CONCEPTION OF CAE SYSTEM SUPPORT FOR PROTECTIVE COATING DEPOSITION PROCESS DESIGN IN AGROINDUSTRIAL COMPLEX

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Abstract. Currently in agricultural complex there exists a significant requirement in life time improving of the different processing equipment. One of the most promising and advanced ways to improve the resource of technological equipment is the protective and functional coatings thermal spray deposition for reconditioning and hardening of the core parts and movable operating elements, such as: parts of mixers of variable constructions and purposes, blades and scrapers of different machines, calenders, sliding bearing and mechanical seal parts, tank equipment and heat exchanger work surfaces, high speed centrifugal separator and decanter parts, conveyors and draw plates. Using of the proposed intelligent automated design system (CAE-system) enables considerably decrease costs and time for development of effective resource-saving technological processes of manufacturing coated equipment parts, improve quality and increase designers and technologist labour productivity. The software package being implemented at the same time allows to effectively carry out computational experiments for a comprehensive study and prediction of the resulting coatings of various functional purposes with enhanced physical, mechanical and operational properties. The paper presents the concept, architecture, principles of design and approach to development of the proposed CAE-system and highlights the potential for its further implementation in the practice of processing industries repair facilities and specialized service centres of the agroindustrial complex.

Keywords: agroindustrial complex, CAE-system, protective coating, decision support system.

Introduction

Currently, in the agroindustrial complex (AIC) there is a need for restoring and hardening parts of processing equipment. The analysis showed that 85–90 % of machine parts fail due to mechanical, abrasive, hydroabrasive, corrosion-and-mechanical and oxidative wear, with 75 % of the parts being rejected are repairable. Current trends in the intensification of production processes lead to accelerated wear of parts, and in these conditions the task of restoring and increasing the durability of key parts, components and assemblies of machinery and equipment becomes even more important and relevant. Under these conditions, the real strategy for ensuring the operability of processing equipment in the AIC is to restore and strengthen the parts [1-3].

In economically developed countries the restoration of worn parts is very widely developed. The leading industrial enterprises of the world pay the most serious attention to strengthening and modernizing the technological equipment. The companies that manufacture machines and specialized firms for restoration of worn parts are engaged in the promotion and development of the technology for restoring parts. Restored parts are 1.5-10 times cheaper than new parts, and, as a rule, are not inferior in terms of resources [4-9].

For AIC processing industries, the restoration and hardening of mixing parts of various designs and applications, knives and scrapers of various machines, calenders, sliding bearings, mechanical seals, capacitive equipment of various types and purposes, parts of heat exchanging equipment, parts of separators is relevant. To solve the problems of restoration and hardening different kinds of materials are used, such as WC / CoCr, stellite, nickel corrosion-resistant steels, WC / Ni, WC / NiCrBSi, nickel alloys (hastelloy, etc.), Cr_2O_3, Al_2O_3 / TiO_2, Ni, babbit, bronze, Al, WC / MoCrSi [1-9].

Currently, the technologists involved in the development of technological processes of hardening and/or restoration of parts are facing the following problems[4-9]:

1. there is a very large variety of different parts to be strengthened and/or restored;
2. operating conditions of these parts differ significantly from each other, and the parts themselves are subject to various types of wear;
3. there are many materials for coating;
4. there are various coating methods.

A significant increase in the resource is important with the rational use of metal-polymer coatings and powdered hard alloys, which usage is constantly increasing. One of the most promising, modern and effective technological methods of applying composite materials on the surface of worn parts is plasma spraying and plasma surfacing that most fully meet the technical and technological requirements (high productivity, wide possibility of doping applied coatings, large input control range heat in the main and filler materials, the possibility of applying any filler materials, etc.) [2;3;8-10]. Due to the technical and economical advances currently plasma spraying technologies occupy the dominant position on the thermal spray market worldwide, while the other thermal spray methods have became more the niche-technologies [10;11].

Until the mid-1990s, the coating spraying process was controlled using the following iterative procedure: determination of technological parameters, sputtering, and study of the sample properties. This procedure was repeated until samples were obtained with satisfactory characteristics, after which the deposition regimes were fixed. However, the equipment for spraying is very sensitive to wear, and therefore, the application of this method does not allow to ensure the stability and reproducibility of the properties of coatings [12-17].

From the beginning of 2000 the new researches in plasma computational modelling based on modern computational technologies, mathematical methods and big data management approaches were streamlined with an aim to make a plasma spray model qualified for engineering technological computations [18-35].

Despite of undeniable progress reached in plasma spraying modelling designing a plasma spraying process is still a big issue: the complexity of the design of the plasma torch, the complexity of mathematical modeling and the problems of stability of the process of spraying still require many natural and virtual tests [36-40]. A further increase in the efficiency of using plasma spraying is associated with the development of methods and means of automation and computerization of the spraying process. To obtain coatings with the required propertiesit becomes necessary to develop a specialized CAE system [2;3;10;11;41-43].

The objective and scope of the current work is to present the concept, structure, basic assumptions, main technical and technological aspects and possibilities (potential and realized) of the CAE-system designed as a result of series of researches provided by the authors[2;44-48].

Materials and methods

The main task of the CAE-system is to increase the level of intellectual activity and labour productivity of the technologist and its use allows to design an optimal technological and technical solutions aimed at improving the quality of machine parts, as well as shortening the time and cost of developing technological processes.

The following key elements are necessary for development and implementation of a full-fledged CAE-system of gas-thermal and plasma coatings and the technology of their application:

1. Engineering methodology, reflecting the optimal scenarios for the development of gas-thermal coatings by the technologist and technology of their deposition.
2. Physical and corresponding mathematical models describing all the necessary steps of the engineering methodology.
3. Software and hardware that implements the appropriate mathematical models and linking them into a single CAD system, providing a convenient interface for the technologist to effectively go through all the steps of the engineering methodology and, ultimately, develop a gas-thermal coating and its application technology.

The basis of the CAE-system (Figure 1) is connected in a single complex: a knowledge base, database, analytical subsystem and a software module used by the technologist for the calculations necessary for the implementation of a specific technological process.

The **knowledge base** is a systematic repository that combines all types of information needed by a process engineer to make sound and rational decisions during the development of the hardening and/or restoration process. The search for relevant information in the knowledge base is optimized based on typical operating scenarios.

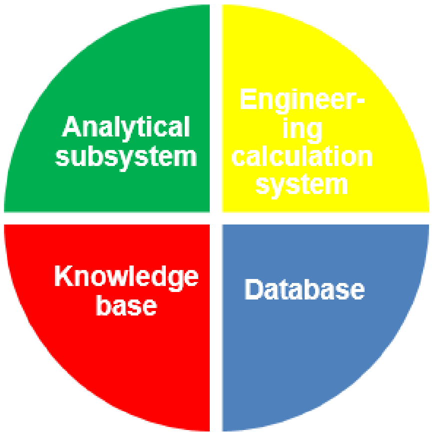

Fig. 1. **Proposed CAE-system main modules**

The **database** includes all the formalized data used by the process engineer and research engineer in the work.In general, when determining the properties of a coating, the actual operating conditions are modelled by the conditions of experiments and the parameters of the real part are measured by the parameters of the test specimen with a sprayed coating. Thus, the actual operational properties of gas-thermal coatings are described by a multidimensional value space. A coating with specified properties is formed during the gas-thermal spraying process, which is described by 3 main groups of parameters: parameters of the spraying process, properties of the sprayed material and properties of the sprayed powder. The database should include the following experimental data:

- physical, chemical and mechanical characteristics of materials from various literary sources;
- physical, chemical and mechanical properties of gas-thermal coatings from various literature sources, as well as those obtained during the experiments.

The **analytical subsystem** is a bundled and integrated with the database set of tools and methods used to search for relationships in large data arrays.These families of methods are called Datamining. It is of interest to use these methods by research engineers to heuristically analyse the contents of the database and determine potentially interesting research directions in the development of new coatings and ways to increase the efficiency of thermal spray technological processes.

The **engineering calculation system** is used by the technologist to make the calculations necessary for the development and implementation of a specific technological process.

Results and discussion

The developed CAE-system is a software package that allows the technologist to implement based on the technical specifications for the hardening and/or restoration of parts:

- choice of material and structure of the coating;
- selection of the optimal coating method;
- development of hardening and/or restoration process.

Based on the analysis made by the authors, it was revealed that the knowledge base (Figure 2) should consist of 5 clusters with the following conditional names: “Science and technology”, “Community thermal spraying”, “Technical and software”, “Coatings usage”, “Materials and coatings”.

As the analysis shows, for a full description of gas-thermal coatings, it is necessary to use 64 parameters, which are in fact properties of the coating. At the same time, most of the properties are variable values depending on the operating conditions and parameters of the coated part (Figure 3).

Generally, the data included in the database are given in sources without specifying the equipment on which the data were obtained, the accuracy of measurements, sometimes even without the conditions in which the tests were conducted. The most obvious and often similar problems are found in the tables of qualitative properties. So, for example, the record that the coating has high corrosion resistance does not make sense, if the environment in which the tests were carried out is not described.

It also very rarely provides information on how to build quality scales. For example, it is likely that different experiments have used different boundaries between the "good" and "satisfactory" categories.

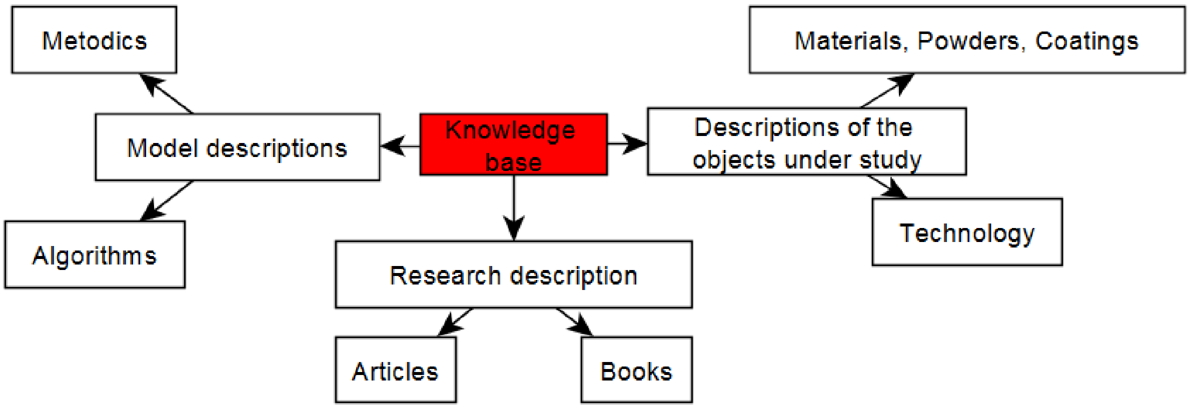

Fig. 2. **Integrated knowledge base structure**

During the process of plasma spraying, physicochemical processes are essentially heterogeneous in nature and duration of the process occurs at the macro, micro, and nanolevels. Because of this, the same object involved in the process of plasma spraying must be considered at various levels and in conjunction with other objects. For example, the chemical composition of the starting materials can be judged only on the potential use of coatings that can be obtained from them. Moreover, to fully describe the properties of the initial powders and determine the possibility of their use for coating in each specific case, it is also necessary to consider the size, shape, distribution of particles and the homogeneity of the chemical composition of the powder.In order to clarify the situation with the ambiguity of the properties of gas-thermal coatings, the structure of the database being developed presents the covering property as the result of anvirtual numerical experiment.

Based on the proposed knowledge base and database concept the program "Plasma Data Expert" was developed and patented [49]. The program is designed to collect, centralize and for heuristic analysis of technological data used in the development of the technological process of restoration and hardening of engineering parts. The program provides support to the process engineer and research engineer in the field of gas-thermal spraying at all key stages of work and allows to solve the following tasks:

- intuitive collection and automatic systematization of all formalized data used by the process engineer and research engineer in the work;
- search and evaluation of the suitability of existing technological processes, potentially suitable for the implementation of a specific technical specification for the restoration and/or hardening of the part;
- search and provide relevant source data for the program for the selection and synthesis of equipment and technological means for the implementation of the technological process of spraying;
- search for relevant, practically significant and new scientifically-oriented directions for conducting research in the field of gas thermal spraying technology;
- analysis of experimental data in the field of gas-thermal spraying using modern methods of intelligent information processing and automated search for analytical dependencies.

The program is implemented as a Web application running on a server computer. The program includes a databaseand provides structuring of the data stored in it in the form of a single graph according to specially developed algorithms. Due to this special structuring, the program allows for heuristic data analysis using plug-in separate Data Mining tools. The results of the analysis are further used to search for analytical dependencies using genetic algorithms and symbolic regression modules included in analytical subsystem (Figure 4).

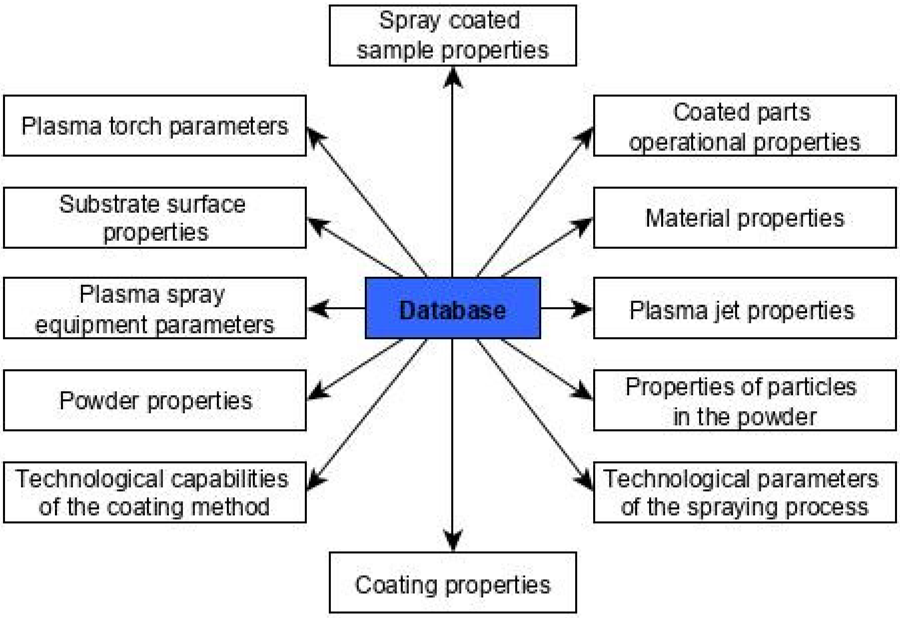

Fig. 3. **Integrated database structure**

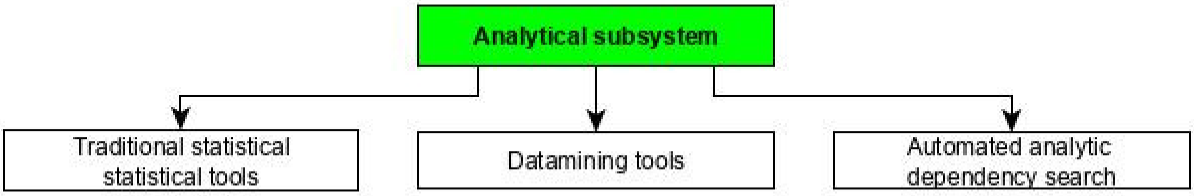

Fig. 4. **Integrated structure of analytical subsystem**

Also, on the basis of the researches provided by the authors, the program "PT Material Heuristic" [50] was developed and patented, designed to collect and structure the properties of materials and coatings used to restore and/or harden parts of agricultural machinery and processing equipment of the agro-industrial complex.

Conceptually, the program is a production knowledge base and provides structuring of the data stored in it as a single graph using special algorithms and further clustering using Kohonen neural networks and searching for analytical dependencies using Analytical subsystem (Figure 4).

The program operates with the following basic experimental data:

- physical, chemical and mechanical characteristics of materials from various literary sources;
- physical, chemical and mechanical properties of gas-thermal coatings from various literary sources, as well as those obtained during the experiments;
- technological regimes and conditions under which gas-thermal coatings were (or should be) obtained;
- information about the conditions – "context", in which the above characteristics of the starting materials and coatings retain their adequacy and applicability.

The engineering calculation system (Figure 5) consists of several program blocks, each of which performs a specific, logically perfect set of functions.The element of the engineering calculation system representing the greatest scientific complexity is the block for calculating the technological modes of plasma spraying of coatings. This block is based on a mathematical model of the plasma spraying process developed by the authors.

The second responsible, complex and knowledge-intensive task requiring solution is the choice of a rational coating material, which uses a database and allows a heuristic analysis and selection of several most appropriate coating material options.

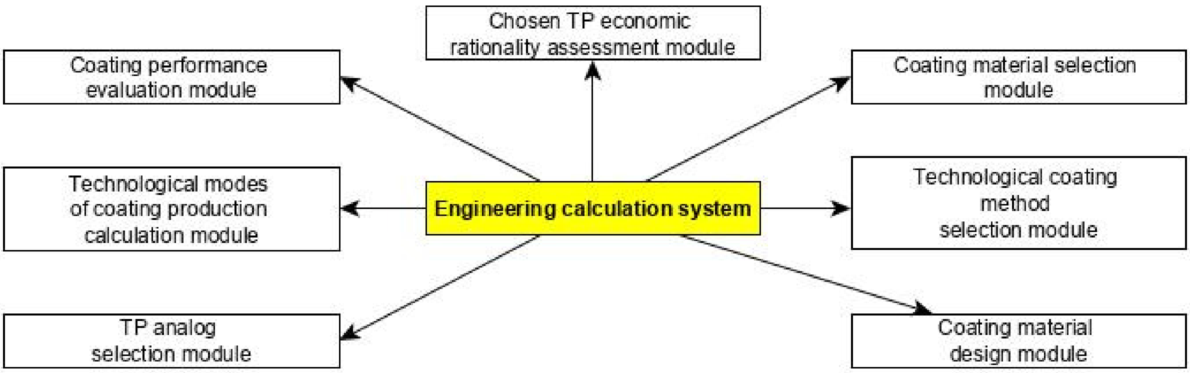

Fig. 5. **Integrated structure of engineering calculation system**

For practical implementation of the Engineering calculation system, the following software products were developed and patented: "System for calculating and optimizing technological modes of applying protective coatings" Protection "(RP" Protection ") [51]," Optimizing technological methods for applying strengthening coatings (TST Optimal Renovation)"[52] and "Optimization of technological regimes for applying protective coatings by plasma methods (TST Plasma Renovation)" [53] based on the previously developed mathematical models and algorithms presented in Chapter 2 of this work.

The developed programs consist of the following program modules intended for:

- choosing the material for coating;
- constructing the coating structure;
- selecting the optimal technological method of coating;
- calculation of technological modes of plasma spraying of coatings;
- assessing the economic rationality of the selected process;
- optimization of the technological mode of spraying to achieve maximum economic rationality of the developed process while maintaining the required properties and performance characteristics of the resulting coating;
- assessing the performance of the coated part.

The developed programs form the submitted engineering calculation system allow based on the technical specifications for hardening and/or restoring parts of agricultural equipment and processing equipment of the AICto execute:

- choose the material and structure of wear-resistant, erosion-resistant and corrosion-resistant coatings;
- technical and economic analysis of methods for applying hardening coatings;
- selection of the optimal method of applying hardening coatings;
- calculation and optimization of the technological modes of hardening and/or restoration of the part by the method of plasma spraying.

The described programs are developed on Ruby programming language, work on stand-alone PCs underWindows-and Linux based operation systems with the following minimum system requirements: IBM PC 1GHz CPU, 512 Mb RAM, 4 GB HDD.

The scientific novelty of all five developed programs is confirmed by state certificates of registration of computer programs issued by the patent authorities of the Russian Federation [49-53].

Figure 6 shows the integrated CAE-systemwith its interaction with the process engineer.

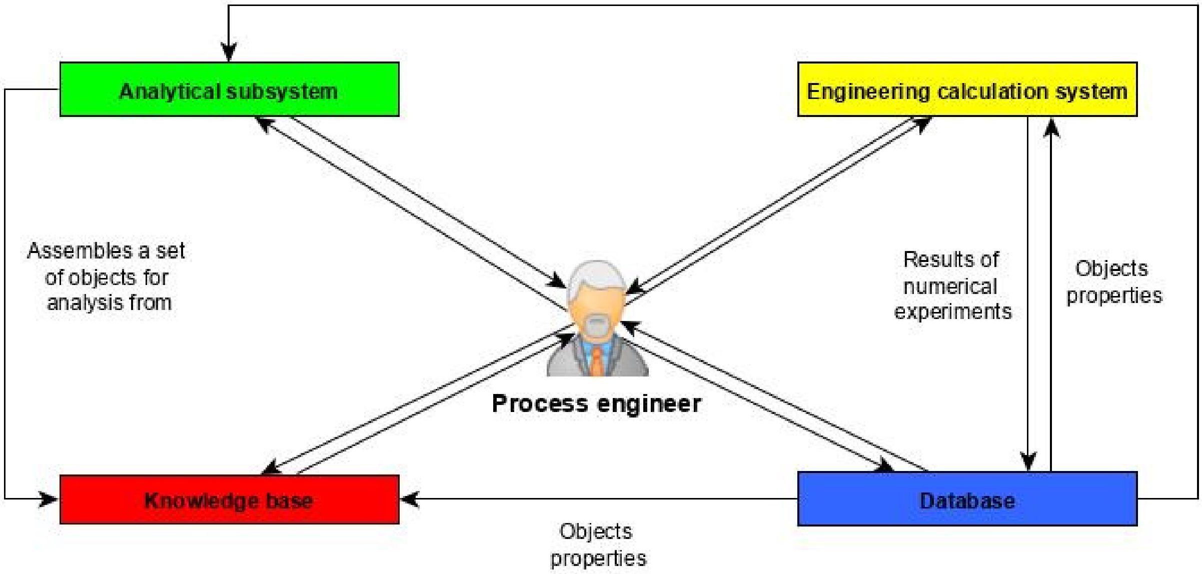

Fig. 6. **Integrated structure of proposed CAE-system**

Conclusions

The application of the proposed intelligent CAE-system can significantly reduce the cost of developing of resource-savingtechnologies (technological processes and equipment) for reconditioning and hardening of AIC processing equipment parts, improve their quality, and increase the productivity of designers and technologists. The software package implemented at the same time makes it possible to effectively carry out computational experiments for a comprehensive study and forecasting of the obtained coatings of various functional purposes with enhanced physical, mechanical and operational properties.

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