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AN OPTIMIZED AND A NEW MODEL OF AN ELECTRICAL DISCHARGE MACHINE USING TRIZ

***Sreebalaji V S[1] and Saravanan R[2]**

[1]Department of Mechanical Engineering, SCSVMV University, Kanchipuram,Tamilnadu-631 561, India
[2]Department of Mechanical Engineering, Bannari Amman Institute of Technology, Satyamangalam, Tamilnadu-638401, India

ABSTRACT

Electrical Discharge Machining (EDM) process is based on thermoelectric energy between the work and an electrode. A pulse discharge occurs in a small gap between the work piece and the electrode and removes the unwanted material from the parent metal through melting and vaporization. The electrode and the work piece must have an electrical conductivity in order to generate the spark. Dielectric fluid acts as a spark conductor, concentrating the energy to a very narrow region. This paper proposes two methodologies to maximize the Material Removal Rate (MRR) and minimize the Surface Roughness (SR) in Electric Discharge Machining. First one proposes an optimization methodology for selection of best process parameters by considering four important operating parameters such as Discharge current, Source voltage, Pulse-on time and Pulse-off time and second one offers a new design of EDM namely Eco-Friendly Electric-Discharge Machining (E-EDM) using structured Innovation technique called TRIZ by replacing dielectric fluid and introducing ozonized oxygen into existing EDM design to eliminate harmful effects generated while machining by using dielectric fluid. Hope the proposed innovative eco-friendly EDM design using TRIZ inventive principles will definitely reduce environmental burden since Eco-friendly design is the need of the hour.

Keywords: *EDM, Dielectric, Eco- friendly, Ozonized Oxygen and TRIZ.*

1. Introduction

In 1970, the English scientist, Priestley, first detected the erosive effect of electrical discharges on metals. The EDM process can be compared with the conventional cutting process, except that in this case, a suitably shaped tool electrode, with a precision controlled feed movement is employed in place of the cutting tool and the cutting energy is provided by means of short duration electrical impulses. EDM has found ready application in the machining of hard metals or alloys (necessarily electrically conductive) which cannot be machined easily by conventional methods. It thus plays a major role in the machining of dies, tools, etc., made of tungsten carbides, satellites, alloys used in the aeronautics industry. EDM is also used to machining of exotic materials, refractory metals and hard enable steels. This process has an added advantage of being capable of machining complicated components and making intricate shapes. Surgical components are being machined by this process since EDM is one of the unconventional processes which can produce better surface quality. There are quite a number of problems still to be solved to enable the process to be adopted on an extensive process. Lower Material Removal Rate (MRR), Poor Surface Quality (SQ) is the real time EDM process limitations. In other words, maximizing the MRR, minimizing the surface roughness value are the real time EDM process objectives. The wear rate on the electrode is considerably higher. Sometimes it may be necessary to use more than one electrode to finish the job. The energy required for the operation is more than that of the conventional process and hence will be more expensive. The ignition of spark discharge in a contaminated die electric fluid is an another real time process limitation since contamination of the dielectric fluid will affect machining accuracy. To start with, the dielectric is fresh, that is, it should be free from eroded particles, since eroded particles from the work piece contaminates the dielectric fluid. The dielectric should be filtered before reuse so that the contamination of the die electric will not affect machining accuracy. To decrease the pollution caused by the use of liquid dielectric which leads to production of vapor during machining [1].To overcome mentioned real time process limitations of EDM, an optimization model is needed to select the best input process parameters to maximize the Material Removal Rate (MRR) and minimize the Surface Roughness (SR).

**Corresponding Author - E- mail: balajivsv@rediffmail.com*

2. Current Research Trends in EDM Development

There are two kinds of research trends are carried out by present researchers as far as EDM is concern. One is called Modeling technique and other one is called Novel technique [1]. Modeling technique deals with Mathematical modeling, Artificial Intelligence and Optimization techniques like Regression analysis, Artificial neural network, Genetic algorithm etc., respectively are used to validate the efforts of input parameters on output parameters since EDM is a complicated process of more controllable input parameters like machining depth, tool radius, pulse on time, pulse off time, discharge current, orbital radius, radial step, offset depth and output parameters like Material Removal Rate (MRR) and Surface Quality (SQ). Novel techniques deals how other (unconventional) machining principle such as ultrasonic can be incorporated into EDM to improve efficiency of machining process by get better material removal rate, surface quality. Novel techniques have been introduced in EDM research since 1996 [1]. This research work is a revelation to introduce TRIZ in EDM novel research trend.

3. Modeling and Optimization of EDM Process

Unlike milling and drilling operations, operating speeds in EDM are very low. To enhance these speeds, large electric current discharge is usually required, but it reduces the dimensional quality of machined surface. Similarly the material removal rate is also affected by the other process parameters. These parameters are selected from standard tables or by experience to improve the output performance of the process. The computer controlled environments involving online process control, this selection is not an easy task. Today many optimization techniques are being used in EDM practice to obtain the best process parameters. In related with optimization of EDM process [2], the methodology one has been carried out with an experiment on die-sinking spark erosion electric discharge machine with copper electrode and a steel rectangular work piece. Kerosene is used as a dielectric. The specifications of the machine are M/S Electranica - Pune, Model M-100 spark erosion machine with the capacity of 4 KVA, Input 400V/3 phase/50 Hz, worktable area of 250 mm x 150 mm along with accessories of pulse generator, die electric tank and pump. In this work, Discharge current (I), source voltage (V), pulse-on time(T_{on}) and pulse-off time (T_{off}) are accounted as design variables and are varied alternatively. Corresponding material removal rates and roughness average (Ra) have also been noted down. and Table 1 shows the experimental data.

Table 1: Experimental Data

V (volts)	I (amp)	T_{on} (μsec)	T_{off} (μsec)	MRR (g/hr)	Ra (μm)
80	6	6.4	400	0.2	2.62
80	6	800	12.8	0.3	2.87
80	16	6.4	400	0.3	3.05
80	16	800	12.8	10	7.63
80	48	100	12.8	63	9.75
160	6	800	12.8	0.2	2.68
160	16	100	12.8	20.4	8.32
160	16	800	50	12.8	7.85
160	48	100	12.8	55.1	9.31
160	48	800	400	44	10.61
200	6	6.4	400	0.3	2.05
200	6	800	50	0.3	2.69
200	16	100	12.8	21.6	8.32
200	48	6.4	12.8	7.6	4.27
200	48	800	50	54	10.43

Input and output data is normalized properly before the training process. On several trails a 4-5-2 CPNN architecture is considered as a reliable model of the system which shown in Fig. 1.

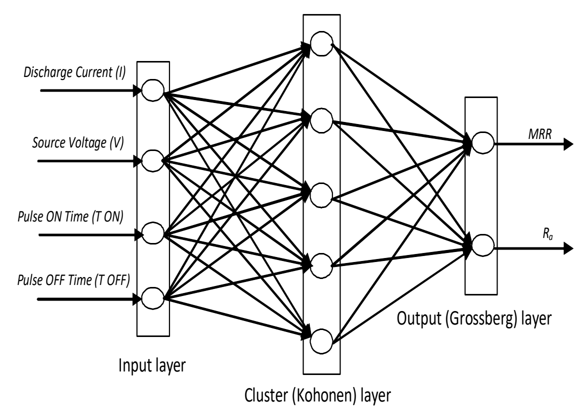

Fig. 1 CPNN 4-5-2 Architecture

Fifteen training sets are used with maximum values of adaptive learning rates α=β=0.9. As a termination criterion 500 training cycles are employed. Programs are developed in MATLAB environment for both CPNN and BP networks. It is seen that for same network architecture and total number of cycles, CPNN outperformed compared with BPNN model in most of the cases. Total training time is 10 seconds on a X86-based PC having 3 GHz Intel processor and 512 MB RAM. After the proper network weights are obtained, the model is used for obtaining optimization results with SA algorithm. A single objective optimization algorithm will normally be terminated upon obtaining an optimal solution. However, for most of the multi-objective problems, there could be a number of optimal solutions. Suitability of one solution depends on a number of factors including user's choice and problem environment and hence finding the entire set of optimal solutions may be desired. In the present work objectives are maximization of MRR and minimization of surface roughness (R_a), which are functions of decision variables namely, current, voltage, pulse-on-time and pulse-off-time. But there is no such mathematical equation, which relates these objectives with the decision variable. ANN model establishes the relation between inputs (decision variable) and outputs (objectives). Thus this model can be employed to determine the objective function values.

For optimization problem the objective function is defined as:

$$\text{Minimize } f(I,V,T_{on},T_{off}) = -w_1 MRR + w_2 R_a$$

Subject to
$$5 \le I \le 50$$
$$80 \le V \le 200$$
$$5 \le T_{on} \le 800$$
$$10 \le T_{off} \le 400$$

Where w_1, w_2 are weighing parameters required to make it non-dimensional form. Constraints are normalized and handled by penalty function approach, which converts a constrained problem to an unconstrained one by modifying the search space. A penalty value is defined to take the constrained violation into account. This term is added or subtracted depending on whether the problem is that of minimization or maximization, respectively. Present algorithm attempted to handle constraints with its main algorithm. Simulated annealing algorithm is also implemented in MATLAB with the following parameters:

Initial temperature T	=	400
Termination criterion T_{low}	=	10^{-5}
Boltzmann constant K	=	10
Cooling rate k_1	=	0.9
No. of cycles per temp. N	=	100

The program is tested for simple cases before implementing over the current problem. The function values are simultaneously computed as outputs of neural network in a single step. A move is made only when there is an improvement in both objective functions. Otherwise the point is selected with a probability computed from both function values as given in the following equation.

$$P(E) = \min\left(1, \prod_{i=1}^{R} \exp(-E_i / KT)\right) \quad (1)$$

Table 2 shows the optimum design parameters and corresponding values of objective functions during various runs of the program. It can be seen that the solution in trail number-7 giving a maximum possible MRR and minimum value of R_a. Fig. 2 shows the optimization trend during SA for this trail.

Table 2: Optimization Results

Trail number	Input and output parameters					
	I	V	T_{on}	T_{off}	MRR	R_a
1	16.14	152.83	666.43	335.6	54.834	2.1631
2	9.391	144.64	306.72	241.17	52.13	2.0987
3	35.09	141.7	414.02	113.93	53.128	2.4753
4	8.797	146.82	325.25	292.08	55.173	2.8517
5	39	149.03	555.28	362.29	54.824	2.6324
6	13.67	105.18	69.026	153.41	51.905	2.0135
7	33.9	127.89	412.22	109.59	54.938	2.0739
8	7.297	83.516	156.3	108.65	53.313	2.0987
9	31.24	148.33	474.96	277.45	54.834	2.3112
10	23.01	115.61	224.68	247.62	54.437	2.8612

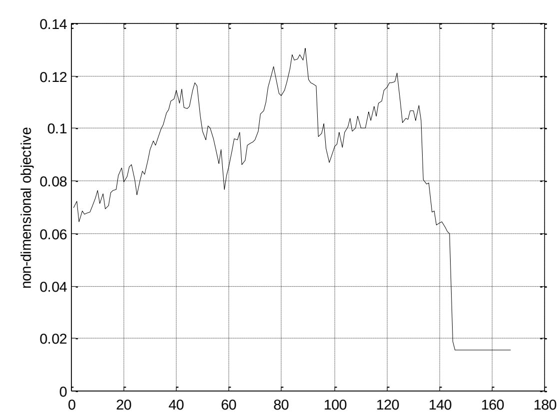

Fig. 2 Convergence of SA Algorithm during Seventh Trail

4. Conclusion on Methodology One

A constrained multi-objective optimization methodology for EDM process has been presented using simulated annealing approach. A reliable function generated from counter-propagation neural network was employed to evaluate the non-dimensional multiple objective values. The results were shown for the simple case of die-sinking example with four important operating parameters. Advantages of the method compared to conventional parameter selection were highlighted.

5. A Novel Research in EDM through a Structured Innovation Technique TRIZ – Methodology Two

TRIZ is a problem solving method based on logic and data, not intuition, which accelerates the research ability to solve any kinds of problems creatively from day today life to emerging Engineering and Technological field. TRIZ also provides repeatability, predictability and reliability due to its structure and algorithmic approach. "TRIZ" is the (Russian acronym for the "Theory of Inventive Problem Solving"). G.S. Altshuller and his colleagues in the former U.S.S.R. developed the method between 1946 and 1985. He discovered that evolution of technical system follows predictable patterns. Indeed, inventiveness and creativity can be taught.

TRIZ, an algorithmic methodology, has validated itself by solving thousands of difficult technical problems. It remained underground in the USSR where it was developed in secret by an intellectual elite. With the fall of the Soviet Union, TRIZ has reemerged in the West. Today many fortune 500 companies are successfully applying TRIZ. TRIZ is a rapid, creative approach for solving problems - not just ordinary problems, but also "impossible-to-solve" problems. The word "impossible" really means "impossible by previously known means." Given a good inventive technique, the impossible becomes the possible. The TRIZ approach is included in a rather rigorous step-by-step process, somewhat similar to an algorithm, although not as rigorous as a formal mathematical algorithm. This problem-solving algorithm is called ARIZ (another Russian acronym meaning "Algorithm for the Solution of Inventive Problems").The research has proceeded in several stages during the last sixty years. The three primary findings of this research are as follows:

1. Problems and solutions are repeated across industries and sciences. The classification of the contradictions in each problem predicts the creative solutions to that problem.

2. Patterns of technical evolution are repeated across industries and sciences.

3. Creative innovations use scientific effects outside the field where they were developed [3,4].

TRIZ is an international science of creativity that relies on the study of the patterns of problems and solutions, not on the spontaneous and intuitive creativity of individuals or groups. More than four million patents have been analyzed to discover the patterns that predict breakthrough solutions to problems. TRIZ research began with the hypothesis that there are universal principles of creativity that are the basis for creative innovations that advance technology [9]. If these principles could be identified and codified, they could be taught to people to make the process of creativity more predictable. The short version of this is:

Somebody someplace has already solved this problem (or one very similar to it.)
Creativity is now finding that solution and adapting it to this particular problem.

5.1. Essence of TRIZ

This question must be most basic and important for us to teach/learn TRIZ. There are many important principles and methods in TRIZ, such as:

1. 39 Altshuller's Generic Engineering Parameters.
2. Contradiction Matrix.
3. 40 Principles of Invention.
4. 76 Standard Inventive Solutions.
5. Trends of Evolution of Technical Systems.
6. ARIZ Algorithm etc.,

6. Problem Context of Novel Research in EDM using TRIZ

Since operating speeds in EDM are very low. To enhance these speeds, large electric current discharge is usually required, but it reduces the dimensional quality of machined surface. Similarly the material removal rate is also affected by the other process parameters. To increase the machining efficiency of EDM in terms of improving the Material Removal Rate (MRR) and Surface Quality (SQ), the structured innovation technique called TRIZ has been attempted in the second methodology to develop a new model of EDM, since all optimization techniques can yield better result to the certain level.

6.1. Discussion of problem

This is an excellent example of a non-trivial (and hence interesting) problem. There is a desirable output/characteristic that we need (in this case material removal rate) that unfortunately appears to be associated with something costly or unwanted (in this case, increase in machining time). In the language of TRIZ we call this a contradiction. The identification and resolution of contradictions is a key element of the TRIZ problem solving ethos. Inside all interesting problems we invariably find one or more such contradictions. If we can identify these contractions and resolve them we will have devised a high quality solution to problem – not merely a better compromise, but an innovative solution that breaks free from the existing constraints and provides a step-change towards an ideal system. This contradiction can be expressed in general as a simple fig. 3, which typically takes this form [10,14]:

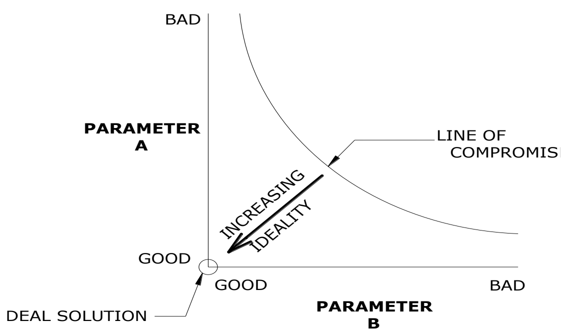

Fig. 3 Contradiction Expression

As we try to improve one parameter (material removal rate) the other (machining time) becomes worse, and vice versa. It would appear that we are constrained to remain on line of compromise curve, which defines the set of possible compromise solutions available to us. What we would like to able to do is to move off the line of compromise curve to a more ideal solution – i.e. in the direction shown by the dark arrow. To achieve this we need to find a way of resolving the contradiction. In the case of this particular problem we are looking for shown in fig. 4

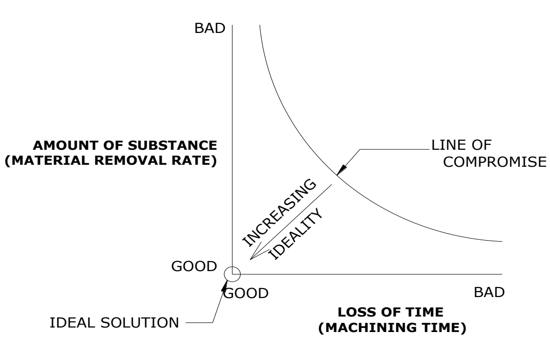

Fig. 4 Contradiction Expression for this Problem

6.2 Tackling the problem

In this case, it has been decided to use one of the classic tools from the TRIZ toolkit for solving contradictions: The Contradiction Matrix. To resolving contradictions, the method is a three-step systematic process :

Step 1: Identify the contradiction(s) in the problem, and classify them according to the nature of the contradictory system parameters.

Step 2: From the TRIZ toolkit, use a statistically derived look-up table (the Contradiction Matrix) to determine which generic Inventive Principles have been successfully used in the past to resolve contradictions.

Step 3**:** Take the generic Inventive Principles suggested in Step 2 and interpret/apply them to specific problem [11]. Though this final step it is possible to generate not just one possible solution, by usually a surprisingly large set of candidate conceptual solutions.

Step 1: Identifying the Contradiction(s)

TRIZ deals with two types of contradictions: Technical Contradictions and Physical Contradictions. When improving one parameter another gets worse - such as when designing a table, the stronger and more rigid we make it, the heavier it becomes - is called a technical contradiction of strength versus weight. In this particular case, as we want to improve material removal rate, machining time increases. A Physical Contradiction, on the other hand, is characterized by having the contradiction derived from the same system parameter – for example an umbrella needs to be both large (when in use) and not large (when not in use).

What is an Engineering Parameter?

There are 39 generic engineering parameters that, when combined in opposing pairs, can define any engineering contradiction. The parameters describe both the things we want (or inputs we must make) and the consequences – the things we don't want. To use the matrix, we have to match our problem to the parameter and we then have to ask the right question: which of the 39 parameters describes our contradiction?

Step 2: Using Contradiction Matrix

Before the Contradiction Matrix can be used it is necessary to map the specific problem parameters (material removal rate and machining time) onto the generic parameters used by the Contradiction Matrix. In this particular case, an appropriate mapping was arrived as:

Parameter 26 = Amount of substance matched well with Material Removal Rate (MRR)

Parameter 25 = Loss of time matched well with Increase in Machining Time

The full description of each of this parameter is given below [10].

Parameter 26 Amount of substance: The number or amount of a system’s materials, substances, parts or subsystems which might be changed fully or partially, permanently or temporarily.

Parameter 25 Loss of time: Time is the duration of an activity. Improving the loss of time means reducing the time taken for the activity. Cycle time reduction is a common term.

What is the Contradiction Matrix?

The Contradiction Matrix is based upon a statistical analysis of a very large number of existing patents. Each patent was found to solve a problem using one (or more) of a very limited number of generic Inventive Principles (just 40). The matrix maps the inventive principles according to the generic contradictions (defined by opposing engineering parameters) that were most frequently solved by them. The 39 Generic Matrix Parameters are shown in Table 3.

Table 3: The 39 Generic Matrix Parameters

1.Weight of Moving object	9.Speed	17.Temperature	25.Loss of time	33.Ease of operation
2.Weight of Stationary Object	10.Force	18.Brightness (jargon)	26.Quantity of substance	34.Ease of repair
3.Length of Moving Object	11.Stress or Pressure	19.Use of energy by moving object	27.Reliability	35.Adaptability
4.Length of Stationary Object	12.Shape	20.Use of energy by non moving object	28.Measurement accuracy	36.Device complexity
5.Area of Moving Object	13.Stability of Object’s Composition	21.Power (jargon)	29.Manufacturing precision	37.Difficulty of detecting and measuring
6.Area of Stationary Object	14.Strength	22.Loss of energy	30.External harm affects the object	38.Extent of automation
7.Volume of Moving Object	15.Duration of Action by Moving Object	23.Amount of substance	31.Object generated harmful factors	39.Productivity
8.Volume of Stationary Object	16.Duration of Action by Stationary Object	24.Loss of information	32.Ease of manufacture	

This contradiction is used with the Contradiction Matrix to obtain suggested Inventive Principles. Contradiction to improve Material Removal Rate(MRR) Improving Parameter is well matched with Amount of substance (MRR) and Worsening Parameter is well matched Loss of time (Increase in Machining time).These two parameters are used to cross-index the Contradiction Matrix to obtain the following four Inventive Principles that (statistically) have been found to be the most successful ways of obtaining better material removal rate without more machining time.

Step 3 : Inventive Principles

The following inventive principles are suggested by contradiction matrix between the parameters Amount of substance and Loss of time.

18 Mechanical vibration
38 Strong oxidants
35 Parameter Change
16 Partial or excessive action

6.3 Application of inventive principle(s)

Having derived some suggested Inventive Principles, to apply the principles to this particular problem. This is the part of a recurring theme in TRIZ that the sequence follows a chain like Specific Problem-General Problem - General Solution-Specialized Solution to Specific Problem. The next step is, to understand the suggested inventive principles [9,11] to appreciate the full definition of each principle before attempting to apply it. In this case, the suggested four generic principles’ definition with some examples are given below for better reference to understand, validate the research findings and to propose a new design.

Principle #18.Mechanical vibration

A. Cause an object to Oscillate or Vibrate.

B. Increase its frequency even up to the Ultrasonic.

E.g. Distribute powder with vibration.

C. Use an object‘s resonant frequency.

D. Use piezoelectric vibrators instead of mechanical ones.

E. Use combined ultrasonic and electromagnetic field oscillations.

Principle # 38 .Strong Oxidants

A. Replace common air with Oxygen - Enriched air.

B. Replace enriched air with pure Oxygen.

C. Expose air or oxygen to ionizing radiation.

D. Use ionized oxygen.

E.g. Ionize air to trap pollutants in an air cleaner

E. Replace ozonized (or ionized) oxygen with ozone.

E.g. Speed up chemical reaction by ionizing the gas before use.

Principle # 16.Partial or Excessive Action (Application of Principle 3 and 9)

A. Change an object’s structure

B. Make each part of an object function in condition most suitable or its operation.

C. Make each part of an object fulfill a different and useful function.

E.g. Multi function tool.

D. Replace with anti- actions to control harmful effects.

E.g. Buffer the solution to prevent harm from extreme of PH.

E. Create before hand stresses in an object to oppose undesirable working stresses.

Principle # 35.Parameter Change

A. Change an object's physical state.
B. Change the concentration or consistency.
C. Change the degree of flexibility.
D. Change the temperature.

At this point in the problem solving process, appropriate problem and technological domain knowledge is important. The final solution derived from these principles were used to validate the previous research findings and to justify how well this novel approach TRIZ can be used in emerging engineering and technological research domain to reduce the research time, cost and to give right direction, solution to research.

7. Validation of TRIZ with Experimental Research Findings on following Suggested Matrix Principles

Principle # 18 Mechanical Vibration

Rajurkar et al [12,13] has indicated some future trends activities in EDM machining on advanced materials, mirror surface finish using Powder Additives and introduction of Ultrasonic Vibration to the electrode is one of the methods used to expand the application of EDM and to improve the machining performance on difficult to machine materials. Guo et al [5] has proposed the higher efficiency gained by the employment of Ultrasonic Vibration is mainly attributed to the improvement in die electric circulation which facilitates the debris removal and creation of large pressure change between the electrode and the work piece, as an enhancement of molten metal ejection from the surface of the work piece. Ogawa et al [15] proved that the depth of micro holes by EDM with Ultrasonic Vibration becomes about two times as without ultrasonic vibration and machining rate increased. Kunieda et al [6] introduced an improvement of dry EDM characteristics using Piezoelectric Actuators to help in controlling the gap length to elucidate the effects of the piezoelectric actuator an EDM performance simulator developed to evaluate the machining stability and MRR of dry EDM.

Principle # 35 Parameter Change

Zhang et al. [7] studied the ultrasonic EDM in gas. The gas is applied through the internal hole of a Thin Walled Pipe Electrode.

Principle # 16 Partial or Excessive action

This principle is an application of Principle #03 Local Quality and Principle #09 Preliminary Anti-Action. Principle # 3 suggests change an object structure, Q. H. Zhang et al [8] has proved this suggested principle by introducing an investigation of Ultrasonic-Assisted Electrical Discharge Machining in gas with thin walled pipe electrode i.e. Tube Electrode. Principle #9 suggests that do an action with harmful effects, for example, buffer a solution to prevent harm. Q. H. Zhang et al [8] has proved and validated this suggested principle by introducing gas in Ultrasonic Electrical Discharge Machining (UEDM) by avoiding using electrolyte.

8. New Design of E-EDM using TRIZ for better Material Removal Rate (MRR) in EDM

Principle # 38 Strong Oxidants suggests replace common air with Oxygen - Enriched air, Replace enriched air with pure Oxygen, Expose air or oxygen to ionizing radiation, Use ionized oxygen, replace ozonized (or ionized) oxygen with ozone. e.g. Speed up chemical reaction by ionizing the gas before use. As per the principle # 38 recommendation, we propose a new design E-EDM by introducing ionized oxygen into EDM by replacing die electric fluid from the existing EDM process, since EDM current research already started introducing dry EDM (i.e. introducing any gas medium) by removing dielectric fluid, it validates our findings that dielectric can be eliminated from the existing design of EDM. As guided by the inventive principles recommendation that by introducing ionized oxygen into EDM by eliminating dielectric fluid and in further it can speed up material removal rate. Block diagram of new experimental design of E-EDM using TRIZ is shown in Fig. 5.

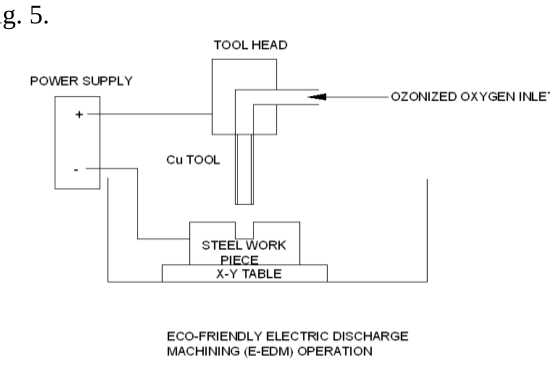

Fig. 5 New Experimental E-EDM Design

Added advantages of new design E-EDM are flushing is not required to circulate liquid die electric since die electric is replaced by ionized oxygen. It is a power saving new EDM design since die electric circulating pump, filter have been removed from the circuit.

9. Conclusion

Simulated Annealing (SA) based Counter Propagation Neural Network (CPNN) model has been developed successfully for selecting an optimal process parameter set in accordance to maximize Material Removal Rate (MRR) and Surface Quality (SQ). As a result SA based CPNN has been successfully used in optimization of the EDM process in the first methodology. To achieve further improvement in MRR and SQ, the new technique TRIZ (Structured Innovation) has been attempted in the second methodology to model and develop a new experimental design of E-EDM and the same has been obtained with short span of three months time using this structured innovation technique called TRIZ where as by conventional trial and error approach took more than thirteen years to come up with the some new designs of EDM. The integration of TRIZ methodology into design, help the designers to maximize the utilization of the resources of a system to meet the objectives of a new design development. TRIZ offers maximum results with minimal effort and without any unwanted effects. The application of TRIZ accelerates the search for breakthrough solutions and gives users the ability to reach greater levels. Several teams of engineers working for several years could not come up with a solution as elegant as the one got with TRIZ in a few weeks. Engineers love TRIZ because it treats creativity as a discipline to be mastered, not as right-brain hocus-pocus. TRIZ methodology fulfills the environmental requirements even from conceptual design stage. The outcome of this research work in the development of a new methodology for applying TRIZ for EDM design for Environment by overcoming the limitations of existing EDM process by adapting one of the most useful tools of TRIZ - the Inventive Principles.

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