Chapter 10

Supercharging and turbocharging

Supercharging can be defined as the introduction of air (air fuel mixture) into an engine cylinder at a density greater than ambient. This is allows a proportional increase in the fuel that can be burned and hence raised the potential power output.

The principle objective is to increase power output not to improve efficiency, although the efficiency may be benefit.

Figure 1 show an ideal naturally aspirated dual combustion cycle. Point 1 denotes the beginning of the compression stroke.

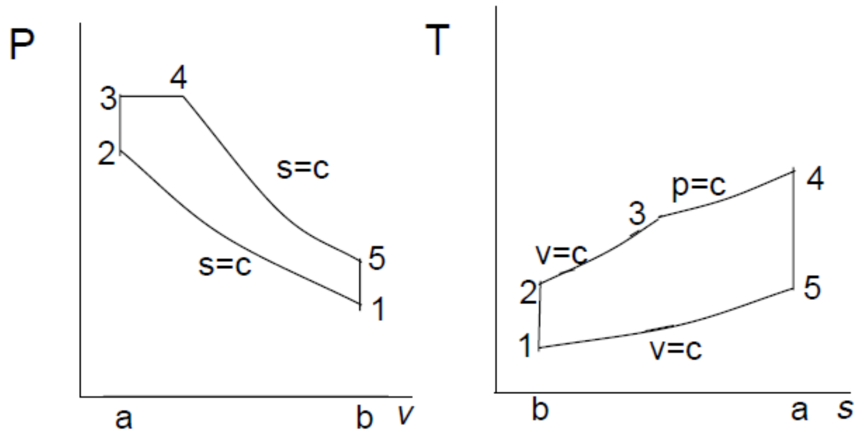


Figure 1

Figure 2 show a typical arrangement of an engine fitted with a mechanically driven supercharger.

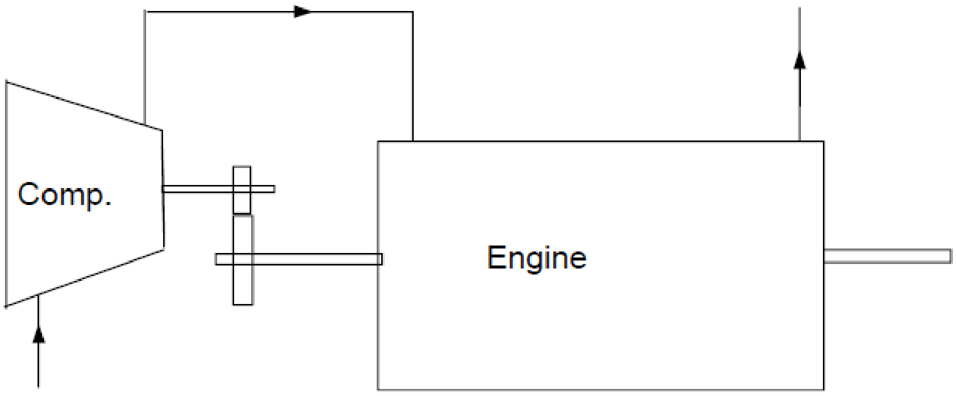


Figure 2

Figure 3 compare a naturally aspirated and supercharged ideal cycle. The supercharged cycle start at a higher (and density) point $\bar{1}$. Extra fuel can be burned between $\bar{2} - \bar{4}$ because more air is available (the same volume but higher density). Two things are clear: the supercharged engine has a greater power output and much higher maximum pressure. Unless the engine is designed to be supercharged, the high maximum pressure may not be acceptable; the engine may not be with stand the stress involved.

Compressors

The compressor used in the supercharger uses energy to produce work. Where the compressor gets this energy is essential in determining total engine efficiency. Because the power output of the engine increases when using a supercharger some of this power is used to drive the compressor. The amount of work that is produced by the piston is therefore divided into running the compressor and running the engine. In a turbocharger the exhaust gas is used to drive the compressor, therefore all the work from the cylinder is in running the engine. The work input into the compressor can be computed from the 1st law of thermodynamics.

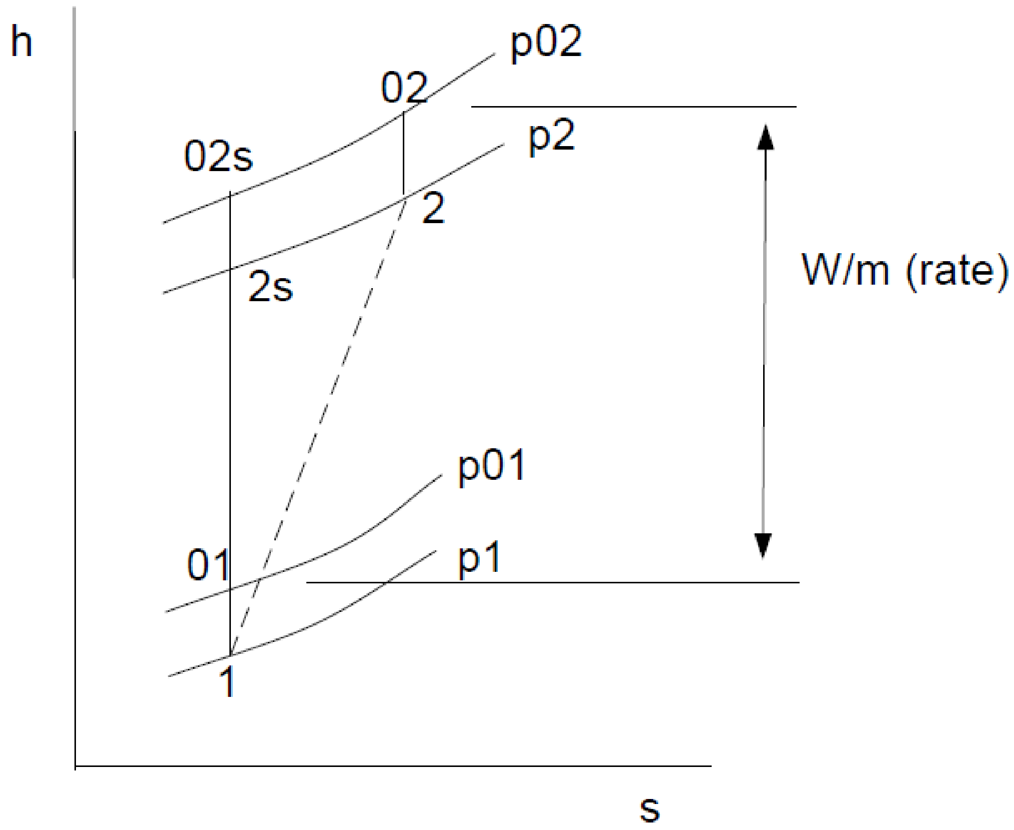


Figure 3 h-s diagram for the compressor

The compressor isentropic efficiency corresponding to the h-s diagram is defined by

$$\eta = \frac{h_{02s} - h_{01}}{h_{02} - h_{01}}$$

For an ideal gas

$$\eta = \frac{T_{02s} - T_{01}}{T_{02} - T_{01}}$$

Since process 01-02 is isentropic then

$$\eta c = \frac{(\frac{P_{02}}{P_{01}})^{\frac{\gamma-1}{\gamma}} - 1}{\frac{T_{02}}{T_{01}} - 1}$$

The power required to drive the compressor is then obtained from

$$\dot{W} c = \frac{\dot{m}a\ cp\ T_{01}}{\eta_c} [(\frac{P_{02}}{P_{01}})^{\frac{\gamma-1}{\gamma}} - 1]$$

Turbocharging:

Turbocharging is a specific method of supercharging. An attempt is made to use the energy of the hot exhaust gas of the engine to drive the supercharging compressor.

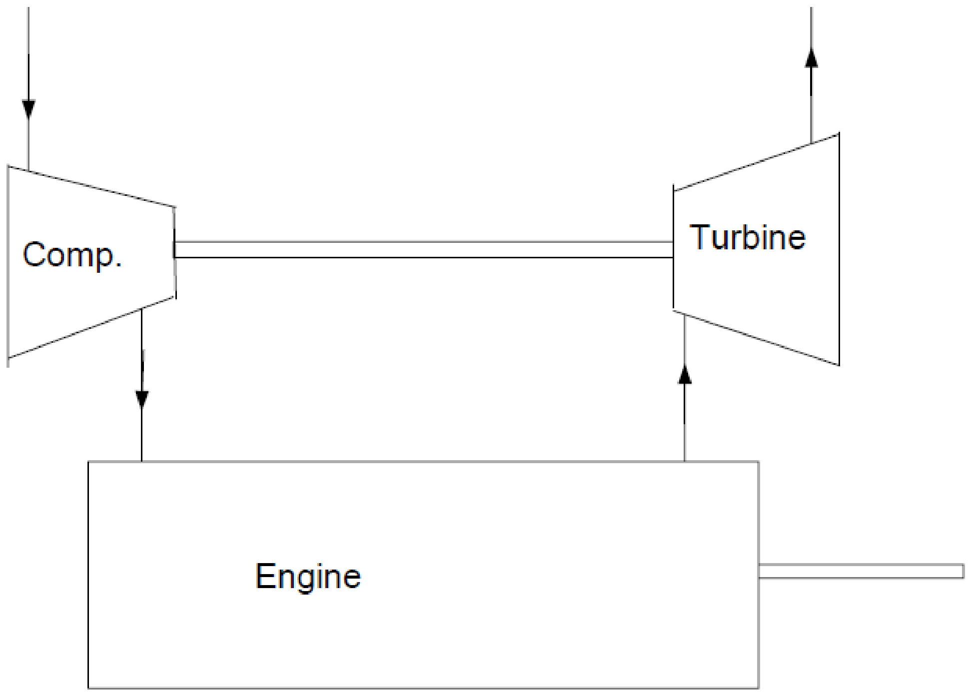


Figure 4 turbocharger

Turbines

The turbine in a turbocharger acts as an aid in the total efficiency of the purpose of turbocharging. By having the exhaust gases go into the turbine energy is being reused to drive the compressor. The reason the turbine can do work is because the temperature of the gases are hot enough to have high energy content. In a turbine the gases do work on the blades of the turbine, but the end effect is the turbine producing work on a shaft. The h-s diagram that describes the process of a turbine is shown in Figure 5. From this diagram the efficiency of the turbine can be solved for using the enthalpy terms. The efficiency for a turbine can be calculated by dividing the actual power output by the theoretical work output.

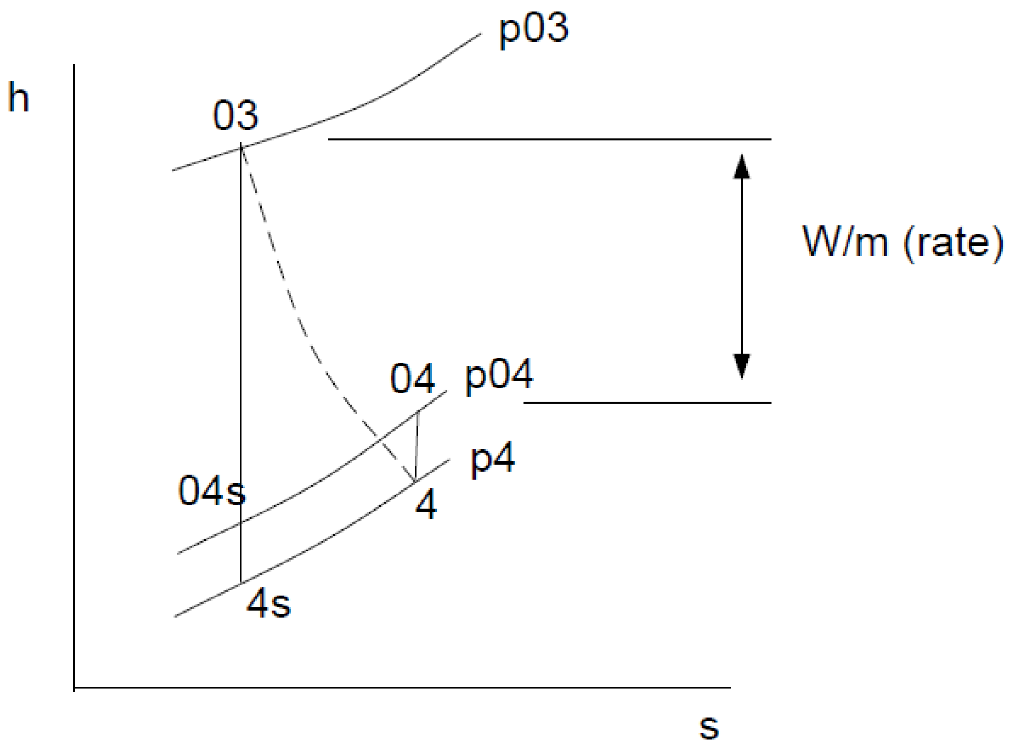


Figure 5 h-s diagram of the turbine

$$\eta T = \frac{h_{03} - h_{04}}{h_{03} - h_{04s}}$$

For an ideal gas

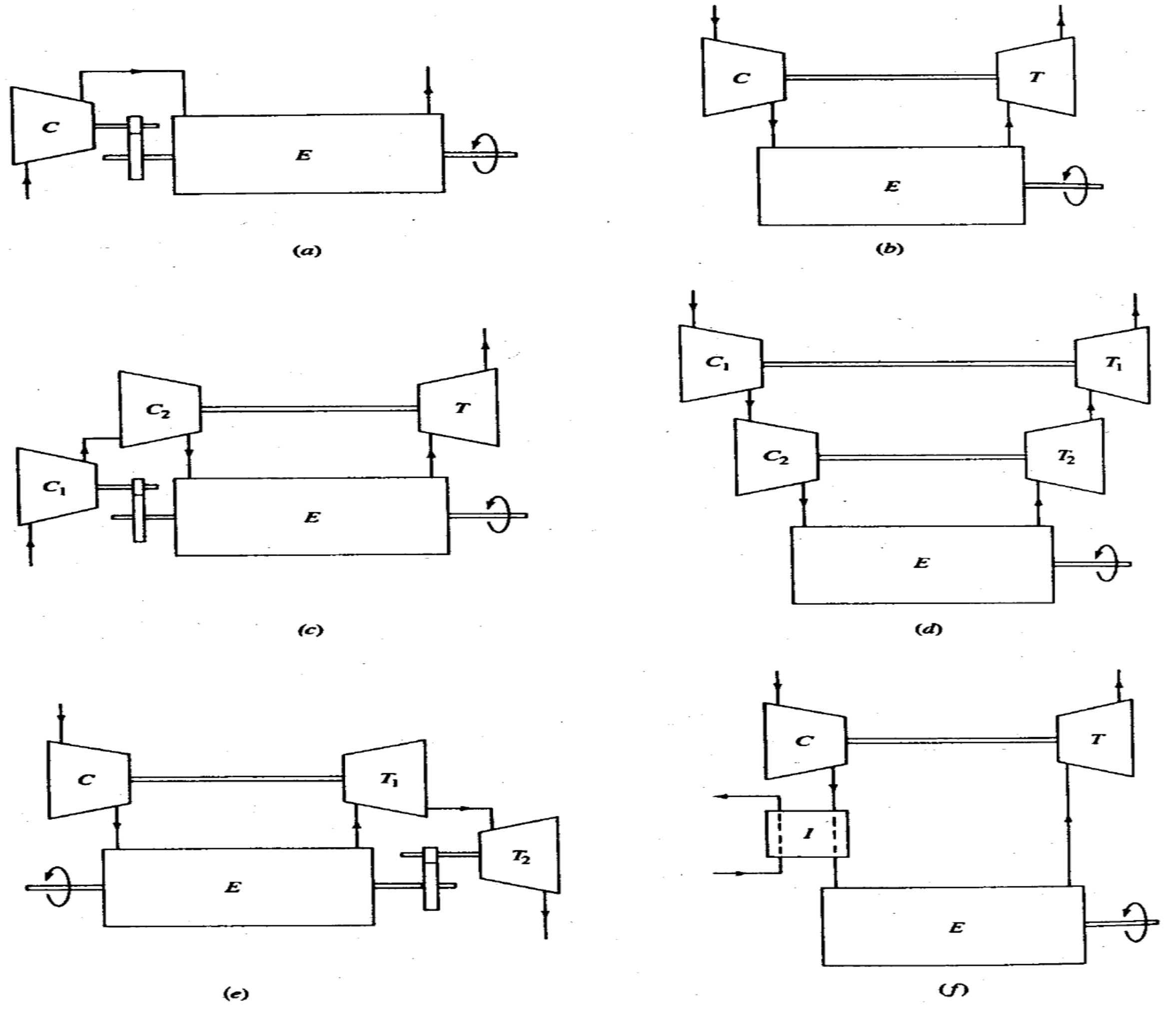
$$\eta T = \frac{T_{03} - T_{04}}{T_{03} - T_{04s}}$$

$$\eta T = \frac{1 - \frac{T_{04}}{T_{03}}}{1 - (\frac{P_{04}}{P_{03}})^{\frac{\gamma - 1}{\gamma}}}$$

Since process 03-04s is isentropic then the power is

$$\dot{W}T = \dot{m}e(h_{03} - h_{04}) = \dot{m}e\ cp\eta_c\ T_{o3}[1 - (\frac{P_{04}}{P_{03}})^{\frac{\gamma - 1}{\gamma}}]$$

Figure 7 shows types of superchargers



Charge cooling:

Compression of a gas in an adiabatic compressor is accompanied by a temperature rise. This temperature rise will depend on the pressure ratio and the efficiency of the compressor. Anything that helps reduce the inlet manifold air temperature will increase the density of the air and that increase the mass of air in the cylinder. It follows that reducing temperature will enable more fuel to be burnt and the power output to increase.

Since the compressor delivery temperature T2 is greater than the ambient temperature, it is possible to use a simple heat exchanger to reduce T2. This could be an air to air or air to water system. Since the charge cooler is fitted between the compressor and the engine, the installation is often called the aftercooler or intercooler.

The performance of a charge cooler is measured by its effectiveness (Ɛ), which is the temperature drops of the air being cooled divided by the maximum possible temperature drop.

$$\epsilon = \frac{T_{2a} - T_{2b}}{T_{2a} - T_w} = \frac{actual\ temperature\ drop}{maximum\ possible\ temperature\ drop}$$

T_{2a} the inlet temperature of the warm air

T_w the temperature of the cooling fluid