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Fundamental investigation on Laser-Micro EDM based micromachining technology

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14. ABSTRACT
Micromachining is a promising technology for the production of miniaturized parts. Laser micromachining is widely used for this purpose. Laser micromachining has advantages because of its higher material removal rate (MRR). However, its main disadvantage is the poor
machining quality due to the heat affected zone (HAZ). On the other hand, micro-electrodischarge machining (microEDM) can fabricate better quality micro features due to the absence of the dominant HAZ zone. Though, this enhancement comes at the cost of very low MRR. To overcome the problem associated with these two types of machining, a hybrid technique is required to integrate the advantages of LASER micromachining and microEDM. In the hybrid process a rough machining is carried out first by LASER followed by a fine operation using microEDM. Thorough fundamental investigation of 3-D micromachining based on Laser and microEDM has not been carried out yet. Therefore, this research targets to investigate LASERmicroEDM based combined micromachining technique. We will retrofit an existing microEDM machine by integrating a modular fiber laser head. A mathematical model will be developed
from basic heat conduction model to predict how the proposed hybrid processing technique will affect feature profile, MRR and HAZ. Further experimental validation and optimization of the process parameters will be carried out to achieve best machining performance. The successful completion of this project will provide comprehensive knowledge about LASER-micorEDM based hybrid operation. This knowledge can be used for fabricating miniature parts for aerospace industry (such as micro holes for turbine blade cooling), automotive industry (micro holes for fuel nozzle), healthcare sector (micro-features for a cardiac stent), and electronic industry (interconnectors for circuits), etc. In future, the expertise developed from this project can be employed for developing new manufacturing machine. The future machine will be more sustainable from an environmental perspective as it will combine two machining operations into
a single platform.

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Technical Report: Fundamental Investigation on Laser-EDM Based Micromachining Technology (FA2386-18-1-4037)

1. Abstract

Micromachining is a promising technology for the production of miniaturized parts. Laser micromachining is widely used for this purpose. Laser micromachining has advantages because of its higher material removal rate (MRR). However, its main disadvantage is the poor machining quality due to the heat affected zone (HAZ). On the other hand, micro-electro-discharge machining (microEDM) can fabricate better quality micro features due to the absence of the dominant HAZ zone. Though, this enhancement comes at the cost of very low MRR. To overcome the problem associated with these two types of machining, a hybrid technique is required to integrate the advantages of LASER micromachining and microEDM. In the hybrid process a rough machining is carried out first by LASER followed by a fine operation using microEDM. Thorough fundamental investigation of 3-D micromachining based on Laser and microEDM has not been carried out yet. Therefore, this research targets to investigate LASER-microEDM based combined micromachining technique. We will retrofit an existing microEDM machine by integrating a modular fiber laser head. A mathematical model will be developed from basic heat conduction model to predict how the proposed hybrid processing technique will affect feature profile, MRR and HAZ. Further experimental validation and optimization of the process parameters will be carried out to achieve best machining performance. The successful completion of this project will provide comprehensive knowledge about LASER-micorEDM based hybrid operation. This knowledge can be used for fabricating miniature parts for aerospace industry (such as micro holes for turbine blade cooling), automotive industry (micro holes for fuel nozzle), healthcare sector (micro-features for a cardiac stent), and electronic industry (interconnectors for circuits), etc. In future, the expertise developed from this project can be employed for developing new manufacturing machine. The future machine will be more sustainable from an environmental perspective as it will combine two machining operations into a single platform.

2. Introduction

2.1 Background study

The demand for microproducts and components are rapidly increasing in automotive, aerospace, electronics, optics, medical devices and communications industries (Rajurkar, Sundaram, & Malshe, 2013). Therefore, micromachining is drawing more and more attention by the researchers around the world. There are various ways to carry out micromachining operations. However, all the processes can be broadly categorized into two major classes namely beam based micromachining and tool based micromachining (Rahman et al., 2010). Laser micromachining and micro electro-discharge machining are examples of beam based and tool based micromachining respectively. Laser micromachining techniques are being used by various industries such as automobile, medical semiconductor and solar cell industries (Fernando A. Lasagi, 2011). Laser machining is a fast manufacturing process but, the end products from conventional Laser micromachining suffers from Heat Affected Zone (HAZ) (Jabbareh & Asadi, 2013). Moreover, for deep engraving Laser micromachining causes the structures to be tapered (Ghosal, Manna, & Lall, 2014). The use of ultra-short pulse Laser machining may overcome the problem of HAZ however, ultra-short pulse laser system is very expensive and material removal rate (MRR) is significantly slow (Meijer et al., 2002). On the other hand, microEDM can produce parts with good quality if compared to conventional Laser machined products (A. Al-Ahmari, Rasheed, Mohammed, & Saleh, 2015), it is also a cheaper solution than ultra-short pulse Laser machining system. However, the machining rate is also considerably slower for microEDM process. MicroEDM process is usually carried out in two ways. The first technique is called die sinking EDM which is basically a 1D motion of the EDM tool/die to create the imprint of the die on the workpiece. Example of die sinking microEDM is to create fine holes for nozzles. The second technique uses a cylindrical tool to scan in 3D motion, like conventional milling to create 3D micro patterns on the workpiece. So far researchers have tried to use Laser-microEDM hybrid processing only for 1D operation i.e for die sinking case to create fine holes at a faster rate (A. Al-Ahmari et al., 2015) (Li, Diver, Atkinson, Giedl-Wagner, & Helml, 2006). Laser assisted other machining processes have been reported by various researchers. Some examples of Laser assisted machining operations are Laser assisted turning, Laser assisted milling, Laser assisted water jet machining etc (Lee, Woo, Kim, Oh, & Oh, 2016). Researchers also reported Laser –microEDM based hybrid assembly system for miniature products (Zhu, Dhokia, Nassehi, & Newman, 2013), although, hybridization of scanning 3D microEDM and Laser micromachining has not been reported so far. Some researchers conducted research on the improvement of microEDM technology by introducing workpiece vibration (Rajurkar et al., 2013). Vibration of the workpiece improves the smooth removal of the debris from the workzone thus enhances the material removal rate (MRR).

Modeling of Laser micromachining is important for predicting HAZ and taperness of the machined product. Yang et. al (Yang, Brandt, & Sun, 2009) developed a fundamental model based on basic heat conduction equation for Laser machining process. Mishra et. al (Mishra & Yadava, 2013) also took a similar approach for modelling the HAZ zone, taperness and MRR for Laser machining process. Ghosal et al (Ghosal et al., 2014) developed a statistical modeling framework to detect the above. The input parameters that they considered are Laser power, frequency, gas pressure etc. Some researchers also used Artificial Neural Network (ANN) based method for modeling Laser micromachining process.(Patel, Sheth, & Patel, 2016) (Mehrabi, Azdast, Benyounis, & Moradi, 2017). Teixidor et. al. modeled laser micromachining process using machine learning approach (Teixidor, Grzenda, Bustillo, & Ciurana, 2015).

Many researchers have also contributed on modelling of EDM process. Many of them (Somashekhar, Panda, Mathew, & Ramachandran, 2013), (Deshmukh, 2013),(Shao & Rajurkar, 2015) developed the model from basic heat conduction equation. Several researchers modeled microEDM process using the ANN method(Porwal & Yadava, 2012) (Mathew, Calicut, Dean, & Calicut, 2014)(M.S.Vijayanand & M.Ilangkumaran, 2016). Other approach like response surface methodology based modeling for EDM process was carried out by different researchers (Assarzadeh & Ghoreishi, 2013).

2.2 Motivation of research

Laser micromachining and Micro electro- discharge machining (microEDM) are two widely used methods in the field of non-conventional micromachining. Laser machining has a problem of poor machining quality. However, the processing time for Laser machining is very fast. On the other hand material removal rate (MRR) hence the processing time for microEDM is quite slow, but the end product is of superior quality as compared to Laser machined products. A laser-microEDM based hybrid technique can produce fine quality machined parts with lower machining time. **However, not much investigative research has been carried out on Laser-**

microEDM based hybrid process for 3-D micro machining. Further a fundamental mathematical model is required to understand the insight of this proposed hybrid process. The model will also help us to understand how different Laser and microEDM machining parameters such as scanning speed, Laser power, microEDM will affect outcome of the hybrid processing techniques such as MRR, HAZ and taperness.

2.3 Significance of the research

Successful completion of this project will create new knowledge about Laser-microEDM based hybrid machining process, which will have significant impact on the micro manufacturing sector of the world. Furthermore knowledge obtained from this project may lead subsequent development of new machine that can carry out the above mentioned hybrid micromachining process. Also this project may lead to developing new intelligent algorithm to predict product quality and production time for different material when using Laser-MicroEDM based hybrid process. This new hybrid technique has several potential applications in various industrial sectors such as aerospace, automotive, biomedical, MEMS, and Si microfabrication etc.

3. Statement of Objectives

The main aim of this research is to investigate various aspect of Laser-microEDM based hybrid micromachining process to find the answer of the research questions described above. To achieve this we have identified core research objectives.

1. To experimentally investigate the Laser-microEDM based hybrid process.
2. To derive a mathematical model for describing the Laser-microEDM based hybrid micromachining technique using ANN based approach.
3. To validate the model output and the experimental findings.

4. Results and Discussions

In the first stage of our research we have conducted thorough experiments to observe the laser parameters' effects on the overall performance of the laser-microEDM (LBMM-µEDM) based hybrid micromachining process. Our study suggests that if an increased scanning speed at a lower laser power is used for the pilot hole drilling by the LBMM process, it could result in significantly slower µEDM machining time. On the contrary, if the higher laser power is used with even the highest scanning speed for the pilot hole drilling, then µEDM processing time was faster than the previous case. Similarly, µEDM time was also quicker for LBMMed pilot holes machined at low laser power and slow scanning speed. Our study confirms that LBMM-µEDM based sequential machining technique reduces the machining time, tool wear and instability (in terms of short circuit count) by a margin of 2.5 x, 9 x and 40 x respectively in contrast to the pure µEDM process without compromising the quality of the holes.

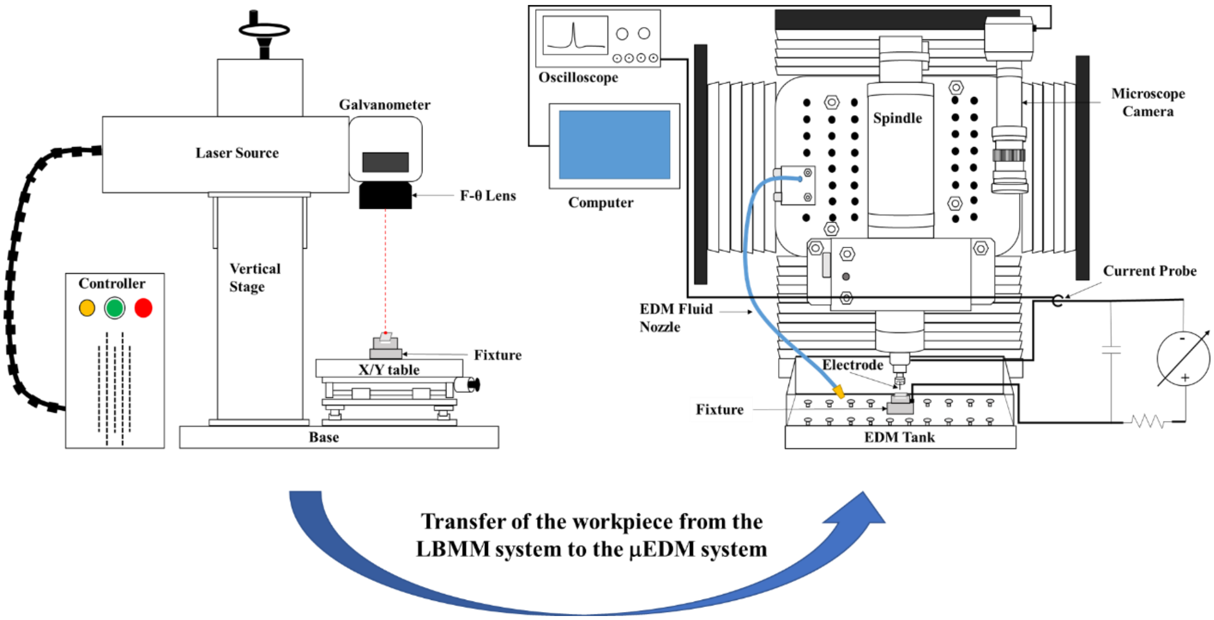

Fig.1: Schematic illustration of the sequential micromachining process LBMM-μEDM.

Fig. 1 shows the illustration of the process of conducting the propose LBMM-μEDM process.

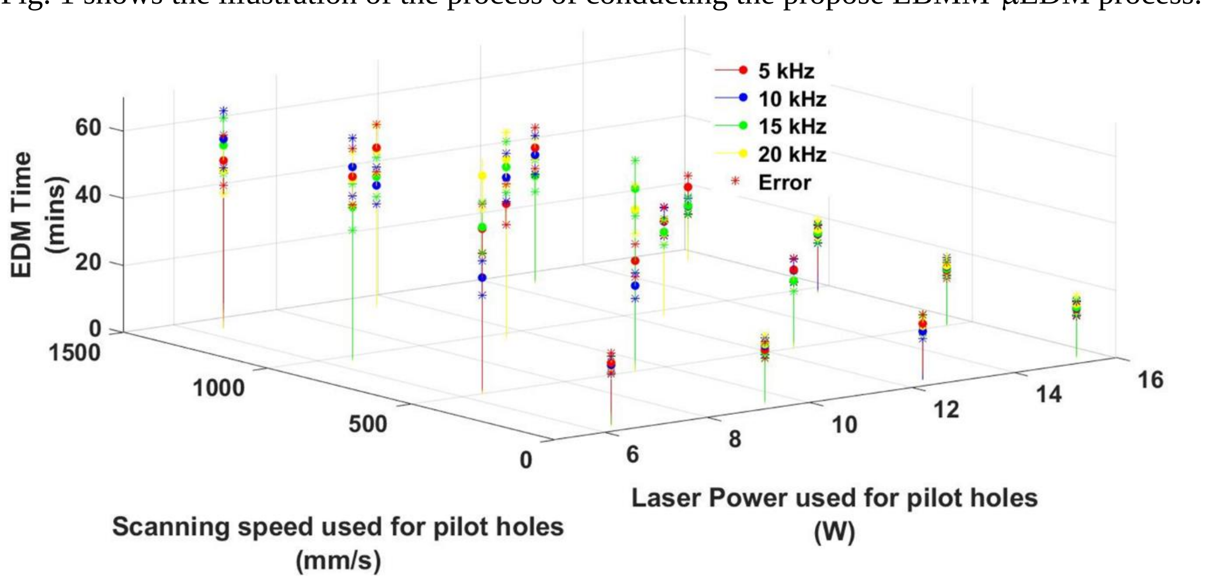

Fig. 2 The effect of the incident laser power, scanning speed and pulse frequency (used for the pilot hole machining) on the μEDM processing time for the final finishing of the pilot holes. The error bar represents the machining uncertainty.

Fig.2 demonstrates how the μEDM machining time is varied for the pilot holes drilled with various laser power, scanning time and pulse frequency. Our study confirms that pulse frequency has no significant effect on the μEDM machining time. We observed that pilot holes machined with higher laser power and slower scanning speed requires lesser time to be fine finished by μEDM. However, for the LBMMed holes machined with fast scanning speed, the effect is the opposite.

In the next stage of our research we have conducted the mathematical modeling of the laser-microEDM (LBMM-μEDM) based hybrid micromachining process. Our experimental study observed that the μEDM finishing operation's various output parameters are influenced by the morphological condition of the LBMMed holes. Hence, an artificial neural network(ANN) based dual-stage modeling method was developed to predict the sequential process's outputs. The first stage of the dual-stage model was utilized to predict various LBMM process outputs from different laser input parameters. Furthermore, in the second stage, LBMM predicted outputs (such as pilot hole entry area, exit area, recast layer, and heat affected zone) were used for the final prediction of the sequential process outputs (i.e., machining time by μEDM, machining stability during μEDM in terms of short circuit/arcing count and tool wear during μEDM). The model was evaluated based on the average RMSE (Root Mean Square Errors) values for the individual output parameters' complete set data, i.e., μEDM time, short circuit/arcing count, and tool wear. The values of Average RMSE for the parameters as mentioned earlier were found to be 0.1272(87.28% accuracy), 0.1085(89.15% accuracy), 0.097 (90.3% accuracy), respectively.

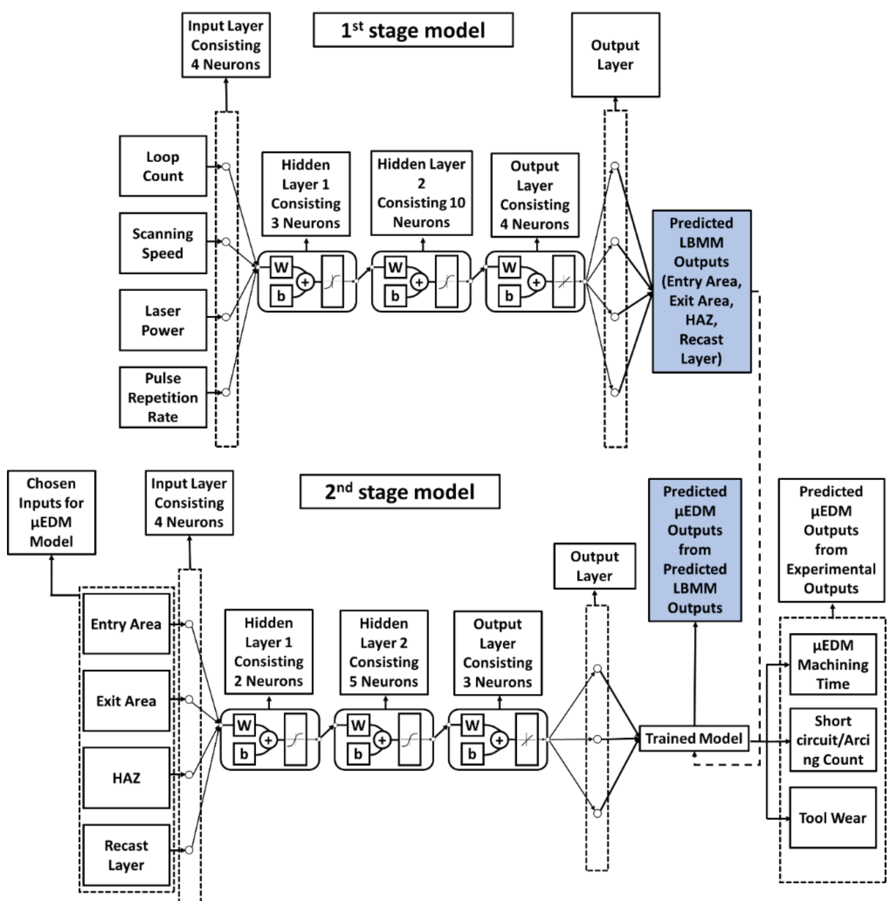

Fig. 3 Flow and architecture of the proposed dual-stage ANN model for the LBMM-μEDM process

Fig.3 illustrates the complete flow and the architecture of the proposed dual-stage sequential model for the LBMM-□EDM process. The model was implemented using MATLAB software. It can be seen from Figure 5 that the first stage of the model (for LBMM) has two layers with 3 and 10 neurons, respectively, in the first and second layer. For the second stage (for μEDM), the number of layers was two, with 2 and 5 neurons in the layers. The activation function used in the hidden layers and the output layer was the sigmoid function and linear function. The option for two layers was selected as we observed from our preliminary training that a network deeper than two layers did not improve the network performance much in terms of prediction accuracy for training and test data set. Next, the hidden layers' size was optimized by iterating the model from 1-1 topology to 20-20 topology. For every combination of hidden layer size, the root mean square error (RMSE) value of each predicted variable was computed, and the average RMSE of all variables was calculated for both the training and test datasets. The average RMSE for the training data was decreased with a more complicated (with a high number of neurons) topology. However, the average RMSE for the test dataset was found to have the lowest value for a certain number of neurons in each hidden layer selected for deciding the network's topology, as stated above. Using the optimized hidden layer size, the MIMO model was iteratively trained 100 times. The average RMSE of all the output variables (both for training and the test dataset) was computed and stored in an array during the training. The model was then chosen with a low and similar average RMSE for the train and the test dataset. Both the stages of ANN modeling applied the strategy mentioned above for selecting the best-fitted model.

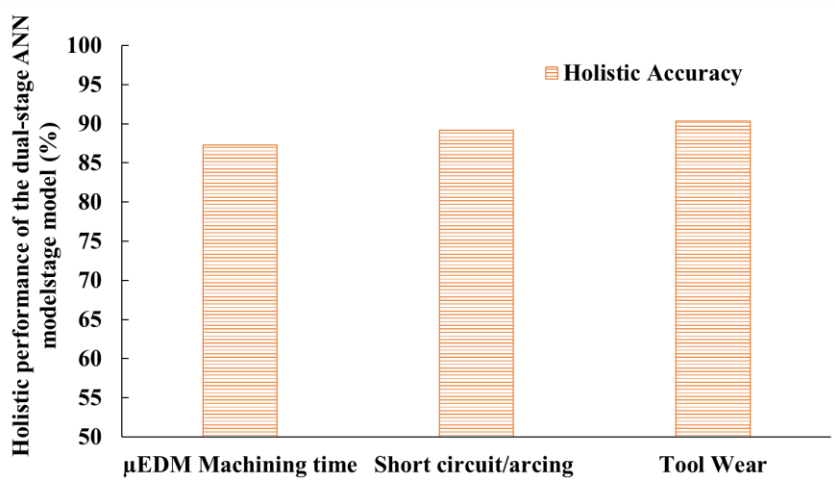

Fig 4: Holistic performance of the dual-stage ANN model for μEDM machining time, short circuit/arcing count, and toot wear.

The corresponding holistic prediction accuracy of the dual stage model is shown in Fig 4, which is in a range of (~87% to ~90%).

5. Conclusions

Thanks to Allah SWT, we managed to achieve all the objectives of the project. This project has resulted two Q2 WoS publications and few more are in the pipe line.

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