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An Exhaustive Review of Die Sinking Electrical Discharge Machining Process and Scope for Future Research

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***Abstract*—**Electrical Discharge Machine (EDM) is especially used for the manufacturing of 3-D complex geometry and hard material parts that are extremely difficult-to-machine by conventional machining processes. In this paper authors review the research work carried out in the development of die-sinking EDM within the past decades for the improvement of machining characteristics such as Material Removal Rate, Surface Roughness and Tool Wear Ratio. In this review various techniques reported by EDM researchers for improving the machining characteristics have been categorized as process parameters optimization, multi spark technique, powder mixed EDM, servo control system and pulse discriminating. At the end, flexible machine controller is suggested for Die Sinking EDM to enhance the machining characteristics and to achieve high-level automation. Thus, die sinking EDM can be integrated with Computer Integrated Manufacturing environment as a need of agile manufacturing systems.

***Keywords*—**Electrical Discharge Machine, Flexible Machine Controller, Material Removal Rate, Tool Wear Ratio.

I. INTRODUCTION

ELECTRICAL Discharge Machining (EDM) is a non-conventional process. EDM originally observed by English Scientist Joseph Priestly in 1770. At early stage of development EDM was very imprecise and riddled with failures. Further two Russian scientists, Dr. B.R. Lazarenko and Dr. N.I. Lazarenko in 1943, developed EDM process. Also they invented the relaxation circuit and a simple servo controller too, that helped maintain the gap width between the tool and the work-piece. Further research is contributed in the development of EDM process for the improvement of machining characteristics in the direction of material removal rate and surface finish.

A. EDM Working Principle

EDM is thermal erosion process where controlled electric spark discharge takes place between tool and work-piece to have the eroding effect on work-piece to form a replica of tool on work-piece. As there is no mechanical contact between both electrodes during whole process and erosion is produced by electrical discharge. Electrical conductivity of electrode and work-piece is the basic requirement of this process. So, electrical resistivities of both electrodes must lie between 100 and 300 Ω cm [1, 2]. This electric sparking process is carried out in a dielectric liquid or in gas [3-6]. Dielectric mush have low-viscosity, high dielectric strength, quick recovery after breakdown, effective quenching / cooling and flushing ability [7-11]. Flushing methods are classified into four main categories: immersion flushing, jet flushing, normal flow and reverse flow. Breakdown of dielectric is initiated by moving the tool electrode towards (near the) work-piece and forming a plasma channel [12]. The location of breakdown is generally between the closest points of the electrode and of the work piece. Due to spark breakdown, voltage falls and current rises abruptly that causes numerous randomly ignited monodies charges, which forms the crater at spot of discharge on work piece. As plasma channel has been created due to ionization of dielectric this lead the conductivity of gap and because of applied current heat is generated around a range of 8000 to 20,000 °C [13-15] at the crater spot. The size of a crater is determined by discharge energy, which can be set on the machine by setting the discharge current and the discharge duration [16-19]. This will cause strong heating of the work piece material (but also of the tool electrode material), rapidly creating a small molten metal pool at the surface [20-22]. A small quantity of metal can even be directly vaporized, some of is flushed with dielectric in the form of debris and remaining will be re-solidify (recast layer / white layer) due to dielectric. The material removal rate is determined by the crater size and the frequency of crater generation [23], i.e. discharge energy and the frequency of discharges. Finally, the cavity produced in the work piece is approximately the replica of tool [24].

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II. DEVELOPMENTS IN EDM

For review purpose this paper has been categorised in two major category. First part deals with the developments in the field of EDM in last few decades and classified them in five major classes as: process parameter optimization, multi- spark techniques, powder mixed EDM, servo control system and pulse discrimination techniques. Final part of the paper explains the need of automation and the integration of existing die sinking EDM with the flexible machine controller to fulfill the today's need of agile manufacturing systems. The main objective of EDM researchers has been high material removal rate (MRR) and better surface finish (SF) at lower tool wear ratio.

A. Influencing Process Parameters

EDM process not only depends on capacities of machine but also depends upon processing parameters. There are so many parameters that affects the EDM process, some of the major influencing process parameters like discharge voltage, frequency of current, gap between tool electrode & work piece, ignition delay time, pulse on time, pulse off time, polarity, flushing type, properties of dielectric media, conductivity of electrodes, eroding area etc. All these process parameters play a vital role in deciding machining characteristics like surface finish, energy consumption and efficiency (MRR) of EDM process. Researchers have reported that most influencing process parameters are discharge current [25-35], pulse on time [25-31, 33-35], pulse off time [25, 26, 28, 30, 34, 35] and dielectric liquid pressure [29, 31, 32, 36].

B. Multi Spark

Conventional EDM has only one discharge point for each pulse. To obtain multi spark in single pulse tool electrode was divided into two parts [37-39] and multi parts [40-43]. These electrodes were electrically insulated from each other and connected to the pulse generator for getting multi / parallel spark in a single pulse. Experimentally it was analyzed that in single pulse, conventional EDM gives one spark, whereas multi spark EDM gives multiple sparks depending upon division of electrodes in number of parts. Power consumption for conventional EDM as well as multi spark EDM is same but in multi spark EDM the power generated in gap is 'n' times the number of electrode part as compared to conventional EDM within a single pulse. Due to this surface finish [40, 43] and MRR [39, 40, 43] is higher in multi spark EDM, at low energy consumption as compared to conventional EDM [39].

C. Powder Mixed EDM

As mentioned above in section IA, white layer is hard and contain micro-cracks, caused by high tensile residual stresses exceeding the ultimate strength of the material [26, 28]. This surface imperfection further reduces the fatigue, wear and corrosion resistance of Electrical Discharge Machined components [44-48]. Instead of post-machining processes to remove damaged surface layer and to restore the surface properties, powder mixed electrical discharge machining (PMEDM) [49] is suggested. In PMEDM the powder of aluminum (Al) [50-52, 56, 57, 61, 62, 66, 67], chromium (Cr) [52, 53, 66, 67], graphite (Gr) [55, 56, 62], copper (Cu) [52, 57], and silicon (Si) [54, 56, 62, 66, 67] were mixed with dielectric media and experimentation were performed. It was reported that conductive and inorganic oxide particles in the powder mixed dielectric increase the MRR [51, 52, 58-61] and improve the mirror-like [52, 61-65] surface quality of the work-piece. It was also observed that hardness, abrasion and corrosion resistance of the machined surface improved significantly [56, 66, 67]. Size of powder particle, quantity of powder and type of dielectric media also plays vital role in machining [52].

D. Servo Control

Servo control is one of the most important control device for EDM process as it regulates the dimension of discharge gap that drives the machining performance and stability. It is not necessary to get healthy spark for two successive pulses even after maintain a constant discharge gap between electrodes. This is may be because of peaks and valleys on work piece surface, debris in dielectric that changes its gap conductive property. An adaptive control system [68-71] maintains a desired gap that gives healthy spark, prevent harmful arcing and short circuit. Further [72-74] a new optimized adoptive control system was developed that not only detect undesirable machining conditions in advance but also take appropriate preventive actions before the situations really occur. Because of poor flushing condition debris creates an arcing between the electrodes as observed by Rajurkar and Wang [75-78] and proposed model reference adaptive control system. In this system, on-line optimization software with new servo control interface circuit was developed on the base of model reference control theory. Self- tuning adaptive servo control system [79-81] with feedback signal from EDM, was developed. This has better control performance of stochastic EDM process with good flushing system. To suppress the process noise disturbance in control system, EDM jumping proposed [82] with self–tuning controller [83]. On-line adjustment of all controllable parameters in EDM is still difficult due to the stochastic and dynamic nature of EDM. Still skilled machine operators are required to handle the EDM. Researchers [84-87] combine the different technique (fuzzy, ultrasonic vibration, pulse generator and servo feed control system) in adaptive controller for improvement of machine efficiency (MRR). Hayakawa et al [88] was developed a new on-line gap measurement and control system with the help of EDM oil (dielectric) pressure. This minimized short-circuiting and debris flashing problem in EDM process.

E. Pulse Discriminating

EDM pulse is generally classified into several types they are, open pulse, spark pulse, arc pulse, short pulse, and off pulse [89, 90]. For material removal, sparking pulse is required which give better surface finishing than other pulse type [91, 92]. Whereas, arc and short pulses gives rough surface finish and EDM gets unstable caused by concentration of conductive particles between tool and work-piece gap [93], this machining condition is harmful. In order to overcome from such circumstances a skilled operator is required to take a corrective action to stable the machine by adopting proper corrective measures. Further different online controllers were developed; polynomial function based Abductive network [89, 94], pulse-discriminating type analyser [95], radio frequency analyser [96, 97], neutral network base [90, 98], fuzzy base pulse discriminator system [99, 100] and digital signal processing base [101]. These controllers identifies EDM process pulses and discriminates it and take proper corrective measures to stabilise the machine.

F. Optimisation

Usually machining parameters are determined by operator experience or handbook values. However, this does not ensure that the selected machining parameters result in optimal or near optimal machining performance. To overcome this, most influencing EDM process parameters were optimized to achieve low tool wear ratio and better surface finish with high efficiency (MRR). Researchers have performed experimentations on different combinations of tool and work-piece materials for the generation of data. Collected data were used for building a model with the help of Fuzzy [102-104], Taguchi method [102, 105-108], Neural Network [109-116], Adaptive Neuro Fuzzy Inference System [110, 117-119], Design of Experiments [105, 108, 115, 120, 122, 123], ANOVA [105, 106, 122, 124], Genetic Algorithm[111, 112, 114-116] and hybrid techniques. Confirmation experiments were conducted to validate these models and process parameters were optimized for predicting the desired machining characteristics. All these models are electrode (tool and work-piece) material and machine dependent.

III. Need Of Automation

A case study presented by Zeng et al. [125] where a mobile phone mould making industry uses 4500 to 7500 electrodes simultaneously for different cavity of mould. Each cavity requires rough, semi finish and finish operations, which in turn required three different tools. Machine operator has to perform variety of task simultaneously like machining parameters feeding, tool off set, editing of the programs, tool changing and so on. To handle such situations skilled operators are needed and to avoid the human error under such circumstances automated system is essential that can replace human task.

EDM survey [126] has discussed some typical issues which still require special attention to make integration of Die Sinking EDM for manufacturing systems. Researchers [127, 128] have proposed the concept of EDM integration with CIM environment. Further Rajurkar and Wang [129] emphasized on the integration of EDM into future agile manufacturing systems which requires the EDM control system to have capabilities of high level automation and ability to share CAD/CAM resources with remote EDM system and other remote manufacturing facilities.

The usage of die sinking EDM is increasing in manufacturing industries. Performance of die sinking EDM depends upon the skill of operator. To eliminate the skill operator's dependancy there is a need to develop a data base of EDM process parameters. S. Chakrabarti et al. [130] has attempted the design and implementation of a minimal Management Information System(MIS) for handling Abrasive Water Jet Machining, EDM and Wire-cut EDM data which can be extended with suitable design enhancements to handle different manufacturing systems logically by interacting with the end user. Author has also emphasized the need for development of MIS for other non-conventional machining process. For development of MIS, statistical data would be generated by carrying out extensive experimentation on different combinations of tool electrode – work piece materials. Further from these data, optimized process parameters like discharge current, pulse on time and pulse off time would be determined and validated. To feed these optimized process parameters from MIS to EDM, a controller is needed. To achieve the automation and to reduce the operators dependancy integration of flexible controller (PLC) with the existing die sinking EDM is proposed.

IV. Proposed Automated System

Programmable Logic Controllers (PLCs) are used in every aspects of industry to expand and enhanced production. Where older automated system uses hundreds or thousands of relays, a single PLC can be programmed as a replacements. The functionability of the PLC has evolved over the years to include capabilities beyond typical relay control: sophisticated motion control, process control, distributive control systems, and complex networking have now been added to the PLCs list of functions. PLCs provide many benefits which includes increased reliability, more flexibility, lower cost, communication capability with other controllers/computers to perform functions as supervisory control, data gathering, monitoring devices and process parameters, faster response time and easy to troubleshoot.

Fig. 1 depicts the schematic diagram of EDM-PLC interface of the proposed system.

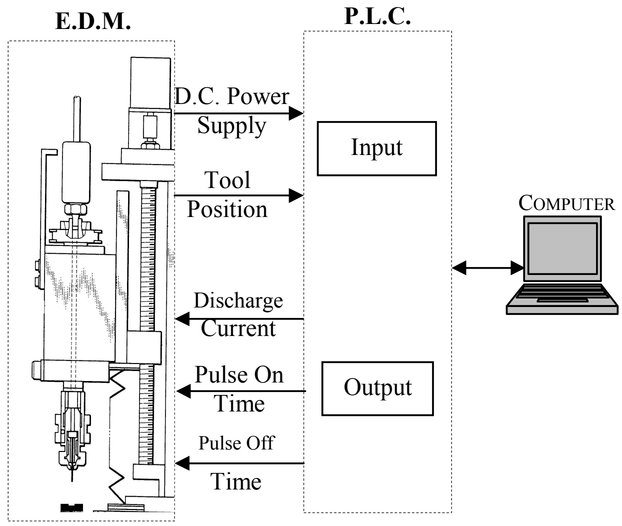

Fig. 1 Schematic diagram of EDM-PLC interface

In this system, D.C. Power supply from capacitor bank and tool position of the existing die sinking EDM would act as an input to PLC. The most influencing process parameters of EDM, discharge current, pulse on and pulse off time will be fed to PLC through computer. This PLC is attached to computer serial port through RS232 cable, Supervisory Control and Data Acquisition (SCADA) system will used to communicate with PLC.

SCADA uses standard protocols for communication, thus distributing functionality across a LAN and WAN. A user screen will be designed using Human-Machine Interface, where a machine operator will select / feed the name of electrodes, required surface finish and finish depth. HMI will be linked to database of SCADA from where optimized EDM process parameters will be generated for three machining region i.e. rough, semi-finish and finish operations. Operator will be assigned a right to edit these parameters if required. These parameters can be fed to suggested controller at once by clicking a single button. Controller will switchover from rough machining regime to semi-finish and finally finish regime automatically depending upon incursion of tool in work piece material.

In posterior research, this stand alone die-sinking EDM will be interface with standard CAM/CAM software and CIM system.

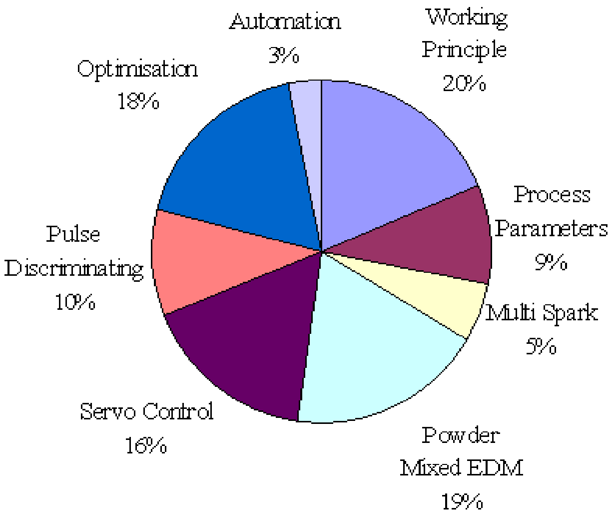

Fig. 2 Distribution of Reviewed Research Publication

Fig. 2 shows the research done in various areas of EDM process for improving its performance measures. It is seen that 20% of the surveyed papers describes the working principle of EDM, 19% contributed towards addition of metal powders in dielectric, 18% work focused on process parameter optimization, 16% work emphasized on servo control, 10% on pulse discrimination and 5% on multi-spark for enhancing the performance of the machine. It is clearly seen that only 3% of the surveyed work attempted towards automation of EDM process. Hence there is a need to reduce the operators dependancy and interface the existing die sinking EDM with a flexible machine controller so that it can be integrated with CIM environment as need of agile manufacturing.

V. Conclusion

Authors have conducted a review of published work in past few decades and it is observed that majority of research have been made in the direction for improving the performance measures in terms of MRR and SR with the help of multi-spark technique, powder mixed EDM, servo controller developments, pulse discriminating system and optimization of parameters. As shown in Fig. 2 very few attempts have been made to develop high level automation for die sinking EDM.

Authors have suggested a new PLC based flexible controller for conventional die sinking EDM to achieve

- High level of automation.
- Sharing of CAD/CAM resources.
- Remote operation of EDM.
- EDM -Interface with other manufacturing facilities / network.
- Reduce operator dependency.
- Higher MRR with better SR.

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