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DIAGNOSING MICROPROCESSOR-CONTROLLED SYSTEMS

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Summary. The paper presents the problem of diagnosing microprocessor-controlled systems of working machines. The methods applied most often to estimate their technical condition have been described. The direction of further development of diagnostic systems of electronically-controlled units has been also proposed, the ultimate goal being the evaluation of the state of both the working process and particular final controlling elements of the system.

Key words: microprocessor controller, working unit of a machine, diagnostics

INTRODUCTION

Today microprocessor-controlled systems are applied more and more often in vehicles and working machines. The distinguishing feature of these systems is the lack of direct mechanical (hydraulic, pneumatic) links between particular elements, since mechanical connections have been replaced by electrical connections. The main advantage of such a solution is that it enables working process optimization, depending on several parameters. Another advantage is the fact that control over the operation of a machine or its units is practically unlimited, i.e. there is no need to stick to the rules that must be strictly observed in the case of mechanical control, where the constructor has to take into account certain limitations and technological conditions, and cannot freely set the working characteristics of particular elements. With mechanical control it is difficult, or even impossible, to make one parameter depend on two other, independent parameters. The memory of microprocessors can store algorithms of system behaviors dependent upon several or even several dozen parameters, which enables full optimization of operation of a controlled machine or its units. Such a solution allows to increase machine efficiency, improve the quality of the process, reduce production costs, make machine operation more comfortable and reduce the adverse environmental impact. For instance, in mechanically controlled combustion engines the ignition advance angle is changed with a pressure-regulating or centrifugal governor, i.e. depending on the pressure in the suction manifold or engine speed. In modern electronically-controlled engines the ignition advance angle is changed depending on several parameters characterizing the actual conditions of motor operation at a given moment, i.e. motor load, rotational speed, motor temperature, etc.

Electronically-controlled systems are at present commonly applied to control the working units of vehicles and complex working machines. A great advantage of such systems is that the controller can be easily reprogrammed, which allows to change the working characteristics of the whole system in a simple way [Günther 2002, Wierzbicki 2003a, b].

STRUCTURE AND FUNCTIONING OF MICROPROCESSOR-CONTROLLED SYSTEMS

A block diagram of a microprocessor-controlled working unit of a machine, with an information flow diagram, is shown in Figure1. The main element of this system is a controller converting input signals (coming from adjusting components) into output signals (information sent to various final controlling elements changing the working parameters of the system) according to the algorithm (program) recorded in the internal memory. The structure of such a controller is presented in Fig. 2. The measuring elements of the control system (Fig. 1) measure input quantities (variables) $x_1, ..., x_n$, (determined by the user), characterizing the actual parameters and operation conditions of the system at a given moment, e.g. ambient temperature and temperature of working elements, pressure, load, etc. These quantities are converted by special elements (converters/transformers) and transmitted in the form of electric quantities to the control unit (controller). Then the information is converted by the controller, based on the algorithm stored in the memory, into output signals $u_1, ..., u_n$, and sent to final controlling elements (adjusting components). These elements convert the electric quantities into physical quantities $v_1, ..., v_n$, e.g. shift, rotation, which allows to reprogram the system, as its operation conditions change as a result of these transformations. The actual operation conditions are measured by measuring elements, converted into electric quantities and transmitted to the controller. The controller compares the measured values with input quantities and, if significant differences are found, sends correcting signals $u'_1, ..., u'_n$ to final controlling elements. This solutions makes it possible for the system to correct the parameters of particular elements so that output quantities are similar to input quantities [Niziński and Wierzbicki 2003].

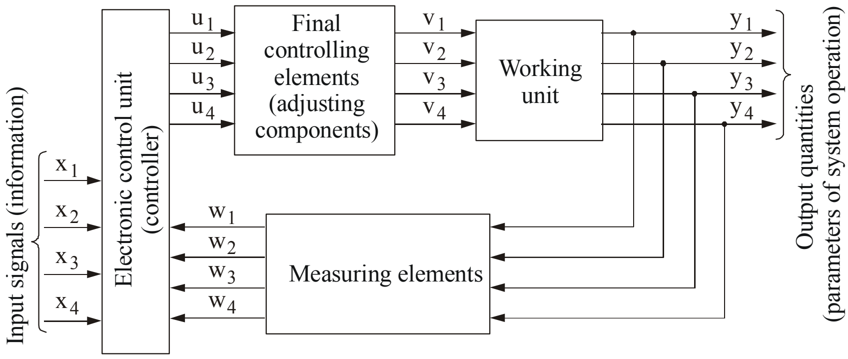

Fig. 1. Block diagram of an electronically-controlled working unit with an information flow diagram

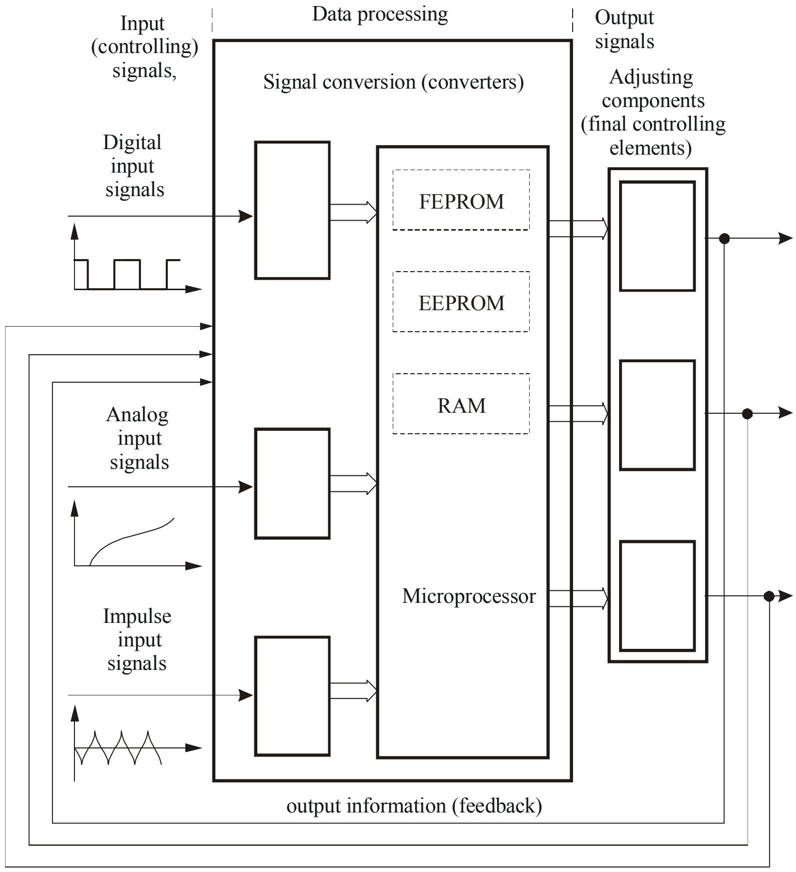

Fig. 2. Block diagram of a microprocessor-controlled working unit of a machine

As already mentioned, microprocessor-controlled systems enable to optimize operation parameters taking into account several factors. Impulses controlling elements of the system are calculated, using mathematical formulas, by the processor which generates controlling signals not only on the basis of present conditions, but also the recorded history of changes in particular signals.

An example of controlling information generation by a microprocessor may be the algorithm used for determining fuel charge in Chrysler motor-car engines. In these engines fuel charge is regulated by injector opening time. Under normal conditions (faultless performance), this time is calculated by the microprocessor from the following dependence [Merkisz and Mazurek 2002]:

$$Q = LOAD \times BASE \times OXYG \times ADAP$$

Successive terms of this expression are calculated from the following relations:
LOAD – fuel charge depends on the amount of fuel being sucked:

$$LOAD = \frac{RPA}{MAXRPA} \times \frac{MAP}{BARO}$$

where:

RPM – engine speed at the moment (revolutions per minute);
MAXRPA – maximum engine speed (revolutions per minute);
MAP – manifold absolute pressure;
BARO – barometric pressure.
BASE – fuel charge depends on the parameters of engine operation at the moment:

$$BASE = TPS \times ECT \times IAT \times BAT$$

where:

TPS – value of the signal emitted by the throttle position sensor;
ECT – engine coolant temperature;
IAT – intake air temperature;
BAT – correction coefficient dependent upon the voltage in the wiring system of the vehicle.
OXYG – coefficient linking the fuel charge to the signal emitted by the oxygen sensor (measuring the oxygen content of exhaust gases), probe λ;
ADAP – coefficient adapting the fuel charge:

$$ADAP = (STFT \times LTFT)$$

where:

STFT – short-term fuel trim;
LTFT – long-term fuel trim.

It should be emphasized that the weights of particular terms during motor operation may be different. For examples, such a system can, but does not have to, make use of probe λ signals. When the engine is cold, the system operates within the so called open loop, ignoring *STFT* and taking into account the value of *LTFT* only, stored in the processor's memory (record of former values of the fuel trim coefficient). With an increase in temperature, the processor starts to operate within the close loop, taking into account probe λ signals. The other values of controlling signals may be determined in a similar way. The above considerations suggest that microprocessor-controlled systems permit practically unconstrained (proposed by the constructor) control over working parameters, based not only on the information obtained from many sensors controlling the working conditions of a system, but also on the feedback information obtained from the elements controlling the output parameters of a working unit.

DIAGNOSTICS OF MICROPROCESSOR-CONTROLLED SYSTEMS

The final controlling elements of microprocessor-controlled machines and devices cannot be diagnosed according to the simple symptom-damage pattern. This results from the fact that when a damage or defect occurs, the control system receives wrong signals or no signals at all, which provides the basis for making certain decisions. The further operation of the system does not always depend upon the impact of a damage, sometimes it depends on the decision made by the microprocessor only. This system localizes the defect and evaluates its effect on faultless performance according to the criteria stored in the memory.

The process of fault detection in the system goes as follows: the microprocessor compares the measured value with the expected value recorded in the controller's memory. If there are significant differences between the measured signals and those recorded in the microprocessor's memory, the system determines the effect of the damage on further operation. Depending on the seriousness of the problem, the microprocessor may make the following decisions:

– the defect has an insignificant effect on the proper functioning of the system – the problem is signaled (e.g. the control light starts to flash), and the information about the problem is recorded in the microprocessor's memory. The system can operate, and the signal from the damaged element is replaced by the averaged value of this signal stored in the processor's memory;
– the defect has a significant effect on the proper functioning of the system – the problem is signaled, and the information about the problem is recorded in the microprocessor's memory. The system goes into emergency mode. In emergency mode the system operates at a lower capacity, which results in reduced efficiency of the machine, or even environmental nuisance. The user must take steps to eliminate the damage or defect as soon as possible;
– the defect is critical – the problem is signaled provided that the controller is not damaged as well. In such a case machine running is stopped until the damage is eliminated.

It should be stressed that the use of microprocessor-controlled working units of machines enables to program any diagnostic rules. The rules recorded in the controller's memory are often completely different from the relations typical of mechanically controlled systems. An example may be here a relation observed while controlling a combustion engine. In the output system of a mechanically controlled engine, or an electronically controlled one of the older type (without the second probe λ monitoring the operation of the catalytic converter), a damage to the catalytic reactor does not affect engine operation, whereas in modern engines the controller is immediately informed about such a damage. This means that the engine controller may go to emergency mode, which manifests itself by reduced engine power or its lower dynamics. The engine's reaction to the problem is not related to the effect of the damaged catalytic converter on its operation, but to the criteria adopted by the constructor. According to these criteria, recorded in the form of rules in the controller's memory, the above damage is classified as critical, due to the adverse environmental impact of the engine, even if it has no direct influence on engine operation. This shows that the controller's reaction to engine damage may differ considerably from that typical of mechanically controlled systems.

The process of fault identification and detection by the controller in the systems discussed above is usually a two-stage one. If a fault is detected, the controller first records information about the error, and the parameters at which it occurred, but data on this error are stored in the processor's memory only. If the same defect is detected again at similar parameters, a diagnostic decision is made (e.g. the control light starts to flash). If the defect is not identified when the engine is started again, the information on this problem stored in the processor's memory is deleted. It should be noted that with the above solution different defects may give similar symptoms, so their fast localization is practically impossible without referring to the information stored in the processor's memory.

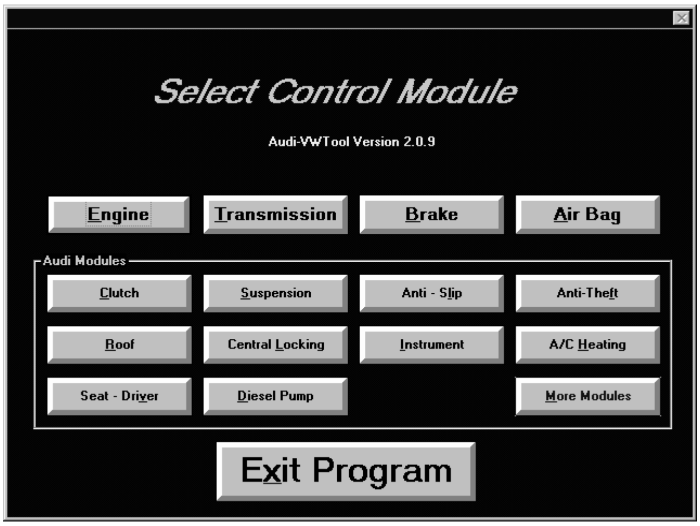

Fig. 3. Window of a diagnostic program enabling to choose a unit which is to be diagnosed

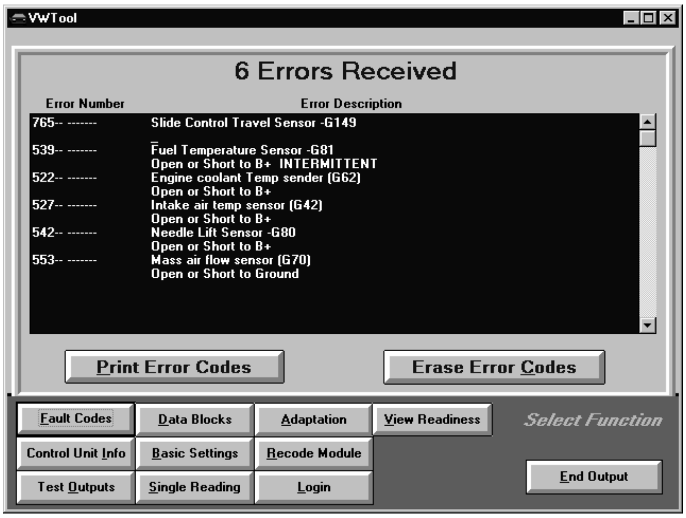

Fig. 4. Window providing information on the errors recorded in the controller's memory

Electronically-controlled working units are applied on a large scale, but their producers used to establish and follow their own standards, due to which their proper diagnostics required specialized diagnostic equipment. In order to standardize the diagnostic procedures and facilitate the diagnostic process, the OBD II (On Board Diagnostic II) standard was introduced in the USA, followed by EOBD in Europe. Both standards impose certain solutions on producers, which allows to use universal diagnostic tools and socket, and to classify and code all defects or damages in a uniform way. Figure 3 presents a window of a diagnostic program enabling to diagnose all systems in a modern car. Figure 4 shows a window of this program providing information on certain defects, damages or faults in the system examined [Merkisz and Mazurek 2002, Wierzbicki 2003a, b].

CONCLUSIONS

It may be concluded that at present the process of diagnosing microprocessor-controlled systems is generally limited to testing electric circuit continuity and evaluating the operation of particular elements under steady-state conditions, i.e. to performing control and measuring functions. The diagnostic systems of working units, applied commonly in cars, permit only the evaluation of the tasks performed by these units. The process of proper diagnostics of these elements, that would include both evaluation of their present state and forecast of its future changes, is not realized. Therefore, it seems that new data analysis algorithms should be formulated. Such algorithms should allow to determine not only the quality of a given working process, but also the functioning of particular elements, e.g. by means of signal analysis during transient states, where a change in the value of one signal makes it necessary to measure and analyze changes in working parameters. The time required to adjust the working parameters of a system to new input variables depends on the technical condition of final controlling elements. This results from the fact that in the case of changes in input quantities the controller generates the same signal, regardless of the technical condition of final controlling elements. If the signal emitted by controller includes information about technical condition, it evokes certain reactions in these elements. This in turn affects changes in the working parameters of the system. They are measured by measuring elements and the controller is informed about the effects of the signals generated on the operation of the whole system. On this basis the controller starts to send correcting information, and the process is continued until the values of the signals generated by the measuring elements become similar to the input quantities.

To sum up, new algorithms for diagnosing microprocessor-controlled working units should be proposed, in order to both evaluate a given working process running under steady-state conditions, and determine the technical condition of particular elements of the system.

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