PISTON INTERNAL COMBUSTION ENGINES

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Contents

Summary

In this chapter fundamentals of development of piston Internal Combustion Engines (ICE) are explained which are applied in a structure of energy systems of transport systems for automobiles, locomotives and marines.

1. General information

An engine is an energetic machine transforming any kind of energy into mechanical work

Heat engines are machines, transforming heat energy into mechanical work.

By purpose heat engines are classified into ***stationary*** and ***transport*** engines.
The transport engines have the following special features:

- multi-regime operation requiring a high efficiency of their performance in the wide range of their speed and load operating modes;
- remain operative when the engine is inclined;
- increased demands for lowering the mass and dimensions.

By the method of heat addition to the working medium, one distinguishes between ***the internal combustion engines (IC engines) and the engines with external heat addition (EHA engines).***

IC engines are characterized by the following features:
- fuel combustion, heat release and transformation of a part of heat into mechanical work occur directly in the engine cylinder;
- the working medium is renewed during the engine operation.

EHA engines are characterized by the following features:
- heat is added to the engine outside the cylinder (generally - in the heat exchanger);
- the working medium is not renewed and circulates in different aggregate states along the closed contour;
- work is done inside a turbine or expanding cylinder.

IC engines compared to EHA engines usually have considerably smaller dimensions and mass per unit power produced. This is the reason why they are the main type of transport power plants today.

By the design of the elements used for transforming the energy of the burned fuel into mechanical work one distinguishes:
- ***piston-type IC engines*** with pistons moving back and forth (reciprocating) (PIC engines);
- ***engines with rotating pistons*** and Wankel rotary IC engines (RIC engines);
- ***gas-turbine engines*** (GT engines);
- ***jet engines*** (J engines).

For several reasons mostly in view of the problems of obtaining good economy RIC, GT and J engines have not found wide application on land transport, where the power-plants are (mostly) the PIC engines.

The construction base of the PIC engine consists of two mechanisms (Figure 1) - crank mechanism (1) and gas-exchange mechanism (2) mainly casting-mounted (3).

The crank mechanism involves the crankshaft (4), piston (5) and connecting rod (6). It is destined to transform the reciprocating motion of the pistons to the rotational motion of the crankshaft.

The function of the gas-exchange mechanism is the renewal of the working medium during the engine operation. In the construction of the actual PIC engine, the valves-type gas-exchange mechanism is usually applied. It is composed of the two systems of spring-returned valves (7) one of which represents locking-regulating arm of the intake duct and the other does the same function of the exhaust system (8). The valves are put in action by the cam (9) located on the camshaft (10) which is rotated by the crankshaft. Both the shafts are synchronized at angular position.

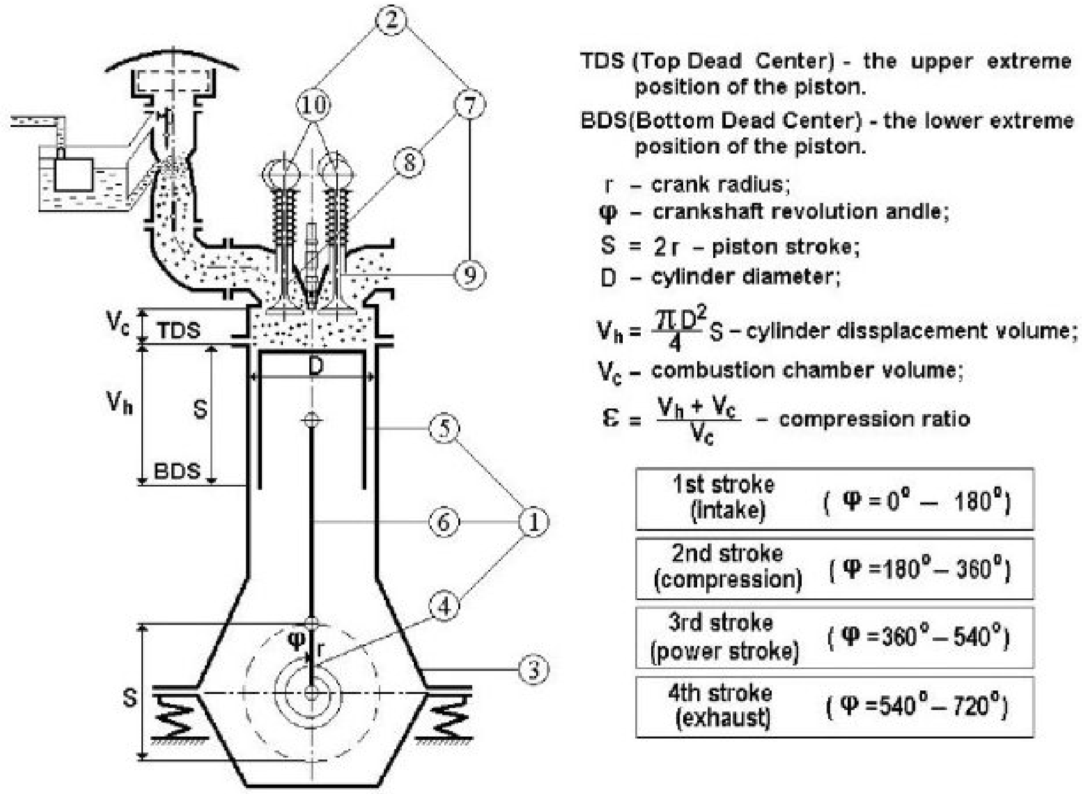

Figure 1: Geometric parameters of IC Engines

Useful work is produced by transforming the energy of the burned fuel into mechanical work as the piston travels between the top and bottom dead centers (TDC and BDC) while the intake and exhaust valves are closed (combustion-expansion processes). The working cycle of the PIC engine involves several subsidiary processes needed to make possible and to optimize the conditions of the realization of this basic process. It starts with the intake process as the piston moves from the top to the bottom dead centers while the intake valves are opened and exhaust valves are closed. Its aim is to fill the cylinder with the fresh charge. Then the compression process follows as the piston travels between the bottom and top dead centers while the intake and exhaust valves are closed. Its aim is to increase the thermodynamic parameters and concentrate the fuel-air mixture in a small volume to accelerate the inflammation of the fuel. Before the termination of this process nearby the TDC, the working medium ignition takes place. The exhaust process (evacuation the exhaust gases from cylinder) as the piston moves from the bottom to the top dead centers while the exhaust valves are opened and intake valves are closed, completes the working cycle.

The construction of the PIC engine also has service systems needed to support its normal working state. The main systems are:

-the cooling system designed for the maintenance normal thermal state of the engine;
-the lubricating system designed for the maintenance of the normal working state of rubbing elements of the engine;
-the fuel supply system is designed to feed the required quantity of fuel into the cylinder for the required operating mode.

PIC engines may be classified by several features:

- by the method of the working medium ignition - into ***spark-ignition*** and ***compression-ignition*** engines (diesel engines);
- by the method of power control - into engines with ***quantitative*** and ***qualitative*** control;
- by the method of mixture formation - into engines with ***external*** and ***internal mixture formation.***

IC engines with a ***quantitative*** control - at most operating modes the power is controlled by the variation of the amount of the fuel-air mixture fed to the cylinders with minor variation of its composition.

IC engine with ***qualitative*** control - a varied quantity of fuel is injected into a stable quantity of air charge which practically does not influence the total quality of fuel-air mixture, but changes dramatically its composition.

Spark-ignition engines are specified by quantitative power control and external mixture formation. In these engines two kinds of fuel may be used: liquid (petrol) - ***petrol engines*** and gas (natural, producers, generator gas) - ***gas engines***.

Spark-ignition engines are classified into two modifications: ***carburetor engines*** (fuel-air mixture admitted into the cylinders is prepared externally in a device called the carburetor) and ***engines with fuel sprayed by a fuel pump*** (FP) via a fuel injector into the intake system (generally - at the intake valve) by the signal of the control unit which is formed on the basis of information from the complex of sensors (air flow, crankshaft speed, throttle valve position, etc).

At present, petrol engines with fuel injected by a fuel pump via a fuel injector into the intake system or into cylinder replace more and more carburetor engines.

Compression-ignition engines are specified by qualitative power control and internal mixture formation.

2. Basic Concepts

2.1. Geometric Parameters

By the principle of working processes organization, one distinguishes ***two- and four-stroke PIC engines***. The stroke is the totality of processes occurring in the engine cylinder as the piston travels between the top and the bottom dead centers. In a four-stroke IC engine the working processes are realized during two crankshaft revolutions, whereas in a two-stroke engine - during one revolution.

2.2. Air Access Coefficient

Depending on the engine-operating mode the fuel-air mixture may have different relative content of fuel and air. The fuel-air mixture composition is estimated by the excess-air coefficient α.

The ratio of the mass of air contained in the mixture to its minimal mass which is theoretically required for the complete combustion of the whole fuel portion is called the excess-air coefficient - α:
$\alpha = 1$ – stoichiometric mixture;
$\alpha < 1$ – reach (with fuel) mixture;
$\alpha > 1$ – lean (with fuel) mixture.

2.3. Filling Efficiency

The amount of fresh charge admitted into the cylinder by the end of the intake process is influenced by:
- the level of hydraulic losses in the intake duct;
- heating of the fresh charge;
- the amount of the residual gases.

The intake process perfection is estimated by the filling efficiency η_v which is the ratio of the amount of the fresh charge that fills the cylinder to such an amount of the fresh charge which could theoretically fill the displacement volume if the pressure and temperature in the cylinder at the end point of the intake stroke are equal to the pressure and temperature of the fresh charge at intake.

2.4. Valve Timing Phases

In the actual cycle the beginning and end of the intake and exhaust processes do not correspond to the beginning and end of the intake and output strokes. The periods expressed in degrees of crank rotation angle during which the valves are open or closed are called the timing phases.

The instant of exhaust process start is adjusted to minimize the sum of the following parameters (Figure 2):
- losses of useful work during the free exhaust;
- work spent for the forced exhaust.

The period, when both the valves are open is called the valves' overlap; a' - r - b" –

valves' overlap period during which the blow down of the cylinder is realized.

Blow down of the cylinder – the fresh charge is entering the cylinder through the intake valve and the exhaust gases and part of the residual gases are evacuated through the exhaust valve.

Usually the intake valve is closed after the BDC and the compression process starts.
If $p_k > p$ at the beginning of the compression stroke the filling process continues.
This process is called charging.

If $p_k < p$ during the period of intake valve closure retard, the piston expels a portion of the fresh charge from the cylinder back to the intake system: the back throw takes place.

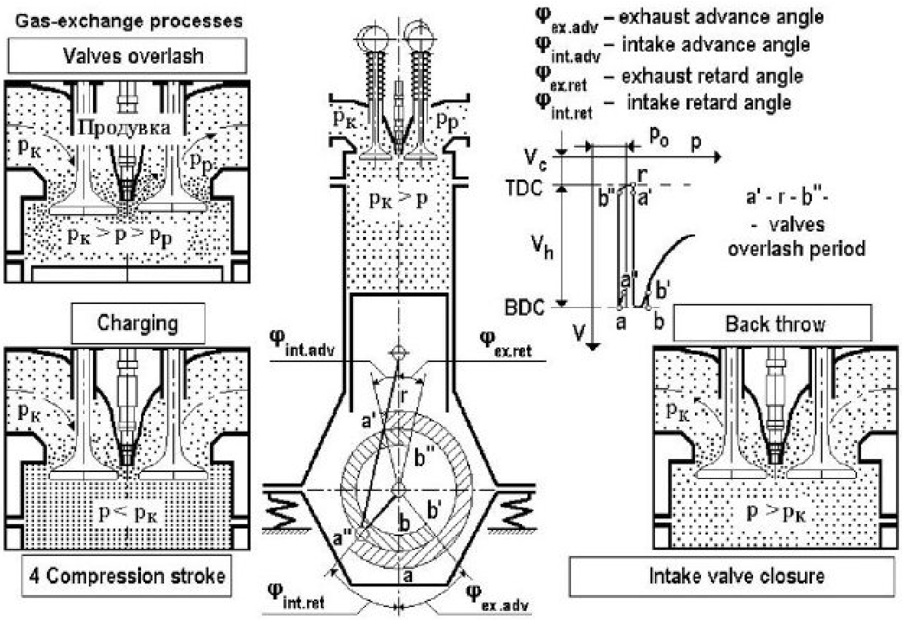

Figure 2: Valve Timing Phases

2.5. Energy Balance of a Piston-type Internal Combustion Engine

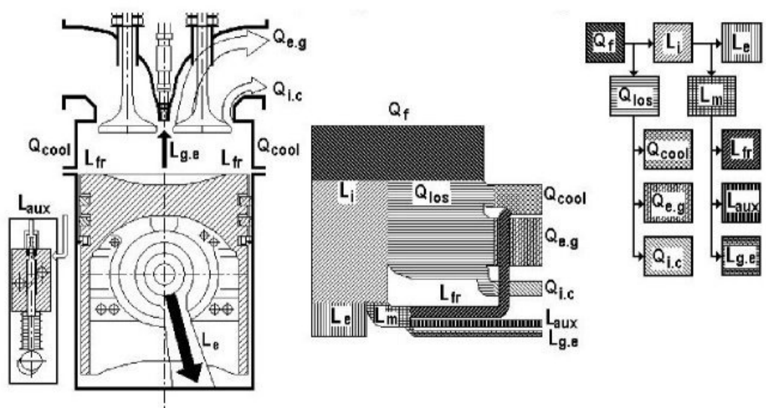

Figure 3: Energy balance of a piston-type internal combustion engine

$Q_f = G_{cf} \cdot H_u$ - heat fed to engine cylinder during its whole working cycle; G_{cf} - cycle fuel delivery; H_u – lower heating value.
The heat Q_f is spent for (Figure 3): performing the indicated work L_i; heat losses Q_{los}.
The indicated work is spent for: performing useful (effective) work L_e; overcoming the losses inside the engine (mechanical losses) - L_m.

The indicated work L_i is the surplus work of the compression - L_{exp} and expansion - L_{exp} strokes.
$L_i = L_{exp} - |L_{com}|$.

Q_{los} comprises: heat losses into the cooling system - Q_{cool}; heat losses with the exhaust gases - $Q_{e.g}$; heat losses due to incomplete combustion - $Q_{i.c}$; heat losses during the gas-exchange processes - $Q_{g.e}$.

Mechanical losses are summarized as the work lost for: friction losses - L_{fr}; auxiliary mechanisms drive losses - L_{aux}; gas-exchange processes realization- $L_{g.e}$.

The energy balance shows how the energy obtained at the complete combustion of the whole fuel portion fed to the cylinder per one working cycle Q_f is divided into the useful (effective work) L_e and main kinds of losses.

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Biographical Sketches

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