameters and /or low or raised centre hump
- Different compression ratios
- Varied injection systems.

The characteristics of the injection system were varied from reduced injection intensities (= longer injection duration) at a slightly higher injection pressure to a very high injection rate for a short injection period at high pressure. The measured combined effects were carefully analysed and compared with each other in order to improve the NOx-soot-fuel consumption trade-off situation. One of the results from this research programme has been that an increased injection intensity in combination with a NOx-neutral increase in compression ratio and peak pressure was the best compromise with regards to all three emissions (CO_2, NOx, soot). These results were transferred into the design of the 48/60B and the measurements achieved so far are fully in line with those from the 1L 32/40 research engine.

Given the possibility of stricter NOx emission legislation later in this decade, the NOx level can be considerably decreased far below the current IMO curve, down to a level of 7 - 8 g/kWh, by use of fuel-water emulsification (FWE) technology, which has the additional advantage of slightly reducing soot formation, a highly welcome effect. For still lower levels than this, selective catalytic reduction (SCR) units can reduce NOx emissions to approximately 2 g/kWh, much lower than that of a state-of-the-art aeroderivative marine gas turbine.

Conclusions

By adopting well-proven design features of an engine on the market since 1989, improving and/or re-designing other decisive engine components and by introducing the new high-efficiency, high-pressure TCA turbocharger series, a new highly-rated 48/60B diesel engine is ready to be marketed only a relatively short time after the go-ahead for this project was given. With simultaneously increased output and decreased weight, the new MAN B&W engine is leading the market in terms of its output-to-piston area ratio (Fig. 18). Based on the extensive test series on a 32/40 single-cylinder research engine and simulation calculations, the 48/60B has a much better fuel efficiency than the predecessor engine, the 48/60, a NOx level below the IMO's NOx cycle limits and a smoke emission at part load which means invisible smoke from 100% engine load to less than 25% load.
Truly – the allure of power!

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