DIAGNOSTICS FOR LOW-POWER INTERNAL COMBUSTION ENGINES

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Abstract. Machinery and equipment used in agriculture and forestry is often equipped with low-power internal combustion engines and require frequent adjustments and diagnostics. No diagnostic method has been developed so far, which would allow a simple and quick assessment of engine technical condition, its correct adjustment, and driven system state. The proposed self-braking and self-driving method makes it possible to assess the correctness of machine (tool) work.

Key words: internal combustion engine, diagnostics, self-driving, self-braking

Introduction

In recent years, many manufacturers of garden tools and machinery have appeared in the market. Equipment offered by them includes: brush cutters, chainsaws, garden rotary mowers, bar mowers, snow removers, garden mini tractors, etc. All these machines are driven by both two- and four-stroke low-power internal combustion engines (up to ca. 3 kW). These machines are offered in versions both for amateurs and professionals, owing to which prices have become attractive. Both groups of machines are designed for different loads and work character. As a result of intensive operation of these machines, their frequent servicing is necessary, including oil change, adjustments, maintenance, and inspections carried out after season. Preventive repairs are often needed in order to avoid occurrence of a defect making further machine operation impossible. Diagnostic test is the basic operation aimed at keeping technical equipment efficient and ready to operate. Equipment listed before is a subject to symptom diagnostics, and defects are eliminated only after they have shown as an out-of-order or unserviceable state [Żółtowski 1996; Merkisz et al. 2007]. Earlier, diagnostic equipment was not designed and produced due to limited popularity of these machines, and specialised companies using machinery and tools driven by low-power internal combustion engines had their own technical back and service personnel. Therefore, it is necessary to develop an effective and cheap diagnostic methods for them.

Diagnostic methods for low-power machinery

The purpose of the research was to develop an automatic diagnostic method, which would allow assessing technical condition of the whole machine on the basis of lowest possible number of tests, and to locate any damage or disturbances in correct operation. A method known in literature as an internal combustion engine self-driving and self-braking was selected from the group of possible diagnostic methods. The proposed method is an old one, developed in 1960s, although it hasn't been universally applied due to the problems with acquisition of signals and high cost of sensors used in measurements. Introduced modification of this examination was a preliminary test intended to determine whether precise diagnostics is necessary. Currently, with digital technology at hand, it is possible to set up measuring circuit hardware at a little financial resources involved. This method is based on measurements of angular velocity ω and angular acceleration ε of engine crankshaft while it accelerates after sudden increase in fuel dose, and while reducing angular velocity ω of engine crankshaft from its maximum value to zero, due to ignition or fuel cut-off. This method allows carrying out quantitative assessment of internal combustion engine effective power and power of losses - both internal engine losses and power expended on overcoming work resistance of the whole kinematic chain attached to the engine (working elements).

Theoretical grounds of the method

A change in angular velocity ω of engine crankshaft generates reactive torque M_I [Hebda et al. 1980]:

$$M_I = I_R \cdot \varepsilon \tag{1}$$

where:

I_R – reduced moment of inertia for engine elements in rotary and to-and-fro motion [$kg \cdot m^{-2}$],

ε – angular acceleration of crankshaft [$1 \cdot sec^{-2}$].

The value of reduced moment of inertia is not the subject to changes during engine operation, therefore reactive torque M_I will depend on the value of engine crankshaft angular acceleration ε. Engine self-braking effect is obtained when we suddenly increase fuel dose while engine works idle, then $\varepsilon>0$. The Dynamic moment M_d generated during fuel combustion is compensated by the moment of internal engine losses M_{sw} and reactive torque M_I. Since $M_d – M_{sw} = M_e$, in that case $M_I = M_e$, that is we determine effective moment M_e by determining the value of reactive torque M_I. Engine self-driving will occur in case if $\varepsilon<0$, that is when we cut off fuel supply or turn off ignition while engine works at maximum speed. Reactive torque M_I, which is the engine driving factor, is balanced by the moment of internal losses M_{sw}. By determining reactive torque value, we determine the moment of combustion engine internal losses. Drawing up the $\varepsilon=f(\omega)$ characteristic, we define engine behaviour in self-braking and self-driving phases.

Research results

Researchers at the Department of Mechanical Engineering and Agrophysics, Agricultural University of Cracow have built a prototype diagnostic tester for determining engine power and power of losses. It has been made in digital technology using the AVR series microcontroller. This tester allows reading out parameters and creating the ω = f(t), ε = f(t) characteristics, and then data transmission to a desktop computer in order to present the above characteristics in graphical form [Langman 2010].

Fig. 1 shows the ω=f(t) characteristics for internal combustion engines: one fully operational, and the other heavily used and incorrectly adjusted (damaged). It is visible that lines representing an increase in crankshaft angular velocity, and drop of angular velocity for fully operational engine are straight, while in case of damaged engine the function departs from the pattern. Straight lines indicate correct operation of all engine systems, as well as constant internal resistance value, which is characteristic for fully operational engine.

Fig. 2 presents the ε=f(ω) characteristic developed on the basis of the ω=f(t) characteristic shown in Fig. 1. It is visible that the values of crankshaft angular acceleration and angular lag for fully operational engine are constant in the whole range of changes in angular velocity of internal combustion engine crankshaft, which indicates its correct operation. In case of damaged engine this function departs from the pattern, and engine defect is indicated by a signal peak different than the trend.

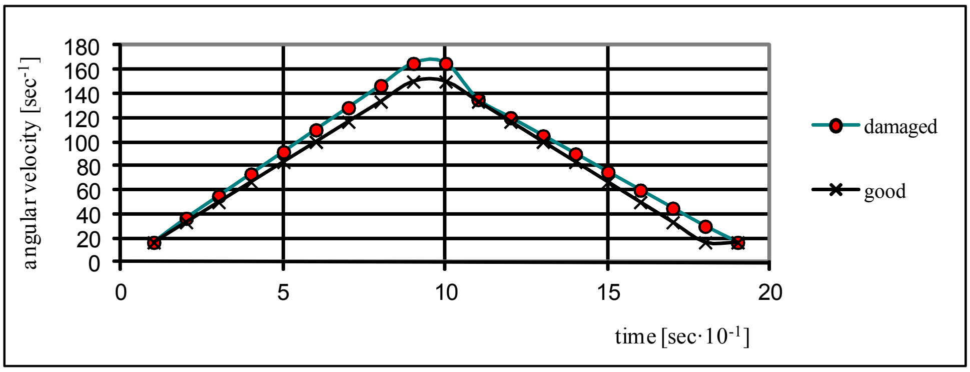

Fig. 1. The ω = f(t) characteristics during acceleration and braking of 2 engines

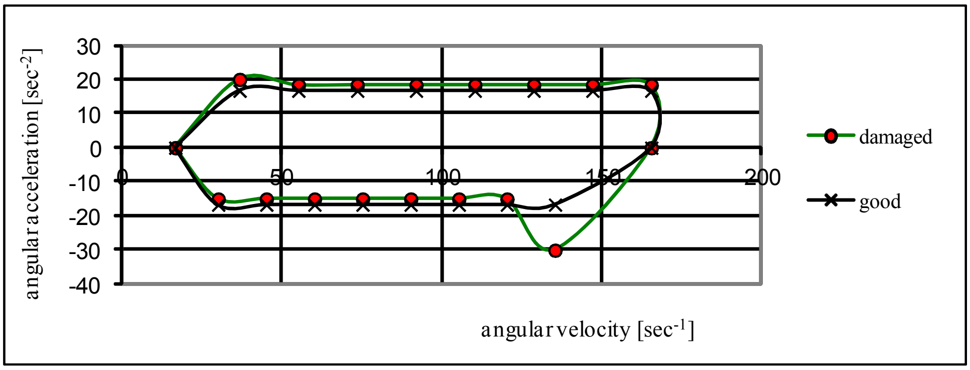

Fig. 2. The ε=f(t) characteristic developed on the basis of the ω = f(t) characteristic from Fig. 1

Diagrams shown above (Fig. 1 and Fig. 2) specify the condition of the examined engines. Diagram from Fig. 2 illustrating angular acceleration changes in function of angular velocity is primarily used in interpretation of technical condition. This form of function is not proper for building the diagnostic concluding module based on artificial neural networks, because more than one angular acceleration value corresponds to one angular velocity value [Tadeusiewicz 2007, Niziński et al. 2002]. Therefore, a diagram in form of the ε=f(t) characteristic (Fig. 3) has been developed. As a result of this we obtain stretching of the diagram shown in Fig. 2 so as to ensure that one angular acceleration value corresponds to one measurement time value t.

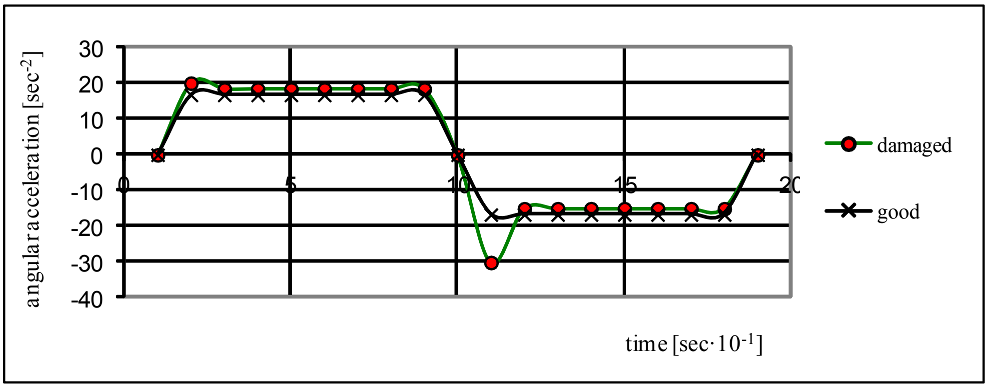

Fig. 3. The ε=f(t) characteristic for operational engine and engine with defects

Computing the next derivative (Fig. 4) causes increase of changes in places, where significant differences occur. It is possible to read out correctly the differences in trajectories of the characteristics, which allows implementing the data to the diagnostic concluding module.

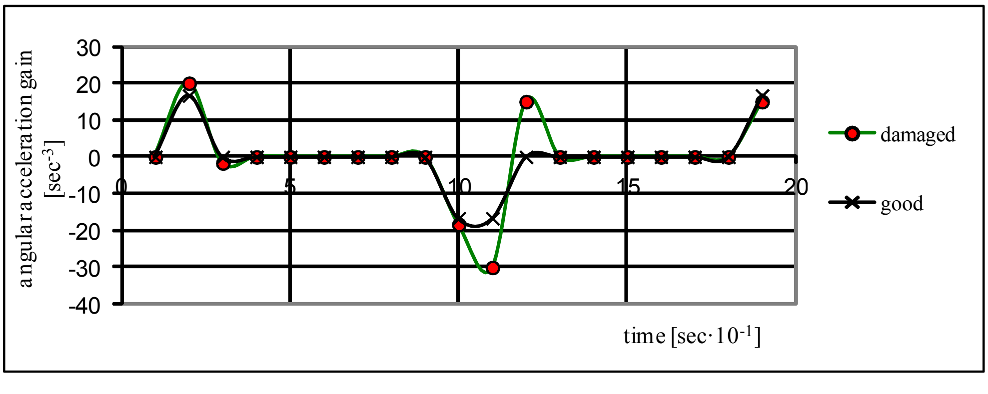

Fig. 4. The ε=f(t) characteristic for operational engine and engine with defects in feed system and higher internal resistance values

While analysing the above characteristics we may observe that any defects occurring in the engine or in the system of power transmission to machine working elements bring about visible distortion of the ω=f(t) and ε=f(ω) characteristic trajectories, which may be the basis for object diagnosing process. Upper (positive) part of the ε=f(ω) characteristic is formed by the processes taking place in an engine during increase in crankshaft angular velocity and may indicate defects occurring in feed and ignition systems and crankshaft and pistons assembly, or improper engine adjustment. Lower part of the above characteristic (negative part) indicates a higher engine internal resistance values, and resistance put up by attached working units due to failure conditions occurring in them. Computing a double derivative of the ε = f(ω) function allows to obtain characteristics that may be interpreted by diagnostic systems in order to provide diagnosis.

Conclusions

1. Considering the low power of driving engines in the discussed machines, any defects or improper engine adjustment cause noticeable change in its basic operating parameters.
2. The ε=f(ω) characteristics illustrate both technical condition and adjustment of the engine, and they can also determine a technical condition of kinematic chain of machine working elements attached to the engine.
3. The proposed self-driving and self-braking method as a method used to diagnose machines driven by internal combustion engines is simple and efficient.
4. The ε=f(ω) characteristics shown in Fig. 4 allow proper diagnostic concluding based on the ANN, which considerably reduces time required for diagnostic process.

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DIAGNOSTYKA SILNIKÓW SPALINOWYCH MAŁYCH MOCY

Streszczenie. Maszyny i urządzenia stosowane w rolnictwie i leśnictwie często wyposażone są w silniki spalinowe małej mocy i wymagają częstych regulacji oraz diagnostyki. Dotychczas nie opracowano metody diagnostycznej, która w prosty i szybki sposób określiłaby stan techniczny silnika, poprawność jego regulacji oraz umożliwiłaby określenie stanu układu napędzanego. Zaproponowana metoda samohamowania i samonapędzania pozwala na określenie poprawności pracy maszyny (narzędzia).

Słowa kluczowe: silnik spalinowy, diagnostyka, samonapędzanie, samohamowanie

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