RECOGNITION OF FUEL FEEDING SI ENGINES WITH USE OF DIMENSIONAL AND NONDIMENSIONAL VIBRATION PARAMETERS

Marek Flekiewicz, Paweł Fabiś

Silesian University of Technology
Krasińskiego 8, 40-019 Katowice, Poland
tel. +48 32 6034363, fax +48 32 6034108
e-mail: marek.flekiewicz@polsl.pl

Bartosz Flekiewicz

Auto Gaz Śląsk sp. z o.o.
Brygadzistów 82a, 40-807 Katowice, Poland
tel. +48 32 6096412, fax +48 32 2516468
e-mail: bflekiewicz@autogaz.com.pl

Abstract

The availability of gaseous fuels like natural gas and propane butane mixtures has lead to worldwide popularity of internal combustion engines running dual fuel or alternatively gas powered. They are known as fuels more resistant to knocking than conventional liquid fuels and as ones less pollutant, their better mixing with air is also well recognized.

There have been many published works on the use of gaseous fuels but actually the problem of the combustion noise, as a very important source of acoustic discomfort is not receiving attention. Combustion noise occurs in two forms, direct and indirect. It is transmitted throughout the engine block as a vibration at a different spectrum of frequencies. In this study an attempt is made to correlate the combustion noise to the operating parameters for LPG and CNG powered engine as compared to petrol fuelled engine. Combustion pressure and vibration of cylinder block data are measured and presented for engine running on LPG/CNG and compared to the results obtained for engine fed by petrol. Signals of multiple resonances in combustion chamber and corresponding vibration signals of cylinder block of engine were considered for one combustion cycle. A four cylinder, 1.6 dm^3 spark-ignition engine converted to run on LPG and CNG was tested in the project.

The engine test stand was fully computerized and the cylinder pressure data, acceleration of vibration of engine block, crank angle data was stored on a PC. The influence of engine speed, load on combustion and engine block vibration was examined for all fuels. A few of well know diagnostic parameters were used for comparison of the engine noise for operation on petrol, LPG and CNG.

Keywords: *vibration, combustion noise, gaseous fuel, LPG, CNG*

1. Introduction

The main goal of the research program connected with the combustion process validation was to design a real time combustion process control system.

In-Cylinder transformation of chemical energy into mechanical results a complicated process. Direct indicated pressure measurement is very expensive. According to the research that has already been done [1, 2], there is a close correlation between combustion process represented by means of indicated pressure, and engine body vibrations.

Vibration processes that are common for engine operation, are constituted of a cycle of repeated in time sequences, the following sequence does not match the previous one when field phenomenon components are taken into account.

Combustion process validation on the basis of registered vibration signals requires identification of engine body resonance frequencies [3]. Definition of spectral transfer functions for the chosen test points makes the results analysis easier and enables an optimal location of sensors on the engine block. Combustion process analysis with the use of vibroacoustic methods is very complex and difficult especially taking into consideration the necessary analysis of non-stationary and cyclostationary signals. Test results of the influence of fuel type on indicated pressure and engine block vibrations have been presented in this article.

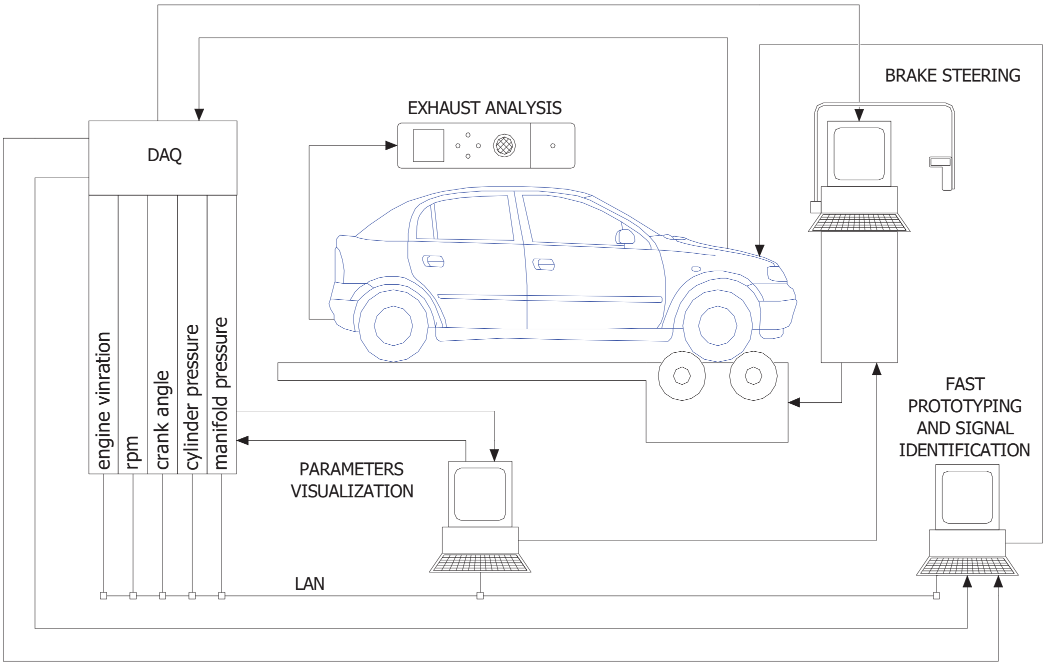

Fig. 1. Schematic diagram of experimental setup

Evaluation of engine block vibration level was done with the use of selected diagnostic pointers, factors. Their values calculated separately for different operating conditions of engine fed by different fuels, suggest their possible application in recognizing fuel feeding the engine. Pointers applied in the project for engine block vibration signal analysis are listed in table 1.

Tab. 1. Definitions of main values and factors

	Value or Factor	*Definition*	*Value or Factor*	*Definition*
1	Peak value	$y_p = \max\limits_{0\langle t\langle T}\lvert y(t)\rvert$	Crest factor	$CF = \frac{y_p}{y_{RMS}}$
2	RMS	$y_{RMS} = \left[\frac{1}{T}\int_0^T y^2(t)dt\right]^{\frac{1}{2}}$	Shape factor	$SF = \frac{y_{RMS}}{\bar{y}_{abs}}$
3	Average absolute value	$\bar{y}_{abs} = \frac{1}{T}\int_0^T \lvert y(t)\rvert dt$	Impulse factor	$X_i = CF \cdot SF = \frac{y_{RMS}}{\bar{y}_{abs}}$
4	Kurtosis	$K = \frac{\frac{1}{T}\int_0^T (y(t)-\bar{y})^4 dt}{\left(\sqrt{\frac{1}{T}\int_0^T (y(t)-\bar{y})^2 dt}\right)^4}$	Clearance factor	$L_I = \frac{y_{P-P}}{\left(\frac{1}{T}\int_0^T \sqrt{\lvert y(t)\rvert}dt\right)^2}$

In the table 1, y(t) is the original sampled time signal, T – is time of engine cycle.

2. Test setup

The tested object was an SI engine of 1,6 dm^3 of displacement, fed with petrol, LPG and CNG. During the test procedure indicated pressure in 4^{th} cylinder and vibration acceleration in two points on engine block were registered in three series.

For each of the fuels, acquisition procedure registrations were made in time domain, with the use of two transducers. Transducers were registering vibrations accelerations in y and x axis in the 4^{th} cylinder zone. Test procedure was done with the use of pressure transducer type 6121 working together with charge amplifier 5011, crankshaft position sensor type 2613B by Kistler, and acceleration transducers ICP from PCB together with Roga Instruments signal amplifier type PA 3000. Signals were acquired with the use of eight channels PCI card by National Instruments (NI PCI-6143) controlled by application written in LabView environment.

Variations of both tested engine load and speed were completed on a BOSCH FLA 203 roller bench. Figure 1 shows the dataflow diagram in the described system.

3. Results and discussion

Combustion pressure is the one of main factors determining engine body vibrations. Figure 2 presents the combustion hardness as a representative excitation for different fuels. Variation of those extortions complicates the analysis of combustion process based on vibration signals, which determines the necessity of using of complex signal processing methods in time or angular domain. Alternative gaseous fuels are very popular nowadays, their combustion occurs in the way different from the petrol. According to the research that has been done, it can be noticed that gaseous fuels quickly and completely mix with air, in a consequence giving more homogenous mixtures enabling its more even distribution to all cylinders.

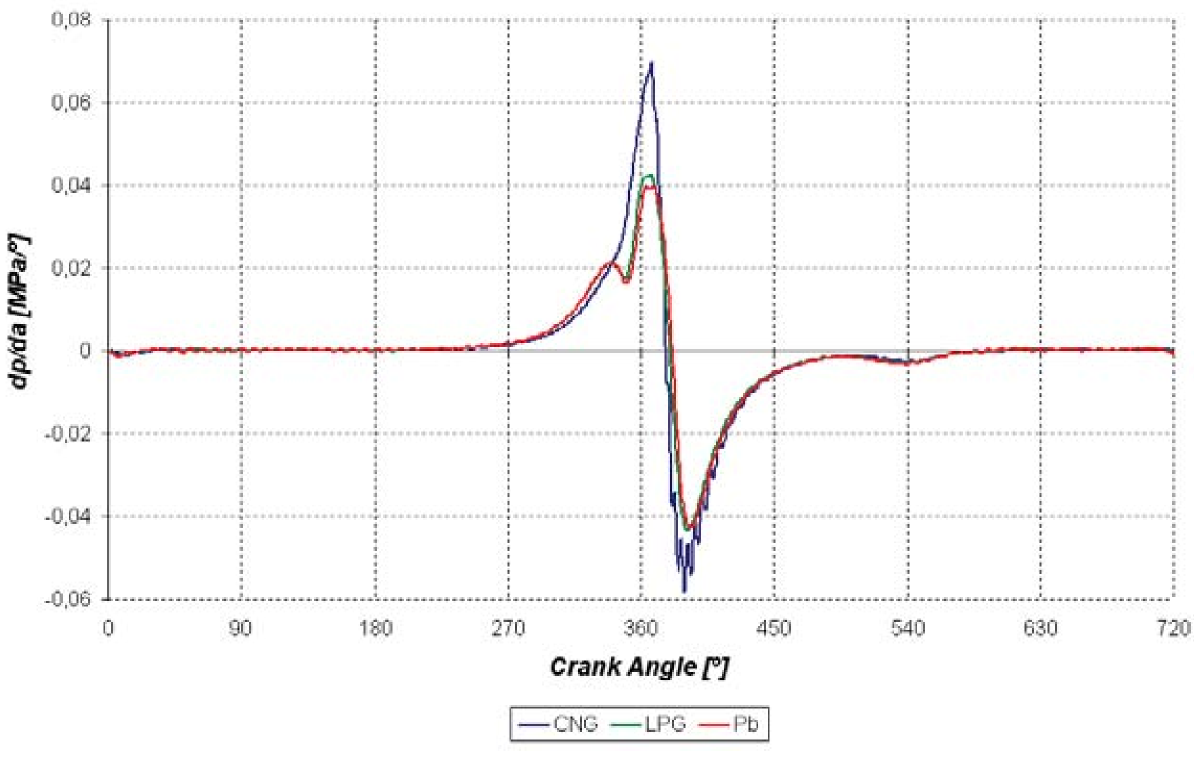

Fig. 2. Combustion hardness traces for all kind of fuels (2000 rpm, full load)

As a result, the use of LPG and CNG offers more smooth and silent engine operation. That is confirmed by indicated pressure and engine body synchronously averaged accelerations traces presented in figures 3-5, together with detailed combustion process analysis especially concerning comparison of combustion time of petrol and LPG [4]. During the test procedure, acceleration effective values were averaged for each engine cycle. Together with the increase of engine speed, effective values of body vibrations accelerations rise.

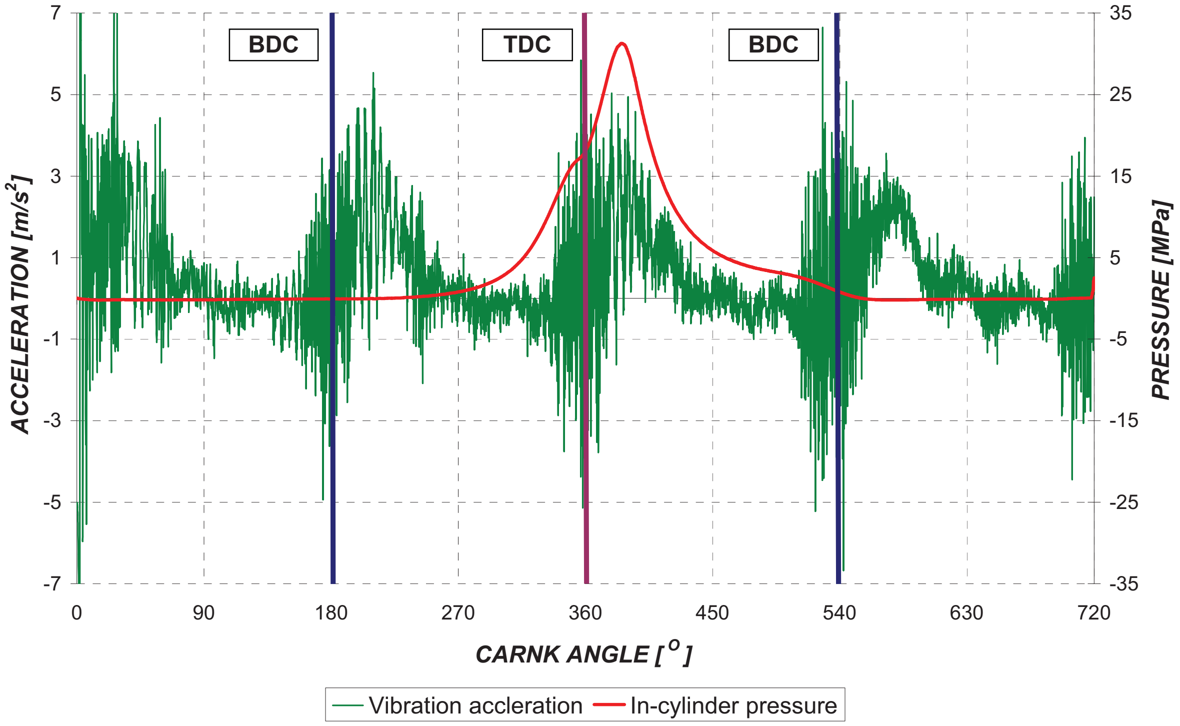

Fig. 3. Traces of fourth cylinder pressure and vertical vibration for engine fuelled by petrol (rpm=1500, full load)

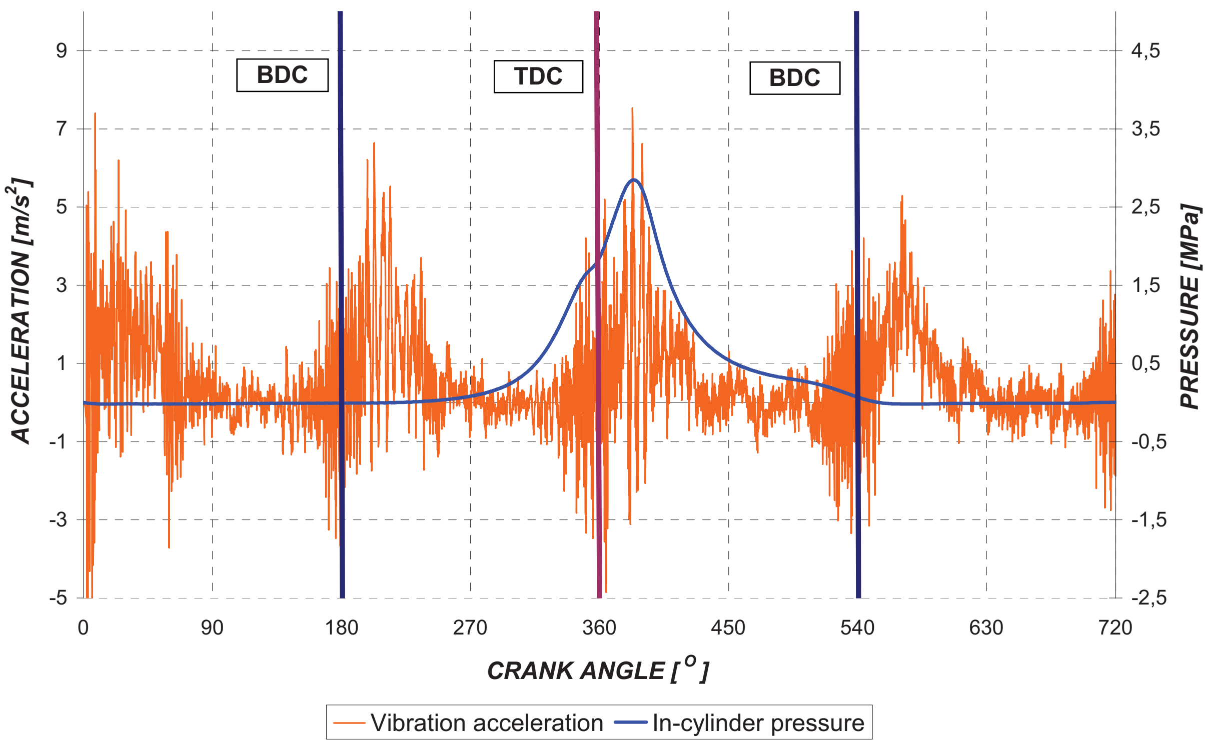

Fig. 4. Traces of fourth cylinder pressure and vertical vibration for engine fuelled by LPG (rpm=1500, full load)

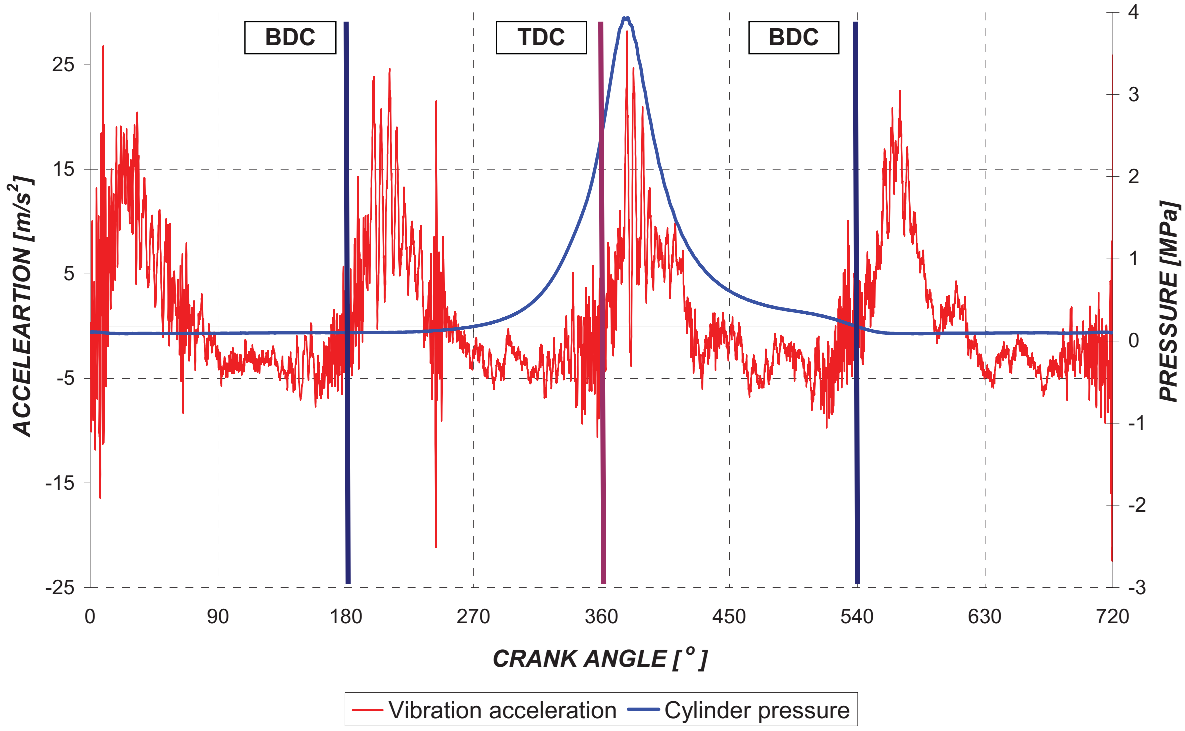

Fig. 5. Traces of fourth cylinder pressure and vertical vibration for engine fuelled by CNG (rpm=1500, full load)

Figures 6 to 13 present variations of selected pointers values in function of rpm's for different fuels. Value of every pointer was estimated for the averaged raw vibration signal, which duration time was covering compression and combustion process in the cylinder of the tested engine.

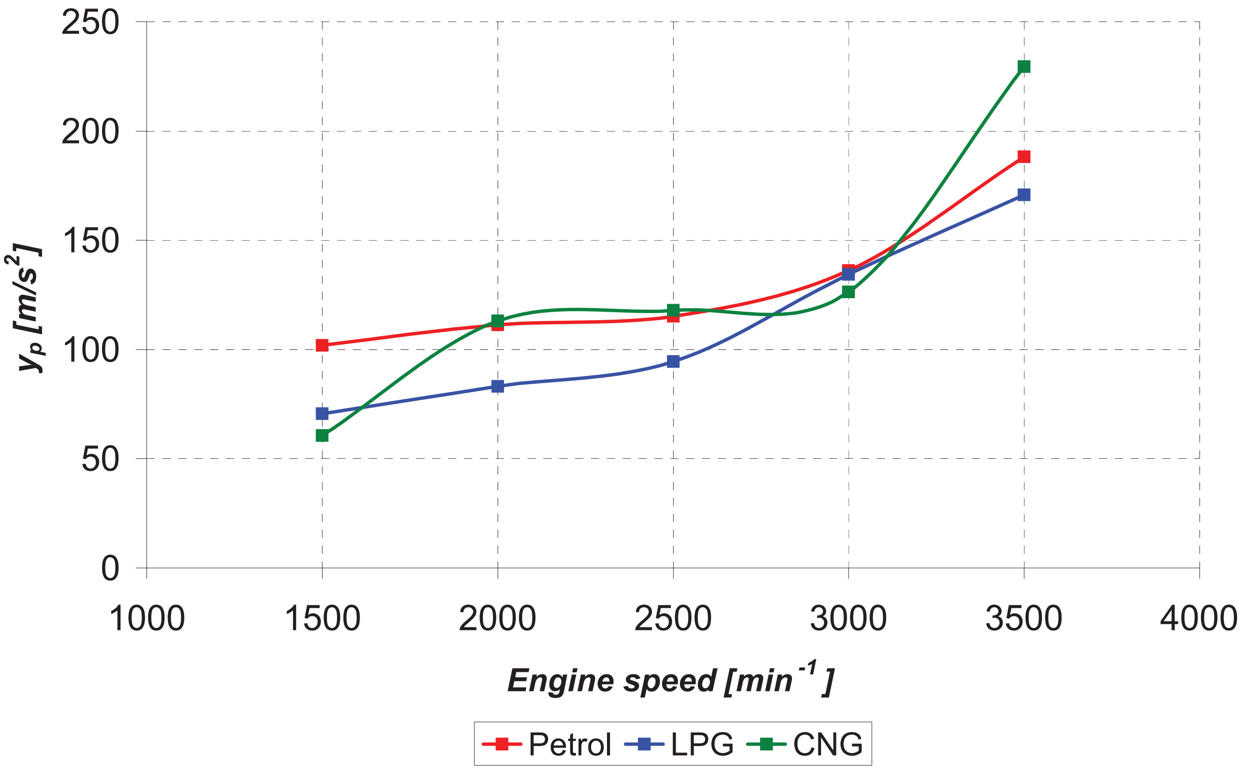

Fig. 6. Peak value of engine block vibration signal as a function of engine speed (full load)

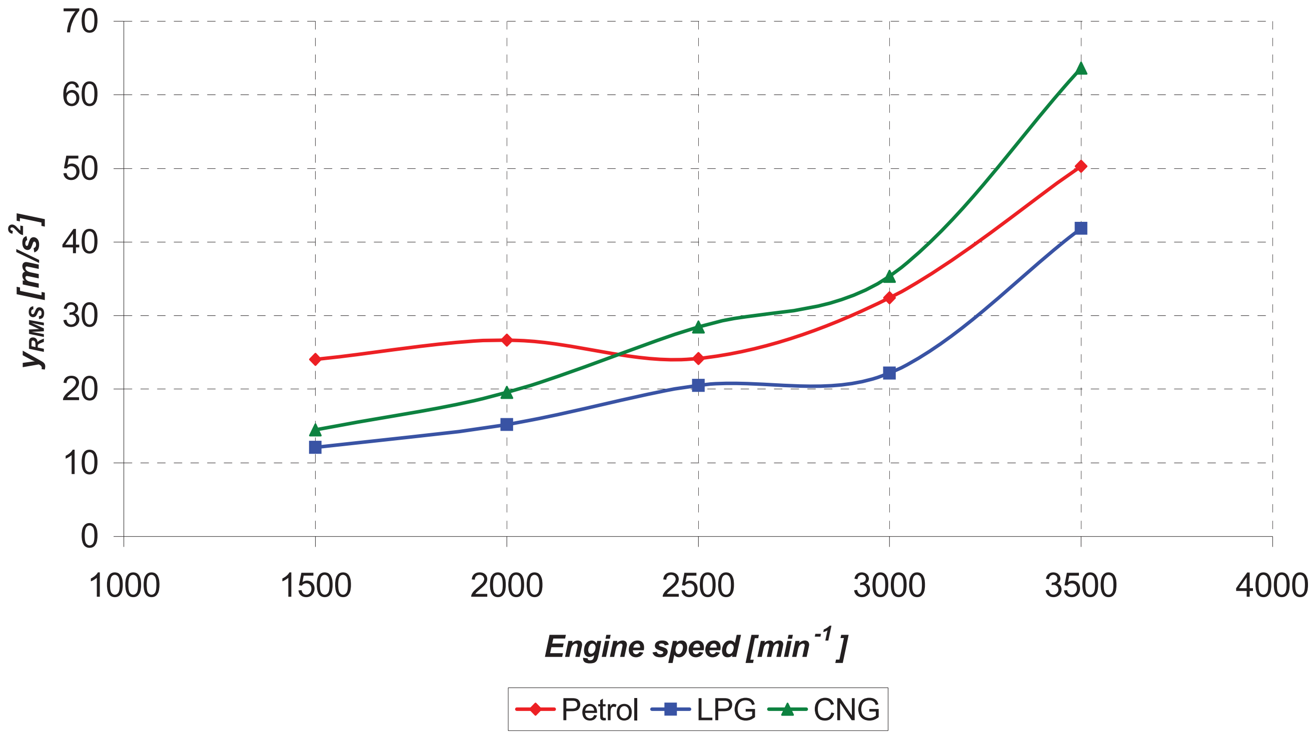

Fig. 7. RMS of engine block vibration signal as a function of engine speed (full load)

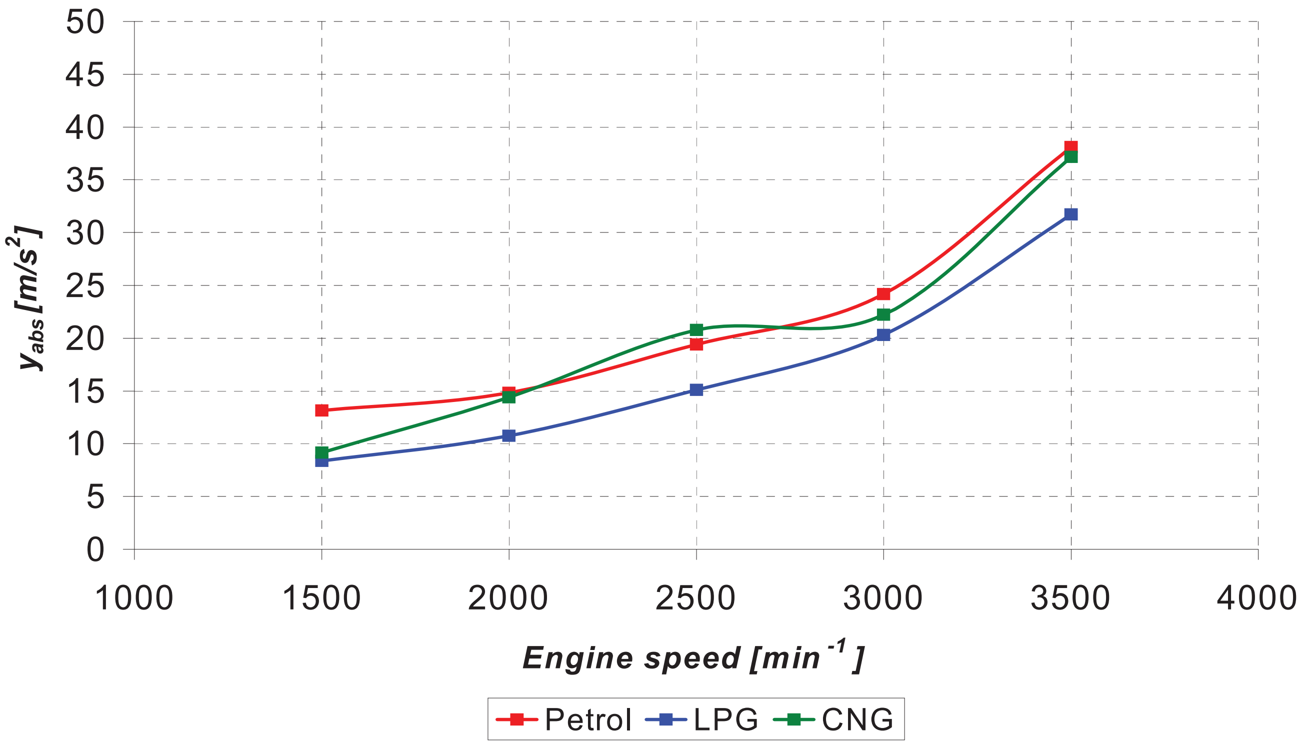

Fig. 8. Average mean value of engine block vibration signal as a function of engine speed (full load)

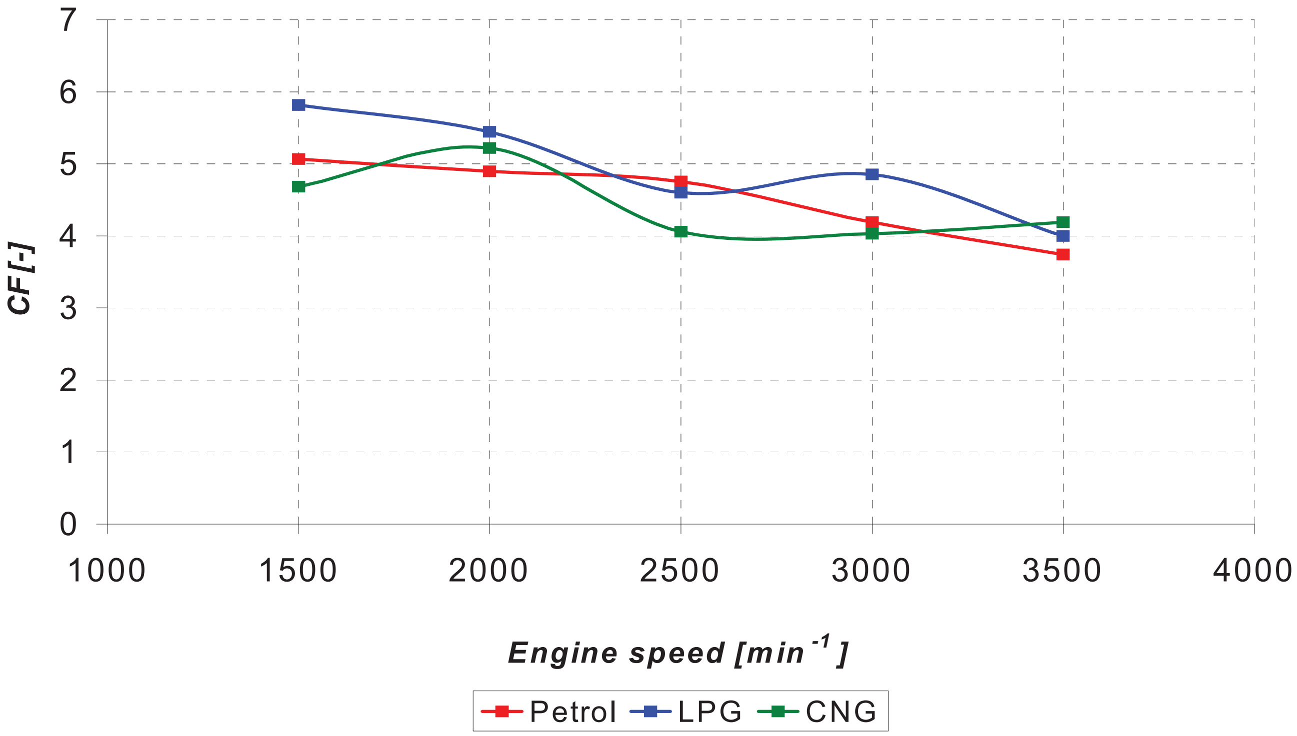

Fig. 9. Crest factor of engine block vibration as a function of engine speed (full load)

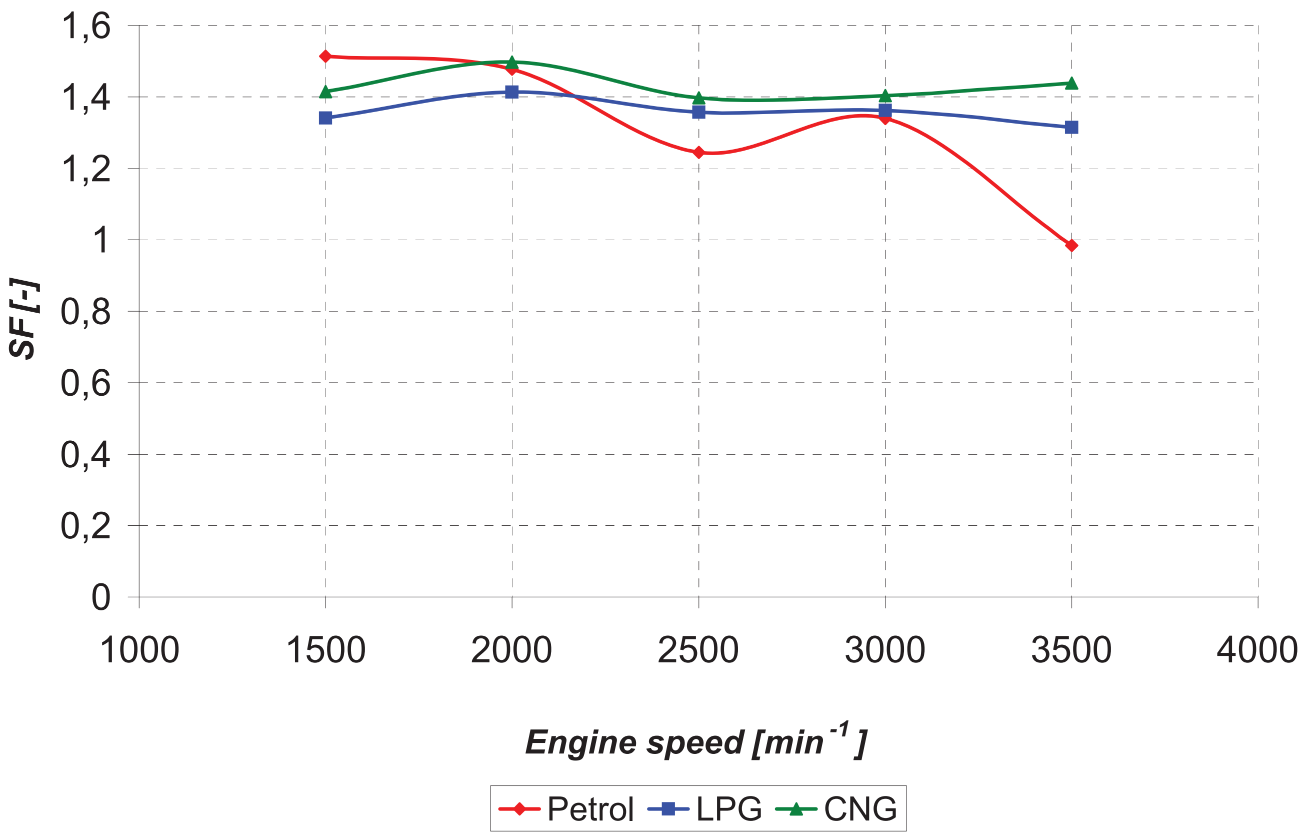

Fig. 10. Shape factor of engine block vibration signal as a function of engine speed (full load)

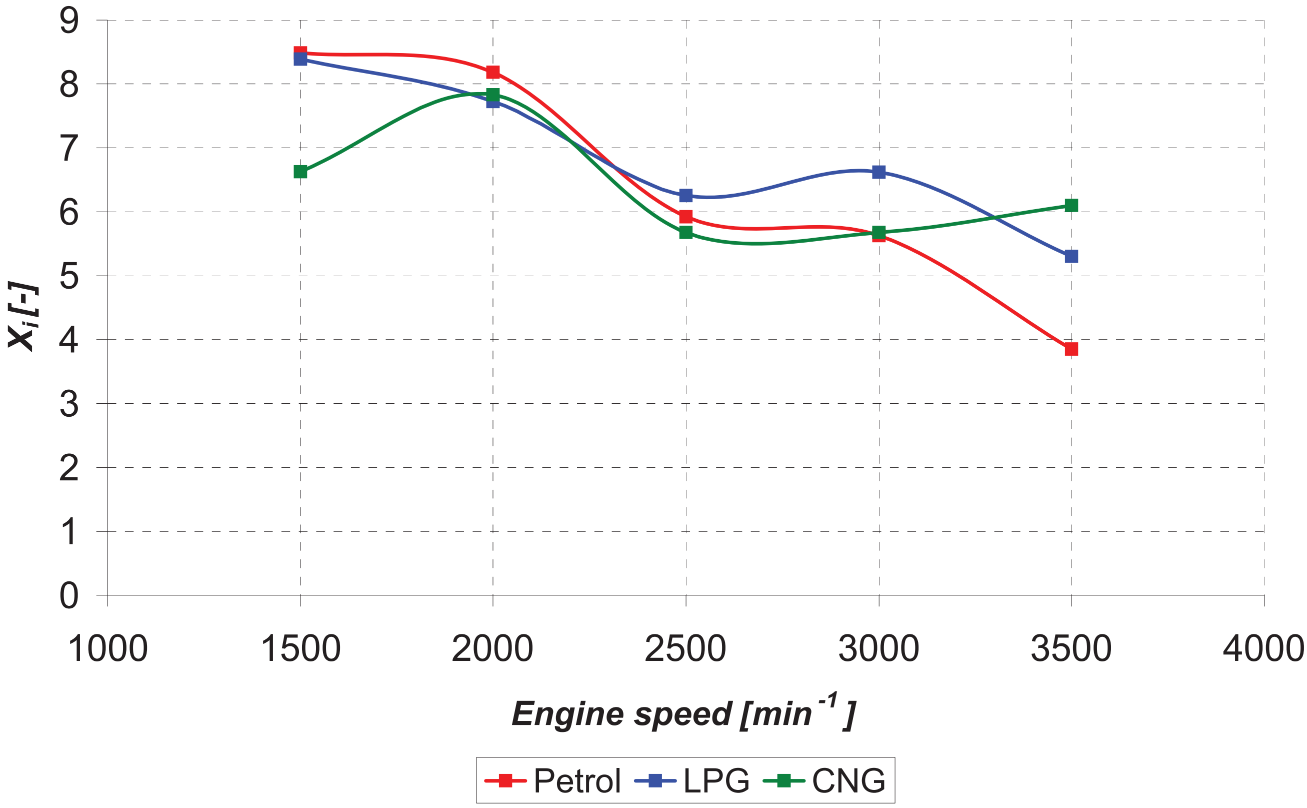

Fig. 11. Impulse factor of engine block vibration signal as a function of engine speed (full load)

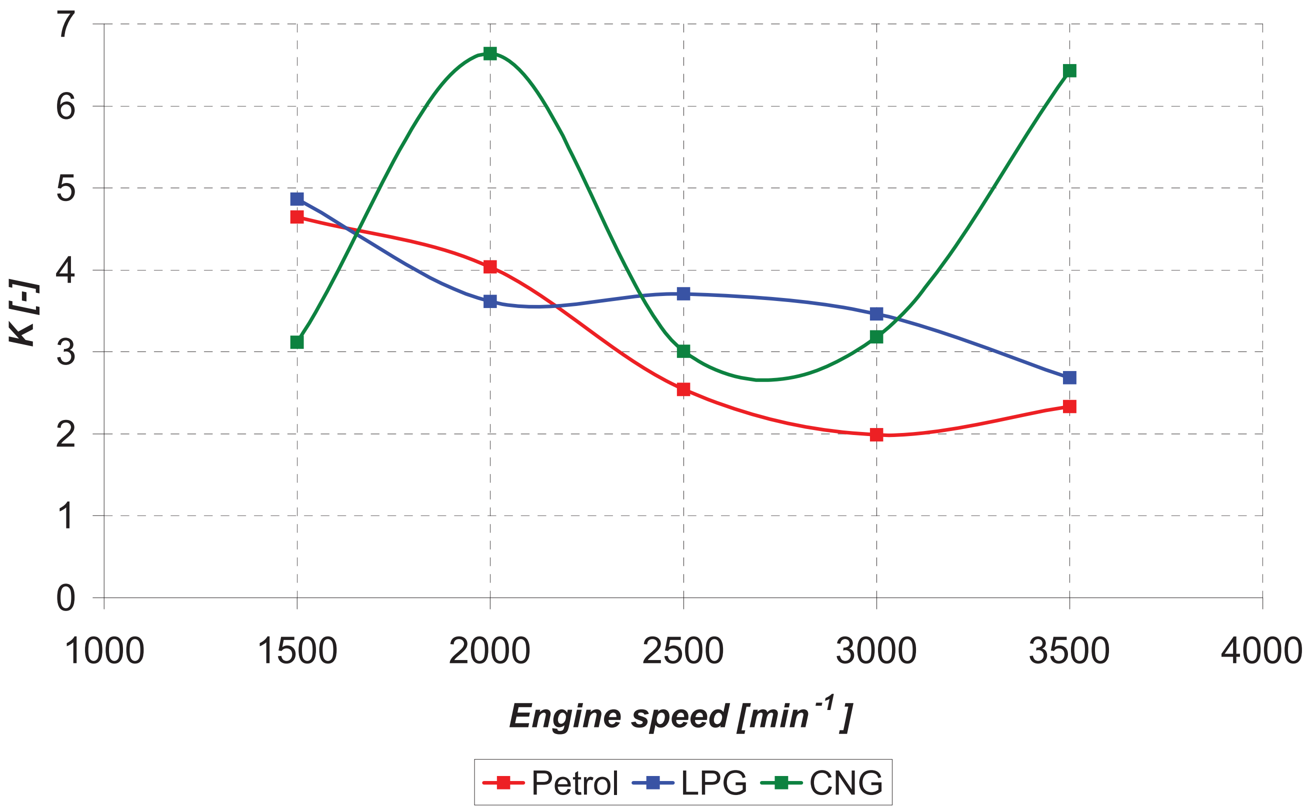

Fig. 12. Kurtosis of engine block vibration signal as a function of engine speed (full load)

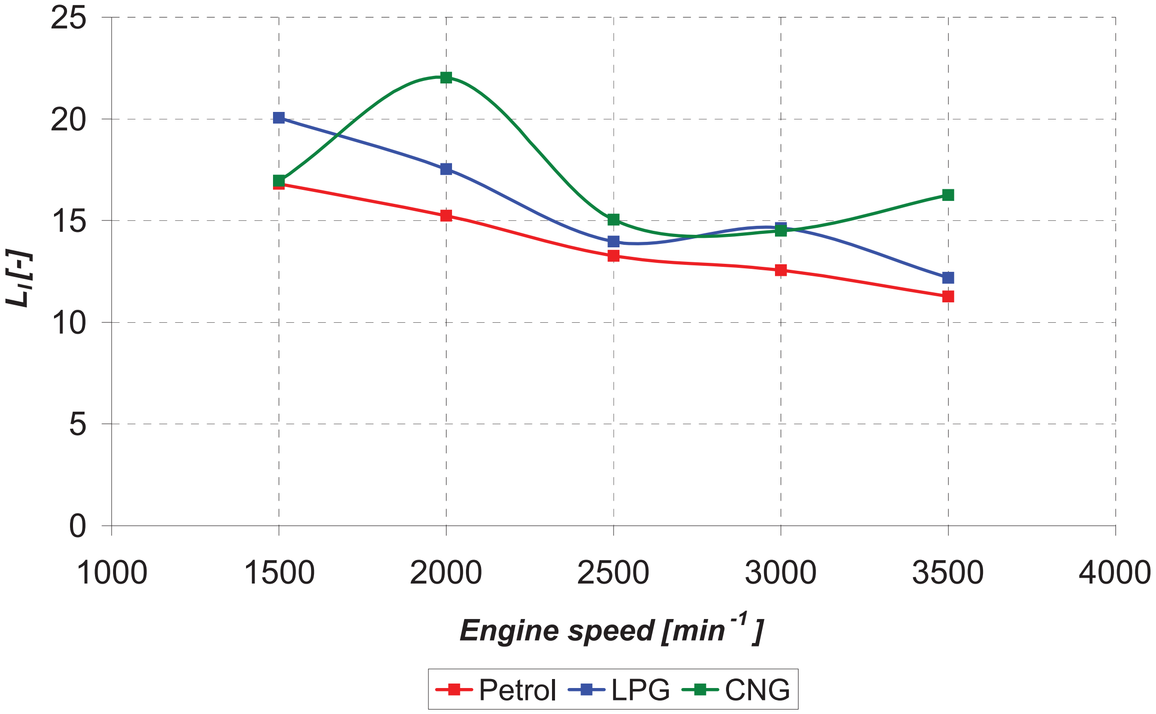

Fig. 13. Clearance factor of engine block vibration signal as a function of engine speed (full load)

4. Conclusion

CWT allows both recognition of fuel feeding the engine, as well as identification of improper combustion process. The use of CWT in normal operating conditions of the vehicle becomes however complicated. Tests completed in the project show, that for fuel type recognition it is satisfactory to use factors listed in table 1. Variations of those factors were presented for engine maximum load (figures 6 to 13). High load and rpm's cause a significant increase of engine block vibration level. That increase is connected not only with combustion pressure and inertia forces, but also high noise level. However, low signal to noise ratio does still allow identifying fuel type used for the engine propulsion.

For all calculated parameters, a significant variation in their traces with the increasing engine speed can be noticed. Some of the pointers, for a certain range of engine speed do indicate the difference between values obtained for gaseous fuels and petrol. These engine speed ranges providing best sensibility of chosen parameters for the purposes of fuel recognition, have been presented in the table 2.

Tab. 2. The range of the best sensibility of values or factors

	Value or Factor	*rpm range of the best sensibility for LPG only*	*rpm range of the best sensibility for LPG and CNG*
1	Peak value	Idle, 1500- 2500	Idle, 2000-2500
2	RMS	Idle, 1500- 3500	Idle, 2500-3500
3	Average absolute value	Idle, 1500- 3500	
4	Crest factor	Idle, 1500- 1800	Idle, 2500-3000
5	Shape factor	Idle, 1500- 1700	Idle, 2000-3500
6	Impulse factor	Idle, 3000- 3500	Idle, 2500-3000
7	Kurtosis	Idle, 2500- 4000	Idle, 2500-3000
8	Clearance factor	Idle, 1500- 4000	Idle, 1600-2500

From all demonstrated pointers, the shape factor shows satisfactory resolution, for the fuel recognition features at the idle, and for both low and high engine speed.

Moreover research that has been done so far leads to following conclusions:

- in cylinder pressure variations essentially influence the value of engine body vibration signal,
- fuel type feeding the engine does significantly affect combustion hardness,
- increase of engine load and speed causes the increase of indicated pressure peak values with the increasing load and engine speed, engine block vibration accelerations effective values were rising.

Furthermore analysis of obtained results shows that minimum sampling rate should be around 50 kHz. Registration used in case of combustion process triggered by crank position signal with resolution of 1° or 0,5° does not give satisfactory result, especially for low engine speed.

Acknowledgements

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