GEOMETRIC CONTROL MODELS OF CARS' EXHAUST GAS RECIRCULATION

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ABSTRACT

Ensuring compliance with requirements for the emission of harmful substances in accordance with the standard Euro-4 is one of the priorities in the design of devices associated with a reduction in toxicity of motors [1, 2]. Up to 60% of harmful emissions into the atmosphere accounts for road transport.

The use of modern information technologies of visualization and three-dimensional computer modeling of devices of systems intended for toxicity decrease of cars allows for a systematic analysis at any level of difficulty. The technical result of creation of threedimensional computer geometric models (hereinafter – TDCGM) means reduction in time and computing resources spent on the design. The objective of the author is to investigate a new technique for creation of geometric control models of EGR system.

The data for visual analysis with the help of 3D images of the EGR control system components are analyzed, the choice of software is justified and 3D modeling of recirculation valve for the car «Kalina-2» is conducted. In particular, there are improvements in layout scheme of recirculation valve, control parameters of its materials and weight and size characteristics. A method is proposed to simplify design and calculation of transient electromagnetic processes of synchronous stepper motor with permanent magnets, ensuring the operation of the valve.

The practical application of the method enables to reduce the timing of preliminary design stage, to improve the weight and size parameters, to calculate the transient electromagnetic processes for subsequent optimization of parameters of EGR system by criterion of reduced power losses of an automobile engine.

Keywords: *environmental safety, car, exhaust gas recirculation, system analysis, virtual space, simulation.*

Background. *Ensuring compliance with requirements for the emission of harmful substances in accordance with the standard Euro-4 is one of the priorities in the design of devices associated with a reduction in toxicity of motors [1,2]. Up to 60% of harmful emissions into the atmosphere accounts for road transport.*

The use of modern information technologies of visualization and three-dimensional computer modeling of devices of systems for decrease in toxicity in cars allows for a systematic analysis at any level of difficulty. The technical result of creation of three-dimensional computer geometric models (hereinafter- TDCGM) is reduction in time and computing resources spent on the design.

Methods of automatic construction of TDCGM are widespread now, they focus on extracting the basic models of pre-created database to change the values of their parameters according to the geometry data of designed devices or predetermined manner [3]. However, these methods do not provide adequately for solving problems of parameters' optimization and increase in efficiency of devices, in this case – EGR system of cars.

Objective. *The objective of the author is to investigate a new technique for creation of geometric control models of EGR system.*

Methods. *The author uses analysis, comparative method, 3D- modeling, computer simulation.*

Results.

Disposition of toxicity problems

The most toxic components of exhaust gases of gasoline engines are carbon monoxide (CO), nitrogen oxides (NO_x), hydrocarbons (C_nH_m), and lead, if leaded gasoline is consumed. Problems of environmental safety have led to the creation of EGR system (Exhaust Gas Recirculation), the main objective of which was reduction of toxicity of exhaust by returning part of the exhaust gas from the outlet into the inlet manifold. The gas outlet reduces the combustion temperature of gas of the fuel-air mixture in cylinders, which, in fact, leads to a decrease in the amount of NO_x in exhaust gases. The fee for such a change: reduction in engine power, resource of particulate filter, increase in fuel quality requirements (sulfur content).

The EGR system has a limited life. With sufficiently high quality fuel it is necessary to replace all of its components after 70–100 thousand km run. With low-quality fuel – the allowable limit is 50 thousand km. That is, the adjustment of the recirculation valve must be such as to increase the fuel quality and to minimize the loss of engine power.

Table 1

Classification of data for visual analysis

Type of data	Examples of data
univariate	dimensional arrays, time series
bivariate	points of two-dimensional graphs, geographic coordinates
multivariate	results of experiments data in specialized scientific or technical format (CEOS, HDF, etc.) in format of CAD software for 3D-modeling (*.frw, *.cdw, *.m3d, *.dwg, *.easm, *.xls, etc.), standard graphics files (BMP, TIFF, etc.)., financial indicators
texts and hypertexts	newspaper articles, web-documents
hierarchical and linked	subordination structure in the organization, e-mails of people, hyperlinks of documents
algorithms and programs	information flows, debugging operations

Table 2

Cost of software for 3D-modeling

Name of a software package	Manufactured by	Cost, Euro
SolidWorks	SolidWorks	5500
SolidWorks Professional		6900
SolidWorks Premium		9100
Autodesk Inventor Professional Commercial New NLM EN	Autodesk	5590
Inventor Professional Commercial New SLM EN		4470
Inventor Suite Commercial New SLM		3190
Kompas-3D	Ascon	1900
T-Flex 3D	TopSystem	2300

Evaluation of visualization tools

For all stages of processing information on recirculation system state it is necessary to carry out numerical modeling of its parameters to determine the operating characteristics of the simulated object and select the optimal operating conditions at the design stage.

Visualization is an essential part of the process of numerical simulation, providing analysis and correct interpretation of calculation results, as well as further work with the computational model.

Table 1 shows the classification of the data, which are associated with visualization tools [4].

For visualization of the data types listed in Table 1, the following visualization techniques are applied:

- standard 2D / 3D-images – line graphs, bar graphs;

- geometric transformations – scatter diagrams, parallel coordinates;

- display of icons – needle icons and star icons;

- methods oriented on pixels – recursive templates, cyclical segments;

- texts of web documents;

- hierarchical images – tree maps and overlay of measurements.

CAD-programs (from English. computer-aided design/drafting – automated tools designed for two- and / or three-dimensional geometric design, creation of design and / or technical documentation), carry out all of these visualization techniques. The most common are: KOMPAS –3D, Pro / ENGINEER, CorelDRAW, AutoCAD, SolidWorks, Microsoft Excel. Data exchange format between programs: igs.

Inexpensive package KOMPAS –3D, which cost as compared to other simulation programs is shown in Table 2, allows the user to create all sorts of drawings and descriptions of them, as well as to carry out these methods of visualization.

Modeling of products in KOMPAS-3D can be carried out using ready-made components ("bottom-up"), designing components in the context of construction ("top-down"), based on the layout scheme (for example, kinematic scheme), as well as a mixed manner. An easy modification of resulting models is provided.

Disadvantages of KOMPAS- 3D: there is no kinematic, strength, temperature, frequency analysis; there is no possibility of calculating electrical parameters and ergonomic features. However, a large number of design documentation in accordance with the requirements of Unified system for design documentation at machine-building enterprises (automotive, aerospace industry, members of scientific and production associations) was created in the program KOMPAS-3D.

More expensive programs, such as, SolidWorks have more function capabilities for designing and creating photo-realistic images. But in this case, it is impossible to do without selecting additional software environment for the transfer of geometry in the external design packages or package for development of control programs.

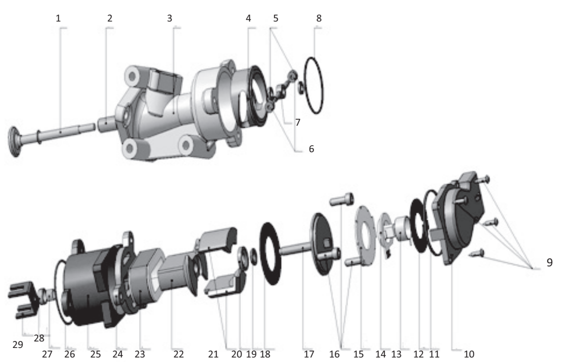
In modeling the recirculation control system with an electromechanical valve, synchronous stepping motor and the motor which drives the valve, it is advisable to select a software environment Maxwell of Ansoft company for calculating the parameters of rotating electrical machines. In the environment of KOMPAS-3D only shape of the object is given, in the package Maxwell (2D, 3D) – material parameters, the direction of magnetic field lines, parameters of devices are calculated [4,5].

Information support of car service enterprises should evolve to meet new modeling techniques [6,7]. Common cases of solving geometric modeling tasks, to which the majority of engineering problems belong, require modern methods of three-dimensional computer modeling [8].

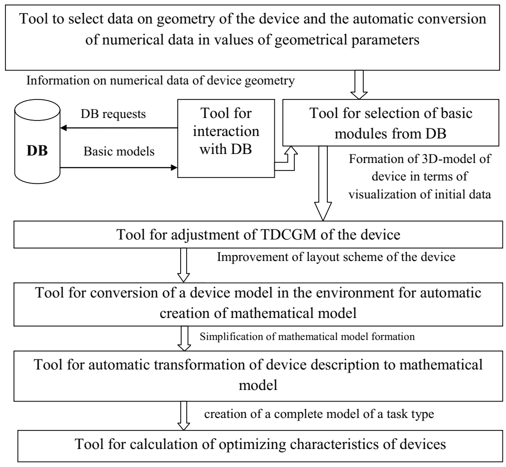
Recirculation control algorithm

Electromechanical recirculation valve has several provisions to regulate, it is the most promising for control as compared with the vacuum recirculation valve (it has only two positions – «open» and «closed") and the solenoid valve (several provisions of the regulation, but the reliability level is lower).

Recirculation valve operation depends on engine speed, coolant temperature, engine load. The first de-



Pic. 1. 3D-images of EGR system.
1-*valve;* 2- *sleeving;* 3-*valve body;* 4-*carrier's holder;* 5- *distance ring;* 6- *bearing;* 7- *carrier;* 8- *gas seal;* 9- *wood screw 4–3 x 13.3 GOST 1144–80;* 10- *sensor body;* 11- *seal;* 12- *potentiometer's plate;* 13- *spring;* 14- *runner;* 15-*sensor cover;* 16- *Hexogon socket head cop screw ISO 4762- MS x 16–10.9;* 17- *rotor;* 18- *magnet;* 19- *thrust ring;* 20- *rotor's bearing;* 21- *side magnetic core;* 22- *central magnetic core;* 23- *coil;* 24- *base box;* 25- *body;* 26- *connective seal;* 27- *sleeve- type bearing;* 28- *rotor's seal;* 29- *plug.*



Pic. 2. Method for construction of TDCGM and optimization of parameters of simulated devices.

pendence means that at 700–800 rpm to 1100–1200 rpm idle running is on, combustion gas temperature is unessential, and consequently nitrogen oxides are not formed and recirculation is not required. Within 4700 rpm full throttle mode switches on, that is, the throttle valve is opened to 100%, and therefore, the engine requires maximum power. To ensure it a rich fuel mixture is required, and this contradicts the recirculation system, where the engine control unit implements the program «lean mixture».

Dependence of switching on recirculation system of the temperature is within a certain range when the engine is considered hot (45–60 C° or higher). The rationale for switching on the system is to increase the combustion temperature in cylinders of the engine, which leads to the formation of nitrogen oxides.

The dependence of the load on the engine is determined by the absolute value of the actual air mass flow. The maximum opening of the valve is achieved at maximum speed and maximum load at recirculation, i. e. 4600–4700 rpm and 100% opening throttle valve.

To illustrate recirculation control algorithm, Pic. 1 shows the model of control system modules: electromechanical valve EGR, electric motor and position sensor of electric motor, created in Kompas-3D. Movement of the valve is performed by fixed carrier 7, rotating around the valve axle 1 on carrier's holder 4. The carrier 7 is fixed by means of distance rings 5 so that its movement along the valve is not present, and rotation is performed smoothly. Similarly, the sleeving 2 provides even, without distortions and jamming movement of valve 1. Movement of the carrier 7 along the carrier's holder 4 is supported by bearings 6 impregnated with a high temperature lubricant (graphite). Gas seal 8 is used to prevent the flow of exhaust gases into the atmosphere.

The rotation of the carrier 7 is carried out by plug 29 which is rigidly attached to the rotor 17, and the rotation of the latter is carried out by transverse flux which occurs as a result of the passage through the coil 23 of current of a certain value depending on the opening conditions of the valve. Four-pole permanent magnet 18 is glued to the rotor 17. The smooth rotation of the rotor is provided by sleeve-type bearing 27 and roller bearing 20.

Two magnetic cores 21 and 22 with poles form two closed magnetic flux at these poles. By connecting the coil to the voltage current starts to flow on it, which enhances the flux of the center magnetic core 22, whereby the rotor comes into motion. After turning off the voltage, return of the rotor 17 to the starting position is performed with the help of the spring 13. The runner 14 is rigidly attached to the rotor 17and it moves along the plate of potentiometer 12 when the rotor turns. The plate has two tracks, one of them is resistive. On the runner there is a jumper by which the closure of tracks occurs.

Synchronous stepper motor with permanent magnets performs functions of the actuator for opening and closing the EGR valve. The excitation winding of electric motor acts as magnetic core and creates a magnetic field. At design stage it is necessary to calculate its parameters and optimize (minimize) the air gap between the stator and the rotor.

To accelerate the design process and to simplify simulation in the software environment Maxwell models of other applications can be used. Pic. 2 schematically illustrates a method of automatic construction of TDCGM and optimization of the parameters of the simulated devices by converting from one medium to another.

Information model of the device is constructed in terms of visualization of initial data and formed by a specialized 3D-graphics interface. On its basis 3D-model of the device structure is automatically generated, and in turn it provides the automatic creation of a mathematical model in the medium Maxwell. In this case, the simulation can be represented as a process of automatic transformation of design descriptions through an information model for the topological and further to the mathematical model.

The basic model for all versions is TDCGM built before that meets the application conditions of the designed device – for example, to build TDCGM of recirculation valve it is possible to use the geometric models of other valves built before that. If the device requires the assembly of several components, ready-made basic models of these components are used- for example, the EGR valve assembly with a magnetic core.

A tool to select data on geometry of the device, taken to build TDCGM is a software module that allows the user to interactively make a choice of geometry data of items and their location (file on the hard disk of a personal computer, a local computer network or network database). Formation of 3D-model of the device from the point of view of visualization of initial data means that in the model various visualization techniques can be used (e. g., cross-section of details of the device, some sections of the model, element selection) to analyze its parameters, and further optimization using the criterion for minimizing the loss of engine power when controlling recirculation.

Tool for conversion of the model in the environment for automatic creation of mathematical model is a pro-

gram for exchanging data between CAD-programs in accordance with the given format.

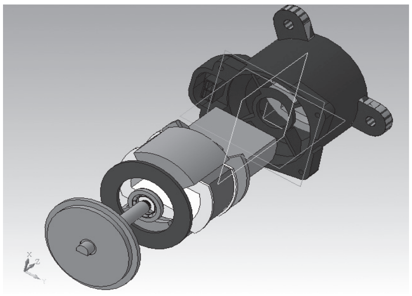
Conversion of the model of the synchronous stepper motor from the environment in KOMPAS-3D in the environment 3D-Maxwell (or 2D) includes not only drawing in the geometry of the machine, but also the creation of a complete model with the type of a task is a transition process with a rotational movement [4]. Moreover, 3D-Maxwell allows to calculate the transition process from the current and voltage sources with arbitrary time dependences. This feature enables to solve the equations of the magnetic field, electric current, movements in the strict joint wording and calculate the characteristics of the recirculation valve control.

Based on the basic models of recirculation valve devices, created in an environment Kompas-3D, the simulation of such a valve with assembly with a magnetic core was performed (Pic. 3).

It has been noted that in KOMPAS-3D only shape of the object is defined, an arrangement of elements of devices was performed and the environment Maxwell (2D, 3D) defines material parameters, directions of magnetic field lines, parameters of the synchronous stepper motor of recirculation valve are calculated. The economic effect of reducing the weight of the designed product (synchronous stepper motor with a magnetic core) is given by:

$E_{mat} = (Q_{bas} - Q_{des}) \cdot P \cdot C_{all}$, *[rub./piece]*

where Q_{bas} *is weight of a basic product;* Q_{des} *is weight of a designed product; P – the wholesale price for 1 kg of metal, rub.;* C_{all} *is coefficient accounting for allowance for processing materials (*C_{all} *= 1,25 ... 1,35).*



Pic. 3. 3D-image of recirculation valve in assembly with a magnetic core.

Calculation data: Q_{bas} *= 0,372 kg,* E_{mat} *= (0,745–0,734) · 980,32 · 1,3 = 14.01 rub. / piece.*

Conclusions. *A method for automatic construction of TDCGM of devices based on basic models and conversion from one simulation environment to another to select the material parameters and calculate control features was implemented in KOMPAS-3D and 2D-Maxwell. Modeling was carried out in the design of complex technical products on the example of electromechanical EGR valve with a magnetic core. The practical application of the method enables to reduce the timing of preliminary design stage, to improve the weight and size parameters, to calculate the transient electromagnetic processes for subsequent optimization of parameters of EGR system on criterion to reduce power losses of the automobile engine.*

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