

Design Fabrication and Testing of Tool Feeding system for In-situ Tool Grinding in Micro-EDM

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ABSTRACT: In micro-EDM the size of the tool used will be of micro dimension. Attachment of micro-tool to the spindle collet is very difficult task because it may not be positioned to the spindle axis. There is need for In-situ tool grinding to prepare the tool on spindle itself. In EDM it is required to maintain a “spark gap” between tool and workpiece, hence there should be a feeding system which continuously maintain the “spark gap” between the tool and workpiece. This paper includes design and development of Flexural Amplified Piezo actuator(FAP) for feed control in In-situ tool grinding setup. Here two different Flexural Amplifiers are designed and analysis is carried out for finding Stiffness, Amplification Factor and Resonance frequency. Electromechanical Forward and Inverse model of the Flexural amplifier are simulated. Experimental evaluation of the stiffness of the flexural amplifier is carried out to compare the analytical and experimental results.

KEYWORDS: Micro-EDM, Flexural Amplified Piezo actuator, In-situ tool grinding.

I. INTRODUCTION

Electric Discharge Machining (EDM) is a non-Conventional, non-Contact, thermoelectric, machining process with no tool force. This process can be used for both electrically conducting and semi-conducting materials, with no regard to their other physical properties. In EDM the tool electrode and workpiece are separated by a small gap of the few hundred microns and connected to the positive and negative terminals of the DC power supply. The small gap called the “spark gap” filled with a dielectric. When the voltage applied across the spark gap is sufficiently high the dielectric breaks down and allows a spark discharge between the electrodes. Thermal energy released which removes material from the workpiece through melting and evaporation.

Principle of material removal in micro-EDM is same as that of conventional EDM but employs micro size tool electrodes and energy involved is also small. By precisely controlling the amount energy released, it is possible to machine micro features on any electrically conductive material. For every pulse, discharge occurs at a particular location where the electrode materials are evaporated or ejected in the molten phase then a small crater is generated both on the tool electrode and workpiece surfaces. The removed material is then cooled and re-solidified in the dielectric liquid forming several hundreds of spherical debris particles which will be flushed away from the gap by the dielectric flow. At the end of the discharge duration, the temperature of the plasma and the electrode surfaces that is in contact of the plasma rapidly drops, resulting in the recombination of ions and electrons also the recovery of the dielectric breakdown strength

In-situ is a Latin phrase which means “on site” or “in position” Attachment of micro tool to spindle collet is very difficult job because of micro dimensions. If micro tool is attached it may not be positioned at the spindle axis, which may cause run out of tool. Producing micro tool for different diameter separately is not efficient, hence larger diameter tool can be reduced on the spindle to the required micro size by in-situ tool grinding. To produce the tool of

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Special Issue 9, May 2016

micro diameter stationary sacrificial block grinding method is used. In stationary sacrificial block the grinding block is fixed. Usually rectangular cross section is used as stationary block. Rotating tool is fed against the sacrificial block to reduce tool diameter.

II. DESIGNING A TOOL FEEDING SYSTEM FOR IN-SITU TOOL GRINDING

In in-situ tool grinding it is required to give continuous feed motion, hence an optimum machining gap is maintained between the tool (sacrificial block) and workpiece (tool electrode) for micro-EDM. Hence it is required to design and develop a suitable tool feeding system to achieve the inter-electrode gap.

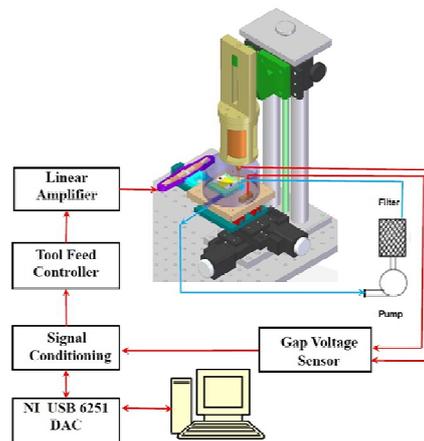


Figure.1. Micro-EDM setup with In-situ tool grinding attachment

Figure.1. shows the Micro-EDM setup with In-situ tool grinding attachment. The micro-EDM setup is a final assembly of 1) Spindle Assembly 2) X-Y Stage Assembly and 3) In-Situ Tool Grinding Attachment. In Micro- EDM there are two electrodes one is tool (sacrificial block) and other is Workpiece (tool electrode). The tool electrode(workpiece) is attached to the spindle and the sacrificial block(tool) is kept inside the work tank. Both tool(sacrificial) and workpiece (tool electrode) are dipped in a dielectric medium such as kerosene supplied into the work tank through the filter and recirculating pump. Flexural Amplified Piezo actuator is used to give the feed motion to the work tank assembly with the help of linear slide. When both electrodes come close to each other, the dielectric medium which is initially nonconductive becomes conductive. During this period sparks will be generated between the electrode. By precisely controlling the amount energy released, it is possible to machine micro features on any electrically conductive material. The gap between the tool and workpiece is sensed by the gap voltage sensor, from this unwanted noise signals are eliminated in the signal conditioning unit. The function of the tool feed controller is to generate the suitable voltage signal according to the gap between the tool and workpiece. This voltage is suitably amplified by the linear amplifier and given to the FAP to produce feed motion to the work tank assembly. The function of the X-Y stage is to give transverse movement to the work tank assembly. In In-situ tool grinding attachment Workpiece is tool electrode and tool is sacrificial block, fixed in the work tank. Work tank is mounted on the linear slide which in turn mounted on the baseplate. FAP is fixed on the base plate and free end is connected to the work tank. Displacement of the FAP displaces the work tank and thus the tool feed is achieved.

III. DESIGNING FLEXURAL AMPLIFIED PIEZOACTUATOR FOR TOOL FEEDING IN IN-SITU TOOL GRINDING

A Piezoelectric actuator converts an electric signal into a precisely controlled physical displacement. Flexural Amplified Piezo-actuator(FAP) consist of 6 piezoelectric stack actuator each of dimension 10*10*20mm.The assembled isometric view of FAP is shown in the Figure 2. The Flexural Amplifier designed is of 35mm in height and 145mm in the width. By considering the stack cross section, the thickness of the Flexural Amplifier is kept as 10mm

The material selected is spring steel. Force displacement analysis of the flexural amplifier is carried out to determine the stiffness and amplification factor.

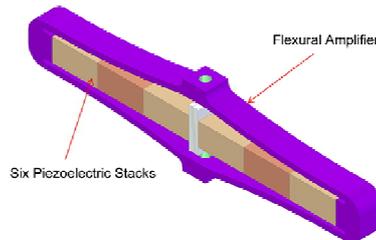


Figure 2 Design of Flexural Amplified Piezo actuator with Stacks

The isometric view of the flexural amplifier design 1 is shown in figure 3(a) the dimension of the flexural amplifier is based on the force displacement analysis carried out in ANSYS 16.2 software. Based on several analyses another optimum design for the flexural amplifier is selected which is shown in Fig 3(b).



Figure 3(a) Flexural Amplifier design-1



Figure 3(b) Flexural Amplifier design-2

IV RESULTS AND DISCUSSIONS

Design of Flexural Amplifier will be based on its Stiffness and Amplification Factor, which is determined by using ANSYS 16.2 mechanical APDL. Stiffness is defined as the rigidity of the object that means, the extent to which it offers resistance to the deformation in response to the applied Load. Amplification factor is the ratio of second order to first order deflections that is ratio of Z-direction displacement to the X-direction displacement.

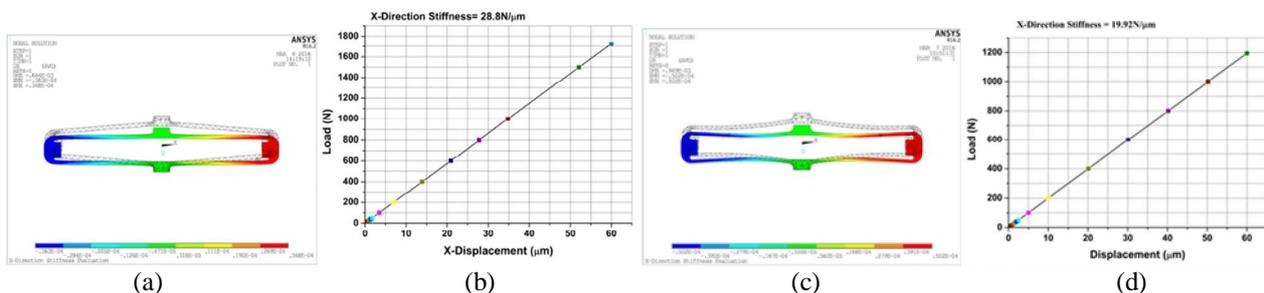


Figure 4 X-direction Stiffness Evaluation of Flexural Amplifier design-1 and design-2

Figure 4(a) shows the X-direction stiffness evaluation of the full section Flexural Amplifier design-1 by applying the load in the horizontal X-direction. Flexural amplifier is fixed at the bottom and kept free at the top. Analysis is carried out for different values of the load and corresponding X-direction displacement are recorded. X-direction stiffness is calculated by plotting a graph of Load Vs X-direction displacement. Slope of the graph gives the X-direction stiffness of the Flexural Amplifier design-1 which as shown in the figure 4(b) The X-direction stiffness of the Flexural amplifier obtained from the graph is 28.8N/µm. Figure 4(c) shows the X-direction stiffness analysis of the complete section Flexural Amplifier design-2 by applying the load within the horizontal X-direction. Flexural Amplifier is fastened at

all-time low and unbroken free at the highest. Analysis is administrated for various values of the load and corresponding X-direction displacement are recorded. X-direction stiffness is calculated by plotting a graph of Load Vs X-direction displacement. Slope of the graph provides the X-direction stiffness of the Flexural Amplifier design-2 that as shown within the figure 4(d) The X-direction stiffness of the Flexural Amplifier obtained from the graph is 19.92N/ μ m.

Amplification Factor is defined as the ratio of Z-direction displacement to the X-direction displacement. Amplification Factor is determined by taking a half section of the Flexural Amplifier, it is Analyzed by applying the different load Horizontally in the X- direction. Flexural Amplifier is Fixed at the bottom and upper end is set free only in the Z-direction. Both Z-direction displacement and X-direction displacement for different Load are recorded. Figure 5(a) Shows the Analysis result obtained from ANSYS 16.2 APDL for half section of the Flexural Amplifier design-1. Amplification Factor is Evaluated by plotting a graph of Z-direction displacement vs X-direction displacement, Slope of the Graph gives the Amplification Factor which is 18.5 as shown in the Figure 5(b).

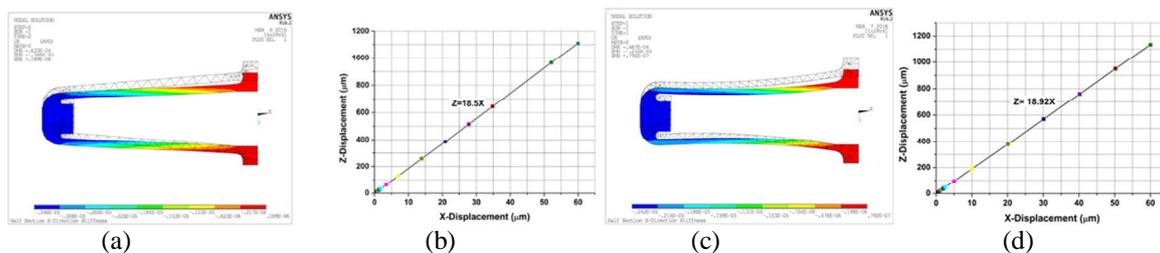


Figure 5 Amplification factor determination of Flexural Amplifier design-1 and design-2

Figure 5(c) shows the Evaluation of the Amplification factor at a load of 100N for Flexural amplifier design-2. A plot of Z-direction displacement Vs X-direction displacement is plotted for different Loads which is included in Figure 5(d) from the Fig Amplification Factor is found to be 18.92 for Flexural amplifier design-2

Harmonic analysis of Flexural Amplifier to determine the resonant frequencies of the Flexural Amplifier. A known magnitude of force is applied along Z-direction of the Flexural amplifier analysis is carried out in ANSYS 16.2 mechanical APDL for a frequency range of 100Hz-2000Hz with 190 stepped sub steps. Resonant frequency of the Flexural Amplifier is obtained from the plot of amplitude vs frequency as shown in the Figure 6(a) and 6(b) From the plot the resonant frequency of the Flexural Amplifier design-1 is approximately 300 Hz and for Flexural Amplifier design-2 is approximately 260Hz.



Figure 6 Harmonic analysis of Flexural amplifier design-1 and design-2

Flexural Amplified Piezo-actuator is used for tool feed control in tool grinding setup for micro-EDM. Unlike other type of actuation systems, the displacement of piezoelectric actuators can be directly related to the applied voltage. However, they exhibit hysteresis behaviour between the applied voltage and the output displacements. This behaviour can be simulated through a mathematical model. The Maxwell's slip model is one of the mathematical models used to eliminate hysteresis in this work. Mechanically, this kind of behaviour could be modelled by using the combination of an ideal spring element and an ideal coulomb friction element.

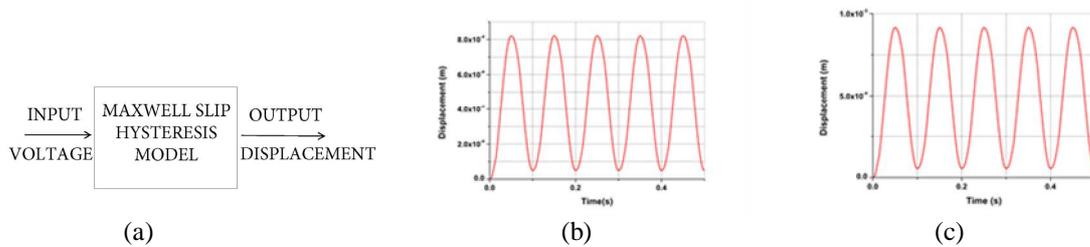


Figure 7 Simulink Block Diagram and simulation results for electromechanical forward model

Simulation is carried out to eliminate the hysteresis effect. Figure 7(a) Shows the Simulink block diagram of Electromechanical Forward model. The model consists of several (10) Maxwell’s slip equation in parallel. MAT Lab software is used for simulation. Input to the model will be sin wave with 75V amplitude and 20Hz frequency. Numerical values of stiffness and amplification factor of the Flexural Amplifier will be used in the block diagram to determine the displacement of the Flexural Amplifier. From Figure 7(b) displacement of Flexural amplifier design-1 is 812µm and design-2 is 912µm shown in Figure 7(c).

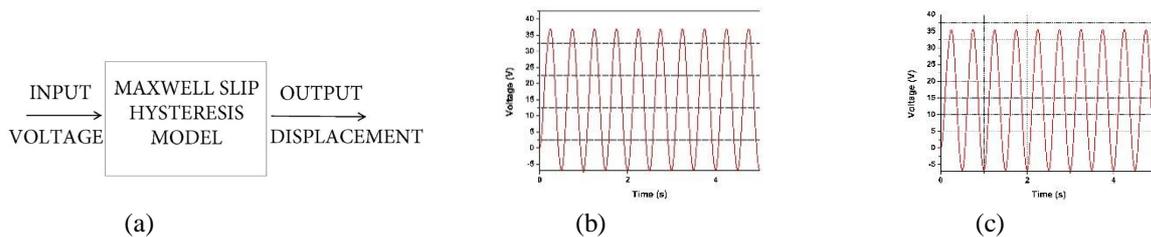


Figure 8 Simulink Block Diagram and simulation results for electromechanical inverse model

Figure 8(a) shows the Simulink block diagram of electromechanical Inverse model. Basically this model is used to determine the voltage required to produce a particular displacement. Figure 8(b) shows the simulation results of electromechanical Inverse Model for design-1. An input sine waves of 100µm amplitude displacement and frequency of 2 Hz is given to block it produces a voltage of 38V. Similarly, design-2 produces a voltage of 35V for same input as shown in figure 8(c).

Experimental Evaluation of Stiffness of Flexural Amplifier

Flexural Amplifier is Fabricated as per design using Wire-EDM Machine. After the Fabrication of the Flexural Amplifier it is required to experimentally determine the Stiffness. Figure 9(a) and 9(b) Shows the Fabricated Flexural Amplifier. A Force Sensing Resistor(FSR) is used sense the force that is being applied and voltage amplifier circuit will convert the applied force into equivalent voltage and displacement sensor is used to measure the displacement of the flexural amplifier for corresponding force. The FSR is basically a variable resistor whose resistance will decrease with increase in the applied force. Figure 10 shows the Force Sensing Resistor(FSR).



Figure 9 Fabricated Flexural Amplifier design-1 and design-2



Figure 10 Force sensing Resistor(FSR)

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Vol. 5, Special Issue 9, May 2016

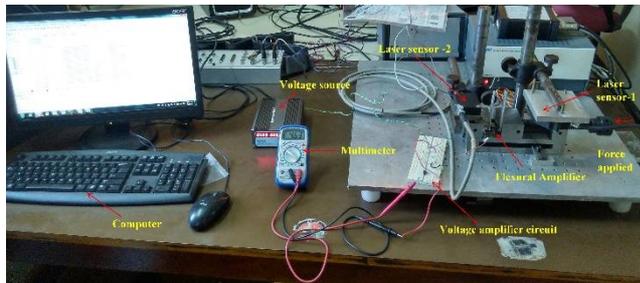


Figure 11 Experimental setup for Stiffness evaluation

Table 1. Experimental Results from stiffness evaluation

Flexural Amplifier design-1			Flexural amplifier design-2		
Voltage (V)	Force (N)	Stiffness (N/μm)	Voltage (V)	Force (N)	Stiffness (N/μm)
4.47	19.63	0.130	4.40	16.55	0.080
4.53	23.073	0.128	4.57	19.639	0.072
4.61	29.116	0.116	4.54	23.073	0.063

Figure 11 shows the experimental setup for stiffness evaluation of the flexural amplifier. Voltage amplifier circuit used is Wheatstone bridge with one of the arm as FSR. Flexural Amplifier is placed in between the vice and force is applied gently. Two laser displacement sensors are used to measure deformation of the flexural amplifier for applied force. The value of applied force is calculated by calibrating the voltage amplifier circuit for different loads. Table 1 shows the experimental results for stiffness evaluation, from table average value of stiffness for Flexural Amplifier design-1 is 0.124N/μm and stiffness for Flexural Amplifier design-2 is 0.071N/μm.

V. CONCLUSION

In this work design of a tool feeding system for In-Situ tool grinding in micro-EDM was carried out. Flexural Amplified Piezo actuator is designed to give required feed motion to the work tank. This Flexural Amplifier is analysed in ANSYS 16.2 Mechanical APDL to determine the X-direction Stiffness, Amplification Factor, and Z-direction Stiffness. Two different designs are analysed. A plot of Load Vs X-direction stiffness is plotted to estimate the X-direction stiffness; slope of the plot gives the X-direction stiffness. Similarly, Amplification Factor is found. Harmonic analysis of Flexural Amplifier is carried out to determine the resonant frequency. Modelling and Simulation of Flexural Amplifier is done in MAT Lab software for forward model and inverse model. In comparison with Flexural amplifier design-1 and design-2, from simulation results it is evident that flexural amplifier design-2 yields better displacement of 912μm while design-1 gives 812μm.

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