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Разработка прототипа пружинного демпфера крутильных колебаний с применением технологии реверс-инжиниринга

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Аннотация. В статье рассматриваются вопросы по разработке прототипа пружинного демпфера крутильных колебаний с применением технологии реверс-инжиниринга (обратного проектирования). В качестве объекта исследования был выбран пружинный демпфер с рессорными пластинами австрийской фирмы Geislinger модели D90/37. Данная модель демпферов получила широкое распространение в составе современных судовых дизелей МАК 8М25. Вопрос создания отечественной модели пружинного демпфера обусловлен рядом проблем, в том числе полным прекращением поставок в Россию подобного типа устройств. Пружинные демпферы являются ответственными элементами машинно-движительных комплексов, от эффективности работы которых зависит в том числе безопасность мореплавания судов. На базе ФГБОУ ВО «АГТУ» при помощи 3D-сканера Range Vision Spectrum, одобренного Федеральным агентством по техническому регулированию и метрологии, были получены CAT-модели составных элементов пружинного демпфера: промежуточная вставка и бронзовая межпружинная пластина. Принцип работы сканера основан на структурированном подсвете и оптической триангуляции. При помощи данных ручной геометрии реального демпфера, а также использования программного продукта КОМПАС был разработан чертеж общего вида модельного пружинного демпфера крутильных колебаний. Моделирование (физического и с применением современных программных продуктов) пружинных демпферов крутильных колебаний позволит накопить теоретические знания и практический задел, что послужит первой ступенью для укрепления технологического суверенитета России в области их проектирования, изготовления и ремонта. Итогом большой проделанной работы научной школы, занимающейся вопросами динамики машинно-движительного комплекса, под руководством заслуженного работника рыбного хозяйства РФ, д.т.н., профессора Покусаева М.Н. будет являться первый отечественный прототип пружинного демпфера крутильных колебаний.

Ключевые слова: пружинный демпфер крутильных колебаний, технология реверсивного инжиниринга, 3D-сканирование, программное моделирование, физическая модель демпфера
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MARINE POWER PLANTS AND THEIR ELEMENTS (MAIN AND AUXILIARY)

Original article

Development of a prototype of a torsional vibration spring damper using reverse engineering technology

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Abstract. The article discusses the issues of developing a prototype of a spring damper for torsional vibrations using reverse engineering technology (reverse engineering). A spring damper with spring plates of the Austrian company Geislinger model D90/37 was chosen as the object of research. This model of dampers is widely used as part of modern marine diesel engines MAK 8M25. The issue of creating a domestic model of a spring damper is caused by a number of problems, including the complete cessation of supplies of this type of device to Russia. Spring dampers are responsible elements of machine-propulsion systems, on the efficiency of which depends, among other things, the safety of navigation of ships. On the basis of the Federal State Educational Institution of Higher Education "Astrakhan State Technical University", using a Range Vision Spectrum 3D-scanner approved by the Federal Agency for Technical Regulation and Metrology, CAT models of the components of the spring damper were obtained: an intermediate insert and a bronze spring plate. The principle of operation of the scanner is based on structured illumination and optical triangulation. Using data from the manual geometry of a real damper, as well as using the COMPASS software product, a drawing of a general view of a model spring damper of torsional vibrations was developed. Modeling (physically and using modern software products) of torsional vibration spring dampers will allow you to accumulate theoretical knowledge and practical groundwork, which will serve as the first step to strengthen Russia's technological sovereignty in the field of their design, manufacture and repair. The result of the great work done by the scientific school dealing with the dynamics of the machine-propulsion complex, under the leadership of the Honored Worker of the fisheries of the Russian Federation, Doctor of Engineering Sciences, Professor M.N. Pokusaev, will be the first domestic prototype of a spring damper of torsional vibrations.

Keywords: torsional vibration spring damper, reverse engineering technology, 3D-scanning, software modeling, physical model of the damper

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Introduction

Today, the Russian Federation is dependent on Western technologies in the field of design, manufacture and repair of torsional vibration spring dampers for a number of reasons:

1. Before the introduction of economic sanctions against Russia, it was possible to purchase spring dampers of torsional vibrations (hereinafter referred to as SD TV) abroad. Currently, all deliveries of leading manufacturers of SD TV in the Russian Federation have been discontinued;

2. Periodic diagnostics of the technical condition of the working capacity of SD TV was carried out exclusively by foreign specialists of manufacturing plants, which is practically impossible in today's realities, [1]. This policy is clearly demonstrated by the example of the largest Austrian company Geislinger, which supplied a significant share of SD TV for marine diesel engines of the domestic fleet;

3. Russia does not have a single testing (service) center for maintenance and repair of SD TV, [2];

4. There is a shortage of engineering personnel in Russia, which is expressed in the absence of qualified design engineers, designers, machine builders, mechanics;

5. The low level of equipment of the material and technical base of industrial enterprises: there are fewer and fewer functioning shipbuilding and ship repair enterprises in Russia, outdated instrumentation, machine tools, etc.

6. The absence of established norms and methods for the diagnosis and maintenance of SD TV in the rules of classification societies: the Russian Maritime Register of Shipping [3] and the Russian Classification Society [4].

All this together confirms the relevance of the study, especially for solving the issue of import substitution in this industry, and consequently reducing dependence on foreign production. The direction of the research correlates with the strategy for the development of the shipbuilding industry for the period up to 2035 (Decree of the Government of the Russian Federation dated 28.10.2019 No. 2553-R), as well as with the strategy of scientific and technological development of the Russian Federation (Decree of the President of the Russian Federation dated 28.02.2024 No. 145).

An acute problem for ship-owning organizations in today's realities is the need for a non-selective assessment of the operability and assignment of the residual resource of previously installed SD TV of foreign production and further replacement with domestic analogues after the full develop-

ment of the resource. To solve this problem, it is necessary to start with modeling the design and operation of SD TV in order to accumulate theoretical knowledge and strengthen practical groundwork in the field of research.

It should be noted that many leading foreign specialists and scientists are engaged in the technical operation of shipboard SD TV [5–8].

Setting the research task

The goal is to develop design documentation for the prototype SD TV based on the full–scale spring damper D90/37 from Geislinger using reverse engineering technology.

One of the main objectives of the research is the study and practical application of reverse engineering technology (concept, methods, stages, advantages and disadvantages).

As previously described in the research of the authors [2], the tendency of the prevalence of PD CC in the composition of modern diesels of the world's leading companies is justified for the following reasons:

1. Features of the design and principle of operation of SD TV with a combination of elastic (due to spring or cylindrical spring plates) and hydraulic damping (due to engine oil entering the damper housing through the crankshaft of a diesel engine) allows you to obtain maximum efficiency of SD to reduce TV, which determines the reliability of the machine-propulsion complex (MPC)

2. The complication of the design schemes of the MDK of modern vessels, and, accordingly, an increase in the risks of dangerous forms of torsional vibrations not only of integer but also fractional harmonic orders.

According to the statistics on the distribution of the number of dangerous forms of TV for standard projects of MDK vessels of the Volga-Caspian basin, 15% of vessels have 3 forms of TV, 6% – 4 forms, 3% – 9 forms. This confirms the fact that the probability of resonant frequencies above the 2nd order falling into the operating frequency range of the main engine will be more significant (for example, for marine diesels Wartsila 6L20, Wartsila 9L20 pnom = 1000 min^{-1}) than for previously used marine MPC circuits with medium-speed diesels (German SKL 8NVD48A2U (8CHNR32/48) and domestic G70 (6HRN36/45). The silicone damper is usually adjustable and is capable of extinguishing no more than 2 dangerous forms of TV, and the range of SD TV varies up to 9 forms of TV.

The SD TV of Geislinger model D90/37, widely used on MAK 8M25 marine diesels, was chosen as the object of research. The object, which has spent its life, was delivered to the Marine Technology Service Test Center of the Federal State Educational Institution of Higher Education "Astrakhan State Technical University" as part of a partnership with a Turkish ship-owning company. The general appearance and design of the Geislinger SD TV is shown in Fig. 1.

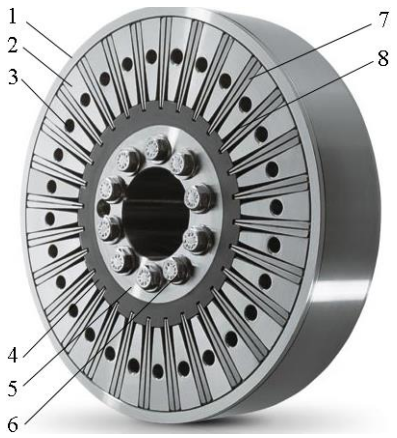

Fig. 1. General view and design of Geislinger SD TV

The design of this type of dampers includes the outer housing 1, the inner rim (asterisk) 4, between which there are intermediate inserts 2, rigidly connected by mounting bolts 6 with the upper

and rear covers of the damper 3. The main working elements of the PD KK are spring spring plates 7, between which bronze inserts are installed. For lubrication, cooling of spring plates and hydraulic damping of torsional vibrations, diesel engine oil is supplied to the housing, which, after passing through all cavities 8, is removed through holes in the lid.

The torsional stiffness of the Geislinger MPC model D90/37 is $4.5*10^6$ N*m/rad.

Initially, the MPC was disassembled to visually assess its technical condition. The stages of the SD disassembly and technical diagnostics procedure are shown in Fig. 2–7 .

Fig. 2. General view of the Geislinger SD TV model D90/37

Fig. 3. Dismantling of the top cover of the SD TV

Fig. 4. General view of the SD TV after dismantling the top cover

Fig. 5. General view of SD TV after stripping from oil

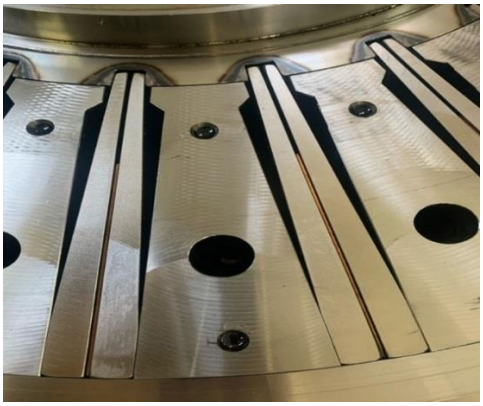

Fig. 6. The element of the intermediate insert with spring plates of the damper

Fig. 7. Holes in the inner rim of the damper for supplying engine oil from the engine crankshaft

Conclusions based on the results of disassembly and diagnosis of SD TV:

1. Disassembly of the SD of the marine engine MAK 8M25C confirmed the compliance of the damper design with the drawing and allowed to determine the product marking number and the name of the manufacturer (D90/37, company: Geislinger, Austria).

2. The results of measurements of the damper dimensions allow us to produce a prototype in compliance with the similarity criterion and further simulate the operation of the damper in various software products.

Methodology and results of the study

The term "reverse engineering" (reverse engineering) refers to the process of researching a physical or virtual object (parts, devices or programs), as well as documentation on it in order to understand how it works, make changes or reproduce this object with similar functions. The main function of reverse engineering in relation to the machine-building industry is to obtain design documentation for parts, assemblies or other products so that they can be reproduced and operated. The experience of using reverse engineering technology has been known since Soviet times: 1. Copying and creating a Tu-4 Soviet aircraft based on the design of the American B-29 bomber. 2. Copying and using German cans for storing and transporting gasoline in American and British troops.

Scanning of some components of the SD TV was carried out at the Department of Shipbuilding and Energy Complexes of Marine Engineering of the Federal State Educational Institution of Higher Education "Astrakhan State Technical University" due to the fact that the material and technical base of the university is equipped with a RangeVision Spectrum 3D scanner [9]. The principle of operation of the scanner is based on structured illumination and optical triangulation. It should be noted that the device has been approved by the Federal Agency for Technical Regulation and Metrology. The general view of the 3D scanner is shown in Fig. 8, and its main characteristics and functionality in Table 1. It should also be noted that in addition to laser scanning, a measurement procedure was also carried out.

Fig. 8. General view of the Range Vision Spectrum 3D scanner

Table 1

Technical characteristics of the Range Vision Spectrum 3D scanner

Scanning technology	structured sublight		
The resolution of the projector	1280 x 800		
Scanning area, mm	540x400x400	320x220x220	135x100x100
Working distance, m	0.96	0.56	0.26
Error, microns	120	60	40
3D resolution, mm	0.25	0.15	0.06
Opportunity to capture the texture	has		
The resolution of the cameras	3.1 Megapixels		
Stitching the model	by markers, by geometry		

The whole process of 3D SD scanning included several stages:

1. Calibration of the 3D scanner: setting the calibration field, pre–adjusting the lenses (adjusting the aperture, for image clarity due to different brightness of external lighting), finding the working distance, adjusting the focus of the projector (the projector projects a structured sublight onto the object when the scanner is working - coded lines and stripes), mixing cameras (for the scanner to work, its cameras should be brought together at one point), lens sharpness adjustment, final camera setup, Fig. 9.

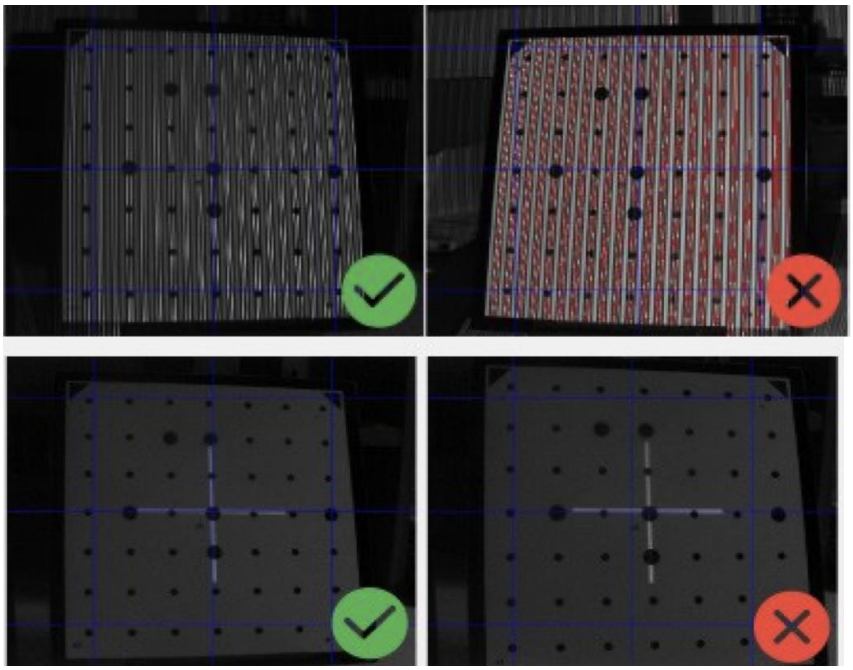

Fig. 9. Calibration of the Range Vision Spectrum 3D scanner

2. Based on the weight and size indicators of SD, the following components were selected as objects for scanning: an intermediate insert and a bronze spring spacer. The obtained CAT models of the parts are shown in Fig. 10, 11. The error of linear and angular dimensions when scanning the model compared to the natural prototype did not exceed 0.3%, which indicates the reliability of the results obtained. Based on Table 1, the error of the Range Vision Spectrum 3D scanner is 120 microns. The accuracy of scanning also depends on the surface of the material, ambient light must fall on it, the scanner may not catch glare.

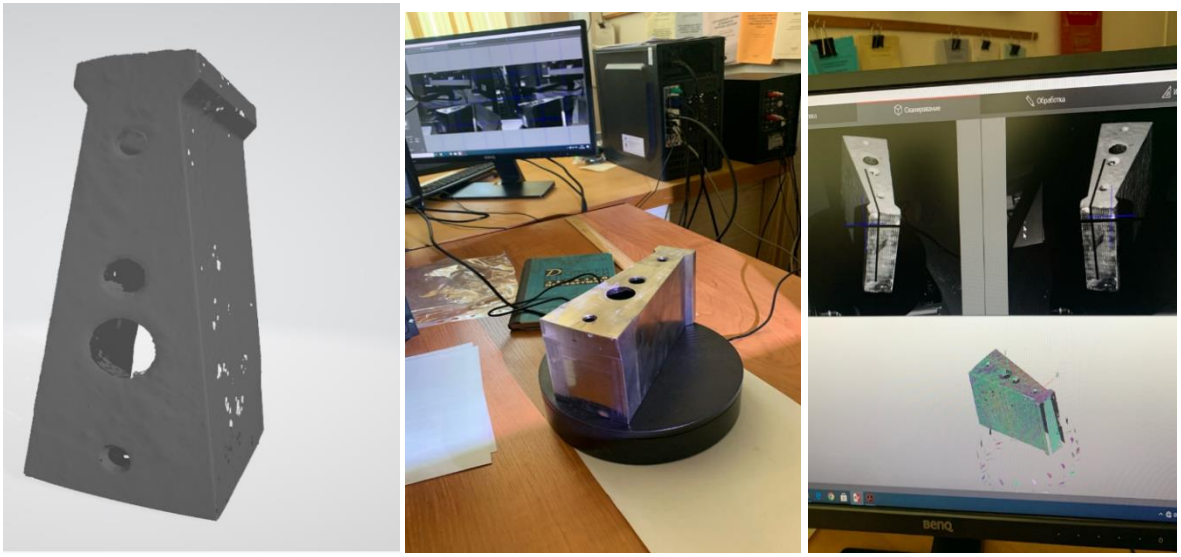

Fig. 10. CAT-model of intermediate insertion of SD TV

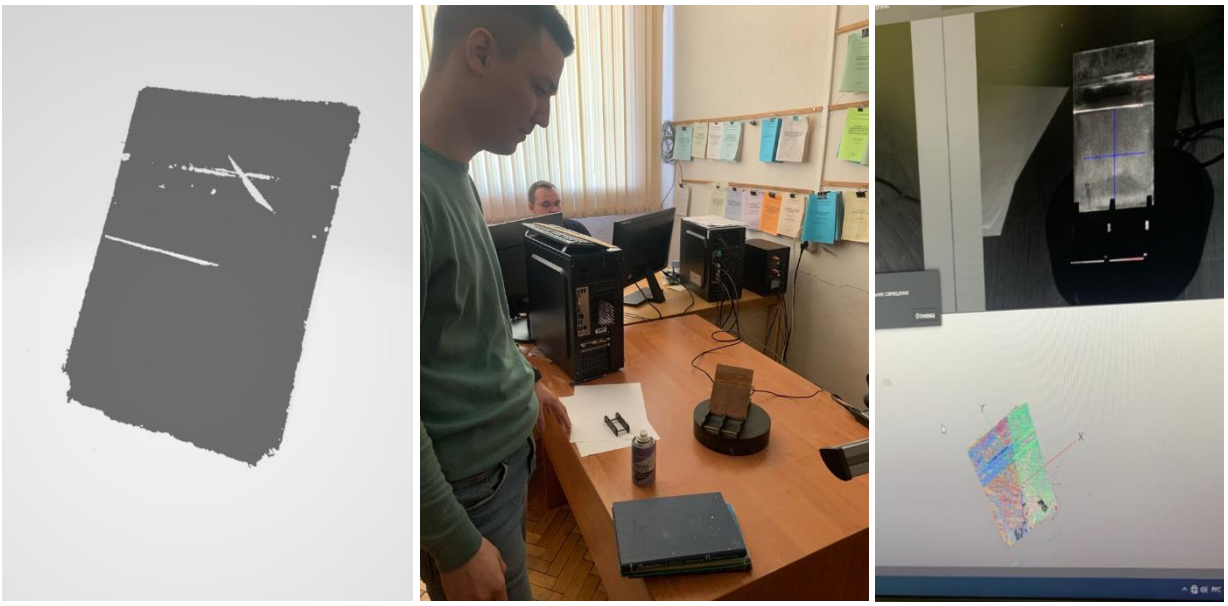

Fig. 11. CAT-model of the bronze spring-loaded insert SD TV

3. Processing of the received model. When the point clouds are finally superimposed, so-called "noises" appear, which must be removed to obtain scanning accuracy. When scanning the elements of the SD TV, a formed cloud of points is obtained, around which there are individual points, which are "noise". The processing of "noise" is carried out manually in the software product. In addition to 3D scanning, manual geometry of all the components of the damper was also carried out, which made it possible, subject to all similarity criteria, to obtain a SD TV model in the COMPASS software product, Fig. 12. If we conduct a comparative analysis regarding the scanning time, the results are as follows, the manual geometry of all the components of the SD TV took about 2 hours, and scanning with a 3D scanner took 15 minutes for all the elements. However, it should be noted that the scanner calibration procedure was about 30 minutes.

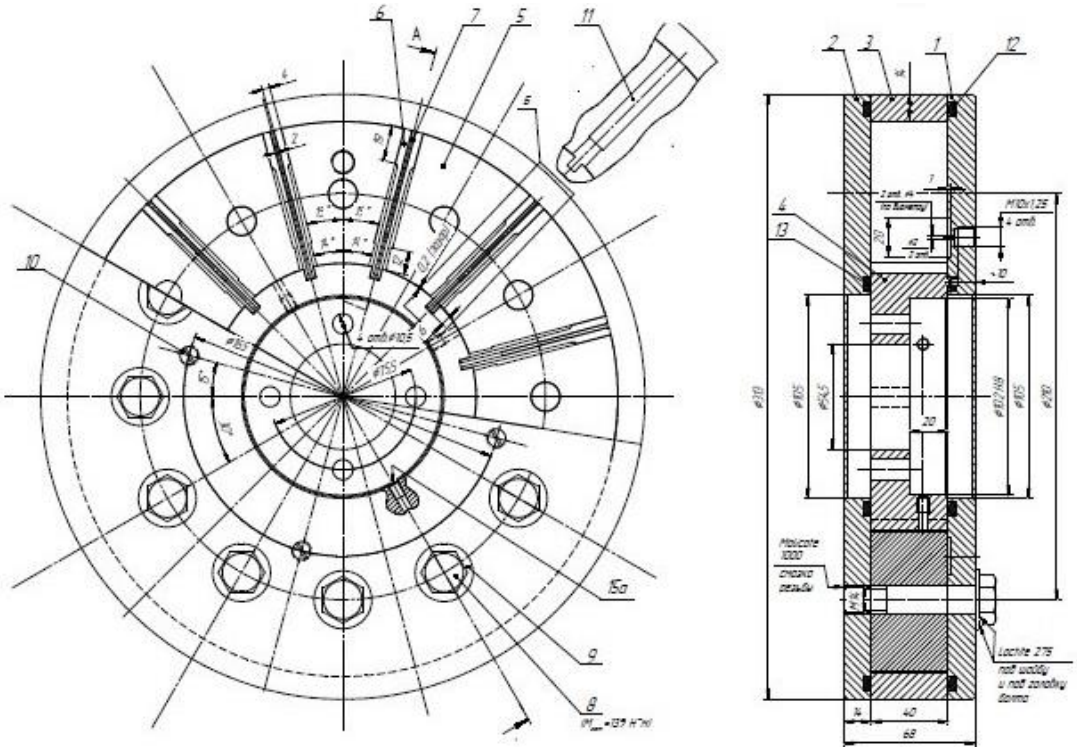

Fig. 12. Drawing of the general view of the model spring damper of torsional vibrations (author's development)

The torsional stiffness of the model MPC is 45826.5 N*m/rad.

The SD TV shown in Fig. 1 and Fig. 12 differ in the number of flywheels, leaf springs, and torsional stiffness, due to the fact that their operating conditions and dynamic characteristics of the real installation (MAK 8M25 marine engine) and the laboratory installation of the Marine Technology Service Test Center of the Federal State Educational Institution of Higher Education "Astrakhan State Technical University" are different.

It should be noted that the results of practical developments formed the basis for a competitive application for a grant under the Start-Take-Off program of the Innovation Assistance Fund.

The main advantages and disadvantages of reverse engineering:

1. Advantages: improvement of project documentation, creation of more efficient production processes, reduction of production costs, development of new products.

2. Disadvantages: the risk of infringement of intellectual property rights.

Conclusions

As a result of the conducted research, the following main conclusions can be drawn:

1. The result of the great work done by the scientific school dealing with the dynamics of the MPC, under the guidance of the Honored Worker of the fisheries of the Russian Federation, Doctor of Engineering Sciences, Professor M.N. Pokusaev, is the developed design documentation for the first domestic prototype of the SD TV;

2. The error of linear and angular dimensions when scanning the model compared to the natural prototype did not exceed 0.3%, which indicates the reliability of the results obtained;

3. The tendency of SD TV to prevail in marine diesels is due to the greater efficiency of damping torsional vibrations, due to the combination of hydraulic and elastic damping;

4. The use of reverse engineering technology is an affordable way to increase the level of technological sovereignty of the country;

5. Reverse engineering allows you to improve project documentation, create more efficient production processes, reduce costs, and develop new products.

ВКЛАД АВТОРОВ | CONTRIBUTION OF THE AUTHORS

М.Н. Покусаев – разработка концепции исследования; А.Д. Ибадуллаев – практическая реализация; К.О. Сибряев – подготовка и редактирование текста; М.М. Горбачев – анализ и интерпретация результатов; Т.В. Хоменко – использование программных продуктов, обработка полученных данных. Все авторы прочитали и одобрили окончательный вариант рукописи.

M.N. Pokusaev – development of the research concept; A.D. Ibadullaev – practical implementation; K.O. Sibryaev – preparation and editing of the text; M.M. Gorbachev – analysis and interpretation of the results; T.V. Khomenko – use of software products, processing of the received data. All authors reviewed the results and approved the final version of the manuscript.

КОНФЛИКТ ИНТЕРЕСОВ | CONFLICT OF INTEREST

Авторы заявляют об отсутствии конфликта интересов.
The authors declare no conflict of interest.

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