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Attempt to assess operational wear of camshaft cams

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ABSTRACT

Purpose: The subject of the research was wear of camshaft cams studied in accordance with results of operation tests. Based on the said tests, the dependence of wear intensity of cams from their angular position was established. The respective calculation results enabled the function of cam fallibility to be determined.

Design/methodology/approach: The research conducted included measurements of normal and excessive wear of camshaft cams. Based on measurements of several dozen cams, their angular positions at which the most intense wear occurred were established. They were described statistically by means of the Weibull distribution.

Findings: Wear intensity of the camshaft cams examined is a function of the cam's angle of rotation. This dependence is characterised by occurrence of two maxima for the angles of ca. -40° and 30°. The cam wear intensity at the first maximum is usually smaller than at the second one. The wear intensity distribution does not depend on the cam type.

Research limitations/implications: During operation, camshaft cams may be subject to accelerated wear. In this study, an attempt was made to assess this phenomenon based on measurements of the cams' geometry aimed at determination of the areas exposed to the most intense wear.

Originality/value: In order to counteract the phenomenon of excessive wear of cams, one should consider altering the geometry of cams in the areas exposed to the most intense wear.

Keywords: Cam; Camshaft; Wear

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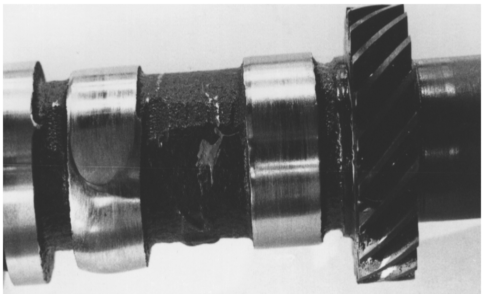
METHODOLOGY OF RESEARCH, ANALYSIS AND MODELLING

1. Introduction

Excessive wear of camshaft cams is a defect occurring in engines of various types of cars (Fig. 1a). It is also accompanied by accelerated wear of cam followers (Fig. 1b). It may take place after a small number of hours of the car's operation, i.e. in cars of several to several hundred kilometres of mileage [1,2]. Material properties are very important for camshaft cams structure. There are many publications on novel technologies for clean materials production which can be use for production of this kind elements [6,7,9]. The surface tension should be take into consideration and to test wear of camshaft cams [8]. In paper [5] some of the authors presented application of vibration method in materials research.

Excessive wear often occurs on only certain camshaft cams and their cooperating cam followers. It exerts a negative impact on the combustion engine operation. In various publications touching upon this problem [1,2], authors were focused on determination of its possible causes, thus confining themselves to confirming the fact that such a phenomenon indeed occurs. Therefore, under this study, a quantitative assessment of operational wear of camshaft cams was attempted. The results of cam wear tests were used to determine the dependence of wear intensity from the cam's angle of rotation. Next, for the points at which the said dependence showed maxima, a distribution of the wear intensity probability was established. For that purpose, the Weibull distribution was used, being one commonly applied in the analysis of durability and reliability [3,4,5].

a)



b)

Fig. 1. Worn-out components of a cam/follower system (on car mileage of 124 km) [1]: a) camshaft with a heavily worn-out first cam (on the left), b) cam follower

2. Wear tests for camshaft cams

The research concerning wear of camshaft cams covered measurements of linear wear of cams of 40 camshafts dismounted from engines of Cinquecento 700. These camshafts displayed symptoms of excessive geometric wear of certain cams. Mileages L [km] of the cars running with the camshafts subject to testing varied from 1,250 to 48,500 [km]. The relevant measurements were conducted by means of a dial gauge of the accuracy of 0.01 [mm] in a system illustrated in Fig. 2. Angle α was being altered within the range from -90 to 90° at every 5° so that the maximum cam lift could occur on the angle of ca. 0°.

The lift values measured enabled calculation of each cam's wear. The linear wear was determined for individual values of angles α according to the following formula:

$$Z = h_t - h \ [mm], \qquad (1)$$

where: Z - linear wear of lift, h_t - theoretical lift of a new cam, h - measured lift of a worn-out cam.

Since the wear in question was calculated based on measurements of cam lift against the dedendum circle (also exposed to wear), hence it was described as lift wear. The dependence between lift wear and angle α has been depicted in Fig. 3.

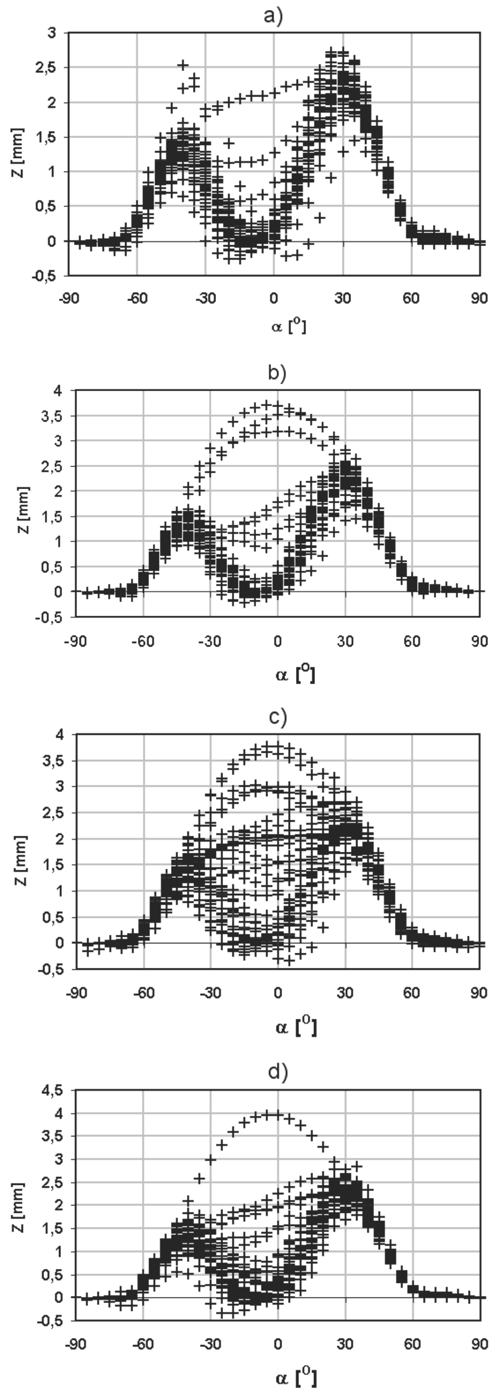


Fig. 3. Dependence of linear lift wear of the cams tested from angle α for the following cam types: a) 1 intake, b) 2 intake, c) 1 exhaust, 2 exhaust

In order to describe the process of excessive wear of cams, also the dependence between lift wear and car's mileage was applied. Such a dependence for angle $\alpha = 0°$ has been depicted in Fig. 4.

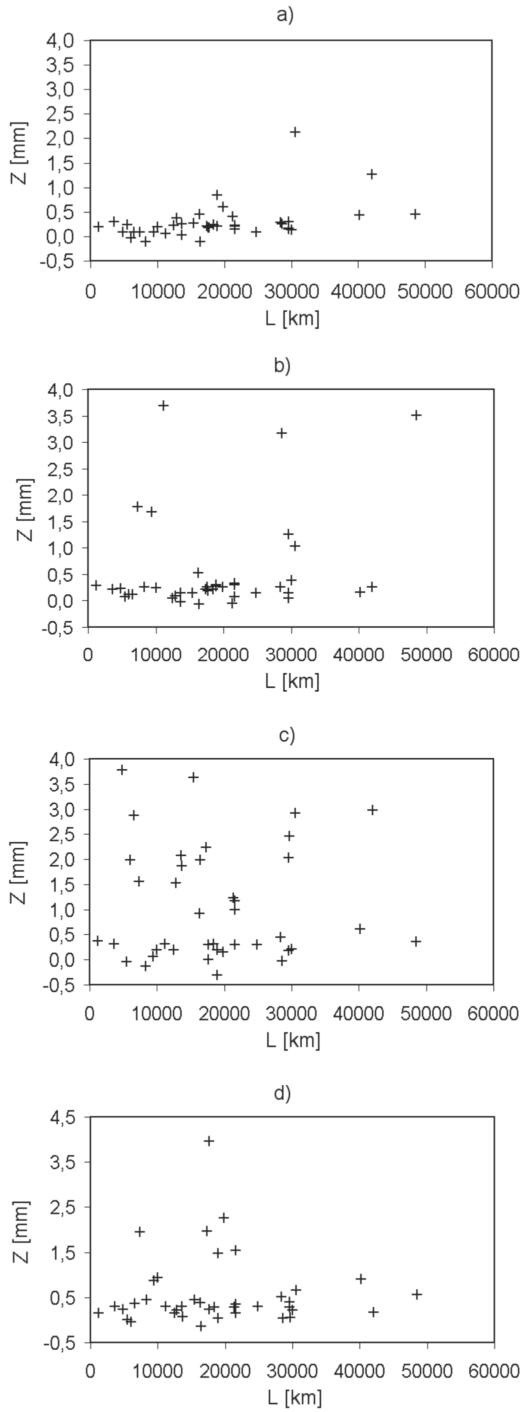


Fig. 4. Dependence of linear lift wear for angle $\alpha = 0°$ from mileage for the following cam types: a) 1 intake, b) 2 intake, c) 1 exhaust, 2 exhaust

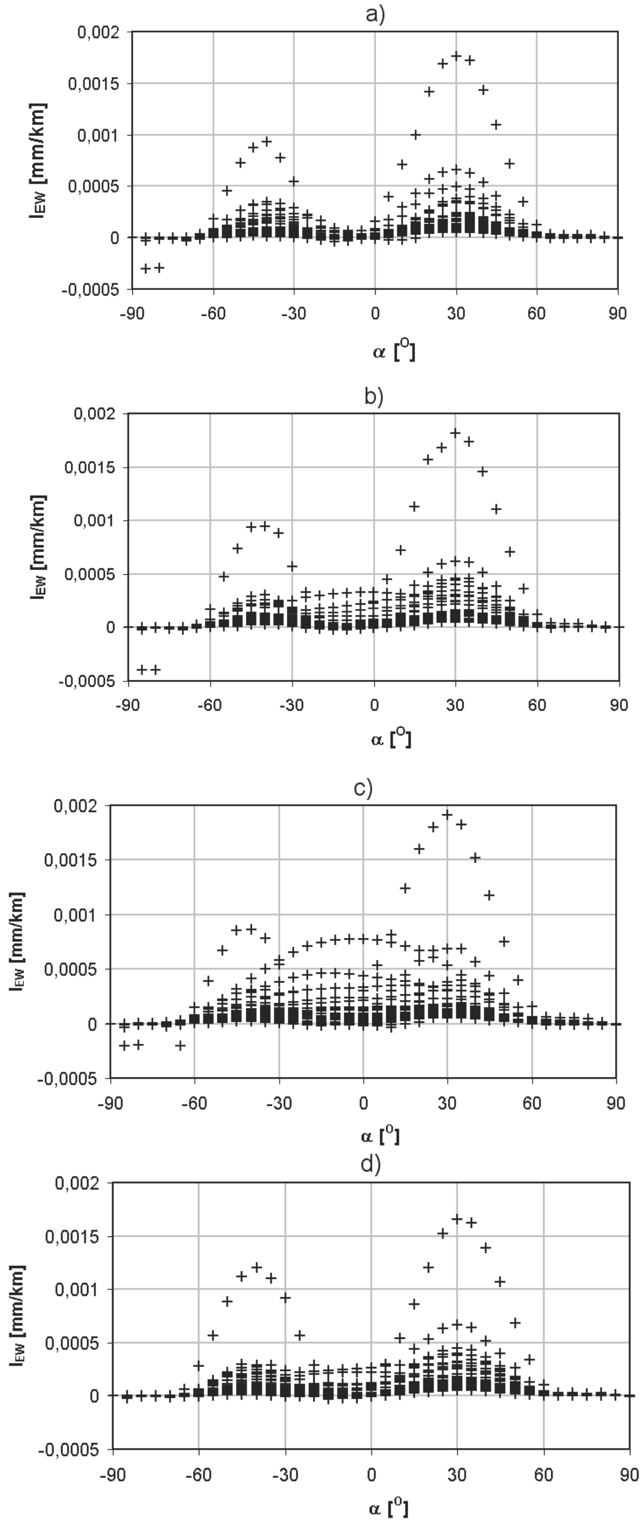


Fig. 5. Operational cam lift wear intensity in the function of angle α: a) intake cam 1, b) intake cam 2, c) exhaust cam 1, d) exhaust cam 2

A graphical illustration of sample test results in the form of a dependence between linear cam lift wear and a car's mileage has been provided in Fig. 4. In order to minimise such an inconvenience, the linear lift wear intensity was analysed, being a relationship between linear wear Z of cam lift expressed in millimetres and mileage L expressed in kilometres:

$$I_{EW} = \frac{Z}{L}\left[\frac{\text{mm}}{\text{km}}\right] \tag{2}$$

Intensity I_{EW} was called "operational", since a reference was made between the wear and the car's mileage (and not friction distance, as it usually happens while analysing various frictional couples). And since it involved the lift wear, it was assumed to be referred to as cam lift wear intensity (index *W*). The results obtained for such wear intensity in all measurements have been provided in four graphs (Fig. 5).

3. Statistical analysis of the research results

The decisive factor for a cam's durability is the highest intensity of its wear.

The operational cam lift wear intensity illustrated in Fig. 5 usually displays two maxima: the smaller one for α = -40° and the larger one for α = 30°. In order to establish their values, a mean and a median (value occurring in the middle of a set after it has been arranged) were determined for the wear intensity (Fig. 6). Fig. 6 confirms the foregoing statement concerning two maxima of wear intensity.

Durability of cams is expressed by mileage until the permissible wear of Z_{dop} is attained. For the sake of the analysis, it was assumed that the wear in question came to 0,5 mm [3]. For each cam, durability was calculated for angle α = 30°. In order to describe the cam durability in statistical terms, fallibility functions F(*T*) were established for them. Such a function is a distribution function of durability. It describes the probability of the cam durability being smaller than the preset value of *T*.

For the mathematical description of this distribution function, the Weibull distribution was applied where it was given by the following formula [3,4]:

$$F(T) = 1 - \exp\left[-\left(\frac{T}{a_W}\right)^{b_W}\right] \tag{3}$$

The equation contains variable *T*, being the durability expressed by the car's mileage, and two parameters:

- scale parameter (a_w)
- shape parameter (b_w).

In order to establish these parameters, logarithms for equation (3) were found twice, and after the applicable conversions, the following form as obtained:

$$ln\{-ln[1-F(T)]\} = -b_W \cdot ln a_W + b_W \cdot lnT \tag{4}$$

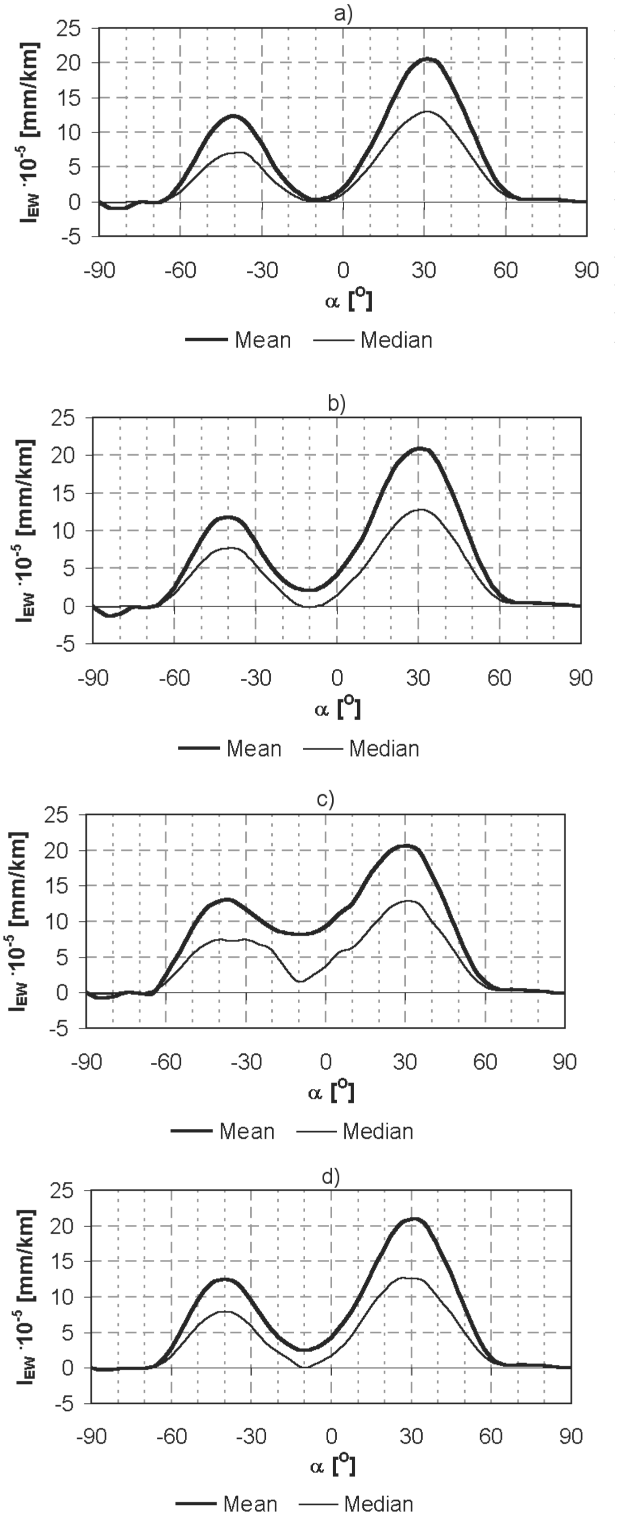


Fig. 6. Mean and median for relative operational wear intensity in the function of angle α: a) intake cam 1, b) intake cam 2, c) exhaust cam 1, d) exhaust cam 2

It is an equation of linear function $y' = a' + b_w \cdot x'$, where $y' = \ln\{-\ln[1-F(T)]\}$, $a' = -b_w \cdot \ln a_W$ and $x' = \ln T$. Therefore parameters a' and b_W were determined by linear regression of the following function:

$$\ln\{-\ln[1-F^*(T_i)]\} = -b_W \cdot \ln a_W + b_W \cdot \ln T_i \quad (5)$$

where: (i = 1, 2,...n), $F \cdot (T_i) = \frac{i}{n+1}$ is referred to as empirical , distribution function, n is the calculated mileage number until the assumed wear has been reached, i is the number of durability T_i after arranging it in a non-decreasing order.

Parameter a_W was calculation according to the following relation:

$$a_W = \exp\left(-\frac{a'}{b_W}\right) \quad (6)$$

The values of the Weibull distribution parameters obtained have been collated in Table 1. For the sake of comparison, distribution functions were also determined for mileage until the threshold wear of L_G is reached for angle α = 30° and α = -40°. The distribution function graphs have been provided in Figure 7. Since the durability was established in [km] of a car's mileage, the distribution functions provided in the said figure were marked as F(L) instead of F(T).

Table 1.
Collation of the Weibull distribution parameters obtained for the individual cams

	Angle α = 30°		Angle α = -40°	
Cam	Weibull distribution parameters			
	a_W	b_W	a_W	b_W
1 intake	4,885	1.584	8,670	1.411
2 intake	5,008	1.502	8,356	1.574
1 exhaust	5,234	1.555	7,954	1.480
2 exhaust	4,771	1.556	8,823	1.396

Having analysed Figure 7, one may conclude that the cams being examined showed excessive wear, since the mileages until the permissible wear had been attained were rather small. Fig. 7 also implies that graphs of the fallibility function F(L) for the individual cams coincide.

This enabled a statistical hypothesis to be proposed that distributions of cam durability probability did not differ in statistical terms. This hypothesis was verified by conducting the λ Kolmogorov-Smirnov test. The test result did not provide any grounds to reject that hypothesis. A similar test result was obtained for the mileage until the permissible wear for angle α = -40°.

Therefore, it can be assumed that wear intensity for all cams is characterised by the same distribution of probability. Hence the statistical operational wear is the same for all cams.

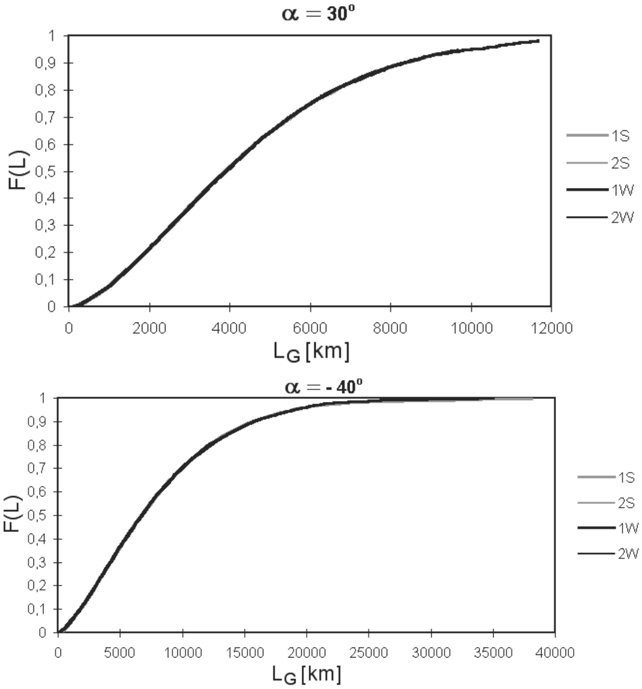


Fig. 7. Distribution functions of mileage L_G until threshold wear of 0.5 mm for: α = -40and °α = 30°

4. Conclusions

Having conducted the foregoing tests and calculations, one may reach the following conclusions:

- Wear intensity of the camshaft cams examined is a function of the cam's angle of rotation. This dependence is characterised by occurrence of two maxima for the angles of ca. -40° and 30°. The reasons for such a state of matters can only be assessed after pressure calculations are conducted taking the relevant dynamic forces into consideration.
- The cam wear intensity at the first maximum is usually smaller than at the second one (Fig. 6).
- The wear intensity distribution does not depend on the cam type. The differences observed are negligible from the statistical point of view.

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