Efficiency improvement of technological preparation of power equipment manufacturing

I A Milukov, A N Rogalev, V P Sokolov and I V Shevchenko
Department of Innovative Technologies of High-Tech Industries, National Research University “Moscow Power Engineering Institute”, Krasnokazarmennaya 14, Moscow, 111250, Russia

E-mail: r-andrey2007@yandex.ru

Abstract. Competitiveness of power equipment primarily depends on speeding-up the development and mastering of new equipment samples and technologies, enhancement of organisation and management of design, manufacturing and operation. Actual political, technological and economic conditions cause the acute need in changing the strategy and tactics of process planning. At that the issues of maintenance of equipment with simultaneous improvement of its efficiency and compatibility to domestically produced components are considering. In order to solve these problems, using the systems of computer-aided process planning for process design at all stages of power equipment life cycle is economically viable. Computer-aided process planning is developed for the purpose of improvement of process planning by using mathematical methods and optimisation of design and management processes on the basis of CALS technologies, which allows for simultaneous process design, process planning organisation and management based on mathematical and physical modelling of interrelated design objects and production system. An integration of computer-aided systems providing the interaction of informative and material processes at all stages of product life cycle is proposed as effective solution to the challenges in new equipment design and process planning.

1. Introduction
Consumer requirements to technical, economic and environmental characteristics of power units, both mobile and stationary, increase continuously over the world because of two major factors: the growing demand of humanity in high-performance power conversion systems and permanently shrinking hydrocarbon reserves; and also due to environmental problems related to their usage which are pollution of the environment and greenhouse gases emissions resulting to global climate change. The latter forces to prescribe in laws a number of equipment characteristics determining the environmental impact both during its operation and manufacturing which essentially affects the competitiveness of products of power engineering industry.

Therefore, the competitiveness of power engineering enterprises in the situation of quickly changing requirements to the characteristics of products can be supported only by speeded-up reaction on occurring environmental changes. It can be provided by organising an effective process of management of life cycle of new products, both already produced and yet planned for production. The sequence of stages of the product life cycle is presented at figure 1 [1].
The quick introduction of new products on the market is often what assures the long-term leadership which is also provided by implementation of new standards, not only by characteristics outrunning those of competitors.

The rate of new product development and introduction on the market depends on the first three stages of the product life cycle, including scientific research, design and also process planning, which in turn determines the duration of production cycle and its cost-effectiveness. Shortening the above-noted stages while maintaining the high quality of works being performed should improve the competitiveness of enterprises in the industry. Automation of product development and process planning based on modelling, both mathematical and physical, is of particular role in improvement of work performance at the discussed stages of life cycle of products.

2. Modelling in computer-aided design
A sustainable tendency of shifting from the physical modelling, which has been applied for a long time along with engineering calculation methods based on empiric data for development of new types of equipment, to computational modelling using the finite elements method has been formed during the last decades. This was the result of confidence in adequacy, high accuracy and universality of models included in software packages for engineering analysis, and also due to aspiration to cost reduction and shortening the lead time which has been planned to accomplish by minimising the experimental component of design. In this respect the experimental check of performance and working efficiency of new units and products has been carried out in the later stages, during the preliminary testing. The experience of using such approach has demonstrated its weaknesses in solving a number of problems which is manifested with particular strength in development of new types of equipment. Problems where one cannot rely solely on finite element analysis methods are those of aerodynamics, heat transfer, burning, and also related issues. The above-noted circumstances have determined the need in usage of integrated calculating and experimental approach during the construction. This approach is based on application of experimental research methods in combination with modern mathematical modelling methods and provides interrelation between informative and material layers. The interrelation of spaces, layers and methods of modelling the product life cycle is presented at figure 2.
The following models to be outlined while modelling various objects during the development process: those of products, technological systems, technological processes, processes in design systems and informative support.

According to its purpose, the modelling is divided into functional, constructive, technological and operational.

According to its type, the modelling is divided into structural and parametric, geometric, prototype (technological), physical and mechanical.

Spaces of modelling are divided into n-dimensional, three-dimensional (geometric) where the two-dimensional one is a particular simplified case. Layers of modelling are divided into informative and material.

The following basic presumptions can be made in order to develop the model of an element of parallel design system:
- the modelling of material and energetic transformations occurs only in elements of the system (a concentrated transformation presumption);
- the mathematical model of the element describes the behaviour of the element as a whole, independently from the way of its connection to other elements of the system (an independence presumption);
- a tree graph which data flows correspond to arcs is a model of a system element on the conceptual level (a hierarchy presumption);
- a general graph that combines elements of the system is a model of design system as a whole on the conceptual level while the data transfer process is of an iterative character (a connectivity presumption).
The aim of development of computer-aided systems is the enhancement of design process on the basis of mathematical methods, optimisation of design and management processes using up-to-date computer and managerial aids [1, 2]. Each of established forms of project management is allowed for implementation with many structural options depending on the specificity of a particular enterprise and on the coverage of problems by mechanisation and automation means.

Design works start with the project statement that reflects the demand of society in getting a technical object. Traditional approach presumes that design works to be finalised with the formation of a set of documents containing enough information for implementation of the object of required quality under the given conditions. Despite their format, the technical assignment and the final set of documents can be considered as a description of the technical object.

Transformation of initial description into the final for complicated technical objects passes through various stages at which intermediate descriptions are forming. These descriptions are called design decisions. Design decisions to be analysed in order to determine the further actions, either completion of design works or choosing the way of their continuation.

In spite of functional purpose, the structure of computer-aided systems divides into three levels and includes the following:
- object-oriented (functional) and object-independent (invariant) subsystems;
- mathematical, linguistic, informative, software, technical, methodical and organisational support;
- components of all types of support.

The intention of support of computer-aided systems determines the composition and the content of support components.

Development of computer-aided systems and complexes provided the transition to the practical implementation of a digital production concept which application allows to reduce significantly the gap between the designer’s creative concept and its physical manifestation by using the digital data (electronic models of product) directly during the process of production. Additive manufacturing technologies providing the production of a part by growing it layer by layer on the basis of a three-dimensional model data play a special role in development of this concept. Particularly due to the use of additive technologies, the quick production of prototypes, i.e., demonstrators that provide the testing of functional features of developed parts and components of new high-end products, is now possible. In turn, it allows for construction of integrated design systems with tight interrelations of objects and processes of both informative and material layers at all stages of the life cycle.

3. Enhancement of processes of design and project planning showed by the example of heat-stressed parts of gas turbine units

Shifting to higher characteristics of the working substance in order to improve the cost-efficiency is a mainstream for development of gas turbine units (GTU). An intensive (by 20–30 K a year) increase of the inlet gas temperature is observed; currently its values for serial engines reach 1873–1973 K. Both Russian and foreign experience had shown that within the last 20–30 years the inlet gas temperature has been managed to increase mostly due to intensification of cooling of turbine parts, primarily blade rows.

When designing the high temperature turbines, a decision of whether an already known design of cooled blade is to be used or the development of a new design is advisable is always to be made. In the general form, the considered problem is multi-parametrical and multi-criterial. Even for the chosen basic cooling circuit the number of simultaneously varying parameters can reach many dozens. Nowadays, the process of design of blade cooling system completes in practice with drawing-up a positive variant, e.g., the variant satisfying expressed requirements but not possessing the optimum values of all criteria. The reason for that is an insufficient automation of the design process; as a result, this process takes much time and design models are not always complete and often depend on designer’s personal perception of physical processes occurring in the cooling passages. The accuracy of obtained results is mainly determined by the adequacy of hydraulic and thermal models of the blade cooling passage [3]. The stated circumstance indicates advisability of shifting to integrated design systems which general distinctive feature is the tight interrelation between informative and material layers.
The final verification of hydraulic and thermal models of the blade is performed after the first set of blades is manufactured according to the mass production technology. In case if essential inconsistency between calculated and experimental values of temperature is detected, refinement works to be performed. It results to additional material cost and lengthens the time of design of the turbine and the power unit as a whole.

The use of additive laser technologies is one of prospective methods of manufacturing of highly engineered parts. Concerning parts of gas turbine engines, this is a selective laser melting technology (SLM) which major advantage is the possibility to produce complex geometry parts without having the complete set of design documentation. The three-dimensional geometric model of the part contains the source information which allows to change the geometry of the part quite quickly if necessary.

A diagram of integrated scheme of design of a gas turbine cooled blade is demonstrated at figure 3.

Figure 3. Integrated scheme of design of cooled blade of the GTU.

The diagram consists of two interrelated modules, the thermal and the tensile those, each of which contains a set of sections. Varying parameters are the geometry and characteristics of cooling passages, heat transfer intensification means and film cooling elements. The geometry of the blade aerofoil outer surface is determined by the results of calculation of the three-dimensional flow process and turbine cascade profiling and does not change during the process of design of cooling system. The thermal module consists of five sections (3, 4, 5, 6 and 7) each of which performs its own function. The source data for the thermal section are the geometrical parameters of heat transfer intensifiers chosen by designer from the heat exchange research materials on the basis of his own experience. The physical modelling sections are the distinctive feature of proposed technique. At the initial stage of design (section 1) the additional experimental research of models of some single cooling passages (section 2) is possible. Models of passages are made using the SLM technology and completely match the geometry of inner cavity of researched segment of the blade cooling passage. The obtained experimental results are used by designer for making a hydraulic model (section 3) and a thermal model (section 6). Such approach allows for improvement of the quality of models being developed.

After making the decision regarding correspondence of developed blade to given criteria (section 14), experimental research for verification of hydraulic and thermal models to be performed before the
preparation of design documentation starts. According to suggested technique, a blade prototype to be produced for thermal and hydraulic testing (section 15). The three-dimensional geometric model of the blade developed as a result of design works is used for making the prototype using the SLM technology. The prototype is to be made a full-scale.

The suggested design approach allows to get the experimentally approved variant of the blade and prevents from its experimental refinement after the mass production is started, and shortening the time required for the launch of mass production of the cooled blade by 9 months which is about 50 per cent of development process duration.

Implementation of direct production technique on the basis of electronic model can be used for the purpose of shortening the terms of project planning for GTU cooled blade manufacturing. In this case the process of design and production of complex geometry ceramic cores which form inner cavities of blade cooling passages is the most labour-intensive. Figure 4 illustrates the compared processes of production of cores either using traditional pressing technique or by fluid moulding using the additive technologies for making the pattern. As follows from presented results, application of additive technologies in combination with fluid moulding allows for shortening the manufacturing period of cores from 2,5–4 months to 2–3 weeks [4].

**Figure 4.** Comparison of traditional technique of ceramic cores production and technique based on digital production technologies: (a) – pressing technique; (b) – fluid moulding using additive technologies.

4. **Conclusion**

The new approach to development of integrated computer-aided systems providing interrelation of spaces, layers and methods of modelling the parts life cycle is suggested. It allows to eliminate the weaknesses of a widely spread approach based on mathematical modelling techniques only. The application of suggested approach is considered regarding the design and project planning in production of heat-stressed gas turbine parts. As it was demonstrated, the implementation of suggested approach in considered case allows for shortening the duration of design stage twice as much while the duration of project planning stage shortens about seven times as much. The suggested approach can be applied for design of complex parts and units of power equipment which provides to shorten the duration of design and project planning stages.
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