Mathematical model of a wheeled tractor steering axle as an object of diagnostics

D. Borysiuk[1], A. Spirin[2], O. Trukhanska[2], L. Shvets [2], V. Zelinskyy [1]

[1]Vinnytsia National Technical University, e-mail: bddv@ukr.net
[2]Vinnytsia National Agrarian University, e-mail: spirinanatoly16@gmail.com

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Summary. Machine-tractor fleet is an important part of agricultural production. Many factors depend largely on its effective operation, namely - reducing production costs, harvesting time, transportation to customers, storage of feed and other industrial and household and domestic processes.

One of the most important areas to increase productivity and efficiency of the machine and tractor units is the most complete use of resources (uptime terms) of machines while reducing the cost of funds for their repair and maintenance. This can be achieved through the development and implementation of effective methods and tools for condition monitoring of machines, including tractors without their disassembly. With these tools, you can define the technical condition of components and assemblies of each machine separately and based on this we can set total amount of preventive and repair operations, and promptly troubleshoot and prevent them.

The paper presents a mathematical model of a wheeled tractor steering axle as an object of diagnostics. A diagnostics matrix has been constructed along with a block diagram of its synthesis.

Key words: mathematical model, diagnostics matrix, analytical model, wheel-tyre tractor, steering axle, diagnostics, faults, failure symptoms, technical condition.

INTRODUCTION

When driven on the road with a rough surface, a tractor treats strokes and performs fluctuations. The main units that protect a tractor from the road dynamic performance and reduce oscillation and vibration to an acceptable level are steering axle and tires.

Long experience shows that uneven road surface and the resulting fluctuations of frame and wheels of the tractor leads usually to a deterioration of its operational and technical qualities.

Properly controlled steering axle of a wheeled tractor provides optimal handling, safety, durability and reliability of its work.

Working with faulty units of steering axle impairs handling and stability of the tractor, reduces the safety of its movement.

Defective steering axle contributes to the appearance of vibration of the frame of the tractor, resulting in weakened riveted and threaded joints, broken alignment of engine and gearbox, have additional load in body parts.

Vibration of entire tractor accelerates its wear out and causes damage of many parts.

Experience of tractor fleet performance shows that steering axle is one of the least reliable and durable tractor units.

From the above mentioned it can be seen how important is the support of steering axle of a wheeled tractor and its individual components in good condition.

ANALYSIS OF RECENT RESEARCHES AND PUBLICATIONS

Diagnostics and resource forecasting of machines are one of the important areas of scientific and technological progress in the field of operation, maintenance and repair of tractors, cars and other vehicles.

Diagnostics of tractors help us to more purposefully conduct the maintenance work, full use of the individual components, while preventing their emergency condition promptly troubleshoot their regulatory options. According to the experience of technical diagnostics operation of mobile vehicles in our country and abroad, it is essential condition to improve the use of mobile vehicles. This result leads to lower costs for spare parts, maintenance and premature repair. The effectiveness of diagnostics will increase with the extent of improvement of tools and methods for its implementation and adaptation of tractors and their units prior to diagnostics. With the improvement of agricultural equipment with modern technology, diagnostics is becoming more important when it is used. It largely depends on the efficient maintenance organization.

To the study of problems of maintenance of agricultural machines were engaged leading scientists mechanics of our country. The scientific premise of "aging" and general issues of repair and maintenance of machines for agricultural purposes were created by works of R.V. Vedenyapina, E.L. Volovyk, N.S. Zhdanovsky, V.M. Mikhlin, B.V. Pavlov, O.I. Selivanov, N.M. Severnyev, S.S. Cherepanov [1, 2] and so on.

The issue of tractors' performance control are elaborated in the writings of S.A. Iofinov, A.T. Lebedev, V.M. Mikhlin, A.V. Nikolaenko, I.P. Terskykh, G.E. Topilin, P.M. Chereyskyy and others. General problems of machine control suitability were dedicated the works of P.M. Volkov, M.Y. Govoruschenko, V.A. Didura, A.V. Mozhalevskyy, B.T. Sadykov, T.A. Serdakov, A.M. Karazov and others. In these writings were presented reasonable ways and means of diagnostics of tractor units and proposed technical solutions of new devices for hydraulic drives' diagnostics.

Among the works performed during maintenance of complex machines, a special place possess the works listed after the words "Check and adjust if necessary ...". The list usually includes the works, the decision of which shall be adopted on the basis of diagnostics (model of so-called planned preventive maintenance or periodic maintenance of the control parameter). Analysis of the experience of the model we can find in the works of G.V. Vedenyapin and his students. Studies, carried out by them, allowed us to classify patterns of maintenance and a formal description of the model planned preventive maintenance (periodic maintenance of control). A great contribution to the development of this model was made by Y.F. Boyko V.M. Mikhlin, N.N. Smirnov, N.Y. Sukhov, A.A. Itskovych, A.V. Chalov, E.E. Chudnovsky [3, 4] and others.

The aim of the study. The study aims to improve the reliability of this important functional unit of wheeled farm tractors - steering axle - by creating a mathematical model of diagnostics of its components and details that binds the failures and malfunctions.

The main part

Solution of logical process automation of diagnostics requires the development of models of tractor units as objects of diagnostics, which describe on one mathematical level the relationship between many possible technical conditions (faults) and the set of values of diagnostic parameters [5].

Replacing the diagnostic object by a model is associated with the allocation of basic, essential elements for the diagnostics and properties associated with the task of determining the actual technical condition of the objects. By this, some items and links of an object which are important in terms of its function as a device, designed to perform a specific job, could be minor for the development of a model of technical device as an object of diagnostics and could be excluded.

Replacing real technical devices by their idealized model allows extensive use of different mathematical methods. Under diagnostic mathematical model of an object we should understand a set of analytical, logical, statistical, graphical and generally any qualitative relationships that bind the output parameters of an object with its input and internal parameters.

The most universal model of diagnostics of an object is to present it as a "black box", the input and output parameters of which have a finite set of values. It is assumed that all possible states of an object form a finite set of states. In this case the object is a "black box" not because its internal structure and parameters are not fully known, but because there is imposed a ban on access to them and the state of the object can be determined only by examining its output parameters (without disassembly) [6].

To represent an object of diagnostics as a "black box" there must be set the following (Fig. 1):

- the number of all the incoming actions Y by stimulating devices and the environment;
- the amount of all the output failure symptoms S;
- the number of all faults of diagnostics object X;
- an operator that converts the number of X and Y in the amount of S:

$$S = A\{Y, X\}. \quad (1)$$

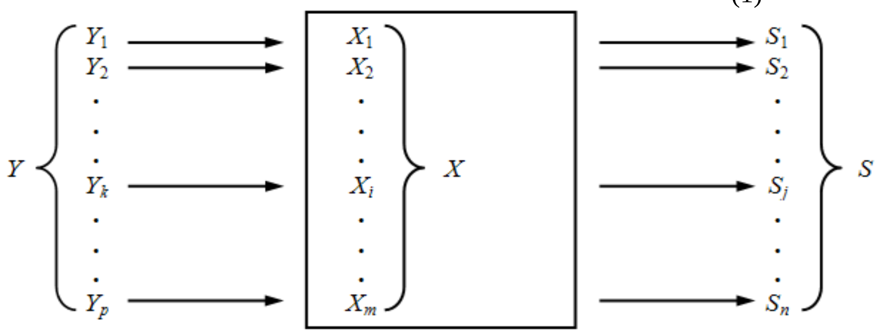

Fig. 1. Presentation of a diagnostics object as a "black box"

Having in mind that the number of elements Y in diagnostics are stabilized (or change for a given law), the expression (1) is converted to the type

$$S = A\{X\}. \quad (2)$$

In other words, any output parameter of a diagnostics object is a function of its technical condition at a given state of inputs.

If the fault of diagnostics object {Xi} is attributed to the initial parameters of the automated system, the diagnostic problem is formulated as follows: by the known failure symptoms {Sj} to determine the unknown faults of the diagnostics object {Xi}.

To solve this problem we need to know the type of operator A, in other words, we require a comprehensive description of the relationships between all initial parameters and all possible states (failures) of the object.

The following describes a number of models of diagnostics objects (tractor units and systems) which differ from each other by different forms of description of these relationships.

If there is an analytical model of the diagnostics object the problem of diagnostics is formulated in general terms as follows.

By the following failure symptoms S_1, S_2, ..., S_n, derived from the relevant measurements to determine the technical condition (fault) of the diagnostics object X_1, X_2, ..., X_m, if known the functional relationships between each diagnostic signal and structural parameters:

$$\begin{cases} S_1 = \varphi_1(x_1, x_2, ..., x_m); \\ S_2 = \varphi_2(x_1, x_2, ..., x_m); \\ .... \\ S_j = \varphi_j(x_1, x_2, ..., x_m). \end{cases} \quad (3)$$

The system of equations (3) is a mathematical model of an object diagnostics having structural parameters m and n diagnostic signals.

The obvious advantage of diagnostics using an analytical model is the possibility of a particular object fault diagnostics, to determine the technical condition of the object not only at the time of diagnostics, but also accumulating the information obtained by several diagnostic tests of the unit, to analyze the change of structural parameters to predict its technical condition.

However, the practical use of such analytical models is limited because of the following circumstances:

- the kind of functions φj for most components and units of a tractor is not set yet;

- if the function φj does not satisfy the conditions of continuity and differentiation for each of its arguments, which usually takes place in the real models, the solution of equations (3) meets great mathematical difficulties;

- the majority of diagnostic parameters, in principle, can not be expressed as analytic functions of structural parameters.

In a number of technical diagnostics of tractors the relationship between the possible technical conditions (faults) and units of tractors and the symptoms of these failures are described as so-called diagnostic matrices.

With many years of experience of MTZ-80 operating and its modifications in the table 1 a matrix is shown of steering axle diagnostics of wheeled farm tractors [7, 8, 9, 10, 11].

In the matrix (see Table 1) we denote the following faults of steering axle of wheeled farm tractors:

x_1 – demolition of working surfaces in the joint steering draft;

x_2 - axle springs breakage;

x_3 - axle springs elasticity loss;

x_4 - deterioration or destruction of hub bearings;

x_5 - easing tightening of the screw conical hub bearings;

x_6 - wear out the steering stub sleeves;

x_7 - impaired regulation of convergence of front wheels;

x_8 - easing tightening of steering stub screw;

x_9 - easing tightening of axle beam nut screw;

x_{10} - easing tightening of the lower stem bolt of steering stub;

x_{11} - easing tightening the threaded connection hub with the wheel drive;

x_{12} - easing tightening the screws of ball pin of the track rod;

x_{13} - easing tightening the threaded joint of track rod with the drop arm of hydraulic power steering;

x_{14} – wear out on the working surface of mounting pin of axle beams with retractable steering axle;

x_{15} - high air pressure in tires;

x_{16} - low air pressure in the tires.

Table 1. Diagnostic matrix of steering axles of wheeled farm tractors (in the example of MTZ-80 and its modifications)

Fault	Failure symptom									
	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}
x_1	1	1	0	0	0	0	1	0	0	1
x_2	0	0	1	1	0	0	0	0	0	0
x_3	0	0	1	0	0	0	0	0	0	1
x_4	1	0	0	0	1	0	0	0	0	1
x_5	1	0	0	0	1	0	0	0	0	1
x_6	0	0	0	0	0	1	1	0	0	0
x_7	0	0	0	0	0	0	0	1	1	1
x_8	0	0	0	0	0	1	1	0	0	1
x_9	0	0	0	0	0	0	1	0	0	1
x_{10}	0	0	0	0	0	1	1	0	0	1
x_{11}	1	0	0	0	0	0	1	1	1	1
x_{12}	1	0	0	0	0	0	1	0	0	1
x_{13}	0	0	0	0	0	0	1	0	0	1
x_{14}	0	0	0	0	0	0	1	0	0	1
x_{15}	0	0	0	0	0	0	1	0	1	1
x_{16}	0	0	0	0	0	0	1	0	1	0

In the matrix (see Table 1) we also enter the failure symptoms indicated above:

S_1 - beating wheel when driving in a straight line;

S_2 - a gap in the spherical joint layer of track rod;

S_3 - sharp jolts and shocks transmitted to half-frame when driving on uneven;

S_4 - the incline of the front of the tractor on its side;

S_5 - creaking in the hub;

S_6 - knocking on the steering knuckles;

S_7 - uncontrollability of the tractor when driving in a straight line;

S_8 - Tractor "leads" to the side while driving on a flat road;

S_9 - increased wear out of the tires of the front wheels;

S_{10} - increased vibration of the axle.

As seen from the Table 1, each failure is characterized by two combinations of values that can accept two conditional "0" and "1" [12, 13, 14, 15, 16, 17, 18, 19, 20].

At the intersection of the i-th row and j-th column we put "1", if i-th failure occurs we can see the occurrence of j-th symptom in the area of its permissible values, otherwise we put "0".

For the synthesis of this matrix we should replace the infinite number of states of technical object with the final set of states, each of which is associated with a particular fault (or combination thereof) or working condition (Fig. 2).

This transformation can be written as

$$\{x_i\}_к = F_x\{x_i\}, \tag{4}$$

where: $\{x_i\}$ – is a set of technical features of diagnostic states of the object, each of which can take in a general an infinite number of values;

$\{X_i\}_k$ - is the final set of technical features of the diagnostic object, each of which can take only two conditionals "0" and "1", which correspond to the absence and presence of the i-th failure;

$i = 1, 2, ..., m;$

F_x – is an operator that converts the amount of $\{x_i\}$ into a number $\{x_i\}_k$ as following: for any i-th parameter x_i is set to "0" if the value is in the area of allowable values, otherwise it is set to "1".

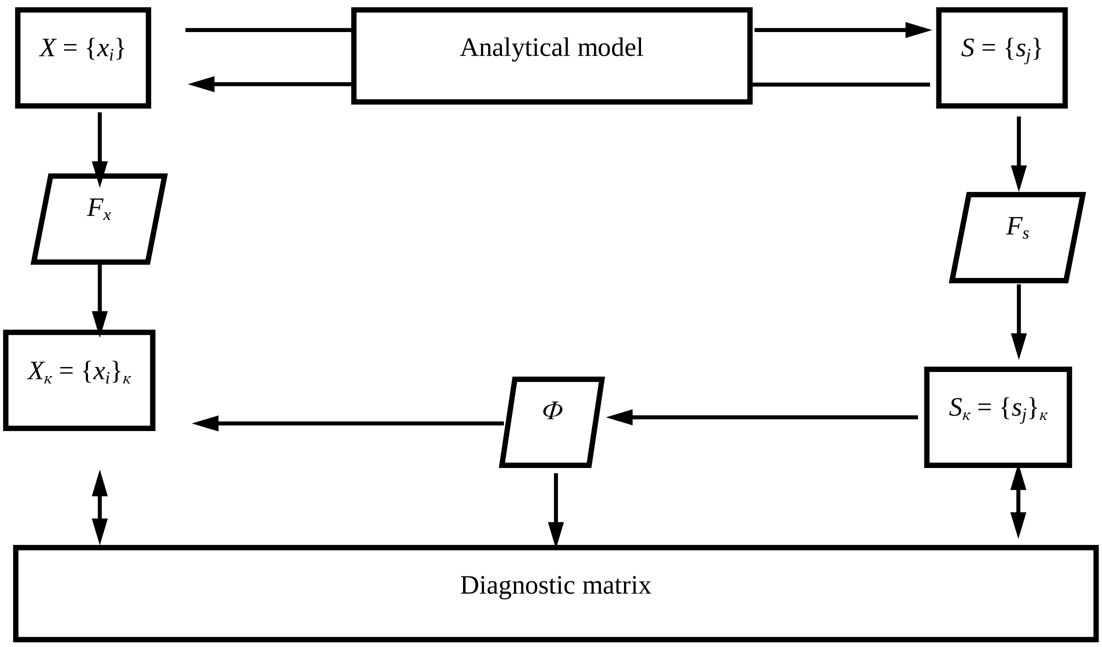

Fig. 2. Block diagram of diagnostic matrix synthesis:
$X = \{x_i\}$ - infinite number of technical conditions of the object;
$X_k = \{x_i\}_k$ - the ultimate number of technical conditions;
$S = \{s_j\}$ - infinite set of technical features of states of the object;
$S_k = \{s_j\}_k$ – the final set of technical features of states of the object;
F_x - operator, converting the number of $\{x_i\}$ into a number $\{x_i\}_k$;
F_s – operator, converting number $\{s_j\}$ into a number $\{s_j\}_k$;
$Ф$ – operator, converting the number of technical states of the object into the number of diagnostic parameters

Converting an infinite number of parameter values into the output process finite number of values of diagnostic parameters can be written as

$$\{s_j\}_к = F_s\{s_j\}, \tag{5}$$

where: $\{s_j\}$ - number of features of output processes, each of which can generally take an infinite number of values in a certain interval; $\{S_j\}_k$ - the final number of diagnostic features, each of which can take only two conditionals "0" and "1"; $j = 1, 2, ..., n;$ F_s – operator, which converts number $\{s_j\}$ into a number $\{s_j\}_k$ as following: for any j-th symptom s_j we assign "0" if the value lies in the area of values that correspond to the healthy state of the object of diagnostics, otherwise we set "1".

As a result of conversions we receive two limit values for $\{x_i\}$ and $\{s_j\}_k$, whose elements are somehow related to each other.

In general terms, this relationship can be expressed as

$$\{s_j\}_K = \Phi\{x_i\}_K \tag{6}$$

where: Φ – is the operator that converts the number of technical states of the object into the number of diagnostic parameters.

Conversion (6) reflects the performance of any technical object as a converter of the number of structural parameters into the number of diagnostic parameters and becomes a modification of the model (1).

Conversion (6) can be expanded using system (3).

The system of equations (3) connects each malfunction symptom S_j with all structural parameters of diagnostic object that reflects the relationships between structural parameters and diagnostic signals.

Diagnostic matrix as a diagnostic object model shows that it is essentially a tabular format a system of equations recording (1).

Parameter S_1 in diagnostic matrix of steering axles of wheeled farm tractors can be seen as an ambiguous Boolean function that depends on the arguments x_1, x_4, x_5, x_{11}, x_{12}. Boolean function depends on x_1 argument if there is a relationship:

$$\varphi(x_1,\ x_2,\ ...,\ x_{i-1},\ 0,\ x_{i+1},\ ...,\ x_m) \neq \varphi(x_1,\ x_2,\ ...,\ x_{i-1},\ 1,\ x_{i+1},\ ...,\ x_m).$$

As it follows from this definition and Table 1, S_1 essentially depends only on x_1, x_4, x_5, x_{11}, x_{12}.

Dependence $S1 = \varphi1$ (x_1, x_4, x_5, x_{11}, x_{12}) is expressed in this case as a function of logical addition (disjunction):

$$S_1 = x_1 + x_4 + x_5 + x_{11} + x_{12}.$$

The appropriate analysis of other symptoms makes it possible to record the system of equations (3) for the diagnostic matrix of steering axles of wheeled farm tractors as:

$$\begin{cases} S_1 = x_1 + x_4 + x_5 + x_{11} + x_{12}; \\ S_2 = x_1; \\ S_3 = x_2 + x_3; \\ S_4 = x_2; \\ S_5 = x_4 + x_5; \\ S_6 = x_6 + x_8 + x_{10}; \\ S_7 = x_1 + x_6 + x_8 + x_9 + x_{10} + x_{11} + x_{12} + x_{13} + x_{14} + x_{15}; \\ S_8 = x_7 + x_{11}; \\ S_9 = x_7 + x_{11} + x_{15} + x_{16}; \\ S_{10} = x_1 + x_3 + x_4 + x_5 + x_7 + x_8 + x_9 + x_{10} + x_{11} + x_{12} + x_{13} + x_{14} + x_{15}. \end{cases} \tag{7}$$

All the successive transformations leading to the synthesis of diagnostic object model in a form of a diagnostic matrix are graphically represented on the block diagram (see Fig. 2). In the case where the diagnostic object model is represented as a matrix of diagnostic, diagnostic problem is formulated as follows.

According to the symptoms of malfunction S_1, S_2, ..., S_n obtained in diagnostic testing, we must determine the fault x_1, x_2, ..., x_m at the time of inspection, if we know the functional relationship between the diagnostic parameters and all structural parameters given in the form of diagnostic matrix or system of equations (7). Each structural parameter and every diagnostic parameter takes only two values: "0" and "1".

It is obvious that to solve the diagnostic problem we require an inverse transformation number of diagnostic parameters into a number of structural parameters, because in the diagnostics the values of diagnostic parameters are known.

In general, the inverse transformation can be represented by the expression

$$\{x_i\}_K = \Phi^{-1}\{s_j\}_K,$$

or in expanded form:

$$\begin{cases} x_1 = f_1(S_1,\ S_2,\ ...,\ S_n); \\ x_2 = f_2(S_1,\ S_2,\ ...,\ S_n); \\ x_m = f_m(S_1,\ S_2,\ ...,\ S_n). \end{cases} \tag{8}$$

The type of functions f_m is easy to establish in each case based on the following considerations.

In the diagnostic matrix (see Table 1) we separately consider one of the columns, such as the first. The matrix shows that the presence of the fault x_1 influenced the simultaneous output of four symptoms S_1, S_2, S_7 and S_{10} from the area of permissible values. The values of other diagnostic parameters only in the presence of the fault x_1 remain within normal limits. So x_1 is a Boolean function, in this case a conjunction (or logical multiplication function):

$$x_1 = S_1\, S_2\, S_7\, S_{10}.$$

The appropriate analysis considered to all other column matrix allows a reverse transformation (3) to write as a system of Boolean functions (conjunctions):

$$\begin{cases} x_1 = S_1S_2S_7S_{10}; \\ x_2 = S_3S_4; \\ x_3 = S_3S_{10}; \\ x_4 = S_1S_5S_{10}; \\ x_5 = S_1S_5S_{10}; \\ x_6 = S_6S_7; \\ x_7 = S_8S_9S_{10}; \\ x_8 = S_6S_7S_{10}; \\ x_9 = S_7S_{10}; \\ x_{10} = S_6S_7S_{10}; \\ x_{11} = S_1S_7S_8S_9S_{10}; \\ x_{12} = S_1S_7S_{10}; \\ x_{13} = S_7S_{10}; \\ x_{14} = S_7S_{10}; \\ x_{15} = S_7S_9S_{10}; \\ x_{16} = S_7S_9. \end{cases} \qquad (9)$$

As it is shown in this example, the process of diagnostics based on an object model diagnostics, expressed as a diagnostic matrix consists of the following stages:

- by the appropriate measurements and conversions (5) the symptoms of malfunction S_1, S_2, ..., S_n are established;
- the values of diagnostic parameters are substituted in Boolean functions (8);
- the values are estimated of all the faults of Boolean functions x_i (i = 1, 2, ..., m) and if x_i = 1, the object possesses an i-th malfunction.

Returning to the block diagram of diagnostics matrix synthesis (see Fig. 2) we can formulate, in general terms, the condition of diagnostics implementation as follows: to perform diagnostics it is enough that the reverse transformation of the number of malfunction and the number of structural parameters (failure) of an object was one-valued.

If the diagnostic matrix synthesis does not fulfill this condition and in the system (8) we have one or two equal functions, when the list of diagnostic parameters is necessary to be added with a new parameter that would enter as an additional argument only in one of the considered equal functions.

CONCLUSION

The mathematical model of the steering axle of wheeled tractors as an object of diagnostics will reveal failures depending on their features that significantly increase the life of agricultural tractors.

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МАТЕМАТИЧЕСКАЯ МОДЕЛЬ УПРАВЛЯЕМОГО МОСТА КОЛЕСНОГО ТРАКТОРА КАК ОБЪЕКТА ДИАГНОСТИРОВАНИЯ

Борисюк Д.В, Спирин А.В., Труханская Е.А, Швец Л.В., Зелинский В.И.

Аннотация. Машинно-тракторный парк является важным звеном сельскохозяйственного производства. От эффективной его работы во многом зависит снижение себестоимости продукции, своевременная уборка урожая, перевозка его потребителям, заготовка кормов и другие производственные и хозяйственно-бытовые процессы.

Один из важнейших направлений повышения производительности и экономичности машинно-тракторных агрегатов есть наиболее полное использование ресурса (сроков безотказной работы) машин при одновременном снижении затрат средств на их ремонт и техническое обслуживание. Этого можно достичь путем разработки и внедрения эффективных методов и средств контроля технического состояния машин, в том числе тракторов, без их разборки. С помощью таких средств можно определять техническое состояние агрегатов и узлов каждой машины отдельно и на основе этого устанавливать общий объем профилактических и ремонтных операций, а также своевременно устранять неисправности и предотвращать их.

В статье представлены математическая модель диагностирования управляемого моста колесного трактора. Построено матрицу диагностики и блок-схему ее синтеза.

Ключевые слова: математическая модель, матрица диагностирования, аналитическая модель, колесный трактор, управляемый мост, диагностирования, неисправности, признаки неисправностей, техническое состояние.