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The MAN B&W V40/50 Diesel engine

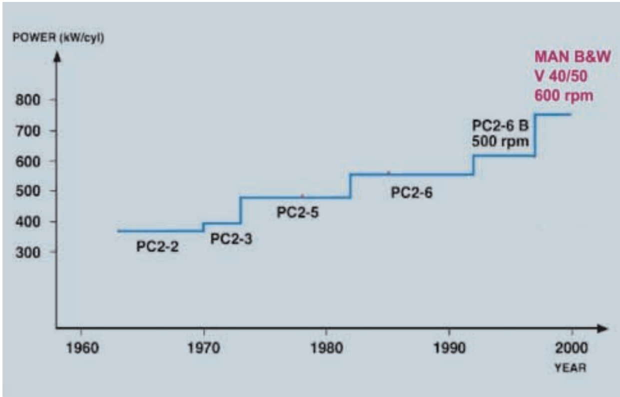
FROM PIELSTICK PC2 TO MAN B&W V40/50

For nearly forty years, S.E.M.T. Pielstick has been developing and manufacturing the 40 cm bore, four stroke, medium-speed PC2 Diesel engine.

At its first issue in 1963 the PC2 rating was 368 kW per cylinder. The evolution has continued gradually up to the present V40/50 featuring an output of 750 kW per cylinder. This result was made possible by a multifold, ongoing development program (Fig. **1**).

The experience, gained on the 3 482 PC2/V40 engines manufactured so far for marine and stationary applications was combined with technological progress in engine design, materials and components (Fig. **2**).

1 Power evolution of the V 40/PC2 engine.



Such track record makes the V40 the most popular engine of its class.

- 77 % of the PC2/V40 population (2 681 engines) are of the Vee configuration.
- 2 600 PC2/V40 are for Marine use.
- **727** PC2/V40 (Fig. **3**) have been installed on cruise vessels (Fig. **4**), car-ferries and RoRo ships.

CAR FERRY	435
CRUISE VESSEL	51
RORO VESSEL	241
TOTAL NUMBER OF ENGINES	**727**

3 V40/PC2 engine references on board car-ferries, cruise liners and RoRo ships.

2 V40/PC2 references.

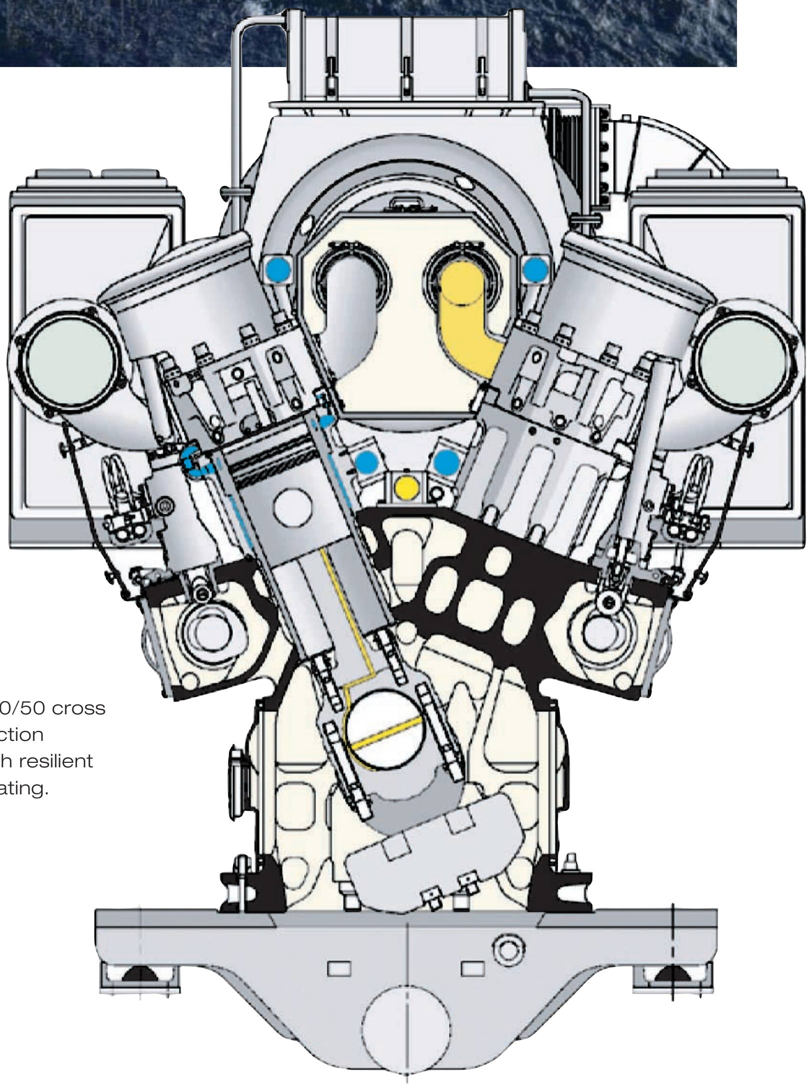
Cyl.	Merchant Marine	Navy	Diesel Power Plant	Nuclear Power Plant	Total Number of Engines
6 L	4 4 8	6 2	4 9	-	559
8 L	1 3 0	8	1 5	-	153
9 L	5 7	-	2 2	-	79
8 V	3 5	7	1 3	-	55
10 V	7 5	-	2 3	-	98
12 V	7 6 9	1 4 6	1 7 8	1 8	1111
14 V	1 3 1	3 6	3 6	6	209
16 V	3 0 2	1 3 0	1 7 0	9 1	693
18 V	2 6 2	2	2 2 8	3 3	525
TOTAL	2 209	391	734	148	3 482

4 Cruise vessel "Pacific Venus".
2 x 12 PC2/V40 2–6 (2 x 6,600 kW).

End of the 90 years S.E.M.T. Pielstick and MAN B&W introduced the latest version of the PC engines, the PC 2.6 B with an output of 750 kW/cylinder at 600 rpm. This engine is being promoted now by MAN B&W Diesel AG, Augsburg under the name V40/50 (for commercial marine

5 V 40/50 technical data.

Cylinder bore	mm	400
Cylinder stroke	mm	500
Speed	rpm	600
Cylinder output	kW/cyl.	750
Mean piston speed	m/s	10
Mean effective pressure	bar	23,9
Max. firing pressure	bar	170
sfoc at 85% MCR	g/kWh	179
Specific engine weight	kg/kW	9.3 – 10.4



6 V40/50 cross section with resilient seating.

market only). The V40/50 is a perfect completion of the MAN B&W 4-stroke Diesel engine program in the output range 9-15 MW and between the engines L40/54 and V48/60.

The present V40/50, if compared with its predecessor, the PC2.6 design, features many important changes on its structure as well as in the details of the engine design (Fig. **5**).

A 10 m/s piston speed is achieved by choosing an engine speed of 600 rpm – synchronising speed for both 50 and 60 Hz generator – and a stroke/bore ratio of 1.25, giving a good compromise between manufacturing cost and engine performance. All components have been dimensioned with a comfortable safety margin (Figs. **6, 7**).

- ❒ Crankcase is made of nodular cast iron with dry engine block – free of wet corrosion – very rigid.
- ❒ Crankshaft is in one piece, made of steel without special treatment in fillets and journals.
- ❒ Camshaft of modular design has large shaft diameter.
- ❒ Cylinder-head is made of nodular cast iron with exhaust valve cages.
- ❒ Liner is in two parts for lube oil consumption control and low wear rate purpose. Only the top part is cooled.
- ❒ Piston is in two parts with a steel crown and a light alloy skirt.
- ❒ Connecting rod is of "Marine" type in 3 parts.

7 V40/50 output and weight.

Engine type	Output (kW)	Weight (t)	
		(rigid seating)	(resilient seating)
12V 40/50	9 000	94	104
14V 40/50	10 500	104	115
16V 40/50	12 000	114	127
18V 40/50	13 500	124	139
20V 40/50	15 000	140	150

- ❒ Turbo-charging system is based on patented MPC manifold using a single turbo-charger (up to 18 cylinders). Turbocharger can be fitted either on coupling side or free end of the engine.

In June 1999 the first V40/50 engines with an output of 750 kW/Cyl. have been put into operation at the powerplant Choloma in Honduras (Fig. **8**). The powerplant equipped with 5 engines 16V40/50 (5 x 12,000 kW), has reached now an average operating time of more than 16,000 h/engine. The average continuous service rating is more than 90% MCR.

The first main overhaul (two year operation = 12 000 h) in the beginning of year 2001 has shown very good results. The guaranteed life time of components could be confirmed and even better life times are expected later:

	actual	expected
piston rings	12 000 h	16 000 h
exhaust valve	24 000 h	32 000 h
conrod bearing shell	12 000 h	16 000 h
main bearing shell	24 000 h	32 000 h

The lube oil consumption of 1.4 g/kWh could be reduced to 0.44 g/kWh after applying the anti-bore polishing ring in June 2001.

8 Choloma power plant Honduras.

PERFORMANCE AND MARKET POTENTIAL FOR FAST FERRY APPLICATION

1 Typical specific engine weights.

Low-speed engines, 70 –170 rpm	20 – 35 kg/kW
Medium-speed engines, 428 – 750 rpm	13 – 18 kg/kW
High-speed engines, > 1000 rpm	5 – 6 kg/kW

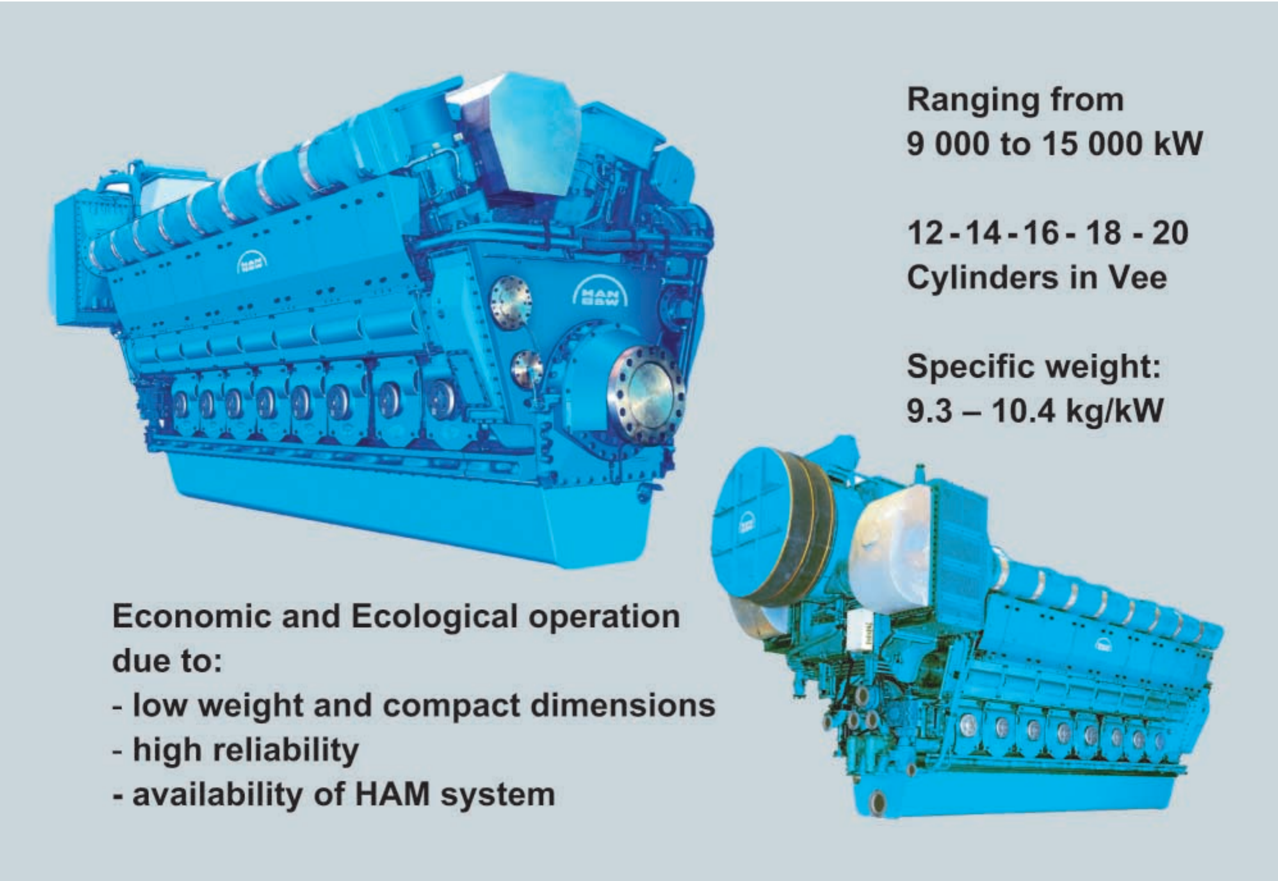
The present market requirements

As on land and in the air, also at sea the transport capacities have been increased drastically in recent years. Overall transport capacity is a product of cargo volume (quantity and size of vessels) and speed. The quantity and size of the huge container ships recently ordered show the increase of cargo volume on the one hand. On the other hand and for more passenger related transportation a remarkable increase in speed could be observed.

As years ago ferries and RoRo vessels were running on 20 knots, nowadays the speed of many vessels often has increased by 50% to 30 knots and more. The average speed of ferries and RoPax vessels of more than 150m length has been increased in recent years by approx. 5 knots (existing fleet: 21.3 knots; vessels on order: 26.0 knots). With increased speed the transport capacity will be increased by the same factor, or less vessels and cargo volume are necessary on a given route. With higher speeds ship owners can increase the competitiveness of their fleets.

On such so-called fast ships or fast ferries the power requirement rises by the third potency of the speed. Thus the installed engine power nearly has been doubled in few years from below 25 MW to 35-60 MW

2 The MAN B&W V40/50 Diesel engine for fast ferries.



and more. These vessel types are very demanding since fuel costs and requirements on machinery and equipment increase while at the same time weight of the vessel becomes more and more critical. Shipyards are forced to optimise these weight-critical vessels with respect to more slender hull forms, less weight of vessels, equipment and engines. Because of the very high fuel consumption and the high price difference between MDO and HFO the combustion of HFO is an absolute demand.

Nowadays most conventional fast ferries and RoPax vessels are equipped with four engines, either with Diesel-mechanical propulsion driving two propeller shafts via double reduction gearboxes or sometimes with Diesel-electric propulsion driving generators for powering of electric motors or POD-drives. With a total required power of 35-60 MW engines of 9000 to 15000 kW MCR output are necessary. This results in a bore diameter of the Diesel engines of at least 40 cm. As weight and dimension are related to bore diameter, bore should be kept at the lowest possible diameter. This consequently results in V-type engines with a high number of cylinders. Cylinder numbers of 16, 18 and even 20 are expected.

Table **1** shows typical specific engine weights of state-of-the-art engines of more than 5 MW and with the capability of burning HFO.

Because of their heavy weight low-speed Diesel engines are simply out of question. On the other hand high-speed Diesel engines do have the disadvantage of a maximum output less than 8000 kW and of a restricted HFO capability. Also gas turbines are getting more and more references, for example for power generation on cruise vessels. However, despite their very low specific weight (4-6 kg/kW including generator), gas turbines cannot enter the RoPax and ferry market due to their inability to burn real HFO.

Consequently the installation of medium-speed Diesel engines seems to be the only possibility for generation of propulsion power onboard fast ferries. But still there is a very high demand to reduce the specific weight of these engines to remarkably lower values. MAN B&W Diesel met these new market requirements and is now able to offer a new engine type V 40/50 with a specific weight of less than 10 kg/kW (Fig. **2**).

The next section will show the big technical and economical advantage fast ferries have, if powered by lightweight medium-speed Diesel engines. This will be shown by a comparison of two identical vessels powered by either typical medium-speed engines with a specific weight of approximately 15 kg/kW or by the new MAN B&W engines type 16V40/50 with a specific weight of 9.5 kg/kW.

3 Main particulars of a typical conventional fast ferry.

Length (LOA):	195 m
Gross tonnage:	30,000 gt
Service speed:	28.5 knots
Power demand of main machinery:	50,400 kW
Service power of main machinery:	42,250 kW
Loading capacity:	1500 passengers, 160 cars, 120 trucks

4 ... powered by different engine types

<u>Alternative 1:</u>	
Engine plant:	4 x 12V48/60 (1050 kW/cyl.)
MCR output:	4 x 12,600 kW = 50,400 kW
Service continuous rating:	83.8% MCR = 42,250 kW
Engine speed:	500 rpm
Specific engine weight:	15.3 kg/kW
Total weight of engines:	772,000 kg per ship (4 engines)
Centre distance:	4,800 mm between two engines
<u>Alternative 2:</u>	
Engine plant:	4 x 16V40/50
MCR output:	4 x 12,000 kW = 48,000 kW
Service continuous rating:	88.0% MCR = 42,250 kW
Engine speed:	600 rpm
Specific engine weight:	9.5 kg/kW
Total weight of engines:	456,000 kg per ship (4 engines)
Centre distance:	3,800 mm between two engines

While fuel oil consumption rises drastically with increased speed, requirements on NOx reduction technologies become more and more demanding. Especially on fast ships where economic aspects are critical, we have to look for NOx reduction technologies with low operating costs and low space and weight requirements. The Humid Air Motor technology (HAM) provides a very attractive solution, which will be discussed in the last section.

9 additional trailers or trucks x 44 trips x 449 EUR =	177,804 EUR
18 replaced cars x 44 trips x 105 EUR =	-83,160 EUR
5 additional cars x 44 trips x 105 EUR =	23,100 EUR
Total additional annual revenue	117,744 EUR

5 Additional laoding capacity of a Superfast ferry.

Influence of engine weight on the performance of fast ferries

MAN B&W Diesel and Deltamarin have made an evaluation of the implications of applying Diesel engines of different weight into the same typical conventional fast ferry. The influence of the engine's speed, dimension and weight on ship's performance and economic efficiency is investigated in detail.

Looking on orders during the recent two years in the ferry and RoRo market, a typical conventional fast ferry with the main particulars given in Figure **3** has been selected as reference vessel.

The Diesel-mechanical propulsion plant consists of four main engines driving two controllable-pitch propellers (CPP) through double reduction gearboxes. The comparison is made with two alternative Diesel engine plants (Fig. **4**).

The most remarkable fact is that the weight difference between the two alternatives amounts to 316 tons. The lighter alternative 4x16V40/50 weighs just 60% of the heavier alternative 4x12V48/60. (The V48/60 engine considered here will soon be replaced by the V48/60B engine with higher output and lower weight.) When looking at a typical fast ferry project there are two players who could benefit from having a lighter engine: the shipyard in the design phase and the owner during investment planning and operation.

From the shipyard's point of view fast ferries are very demanding and difficult ships. They are weight critical ships for two reasons, firstly because they are fast and secondly because their deadweight is small in relation to their lightweight. Because fast ferries lightweight is typically far over two times the size of its deadweight, it is of paramount importance that lightweight will be estimated very accurately at an early stage of design. All extra lightweight, which could not have been estimated correctly in early stages, decreases the ship's deadweight. Because of very high and strong penalties on deadweight, shipyards include a so-called lightweight reserve of 4–6% of the total lightweight. This weight reserve, approximately 500 – 700 tons in the reference vessel, is meant to account for unknown and/or uncalculated weights, which are not taken into account at the design stage. For this reason a main machinery that is more than 300 tons lighter than the original machinery considered, should be very tempting to the yards, as it is able to provide the yard with a 50% increase in its lightweight reserves.

Compared to the shipyard, the owner of such a typical ferry project could benefit in various ways.

The first possibility is to use the weight savings by decreasing displacement. On above reference vessel the reduced displacement could be used to make a more slender hull for the ship powered by the lightweight V40/50 engines. At constant propulsion power this translates into an increase of 0.08 knots in speed. However, this speed increase is not a useful benefit for the owner, since the increase is too small and the speed of a ferry is usually determined by other factors like distance and time schedule.

On the other hand, the reduced deadweight and the more slender hull can result in an estimated 425 kW smaller need for propulsion power to reach the given service speed. This reduction of power required can be translated into a decrease in the amount of fuel burnt. Subsequently the operating costs can be reduced by means of lower fuel costs of approximately 60,000 EURO/year, which amounts to approximately 1% of the total annual fuel costs.

A second and more important possibility to benefit from having lighter engines onboard is to utilise the saved weight to carry more cargo. For this method the ship's hull is not altered. As the ship's lightweight decreases, the amount and weight of cargo it can carry increases.

The additional weight capacity can be used by replacing private cars by heavy load truck trailers and by increasing the lane meters. By assuming trailers to weigh 35 tons and private cars to weigh one ton each, while one trailer replaces two cars, the amount of additional deadweight utilised can be calculated.

It has to be noted that the additional loading capacity only means an additional revenue when the ship sails fully loaded. This, however, only happens during high season. Assuming a typical ferry route of approx. 500 nautical miles in the Mediterranean Sea from Italy to Greece and a high season period of 1.5 months direction south in the beginning of the summer and 1.5 months backwards in the end of summer, 2 x 22 = 44 trips in full loaded condition can be calculated. For fare rates 105 EURO per car and trip and 449 EURO per truck/trailer and trip are assumed. Unit prices used are those published by Superfast ferries.

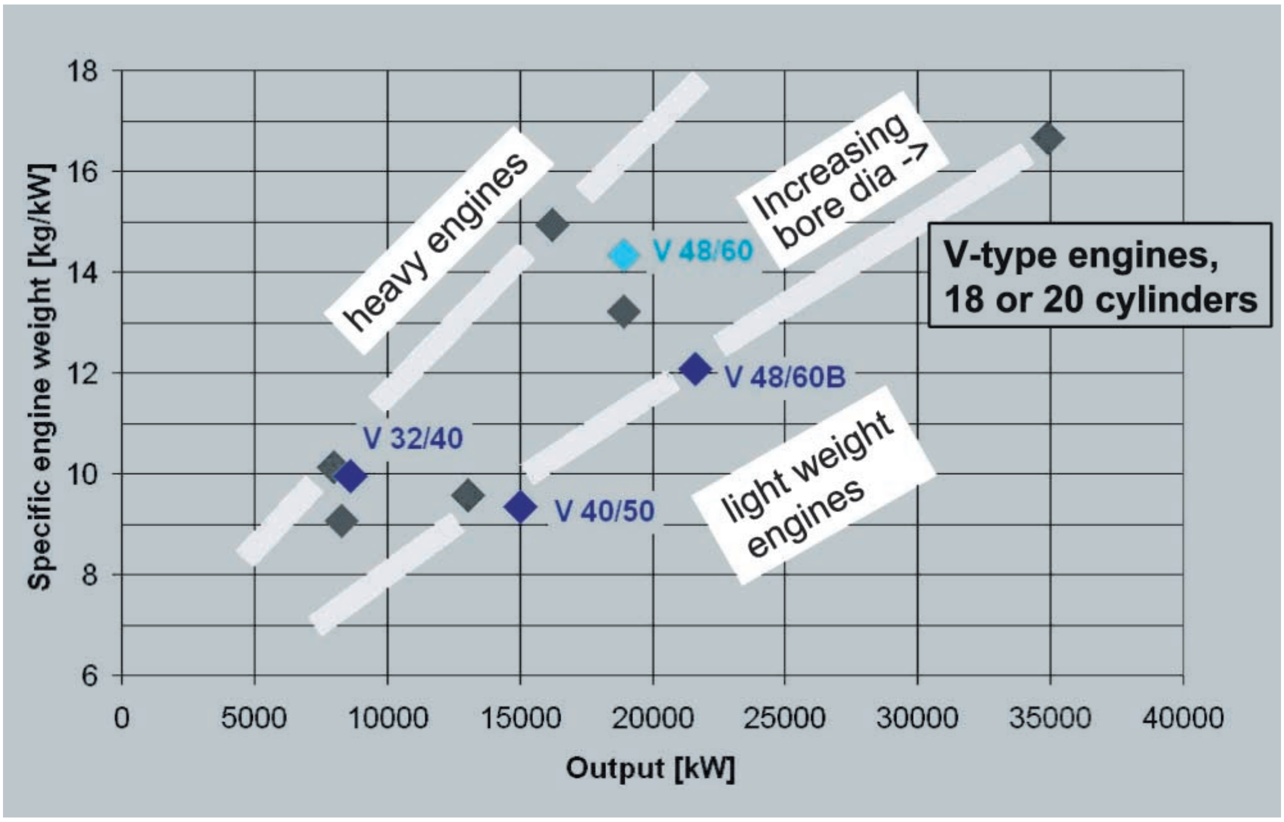
The example in Figure **5** shows a calculation of the revenues which can be achieved using the increased deadweight by replacing 18 cars by 9 trucks and by adding 25 lane meters for 5 additional cars.

The total used additional deadweight amounts to 302 tons based on the above assumptions. It has to be noted that the figures calculated here depend strongly on the specific route. The results are, of course, entirely dependent on freight rates and the length of the high season.

As can be seen from above, the most important economic advantage of a lightweight machinery is to increase the cargo carrying capacity and consequently the resulting annual revenues. It has to be mentioned that the above benefits only can be applied exclusively of each other.

Figure **6** shows that the MAN B&W V40/50 as well as the V48/60B Diesel engines are the lightest each in its specific output range.

6 Specific weight of modern medium-speed Diesel engines.



Influence of centre distance and engine speed

In addition to the low engine weight, two other properties of the V40/50 affect the design and investment costs of a ferry. Compared with the V48/60 the V40/50 engine is characterised by a lower centre distance between two engines (V40/50: 3,800 mm; V48/60: 4,800 mm) and a higher engine speed (V40/50: 600 rpm; V48/60: 500 rpm).

Both factors affect the design and size of the double reduction gearboxes of above reference vessel. The distance between input shafts corresponds directly with the engine's centre distance and the engine speed affects the gearbox ratio. At an assumed propeller speed of 150 rpm the resulting gearbox ratios are 1:4 for V40/50 engine and 1:3.3 for the V48/60 engine. Mainly due to the low centre distance the gearboxes for the 4x16V40/50 propulsion plant are approx. 200,000 EURO lower in investment costs than for the corresponding 4x12V48/60 plant. Further there have to be mentioned weight savings of the gearboxes of approx. 20 tons per plant for the V40/50 solution. This could also be translated into additional annual revenues of 92,400 EURO resulting from 20 additional cars according to the previous section.

In case of Diesel-electric plants, the different engine speeds and their effect on weight and price of the generators have to be considered, too. Exemplary and based on the same assumptions and engine constellation as above the weight of 4 x 12MW-generators running with 600 rpm (4 x 16V40/50) is 25 tons less then that of 4 x 12MW-generators running with 500 rpm (4 x 12V 48/60). There is also a remarkable price difference of approx. 200,000 EURO in favour of the light 4 x 16V40/50 plant.

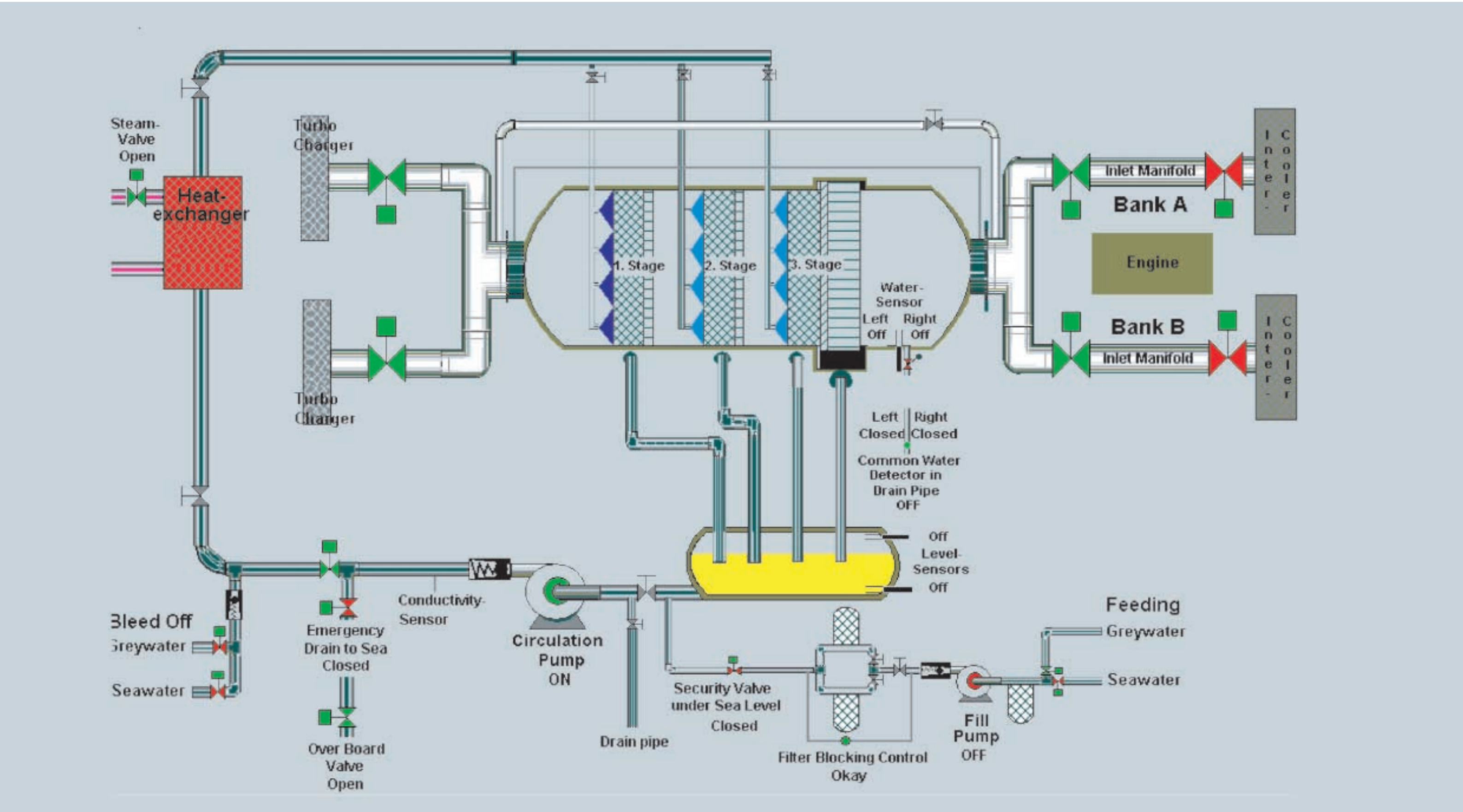
Humid Air Motor – a NOx reduction method perfect for fast ferries

As already discussed before, fast ferries and RoRo vessels require a very light and compact ship design. All equipment has to be optimised in terms of weight and size. Contrary to these economic requirements, however, ecological requirements for low NOx emissions have to be fulfilled as well. Whereas most modern Diesel engines meanwhile conform to IMO rules and regulations with inner-engine measures, more constraining demands on further NOx reduction appeared. In order to comply with local regulations as for example in force in Sweden and to present a clean ship image, ship owners meanwhile ask for NOx levels far below IMO. DNV Clean Design already requires NOx emission values 40% below IMO, which will be in the range of 7 g/kWh NOx emission. However, even Clean Design seems to be only an intermediate provisional stage on the way to NOx emission levels close to 2 g/kWh.

These low NOx levels can only be reached with additional equipment. Two methods are available today: One is to use exhaust gas after-treatment systems such as selective catalytic reduction (SCR) systems, which have the drawback of being very costly in operation. Another method to reduce NOx emission to such low levels is the Humid Air Motor system (HAM), which will be discussed here. Due to its low operating costs and compactness the HAM system is very interesting for applications onboard fast ferries.

NOx generation mainly depends on temperature peaks, which occur during combustion in the cylinder. HAM reduces this "hot spot" phenomenon by humidifying the inlet air. After the turbocharger the compressed and heated air passes through a specially designed humidifier that humidifies and cools the air with evaporated water. This is a distillation process, which makes it possible to use seawater. The cylinders are supplied by air mixed with vapour making the combustion more uniform. A NOx reduction of 70% to 80% can be achieved depending on load conditions. Figure **7** shows the flow scheme of HAM.

The HAM process designed by Munters Euroform GmbH was first bench tested on a MAN B&W 3V40/50 prototype Diesel engine in the research and development facilities of S.E.M.T. Pielstick, which is part of the MAN B&W Diesel group. The in-service verification of performance was then carried out in co-operation with Viking Line on one engine (12 PC2.6, 5,750 kW) onboard the RoRo ferry "Mariella" operating in the Baltic Sea. The HAM system was installed on main engine No. 1 in July 1999 and has reached an operating experience of now 6,000 hours without any major problem having occurred.



7 Flow scheme of a Humid Air Motor system (HAM).

Meanwhile also the three remaining engines onboard "Mariella" are retrofitted with HAM. Two other smaller vessels and a power station in Corsica have been equipped with the HAM system as well.

Since RoRo ferries and similar ships have no use for the exhaust gas heat, the energy is available for evaporating the water. That means the HAM system is absolutely ideal for such kind of ships. Consequently HAM combines many advantages for RoRo ferries while almost no drawbacks can be seen:

1. HAM provides a very high NOx reduction potential to less than 4.5 g/kWh NOx with hardly any additional energy consumption. With preheated water by adding heat into the water circulation even lower levels of NOx emission can be achieved (less than 3.5 g/kWh).
2. No measurable increase in fuel oil consumption.
3. No detrimental effect on reliability.
4. No operating costs by use of seawater ("Mariella" has been using seawater from the beginning).
5. Easy operation. The system responds very satisfactorily to load variations and is self-regulating. In case of failure of the HAM system during operation, enough time is left to switch automatically to low load. In the beginning one of Viking Line's requirements was to be able to switch from standard air system with air cooler to HAM with the engine running. This requirement was met through butterfly valves. Due to the good operating experience, this redundancy is not required any more. In emergency case without HAM and without inlet air cooling it has been checked that the available power is still 50-60%.
6. Low weight of equipment and compact installation. Compared to other NOx reduction measures HAM requires less auxil-

Specific costs in EUR / kW year	HAM	SCR
Specific annual capital costs	6.38	3.19
Specific operating costs at 90% MCR	0.00	10.40
Total specific annual costs	**6.38**	**13.59**
Example 4 x 16V40/50 = 48,000 kW		
Total costs per year for 48,000 kW	**306,000 €**	**652,000 €**

8 Total costs of a HAM and SCR system.

iary equipment. With the exception of the humidifier and a small catch tank in the water circulation no tanks are necessary. Contrary to that SCR systems require catalysts in the exhaust gas channels and storage tanks for urea treatment and supply. Also water adding NOx reduction systems like fuel water emulsion (FWE) or direct water injection (DWI) require large intermediate and storage tanks for fresh water. Since operated with seawater no water treatment plants are necessary for HAM systems. As a consequence of this, HAM has a remarkably lower weight than other NOx reduction plants.

HAM system is often claimed to be very expensive. Currently that is true for the installation costs. There are still few plants which have been built, and due to this no series effects on production could lead to cost reduction. However, as happened with SCR plants years ago, also for HAM a cost reduction of 50% can be expected after being introduced as a standard product. When considering the operating costs of HAM the situation is totally different. Since HAM does not cause any operating costs or an increase in fuel oil consumption, it can be stated that HAM is one of the cheapest NOx reduction technologies during operation.

The following comparison of the total costs of a SCR and HAM system show that HAM is very attractive also from an economical point of view. Assuming a depreciation period of 10 years with an average interest rate of 5% one can calculate annual capital costs of 12.75% of the initial investment costs. The comparison is based on the same reference vessel as in the previous section with an operating profile of 6,000 h/year running with an average load of 90% MCR and a total installed MCR output of approx. 50 MW. NOx reduction is calculated both for HAM and for SCR to be 4.5 g/kWh. The specific investment costs are 50 EUR/kW for HAM and 25 EUR/kW for SCR (without installation costs).

The total costs are calculated in Table **8**, which shows that the HAM system is approx. 50% cheaper than a comparable SCR system. When reconsidering the strong requirements for lowest weight and operating costs, it can clearly be concluded that the HAM system will be one of the most attractive NOx reduction technologies onboard fast ferries.

Summary – MAN B&W V40/50 Diesel engine perfect for fast ferries

In order to meet the new market requirements for fast ferries, MAN B&W Diesel and S.E.M.T. Pielstick have joined their engineering forces and experience to develop a new lightweight engine type V40/50 with highest compactness and lowest specific weight of less than 10 kg/kW. Despite its low weight, the V40/50 engine provides all known features and advantages of modern medium-speed Diesel engines such as low specific fuel oil consumption, the capability of burning heavy fuel oil and at the same time highest reliability and long lifetime of components. Together with the experience in HAM systems MAN B&W Diesel is able to provide complete V40/50 Diesel engine packages perfect for fast ferries and fast RoPax vessels.

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