Creating an Electronic Reference and Information Database for Computer-aided ECM Design

M.V. Nekhoroshev, N.D. Pronichev and G.V. Smirnov
Samara University, 34, Moscow Highway, Samara, 443086, Russia
E-mail: maxnogood@ssau.ru

Abstract. The paper presents a review on electrochemical shaping. An algorithm has been developed to implement a computer shaping model applicable to pulse electrochemical machining. For that purpose, the characteristics of pulse current occurring in electrochemical machining of aviation materials have been studied. Based on integrating the experimental results and comprehensive electrochemical machining process data modeling, a subsystem for computer-aided design of electrochemical machining for gas turbine engine blades has been developed; the subsystem was implemented in the Teamcenter PLM system.

1. Introduction
Currently, aviation engine manufacturers are being transformed to create innovative production processes. Such transformations are based on technical rearmament, organizational enhancements, and implementation of business management principles. Comprehensive informatization is the foundation of innovative production. This is a complex problem most enterprises are trying to solve step-by-step, which is fairly slow. The first stage there is usually about creating computer-aided pre-production design systems, which are built of modules. Some enterprises implement CAD/CAM systems that enable the creation of solid-state 3D models which are then used for automated design of processes and CNC programs. CAE systems are used for engineering analysis of processes occurring in technological systems.

State-of-the-art aviation engine manufacturing is a multifunctional process that contains multiple design objects; computer-aided preproduction design management requires use of PLM systems based on the storing and using product data collected at certain stages of its service life.

This research is to automate the preproduction processes relating to the implementation of electrochemical machining (ECM) of gas turbine engine (GTE) parts. Figure 1 shows the sequence and description of problems to be solved. These problems have been solved by various specialists working in this area of research.

2. Materials and methods
For instance, paper [1] gives detailed examples of physical and mathematical models that became the basis for a computer-aided ECM design module. The module enabled the simulation of processes occurring in an electrochemical electrochemical channel.

Paper [2] is about using a CAD or a CAE system that enabled 3D modeling of ECM processes. The models employed finite elements to analyze the distribution of electric field in the interelectrode gap while factoring in whatever could affect such distribution (e.g. the flow and the passivation effect of electrolyte). The results were made into a database.
Paper [3] is about using a processing simulation method based on finite elements with a spherical cathode to create an adequate numerical ECM control model. To do that, they had used ANSYS to 2D-model the distribution of the electric field and the current density. Results were verified by physical experiments. It was thereby what that the modeling method was on par with engineering calculations in terms of accuracy.

![Diagram of computer-aided ECM design](image)

**Figure 1.** General computer-aided ECM design diagram

In paper [4], the authors designed an ECM process model for subsequent tool electrode profiling. This model was created based on a COMSOL module and had a number of considerable assumptions to simplify calculations; however, it performed well.

Paper [5] covers the issue of optimizing the electrochemical machining of hard-alloy materials. Its authors used a mathematical algorithm of their own making and obtained mode parameters regression equations. They believed that this algorithm was superior to others in terms of how quickly it could return an optimal values, which is crucial for ECM design cost reduction.

Paper [6] describes an original ECM visualization method that employed a high-speed video camera synchronized with the characteristic dissolution points. The data were then confirmed by COMSOL simulation of the dissolution process. If used properly, visualization is a powerful tool that allows one to visualize the process at various stages to adjust them when designing an ECM operation.

In papers on similar topics [7,8,9,10], the authors solved the problems of modeling the ECM process in geometrically complex the interelectrode gap (IEG), an inter-blade gap of a mono-wheel, to describe the complex electrode trajectory. Simulation-obtained data were used in CAD/CAM systems for CNC machining. In the process of modeling, some parameters were assumed to be constant and would be determined by preliminary experiments. The solution optimized the electrolyte flow rate as well as the shape of the tool electrode.

In papers [11,12], the researchers determined the optimal blade airfoil machining parameters to minimize the labor intensity and maximize the cost-effectiveness of the process. This principle can be used to optimize the ECM process.

In particular, results of researching titan alloys [13] were used to define the parameters of machined materials.

To sum up, researchers in this focus area are actively trying to develop various components of computer-aided ECM design systems as well as to invent methodology to verify the process. This is still far from complete, and thus a relevant and demanded work.
3. Developing an electronic reference and information database for computer-aided ECM design

This paper dwells upon the implementation of computer-aided ECM design in a PLM system, which is important for integration of these data in the single information space of the enterprise.

Based on the peculiarities of ECM design, a classification system that includes the following information classes has developed:

- Technological Processes are standard and specific processes that include transition sets;
- Documentation is the set of route and operation maps, tooling documents, control programs, etc.
- ECM Electrolytes is the data on electrolyte compositions, machining parameters plus the array of polarization curve data.
- Tooling is the description of equipment and data on standard and changed-over tooling.
- Electrochemical description contains experimental data on dissolution rates for various electrolytes, materials, and parameters.

Data in the databases created in the system have been recorded by the developers themselves. Information obtained by CAD/CAM/CAE modeling should be added to databases automatically.

Electronic technological environment being created while developing a computer-aided ECM design technology for GTE blades can solve multiple important practical problems:

- it considerably reduces the time to launch the production of new products;
- all technological solutions are tested and refined more thoroughly thanks to process modeling and analyzing a large number of options for decision making;
- testing and refining technological processes takes less time and work;
- knowledge is accumulated and stored while also becoming accessible to young professionals.

The standard electrochemical shaping (ECS) design and operation diagram includes the following steps:

- choose the machining pattern;
- design the tooling;
- choose the electrolyte composition;
- determine the machining allowance values;
- determine the machining parameters;
- choose the equipment;
- design tool electrodes (TE);
- test and adjust the process.

These can be changed depending on the part geometry and the machining pattern chosen.

Machining parameters should be optimized for design to ensure high performance, specified precision, and quality of surfaces machined.

A number of tasks, such as the choosing the machining pattern, the electrolyte composition, the machining parameters, tooling and equipment can be rather easy solved by using standard solutions.

One of the problems the solution of which affects the precision of electrode profiling is about determining the minimum ECM allowance. In mechanical machining, minimum allowance is a sum of three components: shape error, surface roughness, and the depth of the defective layer left from earlier machining. In case of ECM, one has to take into account one more component that is due to the relatively low localization of stock removal (compared to mechanical machining). In mechanical machining, stock is removed exactly in the cutting zone, while in ECM, material can be dissolved in a fairly great range of interelectrode gaps. This depends both on the machining parameters and the localizing capacity of the electrolyte, i.e. its ability to limit the removal to a minimum gap range; This property of electrolytes is determined based on the experimental dependencies of stock removal on the interelectrode gaps while using various electrolytes; these data are presented in the ECM Electrolytes class mentioned above.

To solve the problems relating to determining the optimum allowance for pulse electrochemical
machining (PECM) operations, comprehensive experiments on the electrolyte-dependent localization of the process has been carried out. Figure 2 presents the results of those studies. Analysis of results shows that the localizing capacity of electrolytes should be determined with such gaps where the rate of anode dissolution is zero. This property can be recorded in the e-database to determine the machining allowance.

In our case, the NaClO₄ electrolyte showed maximum localizing capacity with other machining conditions being equal. For the EI-961 alloy, it had minimum active dissolution gap range.

The biggest problems of ECS design are related to the profiling of TE working surfaces as well as to choosing the machining parameters. How well these problems are solved affects the amount and labor intensity of finishing, the performance, and the precision of ECS.

The proposed methodology for the computer-aided 3D ECS design is based on mathematical models and analyzing the spatial evolution of arbitrary surfaces as well as the physico-chemical processes in IEG and near-electrode layers. Figure 1 presents a general computer-aided ECM design diagram.

In the framework of this study, the following steps were done:
1. Modeled the electric fields in the electrolyte [14,15].
2. Experimentally studied the kinetics of electrode processes to determine the boundary conditions on electrode surfaces [14,15].
3. Developed a method for computer profiling of tool electrodes [14,15].
4. Created computer-aided ECM design applications.
5. Provided a parametric translation of ECM design output to the Siemens NX system.

An important part of this work is creating a Siemens NX information and parametric model for CNC milling of tool electrodes profiled based on the computer modeling of GTE blade ECM. This model is implemented in the environment of the calculation module developed earlier that is used to profile tool electrodes for pulse electrochemical machining of GTE parts, whereby the mathematical model developed is applied.

Based on integrating the results of comprehensive experimental studies in [14,15], a database (DB) of the physical properties of aviation material ECM has been designed.

The software for determining the TE profile contains a Source Data Input module for the input of data on part geometry and physical properties of the process simulated.

The computational models take those data from the relational database that contains experimental results. Storing the experimental data in a database that is not within the calculation system enables us to develop a versatile calculation module as well as a convenient system for the input and analysis of experimental results.

The main method were used to design the relational database consisted in building a semantic ER diagram, see Figure 3.

![Figure 2](image1.png)

**Figure 2.** Experimental dependencies of the removal rate on the interelectrode gap for various electrolytes EI-961 alloy: 1 - 4%NaNO₃; 2 - NaClO₄; 3 - 4%NaCl+15%KNO₃; 4 - 1%NaCl+4%NaNO₃; 5 - 10%NaCl; 6 - 4%NaCl

![Figure 3](image2.png)

**Figure 3.** ER diagram of experiment parameters
The ER diagram contains the following entities: Electrolyte, Material (of the workpiece), Series (of the experiment). The Electrolyte and Material attributes determine the results of the Experiment. Indicators recorded in each experiment are the attributes of the Experiment link. Adding the Series entity to the diagram enables analysis of different experiments.

By applying a known ER diagram transformation algorithm, a chart of relational experiment database tables has been obtained, see Figure 4.

As the algorithm requires to reduce data redundancy, the diagram has been refined to specify the Experiment table which uniquely stores sample (material and electrolyte) IDs.

When determining the type of data for the Experimental Conditions fields which are related to Electrolytes, Machined Materials, as well as for the Experiment ID field, a value propagation tool that ensures the integrity of data in the related tables was used.

For the first step of the wizard, the Experimental Conditions table was used as the data source, see Figure 5.

![Figure 4. Diagram of the relational database](image1)

![Figure 5. Choosing the Experimental Conditions table](image2)

When recording the results of experiments with materials and electrolytes that already have an ID in the database, the corresponding ID is chosen from the drop-down menu.

When adding new data to the database, new values can be put in the Machined Materials and Electrolytes tables automatically. The main data management form is supplemented with macros; double-click to run them.

Activating the Machined Materials form triggers Macro1 which opens an additional form that displays the parameters of materials recorded in the database.

The form can be used to add new material IDs. Double-click any field in the row of the material you need in the Machined Materials table to select the material and return to the main form to record the results of experiments with such new material.

In the Electrolytes table, values are added and selected in the same fashion.

The database is to be continuously updated as more materials and electrolytes are experimented with. It is to be included in the electrochemical shaping calculation software. That software is based on iterative ANSYS calculations and will be of use for technologists to optimize the machining parameters, to profile tool electrodes, and to reduce the pre-production time for new products.

4. Conclusion

This paper gives an analytical review on the issues of simulating and visualizing the ECS process; the reviews proves that this focus area is relevant. The paper lays the foundation for the model obtained as applicable to PECM. There were described the principles of research and relational database updates; the database was used to implement the ECS model developed. For that purpose, the characteristics of pulse current occurring in electrochemical machining of aviation materials were studied.

Based on the synthesis of research results, the experimental results, and comprehensive ECM process data modeling, a subsystem for computer-aided design of electrochemical machining for GTE
blades has developed; the subsystem was implemented in the Teamcenter PLM system.

References
[1] Kozak J 2013 Lecture Notes in Electrical Engineering vol 170 p 95
[2] Lei W 2010 Advanced Materials Research vol 97-101 p 4061
[3] Yang Y, Kang M and Fu X Q 2011 Key Engineering Materials, vol 458 p 93
[4] Klocke F, Zeis M, Harst S, Klink A, Veselovac D and Baumgürtner M 2013 Procedia CIRP vol 8 p 265
[5] Mukherjee R and Chakraborty S 2013 International Journal of Advanced Manufacturing Technology vol 64(5-8) pp 781-791
[6] Rebschläger A and Kollmannsperger R 2014 Procedia CIRP vol 14 pp 418-423
[7] Zhao J, Wang F, Xu J and Liu Y 2013 Hangkong Xuebao/Acta Aeronautica et Astronautica Sinica vol 34(12) pp 2841-2848
[8] Wang F, Xu J and Zhao J 2010 Hangkong Xuebao/Acta Aeronautica et Astronautica Sinica vol 31(12) pp 2450-2456
[9] Zhu D, Zhu D and Xu Z 2012 International Journal of Advanced Manufacturing Technology vol 62(1-4) pp 147-156
[10] R Wu, Zhang D and Sun J 2011 Research Journal of Applied Sciences, Engineering and Technology vol 3(9) pp 1007-1013
[11] Korovin E M, Lunev A N and Tsareva V V 2012 Russian Aeronautics 55(1) pp 76-82
[12] Lunev A N, Moiseeva L T and Solomina M V 2007 Russian Aeronautics vol 50(2) pp 193-198
[13] Agapovichvch A V, Balaykin A V, Smelov V G and Agapovichvch A V 2015 Modern Applied Science vol 9(4) pp 151-159
[14] Nekhoroshev M V, Pronichev N D and Smirnov G V 2014 The Open Mechanical Engineering Journal vol 8 pp 436-440
[15] Nekhoroshev M V, Pronichev N D and Smirnov G V 2013 Proceedings of the Samara Scientific Center (Russian Academy of Sciences) vol 15 №6(4) pp 897-900