MariEMS Learning Material - Engine Load Management

This is the fifth compilation by Professor Dr Reza Ziarati on the work of the EU funded Erasmus + MariEMS' partners and material researched by Chief Engineer Mohammed Haque. The material is composed from Chapter 10.

10 Engine Load Management

10.1 Rational

It is well known that the efficiency of a diesel engine is a function of its load level or its load factor. Figure 10.2.1 shows the engine Specific Fuel Consumption (SFC) as a function of the load factor.

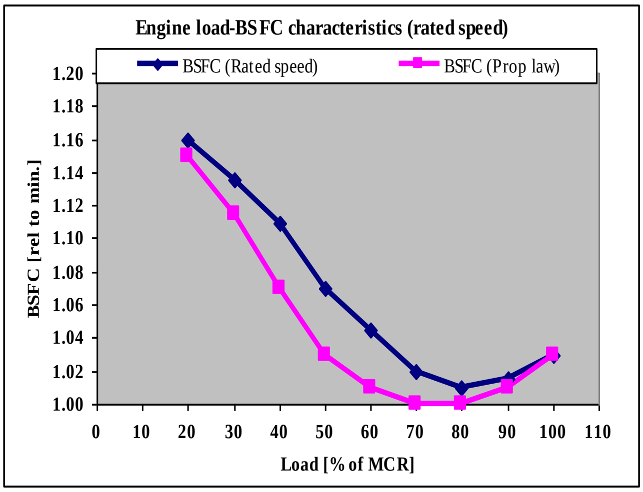

Figure 10.1 - Engine SFC as a function of load factor

Load factor: The engine load factor is defined as the actual power output of the engine relative to its Maximum Continuous Rating (MCR). The Load factor is normally specified in percent. An engine working at 50% of its maximum load has a load factor equal to 50%.

In Figure 10.1, the curve for constant engine speed operation (rated speed) represents operation of electric generation engines such as auxiliary engines, (e.g. diesel generators) and the curve for propeller law shows the main engine operation characteristics. As can be seen there is no significant difference and for both types of application, the engine's SFC varies with the engine load. SFC is a minimum (i.e. efficiency is a maximum) for a certain load level; typically for engines it is in the range of 70 to 90% of an engine's Maximum Continuous Rating (MCR). The above diagram also shows that under low load conditions, the SFC of the engine will increase (engine efficiency will reduce). Although the load on the main engine is primarily dictated by ship speed, the load on the auxiliary engines depends on the ship-board electrical loads that are a function of the number of machines, machinery and equipment being used at each point in time plus the number of engines used to satisfy the requirements. In this Section, it is argued that engine loads should be managed, where possible, so that the engine fuel consumption is minimised. This will effectively mean operating the engines at 70% to 90% load range as discussed above with reference to Figure 10.2.1.

10.2 Load management for main engine

For the main engines in a direct-drive or gear-drive configurations (mechanically linked to propeller), there is not much that can be done as far as load management is concerned as normally ships have one main engine and load management normally applies to cases with more than one engine. It should be noted that it is easy to show that the slow steaming leads to the main engine's operation at low loads at a less efficient load factor. Overall, this low-efficiency operation of main engine has been accepted by industry since the impact of reductions in ship resistances on a ship's fuel consumption is much more effective than increases in the main engine's SFC for slow steaming cases. Therefore, in main engines, non-optimal operation may be allowed due to slow steaming because of slow steaming greater benefits from much lower fuel consumption. However, in such conditions and if slow steaming is going to continue for long term, changes to engines performance characteristics are recommended via changes to turbochargers, injection system and other engine settings (engine adjustments for slow steaming optimised operation). No matter what load the main engine is operating under, it is mostly recommended that the main engine load should be kept at a reasonably steady level under normal operation. This is achieved by keeping the engine speed (RPM) constant. Frequent changes to the shaft rpm, thus engine load, are not efficient and must be avoided.

Fuel Coefficient and Fuel Consumption in Relation to the Load Management

The fuel consumption of a ship depends upon the power developed. Indeed, the overall efficiency of power plant is often measured in terms of the *Specific Fuel Consumption* which is the consumption per unit of power, expressed in kg/h. Efficient diesel engines may have a SFC of about 0.180 kg/kWh. The specific fuel consumption of a ship at different speeds follows the form shown in Fig. 10.2.2

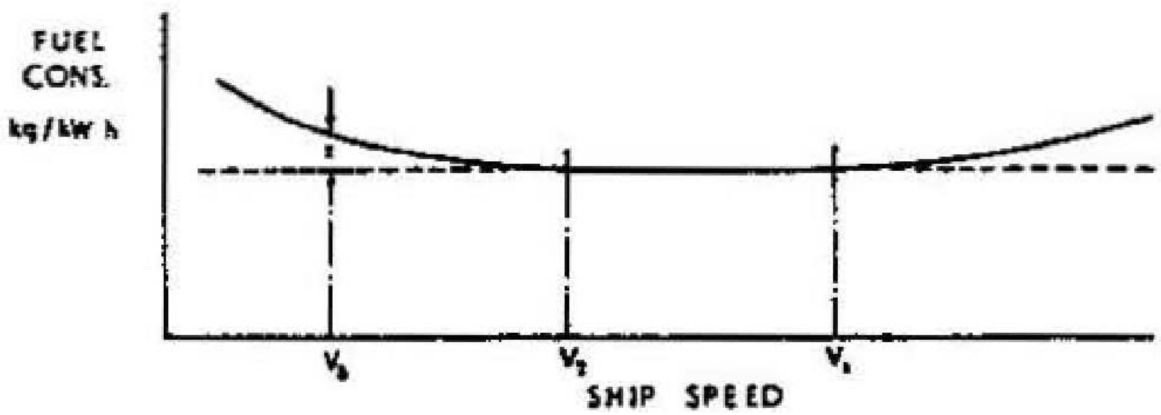

Fig. 10.2 SFC VS Speed

Between V1 and *V2* the specific consumption may be regarded as constant for practical purposes, and if the ship speed varies only between these limits, then:

Fuel consumption/unit time ∝ power developed

Power developed is known as Shaft Power (SP)

Then, the SFC ∝ SP

And since SP ∝ $\Delta^{2/3} V^3$ while Δ is the displacement of the vessel in tonne and V is the speed.

Then SFC ∝ $\Delta^{2/3} V^3$

Or, fuel consumption /day = $\Delta^{2/3} V^3$ / (Fuel Coefficient)

We would keep the Fuel Coefficient and displacement constant for a given ship and compare the fuel consumption at different speed only:

Then, Fuel consumption/unit time ∝ $speed^3$

Hence $cons_1 / cons_2 = (V_1 / V_2)^3$

For example, we can take a ship that uses 20 tonne of fuel /day at 13 knots. If we keep the displacement constant for that vessel and reduce the speed to 11 knots then,

New daily consumption = $20 X (11/13)^3$

= 12.11 tonne

Therefore, we can see that reducing speed by 2 knots saves quite a huge amount of fuel.

Similarly, we can compare the total voyage consumptions at different speeds keeping the displacement same for a given ship.

If D is the distance travelled at V knots then:

Number of days ∝ D/V

But daily consumption ∝ V^3

Therefore, total voyage consumption ∝ $V^3 X\ D/V$

Or ∝ V^2D

i.e. voy. $Cons_1$ / voy. $Cons_2 = (V_1 / V_2)^2 X (D_1 /D_2)$

Hence for any given distance travelled the voyage consumption varies as the ***speed squared***.

For example, we consider a ship that uses 125 tonne of fuel on a voyage travelling at 16 knots.

If the speed of the ship reduced to 15 knots keeping the displacement, weather condition etc. steady

, we can calculate the new voyage consumption

= $125(15/16)^2$ = 110 tonne

Therefore, saving in fuel = 125 – 110 = 15 tonne.

A general expression can be derived for voyage consumption as:

(New voy.cos / old voy. cons) = (new displ / old displ)$^{2/3}$ X (new speed / old speed)^2 X (new distance / old distance)

Outside the range of speed between V_1 and V_2 the SFC is much higher where, if we operate the vessel will incur a heavy fuel cost which will increase tremendously for a slight speed increment.

(Ref: Stoke EA, 2013, Naval Architecture for Marine Engineers (Reed's Marine Engineering Series Vol 4, 4th edition, London, Adlard Coles Nautical.)

10.3 Load Management for Auxiliary Engines

There is ample evidence that shows that load management for auxiliary engines is an effective way of reducing the engines' fuel consumption as well as their maintenance costs. Each ship normally has three or more auxiliary engines; each connected to one electric generator. The engine and generator as a combined system are normally referred to as diesel-generator (DG). On-board ships, and often in order to assure against black out, two DGs are operated for long periods at less than 50% load factor. The periods for which these conditions are sustained can include all discharge ports, standby periods, tank cleaning periods, movement in restricted waters and ballast exchange periods. This often leads to unnecessary simultaneous usage of multiple engines; at low load factors and beyond requirements. As a result, low load factor leads to poor energy efficiency performance. Additionally, the operation of diesel engines at low loads causes poor piston ring seal, sub-optimum turbocharger performance, low specific fuel consumption, elevated thermal stresses and increased specific lube oil consumption. In short, it leads to more maintenance and higher fuel consumption.

10.4 Electrical Load Reduction

It is often possible to reduce energy consumption on board by working towards more conscious and optimal operation of ship machinery and systems. These could be achieved more effectively if planned for each mode of operation. Examples of measures that can be considered include:

- Avoidance of unnecessary energy use via switching off the machinery when not needed. All non-essential and not-required machinery and equipment that do not affecting the ship and personnel safety should be stopped whilst in port and at sea to reduce the load on diesel generators. Such items should be identified first and then procedures for the execution of tasks to be developed and implemented.
- Avoidance of parallel operation of electrical generators when one is sufficient for the purpose. This aspect is covered and fully discussed under "engine load management".
- Optimised HVAC (Heating, Ventilation and Air Conditioning) operation on board. The HVAC system operation should be aligned to outside weather conditions either via automatic settings or manual operations (more important for cruise ships).
- A proper coordination should be maintained on board between deck and engine departments especially for use of machinery/equipment items such as steering gear motors, bilge and fire pumps, winches and mooring equipment, deck cranes and service and deck compressed air usage, etc. so that to reduce loads on generators.

The above activities will lead to reduced electrical power demand. Moreover jobs could be co-ordinated and bundled together so that two generators could be run more effectively and for a shorter period of time. This could be achieved via system planning and more coordinated actions.

10.5 Auxiliary Machinery Use Reduction via System Planning

There is a significant number of redundant machinery on board ships; this allows safe ship operation when one fails as well as for safety-critical situations where two machinery needs to simultaneously operate. In practice, redundant machinery is normally used more than necessary. This could include any type of machinery in particular fans and pumps. Any reduction in use of such machinery can lead to energy efficiency.

Proper planning of the use of number of machinery versus operation mode is an effective way of achieving this objective. Use of simultaneous use of multi machinery in parallel could be reduced via advanced planning and decision making on the number of machines to be used; taking into account the actual operational requirements. For example, when ship is in port, the plan should include switching off one or two engine room ventilation fans as main engine is not operating any more. Another example is the mooring equipment. When mooring equipment is not needed, the related pumps and machinery could be switched off.

To ensure safe operation, all these need to be proactively planned and executed. Without daily planning and establishment of relevant processes, the task of reduction in energy use cannot be accomplished. As emphasised before, coordination between deck and engine departments are of paramount importance for an effective and at the same time safe action to avoid misunderstanding or unexpected consequences.

10.6 Auxiliary Fluid Machinery

This refers to pumps, fans, compressors, etc. that are extensively used on-board ships. There is a number of opportunities to save energy with these machineries that are briefly discussed. The main areas of evaluation include:

Sizing: The sizing of machinery against the actual operation requirements needs to be checked in order to identify cases of over sizing. This can be carried out by monitoring of the machinery operational performance against manufacturer's specification. In addition, the following may be indicative of oversized machinery:

- Continuous throttling of flow in order to match supply with demand (e.g. permanently fixed valve or damper positions).
- Short periods of operation when the machinery is used in on-off mode. For example, in a compressed air system, an oversize compressor will supply air to tank in a shorter period of time than a rightly sized compressor.

For each machinery, a "capacity factor" can be defined that is indicative of over-sizing or under-sizing. Capacity factor may be defined as the "operational capacity" divided by "design nominal capacity". A capacity factor significantly below or above unity is indicative of poor sizing or system's operational anomalies.

Operation profile: The operation profile of machinery represents the machinery's load versus time. Continuously operated machinery at a certain load will represent a steady operation profile.

Machinery with highly variable load will represent a non-steady load profile. Load and operation profiles are normally presented in histogram format, an example of which is shown in **Figure 10.6.1**

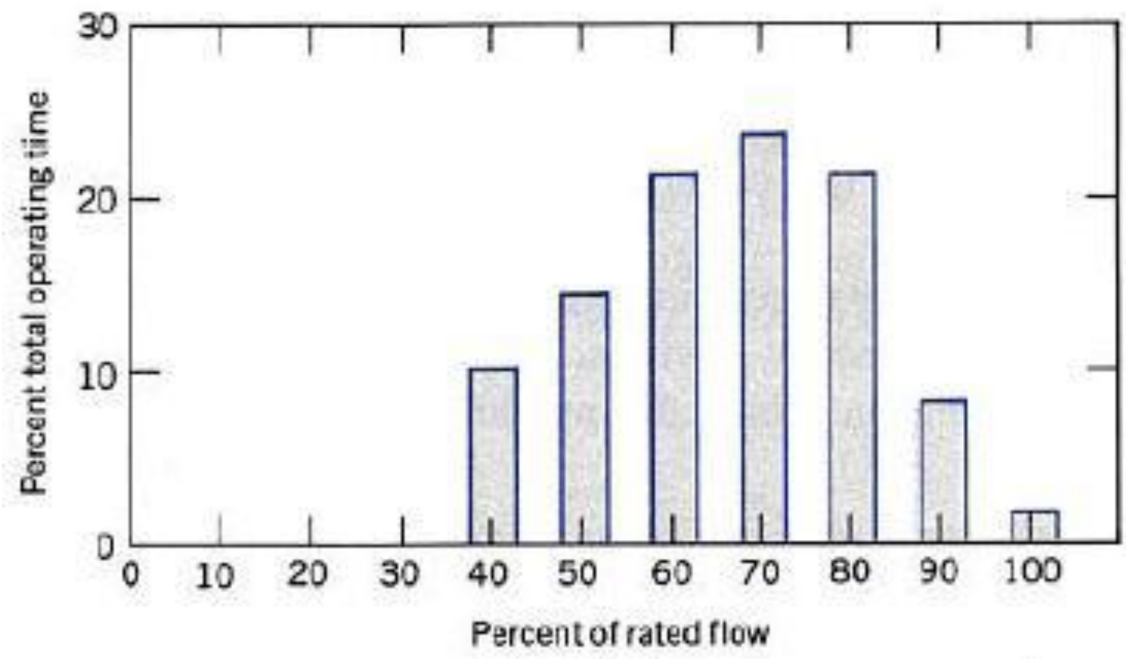

Figure 10.6.1– Load profile for a typical pump

From operation profile, operation management strategy of the machinery could be decided. In particular, method of control and choice of on-off or Variable Speed Drive (VSD) modes can be established. For variation of flow, two methods of flow control could be used (see **Figure 10.6.2**):

- Valve system modulation (changes to valve open area) is the traditional way of flow control. This method of control is energy inefficient.
- Variable Speed Drive (VSD) is used to control flow without throttling. This is the most efficient way of flow control for fluid rotating machinery (see **Figure 10.6.3**).

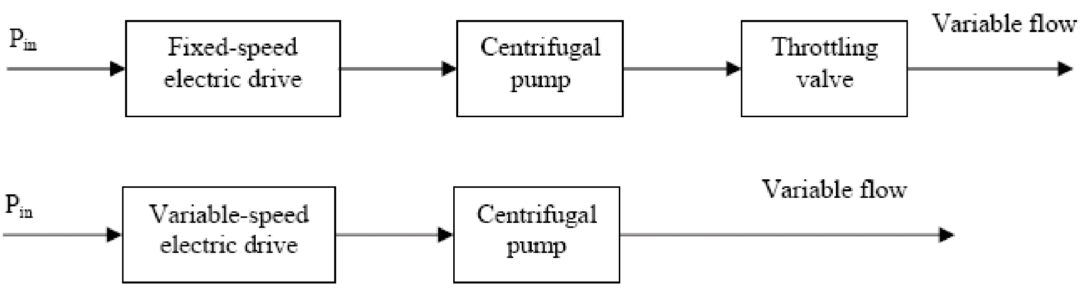

Figure 10.6.2 – Main types of flow control

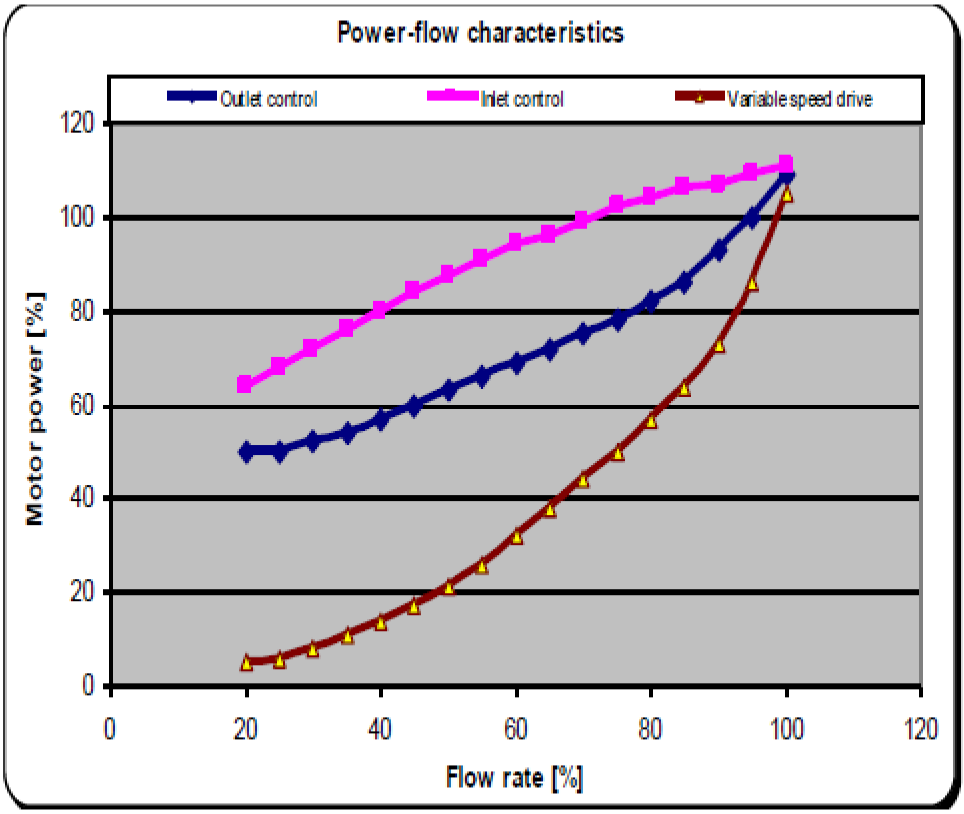

Figure 10.6.3 – Impact of Variable Speed Drive method of flow control on power demand

The load profile for a multi-machinery setup could provide valuable information on method of load sharing strategy and management between machinery.

Operational aspects

Based on the above evaluation and basic characteristics of fluid machinery, the main opportunities for energy saving are:

Fouling reduction: Fouling in fluid machinery is a common cause of performance deterioration. Fouling can be controlled via best-practice maintenance activities. For examples, fans are very sensitive to inlet fouling.

Multi-machinery management: In general in a multi-machinery configuration (e.g. chiller plant compressors), the minimum number of machinery running for a particular duty represents the best machinery management strategy and ensures minimum overall machinery energy consumption.

Reducing idling mode of operation: In addition to operation of the machinery at optimal efficiency, it is prudent to reduce the none-productive operating hours of all machinery especially during port stays and also change over from on to off modes and vice a versa. In general the following policies should be implemented:

- Each machinery should be operated at its optimum efficiency.
- The none-productive hours of operation must be minimised by on-off controls. In particular, late turn-off and early turn-on of machinery should be avoided.

Flow control and management: As discussed earlier, control of flow is an area where significant savings may be made:

- **Throttle flow control:** A pump with variable flow requirements that is controlled by throttling could save energy by:
  - Replace the constant speed drive to variable speed drive (level of saving depends on the pump duty cycle).
  - Replace throttle control with on-off control, if feasible (switch on and off according to demand), especially if some storage capacity can be added to the system.
- **Excessive flow:** For example, pump flow rates in excess of system requirements, lead to increased energy losses. To avoid:
  - Ensure that pump flow is controlled according to process requirements.
  - Review and adjust control settings.
- **Demand control and demand reduction:** The need for flow should be investigated at the demand side. Every effort should be made to reduce demand by:
  - Preventing all leakages.
  - Conservation policies in compressed air, water, conditioned air, etc. lead to reduced energy consumption by corresponding systems.

10.7 Electric Motors

Electric motors provide the drive system for the majority of ship auxiliary and hotel systems. In electric propulsion, electric motors are used for driving the propellers. There are a number of ship auxiliary systems that support the operation of main power plant or required hotel services. Some of these are:

- Engine cooling system.
- Engine fuel system.
- Engines lube oil system.
- Compressed air system.
- Chiller plant for hotel HVAC system.
- Chiller plant for provision area.
- Steam system for hotel services and fresh water generation.
- Fresh water generation systems.

The main components of all the above systems are a number of rotating machinery, all driven by electric motors. Electric motors, excluding propulsion motors, consume the majority of the ship auxiliary electrical loads. Their efficient operation, therefore, is an important element of the overall ship energy management.

Basic characteristic

Electric motors used in ships are invariably of AC (alternative current) type. The typical characteristics of the electric motors are shown in **Figure 10.7.1**.

According to **Figure 10.7.1** and other relevant information on electric motors, the followings are applicable:

- Electric motor efficiency is highest at its rated power. However, the efficiency does not reduce significantly up to about 40%. Below 40% of rated power, efficiency reduces significantly. This threshold of 40% is lower for larger motors.
- Electric motor efficiencies are usually below 80-90% depending on its size, denoting that there are losses associated with such motors. The loss is dissipated in the form of heat.

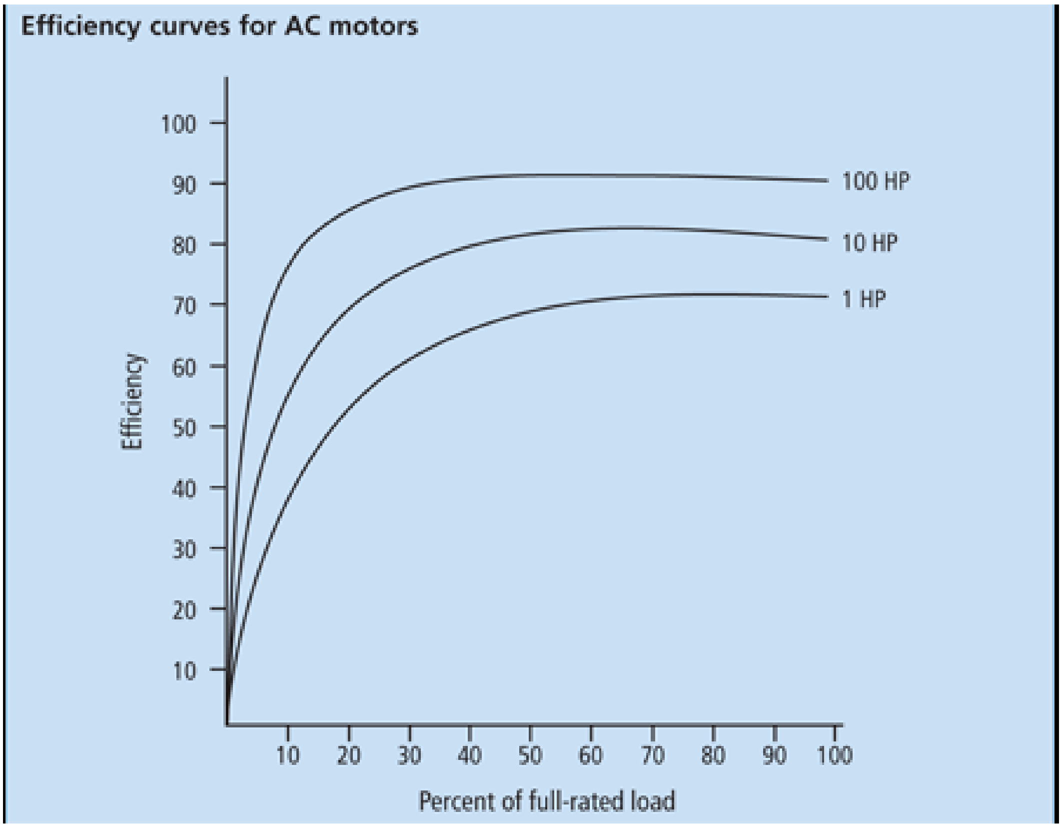

Figure 10.7.1 – Typical characteristic of electric motors

Main energy efficiency aspects associated with electric motors are as follows:

Sizing: The sizing of electric motors against actual performance needs to be checked in order to identify cases of over sizing. This can be identified via monitoring the performance data against the manufacturer's specification.

Operation profile: The operation profile of machinery is indicative of its load versus time. Continuously operated machinery at nominal load will represent a steady operation profile. Machinery with highly variable load will demonstrate a non-steady load profile.

Power factor: In electric motors, power factor is defined as the ratio of the actual power in kW divided by power directly derived using current and voltage of machinery in KVAR. A low power factor means added electric network losses.

In dealing with ship-board electric motors, the above needs to be analysed to find out about their relative efficiency and if there is a need for changing any motors during technical upgrades in order to improve efficiencies. Technical upgrades should be normally considered within the ships' machinery maintenance programmes.

10.8 References and further reading

The following list provides references for this section and additional publications that may be used for more in-depth study of topics covered in this section:

1. "IMO train the trainer course material", developed by WMU, 2013. Viewed on 11th Nov 2016

2. OCIMF "Example of a Ship Energy Efficiency Management Plan", Submission to IMO, MEPC 62/INF.10, 8 April 2011.

3. ABS 2013 "Ship Energy Efficiency Measures, Status and Guidance", http://www.eagle.org/content/dam/eagle/publications/2013/Energy%20Efficiency.pdf, viewed on 7th Nov 2016.

4. MARSIG SEEMP Example, "Ship Energy Efficiency Plan, MARSIG mbH, Revision 0, 2012, http://www.marsig.com/downloads/MARSIG%20-%20SEEMP%20Template.pdf viewed on 11th Nov 2016.

5. "How to determine the efficiency of an electric motor using prony brakes", http://electricalengineering-access.blogspot.co.uk/2015/03/how-to-determine-efficiency-of-electric.html, viewed Nov 2016.