American Journal of Mechanical Engineering, 2018, Vol. 6, No. 2, 48-53
Available online at http://pubs.sciepub.com/ajme/6/2/2
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DOI:10.12691/ajme-6-2-2

Development of Flexible Machine Controller for Electrical Discharge Machine

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Abstract The present experimental work involved the development and evaluation of Flexible Machine Controller for die sinking Electrical Discharge Machine (EDM). Pilot experimentations were conducted to develop a comprehensive EDM experimental database. The Flexible Machine Controller development dealt with the selection and programming of Programmable Logical Controller. The user interface has been developed on the basis of Supervisory Control and Data Acquisition system and the database program has been developed for assisting the user in selection of EDM process parameters. The developed Flexible Machine Controller has been validated with the experimental database. Experimentations carried out for six different work piece materials with the developed Flexible Machine Controller showed 13.12% improvement in the machining time as compared to original machine controller.

Keywords: *electrical discharge machining, flexible machine controller, machining time*

Cite This Article: M. M. Pawade, and S. S. Banwait, "Development of Flexible Machine Controller for Electrical Discharge Machine." *American Journal of Mechanical Engineering*, vol. 6, no. 2 (2018): 48-53. doi: 10.12691/ajme-6-2-2.

1. Introduction

Electrical discharge machining (EDM) is a widely used manufacturing process in industries for high-precision machining of all types of conductive and very hard materials. In recent years, EDM researchers have explored a number of ways to enhance the machining characteristics such as surface roughness, material removal rate and electrode wear rate. Most of the EDM research work relates to improving performance measures, optimising the process variables, monitoring and control the sparking process. Baraskar et al. [1] presented an empirical models for relating the surface roughness and Material Removal Rate(MRR) to machining parameters like pulse-on time, pulse-off time, and discharge current. They concluded that since the influence of machining parameters on surface roughness and MRR are conflicting in nature, there is no single combination of machining parameters, which provides the best machining performance. EDM pulse is generally classified into several types they are, open pulse, spark pulse, arc pulse, short pulse, and off pulse [2,3]. For material removal, different online controllers were developed; polynomial function based Abductive network [2], pulse discriminating type analyser[4], radio frequency analyser [5,6], neutral network base [3], fuzzy base pulse discriminator system [7,8] and digital signal procesing base [9]. These controllers identifies EDM process pulses and discriminates it and take proper corrective measures to stabilise the machine. Market survey showed that many of the CNC capabilities had not being fully utilised by 'toolmakers' [10]. Ho and Newman [11] have carried out die sinking EDM survey within the past decade. It reports on the EDM research relating to improving performance measures, optimising the process variables, monitoring and control of the sparking process. Yilmaz et al. [12] reported a user-friendly intelligent system for parameter selection of EDM. This system was developed in fuzzy set theory of expert rules based on experimental results and knowledge of skilled operators. Wu et al. [13] focused on stabilizing EDM process by establishing a new minimum-variance and pole-placement coupled control law. The said adaptive control system exhibited superior machining ability and capability of stabilizing sparking process.

Earlier research indicates that very limited attempts have been made to develop a high-level automation for die sinking EDM. It was found that die sinking EDM should have high level automation, remote operation accessibility, strong network access capability, ability to share data base for integration of CAD/CAM system. In order to improve EDM performances, the most important issue is to develop a highly stable and easy to use control system. Hence, it was decided to develop a flexible machine controller that has all these capabilities.

2. Methodology

A flow chart in Figure 1 gives the brief outline of the experimental methodology adopted for the present work. The experimentation comprises of development of comprehensive EDM database with different combination of tool electrode material and work piece materials. Pilot experimentations were planned by adopting Center Composite Design (CCD) methodology of Design of Experiment (DoE). The fixed machine controller of die sinking EDM machine used for experimentation was bypassed and machine control was routed through the developed Flexible Machine Controller (FMC). The said FMC is basically a Programmable Logical Controller (PLC) with different electronic components like relay, contactors etc. The FMC was interfaced with user, EDM experimental database and EDM machine. After validating the complete setup of the EDM machine with the developed FMC, the performance evaluation of the complete system was carried out.

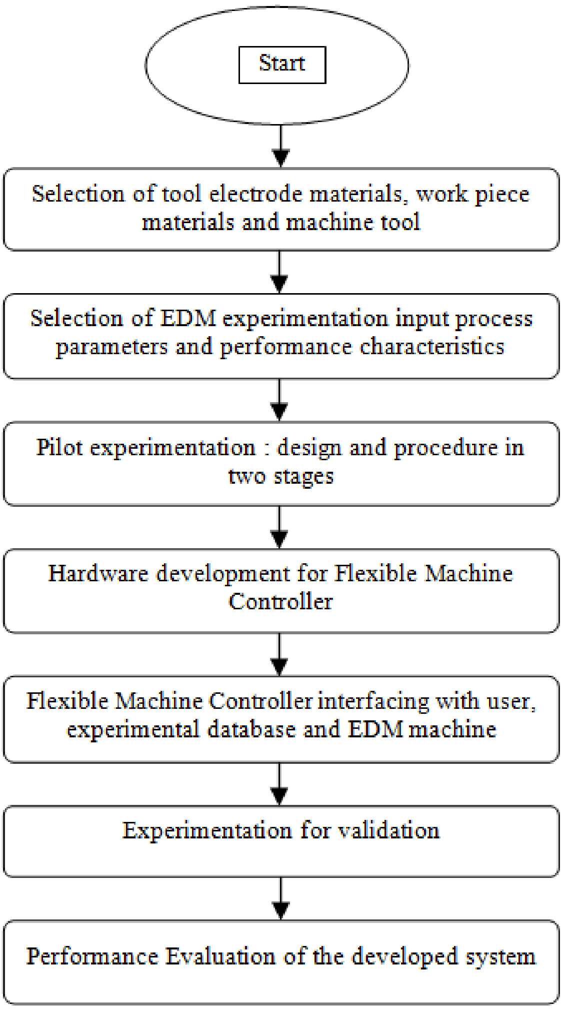

Figure 1. Flow chart of methodology

Commonly used mould and tool die steel materials were selected for experimental investigation as work piece material. The work piece materials used during experimentation were AISI 1040, AISI 52100, AISI M2, AISI D2, AISI P20 and AISI A2. These materials have wide range of industrial applications: plastic injection moulding dies, forging dies, Zn/Al casting dies, automobiles, defence, pharmaceutical, aerospace, ship building industries etc. [14]. Copper of rectangular cross section (20 x10 mm) has been used as the tool electrode which is the highly preferred tool electrode material in die sinking EDM industrial applications [15]. Prior polishing and buffing of tool electrode was carried out before every experimental run.

Experimental investigations were carried out on a die sinking EDM machine (A 25 Spark Generator) of TOOLCRAFT India Ltd., Bangalore, India installed in workshop of Mechanical Engineering Department, National Institute of Technical Teachers Training and Research, Chandigarh, India.

2.1. Selection of Process Parameters

EDM process is stochastic in nature, the machining performance of EDM process depends on number of input process parameters. Each input process parameter has different independent impact on output of EDM such as surface roughness, material removal rate, tool wear ratio and dimensional accuracy. Thus the process parameters namely discharge current, pulse-on time and pulse-off time were chosen based on earlier work of researchers [1,10,16]. The range of values of these process parameters on experimental machine tool control panel used are given in Table 1.

Table 1. Range of parameters

Sr. No.	Parameter	Range
1	Discharge current	1.56 – 23.437 Amp
2	Pulse-on time	2 – 2000 μs
3	Pulse-off time	2 – 2000 μs

3. Pilot Experiments

In order to develop a comprehensive experimental database for the use of Flexible Machine Controller, a series of experimentations were planned. The pilot experiments were conducted to find out the best combination of die sinking EDM input process parameters like discharge current, pulse-on time and pulse-off time. The performance characteristics studied during the experimentations were material removal rate and surface roughness. Center Composite Design (CCD) methodology of Design of Experiment (DoE) was used to investigate the optimal values for machining characteristics. A Face Centered Cubic Design (FCCD) was used for performing the said experimentation. Based on FCCD, twenty experiments were planned to study the entire range of process parameters for a combination of one work piece material and with copper tool electrode material.

Pilot experimentations were conducted by following the standard machining procedure with negative polarity for electrode and positive polarity for work piece material. The dielectric fluid used was EDM oil (Grade 30). Surface roughness was measured using Mitutoyo Surftest and material removal rate was measured/calculated using digital weighing machine.

4. Hardware Development

In the present work, a programmable logical controller has been used as a hardware to develop a flexible machine controller for die sinking EDM machine. Programmable logical controller is an electronic programmable device which can be used for any indusrial application. PLC has strong communication protocols that comunicates with personal computer, web browser and over a network to some other system.

The most influencing input process parameters discharge current, pulse-on time and pulse-off time of die sinking EDM process have been considered in this work to control the EDM machine through FMC. As per industrial feedback and Zeng et. al. [17] there are three machining operations namely rough, semi finish and finish operations which are required to manufacture a die sinking EDM finished product. In the present case, PLC programs in such way that it controls the most influencing process parameters for three machining operations independently with respect to a set depth of cut for each operation. The switching of machining operation from rough to semi finish and semi finish to finish is carried out automatically without operator.

4.1. Selection of PLC

There are different configurations of PLC available in the market. The selection of PLC depends on the type of process to be controlled and number of input output port, expandable I/O port, CPU, memory and scan cycle time. In order to control the die sinking EDM machine and three most influencing process parameters, 35 outputs and one input port is required. So modular type PLC was found to be most appropriate. Allen-Bradley make MicroLogix ™ 1200 (1762 - L24BWA) was selected for the present experimental investigation. This PLC have Central Processing Unit, power supply system, communication port, I/O expandable port and external ether net module. This PLC requires 240 V AC power supply. The I/O base model of the PLC was not insufficient for die sinking EDM process control, so an extension input module Allen-Bradley MicroLogix (1762–IF4), output module Allen-Bradley MicroLogix (1762 –OF4) and Allen-Bradley MicroLogix (1762–OW16) were used in addition with the base model. Figure 2 shows the basic internal architecture of the PLC used in this research work. It consists of a Central Processing Unit (CPU) containing the system microprocessor, memory, and input/output circuitry. The CPU controls all the operations within the PLC and outside the process. The system bus was used for communication between the input/output ports and the input/output units.

5. FMC Interfacing

Developed hardware (FMC) is interfaced with die sinking EDM to control the machining process. To interact with die sinking EDM remotely, a software interface has been developed through which machine operator controls the die sinking EDM and its machining process from a computer.

5.1. User Interface

Human Machine Interface (HMI) is a Supervisory Control and Data Acquisition (SCADA) system developed by using RS View 32 software. HMI allows machine operator to control the die sinking EDM and feed the machining process parameters remotely. RS View 32 software has built-in Visual Basic Application (VBA) feature that allows sharing with other standard softwares. Also have many data channels, OPC server and DDE server to communicate with other network.

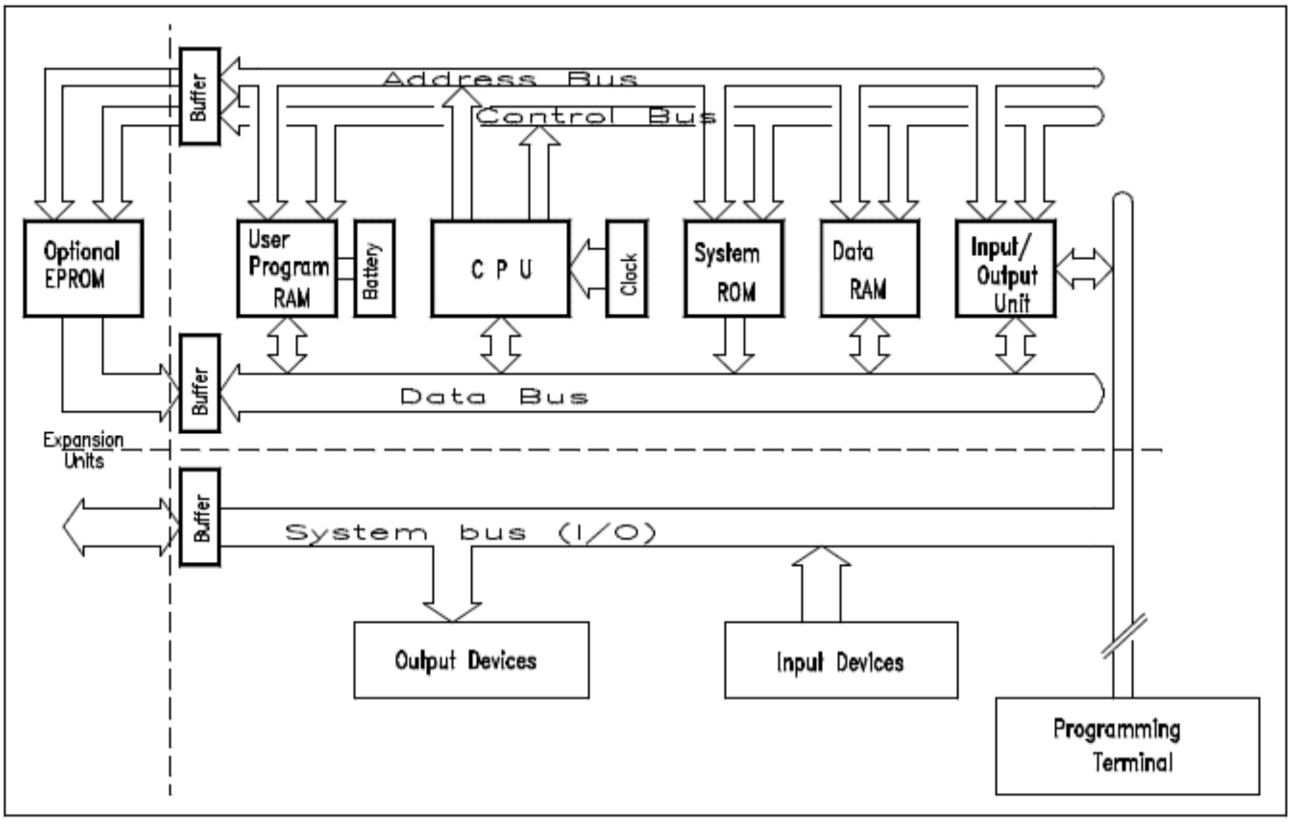

Figure 2. Block diagram of MicroLogix ™ 1200 PLC CPU

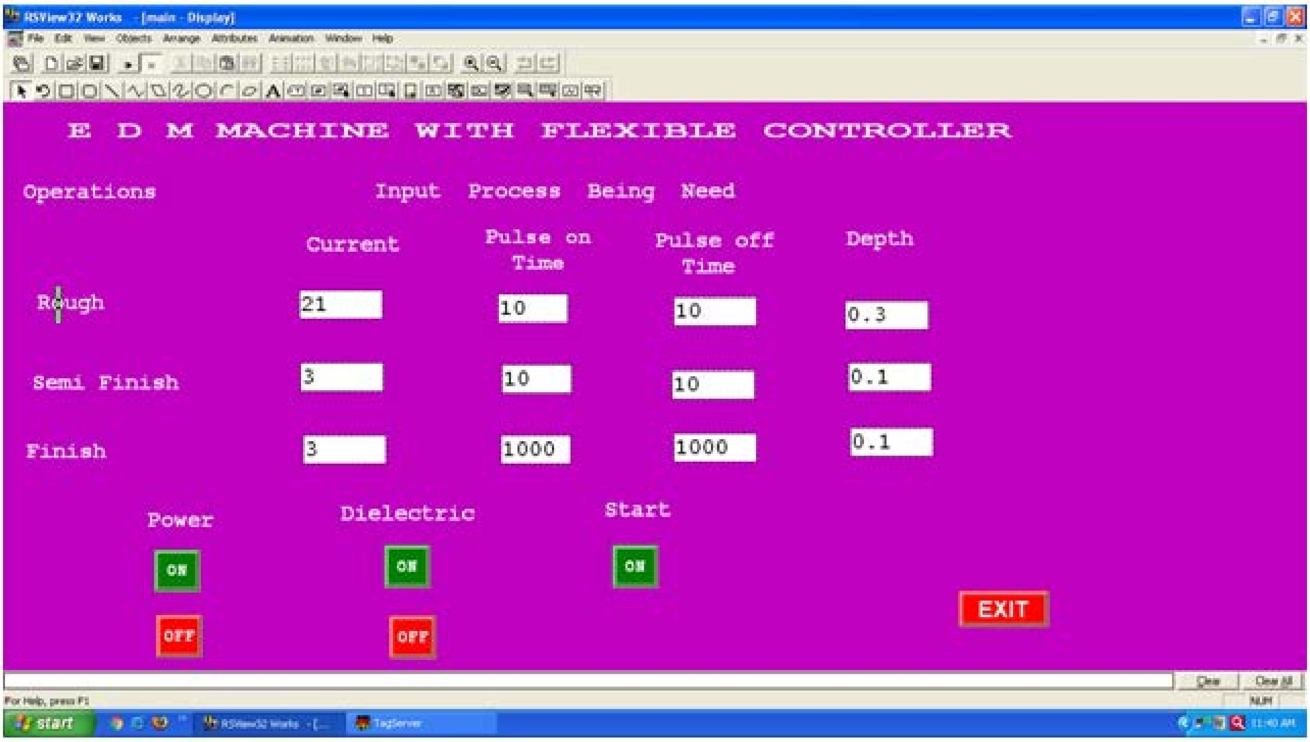

Figure 3. Flexible Machine Controller User Interface

Figure 3 shows the HMI screen for control and feeding EDM process parameters. Machine operator has to feed the EDM process parameters for three machining operation along with respective depth. Numeric input buttons are used for all input process parameters. Power, dielectric and start buttons are used to control the EDM machining process. The PLC was attached to a desktop computer on COM port through RS232 communication cable. Nodes of SCADA communicates with devices through Channel 1 – DH-485 and direct drivers, OPC server as data source.

5.2. Experimental Database Interface

Earlier researchers [11,12] have recommended a Visual Baic.Net database system for non-conventional machining processes on the basis of pilot experimental results. In the present work, a database application has been developed in Visual Basic.NET on the basis of pilot experimental results. The database application links with developed HMI to assist any unskilled operator in the selection of die sinking EDM process parameters for doing machining on die sinking EDM machine.

5.3. EDM Machine Interface

Figure 4 shows the FMC interfacing with die sinking EDM. Machine switch control, triggers the power supply to EDM machine, dielectric fluid pump, quill control, spark pulse polarity, manual or automated mode, spark generation, digital readout, pulse generator and emergency switch features of die sinking In EDM machine, eight contactors has been used to control the discharge current of die sinking EDM through FMC. Each of contactor is isolated and carrying 3.125 Amp current. FMC makes high and low contact depending on the value of current required for operation. For both pulse-on and pulse-off time, the timer IC 555 was used to generate different time intervals in microseconds. The set value of pulse time through HMI is scaled and voltage pulses are sent to IC 555 and the output of IC 555 is connected to die sinking EDM.

Developed FMC interfaces with die sinking EDM as per the program (LADDER LOGIC) developed for PLC. Interfacing has been carried out in different phases so as to integrate the different machine control switches with Flexible Machine

Controller and also providing variable input channels, discharge current control and pulse control (i.e. pulse-on time and pulse-off time). As PLC works on low voltage (0 to 10 V DC), so it cannot be directly interfaced with the die sinking EDM machine used for the experimentation. Therefore, an intermediate hardware circuit was used that makes the communication between PLC and die sinking EDM machine.

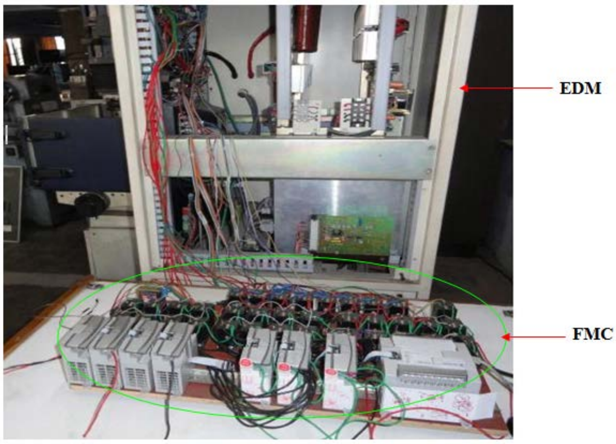

Figure 4. FMC Interface with die sinking EDM

6. Validation

After interfacing of Flexible Machine Controller with die sinking EDM machine, the component level interfacing was tested individually and independently. The validation experimentation was conducted to observe the collaborative effect of Flexible Machine Controller on die sinking EDM machine. Numbers of dry runs were carried out to test the working of the developed Flexible Machine Controller with the machine. After successfully testing the working of Flexible Machine Controller, validation experimentations were performed with AISI 52100 work piece material and copper tool electrode on Flexible Machine Controlled die sinking EDM machine. Input process parameters selected for pilot experimentations are given in Table 2.

Table 2. Process parameters used for Validation experimentation

Experi-ment No.	Process Parameters Used		
	Discharge current, I (A)	Pulse-on time, T_{on} (µs)	Pulse-off time, T_{off} (µs)
1	12.5	500	10
2	21.87	10	1000
3	12.5	1000	500
4	3.12	500	500
5	21.87	10	10

The comparative performance characteristics, MRR obtained by the developed Flexible Machine Controller is shown in Table 3. The maximum deviation of MRR value obtained is 3.81% when the discharge current was the lowest (I = 3.12 A). The said deviation observed in case of MRR is attributed to the spark gap maintained between the work piece and tool electrode due to low amperage of the discharge current and different room temperature while performing the experimentation. (Pilot experiments were performed at room temperature of 8°C–10°C and validation experiments were performed at room temperature of 40°–42°C).

Table 3. Comparison of MRR

Sr. No.	MRR (mm^3/min)		Deviation (%)
	Pilot Experiment	FMC Experiment	
1	24.4328	23.9156	2.11
2	6.7862	6.60872	2.61
3	10.1199	10.3812	2.58
4	0.3822	0.3967	3.81
5	55.7261	56.5336	1.44

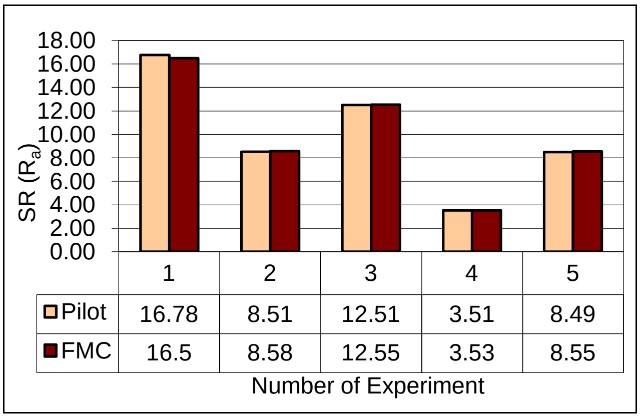

Figure 5. Comparative analysis of surface roughness (R_a) for AISI 52100

Figure 5 shows the variation of surface roughness values, R_a observed with the developed FMC as compared to the pilot experimental results. The results indicate a maximum variation observed for surface roughness values being 1.67%.

Therefore, the results indicate good comparison between the Original Machine Control die sinking EDM machining and the developed Flexible Machine Control die sinking EDM machining.

7. Performance Evaluation

Experiments were designed as per industrial requirement [17], three operations were performed; rough, semi-finish and finish, successively to produce a cavity on the work piece with the copper tool electrode. Same values of input process parameters were used for both (with developed FMC and OMC) experimentations. All other die sinking EDM process parameters like depth of cut (= 0.5 mm), polarity, submerged flushing were kept constant. Six work piece material selected for experimentations were AISI 1040, AISI 52100, AISI D2, AISI M2, AISI P20 and AISI A2 steel whereas tool material used was copper.

The performance parameter used for evaluation was machining time. Table 4 shows the machining time, t_m in minute obtained for different work piece materials. Two sets of experiments were performed with the developed FMC and OMC die sinking EDM machine. The average t_m was calculated for individual work piece material and each controller. Table 4 also shows the percentage variation of machining time with the developed FMC.

Figure 6 illustrates the machining time taken to complete the three machining operations for developed FMC die sinking EDM machine and OMC die sinking EDM machine with different work piece materials. It has been observed that the material AISI P20 takes maximum machining time and the material AISI D2 takes minimum machining time in case of both the controllers. Further, it has been observed that the developed FMC takes 13.12% (5.30 minutes) less machining time for AISI 1040 material as compared to the time it takes on OMC die sinking EDM machine.

Table 4. Machining time for different work piece materials

Controller Type	Ex. No.	t_m (in minute) for work piece material					
		AISI 1040	AISI 52100	AISI M2	AISI D2	AISI P20	AISI A2
Original Machine Controller	1	43.29	43.07	40.55	38.3	55.24	44.34
	2	41.37	37.19	40.11	33.35	56.38	46.26
Average, t_m→		42.33	43.73	40.33	35.82	55.81	45.3
Flexible Machine Controller	1	37.24	43.17	38.37	32.39	54. 38	41.55
	2	36.31	43.3	39.42	32.32	54.52	40.11
Average, t_m →		36.77	43.23	38.89	32.35	54.45	40.83
Variation of t_m (%)		13.12	1.14	3.57	9.69	2.44	9.87

Figure 6 also shows that OMC die sinking EDM machining takes more time for all six work piece materials as compared to the developed FMC. The main cause is that the work piece material loses heat during the manual switchover of machining operations. The range of variation of machining time with the developed FMC was in the range of 1.14 % (for AISI 52100) to 13.12 % (for AISI 1040).

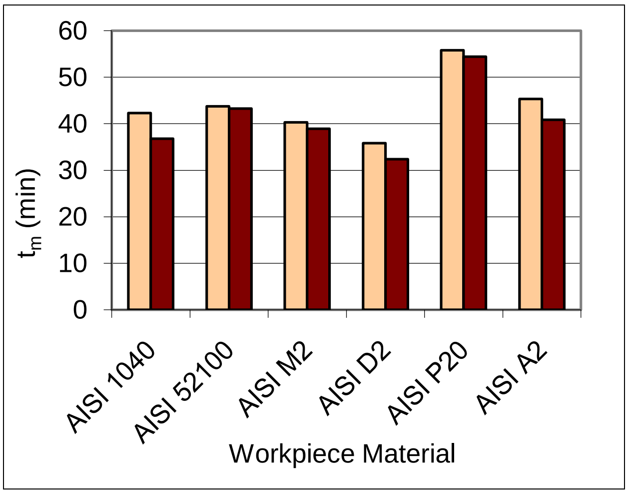

Figure 6. Comparison of machining time of developed FMC and OMC for different work piece materials

The developed Flexible Machine Controller has been found to be very useful as compared to original die sinking EDM machine.

8. Conclusion

After validating the experimentation results obtained with the developed Flexible Machine Controller, the performance characteristic was analysed and the conclusions drawn from the said results are as follows:

- The experimental data base was generated for six different types of work piece materials viz. AISI 1040, AISI 52100, AISI D2, AISI M2, AISI P20 and AISI A2 with copper as tool electrode.
- The validation experimentation carried out with the developed Flexible Machine Controller gives a maximum deviation of 3.81% in case of Material Removal Rate(MRR) and 1.67% in case of surface roughness(R_a) for AISI 52100 material. The results indicate very good agreement between the Original Machine Control die sinking EDM machine and the developed Flexible Machine Controller.
- Experimentations performed for evaluating the machining time with Original Machine Control die sinking EDM machine and the developed Flexible Machine Controller shows less time taken for machining. The said variation of machining time being in the range of 1.14% (for AISI 52100) to 13.12% (for AISI 1040).
- The experimentations results clearly indicate that for all the work piece materials, developed Flexible Machine Controller takes less machining time as compared to machining on Original Machine Control die sinking EDM machine.

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