



## Knowledge based System for Improving Design and Manufacturing Processes for Electrochemical Machining In Computer based Concurrent Engineering

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### ABSTRACT

The traditional design of product, the preceding constraints and limitations are considered sequentially. In order to reduce the product development cycle time and cost and increase quality and productivity, concurrent (simultaneous) design of product and process has been introduced. Electrochemical machining (ECM) is used to tackle exotic alloys of intricate shape and produce complex parts in hard metals with high surface quality and integrity. This paper addresses the concept of the knowledge base system (KBS) for optimization of product design and electrochemical machining process in computer integrated manufacturing (CIM) and computer based concurrent engineering environment. The KBS links with design and manufacturing data bases. The design specification is acquired through a feature based approach. The KBS links with material data base which holds attributes of more than 60 materials. It also links with tool data base which hold attributes of 7 tool's material and also 3 type of electrolytes. KBS is also links with machine data base which hold attributes of different ECM machines. For each design feature, KBS provides information needed for design and manufacturing optimization. The KBS can be used as an advisory system for designers and manufacturing engineers. It can be used as a teaching program for designers and manufacturing engineers and new ECM operators in computer based concurrent engineering environment.

### Keywords

Knowledge baseSystem, ECM, Computer based CE

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## INTRODUCTION

The traditional design of product, the preceding constraints and limitations are considered sequentially. In order to reduce the product development cycle time and cost and increase quality and productivity, concurrent design of product and process has been used. The basic idea of concurrent engineering (CE) is to shorten the time horizon in which the design and manufacturing constraints are introduced. Computer based concurrent engineering environment refers to integration of product design and manufacturing processes. It integrates various activities within the broad scope of the product life cycle [1-4]. In computer based concurrent engineering, the product design is viewed as a strategic task that has a major effect on the manufacturing activities. Design of product determines their quality and 70 to 80 % of the final production cost [5] and 70 % of the life cycle cost of a product is determined at the conceptual design stage [6]. Product design in CE is viewed as a teamwork approach [7]. CE can be used in computer based concurrent design of product and processes. It requires a great deal of co-ordination, integration of various functions. It can be used perfectly in computer integrated manufacturing (CIM). In CIM, the traditionally separate functions of product development, marketing, design, process plan, production, assembly, inspection, quality control, management and so on are all integrated. Consequently, integration requires that quantitative relationships among customer requirement, marketing, product design, materials, manufacturing process and equipment capabilities, and relatives be well understood. In this way for example changes in material requirements, product types, or market demand can be accommodated. Also, high quality is far more attainable via the integration of design and manufacturing [8]. One of the tools for integration of design and manufacturing is expert systems. An expert system (also called a knowledge-based system) is, generally, defined as an intelligent computer program that has capability to solve difficult real-life problems by the use of knowledge base and inference procedures. The goal of an expert system is the capability to conduct an intellectually demanding task in the way that a human expert would. The field of knowledge required to perform this task is called the domain of the expert system. Expert system utilizes a knowledge base containing facts, data, definitions, and assumptions. They also have the capacity for heuristic approach that is making good judgment on the basis of discovery and revelation, and making high probability guesses just as a human expert would [9][10]. Researchers developed electrochemical micromachining EMM setup mainly consists of various sub-components and systems, e.g., mechanical machining unit, micro tooling system, electrical power and controlling system and controlled electrolyte flow system, etc. All these system components are integrated in such a way that the developed EMM system setup will be capable of performing basic and fundamental research in the area of EMM fulfilling the requirements of micromachining objectives[11]. Other researchers discussed about the latest advances and the principal issues in ECM development and related research are raised. Developments in tool design, pulse current, micro-shaping, finishing, numerically controlled, environmental concerns, hybrid processes, and recent industrial applications, are covered [12]. Mount et al analyzed current transients during electrochemical machining (ECM) at a planar workpiece planar tool configuration results in the determination of the important parameters for the ECM process. These have been used in finite difference simulation of the ECM process, which allows simulation of the current transients and tool and workpiece configurations at any time for non-planar configurations more applicable to industrial ECM. Small differences in the simulated and experimentally observed current transients are often observed, which can be attributed to variation of the combined ECM parameters[13]. Mohan Sen, and Shan highlight the recent developments, new trends and the effect of key factors influencing the quality of the holes produced by ECM processes[14]. Labib et al developed of a fuzzy logic controller to add intelligence to the ECM process. An experimental ECM drilling rig, at University of Manchester, was improved through the integration of a fuzzy logic controller into the existing control system. Matlab (Fuzzy Logic Toolbox) was used to build a fuzzy logic controller system, which controls the feed rate of the tool and the flow rate of the electrolyte. The objective of the fuzzy logic controller was to improve machining performance and accuracy by controlling the ECM process variables. The results serve to introduce innovative possibilities and provide potential for future applications of fuzzy logic control (FLC) in ECM. Hybrid controllers that integrate fuzzy logic into the control system allow for "human like" decision-making intelligence to be incorporated into ECM controllers. They focused on feasibility of FLC in ECM [15]. In this paper a knowledge based system for improving design and manufacturing process for electrochemical machining in computer based concurrent engineering environment is developed. It is necessary to define Electrochemical machining here.

## ELECTROCHEMICAL MACHINING

Electrochemical machining (ECM) uses electrical energy to remove material. An electrolytic cell is created in an electrolyte medium, with the tool as the cathode and the workpiece as the anode. A high-amperage, low-voltage current is used to dissolve the metal and to remove it from the work piece, which must be electrically conductive. ECM is essentially a deplating process that utilizes the principles of electrolysis. The ECM tool is positioned very close to the work piece and a low voltage, high amperage DC current is passed between the two via an electrolyte. Material is removed from the work piece and the flowing electrolyte solution washes the ions away. These ions form metal hydroxides which are removed from the electrolyte solution by centrifugal separation. Both the electrolyte and the metal sludge are then recycled. Unlike traditional cutting methods, work piece hardness is not a factor, making ECM suitable for difficult-to-machine materials. Takes such forms as electrochemical grinding, electrochemical honing and electrochemical turning. Characteristic of ECM machining are:

- The components are not subject to either thermal or mechanical stress.
- There is no tool wear during electrochemical machining.
- There is no contact between the tool and work piece.
- Complex shapes can be machined repeatedly and accurately



- Electrochemical machining is a time saving process
- During drilling, deep holes can be made or several holes at once.
- ECM deburring can debur difficult to access areas of parts.
- Hard and also brittle material can be machined easily
- Surface finishes of 25  $\mu$  in. can be achieved

In other words, electrochemical machining (ECM) is a non-traditional process used mainly to machining hard or difficult to machining metals, where the application of a more traditional process is not convenient. In traditional processes, the heat generated during the machining materials is dissipated to the tool, chip, work piece and environment, affecting the surface integrity of the work piece, mainly for those hard materials. In ECM there is no contact between tool and work piece. Electrochemical (electrolyses) reactions are responsible for the chip removal mechanism[16]. The difficulties to cut super alloys and other hard-to-machine materials by conventional process have been largely responsible for the development of the ECM process. The main components of ECM system are a low voltage and high current power supply and an electrolyte. The electrolyte is normally solutions of salts, like sodium chloride (NaCl) or sodium nitrate ( $\text{NaN}_3$ ). It is also necessary pumps, filters, heat exchanger and an enclosure where the reactions occur [17][18][19][20]. There are basically numbers of parameters that affect the work piece tolerances such as current, electrolyte type, concentration, flow rate etc. [21]. In the electronic industry, electrochemical micro-machining (ECMM) is received much attention for fabrication of micro components: by dry etching material is removed at very precise resolution. In recent years, ECM has received much attention in the fabrication of micro parts [22][23][24][25]. An attraction of electrochemical machining is that material removal is unaffected by hardness, and there is no contact between tool and work piece, so that the former can be comparatively softer than the latter, in contrast to conventional processes. Electrolyte is pumped through the electrode gap to remove debris, gas and heat. It has been shown that excessively high or low flow velocities can lead to the formation of vapor bubbles. Hence there will clearly be an optimum flow rate. The flow rate affects the metal removal rate and relative tool wear. Innovative applications of ECM include sawing, grinding, and finishing of thin-walled tubes. Recent advances in pulsed ECM, with dissolution occurring during phases ECM lasting 0.1 to 5 ms, the off-time being 5 to 50 ms have enabled much more accurate ECM. Wire or tube-electrode ECM is also growing in popularity, for example in removal of defective parts or welded samples. The combination of ECM with electrodischarge machining and the incorporation of pulsed voltage has yield higher rates of removal than hitherto achieved by either these processes, and new applications for the new process called electrochemical Spark Machining (ECSM). Production process for ECM is being increasingly suggested. Electrochemical machining (ECM) is used to produce complex parts. An attraction of electrochemical machining is that material removal is unaffected by hardness, and there is no contact between tool and workpiece, so that the former can be comparatively softer than the latter, in contrast to conventional processes. Electrolyte is pumped through the electrode gap to remove debris, gas and heat. It has been shown that excessively high or low flow velocities can lead to the formation of vapour bubbles. Hence there will clearly be an optimum flow rate. The flow rate affects the metal removal rate and relative tool wear. Innovative applications of ECM include sawing, grinding, and finishing of thin-walled tubes. Recent advances in pulsed ECM, with dissolution occurring during phases ECM lasting 0.1 to 5 ms, the off-time being 5 to 50 ms have enabled much more accurate ECM. In the electronic industry, electrochemical micro-machining (ECMM) is received much attention for fabrication of micro components: by dry etching material is removed at very precise resolution. Wire or tube-electrode ECM is also growing in popularity, for example in removal of defective parts or welded samples. The combination of ECM with electrodischarge machining and the incorporation of pulsed voltage has yield higher rates of removal than hitherto achieved by either these processes, and new applications for the new process called electrochemical Spark Machining (ECSM). Production process for ECM is being increasingly suggested. It is necessarily to explain computer based concurrent engineering environment here.

## COMPUTER BASED CONCURRENT ENGINEERING

Researchers described the concurrent engineering method as a relatively new design management system that has had the opportunity to mature in recent years to become a well-defined systems approach towards optimizing engineering design cycles [26]. Because of this, concurrent engineering has been implemented in a number of companies, organizations and universities, most notably in the aerospace industry. In 1990s, CE was also adapted for use in the information and content automation field, providing a basis for organization and management of projects outside the physical product development sector for which it was originally designed. The basic premise for concurrent engineering revolves around two concepts. The first is the idea that all elements of a product's life-cycle, from functionality, reducibility, assembly, testability, maintenance issues, environmental impact and finally disposal and recycling, should be taken into careful consideration in the early design phases[ 27] . The second concept is that the preceding design activities should all be occurring at the same time, i.e., concurrently. The idea is that the concurrent nature of these processes significantly increases productivity and product quality[28]. This way, errors and redesigns can be discovered early in the design process when the project is still flexible. By locating and fixing these issues early, the design team can avoid what often become costly errors as the project moves to more complicated computational models and eventually into the actual manufacturing of hardware[29]. Concurrent engineering replaces the more traditional sequential design flow, or 'Waterfall Model' [30][31]. In concurrent engineering an iterative or integrated development method is used instead[32]. The difference between these two methods is that the 'Waterfall' method moves in a linear fashion by starting with user requirements and sequentially moving forward to design, implementation and additional steps until you have a finished product. In this design system, a design team would not look backwards or forwards from the step it is on to fix possible problems. In the case that something does go wrong, the design usually must be scrapped or heavily altered. On the other

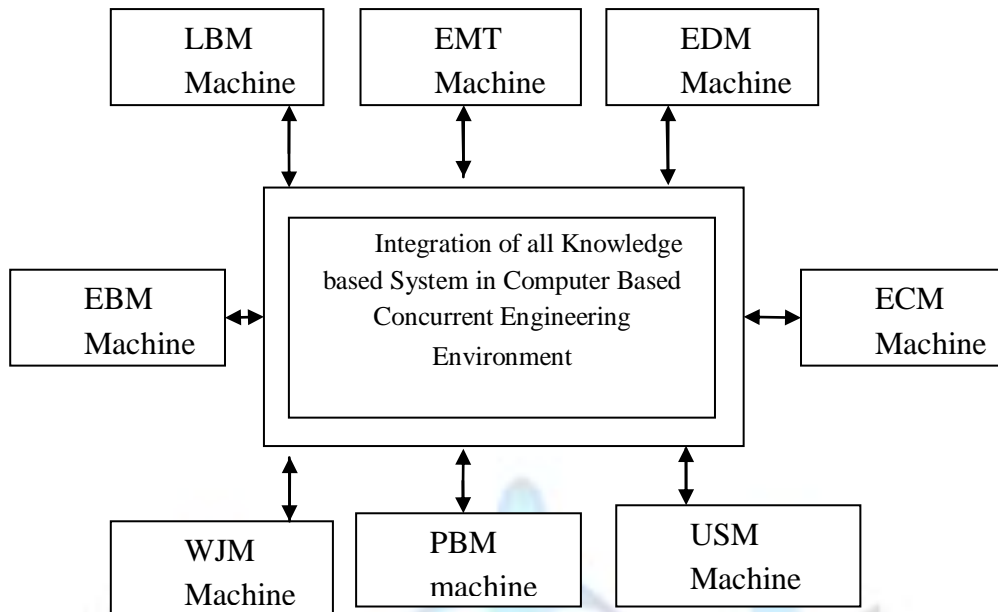




hand, the iterative design process is more cyclic in that, all aspects of the life cycle of the product are taken into account, allowing for a more evolutionary approach to design[33]. Concurrent design comes with a series of challenges, such as the implementation of early design reviews, the dependency on efficient communication between engineers and teams, software compatibility, and opening up the design process. A concurrent design process usually requires that computer models (computer aided design, finite element analysis) are exchanged efficiently, something that can be difficult in practice. If such issues are not addressed properly, concurrent design may not work effectively [34]. There are several research efforts into computer support for concurrent engineering. The best known of these are the DARPA Initiative in Concurrent Engineering (DICE), Open Systems Architecture for Computer-Integrated Manufacturing (CIM-OSA), and Distributed and Integrated environment for Computer-aided Engineering project is called DICE. At least five areas can be identified in which computer based concurrent engineering systems support them by using the information technology and communication and computer technologies: **1-**Sharing information to promote cooperation among the members of multidisciplinary design teams. **2-** Collocating people and programs by making the access to programs, people, and data across the network transparent to the user. **3-** Integrating tools and services with frameworks to allow designers to use different tools with ease. **4-** Keeping all members of the design team apprised of the current state of the design. **5-** Keeping track of design decisions and the reasons for them. DICE is being developed at the Concurrent Engineering Research Centre (CERC) in the West Virginia and was launched in 1988 by the Defence Advanced Research Projects Agency (DARPA) to encourage the practice of CE in the US military and industrial base. The overall aim of the consortium was to develop information architecture for CE in which each member working on a project can communicate and coordinate information through a high speed computer network to support CE practices. They have chosen to use a blackboard for communicating and for control of information flow. CIM-OSA is an Europe-wide research project under the European Programme on Research and Development for Information Technology (ESPRIT) Consortium. The goal of CIM-OSA is to provide an open system reference architecture which supports the definition, development, and continuous maintenance of a consistent architecture and its related operational system. CIM-OSA identifies three levels of integration covering physical systems, application, and business integration. Physical system integration is mainly concerned with communication between systems which is in the domain of information technology standards (e.g. OSI-Open System Interconnection; MAP-Manufacturing Automation Protocol; TOP-Technical Office Protocol). CIM-OSA addresses upper two levels only (application and business integration) and relies on OSI for physical system integration. Some of the CIM-OSA goals and objectives are as follows:1- Enable enterprise operation in real-time adaptive mode through support of operational flexibility and multidisciplinary information integration. 2-Provide CIM reference architecture by modularity and open-endedness. 3- Define a methodology for enterprise structuring through generic service and protocols (e.g. business services, information services, and communication services) and system life cycle specifications (e.g. requirements definition, design specification, build and release, operation, and maintenance).It is clear that the CIM-OSA has a much wider scope of integration compared with CE. Thus, implementation of computer-based approaches for CE should be within the CIM-OSA guidelines to achieve the maximum openness and integration, especially in intra-system and business integration.

## KNOWLEDGE BASED SYSTEM FOR ECM

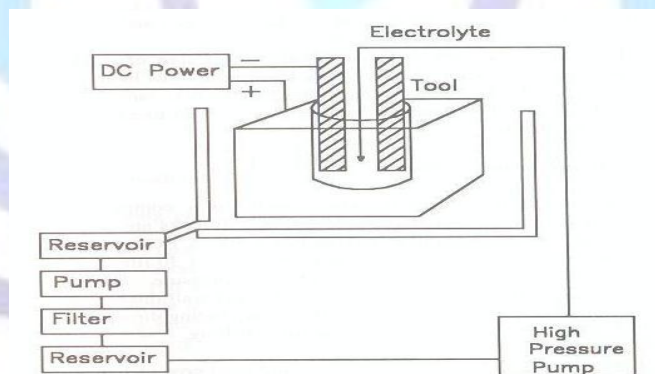
At present most procedures for estimation of machining time and cost and penetration rate and manufacturability evaluation are based on personal knowledge and judgment. The complexity of the process and interrelationship between its process variables means that designer and process planners have limited knowledge of ECM. In planning they have to turn to the literature or experts. The information required by the former is often difficult to obtain. Moreover, the training of both designers and process planners in CIM technology is time-consuming and expensive. Consequently if the knowledge is not available from a reliable source, the ECM product development cycle time and cost increases, and both quality and productivity is likely to decrease. Knowledge-based system KBS provide a route to overcoming these problems. In this paper a knowledge-based system (KBS) is developed to integrate design and manufacturing in computer based concurrent engineering environment for electrochemical machining. The knowledge-based is expressed in computer codes in the form of if-then rules and can generate a series of questions. A mechanism is employed for using these rules to solve problems is called an inference engine. The KBS can communicate with CAD data base and other computer software packages. The latest version of an expert system shell (NEXPERT) based on object oriented techniques is used. The output of the KBS can be used by designers and manufacturing engineers, a typical example of suggestion and estimation of machining time and cost and retrieval all necessary information from working memory for different design feature for Cast Iron work piece material by electrochemical machining is demonstrated at the end of this paper. In this paper a knowledge based system for electrochemical machining has been developed in computer based concurrent engineering environment. The developed program is based on object oriented technique (OOT). The latest model Hewlett Packard (HP) workstation was used in development of the expert systems. The system links with feature based design database. For each design feature, the system evaluates its manufacturability, machining cycle time and cost, and gives useful advice to designer for improving design in term of manufacturability and machining time and cost, penetration rate and etc. The system also gives some advice to manufacturing engineers for selection of optimum machining parameters. The system also works as a teaching system for new manufacturing operators to train them how to work with ECM machine. The KBS contains expertise gathered from both experiment and general knowledge about ECM machine that can be provided to product designers and manufacturing engineers. In general each design feature can be manufactured by alternative processes in concurrent engineering environment. For future work, we need intelligent knowledge base system that for each design feature, generate all alternative manufacturing processes, and estimate machining time and cost and penetration rate and manufacturability evaluation and select the optimum process for manufacturing design future. This is demonstrated in figure 1. In figure1. Integration of all KBS, in a computer based CE environment is shown.



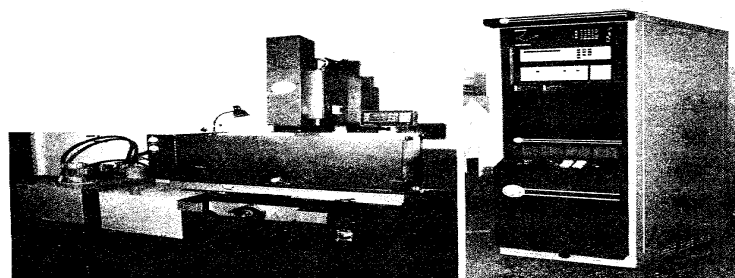
**Fig 1: Integration of all KBS, in a computer based CE environment**

**EXPERIMENTAL VERIFICATION**

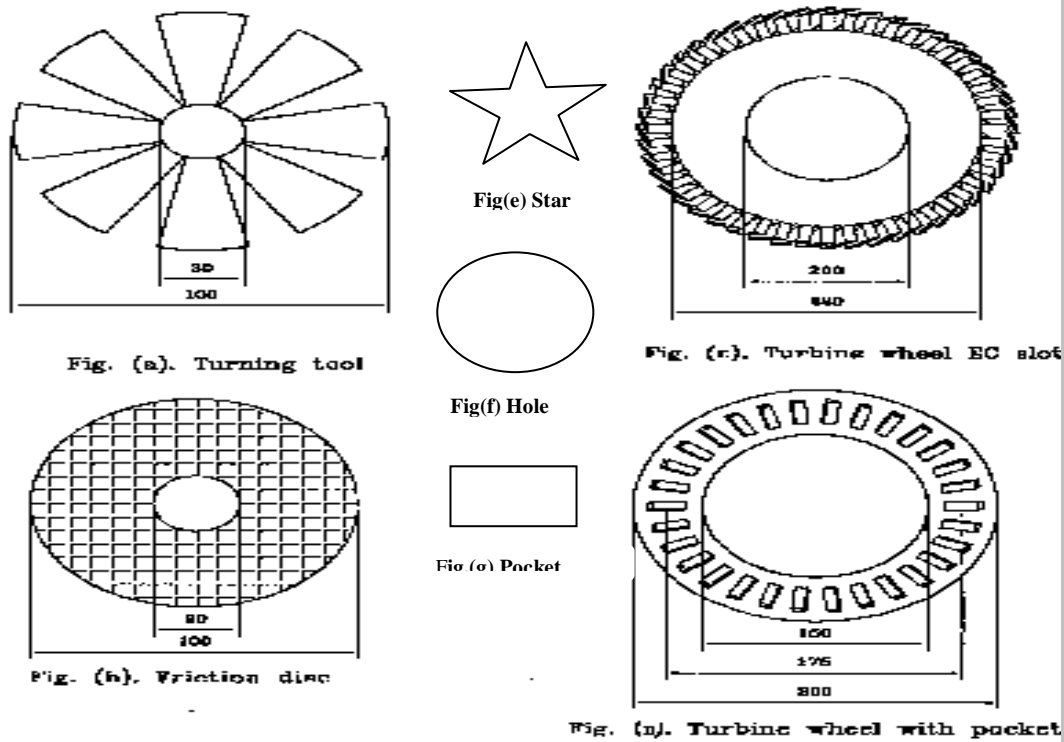
A schematic diagram of ECM machine is presented in Fig. 2 and electrochemical machine apparatus is shown in Figure.3. The work piece was fixed between two metal plates to minimize the over-cut at both sides of the machined hole. During the process, the electrode (tool) makes the penetration movement while the work piece is stationary. According to design features, four types of geometrical tools with copper material were manufactured including: Circular hole with 10mm, rectangular hole with 10mm width and 12 mm length, fraction disk with internal diameter of 10mm and external diameter of 20mm, and star tool with cross sectional area of 10mm<sup>2</sup>. The tools were coated with an electrical insulating made of nylon with thickness 0.1 mm, bonded with adhesive. Feature based approach is used to capture design features. Typical design feature are used in this research are shown in figure 4.



**Fig 2: Schematic diagram of Electrochemical Machining**

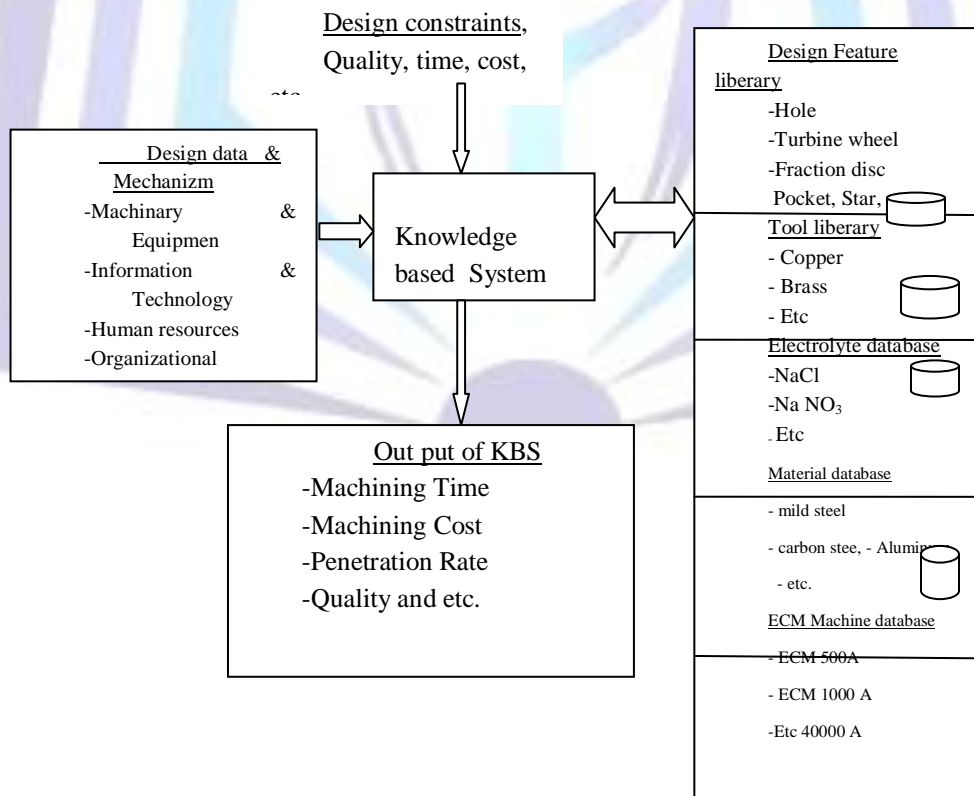


**Fig3: Electrochemical machine apparatus**



**Fig 4: typical design feature in feature library**

Input, Output, Constraint and Features library and databases are used by Knowledge based System is demonstrated in figure 5. The hardness of work piece material was 35 HRC. The chemical composition of work piece material shown in Table 1.



**Fig 5: Input, Output, constraint, features library and databases of ECM KBS system**





In table 1. Chemical composition of work piece material is demonstrated.





**Table 1. Chemical composition of work piece material**

C	MN	Cr	NI	N	W	N b
0.5	9	21	2.15	0.5	1.15	2.15

Machining time and cost and penetration rate of different types of tools for drilling different shape of hole is calculated. This is demonstrated in table 2. The detail output of KBS is demonstrated in the end of this paper.

The sample workpiece material was cast iron, and prepared in the shape of a blank with 50mm wide and 120 mm length, and 20 mm thickness. four types of geometrical tools with copper material were manufactured including: Circular hole with 10mm, rectangular hole with 10mm width and 12 mm length, fraction disk with internal diameter of 10mm and external diameter of 20mm, and star tool with cross sectional area of 10mm<sup>2</sup>. The operation was an electrochemical drilling. Electrolytic solutions of sodium chloride (NaNO<sub>3</sub> at concentration of 100 g/l) is used. ECM process conditions are as follows: Voltage 15V, Current 175A, Gap between electrodes 0.3mm. The KBS described above was compared with experimental ECM hole drilling. The results for four types of Tool shapes are presented in table2.

**Table 2. Comparative results of experimental ECM machining and KBS results for different Tools and design features**

Design Feature	Name and Dimension (depth 10mm)	Knowledge based system			Experimental		
		Penetration rate m/min	Machining time (min)	Machining Cost (\$)	Penetration rate (mm/min)	Machining time (min)	Machining cost(\$)
	Circular hole Diameter 10 mm	1.48	6.77	2.5	1.39	7.2	2.75
	Ractangular hole Width10mm Length12mm	1.1	9.0	3.4	1.02	10.0	3.8
	Star hole Cross sectional area 180 mm <sup>2</sup>	0.71	13.5	5.5	0.65	15.38	5.8
	Fraction disk Interdia 10mm Outer dia 20mm	0.55	18	6.9	0.49	20.4	7.65

In table 3. The Knowledge based system estimates and generates other information for designer and manufacturing engineers in computer based concurrent engineering environment. For each design feature. For example for circular hole drilling with 10 mm diameter and 10 mm depth on cast iron material, KBS estimates and generates all information presented in next section.

## RESULTS OF KBS

In practical for each design feature, KBS estimates machining time and cost, penetration rate and all other machining parameters in less than 30 seconds. For example if design feature is a hole with diameter and depth of 10mm, some of the output of developed KBS for ECM is shown below:

- *Material. type=Cast Iron*
- *Material. valence=2.0*
- *Material. removal rate=17.39*
- *Material. atomic weight=55.85*
- *Material. removal rates at 1000 amperes per cm min=2.21*



- *Material. working voltage=15.0*
- *Material. maximum current= 250.0*

**Information retrieval from the working memory of KBS for selected electrolyte composition attributes:**

- *Electrolyte. composition= NaNo3*
- *Electrolyte.concentrations=240 gram/litre*
- *Electrolyte. temperatures =38 degree of centigrade*
- *Electrolyte. flow rate range = 0.95 litre per m per 100A*
- *Electrolyte. velocity range = 1500 to 3000 m per min*
- *Electrolyte. inlet pressure range =137 to 2060 kpa*
- *Electrolyte. outlet pressure range = 0 to 310 kpa*

**Information retrieval from the working memory of the KBS for selected electrode tool material attributes:**

- *Electrode. type=Copper*
- *Electrode. electrical resistivity =1.71*
- *Electrode. electrode cost = medium*
- *Electrode. strength = 400.0*
- *Electrode. elasticity = 121.0*
- *Electrode. thermal conductivity =0.93*
- *Electrode. melting point = 1082.0*
- *Electrode. spark resistance = poor*
- *Electrode. repair ability = fair*

**Design feature extraction from CAD data base via KBS:**

- *Feature. Type = circular hole*
- *Hole. diameter = 10.0 mm*
- *Hole. depth = 10.0 mm*
- *Hole. surface finish = 10 micrometer*
- *Hole. dimensional tolerance +, - =50*
- *Hole overall cut = 0.13*
- *Hole. taper =0.01*

**Suggestion and estimation of various machining conditions of the KBS**

- *Electrolyte. surface active agents = Necessary*
- *Electrolyte. surface finish improvers = Not necessary*
- *Electrolyte. activators = Not necessary*
- *Electrolyte. velocity = 2000.0*
- *Electrolyte. volume flow rate = 3000.0*
- *Electrode. insulation material type = epoxy*
- *Electrode. insulation thickness = 0.13 mm*
- *Electrode. internal hole type = circular hole*





- *Electrode. internal hole area = 0.20*
- *Electrode. percentage tool wear = 0.0*
- *Machine. gap between two electrodes = 0.3*
- *Machine. range of side overcuts mm = 0.3*
- *Machine. working voltage = 15.0*
- *Machine. maximum current = 175.0*
- *Machine. gap between two electrodes= 0.3*

**Estimation of various parameters and machining time and cost of KBS.**

- *Material. type=Cast Iron*
- *Material. valence=2.0*
- *Material density = 7.86*
- *Material. removal rate=17.39*
- *Material. atomic weight=55.85*
- *Material. removal rates at 1000 amperes per cm min=2.21*
- *Material. working voltage=15.0*
- *Material. maximum current= 250.0*
- *Electrode. type=Copper*
- *Electrode. electrical resistivity =1.71*
- *Electrode. electrode cost = medium*
- *Electrode. strength = 400.0*
- *Electrode. elasticity = 121.0*
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- *Electrolyte. composition= NaNo3*
- *Electrolyte. concentrations =240 gram per litre*
- *Electrolyte. temperatures =38 degree of centigrade*
- *Electrolyte. Flow rate range = 0.95 litre per m per 100A*
- *Electrolyte. Velocity range = 1500 to 3000 m per min*
- *Electrolyte. Inlet pressure range =137 to 2060 kpa*
- *Electrolyte. outlet pressure range = 0 to 310 kpa*
- *Feature. type = circular hole*
- *Hole. diameter = 10.0 mm*
- *Hole. depth = 10.0 mm*
- *Hole. surface finish = 10 micrometer*
- *Hole. dimensional tolerance +, - =50*
- *Hole overall cut = 0.13*
- *Hole. taper =0.01*
- *Machine. gap between two electrodes = 0.3*



- Machine. range of side over cuts mm = 0.3
- Machine. working voltage = 15.0
- Machine. current density = 297.09
- Machine. current efficiency = 0.3
- Machine. maximum current = 175.0
- Machine. feed rate = 1.55
- Machine. power rate = 2.63
- Machine. energy unit cost = 4.0
- Machine. ECM machining time = 6.77
- Machine. ECM energy cost = 0.01
- Machine. penetration rate = 1.48

#### **Estimation of total machining time and cost and output of the KBS for ECM**

- Machine. ECM capital cost = 30000
- Machine. ECM depreciation hour cost = 1.71
- Machine. ECM overhead hour cost = 3.0
- Machine. ECM labour minute cost = 0.17
- Machine. ECM machining maintenance time = 1.02
- Electrolyte. total cost of salt for 500 gallon 20 percent = 50.0
- Machine. ECM total machining cost = 1.72 British pond
- Machine. ECM depreciation cost per part
- Electrolyte. cost per part = 0.01
- Machine. ECM energy cost = 0.01
- Machine. ECM machining time = 6.77
- Machine. ECM depreciation cost per part = 0.25
- Machine. ECM total labour cost per part = 1.46
- Machine. ECM total machining time = 8.59
- Machine. ECM total machining cost = 1.72
- Machine. ECM batch size = 1000.0

## **CONCLUSION**

A KBS for improving design and manufacturing process for electrochemical machining in computer integrated manufacturing and concurrent engineering environment has been developed. The system is linked with design database and manufacturing data bases such as tool, electrolyte, work piece materials, and ECM machine data bases. For each design feature the system then automatically estimates all parameters such as machining cycle time, cost, energy cost, total machining time and cost, penetration rate and other parameters demonstrated above. The system gives some advice to product designer and manufacturing engineers for improving design and manufacturing. It can be used as teaching software for training people who do not know how to work with ECM machine. A feature base design is used for design of parts. Number of design feature is stored in future library. Different types of conductive material for work piece are stored in a database. Various types of conductive material for electrode tools are stored in second data base. Properties of number of electrolyte are stored in third database. Different process parameters and conditions are stored in fourth databases. The Knowledge base system is linked with these data bases, from which advices are supplied to designers and manufacturing engineers. Specification of design features are obtained by interaction with KBS, the system then advises on the optimal process parameters which match between the required quality and efficiency of operation.



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