Université Libre de Bruxelles

Summary

Piston engines
MECA-Y401

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Appel à contribution

Synthèse Open Source

Ce document est grandement inspiré de l'excellent cours donné par Marc Overmeire à l'EPB (École Polytechnique de Bruxelles), faculté de l'ULB (Université Libre de Bruxelles). Il est écrit par les auteurs susnommés avec l'aide de tous les autres étudiants et votre aide est la bienvenue ! En effet, il y a toujours moyen de l'améliorer surtout que si le cours change, la synthèse doit être changée en conséquence. On peut retrouver le code source à l'adresse suivante

`https://github.com/nenglebert/Syntheses`

Pour contribuer à cette synthèse, il vous suffira de créer un compte sur *Github.com*. De légères modifications (petites coquilles, orthographe, ...) peuvent directement être faites sur le site ! Vous avez vu une petite faute ? Si oui, la corriger de cette façon ne prendra que quelques secondes, une bonne raison de le faire !

Pour de plus longues modifications, il est intéressant de disposer des fichiers : il vous faudra pour cela installer LaTeX, mais aussi *git*. Si cela pose problème, nous sommes évidemment ouverts à des contributeurs envoyant leur changement par mail ou n'importe quel autre moyen.

Le lien donné ci-dessus contient aussi un `README` contenant de plus amples informations, vous êtes invités à le lire si vous voulez faire avancer ce projet !

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Merci !

Contents

Chapter 1

Introduction

1.1 Classification

We find a large amount of engines in the market, small, large, different types, ... But some are dedicated to specific applications. First of all, an engine is an **energy converter** and has to satisfy some requirements (cheap, long lifetime, quick start, ...). According to the type of engines, some of them are better fulfilled. Piston engines are on average rather good for all them.

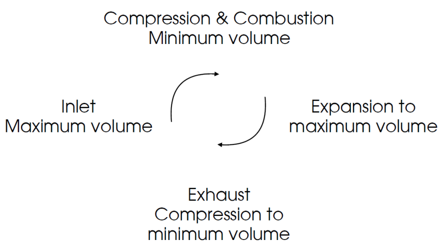

Figure 1.1

The basic principle of an engine is based on the periodic production of mechanical work, using the reaction of fuel with the oxygen of air in a confined space, which produces heat and the pressure in a variable volume produces work:

$$\begin{aligned}&\text{chemical} \rightarrow m_f.\text{LHV} = Q_{in} \rightarrow thermal\\ &\rightarrow pV = nRT \rightarrow mechanical\end{aligned} \tag{1.1}$$

where LHV is the energy content of fuel, the Lower Heating Value. The Figure 1.1 represents the closed cycle for a 4 stroke engine but can be adapted for 2 stroke.

Many classifications can be done following the size, the number of cylinder, ... But the mainly used one consists in 4 criteria:

- **Heat source:** internal or external (heat exchanger and working fluid in closed cycle)
- **Mechanism:** piston-connecting rod-crankshaft, piston-piston rod-crosshead-connecting rod-crankshaft or rotary piston-excenter shaft
- **Ignition:** spark ignition or compression ignition
- **Strokes:** 4 strokes or 2

1.1.1 Heat source

In this course, we only deal with the internal one. In this kind of source, fuel, air and the resulting combustion products are the working fluid. In the external type, the working fluid is in a closed cycle and transfers heat to an exchanger. The advantage of the external one is that we can use almost any fuel, have a more controlled combustion, but it is a more complex system and has less response to load change and there are more losses than the internal.

The internal one is produces more power, there is no need of exchanger and the mechanical part have a temperature lower than T_{max} of the cycle, is low coast and safe. Its disadvantages are vibration, noise, emissions, gases are in contact with the engine and depend on fossil fuel.

1.1.2 Mechanism

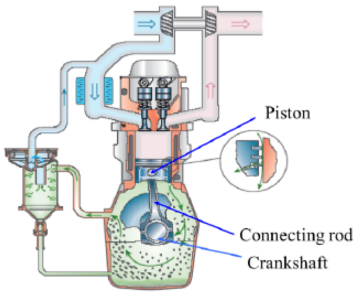

Figure 1.2

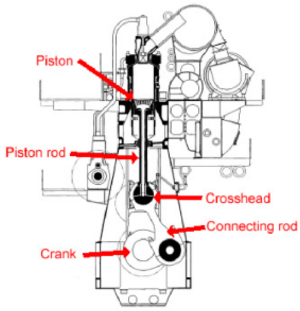

Figure 1.3

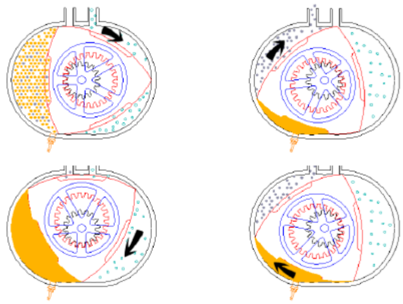

Figure 1.4

- Figure 1.2 - The mostly used mechanism is composed of a **piston** connected to a **crankshaft** via a **connecting rod**. The crankshaft converts the reciprocating movement into a rotating one.

- Figure 1.3 - Another mechanism where we have an additional **piston rod** between the piston and the connecting rod, coupled with a **crosshead**. This avoids the side forces on the piston due to the connecting rod movement. It is commonly used in large engines where side forces would produce too much wear (marine engines for example).

- Figure 1.4 - The third famous mechanism is known as rotary or Wankel engine. It is based on an eccentric rotary motion. The triangular rotor forms 3 combustion chambers that undergo the 4 strokes of a classical engine. So, for one rotation we have 3 power strokes. It is compact and can be operated at higher speed giving a very high power to weight ratio, is smooth and balanced. The challenges relie in the sealing of the combustion chamber, the higher heat transfer, the efficiency, and the emissions.

1.1.3 Ignition

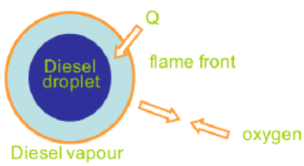

Figure 1.5

The principle of **compression ignition engines** is to auto-ignite the fuel injected into a hot environment by compressing the air. Since the fuel is introduced close to ignition, the combustion is controlled by the mass diffusion of the fuel into the air. So, the work produced is controlled by the mass of injected fuel, air keeping a more or less constant rate. These engines work in lean conditions.

The two major differences of **spark ignition** with compression ignition are the preparation of the mixture before or during the inlet and the ignition by mean of a spark. The combustion is characterised by a turbulent flame propagation. The work is controlled by the amount of air/fuel mixture and these operate in stoichiometric conditions.

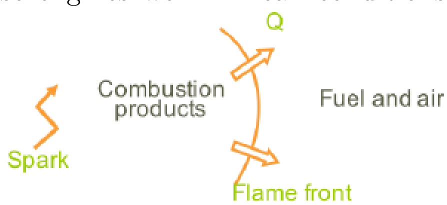

Figure 1.6

1.1.4 Strokes

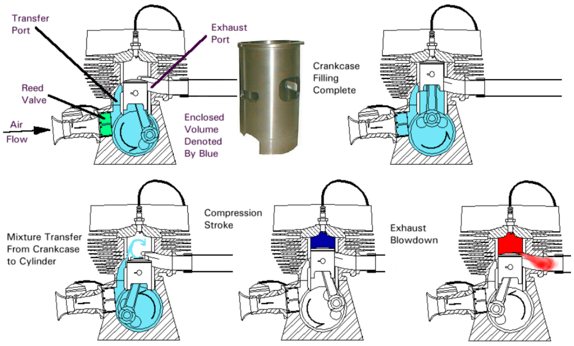

Figure 1.7

In a **two stroke** cycle, there is one work producing stroke every rotation. In the case of spark ignition engine, the scavenging is done through a **transfer port**. The air/fuel mixture is slightly compressed to push the exhaust gas. Once the ports are sealed by the piston, begins the compression followed by combustion and expansion. The exhaust port is first open when expansion. For compression ignition, there is no loss of fuel since the scavenging is done pushing air via a compressor.

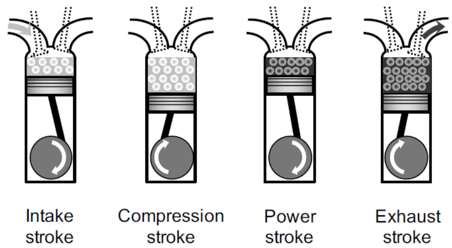

Figure 1.8

The advantages of 2 stroke cycle is that it is more simple, produce more power-to-weight (1 power every rotation) with a more constant torque than the 4 stroke. But we have fuel losses (SI), we need to manage more heat and we must mix oil and fuel for lubrification.

The **four stroke** cycle is composed of an intake, a compression, a combustion and an exhaust stroke. This induces one power stroke per two rotations.

1.2 Cylinder arrangements

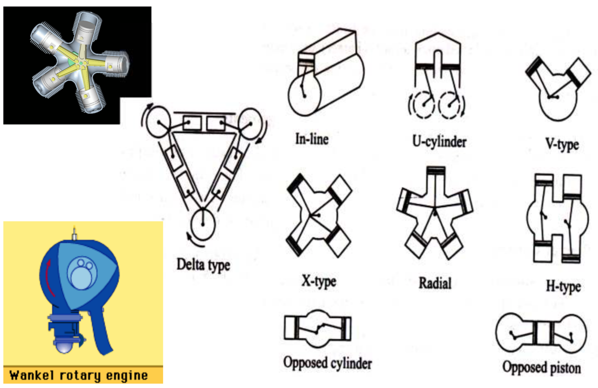

Figure 1.9

There are several arrangement methods. Other than in-line configuration are used in the case of high number of cylinder for the geometry. These are shown on this figure. There is also the W engine. This is in fact composed of two small angle V engine mounted in V type. But what are the advantages and disadvantages of more pistons:

- small degree of speed irregularity due to more power strokes and almost constant torque
- easy to balance, because more force regularity
- saving on R&D and production costs (only copy one piston)
- small dimensions per cylinder → more rpm, power (less inertia)
- cooling, combustion, thermal stresses
- disadvantages: configuration more difficult, more wear (usage), accessibility more difficult (inlet, exhaust).

1.3 Components

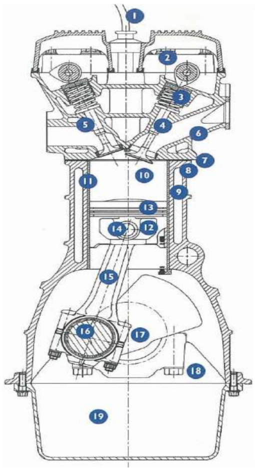

Figure 1.10

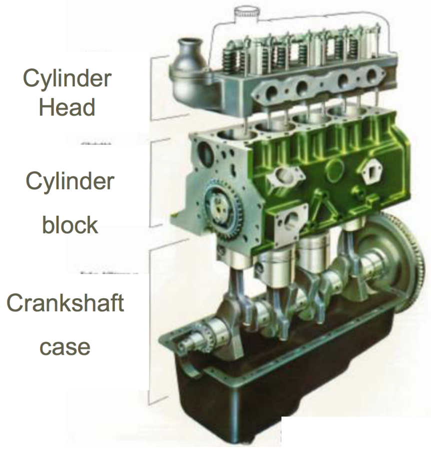

Figure 1.11

1. spark plug
2. camshaft (overhead)
3. valve springs
4. inlet valve
5. exhaust valve
6. cylinder head
7. cylinder head gasket
8. engine block
9. coolant
10. cylinder
11. cylinder liner
12. piston
13. piston rings
14. piston pin
15. connecting rod
16. big end
17. crankshaft
18. mainbearing cover
19. oil sump

- **Cylinder head:** this the enclosure of the cylinder block, contains the combustion chambers and the inlet and exhaust valves.

- **Cylinder block**: very complex part because there are canals within (oil, cooling..), there are also fixing ports. We cast it, we use so iron or aluminum. Iron damps vibrations, is strong, ... (ships). Aluminum is much lighter, so we used it for small cars, disadvantage: is not as strong as iron, too much thermal expansion, that can be a problem, if the dilatation of the aluminium is too large, the piston does not fit anymore and we have leakage.

- **Crankshaft case:** as the name indicates, it contains the crankshaft converting the reciprocating movement into a rotating one and an oil reservoir.

1.3.1 Cylinder

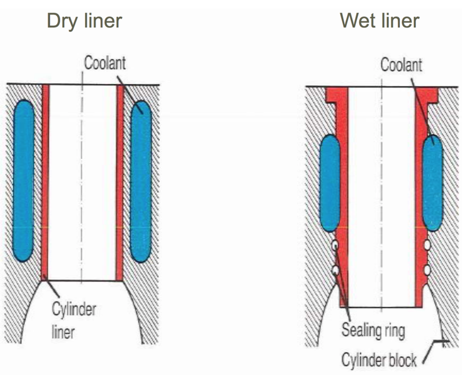

Figure 1.12

Here is a representation of the cylinder, the coolant type more exactly. If we make an engine we have to worry about the lifetime. For ships for example 34 years. We can have liner which is a protection of the insight, we can make it with a special material with special characteristics. We only worry about friction and thermal conduction because the temperature of the piston is high, it must transfer the heat, it transfer it to the piston block. There are also small ports in the liner that can store oil. We also have a coolant, we can have the wet liner or the dry one depending on the position of coolant. Transfer of heat in the wet one is more important but we have leakage risk of the water in the piston chamber from below.

1.3.2 Piston and connecting rod

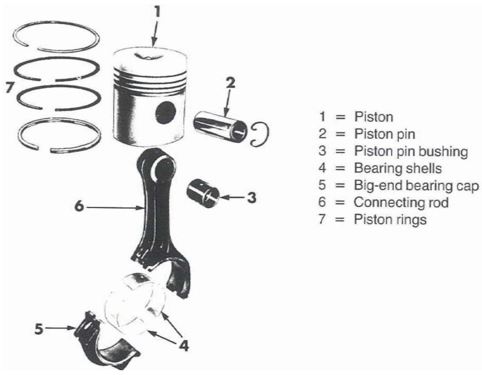

Figure 1.13

The piston is a moving part. In the engine the inertia and the mass is important, we will lose power by resistance if it's too high. Piston rings are responsible for avoiding leakage, heat transfer and friction. We also have to worry about leakage behind the rings when the piston goes up and down and the removal of the oil to avoid its combustion. The reason why it's impossible to have 0 leakage in spark engine is that we always have a horizontal movement (Diesel tends to 0).

This is the moving part, but above this we have cool air or mixture (cool because it will be heated up by the process). The thermal resistance of the piston must be much higher than the engine block, the piston is in aluminum so it expends when heated. We have to manage the thermal behavior to counter this → elliptical geometry when cold and we manage expend to have the good shape when it heats.

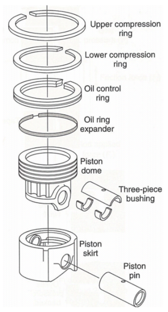

Figure 1.14

The pin has to support enormous force so we use iron, and whole pin because the stresses are bending stresses so we have to remove the weight. The piston is composed of different ring layers. We see that the oil controller ring dispose of an expander to scrape the oil. The compression ring has no expander because the high pressure makes move the ring below then toward the wall when inlet. In practice, one ring is sufficient, but we will have no emergency ring.

1.3.3 Cross section of a piston

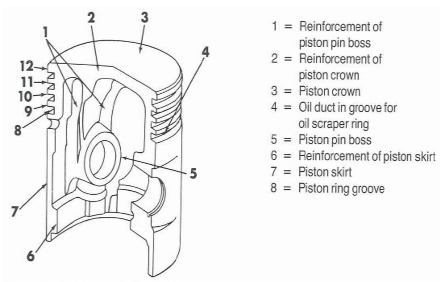

Figure 1.15

Grooves can have different shapes. The efficiency of a spark engine is about 20%, diesel engine 35%. We are looking for increasing this. The skirt is becoming shorter because of the mass.

1.4 Blow-by due to leakage

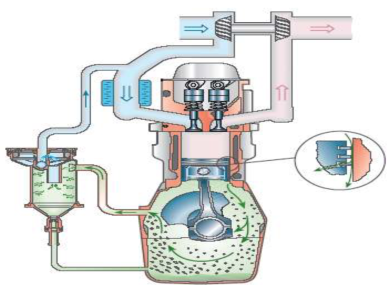

Figure 1.16

What we can have is a gas leakage, that goes into the sump. The consequences are that the fuel mix with oil, reducing its efficiency as the pressure below increases. What we have to do is to evacuate the gases. There is a kind of ventilation. The gases pass through a filter where they are filtered (gas / oil). The gases will be sent to the incoming gas.

Chapter 2

Operating parameters

2.1 Forces on a car

Figure 2.1

The very basic, we need to apply a force to make the car move. Thus our first force and energy are:

$$F = m.a \qquad and \qquad E = F.d \tag{2.1}$$