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Original Research Article

Mechanical load of piston applied in downsized engine

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ABSTRACT

Carbon dioxides, which take part in greenhouse effect and rapid increase of the prices of fuels, are the major reason why it is necessary to design low fuel consumption engines. Automotive sector is one of the few sectors where CO_2 emissions are still increasing very fast, reaching a level by 26% in total only from road transport. So, the European Union acts program in cutting overall emission of greenhouse gases and engineers have to care about environment.

One of the methods that affect lower fuel consumption is engine downsizing. Downsizing is a method to reduce fuel consumption by decreasing engine swept volume. To achieve the same level of performance it is necessary to apply many techniques, with charging being the first of all. Other suitable techniques e.g. variable valve timing or variable compression ratio are used with various combinations.

The subject of this paper was chosen because downsizing is a very interesting trend in automotive engineering. Lots of engines' manufacturers develop and introduce this method. Moreover ecology and economy are also relevant. The paper considers the downsizing method in case of piston. Analysed parameters e.g. Huber–Mises stress and transitional vector displacement in piston before and after downsizing were studied with Finite Element Method approach.

1. Downsizing internal combustion engine

Downsizing in relation to the internal combustion engine is a reduction in swept volume while keeping or increasing engine power [1–5].

Swept volume is usually created by cylinder diameter and piston stroke [6–9] These geometrical parameters and relations between them as factors after and before downsizing decide about downsizing ratio (1) which determinates combustion process as well as thermal and mechanical loads of engine components [2,4,5].

$$W_d = 1 - \left(\frac{V_{sd}}{V_s}\right) = 1 - \left(\frac{S_d(\pi D_d^2/4)}{S(\pi D^2/4)}\right) = 1 - \left(\frac{S_d D_d^2}{SD^2}\right) \tag{1}$$

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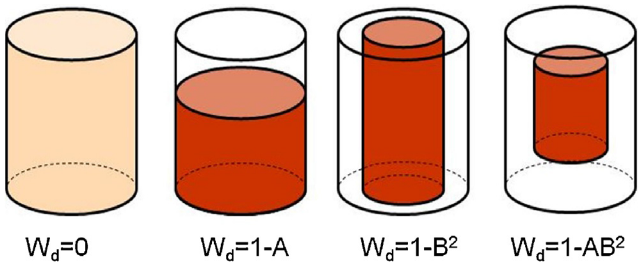

Fig. 1 – Variants of downsizing and corresponding ratios [4].

status:

W_d – downsizing ratio,
V_s – swept volume for one cylinder before downsizing,
V_{sd} – swept volume for one cylinder after downsizing,
S – piston stroke before downsizing,
S_d – piston stroke after downsizing,
D – cylinder diameter before downsizing,
D_d – cylinder diameter after downsizing.

$$\text{if} \quad A = \frac{S_d}{S} \qquad B = \frac{D_d}{D} \qquad W_d = 1 - AB^2 \tag{2}$$

status:

A – downsizing factor for piston stroke,
B – downsizing factor for cylinder diameter.

Downsizing can be implemented in three variants: the reduced stroke ($W_d = 1 - A$), the reduced diameter ($W_d = 1 - B^2$) and by mixed ($W_d = 1 - AB^2$) – Fig. 1.

Thanks to engine downsizing it is possible to achieve not only CO_2 reduction because of lower fuel consumption but also lower mass and size of the engine.

Fundamentals parameter for designing and operation of engine is brake mean effective pressure (p_e) [7,8,10]. So, if it is considered against downsizing to recognize changing of loads it will be transformed as is followed in Fig. 2.

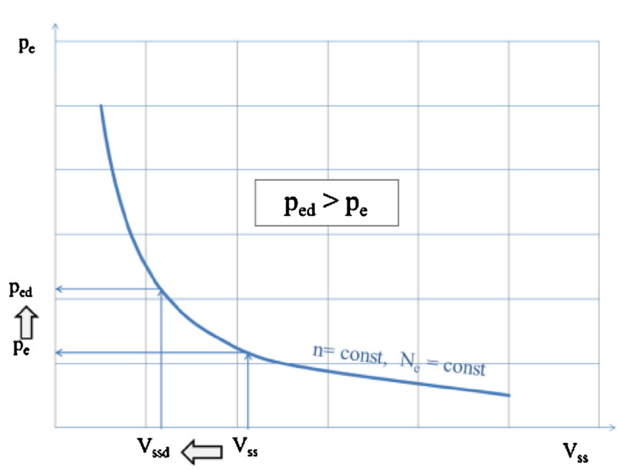

Fig. 2 – Relation mean effective pressure (p_e) vs. swept volume of engine (V_{ss}) for constant values of engine speed (n) and power (N_e) [4]. Index "d" means after downsizing.

Taking into account A and B factors, p_{ed} changes to p_e with formulas.

$$p_{ed} = p_e\left(\frac{V_{ss}}{V_{ssd}}\right) \tag{3}$$

$$p_{ed} = p_e\frac{1}{A}\left(\frac{1}{B}\right)^2 = p_e\frac{1}{AB^2} \tag{4}$$

It means, that gathering downsizing factors it is possible to evaluate loads states of engine components – piston in this case.

2. Piston design and engine performance

The task included in this article is a theoretical introduction to the further modernization works in the project over the downsizing technique to reduce fuel consumption and protect the environment.

To make virtual analysis of engine performance and mechanical load, the piston from real engine was studied.

So, actual data about geometry and materials' properties were equipped from 530i engine manufactured by BMW company [11]. The engine is mounted in a personal car and its technical data fully prefer it to apply the idea of downsizing.

Piston is a very important part of combustion engine, fulfilling several functions as follow [6–9]:

- transfer of gas force,
- kinematic guidance (sometimes with cross head),
- sealing (in combination with piston rings):
  - of crank case against combustion gas blow-by,
  - of combustion chamber against oil blow-by,
- shaping the combustion chamber.

The performance of engine strongly depends on piston work. This is the reason, why it is necessary to develop this part of combustion engine, especially when design of engine is changed.

Specifications of the tested engine [11] were used in reverse engineering to determine the thermodynamic cycle, defining the changes in pressure in the combustion chamber, which were the basis for the designation of the forces acting on the walls of the chamber, including the piston. The swept volume is changed and the support techniques (boost and variable valve timing) are used to determine changes in the operating factors of the engine after downsizing – as below.

In this case engine downsizing was analysed where piston stroke was not changed and cylinder diameter was reduced by 13%, giving downsizing ratio about 0.25.

Swept volume of base engine is $V = 2979$ ccm, giving 27.5 kW of power per one cylinder. It was downsized to $V_d = 2250$ ccm and power of 26.9 kW for a cylinder.

To keep good performance, a charging was applied from 0.1 to 0.13 MPa that increased filling ratio by 40.9%. To avoid