THE ARCHIVES OF MECHANICAL ENGINEERING

VOL. LIII 2006 Number 4

Key words: analysis tolerance, engine crankshaft, geometrical analysis of crankshaft system

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ASSEMBLING OPERATIONS AND TOLERANCE ANALYSIS OF COMBUSTION ENGINE CRANKSHAFT SYSTEM

The volume of combustion chamber consists of head and cylinder spaces. The distribution of volumes in the cylinder depends on accuracy of dimensions, determined by the production process, and precision of the crankshaft system assembling. Therefore, the aim of this work is to present a correct method of assembling, and give an example of analysis of crankshaft system dimensions based on the engine family type Wola-135TC.

1. Introduction

Every contemporary internal combustion engine has been created in the result of work of many generations of design engineers, and the need of perfecting the engines has stimulated the development of design, assembling and calculation methods [1]. The main dimensions that determine correctness of the crankshaft system assembling are: selected dimensions of the body, diameter of the cylinder liner, the distance between the piston pinhole axis and the plane of piston crown, the spacing of the connecting-rod hole axes, the size of the crankshaft inside crank, the fit of pins and holes (the clearances), and the injection advance angle α. The change of combustion chamber volume in individual cylinders plays an important role in design, assembling and technological analysis, as it affects exploitation parameters and smoothness of operation. The engine accuracy is a function of manufacturing precision of individual parts and assembly subunits. The conditions and methods for obtaining adequate precision of engine assembling depend on the distribution of deviations and tolerances of fit, strain deviations (i.e. tightening of screwed joints, forced-in joints, etc.), deviations of unbalance (for example unbalance

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of the crankshaft system), and others. If the above-mentioned deviations exceed permissible tolerances, one must take the assembling to be incorrectly done. The engine assembling process should be carried out in accordance with the technical documentation. It is not allowed to assemble parts and/or subassemblies that are insufficiently clean or damaged.

2. Assembling operations and crankshaft system description

In assembling the crankshaft system, one performs this operation for two subassemblies: the piston with rings, and the connecting rod with half-sleeves and the bush. Assembling these subassemblies into the piston-connecting-rod unit is done after bringing up the piston to a temperature of 140°C. After removing the piston-ring subassembly from the heating cabinet, the connecting rod head is inserted between the piston bosses, and the pin lubricated with oil is used to join the connecting rod and the piston. Then, the pin is secured with stopper rings (Fig. 1).

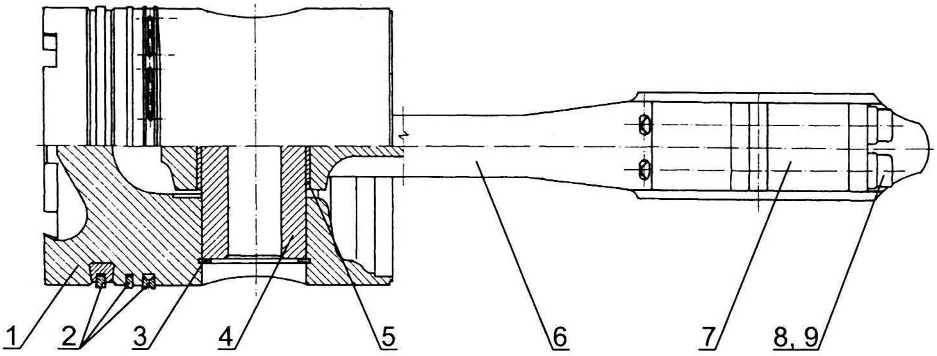

Fig. 1. Piston-connecting-rod assembling set: 1) piston, 2) rings, 3) stopper rings, 4) pin, 5) connecting-rod sleeve, 6) connecting rod, 7) connecting-rod half-sleeve, 8, 9) bolt and sleeve

After assembling the cylinder liners of the crankshaft casing, one performs the XO operation in the body, which consists in putting together the piston-connecting rod subassemblies. The XO operation consists of four basic actions:

X1 – Unscrew the bolts that fix the connecting rods caps, and remove the caps. When disconnecting the cap and the connecting rod shank, one should not fully unscrew the two connecting-rod bolts that are passed through the positioning sleeves in the cap.

X2 – Mount the half-sleeves in accordance with the numbers that are engraved on the rings and on the connecting rods. When assembling the half-sleeves and the piston-connecting-rod subassemblies, one must not tolerate any impurities nether on the sliding surfaces of the pistons, nor on the shaft neck. The set of pistons must consist of piston of equal masses (for example, for pistons of 135 mm diameter from the same selection group, allowable mass difference is 25 g). Similarly, in the set of mass-calibrated connecting rods, the mass difference is 25 g.

X3 – From the set of pistons with connecting rods selected for the engine, take the piston and the connecting rod with the number engraved on its big end that is consistent with the number of the cylinder in which this subassembly will be mounted. The piston ring-joints must be positioned at 120° with respect to one another. Then, by means of a special conical assembling sleeve, insert the piston with the connecting rod into the cylinder liner. Next, assemble the appropriate connecting-rod cap (according to the big end number), and fix it to the connecting-rod big end with the bolts, screwing the bolts home to refusal. Individual bolts must be screwed in with passages of 60° across the diagonal. Before the piston with the connecting rod is inserted into the cylinder liner, the piston skirt with the rings, the sleeve, the crankshaft neck and the connecting-rod bush must be lubricated with oil.

X4 – After assembling the piston-connecting-rod subassemblies, one must check the axial clearance of connecting rods, and measure the projection of piston crown in its top dead centre point over the upper plane of the body (contact line in Fig. 2). For example, this projection must not exceed 0.235 mm for the engine Wola-135R6. After assembling the piston-connecting-rod subassemblies, one proceeds to assembling the heads.

Fig. 2 presents a schematic diagram of one cylinder of a compression-ignition engine with names of its main elements. The abbreviated notation "contact" means the common contact plane of the cylinder liner and the head, while the label "level" indicates the lower reference plain in the engine body. Capital letters (A, B, ...) indicate toleranced linear dimensions of the engine elements.

Based on Fig. 2, we can perform tolerance analysis for the crankshaft system, and determine the functions of combustion-chamber height change $H = f(A, B, \dots, \alpha, D_i)$. By doing so, we obtain the volume of the cylinder combustion chamber, limited by the piston crown from the bottom and the contact surface from the top, equal to

$$V = \frac{\pi \cdot D^2}{4} \cdot H \tag{1}$$

where: D – piston diameter, H – height of combustion chamber at the moment of injection start.

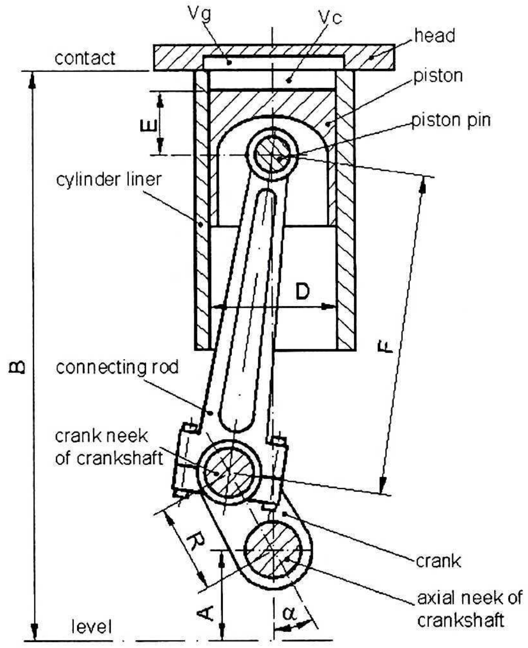

Fig. 2. Schematic diagram of one cylinder of single-row Diesel engine

3. Geometrical analysis of crankshaft system

The volume V of the cylinder combustion chamber depends on toleranced dimensions of the crankshaft system elements, and also on the injection advance angle α. In the analysis, we neglect the influence of temperature on thermal dilatability of individual parts and do not take into account the crankshaft system dynamic properties (extension of this analysis can be done in a PhD thesis). In other words, we neglect all kinds of unbalances of rotating masses, etc. The numerical values of dimensions of the Wola-135TC engine, needed to calculate the tolerances of combustion chamber volume ($T_v = V_{max} - V_{min}$), are given in Table 1 and in sketches of the individual parts, which are assembled in the analyzed crankshaft system (Fig. 3).

A dimensioned schematic drawing of the crankshaft system of Figs. 2 and 3, shown in Fig. 4, was prepared for the use in the geometrical analysis.

Based on this scheme, we derive the analytical formulae for the height H of combustion chamber shown below:

$$H = B - E - \frac{1}{2}D_{10} - D_s + \frac{1}{2}D_{20} - \sqrt{F^2 - R^2 \sin^2\alpha} + \frac{1}{2}D_{30} - \frac{1}{2}D_{3cz} - \\ -R\cos\alpha + \frac{1}{2}D_{40} - \frac{1}{2}D_{4cz} - A \qquad (2)$$

Table 1.

Numerical values of engine dimensions [2]

	Definition	Numerical value
A	Distance between the axis of crankshaft axial neck and the level	$130^{\pm 0,1}$
B	Distance between the contact plane and the level	$610^{\pm 0,05}$
D	Diameter of cylinder liner	$135^{+0,04}$
E	Distance between the piston pin axis and the piston upper plane	$100^{\pm 0,1}$
F	Distance between axes of holes in the connecting rod	$302,5^{\pm 0,05}$
R	Distance between the axes of crankshaft necks: the axial neck and the crack neck	$77,5^{\pm 0,1}$
α	Angle between the axes of connecting rod and cylinder liner (injection advance angle)	30° ± 1°

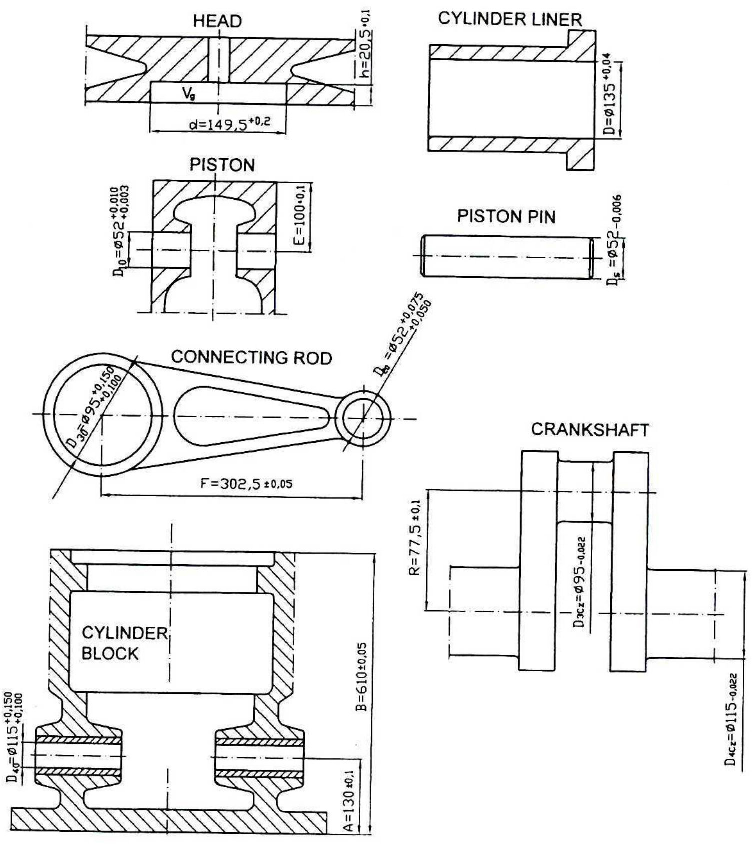

Fig. 3. Sketches of engine component parts with associated toleranced dimensions [2]

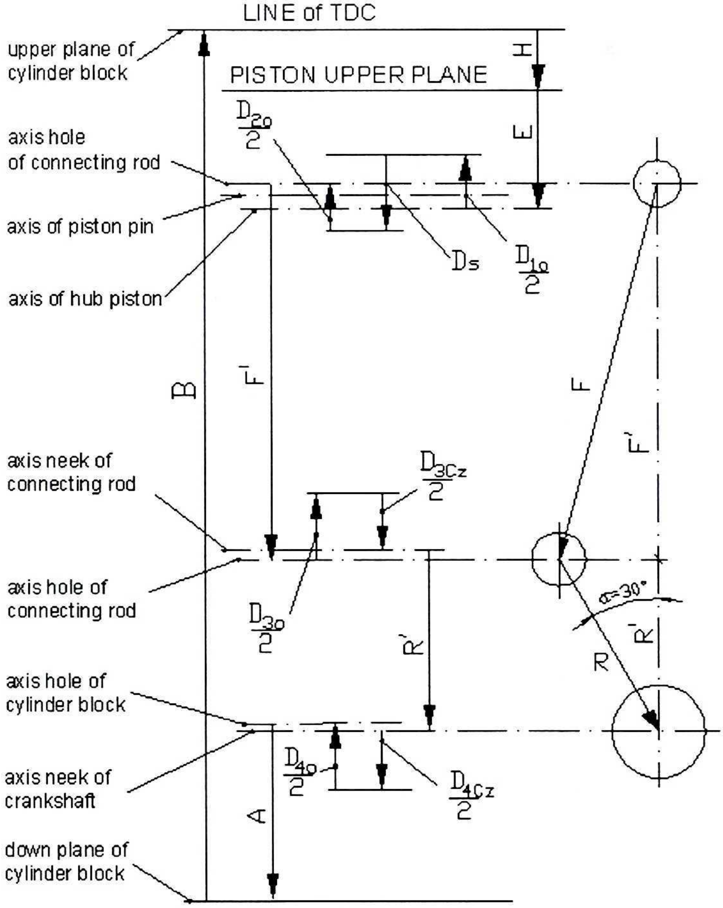

Fig. 4. Dimensioned scheme of engine crankshaft system

We then have:

$$H_{nom} = 610 - 100 - \sqrt{302,5^2 - 77,5^2 \sin^2 30^0} - 77,5 \cos 30^0 = 130 = 12,877 \text{ mm}$$

$$V_{nom} = \frac{\pi \cdot 135^2}{4} \cdot 12,877 = 184226,4 \text{ mm}^3.$$

It follows that the function needed for the analysis of combustion chamber tolerances in individual cylinders has the form:

$$V_{nom} = \frac{\pi \cdot D^2}{4} \cdot H(B, E, D_{10}, D_s, D_{20}, F, R, \alpha, D_{30}, D_{3cz}, D_{40}, D_{4cz}, A) \quad (3)$$

Having formula (2) and function (3), we can derive the equation of tolerances, as follows:

$$T_v = \frac{\pi \cdot D \cdot H}{2} \cdot T_D + \frac{\pi \cdot D^2}{4} \cdot \left(\begin{array}{l} \left|\frac{\partial H}{\partial B}\right| \cdot T_B + \left|\frac{\partial H}{\partial E}\right| \cdot T_E + \left|\frac{\partial H}{\partial D_{10}}\right| \cdot T_{D_{10}} + \left|\frac{\partial H}{\partial D_S}\right| \cdot T_{D_S} + \left|\frac{\partial H}{\partial D_{20}}\right| \cdot T_{D_{20}} + \\ + \left|\frac{\partial H}{\partial F}\right| \cdot T_F + \left|\frac{\partial H}{\partial R}\right| \cdot T_R + \left|\frac{\partial H}{\partial \alpha}\right| \cdot T_\alpha + \left|\frac{\partial H}{\partial D_{30}}\right| \cdot T_{D_{30}} + \left|\frac{\partial H}{\partial D_{3CZ}}\right| \cdot T_{D_{3CZ}} + \\ + \left|\frac{\partial H}{\partial D_{40}}\right| \cdot T_{D_{40}} + \left|\frac{\partial H}{\partial D_{4CZ}}\right| \cdot T_{D_{4CZ}} + \left|\frac{\partial H}{\partial A}\right| \cdot T_A \end{array} \right) \tag{4}$$

Based on formulae (1) and (2) we determine partial derivatives, as shown below, and calculate volume T_v of the cylinder combustion chamber:

$$\frac{\partial V}{\partial D} = \frac{\pi \cdot D \cdot H}{2}, \frac{\partial H}{\partial B} = 1, \frac{\partial H}{\partial E} = \frac{\partial H}{\partial D_S} = -1, \frac{\partial H}{\partial D_{10}} = \frac{\partial H}{\partial D_{3CZ}} = \frac{\partial H}{\partial D_{4CZ}} = -\frac{1}{2},$$

$$\frac{\partial H}{\partial A} = -1, \frac{\partial H}{\partial D_{20}} = \frac{\partial H}{\partial D_{30}} = \frac{\partial H}{\partial D_{40}} = \frac{1}{2}, \frac{\partial H}{\partial F} = -\frac{F}{\sqrt{F^2 - R^2 \sin^2 \alpha}},$$

$$\frac{\partial H}{\partial R} = \frac{R \cdot \sin^2 \alpha}{\sqrt{F^2 - R^2 \sin^2 \alpha}} - \cos \alpha, \frac{\partial H}{\partial \alpha} = -\frac{R^2 \cdot \sin \alpha \cdot \cos \alpha}{\sqrt{F^2 - R^2 \sin^2 \alpha}} + R \cdot \sin \alpha.$$

4. Numerical example for engine WOLA-135R6

Applying the dimensions given in Table 1 we have:

$$\frac{\partial V}{\partial D} = \frac{\pi \cdot 135}{2} \cdot 12,877 = 2729,28,$$

$$\frac{\partial H}{\partial F} = -\frac{302,5}{\sqrt{302,5^2 - 77,5^2 \sin^2 30^0}} = \frac{302,5}{\sqrt{90004,688}} = -1,$$

$$\frac{\partial H}{\partial R} = \frac{77.5 \cdot \sin^2 30^0}{\sqrt{90004,688}} - \cos 30^0 = 0,065 - 0,866 = -0,801,$$

$$\frac{\partial H}{\partial \alpha} = \frac{77,5^2 \cdot 0,5 \cdot 0,866}{\sqrt{90004,688}} + 77,5 \cdot 0,5 = 8,669 + 38,75 = 47,419 \text{ mm}^3.$$

The component tolerances of individual parts of the crankshaft system are given in Table 1 and in the sketches of these parts, Fig. 3. These are:
$T_D = 0,04; T_B = 0,1; T_E = 0,2; T_{D10} = 0,007; T_{Ds} = 0,006; T_{D20} = 0,025;$
$T_F = 0,1; T_R = 0,2; T_\alpha = 2^0 = 0,035\text{rd}; T_{D30} = 0,05; T_{D3cz} = 0,022;$
$T_{D40} = 0,05; T_{D4cz} = 0,022; T_A = 0,2.$
Then, the tolerance of cylinder combustion chamber equals:

$$T_V = 212 \cdot 12,877 \cdot 0,04 + \frac{\pi \cdot 135^2}{4} \cdot$$
$$\cdot \begin{pmatrix} 0,1 + 0,2 + 0,5 \cdot 0,007 + 1 \cdot 0,006 + 0,5 \cdot 0,025 + 0,1 + 0,801 \cdot 0,2 + \\ +47,419 \cdot 0,035 + 0,5 \cdot 0,05 + 0,5 \cdot 0,022 + 0,5 \cdot 0,05 + 0,5 \cdot 0,022 + 0,2 \end{pmatrix}$$

$$T_v = 109.2 + 14306.625 \cdot 2.5042 = 35970\text{mm}^3.$$

It is noticeable that maximal difference between individual cylinder volumes (volume tolerance) can be quite large, although the tolerances of individual parts of the crankshaft system are quite narrow. In a similar way, we can determine deviations of height H and volume V, which can be useful in developing the documentation for design, production and assembling purposes.

5. Conclusion

1. The geometrical analysis of crankshaft system, presented above, gives a basis for examining combustion processes in individual cylinders. It also makes it possible to evaluate thermodynamics of the whole engine [L.3], and facilitates development of design, production and assembling documentation. The presented analysis can be applied by process engineers – programmers to calculating the coordinates necessary for machining the parts on numerically-controlled machines.
2. The calculation of combustion chamber tolerances can also be useful for educational purposes, in tutorials on dimensioned analysis carried out for technical university students.

Manuscript received by Editorial Board, March 31, 2006;
final version, December 15, 2006.

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Operacje montażu i analiza tolerancji układu korbowego silnika spalinowego

Streszczenie

Na objętość komory spalania składa się przestrzeń w głowicy i cylindrze. Od dokładności wykonania wymiarów i staranności montażu układu korbowego zależy rozrzut objętości w cylindrze. Stąd w niniejszej pracy przedstawiono prawidłowy sposób montażu i dokonano analizy wymiarów układu korbowego na przykładzie rodziny silników Wola-135TC.