TECHNICAL UNIVERSITY OF CLUJ-NAPOCA
ACTA TECHNICA NAPOCENSIS
Series: Applied Mathematics, Mechanics, and Engineering
Vol. 58, Issue II, June, 2015

POSSIBILITIES OF INCREASING THE DURABILITY OF THE ARBOR TYPE COMPONENTS OF HEAT ENGINES

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Summary: *The durability and friability of heat engines are dependent on the tribological behaviour of the components and on the specific greasing conditions. The part of tribology also includes aspects of the technical conditions of the engine, the technical, functional, technological and economic criteria of deciding the limits, as well as the procedures to determine the physical and moral wearing (attrition). The process of wearing (attrition) means an unwanted modification of the dimensions and qualities of the surfaces and their position and geometrical shape. Thermic metallisation is one of the technological procedures of processing metallic materials which allows obtaining some new surfaces which fit to specific requirements. The intervention upon a worn-out piece or component in order to regain or remake the initial technical state through the application of some extra material, thus ensuring the working period and the conservation of the structure of the basic material is called reconditioning. The term reconditioning always refers to a reference point while mending refers to an entire system taken on the whole.*

Keywords: *durability, reconditioning, maintenance, shaft (arbor), attrition, metallisation.*

1. INTRODUCTION

Maintenance, according to the STAS 8174/2-77 (state standards), represents the ensemble of all technical actions and organisation actions beeing associated, done with the purpose of maintainig or restoring a technical equipment (device, machine) in the state of fulfilling a specific duty.

As a result, maintenance includes, as a single unit, the whole technical and organising system of maintaining, technical inspections and repairs, activities that ensure not only the working conditions of machines but also the restoration of the technical state in case of damage.

Maintenance is defined as any action that leads to maintaining in a properly working state of a device in utter reliability and maximal safety, and, in case of any damage of that device, set it working again in reliable and safety parameters satisfying for the operating conditions.

There is an increasing awareness of the fact that the workers that use the devices and machines ought to be responsible for the daily maintenance of them, and so, the traditional lines of demarcation between trades become inefficient. Adopting a world-wide class maintenance needs, on one hand, a better integration of maintaining activities within the company, and, on the other hand, a bigger flexibility of trades within the maintenance sub-unit. The term imposed in the Romanian economy, too, especially in the last years.

However, for many people, maintenance is mistaken for upkeep. The difference between the two terms is not only semantic. While upkeep means two categories of actions, repairs and breakdown services, maintenance asociates them new, modern elements like: follow up and statistically process the defects and the flaws, diagnose, ensure quality, processing data. The first law of maintenance can be expressed as this: ineffective machines characterised by a high rate of breakdowns as well as the losses generated by them can be avoided through the design and settings of a proper maintenance system. Many years ago, in the specialised literature in Romania, the “activity of upkeep and repairs” started to be in the focus of specialists, being approached in strict connection to the rest of the activities done within the industrial units, generally based onto an excessively rigid planning.

Momentary or short term interests of the manager seem to motivate the disregard of maintenance but the long term ones are surely compromised by such an attitude. The activity of maintenance must be considered as an investment in the future. The average working time of the machines from one breakdown to another, the lenght of time and the quality of of the maintenance operations can be considered critical elements for the available time of the machines and for the profitableness of the economical unit.

2. THE CRANK AND CONNECTING ROD MECHANISM OF HEAT ENGINES

Due to their construction, heat engines are made of mobile parts, generically called crank mechanism (or crank and connecting-rod mechanism), and immobile components. The crank mechanism is not only under the actions of forces produced by combustion, but also the forces of inertia.

The state uf wearing (attrition) of the crank and connecting-rod mechanism determines the time intervals between the overhauls of the heat engines, trying to ensure a durability as high as it can be, especially in the case of the crankshaft [5].

In most cases of heat engines, an axled or spindled crank and connecting-rod mechanism is used [fig. 1, a] for which the rotation axix of the crankshaft has a point of intersection with the axis of the cylinder. Different from this type of construction it is possible to use offset axis mechanism [Fig. 1, b].

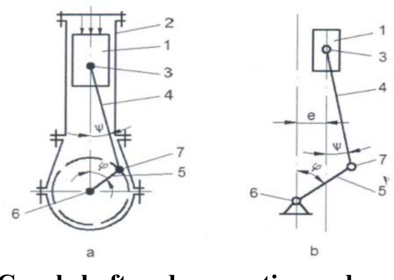

Fig. 1. Crankshaft and connecting rod mechanism
a - axled; b – off set axis; 1 - piston; 2 - cylinder; 3- bolt; 4- connecting rod; 5- crankshaft arm; 6 – drive shaft; 7- crankpin.

The characteristic of the crank and connecting-rod mechanism is the ratio λ = r / l (λ ≤ 1 / 5), where r is the radius of the crankshaft and l is the lenght of the connecting-rod (or simply conrod). The kinematics of the component parts of the crank and connecting-rod mechanism is studied in stabilised working conditions of the engine for which we consider the angular speed of the crankshaft as being constant.

The position of the crank and connecting-rod mechanism is specified by the angle φ made by the crank throw with the axis of the cylinder in the direction of rotation and by the inclination angle of the connecting rod to the axis of the cylinder ψ. The influence of being offset axled can not be omitted in order to determine the position of the piston while doing a full piston stroke as important errors may appear (about 25 % for $\varphi = \pi / 2$).

The mathematical formulas used to determine the space x, the velocity and acceleration are esteblished according to the type of driving mechanism and are presented in table 1. Mathematical formulas for calculating s, v, and a.

Table 1.

Axled crank and connecting-rod mechanism	The law o the motion coursed by the piston	$x = r\,[(1-\cos\varphi) \pm \frac{\lambda}{4}(1-\cos 2\varphi)]$
	The law of the velocity of the piston	$v = r\omega\left(\sin\varphi \pm \frac{\lambda}{2} sin2\varphi\right)$
	The law of acceleration	$a = r\omega^2 (\cos\varphi \pm \lambda cos2\varphi)$
Offset axis crank and connecting-rod mechanism	The law o the motion coursed by the piston	$x = r\,[(1-\cos\varphi) \pm \frac{\lambda}{4}(1-\cos 2\varphi) + \lambda K \sin\varphi]$ $K = \frac{e}{r}$ where e is the value of distance between axes
	The law of the velocity of the piston	$v = r\omega\left(\sin\varphi \pm \frac{\lambda}{2} sin2\varphi + \lambda K sin\,\varphi\right.$
	The law of acceleration	$a = r\omega^2 (\cos\varphi \pm \lambda cos2\varphi - \lambda K sin\,\varphi)$
		$\omega = \frac{\pi n}{30}$

From the analysis of the formulas from table 1 results that the motion coursed by the piston of the mechanism (piston stroke) from fig. 1, b differs from the one in fig. 1, a and the difference is "$\lambda K sin\,\varphi$" that takes the distance between the axes into consideration. The motion coursed by the piston in the case of offset axled crank and connecting-rod mechanisms is higher than in the case of axled ones (actually $\lambda K = 1{,}10 \dots 0{,}06$, for usual values used in engine construction.

In case of running an engine, mainly the following forces act upon the elements of the crank and connecting-rod mechanism: the forces generated by the pressure of the gases in the cylinder, forces of inertia, forces of friction (attrition) and forces generated by the own weight of the system.

The forces produced by the pressure of the gases are inner forces that balance inside the engine and are not transmitted to the supports. The resulting force of the gas pressure in the cylinder applied to the head of the piston is given by the formula [4]:

$$F_p = \frac{\pi D^2}{4} (p_g - p_0), \qquad (1)$$

where :D is the diameter of the cylinder

P_g – the indicated pressure of gases (daN / cm^2)

P_0 – the pressure of the environment (daN / cm^2)

The forces of inertia are produced by the masses of the moving parts of the crank and connecting-rod mechanism having an accelerated movement: the piston, the connecting rod and the crankshaft. According to the type of of movement of these masses we can group them as inertia produced by the components making a translatory motion, inertia produced by the components making a rotary (rotational) motion and the connecting rod's own inertia. On the whole, these forces are transmitted outwardly from the mechanism to the supports, consequently causing vibrations of the engine.

If the engine is rigidly fixed on a frame, the forces acting upon the cylinder would be felt by that frame. In the case of an engine that is elastically fixed on a frame, the forces are not transmitted outwardly to that frame.

In the case of poly-cylindrical engines, the forces of inertia can form a moment of force tending to capsize in the plane of the cylinders, and after that, according to the position of the cylinders and pistons, these forces can be totalized or they can reciprocally counterbalance each other.

The inertia caused by the components that form the piston group (the piston, the segments and the bolt) is given by the formula obtained by taking into consideration the first two terms from the developing of the series of the following relation:

$$a = r\omega^2 (\cos\varphi \pm \lambda cos2\varphi) \qquad (2)$$

The force of inertia F_{ir} is calculated with the realation:

$$F_{ir} = m_p a_p = \pm\, m_p\, r\omega^2 (\cos\varphi \pm \lambda cos2\varphi) \quad (3)$$

where: m_p is the total mass of the components

a_p is the acceleration of the piston

The inertia calculated through the formula (3) acts along the axis of the cylinder having a varying direction through a full cycle (ful piston stroke), always opposing the acceleration and, consequently, it is summed up to or extracted from the force given by the pressure of the gases F_p, formula (1).

The inertia of the components doing a rotary motion is calculated with a formula like:

$$F_{ir} = m_r \rho_g \omega^2 \qquad (4)$$

where: m_r is the mass of the components having a rotary movement concentrated in the centre of gravity

ρ_g is the radius of the centre of gravity to the rotational axis.

For the crankshaft, taking account of all its components and the position of the centre of gravity of each part (crank arms, shafts, crank pin, counterweights) the formula can be: [4]

$$F_{ir} = \omega^2 (m_{bc}\rho_{Gbc} + m_{cg}\rho_{Gcg} + m_{fm}\rho_{Gfm}) \quad (5)$$

where the indexes refer to crank arms (bc), counterweights (cg) and shifts (fm).

The force F_{ir} operates in the plane of the crankshaft and can be replaced with two forces: F_{iro} – the horizontal component and F_{irv} – the vertical component (fig. 2) therefore obtaining:

$$F_{iro} = F_{ir} \sin\varphi \qquad (6)$$

$$F_{irv} = F_{ir} \cos\varphi \qquad (7)$$

The two components, F_{iro} and F_{irv} create vibrations on the cylinder axis and, respectively, on the plane perpendicular to the cylinder axis.

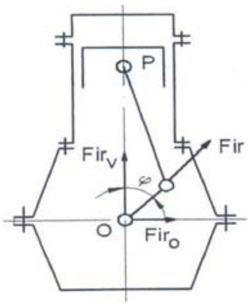

Fig. 2. Scheme of the forces of inertia

The forces of inertia of the connecting rod resulting from the plane movement of the rod will be expressed according to the corresponding to the three accelerations, an therefore we have [4]:

- The inertia corresponding to the translatory motion F_{ib1};
- The inertia corresponding to the normal acceleration of the rotary motion F_{ib2};
- The inertia corresponding to the tangent acceleration from F_{ib3};

Considering a point A of the connecting rod, situated at distance"x" to the centre of gravity of the rod, the elementar forces of inertia will be those from fig. 3.

The study of forces involved in the movement of the connecting rod in proportion to its own centre of gravity shows that the forces of inertia are reduced to a single force resulting from the translatory motion and a momentum of the couple of tangential forces of inertia M_{ib}.

The resulting force transmitted by the piston will represent the sum of forces of pressure and those of inertia.

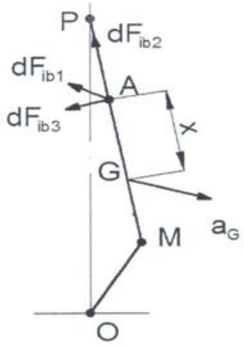

Fig. 3. Forces of inertia of the connecting rod [4]

$$F = F_p + F_i = = \frac{\pi D^2}{4}\ (p_{g} - p_o) - m_{tot}\ a_p, \quad (8)$$

where: m_{tot} is the total mass of the piston group and the part of the rod that makes the translatory movement, considered as mass concentrated in the connecting rod small end.

The force F from formula (8) can be separated into parts to the normal component of force to the cylinder and to the axis of the connecting rod (fig. 4) as follows:

$$F_n = F\ .\ \mathrm{tg}\psi \quad (9)$$

$$Fb = \frac{F}{cos\psi} \quad (10)$$

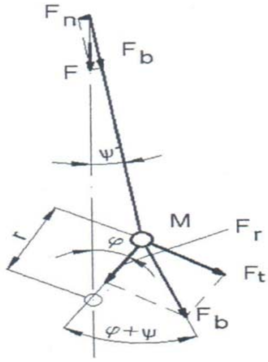

Fig. 4. Forces within the crank and connecting-rod mechanism

In the crank button (M), the force from the connecting rod can be decomposed into component F_t to the normal component to the plane of the crank throw and component F_r to the direction of the arms of the crank throws.

$$F_t = F_b \cdot \sin(\psi + \varphi) = \frac{F \sin(\psi+\varphi)}{cos\psi} \quad (11)$$

$$F_r = F_b \cdot \cos(\psi + \varphi) = \frac{F \cos(\psi+\varphi)}{cos\psi} \quad (12)$$

The momentum will be given by force F_t and it is:

$$M_t = F_b\ r \sin(\varphi + \psi) = F_t\ r \quad (13)$$

Equalising the mechanical work created by the pressure of the gasses and the equivalent mechanical work used at the crank, the following formula will result:

$$M_t \cdot d_{\varphi} = F \cdot d_s, \quad (14)$$

From which the expression of the working momentum can be otained as follows:

$$M_t = F \cdot \frac{d_s}{d_\varphi} = F \cdot r \cdot \left(sin\varphi + \frac{\lambda}{2} \cdot sin2\varphi \right) \quad (15)$$

The expression in the brackets points out the variable character of the working momentum that acts upon the main arbor of the engine even if the force F might have a constant value.

This variation in time of the driving couple, according to formula (15), causes a variation of the angular velocity throughout a full working cycle or piston stroke. In order to limit the variation of the angular velocity, the insertion of a flywheel is necessary to make the movement uniform. A direct consequence of the periodical variation of forces is the fatigue-stress of the components of the crank and connecting-rod mechanism.

3. CONSTRUCTIVE ELEMENTS OF THE CRANCKSHAFTS

The shape and size of the cranckshafts (Fig. 5) depend on a broad range of factors like: the number and position of the cylinders, stroke of the pistons, the value of the resulting pressure that acts upon each piston, the working turn of the crankshaft and so on.

The longer the course of the pistons is, the smaller the turn of the crankshaft is. In fig. 5 a crankshaft belonging to a Diesel engine is presented, the number of crank pins beeing equal to the number of cylinders. The crankshafts transmit the momentum to other components they are assembled together to.

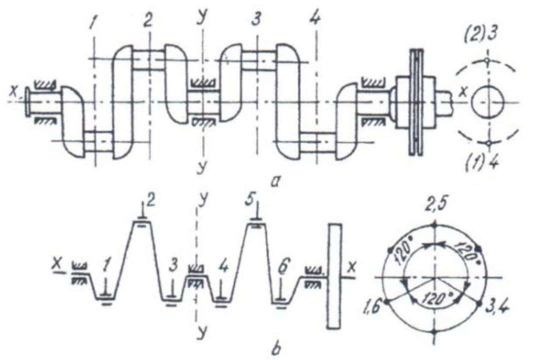

Fig. 5. Crankshaft [4]

The crankshaft consists of crankpins and crank throws. The number of crank throws is equal to the number of cylinders of an engine.

Choosing the material for crankshafts will be made according to the power of the engine, the type of the engine, the nature of stress, the working conditions as well asthe weight of the engine. There are used types of steel with $\sigma_r > 50$ daN / mm^2 , from the group of carbon steels and alloy steels. The procedures of manufacturing the semi-finished products for crankshafts are forging, moulding and so on.

For fast engines, the crankshaft is made up in one piece, (undismountable). Its constructive shape is dependent on the number and position of the cylinders, on rigidity and so on. It is prefered a construction in which each cranck throw is supported by two crankshaft bearing journal, which construction is suitable from the point of view of rigidity and is frequent at compression ignition engines. At the spark ignition engines, where the burning pressures are smaller, a decreased number of crankshaft bearing journals are used, two crankpins being integrated between two crankshaft bering journals.

4. RECONDITIONING THE CRANKSHAFTS OF HEAT ENGINES

The crankshaft is one of the most important and expensive sub-assembly of the engine and because of this, for its manufactoring, alloy steels of high resistance are used.

The procedures of reconditioning the crankshaft are:

- Cold coating (at a maximum temperature of 200 ˚C) using usual steel wires or non-ferrous materials (alloys of Al, Cu, Zn a.s.o.) on an adherent layer of Mo;
- Cold coating (at a maximum temperature of 200 ˚C) with alloy powders (with Cr, Ni, Mo, Zn, W, Co, a.s.o) on an adherent layer of Cr-Ni powder;
- Hot coating (at a temperature from 900 to 1100 200 ˚C) with alloy powders and simultaneously or intermittently sintered;

- Welding with special electrodes: uses metallic materials or powders, made up in eutectic points, resulting an additional material with a minimal temperature of deposition and the specific advantages of it.

Reconditioning through metallisation (metal covering) is a method of laying down, on mettalic or non-metallic surfaces, some layers of metals proceeded from fine particles of melted metal driven by a jet of compressed air or inert gas.

5. CONCLUSIONS

Metallisation (or metal covering) ia a performant reconditioning procedure with very good results in reconditioning crankshafts of heat engines. Hardness, tenacity as well as resistance to shear of the superficial layers increase with the application of the metallised layer.

The adherence of the pulverized (powdered) layers is a complex phenomenon, first of all of mechanical type, and, in a smaller extent, of physical or chemical one.

This depends on the following factors:

- The shape of the metallised piece;
- The roughness or rugosity of the surfaces;
- The fineness of grain (granulosity) of the pulverized particles;
- The thickness of the coat layer;
- The temperature of the pulverized particles;

The process of metallisation is followed by grinding in order to ensure a sutable quality of the surfaces in contact.

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POSIBILITĂȚI DE CREŞTERE A DURABILITĂȚII PIESELOR DE TIP ARBORE PRIN RECONDIȚIONARE DE LA MOTOARELE TERMICE

Rezumat: *Durabilitatea și fiabilitatea motoarelor termice sunt dependente de comportarea tribologică a componentelor și de regimurilor specifice de ungere. Partea de tribologie cuprinde, de asemenea, aspectele stării tehnice a motorului, criteriul tehnic, funcțional, tehnologic și economic de stabilire a stării limită, cât și procedeele de determinare a uzurii fizice și morale. Procesul de uzare înseamnă modificarea nedorită a dimensiunilor, calității suprafețelor, poziției și formei lor geometrice. Metalizarea termică este unul din procedeele tehnologice de prelucrare a materialelor metalice, care permit obținerea unor suprafețe noi, care să răspundă unor cerințe date. Intervenția asupra unei piese uzate, pentru refacerea stării tehnice inițiale prin aplicare unui material de aport, cu garantarea duratei serviciu și conservarea structurii materialului de bază se numește recondiționare. Noțiunea de recondiționare se referă totdeauna la un reper, în timp ce noțiunea de reparație se referă la un ansamblu luat în totalitate.*

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