Materials used in a construction of a camshaft mechanism

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Abstract: The paper deals with an importance of camshafts as important parts of mechanisms being used in production engineering as well as in special equipment. Material composition of camshafts together with a complexity of its profile construction and character of motion has impact on kinetic and dynamic parameters of a mechanism as well as a whole machine.

1. Introduction

Several mechanisms enabling transformation of motion, thus a change of its kind are used in mechanical engineering practice. In practice the mechanisms the most often used for a transition of a rotational movement into a straight-line one are worm-geared, screwed, camshaft and cranked ones. There are basic kinds of transformation mechanisms illustrated in the Fig. 1 – a screwed mechanism, a gear wheel and a gear rack, a worm and a worm rack, cam mechanisms, cranked mechanism centrical and eccentric, a cranked mechanism with a bar link, a cranked mechanism with a rotating block.

2. Camshaft mechanism

Camshaft and eccentric mechanisms transform a rotational motion into an advance reversible motion with a small travel. A cam is mounted on a shaft. The motion and a force are transferred from a driving shaft through a lever-type mechanism on a working unit. Requested speed and trajectory course will be reached through a cam shaping.

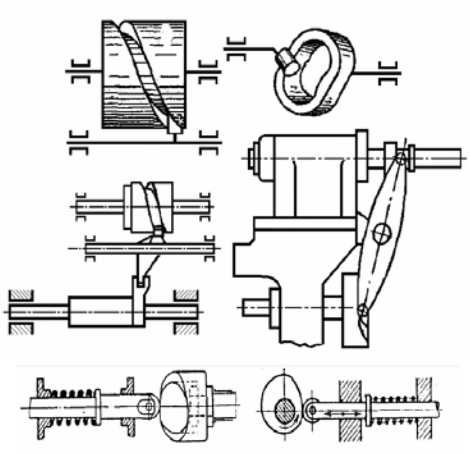

Fig.1 Examples of application of cam mechanisms for a transition of a rotation movement into a straight-line one

The cam mechanisms are plane or triaxle curvilinear mechanisms. The cam mechanisms are used to transform a rotational motion into a periodical straight-line motion, or a periodical rocking or a rotational motion (Fig.2).

From a construction view the cam mechanisms fit the best to perform short travels. The trajectories of such motions can be increased through engagement of a gearing mechanism (a gear lever or a gear lever system) with a needed gear ration between a cam and an effective body. An advantage is a simple performance of a requested motion of a driven element and a simple replacement of a kinetic relation, travel size and a motion time through a replacement of a cam.

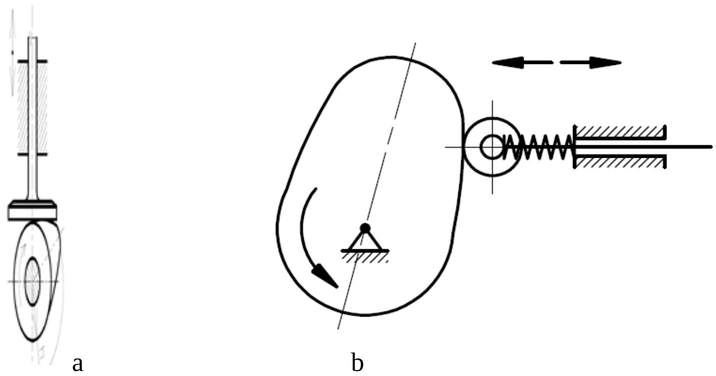

Fig. 2 Cams used in
a- automotive industry, b- in production engineering

Advantages:

Possibility to reach ideal dynamic ratios for a straight-line motion, applicability mainly for mass production automatic machines

Disadvantages:

A small travel, demanding production, higher demands on material hardness (resistance to impression and wear)

A cam mechanism consists of:

1. A frame that is a fixed part of a machine,
2. A driving element – a cam that can begin through its construction a loose (Fig.3/a) or a forced motion of an effective element of a mechanism (Fig.3/b)
3. A driven element that used to be an effective element of a mechanism (a pulley, a tappet).

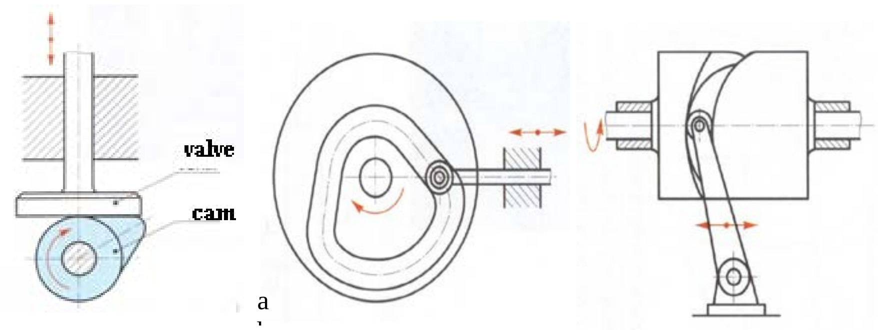

Fig. 3 Main joints of a cam with an effective body od a mechanism
a- loose joint, b- forced joint

A main element of a camshaft mechanism is a cam, an associated element is a pulley or a tappet that does not roll away as a pulley, but it slides. Contact of a pulley, a tappet is a force one and it used to be secured with a spring.

Classification of camshaft mechanisms:

- A tappet with a tip, an axis passes through a cam rotation axis (Fig.4/a),
- A tappet with a pulley, an axis passes through a cam rotation axis (Fig.4/b),
- A tappet with a pulley, the axes are skew (Fig.4/c),
- A rocker arm with a pulley (Fig.4/d),
- A flat tappet (Fig.4/e),
- A flat rocker arm (Fig.4/f).

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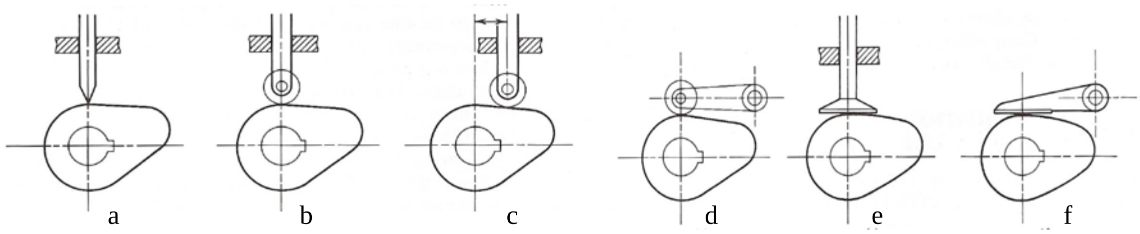

Fig.4 Kinds of cams with a different tappet construction

3. Cam production and used material

A cam – is a disk, whose each point on its circumference is a part of a circle with a slot or a nib. In fact a cam profile represents a trajectory of a motion of a driven element; an instantaneous velocity and acceleration depend of its position and subsequently its dynamic parameters as well. These parameters cause inter alia large, often impact stress on a cam, and become evident in its wear and in a change of its kinematic parameters in relation with a driven element. It finally results in non-standard parameters of bending up to mechanism destruction.

AS profile of each cam is composed of:

- A basic circle,
- Two effective parts (sides)and a cylindrical part,
- A leading and a finishing parts (a transition part).

Just a selection of a suitable material for production of a cam and mainly quality of its surface at loose as well as at forced motion is a significant factor for an application of a camshaft mechanism of a given construction in production engineering and often in special equipment as well.

A cam is a component or a component part (as an example of a camshaft) characterized by its general shape – particular points of a cam surface are at a different distance from a rotation axis. A function of a cam is to transform a rotational motion into a straight-line reversible one so that its shape in rotation causes a motion of another component leaning against a cam – e.g. in control of valves of a combustion engine (Fig.5).

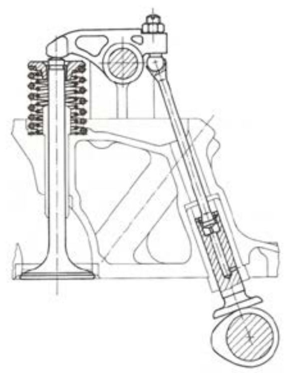
Fig.5 Camshaft mechanism for valve control

The paper deals with material composition of cams that are largely applied in mechanisms in production engineering as well as in special equipment. They exercise a significant influence on kinematic and dynamic parameters of a whole mechanism as well as a machine through their variable technical parameters and their location in a construction of mechanisms. Especially a material composition of cams predetermines their particular practical application from a view of an operational stress.

As a rule nowadays the cams are produced by milling operations on CNC machines. After then they are ground aiming to increase an accuracy and surface quality. An option is an application of a copier, where another cam serves as a counter gear. If an absolute accuracy of production is not required, the consideration about pressing operations or exact shearing comes on force. In case when the cams are heavy stressed and therefore they need to be produced from strong hardly Machin able materials, an electro erosive machining is used.

3.1 A tappet

The main task of a tappet is to absorb a tangential force from a cam and a subsequent transfer onto a distribution pushrod (Fig.4). Tappets used to be hollow bucket-type with a cylindrical profile or with a disk profile. An advantage of bucket-type tappets is a possibility to replace it without dismantling of a camshaft, on contrary, an advantage of disk tappets is a simpler production due to a cylindrical line of a smaller diameter. The mentioned valve distribution disposes of disk tappets.

A contact area with a cam (from a view of a material and a surface treatment highly significant area) used to be hardened from 50 HRC up to 60 HRC hardness, then processed through finishing technologies, in particular ground and lapped ones. A pushrod sits on a base of a tappet or on a top end. Lubrication is performed through a pressure of oil assigned for lubrication of bearings on a rocker arm.

Theoretical contact area between a cam and a tappet is a line (eventually a point). In order to prevent from a significant wear of a contact area, the tappet used to be shifted from an axis by 2mm up to 3 mm, resulting in tappet swiveling.

3.2 Cam material

A cam has homogenous mechanical features in its whole volume. Choice of a suitable material depends on a maximum value of a contact pressure in a working cycle of a cam mechanism that has been obtained by calculation from a dynamic solution of a particular cam.

Table 1. Materials used for production of a cam with no tempered surface layer

steel STN	Way of material treatment	Cam width l[mm]	Minimum tensile strength R [MPa]	Tensile yield point R_p 0,2 [MPa]	Hardness HB	Admissible pressure „p „ for 10^8 life cycles [MPa]
11 500	Thermally non-treated	130	490	265	141	313
11 600	Thermally non-treated	130	588	314	169	375
11 700	Thermally non-treated	130	686	363	197	437
12 050	Normalizing	100	530	305	152	337
12 050	Heat treatment	40	640	390	192	426
12 061	Normalizing	100	660	382	189	419

12 061	Heat treatment	40	720	420	210	466
13 240	Heat treatment	40	780	540	239	530
13 240	Heat treatment	25	880	635	269	596
14 140	Heat treatment	40	883	637	270	599
14 140	Heat treatment	100	785	539	240	532
15 241	Heat treatment	40	1177	981	359	796
15 241	Heat treatment	40	1716	1372	51 HRC	1099
16 640	Heat treatment	140	1569	1275	49 HRC	1045
14 209	Quenching	40	2100	1700	61 HRC	1392

For some cams it is more suitable to reach different features of a surface and a kernel. Mechanical features differ in a cam section. On a functional surface area the hardened layer is created through chemical-and-heat treatment, it means quenching, cementing, nitriding or a combination of technologies, nitro carburizing or carbonitriding.

Table 2 Materials for a cam with a hardened surface layer

	Kernel			Surface layer		
steel STN	Cam width l[mm]	Minimum tensile strength R [MPa]	Tensile yield point R_p 0,2 [Mpa]	Way of treatment	hardness HRC	Admissible pressure p for 10^8 life cycles [Mpa]
12 020.4	30	490	295	cementing, quenching	58 up to 61	1300 up to 1390
14 220.4	30	785	588			

14 223.4	15	883	687			
14 230.4	40	981	794			
16 220.4	30	883	637			
16 420.4	30	932	735			
15 230.6	250	780	635	nitriding	60	1360
15 330.6	250	834	637			
14 140.4	40	1716	1373	Nitro carburizing, quenching,	56 up to 60	1240 up to 1360
11 600.1	60	580	314	Surface hardening	55 up to 59	1210 up to 1330
11 700.1	60	686	363			
12 051.6	30	640	390			
14 140.7	25	932	785			
15 241.7	40	1177	981			

3.3 Camshaft

Straining of a camshaft is the same as for a crankshaft – mostly fatigue and wear. Its task is to open and to close valves on cylinders by rotation of special shaped cams. This directly implies that number of revolutions of a camshaft per minute will be equal to a half of revs of a crank shaft. The most common material for a production of a cam shaft is nowadays a shortly chilled grey cast iron Fe-3.2C-2Si- 0.8Mn-0.8Cr-0.2Mo, or Fe-32.C-2Si- 0.8Mn-1.2Cr-0.6Mo. An effect of a short chilling causes, that a kernel does not have enough time to cool down at a needed speed and it still remains as a grey cast metal, meanwhile the surface has changed into a white cast metal. In some engines there is applied a lighter camshaft made of a forged steel Fe-0.2C-0.3Si-0.8Mn-1Cr- 0.2Mo, which is carburized after forging. Reduction in weight while keeping requested mechanical features is achieved also with a sintered alloy Fe- 0.9C-0.2Si-0.4Mn-4.5Cr-5Mo-3Cu-2V- 6W. Heavy stressed camshaft is coated as a rule with a TiN layer through PVD method.

4. Straining of cams through impacts effects

An impact is a dynamic interaction of two bodies, whereby mechanical energy is transferred. Impact energy is transformed into tensile, deformation and heat energy. Generally, the impacts in mechanisms are unfavorable phenomena.

What do the impacts cause:

- Wear of functional areas,
- Functional areas impression,
- increase of clearances,
- degradation of working accuracy,
- they are sources of unwanted vibration and noise.

Sources of impact rise:

- inappropriate kinematic links (improper construction of a mechanism),
- unbalanced rotating masses.
- insufficient lubrication (self-excited vibrations),
- hard impacts,
- inadmissible overloading of a machine.

Measures to decrease a size of impacts:

- higher accuracy of produced components,
- balancing of rotors and accurate mounting of components,
- frame of a machine and a base stiff enough,
- use of machine in accordance with regulations, proper maintenance,
- application of damping and tensile elements in kinematic chains,
- better machine design concept (relieved construction of movable parts,).

5. Conclusion

A cam forms a significant part of three-element mechanisms. Its profile, dimensions of driving and driven elements define a lifting relation taking into consideration individual deformation ratios and a rigidity of an element for requested operation. During its movement the cam is exposed to effects of significant forces at a contact performing a direct influence on its surface that may result in damaging of contact areas. Such damage becomes evident in form of pitting that develops from small cracks on a surface of a working surface. Therefore a correct choice of material of particular elements in a design of a cam mechanism, especially a cam, is the first presumption for a reliable operation of the mechanism.

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