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MATHEMATICAL MODEL OF THE STEERING SYSTEM OF TOYOTA CAMRY VEHICLES AS AN OBJECT OF DIAGNOSTICS

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Cars are a dynamic system with lots of parts, units, systems and units. One of the units responsible for the safety of the car is steering. Existing methods and means of diagnosis of steering can be characterized by low efficiency. For various reasons, both declarative and real existing (supported equipment) methods usually have low accuracy and inability to localize malfunctions. Currently, in most cases, the roller control system faults are found on external grounds. It is possible to improve the quality of the process of diagnosis of steering control, including the creation of new mathematical models of their functioning.

Existing methods and means of diagnosis of steering as an integral element of road transport are analyzed. It is established that existing methods and means of diagnosis of steering do not fully allow to determine their current technical condition, which requires the development of mathematical models of their units and parts as an object of diagnosis.

Toyota Camry's cars are selected as a diagnosis object. The analysis of the design of the steering of the car "Toyota Camry" as an object of diagnosis is presented. Replacing real technical devices by their idealized models allows you to widely use different mathematical methods. The mathematical model is proposed in general, which is a system of functional dependencies between each diagnostic signal and structural parameters. Toyota Camry cars are drawn up for the steering car control, which includes a list of malfunctions and signs of malfunctions.

The proposed mathematical model of diagnosing the steering of the car "Toyota Camry" will reveal the malfunctions of its units and parts, depending on their features with the help of an artificial neural network.

Key words: *mathematical model, diagnosis, car, steering, diagnosis matrix, malfunction, malfunction, Boolean function, artificial neural network.*

Eq. 3. Fig. 4. Table.1. Ref. 21.

1. Problem formulation

The steering wheel vehicle provides a change in the direction of traffic in accordance with the driver's managerial influence, as well as maintaining the given direction of traffic, despite the presence of external breaks (transverse slope of the road, lateral wind, unevenness of tangent reactions in wheel contacts with road, etc.). Two performance and stability are used to evaluate these functions - respectively. In addition to vehicles, in the part of the steering, the requirements of maneuverability, ease of management [1, 2] are presented. The realization of all these requirements in the conditions of operation is carried out due to the perfection of the design and the necessary level of technical condition, which is provided by the technical service of the enterprise. Diagnosis plays an important role in maintaining the reliability of car steering, among other technological operations.

The complexity of diagnosing the steering of cars is determined by many reasons. First, the performance indicators of the steering control depend on the technical and mode characteristics. Secondly, there are actually no reliable tools for controlling the technical condition of the steering in operation. The steering backlash often indicates malfunctions.

The statistics of failure of individual units and units of cars show that 30% of all failures are the refusal of steering [3, 4]. Therefore, research aimed at improving the methods and means of diagnosing the steering of the car "Toyota Camry" is a relevant scientific and technical task.

2. Analysis of recent research and publications

An overview of theoretical and experimental research in the field of operation and determination of the technical condition of the steering of cars [3-9] showed that today certain scientific, methodological and technical bases of technical service of auto-mobil management systems have been created. However, existing technologies and methods of diagnosis, control and evaluation of the technical condition of individual elements of the steering do not take into account the peculiarities of their functioning.

The problem of improving the tools and methods of determining the technical condition of the steering of cars is presented in the works [10-13], during the analysis of which it is established that most methods of diagnosis of steering do not take a sufficient consideration of the peculiarities of their functioning, differ in high cost and complexity of the equipment used.

In the course of the analysis of recent studies and publications on the topic presented it was found that specific mathematical dependencies of determining the technical condition of the steering of cars were not detected.

3. The purpose of the article

The reliability of cars depends on the reliability of their units and units, and one of these units is the steering.

Increasing the accuracy and reducing the complexity of diagnostic work in the technical service of the steering can be achieved by improving diagnostic tools with the possibility of digitizing the received direct measurement of data and subsequent processing of them using a mathematical apparatus.

The purpose of the study is to increase the service life of the toyota camry car steering, due to the study of its working parameters on the basis of the developed mathematical model of diagnosing its units and parts, which takes into account both malfunctions and signs of malfunctions.

4. Results and discussion

The steering is intended to change the direction of the car by turning the front controlled wheels and consists of a steering mechanism and a steering drive. Cars in the steering use an amplifier that facilitates the control of the car, reduces shocks on the steering wheel and increases the safety of traffic.

The Toyota Camry car is installed with a steering wheel with a gear rail type. The steering car "Toyota Camry" consists of a steering wheel, a steering column, a steering mechanism equipped with a hydraulic boost, and two steering rods connected by ball hinges with rotary fists of the front suspension. The steering wheel of the Toyota Camry cars is equipped with a driver's safety pillow, in the center of the steering wheel a sound signal is installed. The steering wheel hub is attached to the rod shaft [3].

The steering column (Fig. 1) is traumatic, adjustable in height, equipped with energy-absorbing elements that increase passive safety, and an anti-landscape device in the ignition lock that blocks the wheel shaft. The steering shaft is connected to the steering shaft with a cardan hinge. On the steering column are also located organs of lighting of the headlights, indicators of rotation, washing and wind glass cleaner.

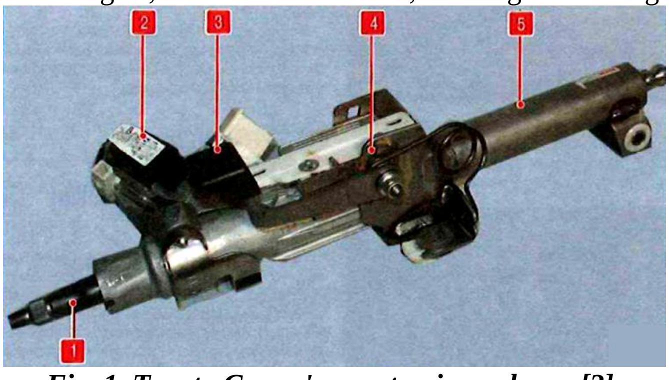

Fig. 1. Toyota Camry's car steering column [3]:

1 – the shaft of the steering column; 2 – ignition lock; 3 – the lever of adjusting the position of the steering column; 4 – mechanism of regulation of the position of the steering column; 5 – the steering column body

The steering mechanism (Fig. 2) is installed in the hood of the car. The crankcase of the steering mechanism is fixed to the cross -section of the front suspension.

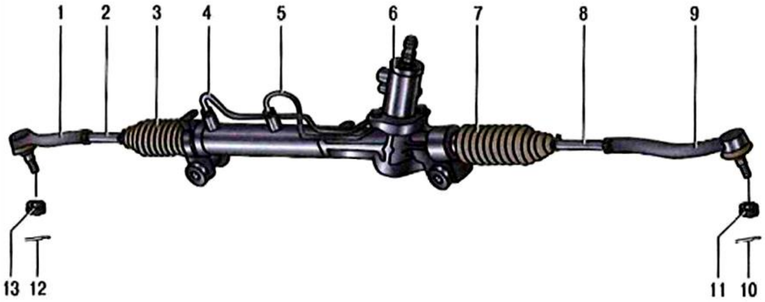

Fig. 2. Steering mechanism [3]:

1, 9 – steering tips; 2, 8 – steering; 3, 7 – protective covers; 4, 5 – pipelines; 6 – the housing of the steering mechanism; 10, 12 – splints; 11, 13 – nuts

The pressure of the working fluid in the hydraulic boost is created by a blade type pump, which is mounted on the engine bracket and is driven by a polyclinic strap from the crankshaft pulley. The trailing valve installed in the pump maintains the required pressure of the working fluid in the steering hydraulic boosting depending on the speed of the crankshaft. The steering heater tank is mounted in the hole space on the bracket of the battery fastening shelves and connected by hoses with the pump of the steering control and the main return of the working fluid. With the refusal of the steering amplifier, the possibility of driving the car is stored, but the efforts of resistance forces on the steering wheel increases.

The steering thrust is attached to the rail of the steering mechanism with ball hinges. The steering tips with the help of ball hinges are attached to the rotary fists of the front undergrowth. From the rotation in the tip the steering thrust is fixed with a nut. The rotation of the steering in the ball hinge relative to the tip regulate the ascent of the controlled wheels.

The steering is a complex and balanced complex of interrelated units and units. If something fails in the car steering or does not work correctly, it is more difficult for the driver to operate the vehicle and the risk of getting into a road accident increases.

The steering mechanism is a holistic knot, it is forbidden to disrupt the completeness of its parts.

Noise, change in sensations in manipulation with the steering wheel and knocking are the main signs of malfunction in the steering system. The general rule in any of these cases is the need to inspect the car by a specialist, since the steering system and its components because of their complexity, as a rule, are not subject to repair, but replacement.

All the main routine controls should be eliminated in the shortest possible time. Otherwise, the driver is at risk of both himself and his passengers.

Due to the automation of the logical process of diagnosis, it is possible to prevent the above faults of the steering.

Solving the problem of automation of the logical process of diagnosis requires the development of models of steering elements as diagnostic objects that describe at one mathematical level the relationship between many possible malfunctions and many values of diagnostic parameters.

Replacing the object of diagnosis of the model is associated with the selection of basic, essential for diagnosis of elements and properties related to the task of determining the true technical condition of the objects. In this case, some elements and ties of an object, which are extremely important in terms of its functioning as a device designed to perform a certain work, become secondary and can be excluded as a technical device as a diagnostic facility.

Replacing real technical devices by their idealized models allows you to widely use different mathematical methods. The mathematical model of the object of diagnosis means many analytical, logical, statistical, graphic and in general any qualitative relationships that associate the output parameters of the object with its input and internal parameters.

The most versatile model of the object of diagnosis is the presentation of it in the form of a "black box", the input and output parameters of which have the final set of values. It is assumed that all possible states of the object form a final 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 the prohibition of access to them and the state of the object can be determined only by exploring its initial parameters (without disassembly) [3].

To represent the object of diagnosis in the form of a "black box" must be set (Fig. 3):

To represent the object of diagnosis in the form of a "black box" must be set (Fig. 1):
- the number of all input actions *Y* from stimulating devices and the environment;
- the number of all initial signs of malfunction *C*;
- the number of all malfunctions of the object of diagnosis *B*;
- Operator A that converts quantity *B* and *Y* to quantity *C*:

$$C = A\{Y, B\}. \qquad (1)$$

Considering that during diagnosis, the quantity of Y stabilizes (or change according to the given law), the expression (1) will turn into a species:

$$C = A\{B\}. \qquad (2)$$

In other words, any output parameter of the object of diagnosis is a function of its technical condition at this state of inputs.

If the malfunction of the object of diagnosis {Bi} is attributed to the output parameters of the autoatized system, then the diagnostic problem is formulated as follows: by known signs of malfunction {Cj} to determine the unknown faults of the diagnostic object {Bi}.

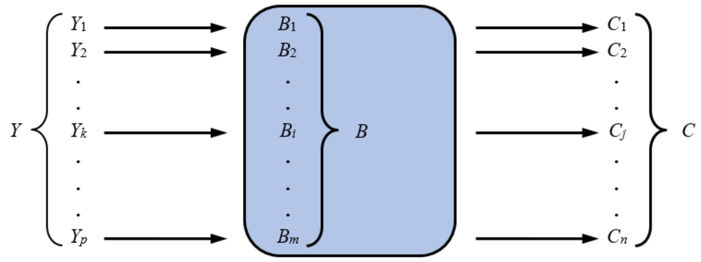

Fig. 3. Presentation of the object of diagnosis in the form of a "black box"

In order to successfully solve this problem, you need to know the type of operator *A*, in other words, a comprehensive description of the links between all the original parameters and all possible states (faults) of the object is required.

Below is a number of diagnostic models that differ in different forms of description of these relationships.

In the presence of an analytical model of the object of diagnosis, the task of diagnosis in general is formulated as follows. According to the signs of malfunction $C_1, C_2, ..., C_n$, obtained as a result of appropriate measurements, determine the technical condition (malfunction) of the object of diagnosis $B_1, B_2, ..., B_m$, if the functional dependencies between each diagnostic signal and structural parameters are known:

$$\begin{cases} C_1 = \phi_1(B_1, B_2, ..., B_m); \\ C_2 = \phi_2(B_1, B_2, ..., B_m); \\ .... \\ C_j = \phi_j(B_1, B_2, ..., B_m); \\ .... \\ C_n = \phi_n(B_1, B_2, ..., B_m). \end{cases} \qquad (3)$$

The equation system (3) is a mathematical model of the object of diagnosis that has m structural parameters and *n* diagnostic signals.

An obvious advantage of diagnosis using an analytical model is the ability to obtain a specific malfunction of the object of diagnosis, which allows to determine the technical condition of the object not only at the time of diagnosis, but also, accumulating information obtained for several diagnostic examinations of the object, analyze the change in structural parameters in order to forecast its technical condition.

However, the practical use of such an analytical model is still limited due to the following circumstances:

- the type of function φ_j for most nodes and mechanisms has not yet been established;

- if the function φ_j does not satisfy the conditions of continuity and differentiation for each of its arguments, which usually occurs in real models, then the solution of the system of equations (3) is associated with great mathematical difficulties;

- most diagnostic parameters, in principle, cannot be expressed in the form of analytical functions of structural parameters.

In a number of work on technical diagnosis of machines and mechanisms, possible technical conditions (malfunctions) of units and systems and signs of these faults are described in the form of so-called diagnostic matrices [6, 9, 14-21].

From the experience of the long -term operation of the Toyota Camry cars, Table 1 presents a matrix of diagnosis of the steering control, which they are equipped [3, 4, 11].

Table 1

Diagnosis of the Power Control of the Toyota Camry cars

Tyota Camry car control of the car control of the car	**A sign of malfunction the steering car "Toyota Camry"**				
	C_1	C_2	C_3	C_4	C_5
B_1	+	-	+	-	-
B_2	+	-	-	+	-
B_3	+	-	-	+	-
B_4	+	-	+	-	-
B_5	-	+	-	-	-
B_6	-	+	-	-	-
B_7	-	+	-	-	+
B_8	-	+	-	-	+
B_9	-	+	+	-	-
B_{10}	-	+	-	-	-
B_{11}	-	+	-	-	-
B_{12}	-	+	-	-	-
B_{13}	-	+	-	-	-
B_{14}	-	-	+	-	-
B_{15}	-	-	+	-	-
B_{16}	-	-	+	-	-
B_{17}	-	-	+	-	-
B_{18}	-	-	+	-	-
B_{19}	-	-	-	+	-
B_{20}	-	-	-	+	-
B_{21}	-	-	-	-	+

In the diagnosis matrix, we denote the following malfunctions of the steering of the car "Toyota Camry": B_1 – a violation of the stretch of the spring of the stop of the rail; B_2 – weakened tightening of the bolts of the steering mechanism; B_3 – wear of the spherical hinges of the steering rods; B_4 – wear of the steering shaft; B_5 – sliding the belt of the drive of the pump of the hydraulic booster; B_6 – damage to the belt of the drive of the pump of the hydraulic booster; B_7 – insufficient level of working fluid; B_8 – air entering the hydraulic system; B_9 – distortion or damage of hoses; B_{10} – insufficient pressure of the pump of the hydraulic booster; B_{11} – increased internal origins in the pump; B_{12} – leakage of fluid from the steering mechanism; B_{13} – the distortion or damage of seals of the steering mechanism or distributor; B_{14} – difficulty in the interior hinges and/or hinges of the steering rods; B_{15} – deformation of the rail of the steering mechanism; B_{16} – damage to the gear bearing; B_{17} – damage to the pressure control valve; B_{18} – damage to the pump rotor roller bearing; B_{19} – touching hoses to the body; B_{20} – weakened mounting of the steering rods and/or ball hinge of the tips; B_{21} – weakened tightening of the pump mounting bolts.

Also in the diagnosis matrix, we introduce signs of the above faults of the steering of the car "Toyota Camry": C_1 – increased free course of the steering wheel and knocking in steering; C_2 – tight rotation of the steering wheel; C_3 – fuzzy return of the steering wheel to the average position; C_4 – noise (knock) in steering; C_5 – increased noise of the hydraulic pump. As can be seen from Table 1, each malfunction is characterized by a certain combination of values of its features, which can take two conventional values: «-» or «+».

At the intersection of the *i*-th row and the *j*-th column is put «+» if in the presence of the I-th malfunction there is a output of the *j* -th trait from the area of its permissible values, otherwise "-«-».

In the tasks of diagnosis and forecasting, the fuzzy neural network plays the role of a universal function of function from several variables.

In Fig. 4 presents an artificial neural network to determine the faults of the steering car control of the Toyota Camry car functioning of which is determined by a diagnostic matrix (Table 1).

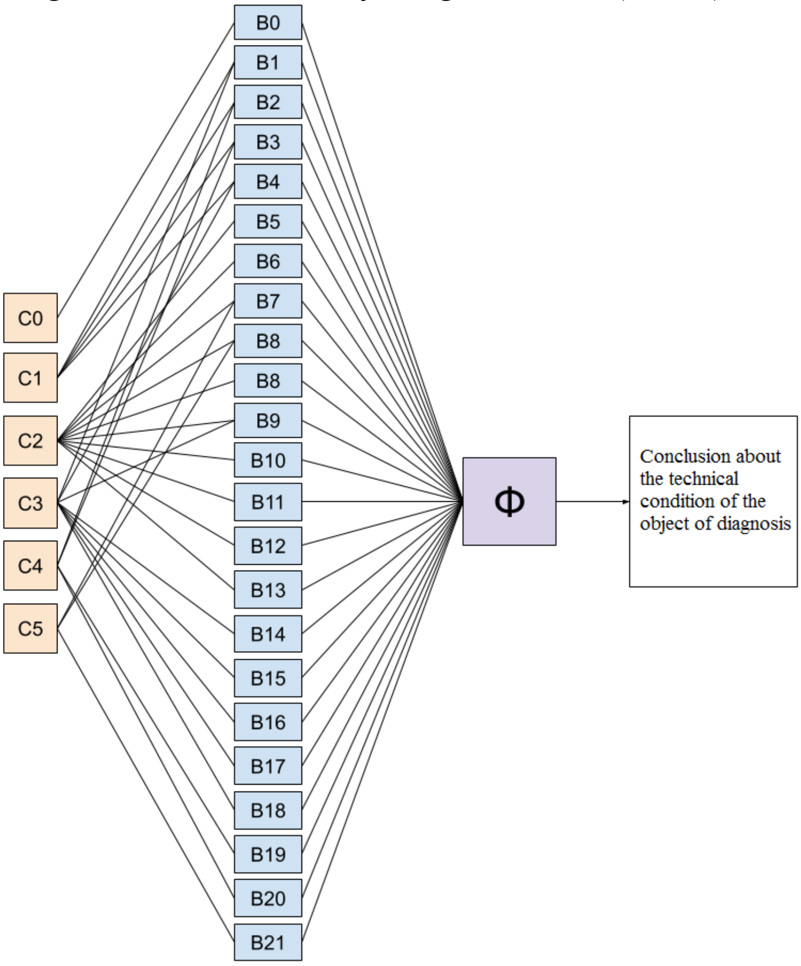

Fig. 4. This an artificial neural system:

C1… C5 – ***signs of steering malfunction;*** **C0** – ***absence of signs of a malfunction of the steering;*** **B1… B21** – ***steering malfunctions; B_0 is the robust state of steering;*** **Φ** – ***the operator that converts the number of technical states of the object into the number of diagnostic parameters***

According to the artificial neural network of malfunction of the object of diagnosis, you can be written in the form of a boolean function of input signals:

$B_1 = (C_1 + C_3) \cdot \bar{C}_2 \cdot \bar{C}_4 \cdot \bar{C}_5;$ $B_8 = (C_2 + C_5) \cdot \bar{C}_1 \cdot \bar{C}_3 \cdot \bar{C}_4;$ $B_{15} = C_3 \cdot \bar{C}_1 \cdot \bar{C}_2 \cdot \bar{C}_4 \cdot \bar{C}_5;$

$B_2 = (C_1 + C_4) \cdot \bar{C}_2 \cdot \bar{C}_3 \cdot \bar{C}_5;$ $B_9 = (C_2 + C_3) \cdot \bar{C}_1 \cdot \bar{C}_4 \cdot \bar{C}_5;$ $B_{16} = C_3 \cdot \bar{C}_1 \cdot \bar{C}_2 \cdot \bar{C}_4 \cdot \bar{C}_5;$

$B_3 = (C_1 + C_4) \cdot \bar{C}_2 \cdot \bar{C}_3 \cdot \bar{C}_5;$ $B_{10} = C_2 \cdot \bar{C}_1 \cdot \bar{C}_3 \cdot \bar{C}_4 \cdot \bar{C}_5;$ $B_{17} = C_3 \cdot \bar{C}_1 \cdot \bar{C}_2 \cdot \bar{C}_4 \cdot \bar{C}_5;$

$B_4 = (C_1 + C_3) \cdot \bar{C}_2 \cdot \bar{C}_4 \cdot \bar{C}_5;$ $B_{11} = C_2 \cdot \bar{C}_1 \cdot \bar{C}_3 \cdot \bar{C}_4 \cdot \bar{C}_5;$ $B_{18} = C_3 \cdot \bar{C}_1 \cdot \bar{C}_2 \cdot \bar{C}_4 \cdot \bar{C}_5;$

$B_5 = C_2 \cdot \bar{C}_1 \cdot \bar{C}_3 \cdot \bar{C}_4 \cdot \bar{C}_5;$ $B_{12} = C_2 \cdot \bar{C}_1 \cdot \bar{C}_3 \cdot \bar{C}_4 \cdot \bar{C}_5;$ $B_{19} = C_4 \cdot \bar{C}_1 \cdot \bar{C}_2 \cdot \bar{C}_3 \cdot \bar{C}_5;$

$B_6 = C_2 \cdot \bar{C}_1 \cdot \bar{C}_3 \cdot \bar{C}_4 \cdot \bar{C}_5;$ $B_{13} = C_2 \cdot \bar{C}_1 \cdot \bar{C}_3 \cdot \bar{C}_4 \cdot \bar{C}_5;$ $B_{20} = C_4 \cdot \bar{C}_1 \cdot \bar{C}_2 \cdot \bar{C}_3 \cdot \bar{C}_5;$

$B_7 = (C_2 + C_5) \cdot \bar{C}_1 \cdot \bar{C}_3 \cdot \bar{C}_4;$ $B_{14} = C_3 \cdot \bar{C}_1 \cdot \bar{C}_2 \cdot \bar{C}_4 \cdot \bar{C}_5;$ $B_{21} = C_5 \cdot \bar{C}_1 \cdot \bar{C}_2 \cdot \bar{C}_3 \cdot \bar{C}_4;$

Thus, the basis of the functioning of the artificial neural network is the following assumption: in the presence in the object of diagnosis of malfunction in the process of diagnosis B_i, at least one of the signs having «+» in the I-th line of the matrix is always observed, and never appears none of the signs that accept the value «-»in the *i* line.

In general, the localization of malfunctions with the help of a diagnostic matrix is similar to the work of the system of neurons.

The use of artificial neural systems will allow to increase the performance of diagnosing means by parallelization of diagnostic information processing flows.

5. Conclusion

In the course of the analysis of recent research and publications on the topic presented, it was found that specific mathematical dependencies of determining the technical condition of the steering of cars were not revealed.

The analysis of the design of the Toyota Camry cars design as an object of diagnosis is presented.

The Toyota Camry car steering system, as a diagnosis object, is presented in the form of a "black box", the input and output parameters of which have a final set of values.

Toyota Camry, a diagnosis matrix is drawn up for the Toyota Camry cars, which includes a list of faults and malfunctions. Diagnosis matrix as a diagnostic model shows that it is a tabular form of recording a mathematical model of the object of diagnosis.

Automation of the logical process of determining the malfunctions of the steering of the car "Toyota Camry" by developing an artificial neural network, the functioning of which is determined by a diagnostic matrix.

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МАТЕМАТИЧНА МОДЕЛЬ РУЛЬОВОГО УПРАВЛІННЯ АВТОМОБІЛІВ «TOYOTA CAMRY» ЯК ОБ'ЄКТА ДІАГНОСТУВАННЯ

Автомобілі є динамічною системою з великою кількістю деталей, вузлів, систем і агрегатів. Одним з агрегатів, що відповідають за безпеку руху автомобіля є рульове управління. Існуючі методи та засоби діагностування рульового управління можна охарактеризувати низькою ефективністю. З різних причин як декларативні, так і реально існуючі (підтримувані обладнанням) методи, зазвичай, мають низьку точність і нездатність локалізувати несправності. Наразі в більшості випадків несправності системи рульового управління виявляються за зовнішніми ознаками. Підвищити якість процесу діагностування рульового управління можна, в тому числі, і створенням нових математичних моделей їх функціонування.

Проаналізовано існуючі методи та засоби діагностування рульового управління, як складового елемента автомобільного транспорту. Встановлено, що існуючі методи і засоби діагностування рульового управління не в повній мірі дозволяють визначати їх поточний технічний стан, що вимагає розробки математичних моделей їх вузлів та деталей як об'єкта діагностування.

Як об'єкт діагностування обрано рульове управління автомобілів «Toyota Camry». Представлено аналіз особливостей конструкції рульового управління автомобілів «Toyota Camry», як об'єкта діагностування. Заміна реальних технічних пристроїв їх ідеалізованими моделями дозволяє широко застосовувати різні математичні методи. Запропоновано в загальному вигляді математичну модель, яка представляє собою систему функціональних залежностей між кожним діагностичним сигналом і структурними параметрами. Для рульового управління автомобілів «Toyota Camry» складена матриця діагностування, яка включає перелік несправностей та ознак несправностей.

Запропонована математична модель діагностування рульового управління автомобілів «Toyota Camry» дозволить виявити несправності його вузлів та деталей в залежності від їх ознак за допомогою штучної нейронної мережі.

Ключові слова: *математична модель, діагностування, автомобіль, рульове управління, матриця діагностування, несправність, ознака несправності, Булева функція, штучна нейронна мережа.*

Ф. 3. Рис. 4. Табл. 1. Літ. 21.

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