Research of diagnostic of combine harvesters at levels of hierarchical structure of systems and units of hydraulic system

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Abstract. The problem of diagnosing by external signs of the technical conditions of hydraulic systems of combine harvesters was formulated by the authors in the following way: we need to build a decisive rule that allows us to determine the presence of individual failures in the object from the observed external sign. As an example, we made a research on four general processes, often performed by the main hydraulic system of the harvester: raising the harvesting part, lowering the harvesting part, turning the unloading auger from the transport position to the working one, and turning the unloading auger from the working to the transport one. Failures characterize the technical condition of the harvester subsystems, which in turn consist of many different aggregates and parts. To restore working capacity, it is necessary to demonstrated failures of elements at the level of the hierarchical structure of the harvest, where this restoration is most effective for the conditions of a particular enterprise. Thus, for developing universal diagnostic tools, it is more efficient to identify failures at the lower level with a certain margin of diagnosis depth. The results of research made it possible to implement an intelligent operator support system for the collection and analysis of information about the technical condition of hydraulic systems of combine harvesters and imitate the work of a highly qualified specialist in the field of technical diagnostics.

1. Introduction

Combine harvester – the most complex mobile machine used in agricultural production [1]. The operation of the combine is provided by the combine-operator, who usually has only superficial
knowledge about the structure and technological process of the machine and even more limited knowledge and skills in managing the technical condition (as known, the lack and low level of qualification of personnel is one of the most acute problems of agricultural production) [2]. This leads to the fact that most often the operator is not able to not only carry out maintenance and repairs in a quality and timely, but even correctly describe the external manifestations of the failure and inform their diagnostician that they are correctly entered into the IT system [3].

Therefore, the communication between the operator and the master diagnostician can resemble a doctor’s dialogue with the patient: the operator lists the “complaints” about the machine, and the diagnostician asks clarifying questions in order to identify external signs of a malfunction and to collect the necessary information for further diagnosis [4]. This situation can be given a rational explanation [5]. The increasing complexity of modern technical and human-machine systems (for example, the operator–harvester system) has led to the fact that their behaviour is similar to the behavior of living organisms: it is difficult to understand and identify causal relationships in it (the system) without deep knowledge about its structure and organization of all processes [6]. An untrained person can notice only deviations (or violations) in behavior, provided that he has formed a subjective idea of normal behaviour [7]. Note that the effectiveness of the diagnosis and the quality of the diagnosis depends on the quantity and quality of the prior information obtained before the diagnosis process [8].

If before the start of diagnosis, it is known that the machine (for example, Slavutich KZC-9F) does not turn on grain unloading, then only subsystems for turning on the electrohydraulics unloading, electronic blocking (K-13-1 sensors) [9] and elements of main hydraulic system will be tested [10], and not entire hydraulic system or machine [11]. Therefore, in this work, we consider the process of generating a prior information for diagnosing of combine harvester. To identify external signs of failure, we consider the interaction of the operator with the machine during operation as directed [12]. To describe this process, it is advisable to consider of combine harvester in the form of a system that interacts with external environment and operator [13], which contain “inputs” and “outputs” [14].

2. Materials and methods

From the point of view of operating efficiency, the scheme characterizing the output effect of the system is of the greatest importance. However, the evaluation of the effect of the operation of the combine is not included in the scope of the operator’s tasks, but rather the task of a manager, agronomist, engineer, economist. The operator is responsible for the quality of the technological process of the machine (and only therefore, the quality affects the output effect from the use of the machine), so we should consider the interaction of all process circuits.

Let’s consider the process circuit of the main hydraulic system of the combine. Inputs ($X$) in this case are the control actions (commands) of the operator. These inputs condition the execution of the certain operations on the hydraulic system – processes. The results of the processes – outputs ($Y$) are new states of aggregates and working units of the combine. For the implementation of the process, except the inputs, the execution of certain conditions ($U$) is necessary. For example, to perform all the processes, the main hydraulic system in operable condition is a working engine, and if we consider the process of lowering the reaper, then at the same time this condition should be fulfilled – “the reaper is not in the lowest position”. Note that we consider only those conditions, the fulfilment of which is subject to habitual perception. Otherwise, these conditions can’t be compared with the direct exchange “machine-operator” circuit. Conditions ($U$) should be divided into two groups: exceptional and non-exceptional. At the same time, by exceptional we will understand the conditions, the fulfilment of which is mandatory for the implementation of the process (in an operable and non-operable state).

For the above example of lowering the reaper, the condition “reaper is not in the lowest position” is exceptional, and the condition “engine is working” is non-exceptional, because in case of failures of some subsystems (hydraulic locks) of raising/lowering the reaper of the main hydraulic system, the reaper can lower even when it is non-operable engine. In solving the problems of controlling the technical condition of the machine, an exchange circuit is considered, which is of interest as a source of information about the technical condition of external signs of failures (figure 1). An external sign of
failure is understood as a criterion for the failure of an element of an object that is perceived by a person as organoleptic without the use of external means of technical diagnosis. The definition of the terms “failure criterion” and “external means of technical diagnosis” are taken in accordance with the standards. The problem of diagnosing by external signs of technical conditions is formulated as follows: it is necessary to build a decisive rule that allows us to determine the presence of individual failures in an object from the observed external sign. The following premise was used to construct the decisive rule: outputs \( Y \) is a function of inputs \( X \), states \( S \), and technical states \( TS \) (characterized by the presence or absence of failures): \( Y = f(X, S, TS) \). As an example, we consider four processes that are most often performed by the main hydraulic system of the Slavutich KZC-9F: raising the harvesting part, lowering the harvesting part, turning the unloading screw from the transport position to the working one, and turning the unloading screw from the working to transport one. Here is a brief description of these processes.

![Figure 1. External signs of the states of the object of diagnosis (zerolevel).](image)

Process 1: “Raising the Harvesting Part”. Input: \( X_1 \) – the “raising/lowering the harvesting part” key is in the “Raise” position. Condition: the engine is running – exceptional; “the reaping part is not in the highest position” – exceptional. Output: “the position of the harvesting part relative to the ground became higher than it was” \( U_{1.1} U_{1.2} Y_1 \).

Process 2: “Descent of the harvesting part”. Input: \( X_2 \) – the “raising/lowering the harvesting part” key is in the “Descent” position. Condition: – the engine is running - non-exceptional; – “the reaping part is not in the lowest position” – exceptional. Output: –“the position of the harvesting part relative to the ground became lower than it was” \( U_{2.1} U_{2.2} Y_2 \).

Process 3: “Turn the unloading screw from the transport position to working”. Input: \( X_3 \) – the key “turn of the unloading screw” is in the “transfer to working position” position. Condition: the engine is running – exceptional; “whether the unloading screw is in working position” – exceptional. Output: “the unloading screw is in the working position” \( U_{3.1} U_{3.2} Y_3 \).

Process 4: “Turn the unloading screw from the working position to the transport”. Input: \( X_4 \) – the key «turn of the unloading screw» is in the “Transfer to transport position” position. Condition: the engine is running – exceptional; “whether the unloading screw is in transport position” – exceptional. Output: “the unloading screw is in the transport position” \( U_{4.1} U_{4.2} Y_4 \).

All of the above inputs, conditions and outputs can take two logical values: TRUE (“Yes”, 1) and FALSE (“No”, 0). Therefore, a description of these processes can be shown in the form of an algebra of logic (logical conjunction – the “AND” operator). The assumption is made that only one input is involved at a time. The manifestation of a non-operable state is described by the system:

\[
\begin{align*}
[X_1 \wedge U_{1.1} \wedge U_{1.2} \rightarrow \neg Y_1; X_1 \wedge U_{1.1} \wedge U_{1.2} \rightarrow Y_1; X_1 \wedge U_{1.1} \wedge U_{1.2} \rightarrow \neg Y_1, \forall j \neq 1.\end{align*}
\]  

(1)

Process 5. Briefly: “the reaping part does not rise”. In detail: “the engine is running”; the reaping part is not in the highest position; the “raising/lowering harvesting part” button has been moved to the “raise” position; the position of the harvesting part has not changed.
Process 6. Briefly: “spontaneous raising of the reaper”. In detail: “the engine is running; the reaping part is not in its highest position; all control keys “Electrohydraulics” are in the neutral position; the position of the harvesting part relative to the ground has become higher.

3. Results and discussion
To describe possible failures, we will separate the combine systems, that is, we will consider the diagnostic model at lower levels of the hierarchical structure (figure 2 – level 1).

Figure 2. Levels of hierarchical structure of systems and assemblies hydraulic Slavutich KZC-9F.

The interaction between the individual systems of the combine is carried out by internal inputs and outputs that are not included in the “operator-machine” exchange circuit. The internal outputs of electrical equipment is the supply of voltage (24 V) to the valves with electromagnetic control (figure 2): EM1 – to the electromagnetic valve controlled; EM2 – to the left electromagnet of the “raising/lowering reaper” section of the five-section electro-hydraulic distributor; EM3 – to the right electromagnet of the section “raising/lowering the reaper” of the five-section electro-hydro distributor; EM4 – to the left electromagnet of the section “turn of the unloading screw” of four sectional electro-hydro distributor; EM23 – to the right electromagnet of the “unloading auger rotation” section of the four sectional electro-hydro distributor. Internal outputs of electrical equipment are internal inputs of the hydraulic system (Internal outputs-inputs). Internal outputs of the hydraulic system: P2 – efforts on the rods of the
hydraulic cylinders to raising/lowering the reaper, sufficient to raise the harvesting part; P3 – an effort on the rods of the hydraulic cylinders for raising/lowering the harvesting part, does not prevent the lowering of the harvesting part (under the action of gravity); P4 – the force on the rod of the hydraulic cylinder of rotation of the unloading auger, sufficient to transfer the auger into working position; P23 – force on the rod of the hydraulic cylinder of the turn of the unloading auger, sufficient to transfer the auger to the transport position. By “sufficient effort” in the given descriptions of outputs is meant such a force that is capable of ensuring the implementation of the corresponding process, provided that the other (mechanical) systems are in working condition. The internal outputs of the hydraulic system are the internal inputs of other systems that turn these inputs into process outputs (figure 2 – level 2). It is advisable to present the main hydraulic system of the Slavutich KZC-9F combine as consisting of standard and excellent parts (figure 2, 2st level). The standard part provides the supply of oil (injection – “N”) of the working fluid in separate parts, which distribute the flow of the working fluid and turn its energy into the internal outputs of the hydraulic system. These failures characterizing the technical condition of the combine subsystems, which in turn consist of many aggregates, parts. To restore working capacity, it is necessary to show failures of elements at the level of the hierarchical structure of the machine at which this restoration is most effective for the conditions of a particular enterprise. Thus, when developing universal diagnostic resources, it is advisable to identify failures at a low level (that is, with a “margin” of diagnosis depth). In this regard, the “downward movement” in the hierarchy will be continued for the hydraulic system.

The results of theoretical and practical research allowed us to implement an intelligent operator support system in the process of collection and analysis of information about the technical condition of the machine without measuring diagnostic parameters – that is, imitate the work of a highly qualified specialist in the field of technical diagnostics. The IT intelligent system is developed and improved (figure 3) in the form of a computer program.

The language of programming of deliberative system is Delphi 7 and the Firebird 2.5 database. This program has the following functionality: description of the structure of combine harvesters; preliminary adjustment of the working units of the combine; adjustment of technological control and troubleshooting.
in units and systems. This allows this system to act as an adviser to the results and allows you to provide qualified assistance during operation, and most importantly in the diagnosis of malfunctions. This IT system can operate in two modes of knowledge acquisition and problem solving. In the mode of acquiring knowledge, the engineer, together with the master diagnostician, form the knowledge base, adding possible problems and the reasons that cause them to the knowledge base. In the problem solving mode, the user communicates with the IT system by selecting the desired combine and system, subsystem and, responding to prompts, IT system has the ability to identify a problem and receive recommendations for solving it.

4. Conclusions
The materials presented in the article are part of the knowledge base of IT system, which contains information about the failures of combine harvesters according to external signs, the causes of the problems and recommendations for their elimination, became the basis of IT diagnostic system.

Using the developed intelligent deliberative system will allow you to control the technical condition of the machine and eliminate the need for heuristic processing of large amounts of information and analysis of complex interrelated processes. This reduces the requirements for the qualification of the operator, in terms of the use of technical means of diagnosis.

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