ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

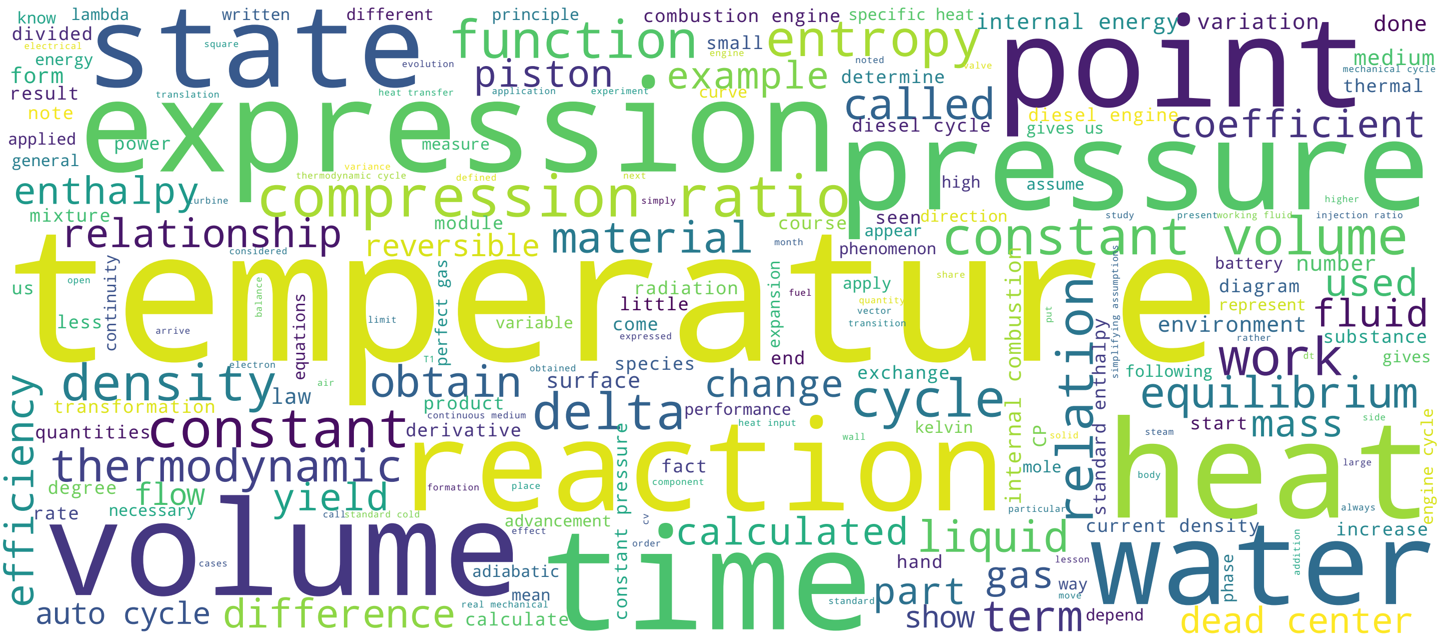
RESCIF
Réseau d'excellence des sciences de l'ingénieur de la Francophonie

Thermodynamique

Moteurs à combustion interne

POLYTECHNIQUE MONTRÉAL Prof. Etienne Robert

Nicolas Léonard Sadi Carnot, 1796-1832



Video

EPFL

Cycles de moteurs à combustion interne

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- Le cycle moteur 4 temps
- Cycle réel vs cycle thermodynamique
- Cycle Otto
- Cycle Diesel

Thermodynamique

Hello and welcome to the module on internal combustion engines, more specifically on internal combustion piston-cylinder type. These are therefore power cycles which aims at producing mechanical work from thermal energy. In this module, we will mainly discuss of the four-stroke engine cycle and simplifying assumptions that we need to bring in order to be able to move from the real mechanical cycle to the thermodynamics which lends itself well to analysis. We will then see the different types of engines of these comments the most commonly used, i. e. the auto cycles and the diesel, as well as the characteristics that make them are associated in terms of performance depending on the design parameters.

Notes

Summary

0m 04s

Concepts de base

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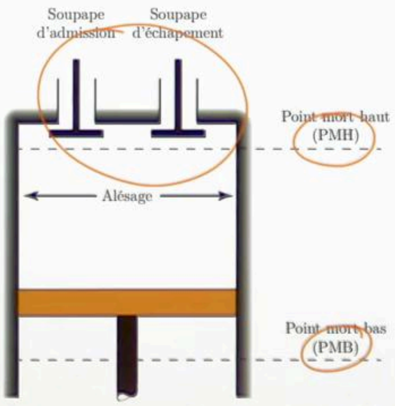


- Paramètres importants
  - Taux de compression

$$r = \frac{V_{PMB}}{V_{PMH}}$$

  - Pression moyenne effective

$$PME = \frac{W_{net}}{V_{PMB} - V_{PMH}}$$

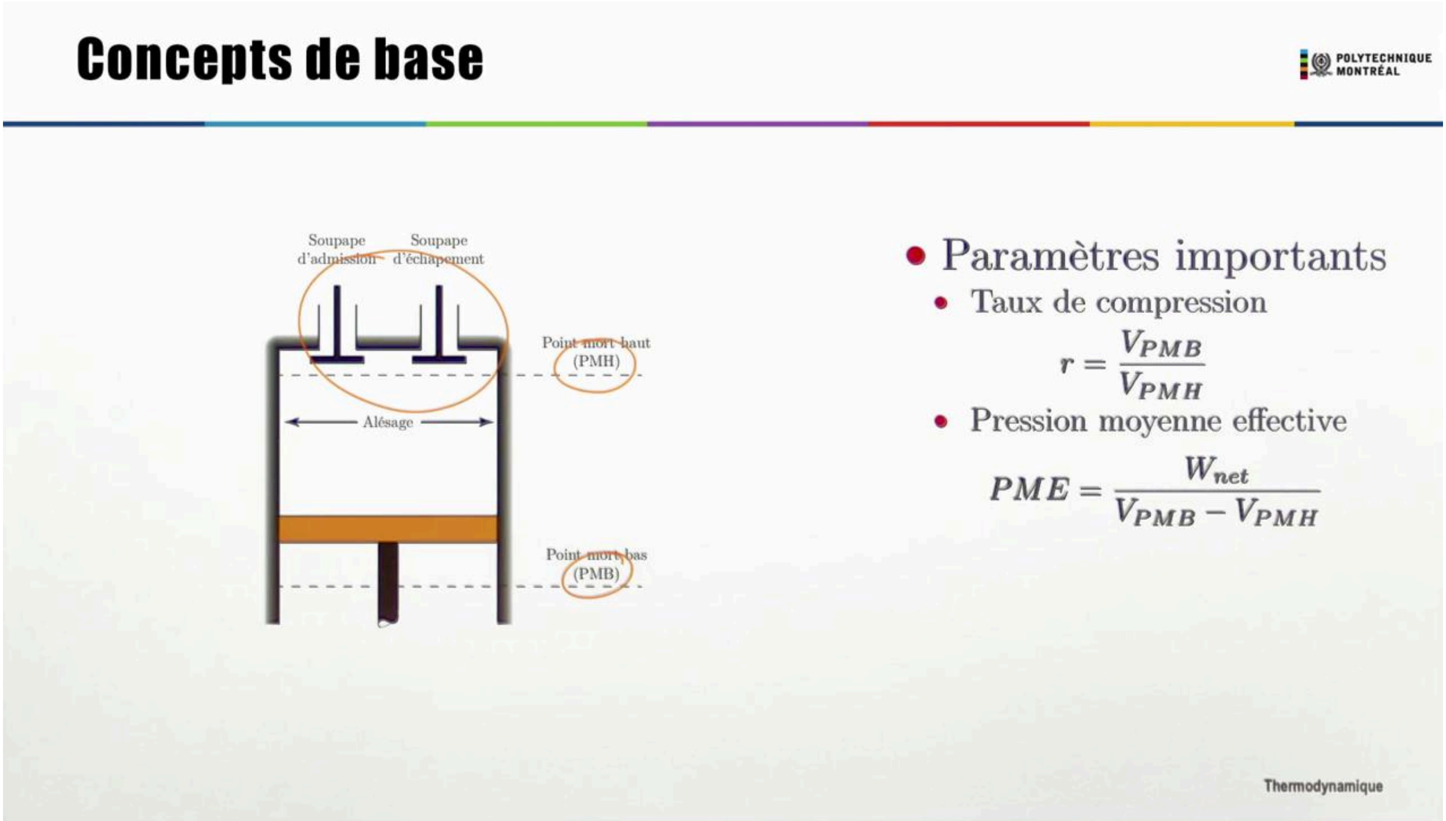
Thermodynamique

So let's start with some concepts basic principles of all internal combustion engine cycles. These are closed cycles or the evolutions of the working fluid take place in a system. It is. The cylinder has a constant diameter which is called the bore. In this one a piston moves with a back and forth movement with little or no friction. The volume swept by the piston between the bottom dead center and the dead center is called the displacement. It is the volume which is generally expressed in liters that gives us an idea of the power of internal combustion engines in cars for example. The exchanges between the system and its environment. The exchange of materials is done through valves. Which are usually located at the end of the piston. One or more of them leave The other vents let in fresh air and the others let out combustion gases. Two important parameters characterize the configuration. First of all, it is the compression ratio which is the ratio of the volume at bottom dead center to the volume at top dead center. The second permanent is the average effective pressure.

Notes

Summary

0m 42s



This is an average value, as the name suggests, of the work done divided by the difference in volume between the first month or the first month down, which allows us to approximate the pressure as if it were evenly distributed throughout the cycle. These two quantities allow us to compare the cycles between them and are used to calculate the expression of the yield.

Notes

Summary

1m 47s

Le cycle 4 temps

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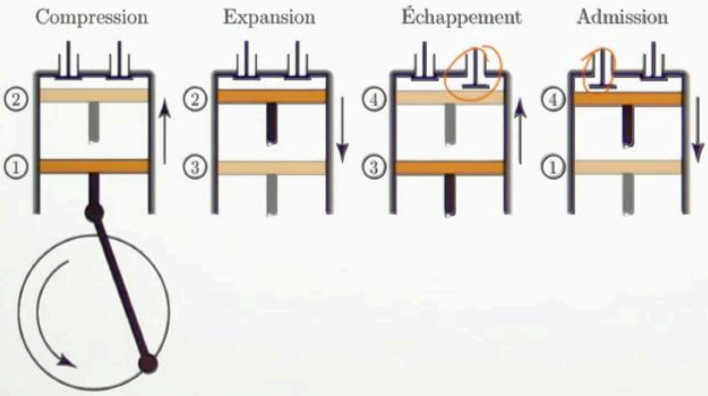

- 4 translations du piston dans le cylindre (2 tours par cycle)

Course	Fonction
1 - 2	Compression
2 - 3	Combustion/expansion
3 - 4	Échappemment
4 - 1	Admission

Thermodynamique

As its name suggests, the four-stroke engine cycle is composed of four successive revolutions, each corresponding to a translation of the piston between the top and bottom points. This translational motion is then converted into a rotational motion of the motor's weapon by an assembly of crank rods. Each translation of the piston corresponds to a half turn of the shaft which makes therefore two rounds for a complete cycle. The first stroke of the piston, when the working fluid is removed by absorbing energy from the motor shaft. Then comes the explosion which is immediately followed by the curve of expansion during which the work of the cycle is extracted. For the third stroke, the exhaust valve is open. And so the movement of the movement of the piston will drain the exhaust gases to the outside of the system. Finally, the exhaust valve is closed and the inlet valve is open, so that the fourth The translation of the piston will suck the fresh gas into the cylinder. Scars are widely used, but there are also mopeds that are only two years old. For two-stroke cycles, the strokes, exhaust and intake are replaced by an injection of exhaust gases, almost simultaneous to the arrival of the fresh gas that has been slightly pressurized beforehand.

Notes

Summary

2m 08s

Le cycle 4 temps

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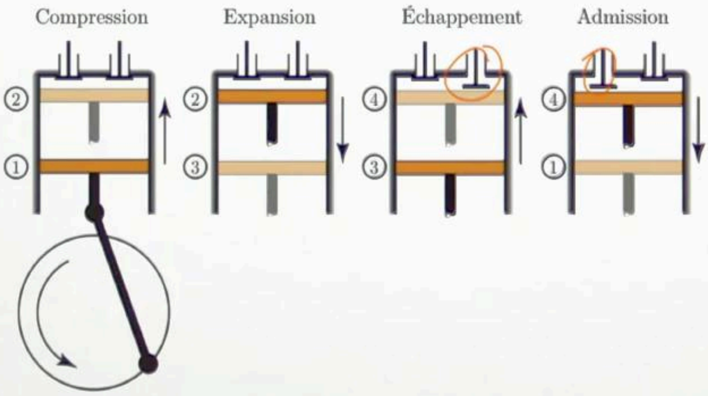

- 4 translations du piston dans le cylindre (2 tours par cycle)

Course	Fonction
1 - 2	Compression
2 - 3	Combustion/expansion
3 - 4	Échappemment
4 - 1	Admission

Thermodynamique

For these cycles, there are generally no valves and the exchange ducts are not used. are opened automatically by the passage of the piston near the bottom dead center.

Notes

Summary

3m 23s

Cycle réel vs cycle thermodynamique

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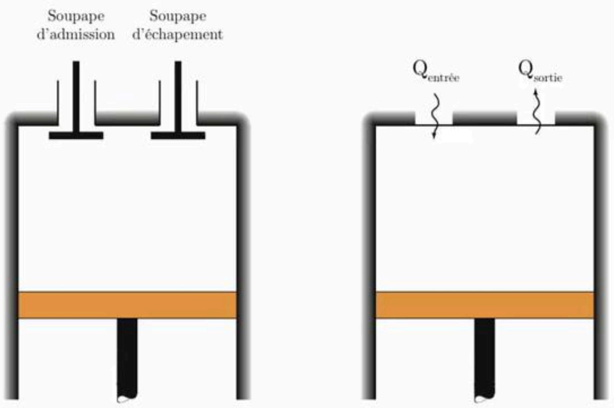

- Hypothèses nécessaires pour permettre analyse thermodynamique
  1. Gaz parfait, air
  2. Évolutions intérieurement réversibles
  3. Combustion remplacée par transfert de chaleur
  4. Échapement remplacé par rejet de chaleur
  5. Capacité thermique constantes à 25°C

Thermodynamique

The real evolution of the fluid in a time are quite complex and to be able to make an analysis thermodynamics, it is necessary to set up a number of simplifying assumptions. First of all, we will consider that we works with air, air, which is considered a perfect gas. Then, we will assume that all transformations involving of work, cutbacks and expansions will continue do so in a reversible and adiabatic way. So it's going to be transformations that are going to be entropic. The most significant abstraction is to ignore all reactions and to replace the exchange of material through the valves by heat exchange through a wall. Finally, we can simplify again the analysis considering that the working fluid has thermal capacities which are constant, evaluated at 25 degrees Celsius. The first four simplifications are the assumptions Bertrand Bar While when we add the fifth, we speak rather of air standard cold starting with the auto cycle which is the idealized cycle for spark-ignition piston engines.

Notes

Summary

3m 32s

Cycle Otto

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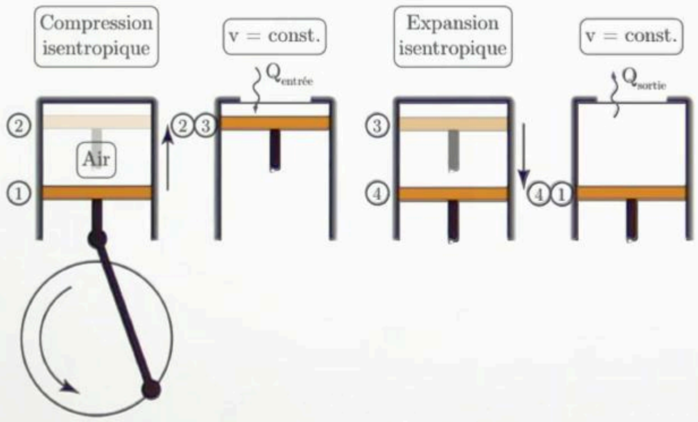

- Cycle idéalisé avec allumage par étincelle
- Apport de chaleur à volume constant
- Bilan d'énergie

$$q_{entrée} = u_3 - u_2 = c_v(T_3 - T_2)$$

$$q_{sortie} = u_4 - u_1 = c_v(T_4 - T_1)$$

$$\eta_{th} = \frac{w_{net}}{q_{entrée}} = \frac{q_{entrée} - q_{sortie}}{q_{entrée}} = 1 - \frac{q_{sortie}}{q_{entrée}}$$

$$\eta_{th} = 1 - \frac{(T_4 - T_1)}{(T_3 - T_2)} = 1 - \frac{T_1(T_4/T_1 - 1)}{T_2(T_3/T_2 - 1)}$$

Thermodynamique

For these engines. The compressed fluid is a combustible air mixture that is ignited by a when the piston is near the dead center. The temperature therefore increases very rapidly, essentially at constant volume. The work is then extracted during of the expansion stroke and the contaminated gases are replaced by a new mixture. During the next two engines, the gas evolutions in the real mechanical cycle are quite complicated and do not lend themselves well to thermodynamic analysis. To simplify things, we will therefore replace the exhaust and intake stroke. Here by. A change in temperature or a heat input at constant volume. In addition, there will be no more talk of combustion between stages two and three, but rather the share of heat, this time again at constant volume. This results in a simplified cycle that is much more amenable to analysis. The quantities of heat entering and outgoing can be calculated simply by balancing between the two stages and three and states four and one respectively. And if we apply the standard cold air assumptions, these quantities are simply equal to the heat capacity at constant volume, multiplied by the temperature difference.

Notes

Summary

4m 32s

Cycle Otto

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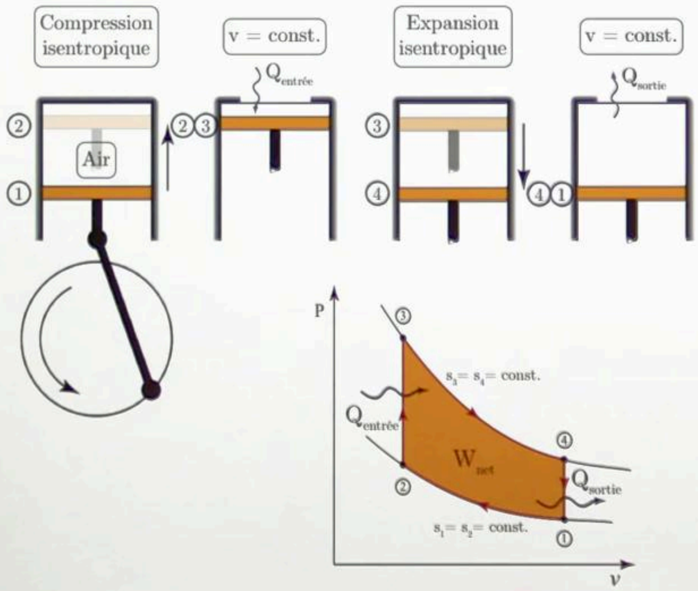


- Cycle idéalisé avec allumage par étincelle
- Apport de chaleur à volume constant
- Bilan d'énergie

$$q_{entrée} = u_3 - u_2 = c_v(T_3 - T_2)$$

$$q_{sortie} = u_4 - u_1 = c_v(T_4 - T_1)$$

$$\eta_{th} = \frac{w_{net}}{q_{entrée}} = \frac{q_{entrée} - q_{sortie}}{q_{entrée}} = 1 - \frac{q_{sortie}}{q_{entrée}}$$

$$\eta_{th} = 1 - \frac{(T_4 - T_1)}{(T_3 - T_2)} = 1 - \frac{T_1(T_4/T_1 - 1)}{T_2(T_3/T_2 - 1)}$$

- Compression et expansion isentropiques

$$\frac{T_1}{T_2} = \left(\frac{v_2}{v_1}\right)^{\kappa - 1} = \left(\frac{v_3}{v_4}\right)^{\kappa - 1} = \frac{T_4}{T_3}$$

Thermodynamique

We thus obtain an expression for the yield, which depends only on the temperatures at the four points of the cycle. It is however interesting to rearrange this equation to show the temperature ratios before and after the compression and expansion phases. These quantities are convenient because we can be calculated from the volume ratio. For an anthropic evolution such as adiabatic and reversible expansion and compression. They are also entropic and therefore we can show the rate of compression R in the expression of the efficiency.

Notes

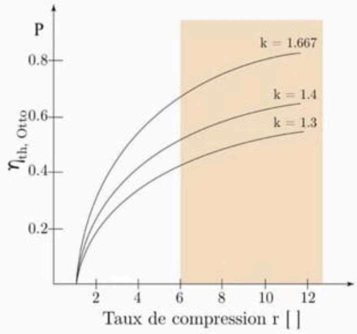
Summary

5m 44s

Rendement du cycle Otto

- Rendement fonction du taux de compression seulement.

$$\eta_{th,Otto} = 1 - \frac{1}{r^{\kappa-1}}$$



Thermodynamique

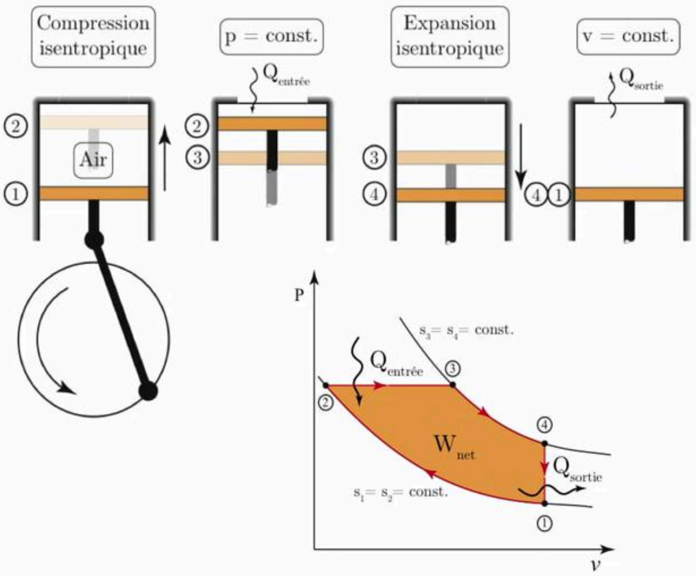
In fact, as volumes 1.2 and three and at the point four and one are identical, we obtain an expression for the efficiency of the auto cycle, which is only a function of the rate compression ratio R and the specific heat ratio kappa. As we usually work with air, Capa is about 1.4 and for compression rates that are used in the auto hemicycle, a yield in the range of 50 to 60 is obtained as shown in the figure. On the other hand, we cannot increase indefinitely the compression ratio in the hope of increasing efficiency. If the compression ratio is too high, we will witness the phenomenon of self-ignition. In the cylinder, a mixture of air and fuel is compressed. If the temperature of this mixture exceeds At a certain temperature, the mixture will ignite even before the that the spark plug has time to provide the spark. If this spontaneous ignition occurs before the piston has reached the dead center, it will have disastrous consequences on the yield, which limits the usable compression ratios for cars. In the range of about 6 to 13.

Notes

Summary

6m 15s

Cycle Diesel



- Cycle idéalisé pour moteurs à auto-allumage (par compression)
- Apport de chaleur à pression constante
- Bilan d'énergie

$$q_{entrée} = h_3 - h_2 = c_p(T_3 - T_2)$$

$$q_{sortie} = u_4 - u_1 = c_v(T_4 - T_1)$$

$$\eta_{th} = \frac{w_{net}}{q_{entrée}} = \frac{q_{entrée} - q_{sortie}}{q_{entrée}} = 1 - \frac{q_{sortie}}{q_{entrée}}$$

$$\eta_{th} = 1 - \frac{c_v(T_4 - T_1)}{c_p(T_3 - T_2)} = 1 - \frac{T_1(T_4/T_1 - 1)}{\kappa T_2(T_3/T_2 - 1)}$$

- Compression et expansion isentropiques

$$\frac{T_1}{T_2} = \left(\frac{v_2}{v_1}\right)^{\kappa-1} = \left(\frac{v_3}{v_4}\right)^{\kappa-1} = \frac{T_4}{T_3}$$

Thermodynamique

In diesel engines, this natural tendency to self-ignition of high temperature fuels is used to avoid the need for to have a candle to initiate combustion. A diesel cycle compresses the air only and the combustion takes place when the fuel is injected at high pressure and at high temperatures around the dead center. Since not all fuel can be injected instantly, the piston has time to start moving downwards and we can therefore assume that the heat input is no longer at constant volume, but rather at constant pressure. Again applying the standard cold air assumptions, the bark, the piston bark or the bulk of the work has been changed are again. They come in sharp. But this time, the heat input is is done at constant pressure rather than constant volume. And the evacuation is always done at constant volume. In the expression of performance, we calculate the heat that enters with CP and that which leaves with cv. We thus obtain an expression of the yield which makes appear a term which comes from the CP to CV ratio that has been introduced in this way. We can again use the relations between peaks to relate volume changes to temperature changes between states one, two, three and four.

Notes

Summary

7m 16s

Exemple : Cycle Diesel

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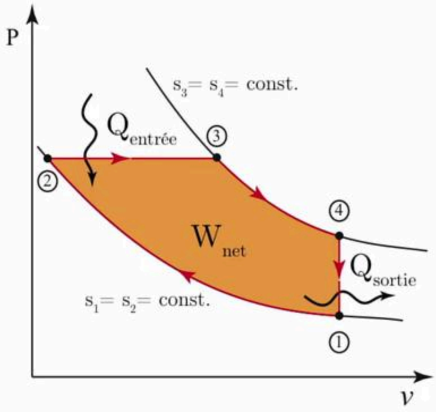

$P_1 = 0.1$ MPa
$T_1 = 300$ K
$r = V_1/V_2 = 18$
$r_c = V_3/V_2 = 2$

- On considère que le fluide de travail est de l'air et qu'il se comporte comme un gaz parfait. En considérant $C_p = 1.005$ kJ/kg*K et $C_v = 0.718$ kJ/kg*K comme variable, trouvez:
  a) Température et pression aux points 2, 3 et 4.
  b) Le rendement thermique du cycle
  c) La pression moyenne effective (PME)

Thermodynamique

On the other hand, in the diesel cycle, the volume in state three is not identical to the volume in state two. So we will not be able to have an expression performance that involves only a single compression ratio. It is necessary to make intervene, another parameter that we will call the injection ratio the ratio between the volumes at point three and point two. This gives an expression for the efficiency that depends on R. The compression ratio RC, the injection ratio and kappa, the specific heat ratio for typical compression ratios of diesel engines between fourteen and 23. The yields of the ideal cycle therefore vary between 50 and 70 % and as in the case of of the auto cycle, this efficiency increases with the compression ratio. However, in the case of the diesel engine, this efficiency will decrease if the injection ratio is increased. The comparison between the auto and diesel engines reveals that a compression ratio equal to the auto cycle is more efficient. However, since the compression ratio of diesel engines is much higher that of car engines in general, in the end, diesel cycles are slightly more efficient in terms of performance.

Notes

Summary

8m 27s

Exemple : Cycle Diesel

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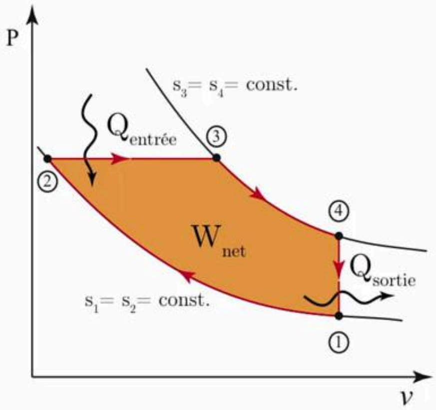

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  a) Température et pression aux points 2, 3 et 4.
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Thermodynamique

Finally, let's consider the example following is a diesel cycle for which we give you the conditions compression ratio at D8 as well as the injection ratio. RC equals two. The thermodynamic analysis requires first to determine all the states. the State two will be calculated by considering the compression it entropic intervening between points one and two with R and Galvez one of 22 for air. Considering the variable thermal capacities, we use the thermodynamic tables and the T2 temperature is calculated at 898.3 Kelvin and a pressure of 5390 kilo pascals. The temperature at point three is then calculated from the gas law perfect with V3 over V2 equals two and P3 equals P2. We obtain T3 equals 1 796.6. For step four, we must again use a relation entropy to find T4 from the volume ratio V4 to V3. This can be calculated by multiplying V1 over V2 by V2 over V3. We find T4 equal to 884 kelvins and by hypothesis we have P4 equal T1. The output of the cycle can then be calculated using the definition we have seen before. So another circuit, that is to say a minus the difference of internal energy plus four -1 divided by the difference of enthalpy H3 minus H2. This gives us a yield of 0. 58 is a two 58 for a twelve.

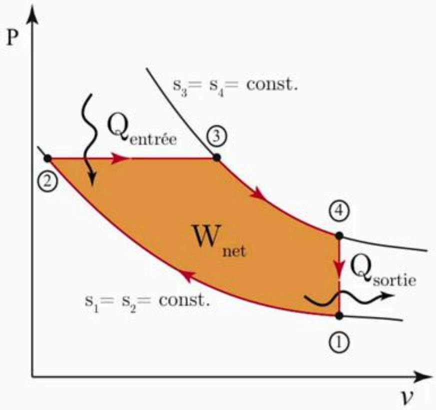
Notes

Summary

9m 30s

Exemple : Cycle Diesel

POLYTECHNIQUE MONTRÉAL



$P_1 = 0.1$ MPa
$T_1 = 300$ K
$r = V_1/V_2 = 18$
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  a) Température et pression aux points 2, 3 et 4.
  b) Le rendement thermique du cycle
  c) La pression moyenne effective (PME)

Thermodynamique

Finally, the average effective pressure is calculated as. The net work divided by the volume swept by the piston. W net is simply the difference between the heat acquired and the heat given up. The difference in volume between the and the low point is calculated from the gas law and the compression ratio one in 22. As we do not know the size of the system and therefore we do not know its mass, the rate must be calculated in size specific, thus per unit of mass, to obtain a result of 760 kilos. Pascal.

Notes

Summary

11m 04s

Conclusions

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This is the conclusion of a module on the thermodynamic cycles of internal combustion engines, more precisely internal combustion engines of the piston-cylinder type. First of all, we have seen that it is necessary to implement a certain number of simplifying assumptions to go from the complex real mechanical cycle to a simplified thermodynamic cycle that is well suited for analysis. We then reviewed the two main types of internal combustion engine cycles. First of all, the auto cycle or the share The heat is generated at constant volume and the ignition is done by spark. Then, we talked about the diesel cycle where the share of heat is done at pressure and the ignition is done by auto ignition. Finally, when comparing these two cycles, we see that in both case, the efficiency of the cycle increases with the compression ratio and that, with equal compression ratio, the efficiency of the auto cycle is slightly higher than the efficiency of the diesel cycle. On the other hand, taking into account the rates compression ratio that can be achieved with diesel engines, This one is in general a slightly higher overall performance than the auto cycle. Thank you.

Notes

Summary

11m 35s