PROBLEMS WITH DETERMINATION OF ROTATION SPEED FLUCTUATIONS AT THE COMBUSTION ENGINE WORK CYCLE

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Abstract

The coefficient of speed fluctuations δ is the one of engine basic operational parameters defining its utilitarian advantages. Such defined this simplest parameter determines the discrepancies from the rotational speed constant within an engine individual cycle. However, the principle of engine run causes the unavoidable fluctuation of engine instantaneous speed. This phenomenon can be utilized as a diagnostic signal. The way of determination of crankshaft instantaneous speed could be the answer to this problem. Determination of engine rotational speed instantaneous value is carried out according to three methods presented below from the less to the most accurate: on the basis of engine torque calculation and eventual computation of velocity ω, on the basis of engine torque measurement and eventual computation of velocity ω, on the basis of measurement of time intervals between consecutive signals generated by the encoder. This is the subject of the following paper.

1. Introduction

The IC engine usually runs 4-stroke cycle with the speed increase during the expansion cycle and successive decrease in following three strokes. The well known dependence allows to calculate the speed fluctuations within the cycle of the most popular version of engine, namely the 4-stroke, 4-cylinder in-line one. Fig. 1 presents the results of such calculation.

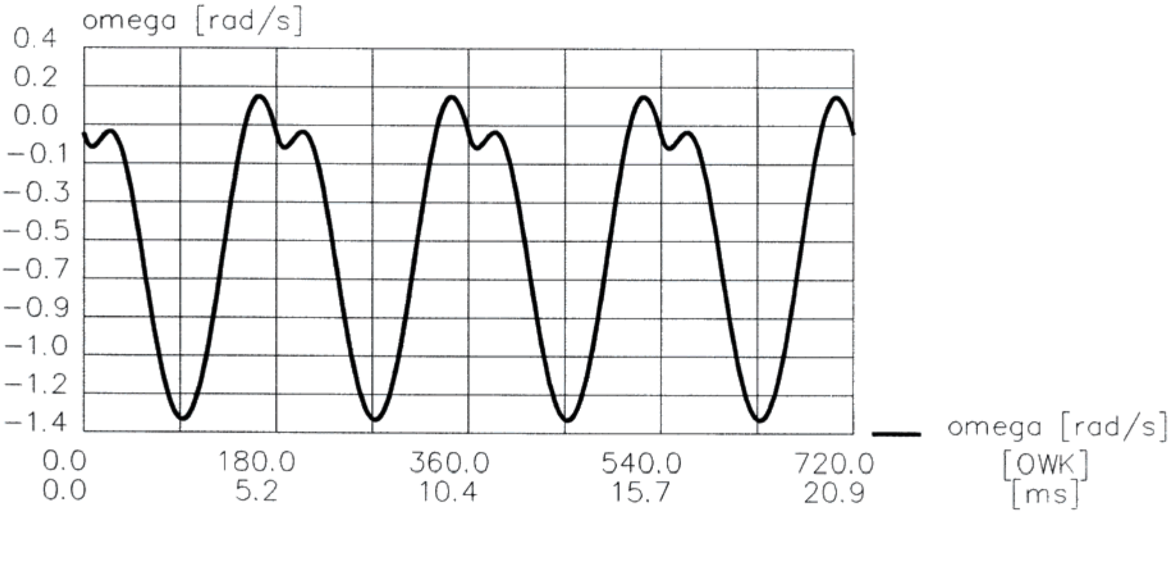

Fig. 1. 4-stroke engine crankshaft speed fluctuations in nominal conditions

As it comes out, so far used methods for determination of momentary speed give the results far from the real value of this parameter. There are also certain problems with the experimental verification of results achieved according to the mathematical models. In order to reveal the convergence of two methods these problems should be solved. This paper is a continuation of efforts carried out within the frames of the KBN grant [1].[1]

2. Comparison between courses of crankshaft instantaneous speed calculated using classic methods and methods of increased accuracy

According to classic rules, the course of crankshaft speed fluctuations could be determined using the following procedure written in PASCAL:

```
for i:=1 to 720 do
begin
    praca:=pole*1e6*(t[i]-ts)*r*pi/180;
    omega[i]:=sqrt(omega[i-1]*omega[i-1]+2*praca/teta)
end;
```

where:

i – control variable,
praca – work of tangential force t[i] within the angle of $\pi/180$,
omega[i] – instantaneous value of crankshaft rotational speed,
teta – mass inertia moment of rotating elements, flywheel in particular.

The changes in crankshaft speed are most legible at low rotational speeds, e.g. for the idle run speed. Fig. 2 presents a diagram of rotational speed changeability determined for a given constant crankshaft speed 750 rpm.

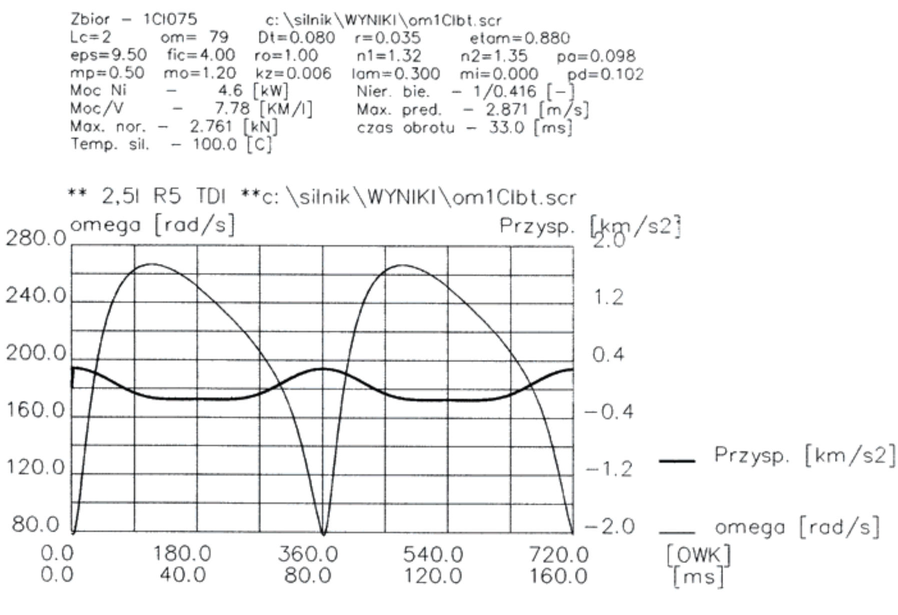

Fig. 2. The course of changes in angular speed ω within one rotation of 2-cylinder engine crankshaft – thin line and the course of piston acceleration for constant crankshaft angular speed

[1] The project carried out within the frames of KBN grant No 1423/T12/2003/25

Basic parameters, for which these results were achieved are presented above the Fig. 2. The most important are:

Lc -number of cylinders,
om -crankshaft constant speed 79 rad/s assumed at the beginning,
Dt -bore,
r -crank radius,
mp -combined mass of elements performing the reciprocal movement.

Above the Fig. 2 there are also some resultants, the maximum piston speed among others.

It is internally contradictive to assume a crankshaft constant speed to determine the fluctuation of the same speed. Actually, the speed fluctuations lead to the course of reciprocal masses accelerations different from those presented in Fig. 2. Therefore accelerations resulting from the rotational speed ω presented as the thinner line could be determined. The courses in Fig. 3 are the result.

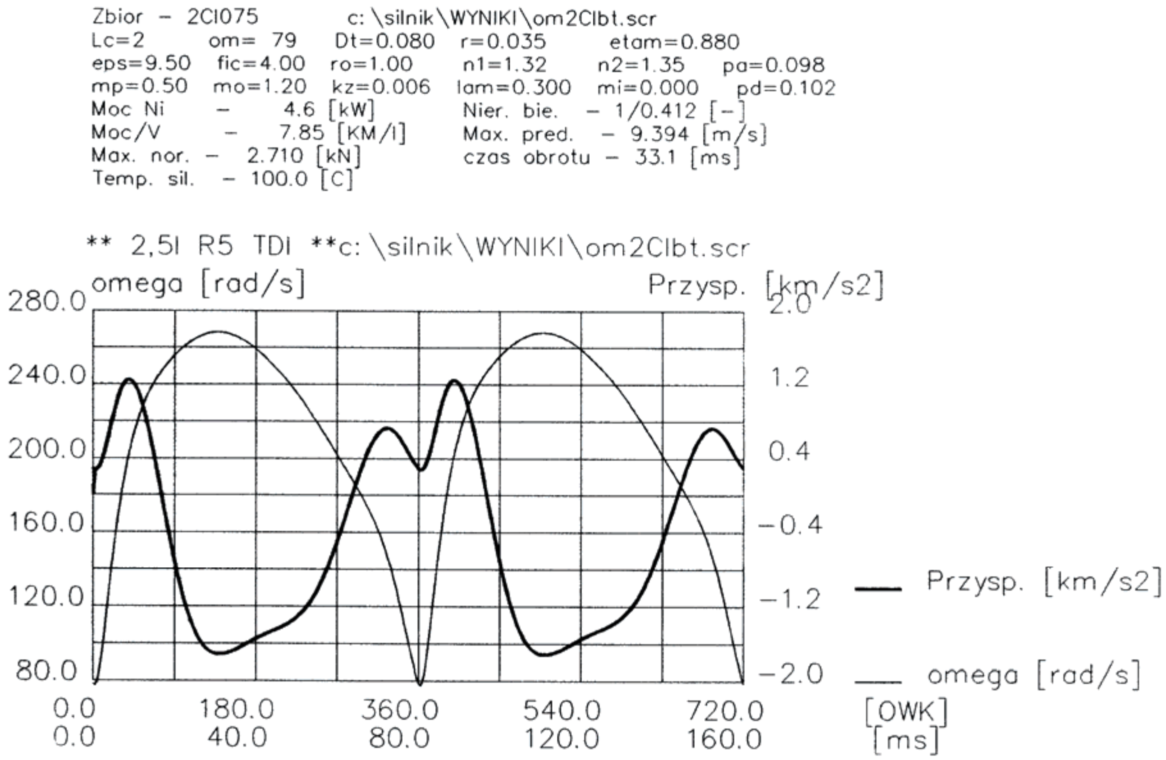

Fig. 3. The course of changes in angular speed ω within one rotation of 2-cylinder engine crankshaft – thin line and the course of piston acceleration for changing crankshaft angular speed assumed as in Fig. 1

The comparison of courses from Figs. 2 and 3 shows considerable errors resulting from the assumption of crankshaft constant speed, particularly for low speeds. For more accurate results one should use the data from Fig. 3 and compute the accelerations of reciprocating masses, and then assume the resulting forces for calculation of speeds. The achieved results have been presented in Fig. 4.

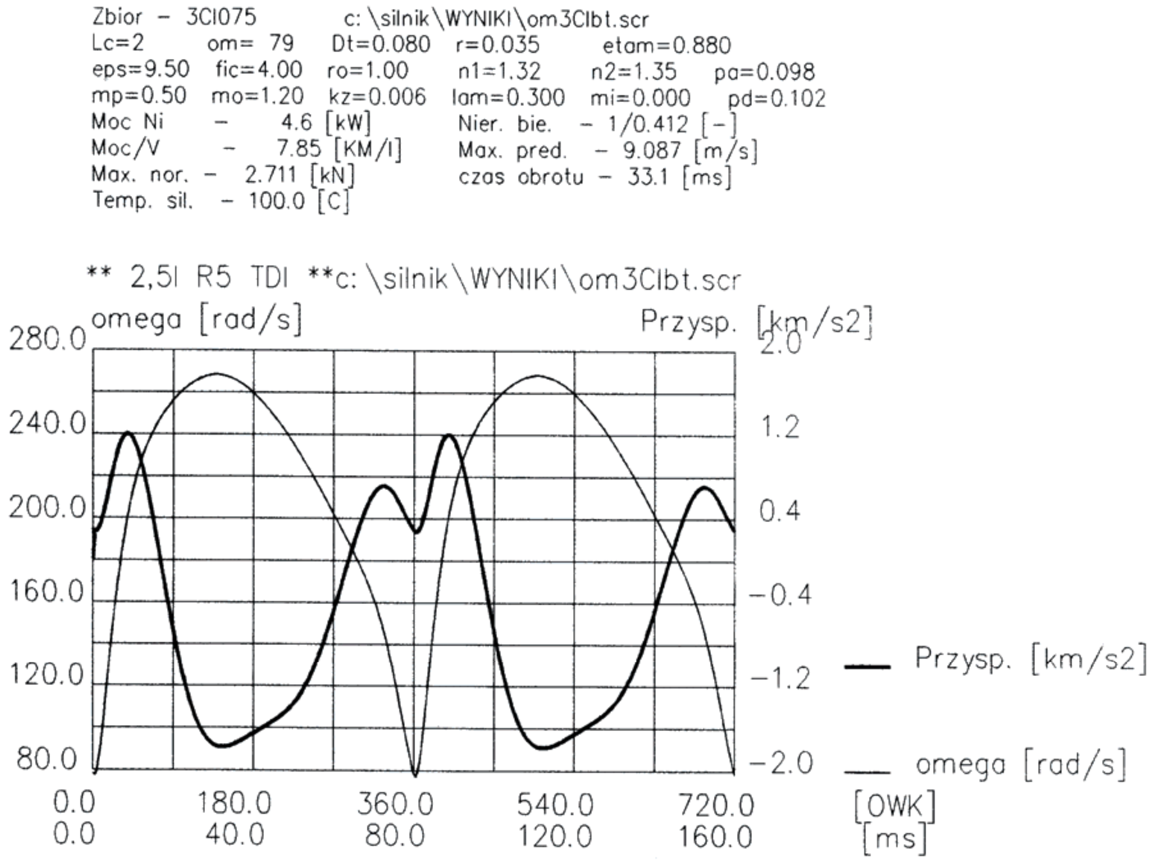

Fig. 4. The course of changes in angular speed ω within one rotation of 2-cylinder engine crankshaft – thin line and the course of piston acceleration for changing crankshaft angular speed assumed as in Fig 3

Comparing the courses from Figs. 3 and 4 a high similarity could be observed, though the differences are still of several percent, e.g. the maximum speed from Fig. 2 is 9.39 m/s, whereas that from Fig. 4 is 9.09 m/s.

The description of the applied procedure suggests that this method allows for kinematic values of crank mechanism elements to get closer to the actual ones.

Variability of crankshaft speed results in significant differences in piston speed from the values described as a combined harmonics of the kind

$$\mathbf{V} = \mathbf{r}\boldsymbol{\omega}(\sin\varphi + \frac{1}{2}\lambda\sin 2\varphi)\,.$$

The course of piston speed fluctuations, that is a sum of two harmonics has been presented in Fig. 5, while the same course but for actual, i. e. variable angular speed – in Fig. 6.

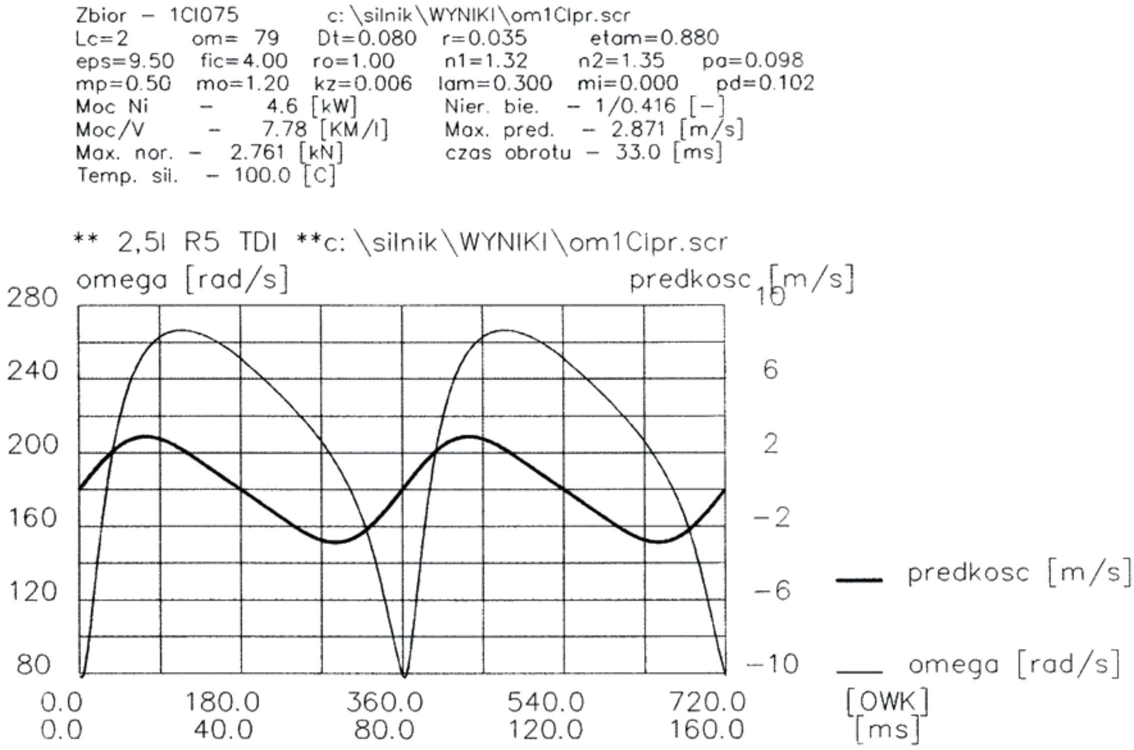

Fig. 5. The course of changes in angular speed ω within one rotation of 2-cylinder engine crankshaft – thin line and the course of piston speed for constant crankshaft angular speed

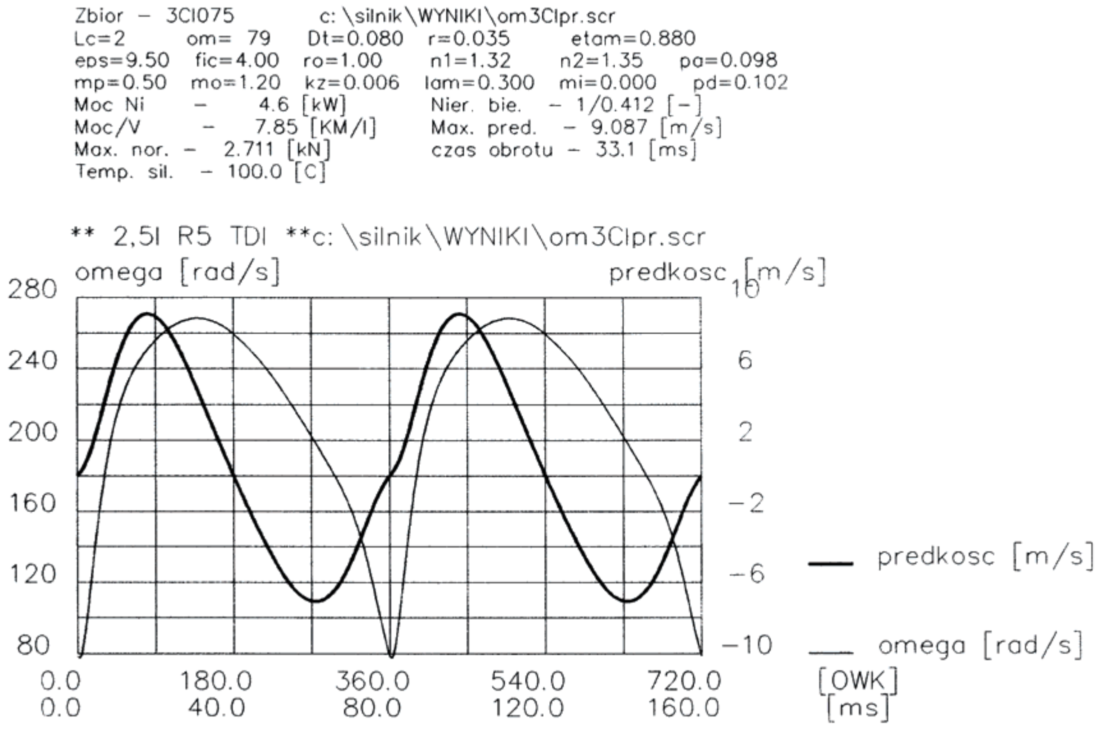

Fig. 6. The course of changes in angular speed ω within one rotation of 2-cylinder engine crankshaft – thin line and the course of piston speed for crankshaft angular speed assumed as in Fig 4

It can be easily noticed that differences in courses of piston speed are quite big. One might anticipate erroneous evaluation of derived parameters when assuming the piston speed as a sum of two harmonics.

3. Experimental definition of angular speed momentary values within a cycle

There could be diverse outcomes of so far presented analyses of instantaneous speed variations. They could lead to the crankshaft torsional vibrations substantially different from those determined according to the classic methods.

Moreover, there is a need for experimental confirmation of theoretical considerations. Such task is not a difficult one as long as the requirements in relation to the measurement accuracy are not too high. The simplest way to determine the instantaneous values of angular speed is to fix a position sensor on crankshaft. Such device is known as encoder. However, the simple theoretical formula encounters the hardware difficulties hard to overcome. The problem consists in sufficiently accurate determination of shaft position. The verification of possibilities and limitations of encoder application to the determination of rotational speed momentary value is carried out at the moment. Measurements of tangential force accompanying the crankshaft rotations have been carried out in order to acquire the experimental data useful for verification of angular speed instantaneous values. According to the generally accepted nomenclature the tangential force is treated as the force acting on a crank radius and causing the same moment as that conveyed to the power receiver. The tangential force to cylinder cross-section ratio will be called as the specific tangential force. Its course has been presented in Fig. 7.

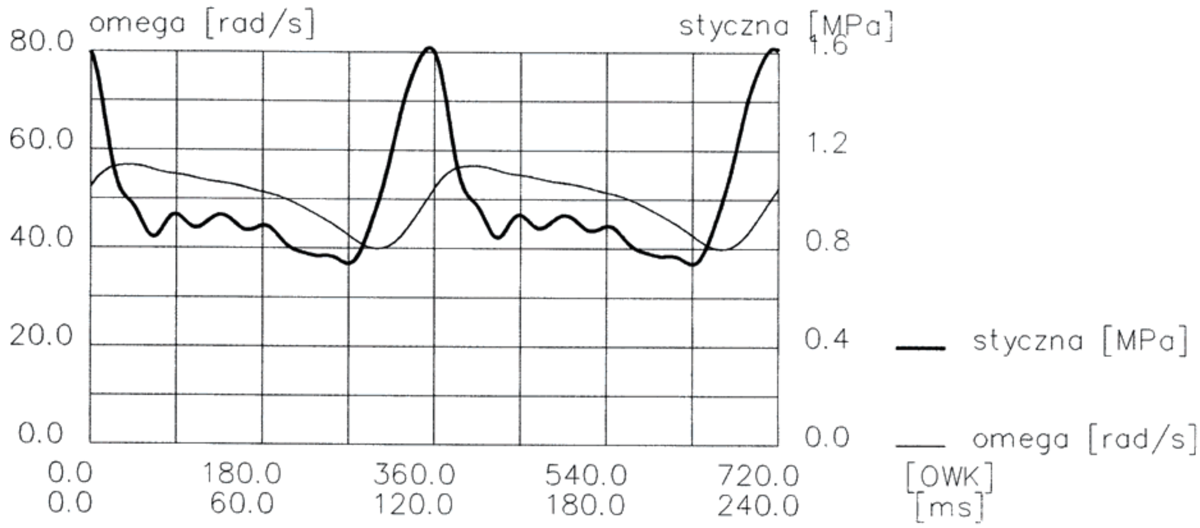

Fig. 7. The course of measured specific tangential force and produced rotational speed throughout one cycle of 2-cylinder engine

There is a simple way to determine digitally the instantaneous value of rotational speed on the basis of the course of specific tangential force. The result of such procedure has been marked with a thinner line in Fig. 7. In order to examine to what extent the rotational speed determined this way is convergent with the speed found with the computational methods the simulation of tangential force has been carried out and the result has been presented in Fig. 8.

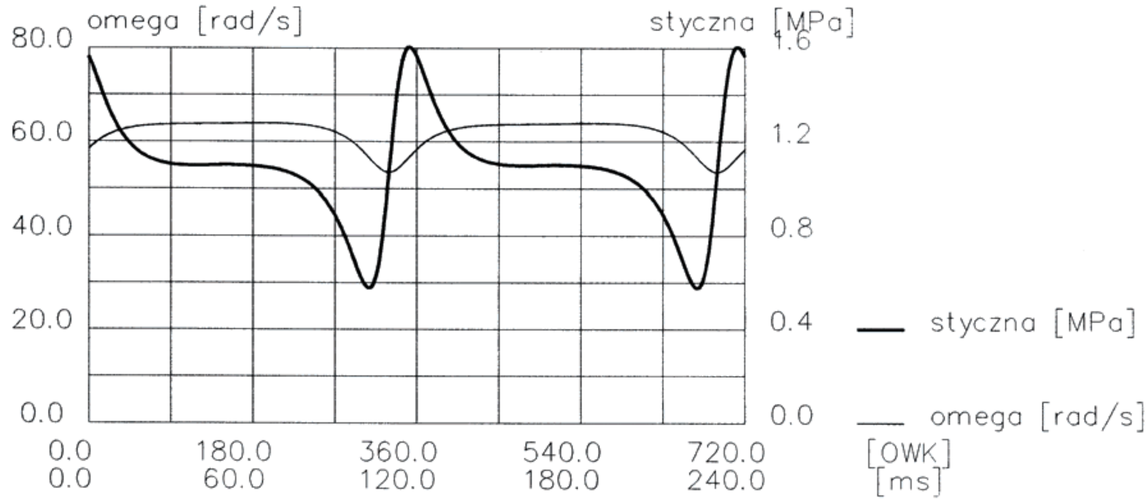

Fig. 8. The course of calculated specific tangential force and produced rotational speed throughout one cycle of 2-cylinder engine

Comparing the courses in Fig. 7 and 8 one can find a similarity in character but substantial differences in values. The basic cause is the difficulty with determination of momentary value of torque driving the assembly of engine and dynamometer shafts. The classic method of determination of so called tangential force, or more precisely the torque transmitted from engine to dynamometer, is merely the approximation of phenomena actually encountered in the vibrating system of engine and dynamometer. In turn, the measurement of torque with the moment meter do not ensure the proper determination of driving torque. The assembly natural vibrations play a significant role, which has been the subject of previous paper [1].

It is worth noting in the end, that equipment made of renown makes have been used for the measurements. Also the joints were of the highest possible stiffness. Two such joints have been presented in Fig. 9.

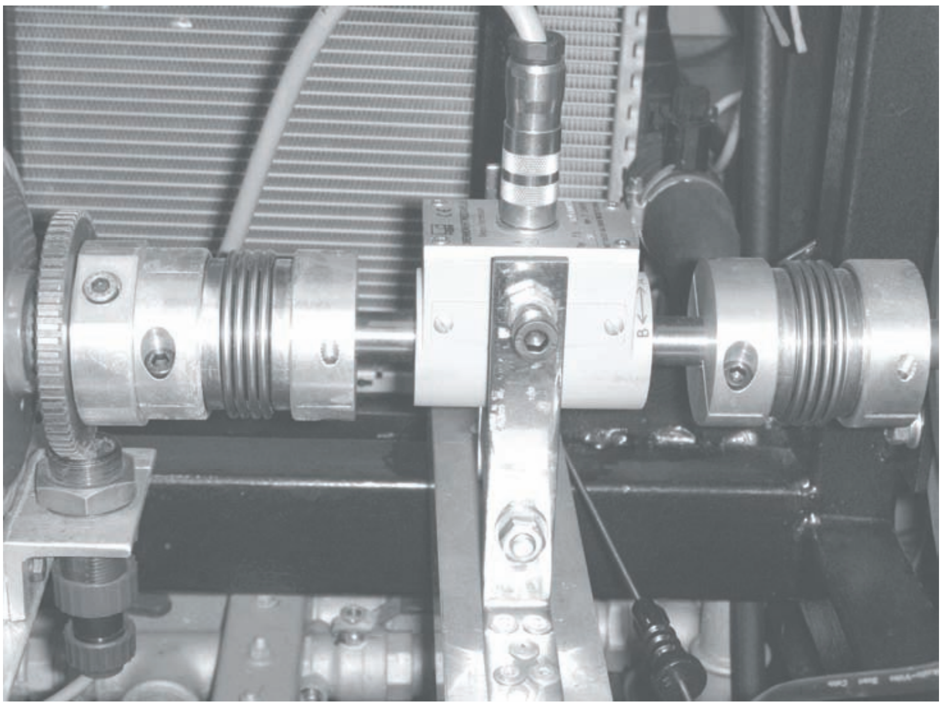

Fig. 9. The engine to dynamometer coupling shaft equipped with moment meter and two bellows joints

Conclusions

Determination of engine rotational speed instantaneous value could be carried out according to three methods presented below from the less to the most accurate:

- on the basis of engine torque calculation and eventual computation of velocity ω,
- on the basis of engine torque measurement and eventual computation of velocity ω,
- on the basis of measurement of time intervals between consecutive signals generated by the encoder.

References

[1] Iskra A. Ograniczenie niekorzystnych skutków pracy silnika na biegu jałowym. KONES’2004. 12-15.09.2004, Kraków – Zakopane.