TEST Engineering & Management

May-June 2020
ISSN: 0193-4120 Page No. 469 - 476

Mathematical Model of the System for Monitoring and Diagnosing the State of the Cotton picker by Complex Technological Parameters

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Article Info
Volume 83
Page Number: 469 - 476
Publication Issue:
May - June 2020

Article History
***Article Received**: 11 August 2019*
***Revised**: 18 November 2019*
***Accepted**: 23 January 2020*
***Publication**: 09 May 2020*

Abstract:
The article discusses a method of constructing a mathematical model of a system for monitoring and diagnosing the state of a cotton-picking machine by its complex technological parameters. To carry out diagnostics of the reliability of work, it is proposed to use Boolean algebra as a mathematical apparatus. The main controlled units and technological parameters that determine the quality of harvesting and productivity are selected. To create a mathematical model, truth tables are constructed that reflect the dependences of the states of the output parameters in the automaton on the states of the input controlled parameters and its internal states. As a result of a series of transformations, elements of the diagnosis are shown in a more compact form depending on the average speed of rotation of a group of spindles, fans and other parameters of the cotton picker on their input conditions. General Boolean functions — mathematical models of diagnoses describing an unsatisfactory and satisfactory condition in terms of complex parameters, are written in disjunctive and conjunctive normal form (DCNF).

Keywords: *Spindle group, stripper, fan, mathematical model, Boolean function, control, diagnostics, object, cotton picker, sensors, complex parameters, automatic machine, performance, quality.*

Introduction

The productivity of the cotton picking machine and the quality of picking raw cotton depend not only on the yield of the cotton field, but also on the reliability of the machine's nodes, strict retention of the technological parameters of the nodes in the set limit, as well as the operational detection of malfunctions or deviations of these parameters from the set value.

The main determining parameters of the productivity of the cotton picker and the quality of the harvest are the integrated technological parameters (working bodies) of the cotton picker with the established limits of change. In this regard, the construction of modern intelligent monitoring and diagnostic systems with appropriate algorithmic and software based on a mathematical model that takes into account changes in the state of the complex parameters of the cotton picker is relevant.

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The aim of the work is the synthesis of a mathematical model that evaluates the reliability of the nodes of the cotton picker by its complex parameters. According to the developed mathematical model, it is possible to build an intelligent microprocessor-based monitoring system and diagnostics of the current state of mobile machines and assemblies by their complex parameters. To solve this problem, it is necessary to: conduct a theoretical justification, select and study the most significantly influencing technological parameters and other external and internal factors and, according to sound theoretical and practical materials, build a mathematical model that accurately assesses the current state of the cotton picker.

Methods

We give the main theoretical provisions on the basis of which it was possible to build a mathematical model of the control system and diagnostics of the cotton picker by its complex technological parameters. To diagnose the reliability of the cotton picker, it is proposed to use Boolean algebra as a mathematical apparatus [2, 3, 8, 9, 11].

2. The initial data for the construction of a mathematical model. According to [1, 5, 6, 7], The cotton picker consists of two harvesting machines, each of which includes one fan, two pneumatic conveying systems, four filming drums, an engine PTO, etc. The initial data for diagnosing the operation of the cotton picker are: the number of controlled spindles - N_{sp} = 6, the number of sensors for monitoring spindle speeds - N_{sps} = 6, the maximum number of pulses generated at the output of each control sensor: n_{sp} = 4 (with normal spindle rotation), the minimum number of pulses generated at the output of each control sensor n_{sp} = 0 (with abnormal spindle rotation); the number of fans - N_f = 2, the number of sensors for monitoring the speed of rotation of fans: N_{fs} = 2, the maximum number of pulses generated in one revolution of one fan - n_f = 1, the minimum number of pulses formed in one revolution of one fan - n_f = 0; the number of strippers in one drum - N_s = 6, the number of sensors for monitoring the speeds of rotation of the strippers - N_{ss} = 6pcs, the maximum number of pulses generated at the output of one sensor for controlling the stripper - N_{ss} = 1, the minimum number of pulses generated at the output of one sensor for controlling the stripper: n_s = 0. etc.

Building a mathematical model of monitoring and diagnostics systems using the integrated technological parameters of a cotton picker.

Conducting operational remote monitoring and diagnostics of the reliability of operation, operational and technological parameters of stationary and moving objects according to their complex parameters is an urgent task and we consider it as an example of a cotton picker.

The main controlled parameters during harvesting of raw cotton by vertical spindle cotton pickers are the parameters given in [1, 4, 10, 13, 14]. Deviations of these parameters from the set values lead to an increase in yield loss, a decrease in the productivity of the cotton picker and a clean harvest of raw cotton.

Diagnosis of the state of the cotton picker by complex parameters requires: conducting experimental studies of the operation of nodes without load and with load; selection of control sensors and their installation locations; development of algorithms and hardware for monitoring and diagnostic devices, development of algorithms and programs for receiving, processing and displaying information, as well as solving a number of other tasks.

In this work, for the synthesis of a mathematical model for diagnosing the reliability of a cotton picker, initial data were selected and the conditions for monitoring and diagnostics were determined. As the initial data, 6 controlled technological parameters were adopted: rotational speeds of two fans; average spindle speed of one spindle drum (from 900 to 1200

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rpm) (there are 12 spindles in one drum). Limit values of the working gap (from 28-40 mm), limit values of fan rotation speeds (from 900-1800 rpm) and other data.

For diagnostics of average rotational speeds of 12 spindles of one spindle drum, they are divided into two subgroups (six spindles in each subgroup). Moreover, it is proposed to carry out simultaneous control of the rotation speeds of all spindles of the spindle drum. Photoelectric sensors are used as a sensor for monitoring spindle speeds, counting the number of passing black and white sectors under the sensors [12].

Moreover, the number of photoelectric sensors is equal to the number of controlled spindles (12 photoelectric sensor). Each sensor is rigidly mounted above the controlled spindle and synchronously moves with it. At the same time, we assume that if the spindles rotate at normal speed, then 3-4 pulses are generated at the outputs of each selected sensor and vice versa if the spindles do not rotate normally, 0-2 pulses are generated at the outputs of the sensors. At each normal fan rotation, one logical signal “1” is generated. In one harvesting machine there are two spindle drums. The electronic on-board system (EBS) evaluates the reliability of the cotton picker using these technological parameters and the above source data. EBS consists of complex circuits and elements: inductive and photoelectric sensors; threshold elements, counters and other blocks. The final processing of information is performed by the microcomputer according to the developed algorithm. According to [2, 3, 8, 9, 11] according to the selected source data and from the synthesis conditions, the functions of the mathematical model of the diagnosis that evaluates the reliability of the cotton picker, the controlled input parameters are described in the form of the following set:

$$X = (f1_{1sp}(X1, X2, \dots, X6), f2_{2sp}(X7, X8, \dots, X12), f3_{3sp}(X13, X14), f4_{wg}(X15, X16), f5_{P}(X17, X18), f6_{A}(X19), f7_{D}(X20)), \quad (1)$$

where X1, X2, ..., X20 are the values of the parameters, respectively, displaying the state of the 1-, 2-, ..., 12th spindles; X13, X14 - parameter values that display the status of the 1st and 2nd fans; X15, X16 - parameter values that display the state of the first and second working slits; X17, X18 - parameter values that display the state of the first and second pneumatic transport system; X19 - the state of the cleaning apparatus relative to the ground; X19 - the state of the engine PTO. In this case, the values of each input parameter (spindle group) can be described as:

$$\begin{aligned} &X1 = f1_{sp}(X11, X12, X13, X14), \\ &X2 = f2_{sp}(X21, X22, X23, X24), \\ &\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \\ &X12 = f12_{sp}(X12.1, X12.2, X123, X12.4). \end{aligned} \quad (2)$$

The input signals of the state of the electronic-on-board system are the output signals of the photoelectric sensors for monitoring spindle speeds. These signals are recorded as binary code and can have the following meanings:

- state of the first subgroup of spindles

$$\left.\begin{aligned} &X1 = 0001, 0010, 0111, \dots, 1111; \\ &X2 = 0001, 0010, 0111, , 1111; \\ &\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \\ &X6 = 0001, 0010, 0111, \dots, 1111. \end{aligned}\right\} f1sp \quad (3a)$$

- state of second subgroup of spindles

$$\left.\begin{aligned} &X1 = 0001, 0010, 0111, \dots, 1111; \\ &X2 = 0001, 0010, 0111, , 1111; \\ &\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \\ &X6 = 0001, 0010, 0111, \dots, 1111. \end{aligned}\right\} f2sp \quad (3b)$$

Changes in the states of input signals (parameters) of fans can be described in the form of the following system:

$$\begin{aligned} &f1_{f} = X1(X1.1, X1.2), \\ &f2_{f} = X1(X2.1, X2.2). \end{aligned} \quad (4)$$

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The values of the input signals of the fan speeds coming from each sensor can have the following binary values:

$$f3_f = X1(1(0);0(1)),$$
$$f4_f = X2(1(0);0(1)).$$

similarly, one can describe the state changes of all other parameters.

Then, according to the methodology for the synthesis of an automaton that implements the above sets can be displayed in the following table form (table 1).

Table 1. Table of states of input controlled parameters, internal and output states of the monitoring and diagnostic system for six controlled parameters of the cotton picker

Input parameters (all possible states of input parameters)									Working gap states		States of the pneumatic transport chamber		Harvester position relative to the ground	PTO rotational speed	Possible internal state automaton (systems)			System output Parameters	
№	Spindle Status						Fan status												
	First subgroup			Second subgroup			The first	Second	The first	Second	The first	Second							
	X1	…	X6	X7	…	X12	X13	X14	X15	X16	X17	X18	X19	X20	Z1		Zi	Y1	Y2
1	0001	…	0001	0001	…	0001	1	1	1	1	1	1	1	1	0		0	0	1
2	0010	…	0010	0010	…	0010	0	1	0	1	1	0	0	0	1		0	0	1
3	0011	…	0011	0011	…	0011	1	1	1	1	1	1	1	1	1		1	1	0
…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…	…
16	1111	…	1111	1111	…	1111	1	1	1	1	1	1	1	1	1		1	1	0

As can be seen from table 1, each spindle can have many states, for diagnosing the average speed of six spindles belonging to one subgroup, it is necessary to control the speeds of each spindle, and for diagnosing the average speed of another subgroup of spindles, it is also necessary to control the speeds of each spindle this subgroup.

In the same way, the state is monitored: fans, the width of the working slit of the cleaning apparatus, the rotation speed of the engine PTO, the position of the height of the cleaning apparatus relative to the ground.

It is assumed here that the satisfactory condition of each spindle, fan, engine PTO, the position of the working slit, sweeper, etc. will have a logical value of "1", and an unsatisfactory state - a value of "0". Based on these considerations, in order to simplify the process of synthesizing a mathematical model of a diagnostic Boolean function [2, 3, 11], we will transform Table 1 to a more convenient form Table 2.

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Table 2.

	Internal states of the machine (system), microcomputers			Spindle average speed (state)		Average fan speed (status)		The state of the working gap of the picker apparatus		Pneumatic chamber system states		Harvester position relative	PTO rotational speed	Output Parameters	
				First subgroup	Second subgroup	The first	Second	The first	Second	The first	Second				
№	Z1		Zi	D1i	D2i	D3i	D4i	D5i	D6i	D7i	D8i	D9i	D10i	Y1	Y2
1	0	..	0	D10	D20	D30	D40	D50	D60	D70	D80	D90	D100	0	1
2	1	..	0	D10	D20	D30	D40	D50	D60	D70	D80	D90	D100	0	1
3	1	..	1	D11	D21	D31	D41	D51	D61	D71	D81	D91	D101	1	0
…	…	..	…	…	…	…	…	…	…	…	…	…	…	…	…
16	1	..	1	D11	D21	D31	D41	D51	D61	D71	D81	D91	D101	1	0

In table 2, for the diagnosis of the state of rotation speed of each subgroup of spindles (six spindles in each subgroup), conventions are adopted. For the first spindle drum, the diagnosis 010 is an unsatisfactory average speed, rotations of the first subgroup of spindles; Diagnosis D11 - satisfactory average rotation speed of the first subgroup of spindles; Diagnosis D20 - assessment of an unsatisfactory average rotation speed of the second subgroup of spindles; Diagnosis D21 - Evaluation of a satisfactory average rotation speed of the second subgroup. To diagnose the condition of the fans, the following conventions are used: diagnosis D30 - evaluation of the unsatisfactory rotation speed of the first fan, diagnosis D31 - evaluation of the satisfactory rotation speed of the first fan, diagnosis D40 - evaluation of the unsatisfactory rotation speed of the second fan, diagnosis D41 - evaluation of the satisfactory rotation speed of the second fan.

In the simplified state tables (table 2) of the input monitored parameters, internal and output states of the monitoring and diagnostics system (according to the six monitored parameters of the cotton picker), the elements of the diagnosis are displayed: average spindle speeds: fans and other working bodies, depending on the state of the input parameters. Considering the fact that Table 3 shows the dependences of the average rotation speed of a group of spindles, fans and other working bodies on their input states (according to logical analysis,), it can be reduced to a more compact form (Table 3).

Table 3.

The order of the receipt input signals	Spindle average speed (state)		Average fan speed (status)		Working gap states		States of the pneumatic transport chamber		Harvester position relative to the ground	PTO rotational speed	Output parameters	
	First subgroup	Second subgroup	The first	Second	The first	Second	The first	Second				
	D1i	D2i	D3i	D4i	D5i	D6i	D7i	D8i	D9i	D10i	Y1	Y2
1	D10	D20	D30	D40	D50	D60	D70	D80	D90	D100	0	1
2	D10	D20	D30	D40	D50	D60	D70	D80	D90	D100	0	1

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3	D11	D21	D31	D41	D51	D61	D71	D81	D91	D101	1	0
…	…	…	…	…	…	…	…	…	…	…	…	…
12	D11	D21	D31	D41	D51	D61	D71	D81	D91	D101	1	0

Using the data in Table 3, using the method of compiling and transforming logical functions [5], it is possible to compose simplified Boolean functions that evaluate the state of a cotton picker in simple disjunctive normal forms (DNF).

The diagnosis - the state of the cotton picker will be unsatisfactory with the following average values of the diagnostic Boolean functions (code combinations), - expression (5) generated by the sensors during spindle rotation and changes in the state of other working bodies of the cotton picker. Recall that in these states up to two pulses are generated at the outputs of each sensor, this indicates an abnormal average rotation speed of this group of spindles. Thus, a system of Boolean functions satisfying the conditions of diagnosis Dн, taking into account the condition of the above-mentioned controlled workers, can be described by the following system of equations of Boolean functions:

$$\left.\begin{aligned}
&D_H1 = \overline{D1} \vee \overline{D2} \vee \overline{D3} \vee \overline{D4}\\
&D_H2 = \overline{D1} \vee \overline{D2} \vee \overline{D3} \vee D4\\
&D_H3 = \overline{D1} \vee \overline{D2} \vee D3 \vee \overline{D4}\\
&D_H4 = \overline{D1} \vee \overline{D2} \vee D3 \vee D4\\
&D_H5 = \overline{D1} \vee D2 \vee \overline{D3} \vee \overline{D4}\\
&D_H6 = \overline{D1} \vee D2 \vee \overline{D3} \vee D4\\
&D_H7 = \overline{D1} \vee D2 \vee D3 \vee \overline{D4}\\
&D_H9 = \overline{D1} \vee D2 \vee D3 \vee D4\\
&D_H10 = D1 \vee \overline{D2} \vee \overline{D3} \vee D4\\
&D_H11 = D1 \vee \overline{D2} \vee D3 \vee \overline{D4}\\
&D_H13 = D1 \vee D2 \vee \overline{D3} \vee \overline{D4}\\
&D_H17 = \overline{D10}\\
&D_H18 = \overline{D20}\\
&D_H19 = \overline{D10}\\
&D_H20 = \overline{D20}\\
&D_H21 = \overline{D10}\\
&D_H22 = \overline{D20}\\
&D_H23 = \overline{D10}\\
&D_H24 = \overline{D20}
\end{aligned}\right\} \qquad (5)$$

In the system of equations (5), the given conventions correspond to the following states of controlled working bodies:

- state of rotational speeds corresponding to the spindles:
-conditions of rotational speeds of the corresponding fans;
- the state of the working slots corresponding to the cleaning apparatus:
- the state of pneumatic conveying systems;
- the state of the harvester relative to the ground;
- the state of rotation of the engine PTO.

The Boolean function that fulfills the conditions for the diagnosis of the cotton picker Dy will be under the following conditions of the average values of the diagnostic functions (code combinations) generated by the sensors during the rotation of the spindles of the cotton picker (6). In these states, three to four pulses are generated at the outputs of each sensor, which indicate a normal average rotation speed of this group of spindles. Thus, a system of Boolean functions satisfying the conditions of the diagnosis Du can be described by the system of equations of Boolean functions (6):

$$\left.\begin{aligned}
&Dy8 = \overline{D1} \vee D2 \vee D3 \vee D4\\
&Dy12 = D1 \vee \overline{D2} \vee D3 \vee D4\\
&Dy14 = D1 \vee D2 \vee \overline{D3} \vee D4\\
&Dy15 = D1 \vee D2 \vee D3 \vee \overline{D4}\\
&Dy16 = D1 \vee D2 \vee D3 \vee D4\\
&Dy13 = D1.1\\
&Dy14 = D2.1\\
&Dy15 = D1.1\\
&Dy16 = D2.1\\
&Dy17 = D1.1\\
&Dy18 = D2.1\\
&Dy19 = D1.1\\
&Dy20 = D2.1
\end{aligned}\right\} \qquad (6)$$

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Results and Discussion

Building a mathematical model of a monitoring and diagnostic system using complex parameters. After a comparative analysis of all possible states of the truth table with possible signs of input signals coming from spindle and fan control sensors and other controlled working bodies of the machine's internal states, average spindle speed Dli, D2i, and condition of fans D3i ,. D4i and other conditions; D5. D6. D7, D8, D9, D10 and also after minimizing all possible Boolean functions compiled [2, 3, 11], the Boolean functions Dy, Dн in disjunctive normal form were synthesized, which established an accurate diagnosis of the reliability of the cotton picker according to its six technological parameters.

Thus, according to (5), the general Boolean function of the mathematical model of diagnosis describing the unsatisfactory state of the cotton picker () in six parameters can be written in the following disjunctive and conjunctive normal form:

$$
\begin{aligned}
D_{н} = f_{sp}[&(\overline{D1} \vee \overline{D2} \vee \overline{D3} \vee \overline{D4}) \wedge (\overline{D1} \vee \overline{D2} \vee \overline{D3} \vee D4) \wedge \\
&(\overline{D1} \vee \overline{D2} \vee D3 \vee \overline{D4}) \wedge (\overline{D1} \vee \overline{D2} \vee D3 \vee D4) \wedge \\
&(\overline{D1} \vee D2 \vee \overline{D3} \vee \overline{D4}) \wedge (\overline{D1} \vee D2 \vee \overline{D3} \vee D4) \wedge \\
&(\overline{D1} \vee D2 \vee D3 \vee \overline{D4}) \wedge (\overline{D1} \vee D2 \vee D3 \vee D4) \wedge \\
&(D1 \vee \overline{D2} \vee \overline{D3} \vee D4) \wedge (D1 \vee \overline{D2} \vee D3 \vee \overline{D4}) \wedge \\
&(D1 \vee D2 \vee \overline{D3} \vee \overline{D4})] \wedge [f_{f}(\overline{D1.0} \vee \overline{D2.0}) \wedge \\
&f_{wg}(\overline{D10} \vee \overline{D20}) \wedge f_{pch}(\overline{D1.0} \vee \overline{D2.0}) \wedge \\
&f_{cps}(\overline{D1.0}) \wedge f_{pto}(\overline{D10}).
\end{aligned}
\tag{7}
$$

According to (6), the general Boolean diagnosis function describing the satisfactory condition () of the cotton picker in six controlled parameters can be written in the following disjunctive and conjunctive normal form:

$$
\begin{aligned}
D_{y} = f_{sp}[&(\overline{D1} \vee D2 \vee D3 \vee D4) \wedge (D1 \vee \overline{D2} \vee D3 \vee D4) \wedge \\
&(D1 \vee D2 \vee \overline{D3} \vee D4) \wedge (D1 \vee D2 \vee D3 \vee \overline{D4}) \wedge \\
&(D1 \vee D2 \vee D3 \vee D4)] \wedge [f_{f}(D1.1 \vee D2.1) \wedge \\
&f_{wg}(D1.1 \vee D2.1) \wedge f_{pch}(D1.1 \vee D2.1) \wedge \\
&f_{cps}(D1.1) \wedge f_{pto}(D1.1).
\end{aligned}
\tag{8}
$$

From the analysis of formula (7), it follows that all the participating subfunctions that reflect the rotation speeds of each spindle, fan, and other states of controlled objects have an unsatisfactory state, i.e. correspond to the diagnosis of Dn. It follows from (8) of the formula that all the participating subfunctions reflecting the rotation speeds of each spindle, fan, and other working bodies have satisfactory states, i.e. correspond to the condition of the diagnosis (Du). A change in the state of any of these subfunctions leads to failure to fulfill the condition of the condition of the diagnosis Du.

Conclusion

A mathematical model of the system for monitoring and diagnosing the technological parameters of the cotton picker was developed, taking into account changes in the state of the complex technological parameters of the cotton picking machine, on the basis of which a practically operational system for monitoring and diagnosing the technological parameters of the cotton picker was built. The application of the developed system helps to increase the productivity of the cotton picker by 4-5% and to improve the cleanliness of the collection of raw cotton.

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