System for recognising and monitoring the technical condition of construction machines

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Abstract. Assessing and predicting machine reliability and failure risks is an essential requirement of international standards for machine safety. The existing methods for determining reliability indicators and risk assessment are based on statistical information about failures and faults that occur during machine operation. Collecting, accumulation and processing of statistical data about failures of machines by traditional methods does not provide the necessary efficiency and reliability of the received information. In this connection forecasting of reliability, estimation, and risk management in production and operation of machines with necessary reliability is not a simple task. Modern diagnostic systems offer unlimited possibilities for the timely acquisition and transmission of information concerning the technical condition of machines, which can be used for the solution of problems. Depending on the structure and location of the transmission, storage and processing of the information, a distinction is made between stationary or remote diagnostics systems. With the modern development of communication and data transmission, remote systems are improved versions of stationary diagnostic systems. In the article the questions of formation of a recognition system and monitoring of a technical condition of building machines by means of the diagnostic information are considered. The main purpose of the development and implementation of the system is to ensure the reliability and safety of operation of construction machines. In order to solve this problem, it is necessary to recognize and promptly prevent the occurrence of failure, which requires the allocation of a special class of intermediate states, called pre-emergency. The results of the implementation of the recognition and monitoring system of construction machines with the help of diagnostic information are presented.

1 Introduction

Fault tolerance and durability are the most important properties of construction machines. These properties are especially important for heavy, energy-intensive machines, whose reliability determines the safety and efficiency of construction work. Typical representatives of construction machines are excavators, loaders, motor graders, bulldozers, etc. [1, 2].

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Any construction machine must ensure that the technological operations are carried out strictly in accordance with the schedule of the works on site. Any machine failure can cause disruption to the construction schedule, which entails significant material and reputational costs for all parties: manufacturer, contractor, customer [3].

2 Materials and Methods

Remote diagnostics is the remote detection of a diagnostic symptom or problem. Important diagnostic information is transmitted from the recording sensors to the control computer via wired or wireless communication links. Remote diagnostics and maintenance refer to both diagnosing faults and taking corrective (maintenance) actions, such as changing settings to improve performance or preventing damage such as breakdows, wear and tear, etc. Remote diagnostics can reduce the laboriousness of diagnostic operations, prevent dangerous situations, increase machine uptime and service life, and improve the efficiency of machine operation. Increasing globalisation, the use of increasingly sophisticated equipment and software also provide opportunities for remote monitoring of the technical condition of machines and timely prevention of failures during operation [3].

When creating a system for continuous monitoring of the technical condition of construction machinery based on remote diagnostics, the challenge is to select the necessary information sources and have a sufficient number of sensors to determine the diagnostic parameters and convert them into signals that can be easily processed or used directly.

Two types of sensor can be used for remote diagnostics: standard sensors fitted to the machine by the manufacturer and additional sensors defined by the design and diagnostic plan.

As the number of sensors increases, the amount of information increases, but so does the complexity of the diagnostics hardware. Therefore, in addition to the built-in (on-board) sensors and limiter status indicators, a minimum number of additional sensors should be installed [4].

Consequently, sources of information about the technical condition of construction machines can be divided into 4 types [5, 6]:
- integrated sensors;
- additional sensors installed;
- sound source (external);
- audible signal from a mobile phone indicates that a restriction indicator or other clear indication of a fault has been triggered.

It is possible to receive data from other systems installed on the machine. These may be various sensors and sensors:
- impact (machine hitting an obstacle, external impact on the machine);
- temperature;
- humidity;
- pressure;
- the flow rate of the hydraulic system;
- noise level;
- vibration level;
- information from sensors of technical condition of the main components of the base machine via OBD2, etc.

Hydraulic systems are widely used in construction, ground and municipal machinery as drive units. Hydraulic motors and hydraulic cylinders are the main power actuators of the hydraulic system. The quality of the transient processes in the hydraulic system of the implement largely determines the reliability and efficiency of the use of the machine as a whole. Deterioration of technical condition of hydraulic systems during operation, caused by
wear of details of tribo-attachments, is the reason of decrease in productivity, non-failure and safety of transport-technological machines use [7, 8]. Monitoring of technical condition of hydraulic drive on results of diagnostics allows us to establish a current state of elements of a hydraulic drive, to estimate reliably a degree of wear, and to predict their resource. In order to receive timely information about possible failures of a hydraulic drive, it is necessary to create a system for monitoring the technical condition of a hydraulic drive and form a database in the decision-making process [9].

The on-board computer receives information about triggering of sensors and stores in its database all history of changes in technical condition of the machine for the period of operation (Fig. 1).

![Fig. 1. The system of remote diagnostics of hydraulic drive of building machines: 1 - sensors: sensors of temperature, pressure, working liquid flow etc., 2 - the terminal of remote diagnostics SDD-19T, 3 - controlling PC.](image)

The system of remote diagnostics of building machines is based on the SDD-19T diagnostic terminal developed in MADI (Fig. 2).

![Fig. 2. SDD-19T diagnostic terminal developed at MADI.](image)

A set of diagnostic sensors via the control module transmits the values of the relevant indicators of the technical condition of the machine to the SDD-19T diagnostic station, which detects, analyses the received information and transmits the data to the control computer via the Internet. The SDD-19T training and research terminal is based on the developments of the Farwater CAN technologies company which have found wide application in remote control systems for agricultural and municipal machines as well as for road transport. Mobile control terminals by Farwater CAN Technology are shown in Figure 3.
The changing technical state of the machine during operation, based on sensor and relay readings, is described using a physical model.

The logical machine model describes possible transitions between physical states. By analysing the sequence of relay or sensor events according to the logic model, it is possible to monitor the correct performance of technological operations if their logic is described in the sequence of activation and deactivation of sensors and relays [10, 11]. For example, an excavator bucket can only be lifted when the wheels are locked or the stops are extended. The machine state logic model describes the permissible time intervals between certain events, the transition between which is possible according to the model. This makes it possible to monitor the correct functioning of the machine.

The technical condition of construction machines can be monitored continuously, during every operation, in automatic mode of monitoring without human intervention. The data can be stored locally in an information database and can be accessed remotely. The service organisation can be informed promptly online about detected problems.

When faults occur, it is possible to analyse the operating history of a particular machine. The history contains the dates and times of activation of sensors and relays installed on the main components of the machine, which are fed in from the diagnostic systems via OBD2 into the external event logs. In addition to the results of retrospective data analysis, the logical model of the machine is supplemented by heuristic rules, which allow predicting changes in the technical condition of structural elements and identifying possible faults at an early stage, before real faults occur [12, 13].

Continuous diagnosis of the technical state of hydraulic drive elements of construction machines, conducted in automatic mode on the basis of a logic model and heuristic rules, makes it possible to prevent possible failures early, allows to improve significantly the quality of maintenance and repair of machines, reduces the number of sudden failures, allows to prevent accidents and reduces the total downtime.

In order to monitor the technical condition of all construction machine models, GPS (GLONASS) trackers must be installed to ensure that diagnostic information can be transmitted both to the cloud and directly to the on-board computer.

All data is transmitted digitally, thus making the machine 'digital'. The information is processed on the on-board computer. Data exchange with external systems is carried out via Wi-Fi and GPRS/LTE/ GLONASS networks [14].

The on-board computer enables intelligent control of construction machines, through which it can not only collect information from sensors and systems, but also develop and transmit commands to machine systems in accordance with the built control model. Control
of a complex of construction machines based on the built models becomes more flexible, easily modifiable, built on intuitive principles and provides an opportunity to implement a system of proactive maintenance and repair of machines based on the actual state with multivariate forecasting [15].

Evaluation of the significance of remote diagnostic information on the technical condition of construction machines can be carried out using an algorithm (Fig. 4), which has at its core an extended approach using statistical accumulated data.

![Algorithm for assessing the significance of diagnostic information.](image)

**3 Results**

More than 50% of failures in these construction machines are caused by hydraulic drive components. It is obvious that improving the reliability of the hydraulic drive of machinery has a significant impact on the operating efficiency of construction machines. In order to confirm the possibility of assessing reliability and predicting changes in the technical condition of hydraulic systems of construction machines on the basis of information obtained from remote diagnostics systems, we performed simulation settings in the MADI laboratory. We simulated hydraulic system monitoring on construction machines. It is equipped with an OBD-2 diagnostic system using the following protocols: SAE J1850 PWM, SAE J1939, ISO14230-4 KWP. In order to assess the technical condition of hydraulic elements we receive signals from two sensors: a pressure sensor and a temperature sensor. The scheme of detecting failure of hydraulic systems of construction machines is shown in Fig. 5, the scheme of installation is presented in Fig. 6.
Fig. 5. Failure detection diagram for hydraulic systems in construction machines.

Fig. 6. Remote diagnostics of the hydraulic system of the construction machine and the software interface.

Pressure transducer to assess the change in working fluid pressure when the hydraulic elements are operating (as the gap in the hydraulic elements increases, the working fluid pressure decreases), below are the parameters of the two pressure transducers used for the simulation:

+ Hydraulic pressure sensor for oil, 50 MPa:
Fig. 7. Dependence of sensor output voltage on hydraulic pressure.

Temperature sensor for hydraulic oil temperature evaluation, models: SE2606, 0 - 5V, resistance values SE2606 (Table 1)

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>-40</td>
<td>52.4 kΩ</td>
</tr>
<tr>
<td>-20</td>
<td>14.9 kΩ</td>
</tr>
<tr>
<td>0</td>
<td>5.0 kΩ</td>
</tr>
<tr>
<td>20</td>
<td>1.9 kΩ</td>
</tr>
<tr>
<td>40</td>
<td>0.8 kΩ</td>
</tr>
<tr>
<td>60</td>
<td>380 Ω</td>
</tr>
<tr>
<td>80</td>
<td>191 Ω</td>
</tr>
<tr>
<td>100</td>
<td>104 Ω</td>
</tr>
<tr>
<td>120</td>
<td>60 Ω</td>
</tr>
<tr>
<td>140</td>
<td>36 Ω</td>
</tr>
</tbody>
</table>

Fig. 8. Dependence of sensor output voltage on hydraulic oil temperature in the hydraulic system.

From this we can determine the temperature value corresponding to the voltage difference as follows (Table 2):

<table>
<thead>
<tr>
<th>t, °C</th>
<th>U, V</th>
</tr>
</thead>
<tbody>
<tr>
<td>85</td>
<td>1.4072</td>
</tr>
<tr>
<td>90</td>
<td>1.2687</td>
</tr>
</tbody>
</table>
As a result of the monitoring, we identified 4 pressure values: $p_1$, $p_2$, $p_3$, $p_4$ are the values of the technical condition parameter of the hydraulic cylinder. When checking the technical condition of the hydraulic cylinder in relation to the temperature factor (suitable for tropical conditions), we have defined 4 temperature thresholds that directly affect the operation of the hydraulic system in construction machines: $t_1$, $t_2$, $t_3$, $t_4$. While the construction machines are running, information on the operating pressure and temperature of the hydraulic oil is monitored in real time. The resulting oil temperature and pressure values will be compared with: $p_1$, $p_2$, $p_3$, $p_4$, $t_1$, $t_2$, $t_3$, $t_4$. The process of comparing parameters is as follows:

- $p_2 < p \leq p_1$ and $t_1 \leq t < t_2$ correspond to the normal condition of the hydraulic cylinder. The status indicator on the terminal shows 1;
- $p_3 < p \leq p_2$ and $t_2 \leq t < t_3$ corresponds to a hydraulic cylinder with a low probability of failure. The status indicator on the terminal shows 2;
- $p_4 < p \leq p_3$ and $t_3 \leq t < t_4$ corresponds to a hydraulic cylinder with a high failure probability. The status indicator on the terminal shows 3;
- $p \leq p_4$ and $t_4 \leq t$ corresponds to the failure status of the hydraulic cylinder. The status indicator on the terminal shows 4.

The following hydraulic cylinder operating parameters have been set on the remote diagnostics unit.

Table 3. Pressure and temperature values set on the remote diagnostic unit.

<table>
<thead>
<tr>
<th>no.</th>
<th>$p$ (MPa)</th>
<th>$U$ (B)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>46</td>
<td>4.6</td>
</tr>
<tr>
<td>2</td>
<td>40</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>36</td>
<td>3.6</td>
</tr>
<tr>
<td>4</td>
<td>33</td>
<td>3.3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>no.</th>
<th>$t$ (°C)</th>
<th>$U$ (B)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>85</td>
<td>1.4</td>
</tr>
<tr>
<td>2</td>
<td>100</td>
<td>0.99</td>
</tr>
<tr>
<td>3</td>
<td>105</td>
<td>0.85</td>
</tr>
<tr>
<td>4</td>
<td>115</td>
<td>0.57</td>
</tr>
</tbody>
</table>

Fig. 9. Pressure and temperature values set to monitor the technical condition of hydraulic cylinders in the presence of clearances and temperature influences.
When a hydraulic cylinder on a construction machine fails under one of the conditions analyzed above, the terminal will display the technical condition of the hydraulic cylinder as shown in Figure 10.

Fig. 10. Schematic diagram of fault detection and failure notification from the terminal: a- Normal condition; b- Hydraulic element with low probability of failure; c- Hydraulic element with high probability of failure; d- Hydraulic elements not working (system failure).

Therefore, the use of operating pressure and oil temperature values obtained from the remote diagnostics system allows the timely determination of risk indicators associated with a component of the hydraulic system of construction machines during operation.

4 Conclusions

The results of the implementation of a system of recognition, monitoring, and proactive remote maintenance of construction machines with the help of diagnostic information showed

- improved uptime of construction machines by preventing failures and malfunctions;
- the elimination of emergency situations when using construction machines due to timely control actions based on prompt diagnostic information;
- reduction of downtime of construction machines due to application of proactive management model of operation processes by 30%.

References