Massachusetts Institute of Technology
DEPARTMENT OF OCEAN ENGINEERING

2.611 SHIP POWER and PROPULSION

Problem Set #5, Diesel Engine Problems, Due: November 14, 2006

1. A diesel engine designer is interested to know the effect of turbo-charging on mean effective pressure and power. The engine he is considering is a 14 cylinder, 4 stroke diesel engine. The rotational speed is 1200 rpm, mean piston speed of 12 m/s, and stroke to bore ratio of 1.25. The following data is estimated:

Note: Review chapter 7 in the text before attempting this problem.
Thermodynamic efficiency = 58.5%
Mechanical losses = 8 %
Heat losses = 9 %
Charge pressure = 3.5 bar <u>over</u>pressure in inlet receiver
Charging is reasonably effective (93%)
Inlet receiver temp 60 Celsius
Air excess ratio 1.8
Lower heating value of fuel 42,000 kJ/kg
Stoichiometric fuel air ratio = 13:1
Gas constant air/exhaust gas R = .287 kJ/kg

a. Calculate engine efficiency, mean effective pressure, and power output. (Note: you can assume that the combustion efficiency is 100%).
b. If an engine of the same size was not turbocharged, what would be the efficiency, mean effective pressure and power (keep assumptions unchanged).

2. The air standard dual-cycle is used to represent the thermodynamic characteristics of a large two-stroke diesel engine. The cylinder volume V_1=1.0 m^3; the compression ratio $r_v = V_1 / V_2 = 13.0$; the value of $r_p = T_3 / T_2 = 1.80$; and the cut-off ratio $r_c = T_4 / T_3 = 1.40$; the temperature of the air entering the cylinder $T_1 = 300K$; and the pressure $p_1 = 1.0$ bar $\left(100kN / m^2\right)$.

Determine:

a. the temperatures T_2, T_3, T_4 and T_5 in K
b. the mass of the gas, *m*, in the cylinder in kg
c. the heat transfers, Q_{H1}, at constant volume; Q_{H2} at constant pressure, and Q_L at constant volume, in kJ
d. the work of the engine per cycle in kJ, and the power per cylinder in kW, when the two-stroke engine operates at 79 rpm

The engine is now fitted with a turbocharger and charge cooler. The compressor pressure ratio of the turbocharger is 3.9 and the polytropic efficiency $\eta_{PC} = 0.83$. The effectiveness of the charge cooler $\varepsilon = \left(T_{COMP} - T_1^1\right) / \left(T_{COMP} - T_W\right) = 0.8$ where the cooling water temperature $T_W = 300^o K$, the air temperature leaving the compressor and entering the charge cooler is T_{COMP} and the temperature of the air leaving the charge cooler and entering the engine cylinder is *T*.

Determine:

e. the temperature of the air leaving the charge cooler and entering the engine cylinder T_1^1
f. Repeat the tasks a through d for the new situation.

Assume that the properties of air are $C_p = 1.00 kJ / kgK$, $c_v = 1/1.40 kJ / kgK$ and $R = .286 kJ / kgK$.

3. Using the data presented in the "Vee-form additions to Pielstick family" article, calculate the engine performance assuming that it can be modeled as an Air Standard Dual Cycle. Use the PC40 engine. Assume that the constant volume temperature rise is T_3-T_2 = 300 K, the constant pressure temperature rise is T_4-T_3 = 800 K, and the air (from a charge cooled turbocharger) enters the cylinders at 300 K and 3 bar.

Determine:

a. the temperatures and pressures at conditions 1 through 5 (the text can be used to help you understand terms you are not familiar with like combustion ratio)
b. the thermal efficiency and sfc of the cycle (section 7.4.3 in text)
c. the mass of air in each cylinder
d. the power output per cylinder
e. the mean effective pressure
f. compare your predicted values with the data in the article
g. provide a justification for any differences

Assume that air has c_p = 1.00 kJ/kg K, γ = 1.4, and the heating value of the fuel (LHV) is 43,000 kJ/kg.

Vee-form additions to Pielstick family

Although the SEMT Pielstick PC40 engine has been well accepted and service results have shown high reliability, the use of large-bore in-line medium-speed engines in ferries, in Japan, has not been entirely successful. Engine induced vibrations on some of Japan's new ferries — none of them with Pielstick engines — have retarded sales of in-line engines recently and the Pielstick designers have therefore brought out two new Vee-type engines, to be known as the PC4-2B and PC2-6B.

The PC4-2B engine is based on the long established PC4-2 design but incorporates components of the younger PC40L engine. However, the Pielstick engineers have increased the piston stroke from 620mm in the PC4-2 to 660mm and the firing pressure from 145 bar to 150 bar.

These changes, combined with the same power output per cylinder (1650bhp) and therefore a decrease in bmep, have improved the specific fuel oil consumption from 183g/kW h to 175g/kW h for the new engine. Further improvements in reliability are also expected.

When some ferry operators in Japan looked at newbuilding installations, they decided to return to Vee-type engines — as a result a number of ferries presently building in Japanese yards are being installed with Vee-form PC2-6 engines. To further improve that engine, the Pielstick designers have taken proven components from the PC20L design and incorporated these into the new PC2-6B. Other minor modifications have been added and the power output per cylinder has been lifted to the 825bhp level of the PC20L machines. The piston stroke has been slightly increased to 500mm but the engine speed is held at 520rev/min.

PC40L service results

At the beginning of 1990 a total of 34 PC40L engines had been ordered and 17 of these were in service.

The first engines (2x 9PC40L) in three ferries have been in service for some two and a half to three years and have reportedly given excellent results. Indeed, the first pair of engines, installed in the 1987-built ferry *New Hamanasu*, have never caused the ship to be delayed or stopped at sea and a sister-ship has achieved the same record even though its engines suffered from some burnt air inlet valves. The valves were changed during a port turnround. Both these ships have now accumulated more than 16 000h of operation.

The third ship in the series suffered some problems with air inlet cams and missed one voyage of 20h duration but has now completed some 15 000h of operation with no further problems.

Heavy fuel of at least 180cSt viscosity is used on *New Hamanasu* and her sisterships, and this has brought no problems.

However, the burnt air inlet valves referred to earlier arose from the ship spending long periods with the engines idling on no load. During these idling periods deposits built up in the inlet ports, due to slight backflow of exhaust gas, and these eventually fell into the air inlet valves and were hammered — ultimately causing burning of the valve seats.

The problem has been solved by simply avoiding long engine idling periods.

Furthermore, some cracks were found in three cylinder heads and a number of fuel pump delivery valves but these were initiated from manufacturing faults.

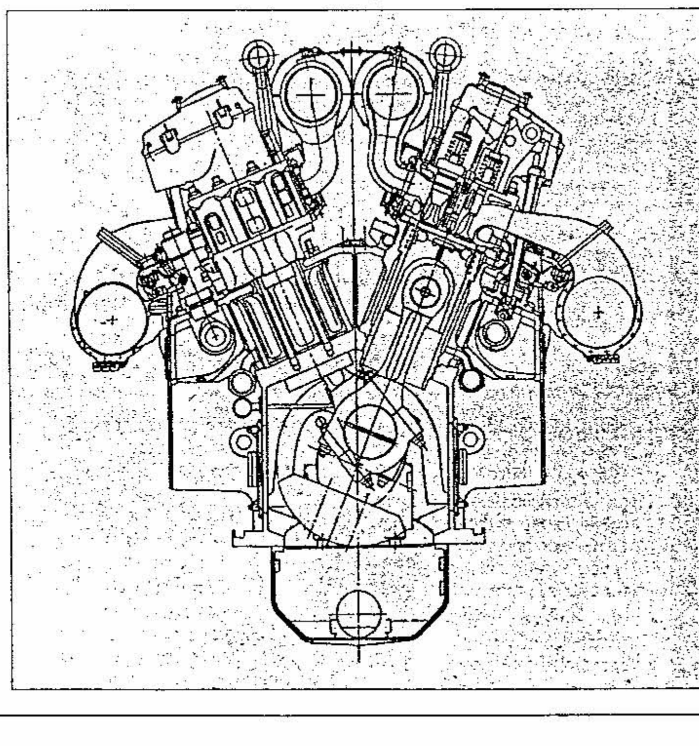
Wear rates

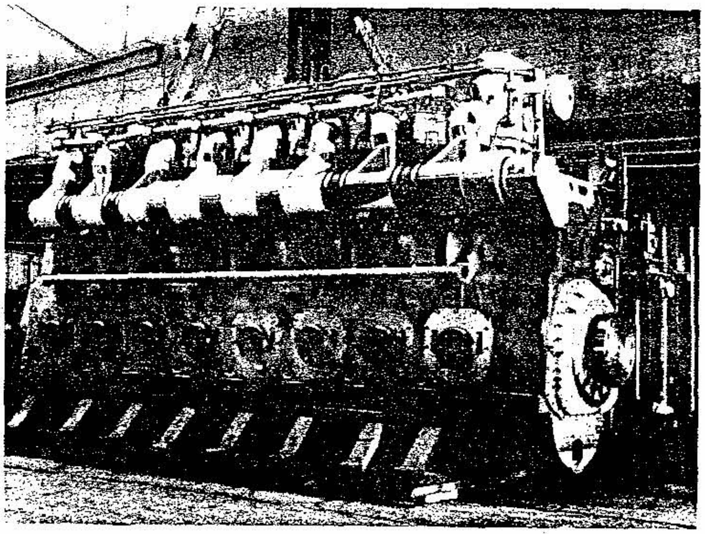
Of two more recently built PC40L-powered ro-ro ships operating in a tramp type service round the Japanese coast, one has had one stop at sea of 8h in a total of two

The new Pielstick PC4 family

Engines	PC4-2	PC4-2B	PC40
Cyl bore (mm)	570	570	570
Piston stroke (mm)	620	660	750
Speed (rev/min)	428	428	375
Piston speed (m/s)	8.8	9.4	9.4
Compression ratio	11.8	13.3	14.0
Cyl output (kW)	1215	1300-1215	1325
Bmep (bar)	21.5	21.6-20.2	22.1
Max press (bar)	145	150	155
Sfoc at mcr (g/kWh)	183	178-175	172

Cross section of the PC4-2B Vee-form medium-speed diesel





Parts of the PC20L engine have been incorporated in the new PC2-6B

years of operation.

Wear in the first engine in service with the vessels has been regularly checked and shown no untoward trends. Some cylinder units have been operated without opening them up until recently and here the wear rate was the same as those cylinders previously inspected — 0.0139mm/1000h on the cylinder liners and 0.022mm/1000h on the piston rings. The specific lubricating oil consumption across all the engines in service has settled down to 0.7 to 1.0g/bhp h.

The otherwise excellent service results have lead to an uprating of the latest 9PC40L engines to be built at Diesel United, in Japan, to a level of 1800bhp/cyl at 360/375rev/min thus maintaining the same bmep.

Satisfactory testbed trials were run towards the end of 1989 with the first of these engines. The second engine in this series was required by the owner to be mounted on elastic suspension elements and the engine was modified to have a special oil sump to maintain good rigidity to the whole set.

The anti-vibration elements are therefore set at an angle, towards the top edge of the sump and, at 273t, the engine represents the heaviest weight yet suspended by Pielstick in this way.

Special sump

An unusual request by a shipowner having four 18PC2.6 engines installed in a car ferry was for no oil drain tanks to be contained in the ship's double-bottom. The Pielstick engineers had, therefore, to design a special oil sump for each of the engines so that a wet sump style of operation could be obtained, as is the case with automotive engines. However, unlike an automotive engine, the lubricating oil is not changed at regular intervals and the engines are burning HFO of up 380cSt viscosity.

Instead of the usual marine standards of around 1 litre of lubricating oil per horsepower, these engines have only 0.3 litre/hp. Filtration and centrifuging of the sump oil follows conventional lines but with the filters sized as if 1 litre/hp of oil was in circulation.

Topping up of the main engine sumps can be done from the storage tanks but also from the sumps of the three 5PA5L auxiliary units.

These auxiliary machines have their sumps drained at regular intervals and severe rejections limits are placed on the lube oil to allow it to be used for topping up the main engines.

After 3500h of operation the owner has reported that the lubricating system is working well. The lubricating oil consumption rate has settled down to a maximum of 0.8g/bhp h and the viscosity of the main engine oil has slowly risen to 17cSt and then remained steady. The TBN rose quickly during the first 200h or so but has since settled down at 36.

These results have proved this original idea which was accepted by Pielstick with some trepidation.