ANALYSIS OF CHARACTERISTIC DESIGN FEATURES OF SMALL INDUSTRIAL COMBUSTION ENGINES

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Abstract
Analysis of design features of small combustion engines produced within last years by worldwide best-known companies has been performed. The application areas of particular engine type (two-stroke engines, four-stroke engines) have been analyzed with regard to their design features. Engine swept volume has been taken as the common reference value for all types of engines. Trends in development of small combustion engines have been shown.

Introduction

Present article came into being based on unpublished wide elaboration's relating analyses of design of small off-road engines. As exit - point it was introduced a review of engines produced in preceding decade by most renowned world firms, and exploited more than once with success even to present day and also the engines of latest generation produced by currently most recognized producers in the world. It is very probable that when certain companies have obtained irrefutable domination in this range nowadays, its successes are at present most adequate in relation to market requirements. However does not have to mean that it is the best solution from theoretical or scientifically point of view. Simply they are introduced at present most optimum solutions, realizing not only more and more demanding requirements of users but also consistent with legal requirements obligatory in the world. Considering that all comparisons with reference to these of design one can with large simplification specify more exactly idea of new generation.

For needs of this elaboration there certain selection has been introduced on the base of partition of engines in industry application (criterion determined by engine swept volume):
1. Engines - up to 100 cc,
2. Engines – in the range of 100 -150 cc,
3. Engines – in the range of 150 - 250 cc,
4. Engines – above 250 cc.

Characteristic parameters for outboard engines can be analyzed under very different aspects, selected applications depending on needs and interests. Hereby one introduced general comparisons of latest designs with indication of differences and of development tendencies. Conclusions from the point of view of protection of company secret of design one can draw out only on the base of given catalogue and not on results of researches whether constructional or technological. Present work can be treated as introduction and can determine only beginning of detailed analyses. Prognosis of directions of development of construction of small engines is
difficult. Taking into account connection with many spheres of science, techniques and technology, without deep knowledge of progress in these spheres - one cannot give of concrete prognoses.

Realizing of theme could be done on accessible of given lists of select parameters. These data requires properly selection in manner giving possibility of comparisons and exploitation properties. Work was based on realization of compositions of engine parameters (not shown because of limited paper volume) and on graphic illustrating analyses of results, which is a very accessible manner of simultaneous review of large given quantities. For every of these four groups it can be presented graphs, which can determine initial point of carrying out comparative analysis.

**Structure of classes of swept volume**

In each classes of swept volume observed is diverse of participation of each category of engines. Figure 1 introduces proportional participation of uses of engine types:

A. Carburetor two-stroke engines
B. Four-stroke overhead valve (OHV) with carburetor
C. Four-stroke side valve (SV) with carburetor
D. Compression ignition (CI) four-stroke
E. Compression ignition two-stroke

![Fig. 1. Participation of engine types in individual classes of swept volume](image)

Engine class of swept volume below 100 cc belongs to two-stroke engines. Participation of this type of engines decreases with growing of swept volume.

**Engines of swept volume to 100 cc**

These engines are source of drive of not large devices held immediately by user and moved in place of work with power of human muscle. Limited range of use, from regard on not large useful power causes, that very essential factor formative utilization of these engines is their price. For this reason producers of such engines try to obtain a maximum simply construction of engine to diminish to minimum costs of production. This is attained for the price of highest fuel specific consumption (wastes of fuel) what influences on costs of exploitation, but it is not so significant in this class of swept volume. This one should explain almost classical design of two-stroke engine in these applications i.e. only the engines with ignition spark and with piston-
system of timing. Usage of other kind of engines has only symbolical character connected rather with investigations by researches and with experiences. However they are commonly used in cross motorcycles as a result of big specific power.

Requirements set to these engines [3] extorted given below exploitation parameters, which are attained by all counting on market products:

- individual low unit mass in borders 3, 75 - 2, 0 [kg/kW]
- high unit power 25 - 40 [kW/dm³]
- small dimensions
- low level of natural vibration
- adaptation to work in at least two positions.

Getting a low unit mass of this class of engines is most important criteria. Well visibly decrease of mass up to 30% to new designed engines is achieved by:

- general used of thin-walled die-casting,
- general used of plastics,
- chrome plating of cylinder,
- production of elements by press-forming technology and powder sintering technology,
- general used of floatless carburetors.

Characteristic feature of die-casting is used in production of cylinder heads, cylinders and crankshaft mini-block. Die-casting elements of engine often take over the function of tool carrier.

Compression ratio of newest generation small two stroke engines achieves value $\varepsilon = 5 - 7$, regardless of power of engine (Fig.2). It is lower value than that of this parameter in older generation of engines ($\varepsilon = 7 - 9$) and includes lower range of value. This trend concern only to this class of swept volume. In other classes this situation is distinctness. Relation of stroke to bore of cylinder (S/D) amounts about value 0,9 and is lower than value of this parameter in older generation of engines.

![Fig. 2. Influence of compression ratio on engine power](image)

![Fig. 3. Influence of stroke/bore ratio on engine power](image)
This tendency is shown in Fig. 3. There is not to observe the change of this parameter as a function of power of engine. Piston speeds of newest generation of small two stroke engines amounts \( c \leq 7 \text{ m/s} \). It is lower than value of this parameter in older generation of engines \( c \leq 9 \text{ m/s} \).

At supposed rotation speed of engine the stroke of piston is selected so that its speed does not achieve too high values, because it influences unfavorably on dynamic load of piston-crank unit. Value of rotation speed in this group of newest generation of small two stroke engines (out of special individual application) oscillates around 3500 \([\text{1/min}]\). In 80\% case of newest design of this generation of two-stroke engines the rotation speed of engine amounts 3000 - 3600 \([\text{1/min}]\). Receiver of power is adjusted exactly to engine by right transmission unit. At assumption of variation of engine torque often reed-valve is used. It helps to achieve a nominal rotation speed by full load of engine, because these engines worked without gearboxes.

**Engines of swept volume 100 – 150 cc**

In this group of engines often and often are four-stroke engines used in placing two-stroke, for which (by increase of swept volume) well known malfunctions are visible. Cost of production of four-stroke engines are similar to the cost of production of the newest generation environmentally friendly two stroke engines. Since a technological barrier exists, which prevents in design of two-stroke engines, removing of such disadvantage as: low effective pressure, high unit fuel consumption and high exhaust gases pollution without obvious design complication is not possible. Proportions in which these two kinds appear of engines are identical. In comparison to above category of swept volume compression ratio grows up and achieves always value \( \varepsilon = 8 \) (Fig.4). The trend is to decrease of weight of engine by identical swept volume or achieve identical power of engine by lower weight. It is necessary to add that for this group of engines the decrease of weight is greater than above, and amounts 40\%. A newest tendency for four-stroke engines is come back of use of side valve timing.

![Fig. 4. Variation of engine power as a dependence of compression ratio](image-url)
Engines of swept volume 150 –250 cc

In this group of swept volume using of two-stroke engine decreases to sporadic applying, where unit weight and power are more important than specific fuel consumption. The swept volume of value 250 cm³ it seems to be an upper limit that generally two-stroke engines achieve. An essence thing is more and more applying of side valve (SV) timing in four-stroke engines. Significant percent of engine design in this group are CI four-stroke engines. For SI engines in this class of swept volume may say that (like above):

- compression ratio grows up to value $\varepsilon = 8 - 10$,
- decrease of S/D ratio to value 0,7,
- decrease of piston speed to value $c = 5,4 - 7,1$.

Moreover may to getting significantly progress in decreasing of engine weight, so means that identical power is achieved by lower weight up to 50%. Comparison indexes of fuel consumption are similar for both kind of timing (OHV and SV) obtained by applying of high compression ratio level in SV engines (Honda EM 5000 $\varepsilon = 8,8$). For this type of engines there are not exactly defined dependency between swept volume and compression ratio (Fig.5).

With reference to above mentioned classes of swept volume, OHV engines are generally equipped in pressure or splashing oil system. In this case the main factor of design depend on position of engine work. In specific conditions on constant work position of the engines, there dominates a splashing oil system. With lubrication system is exactly connected a kind of bearings of connecting rod, crankshaft and camshaft. Generally with pressure oil system there are applied slide-bearings. A slide bearing is generally located in big end of connecting rod and preserves simultaneously a proper lubrication and cooling of these elements by guide rings and slingers systems. To characteristic properties of OHV small engines appropriately it can include complete generally using of wave pushers. The wave pusher is lighter than traditionally design and decreases a dynamic load in timing system by lower values of acceleration. It influences favorably on durability of this system.

![Fig. 5. Compression ratio as a function of swept volume 150 – 250 cc](image)

Engines of swept volume above 250 cc

In this group of swept volume there concentrate a use of SI four-stroke OHV and SV engines and CI four-stroke engines. With increase of swept volume an increase of part of CI
four-stroke engines is observed. In this case there appear on large-scale direct injected CI engines. At low swept volume of direct injection engines the most important are difficulties to obtain a low time of ignition delay.

Till now it is one of the basic conditions to create good engine response and to reduce of engine noise. According to this situation there keep on high level on the market particularly a portion of side valve engines. For SI engines in this class of swept volume may say that (like above):

- compression ratio grove up to value not higher than \( \varepsilon = 10 \),
- decrease S/D ratio to value 0,7 in modern designed engines (Fig.6),
- decrease of piston speed to value \( c = 5,4 - 7,1 \).

![Fig. 6. Distribution of swept volume and stroke/bore ratio in engine class above 250 cc](image)

It is behavioral opportunity to get engine power in border from 4 to 16 [kW] by identical value of rotational speed and in modern designed engines it is set on constant level 3000 or 3600 [1/min]. With growing up of swept volume value, well by growing of power of engine, fuel and oil consumption there increase of role of equipment, which together with design and technology development of engines it is getting itself more perfect.

**Conclusions**

Tendencies of development of industrial engines are strictly defined and this type of engines enables realization of many working processes sometimes in heavy, arduous conditions and more than once unrealizable by man. Application on these engines in many spheres of our life and specialized branches of economy was always very large and continuously grows up. Most important areas of uses these of engines are following:

- agriculture and forestry
- subsidiary drive in different branches of industry
- building and communal economy
- sport and tourism

In every specified sphere of uses participation of internal combustion engines of small power is huge. It exerts of constant pressure on producers to keeping up the requirements of market and also introducing of continuous changes, base of which is progress in related spheres of industry. One of these branches is first of all metallurgy and chemical industry. It influences on application in engines much more of plastics and improves quality of oils, fuels, materials on filters and catalysts.

Industrial engines occupy much more places in aspect of uses than car engines and for this
reason have to fulfill much more than last one greater requirements of versatilities and universalities. There should remember that they are intended to use by persons often unskilled and at this case industrial engines have to assure safety work, facility of service and reliability.

References