IDENTIFICATION OF COMPONENTS OF VIBRATION SIGNAL FROM THE HATZ 1B40 ENGINE

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Abstract

An experiment is described consisting in recording of vibration signals on the body of a HATZ 1B40 single-cylinder compression-ignition engine, applied among other things as a driving source for FOGO power generators. Characteristic time courses fragments of the recorded vibration signals were linked to occurrence of specific phenomena in the working engine and with operation of specific engine mechanisms generating these signals. Potential was found for utilization of the vibration signal recorded on the body of a HATZ 1B40 compression-ignition engine for optimization of simultaneous feeding of the engine with diesel oil and natural gas.
There are potential possibility of application of a simple knock sensor from a spark-ignition engine as a component of a feeding control system of a compression-ignition engine with diesel oil and natural gas. Theoretical time course of vibration signal of the HATZ 1B40 engine, example oscilloscope trace of time courses of signals reflecting, location of mounting of the vibration acceleration sensor on the engine, allocation of the theoretical and empirical time course of the vibration signal of the HATZ 1B40 engine, example vibration signal time courses recorded at the head of an engine fed with various mixtures of air and natural gas and diesel oil with oval-marked fragments corresponding to diesel oil injection are presented in the paper.

Keywords: *mechanics, compression-ignition (diesel) internal combustion engine, vibration and sound, engine control*

1. Introduction: theoretical form of vibration signal

The study [2] presents a so-called theoretical time course and a theoretical spectrum of vibration signal, characteristic of a HATZ 1B40 single-cylinder compression-ignition engine. This engine is applied among other things as a drive source for FOGO power generators. The presented time course and spectrum were obtained by way of theoretical analysis of operation of a four-stroke, naturally aspirated, piston internal combustion engine with valve timing, operated by a single-section piston injection pump at crankshaft speed equal to 3000 rpm (50 rps), conducted with a view to identification of sources of vibroacoustic phenomena in this engine. Occurrence of each event possibly causing a change of stresses in solid materials of engine elements (e.g. due to them striking each other or being reached by a pressure wave propagating in liquids (diesel oil, engine oil) or gases (air, air-fuel mixture, exhaust gas) contained in the engine) is presented in the discussed time course in the form of an individual peak or band, in which these peaks occur (Fig. 1).

So obtained time course and spectrum of vibration signal take no account of transformations of the signal along the way between the place of its origin (the place of occurrence of stresses in elastic solid material of a given engine element) and the place of its recording (the place on the external engine surface where a vibration sensor is located) [1, 3-5]. Therefore, the time course of the real vibration signal can feature not only components (time course elements) directly caused by operation of the analyzed sources of the vibration signal, but also elements connected with propagation of vibroacoustic signals in engine elements, e.g. reflection of mechanical waves from external surfaces of the elements in which they propagate, with occurrence of rumble or modulation, etc.. It is also possible that certain components of the signal shown in the theoretical time course will be missed due to their low value with respect to that of dominating components, following either from relatively low level of generation of these components with respect to the dominating components or from their attenuation along the way from the place of generation to the place of recording.

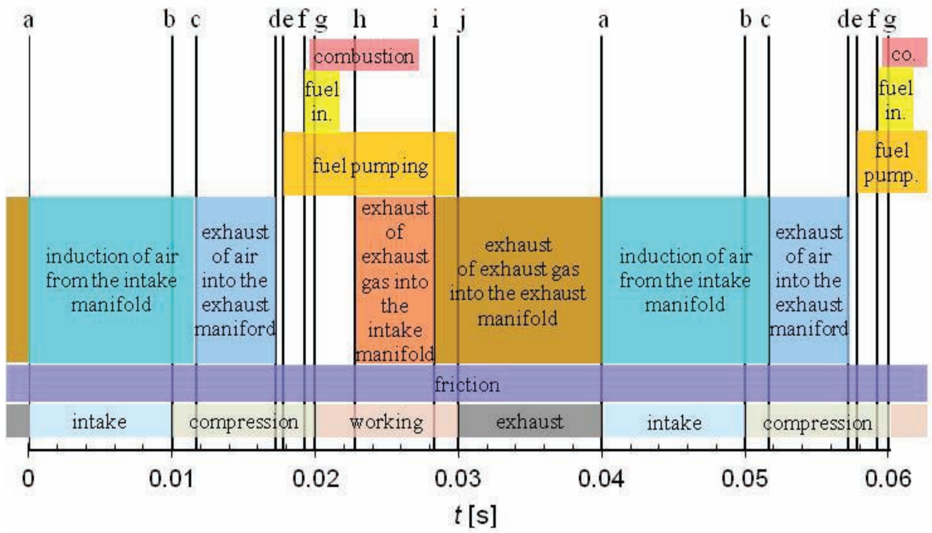

Fig. 1. Theoretical time course of vibration signal of the HATZ 1B40 engine for crankshaft speed of 3000 rpm (the work cycle lasts 40 ms) [2]; **a** *– piston shift at TDC, reciprocating motion of piston-crank system elements, just after strikes of the rocker against the intake valve and just before strikes of the exhaust valve against the seat;* **b** *– piston shift at BDC and reciprocating motion of piston-crank system elements;* **c** *– strikes of the intake valve against the seat and the rocker against the exhaust valve;* **d** *– strikes of the exhaust valve against the seat;* **e** *– start of fuel compression in the injection pump and still before* ***f*** *start of fuel pumping into the injection pipe;* **f** *– start of fuel injection and still before* ***g*** *spontaneous fuel ignition;* **g** *– piston shift at TDC and reciprocating motion of piston-crank system elements;* **h** *– strikes of the rocker against the intake valve;* **I** *– strikes of the intake valve against the seat and the rocker against the exhaust valve;* **j** *– piston shift at BDC, reciprocating motion of piston-crank system elements and end of fuel pumping in the injection pump;* ***colored rectangles*** *– duration of generation of vibrations and sound connected with a given source*

2. Experiment – real form of the vibration signal

For the purpose of verification of the form of theoretical time course of the vibration signal, an experiment was carried out, whereby real signals were recorded from a sensor mounted on an operating engine. For execution of the experiment, a simple measurement line was applied, comprised of crankshaft and intake valve position sensors, vibration acceleration sensor and a four-channel digital oscilloscope. An example oscilloscope trace is presented in Fig. 2. Channel 1 was used to record the signal from the crankshaft position (rotating speed) sensor – clearly positive signal values (signal impulses) occur every revolution of the crankshaft at a specific moment during compression and exhaust strokes. Channel 2 was used to record the signal generated by the engine controller – clearly positive signal values (signal impulses) occur for the top dead center piston position between the compression and working strokes. Channel 3 was used to record the signal from the intake valve opening sensor – clearly positive signal values (rectangular signal jumps) occur for the periods when the valve was open in a degree greater than corresponding to

„closing” (in opening of the valve) and „opening” (in closing of the valve) of the sensor „contact points”. Channel 4 was used to record the signal from the vibration acceleration sensor.

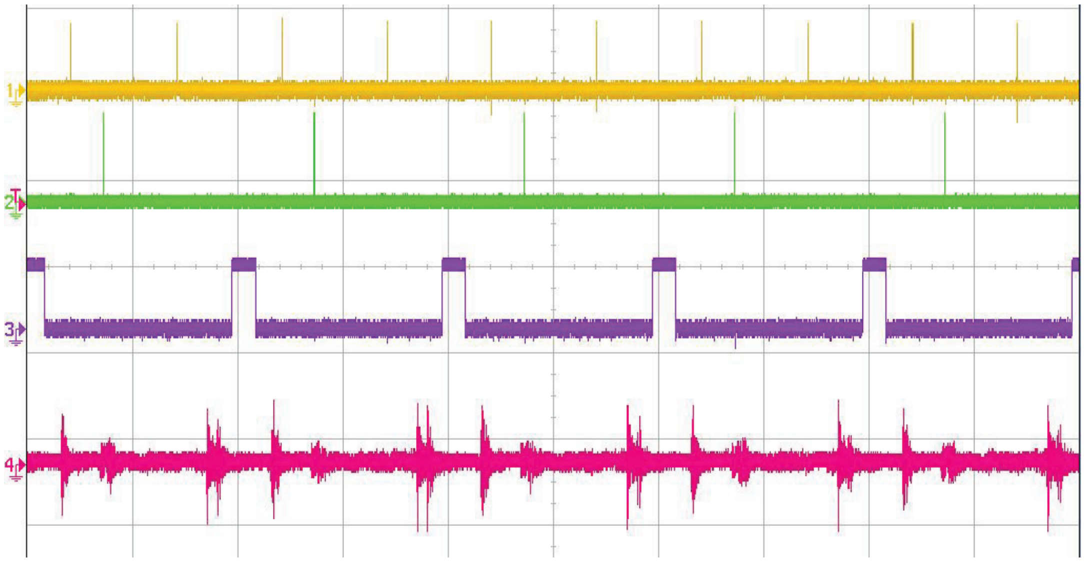

Fig. 2. Example oscilloscope trace of time courses of signals reflecting: - crankshaft position (channel 1), - top dead center piston position between the compression and working strokes (channel 2), - determined level of intake valve opening (channel 3), - vibration accelerations (channel 4); for a HATZ 1B40 engine operating at 3000 rpm; Time base scale: 20 ms per division. Vibration signal value scale: 2 V per division

With the respect to the original engine design, based on which the theoretical time course of vibration signal was executed, in the tested engine the original feeding with diesel oil (utilizing a piston injection pump and a pressure-controlled injector) was replaced with a common-rail system with an electromagnetic-controlled injector, opened at the moment corresponding to injection advance angle equal to 14.5^{o} and closed at the moment ensuring supply to the engine of a dose of diesel oil sufficient for obtaining set power, required for driving the powered device. This was achieved among other things by replacing the original injector with a new one, supplied by an external common-rail system, leaving the original injector pump in the engine (it is mounted inside the engine body, and this way breaching of the engine's functional integrity was avoided) and directing the stream of the diesel oil pumped by it back to the fuel tank – fuel pumping takes place as in the original solution, albeit with lesser flow resistance. At the same time the tested engine was feeding with natural gas, whereas the gas was supplied to the air aspirated by the engine through a passing flow valve, whose outlet was placed in the intake manifold. The dosage of natural gas supplied to the engine was controlled by the degree of opening of this valve, which in turn was strictly related to motion of a stepping motor controlling this valve. The replacement of the engine's feeding manner followed from the need for conduct of research not described here, conducted for the purpose of development of a control system for the analyzed engine, fed simultaneously with diesel oil and natural gas (dual fuel), with a view to ensuring appropriate engine power at possibly maximum limitation of diesel oil consumption at the expense of natural gas consumption.

Since the presented material is dedicated to vibration signals, only the measurement line of these signals will be described in greater detail. The vibration acceleration sensor was placed on the rear wall of the engine head at its connection with the body (on the wall from the side of the crankshaft output towards the driven device), right next to the cylinder axis (ca. 1 cm from the cylinder axis towards the intake manifold), as shown in Fig. 3. The vibration sensor was attached to the engine body by means of a bolt screwed into the opening in the head wall originally serving for mounting of the engine temperature sensor (the original temperature sensor was replaced with a smaller sensor located elsewhere in the head). A piezoelectric-type voltage vibration sensor type

5WK96063 by SIEMENS was used, designed and produced as a knock sensor for spark-ignition engines X 18 XE mounted in OPEL Astra G, Zafira and Vectra B cars. The signal from the vibration sensor was recorded by means of a digital oscilloscope type DSO7034A series InfiniiVision 7000 by Agilent Technologies, allowing for signal sampling at 2 GHz frequency (instantaneous signal values were obtained every 0.5 ns with duration of a single crankshaft revolution of 20 ms). The obtained (recorded) oscilloscope traces of time courses of recorded signals had the resolution of 1000x640 pixels (100 pixels per time base division, which given the time base scale of 20 ms per division gives signal values display every 0.2 ms, and 80 pixels per signal value division, which given the vibration signal value scale of 2 V per division gives vibration signal values display every 25 mV).

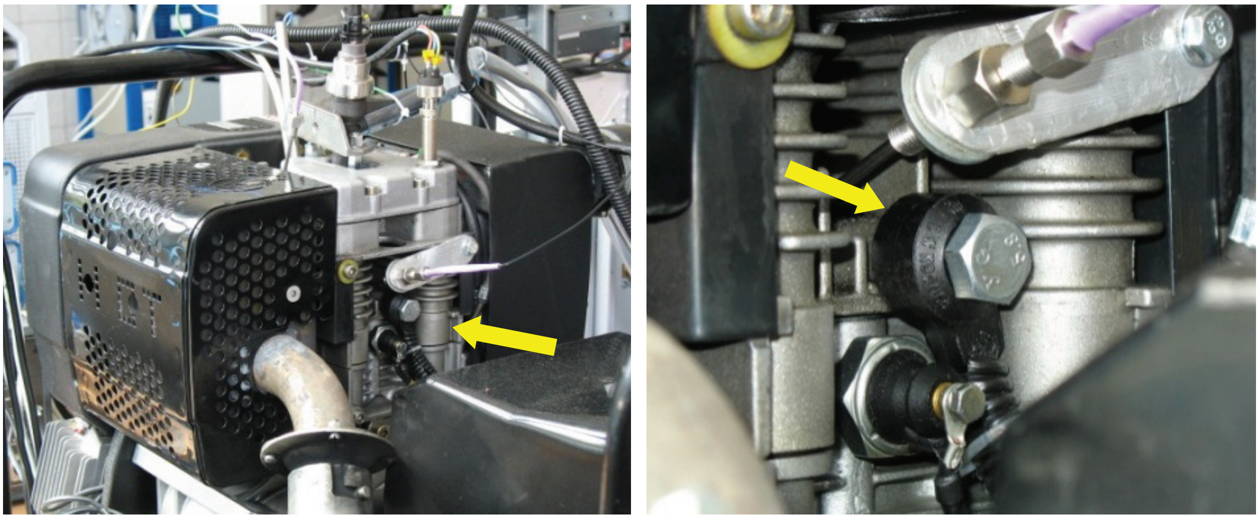

Fig. 3. Location of mounting of the vibration acceleration sensor on the engine (the sensor is indicated with the yellow arrow)

Mutual position of time courses of the four recorded signals (shown in Fig. 2) has allowed for allocation of characteristic fragments of the empirical time courses of vibration signals to appropriate fragments of the theoretical time course that is occurrence of specific phenomena in the working engine and operation of specific engine mechanisms generating these signals. This allocation for an example time course is presented in Fig. 4. Comparing the obtained empirical courses with the theoretical course, it is possible to identify its certain components, e.g.:

- marked with line **a** as originating from piston shift at TDC and from reciprocating motion of piston-crank system elements (precisely at line **a**) and from strikes of the rocker against the intake valve (just before line **a**) and strikes of the exhaust valve against the seat (just after line **a**),
- marked with line **c** as originating from strikes of the intake valve against the seat and strikes of the rocker against the exhaust valve,
- marked with lines **f** and **g** as originating from start of diesel oil injection and spontaneous fuel ignition still before piston TDC between the compression and working strokes, and from piston shift at this TDC and reciprocating motion of piston-crank system elements,
- marked with rectangles fuel in. and combustion as originating from the process of diesel oil injection and the process of air-fuel mixture combustion.

Figure 5 presents several time courses of vibration signals recorded for several different manners of engine feeding. Change of feed manner was achieved by injection of diesel oil into the engine cylinder at constant pressure (from a common-rail system) over varying periods of time (through an electronically-controlled injector) – the diesel oil dose depended on duration of injection. Diesel oil was injected into clean air or into mixtures of air and natural gas of varying percentage composition – the quantity of natural gas supplied to the engine's cylinder depended on the degree of opening of a passing flow valve in the engine's natural gas feeding installation.

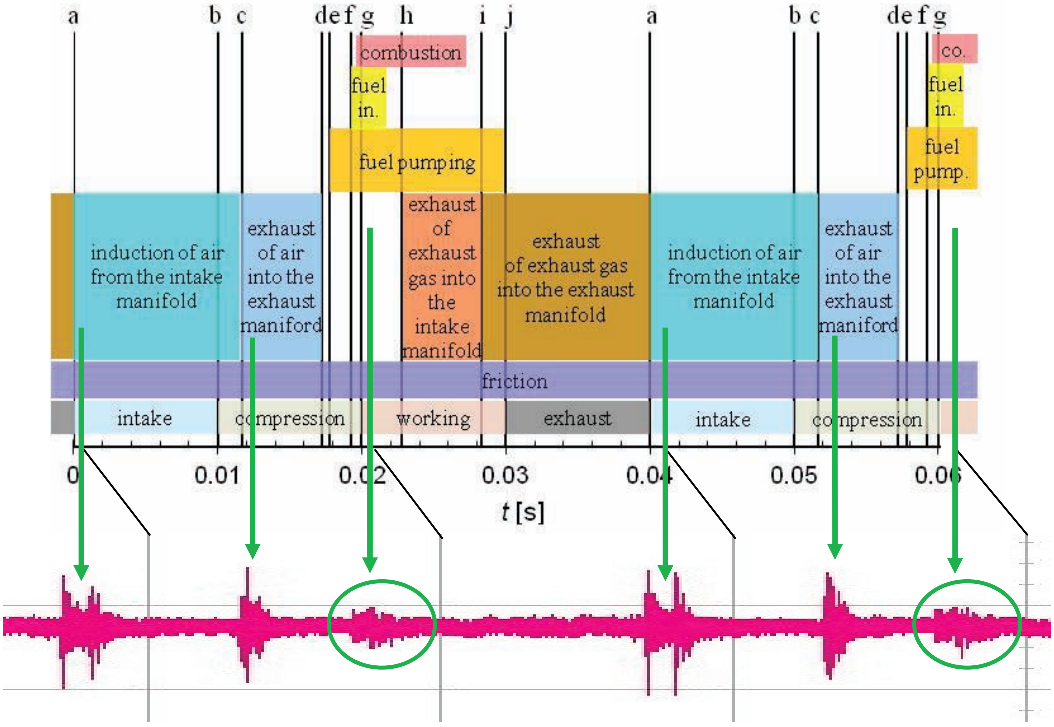

Fig. 4. Allocation of the theoretical (top) and empirical (bottom) time course of the vibration signal of the HATZ 1B40 engine for crankshaft speed of 3000 rpm with marked with ovals fragments corresponding to diesel oil injection, its spontaneous ignition and start of air-fuel mixture combustion

At first glance, similarities are visible between all these courses – preserved is the sequence of double non-zero signal at the limit of exhaust and intake strokes, non-zero signal at the start of compression stroke and broader band of non-zero signal at the end of compression stroke and the beginning of working stroke. Differences are also visible between the obtained time courses of vibration signals obtained for different manner of engine feeding, consisting mainly in differentiation of instantaneous values of these signals. These differences require further analysis, both temporal and spectral, preceded by recording of vibration signals with a more specialized measurement system than that applied in the course of the presented research, i.e. allowing for obtaining values of the sampled signal in numerical form, and not just graphic one (oscilloscope trace). Results of this analysis will be useful for consideration in the control process of an internal combustion compression-ignition engine with dual-fuel feeding (diesel oil and natural gas) of not only the costs of consumed fuel (connected with the difference in consumption and unit costs of both fuels) or exhaust gas toxicity (connected with the difference in the combustion process of both fuels), but also the so-called hardness of the air-fuel mixture combustion process, determining at least operation noise and durability of the engine. Since the results were obtained using a simple knock sensor from a spark-ignition engine, perhaps it could be utilized also in a possible application of results of further research, as an element of engine control system in a compression-ignition engine.

Finally, it should be unequivocally stated that the purpose of research, whose results are presented here, was not assessment of relation of the form of vibration signal time course recorded on the engine body to its feeding manner, but merely at attempt to allocate characteristic elements (fragments) of vibration signal time course to the occurrence of specific events in the working engine and to the operation of specific engine mechanisms generating the same.

3. Conclusion

In the vibration signal time courses recorded on the body of a HATZ 1B40 single-cylinder four-stroke compression-ignition engine, it is possible to distinguish fragments connected with the occurrence of specific phenomena in the engine during its operation and with the work of specific mechanisms of the engine generating these signals.

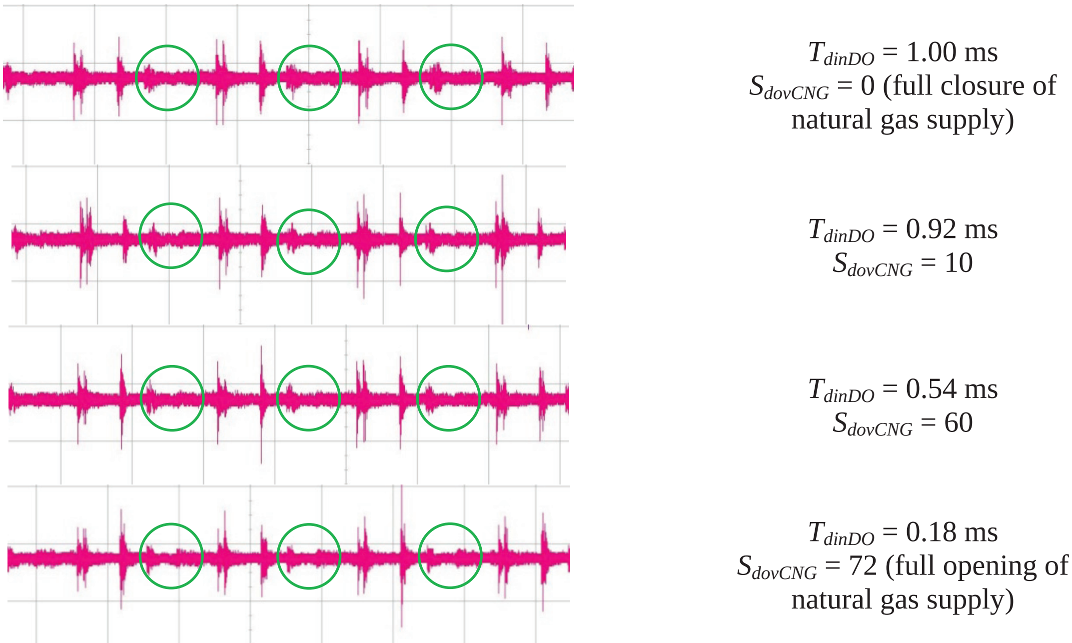

Fig. 5. Example vibration signal time courses recorded at the head of an engine fed with various mixtures of air and natural gas and diesel oil with oval-marked fragments corresponding to diesel oil injection, its spontaneous ignition and start of air-fuel mixture combustion; Time base scale: 20 ms per division. Signal value scale: 2 V per division; TdinDO - duration of diesel oil injector opening (given crankshaft revolution lasting 20 ms); SdovCNG – degree of opening of passing flow valve in the engine's natural gas feeding installation counted; with the number of steps of the stepping motor controlling it (given full closure occurring for 0 steps and maximum opening of the valve occurring for 72 steps)

Regardless of the manner of dual fuel feeding of the tested engine with diesel oil and natural gas, the time courses of all recorded vibration signals feature the same characteristic elements. The observed differences between these characteristic elements, in particular connected with the processes of diesel oil injection and air-fuel mixture combustion, may allow for taking into account the hardness of operation of the tested engine in the process of controlling this engine – in optimization of selection of diesel oil and natural gas doses and in optimization of the starting point of diesel oil injection into the cylinder.

There exists potential possibility of application of a simple knock sensor from a spark-ignition engine as a component of a feeding control system of a compression-ignition engine with diesel oil and natural gas with a view to so-called hardness of engine operation.

Acknowledgements

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