повышению, а ускоренное охлаждение и направленный теплоотвод уменьшению технологической повреждаемости объемов отливки при затвердевании.

Ключевые слова: технологическая повреждаемость, коэффициент гомогенности Вейбулла, ускоренная кристаллизация, жидкая фаза, литейные дефекты.

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UDC 621.74
DOI: 10.15587/2312-8372.2017.105636

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DEVELOPMENT OF A SYSTEM FOR ORGANIZING A MODULAR DESIGN AND TECHNOLOGICAL PREPARATION FOR THE PRODUCTION OF CAST IRON PISTONS FOR INTERNAL COMBUSTION ENGINES

Запропоновано систему модульної конструкторсько-технологічної підготовки виробництва чавунних поршнів двигунів внутрішнього згоряння (ДВЗ). Особливістю даної системи є те, що вона забезпечує можливість одночасного виконання конструкторських, технологічних і організаційних робіт. Показано, що це досягається шляхом використання модульного принципу проектування чавунних поршнів ДВС. Для прикладу реалізації одного з модулів проведено моделювання напружено-деформованого стану монолітних чавунних поршнів.

Ключові слова: *модульна система, поршень ДВС, вермикулярний графіт, напружено-деформований стан, алюмінієвий ЧВГ.*

1. Introduction

When creating modern internal combustion engines (ICE) and improving the quality of existing ones, special attention is paid to the design and technological preparation of the production of their parts, primarily pistons, which from all engine parts work in the most difficult conditions. Pistons determine the reliability and life of the engine as a whole.

Advances in the production of castings of high-strength cast iron with globular and vermicular graphite in recent decades cause increased attention and interest in cast iron as a material for highly loaded parts of diesel internal combustion engines. In the late 80s of the last century, joint research of the departments of internal combustion engines and foundry of the National Technical University «Kharkiv Polytechnic Institute» (Ukraine) carried out research work on the use of cast iron for pistons of perspective diesel engines. As a result of these studies, thin-walled monolithic and composite pistons made from CGI are developed and manufactured.

Traditionally, these works are carried out consistently from the design of the piston to the design of its production technology. Currently, the design and manufacture of internal combustion engines is impossible without taking into account the technological aspects of manufacturing parts and engine components. This can provide a modern technical level of design and technological design of ICE and is the justification of the relevance of conducted research in this direction.

2. The object of research and its technological audit

The object of research is the process of design and technological preparation for the manufacture of ICE cast pistons. Characteristic feature of this object is the complexity of taking into account the interrelationships of individual design elements and the technology of cast ICE pistons production. To identify these relationships, a technological audit of the standard design process is carried out using expert assessments, aimed at identifying the significant factors that determine the bottlenecks in the design system. The rationale for this approach is that in fact there is no uniform opinion on the priority of an element in the design. The design part, based on the use of fundamental design principles from the field of resistance of materials, dynamics and strength of machines, heat transfer, etc. does not take into account the features of the manufacturing technology. In this case, as practice

ISSN 2226-3780

shows, the design side does not take into account the real opportunities provided by the existing level of equipment and technologies. On the other hand, the technological side of the project is based on its real capabilities and does not always provide the opportunity to realize the design ideas to the fullest. This leads to the fact that the operational parameters of the finished cast parts are significantly different from the design ones. It is natural to assume that the correct and justified interrelationship of all elements of design and technological preparation for the production of cast-iron pistons is mandatory for obtaining high-quality and competitive parts.

3. The aim and objectives of research

The aim of research is development of the structure of the system for organizing the modular design of ICE cast iron pistons.

To achieve this aim, it is necessary to solve the following tasks:

1. To analyze potentially important relationships in the structure of design and technological preparation for the production of cast pistons.

2. To carry out a computer simulation of the stress-strain state of cast-iron pistons as an example of the formation of one of the components of the design process.

4. Research of existing solutions of the problem

As the practice of the world's leading design bureaus testifies, technological aspects are necessarily taken into account when designing and applying ICE CAD. In [1], the automated design system is considered as a complex in which all areas of the firm's activities are integrated - from the consideration of market demand, through design and production, to the distribution of products to customers.

Pistons of modern ICEs are a multi-elemental construction in which each element performs its function. It should be noted that the difference in requirements and operating conditions of pistons leads to many of their constructive solutions. In addition, the pistons differ by material and production technology. The joint solution of all these, sometimes contradictory, tasks in one design is not always possible, therefore, at all stages of its creation, it is necessary to maintain an inseparable connection between design and technological developments in order to obtain the optimal design of the piston and ensure the production processability. In order to solve problems of similar complexity, since 2000, the modular technology of designing and manufacturing of machine parts [2] is used.

To date, in connection with the increase in the level of design and technological developments, the requirements for piston structures and their material have significantly increased [3]. Therefore, to further improve the design and technological parameters of cast iron pistons, it is necessary to use modern methods of mathematical modeling.

To ensure a given level of product quality, with a reduction in design costs, the solution of the problem of determining the stress-strain state of the piston based on the solution of the inverse problem, which allows to refine the boundary conditions during the numerical experiment, is considered in [6]. In addition, a two-level design model of the piston is proposed with justification of the accepted boundary conditions and a technique for determining the sufficient level of complexity of the calculation model for preliminary and final calculations. The influence of the thermal component on the overall stress-strain state of the piston and the effect of the piston design parameters on its stress-strain state are studied.

Works [7–12] can be identified among the main directions of ensuring the quality of pistons through the conduct of computer modeling in the resources of the world scientific periodicals.

In particular, the paper [7] is devoted to modeling the stationary state and the temperature field of the transition state of the piston. The results of an analysis of the temperature distribution of a stationary state in a piston of a high-speed diesel engine are presented in [9, 10]. The authors of [8] carry out theoretical studies of thermomechanical conditions inside the piston of a diesel engine. Works [11, 12] are devoted to an extended numerical analysis of engine parts loaded with thermal and mechanical forces.

Thus, the results of the analysis allow to conclude that the pistons of modern ICE are a complex multi-element structure, in the creation of which many factors must be taken into account. To take into account these factors, the modular technology of designing and manufacturing of ICE pistons is used. To ensure a given level of product quality, with a reduction in design costs, computer simulation methods are used.

5. Methods of research

Designing is one of the time-consuming and significant steps in creating a piston. At this stage, the physical and mathematical models of the piston are formed and calculated studies of its stress-strain state.

At the design stage, the development of 3D models and the carrying out of thermal and power calculations are carried out in the SolidWorks (USA) program and its additional module SolidWorks Simulation. In this software product, there is a full toolkit for calculating the stress-strain state (SSS) of the piston, as well as the ability to create materials for calculations based on specified properties.

The application of this program allows:

– to reduce the cost of the model by conducting its testing using the computer instead of costly operational tests;

– to reduce the time required to present products to the market by reducing the number of product development cycles;

– to improve the products by quickly checking a large number of concepts and scenarios before making the final decision, thereby providing additional time for thinking about new designs.

6. Research results

To solve the tasks, it is proposed to divide all the basic works into separate modules that are executed simultaneously in three directions: organizational, design and technological. These modules are integral sectors of a single modular system for organizing the design and technological preparation of the production of ICE cast iron pistons (Fig. 1).

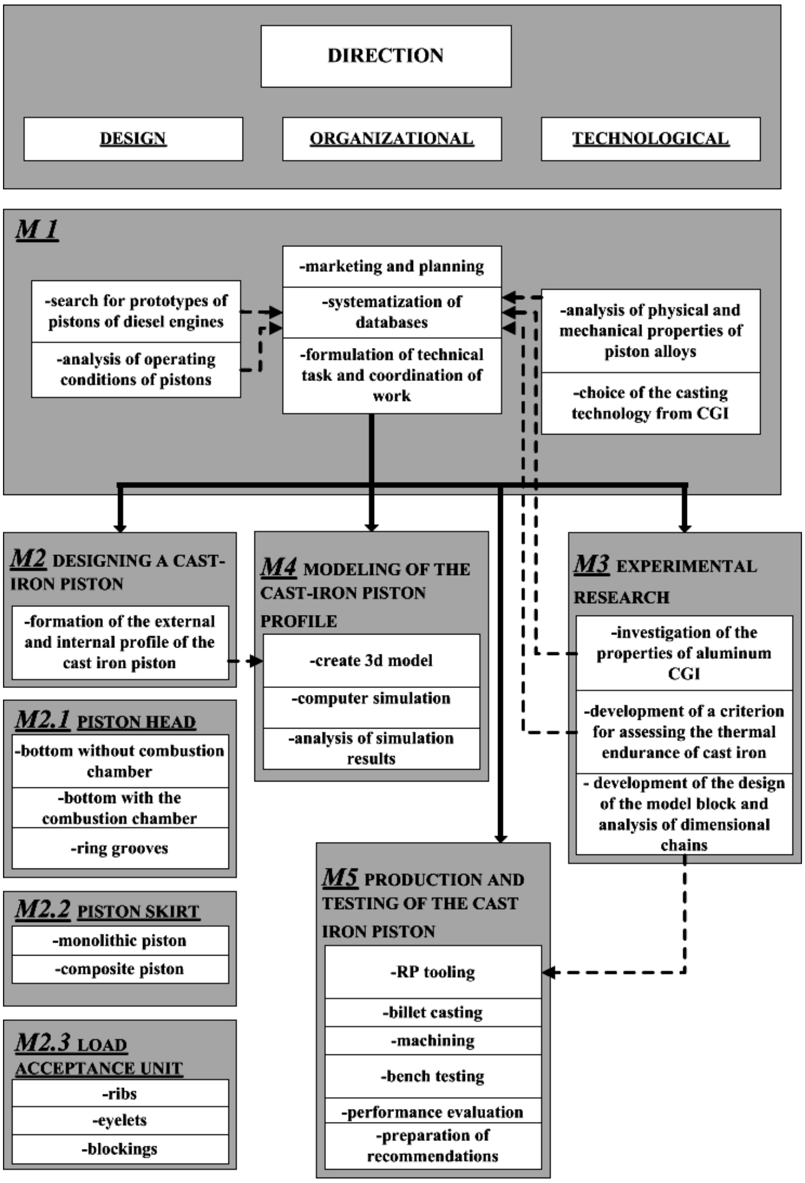


Fig. 1. System for organizing the modular design of cast-iron pistons for internal combustion engines

stages can be the process of computer simulation of the stress-strain state of cast-iron pistons.

If it is necessary to improve the existing or develop new design of the piston, the implementation of the technical assignment begins with the implementation of the design. *Within the competence of the module M-2 for design, as well as modules M-3 for technological and M-4 for organizational design, using the database module M-1 for organizational direction*. At the stage of design and technological design, the most laborious work is done to form the physical and mathematical models of the piston, as well as computational studies of its SSS, three-dimensional models of projected pistons are being developed using modular design.

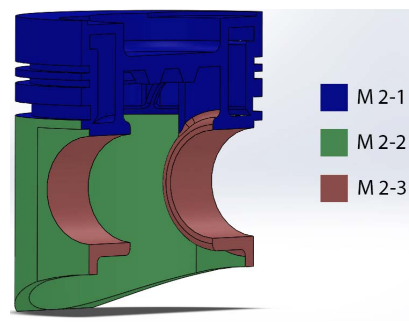


Fig. 2. Projected zones of the piston

Through the modules of the organizational direction, the coordination of the works within the design and technological modules from the beginning of the design to the manufacture and testing of prototypes is carried out.

Creation of different versions of piston structures, for example, monolithic or composite, is carried out by dividing the module M-2 into three submodules of the design engineering direction (Fig. 2):

– *submodule M 2-1 – piston heads*, including bottom with combustion chamber, annular belt and rib stiffeners (for universal piston variants);
– *submodule M 2-2 – piston skirts with* blockings for the piston pin (for monolithic pistons);
– *submodule M 2-3 – load acceptance unit* with eyelets for transfer of load to the piston pin and self-aligning skirt (for compound pistons).

Such design organization makes it possible to obtain universal multi-variant design solutions for individual piston elements, replenishing the database and using it to solve similar problems.

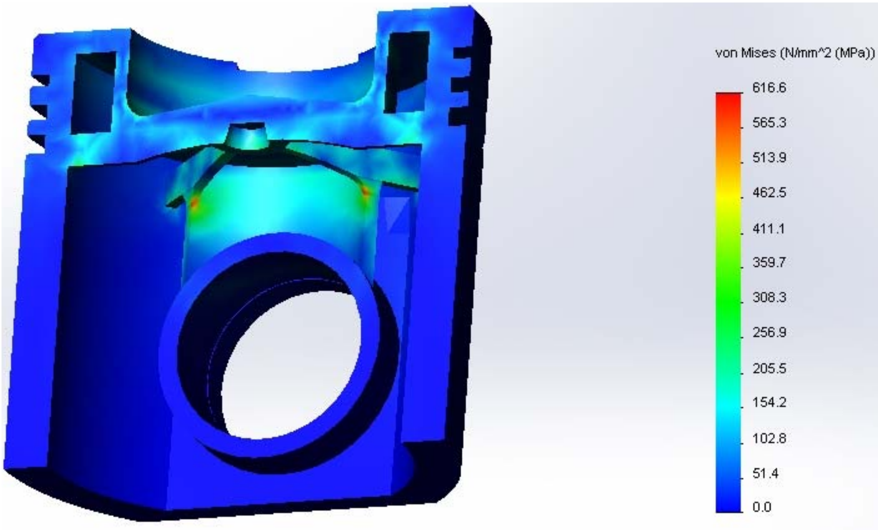
One of the examples of the realization of the design

When creating a three-dimensional model of the piston, the technique of end-to-end design is used, which allows to put the model of the billet into the model of the finished product with imitation of the subsequent machining. The model is fully parameterized and has the ability to change in accordance with changes in the relevant parameters. The computational model of the piston is based on its simplified three-dimensional model. In order to reduce the complexity of calculation and reduce the machining time, it is proposed to use half the piston for the design model in view of its symmetry. Calculation models can have a different level of complexity, depending on the number of kinematic elements entering into them. In this paper, it is proposed to use a simplified entry-level model consisting of one component – the piston.

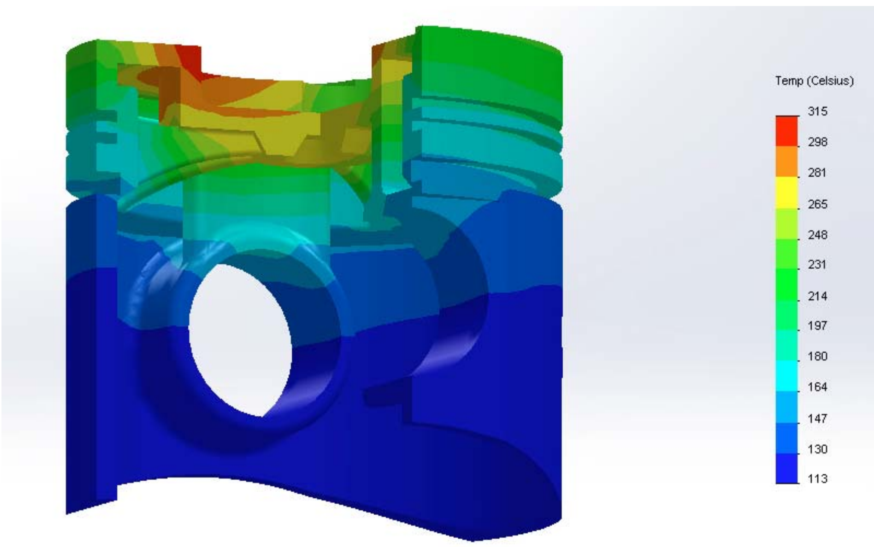
The results of calculations of the stress-strain state and the temperature distribution field in the body of the piston are shown in Fig. 3. The results show that the maximum temperature is 315 °C and concentrated on the edge of the combustion chamber. The stress does not exceed 617 MPa.

During the development of the profile of the cast iron piston, it is necessary to take into account that in addition to solving the tasks of fulfilling the functional requirements imposed on the piston, the profile of the piston must be able to be obtained by technological methods of foundry production. In this regard, trade-offs between design and technological modules are permissible, which may impose some limitations, both on the design of the piston and on the technology of its production.

ISSN 2226-3780



a



b

Fig. 3. Results of calculations:
a – stress-strain state (0–616.6 MPa); *b* – temperature distribution in the piston (113–315 °C)

Opportunities. Additional opportunities in the use of these results in industrial conditions are associated with the elimination of shortcomings due to imperfections in technology. At the same time, it is necessary to put forward the need for effective management as a priority, because without a competent policy of the company's management with regard to production renewal, one should not expect really high rates.

Threats. Obvious risks when using the results are associated with additional costs associated with the introduction of new solutions in the field of design and technological design. Probably at the first stage there is a time-consuming design process, which inevitably requires investments in the modernization of production.

7. SWOT analysis of research results

Strengths. Among the strengths of this research should be noted the possibility of minimizing the time spent on design. The use of the proposed modular principle also provides the opportunity to minimize the costs associated with development of design solutions by manufacturing a series of industrial designs. Necessity in this disappears, since the process of design and technological preparation is conducted in parallel with the use of computer modeling.

Weaknesses. The weaknesses of this research are related to the fact that the implementation of the proposed solutions inevitably faces the problem of upgrading existing equipment and technologies. The limitations imposed on the design process by these factors are manifested in the need to take them into account directly in the design process. This means that the performance characteristics of the finished cast pistons at the output will be lower than the design ones, and sometimes very significant. The need for modernization is associated with significant expenditure in the development of production.

8. Conclusions

1. The interrelations in the structure of design and technological preparation for production of cast pistons are analyzed. It is proposed to divide all the basic works into separate modules, performed simultaneously in three directions: organizational, design and technological. Such design organization makes it possible to obtain universal multi-variant design solutions for individual piston elements, replenishing the database and using it to solve similar problems.

2. Computer simulation of the stress-strain state of monolithic cast-iron pistons as an example of the formation of one of the components of the design process. The results of calculations of the stress-strain state and the temperature distribution field in the body of the piston are presented. The results show that the maximum temperature is 315 °C and concentrated on the edge of the combustion chamber. The stress does not exceed 617 MPa.

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РАЗРАБОТКА СИСТЕМЫ ОРГАНИЗАЦИИ МОДУЛЬНОЙ КОНСТРУКТОРСКО-ТЕХНОЛОГИЧЕСКОЙ ПОДГОТОВКИ ПРОИЗВОДСТВА ЧУГУННЫХ ПОРШНЕЙ ДВИГАТЕЛЕЙ ВНУТРЕННЕГО СГОРАНИЯ

Предложена система модульной конструкторско-технологической подготовки производства чугунных поршней двигателей внутреннего сгорания (ДВС). Особенностью данной системы является то, что она обеспечивает возможность одновременного выполнения конструкторских, технологических и организационных работ. Показано, что это достигается путем использования модульного принципа проектирования чугунных поршней ДВС. Для примера реализации одного из модулей проведено моделирование напряженно-деформированного состояния монолитных чугунных поршней.

Ключевые слова: модульная система, поршень ДВС, вермикулярный графит, напряженно-деформированное состояние, алюминиевый ЧВГ.

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