Experimental Setup for Hot Turning using Induction Heating Application.

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Abstract: This study has been done for the feasibility of the induction heating in hot machining process, specifically in the Hot Turning Methodology. The experimental setup has been prepared for the machining of the hard to cut material, the hard to cut materials are generally termed as it is having poor machinability. The hot turning methodology brings feasibility for machining hard to cut material at ease. The experimental setup introduced in this study is a unique setup. Lot of studies have developed different types of heating setup, that includes, Oxy acetylene flame heating, Ultrasonic Heating, Laser beam heating, Induction heating etc. This study will discuss the development and the selection of the Induction heating as a Heating application for the hot turning methodology of machining.

IndexTerms **– Hot Machining, Hot Turning, Induction Heating, Hard to Cut Material, Arduino, K Type Thermocouple, IR Thermometer.**

I. INTRODUCTION

Dealing with the material having high hardness and strength, it is always hard to cut. Hot machining can be used for machining of such material. Many researchers have tried for hot turning / hot machining methodology with different heating setup. This research has been focused on the heating application with induction heating methodology. The designing of the induction heating setup including copper coil, power supply, and induction heating unit has been carried out in this research. The selection of the heating application methodology has been carried out from the extensive literature review. The induction heating setup is the least explored area of research, that lead to exploration of such heating setup in the hot machining. A part from heating setup, the heat sensing or temperature sensing is also a critical activity to be done during machining. Heat sensing elements has also been explored here. The research includes the feasibility of the heat sensing using K-Type Thermocouple interfacing with Arduino Mega and IR Thermometers, which is also known as pyrometer, a non-contact type thermometer used for temperature sensing. By considering all such parameters, this research will conclude the experimental setup with Induction heating methodology with using proper heat sensing instrument.

II. FLOW OF WORK

The flow of hot turning is as shown in figure 1.

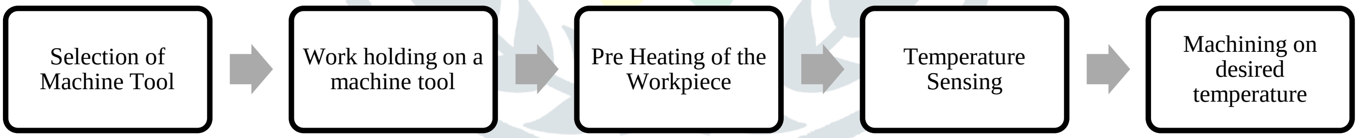

Figure 1 Flow of Hot Turning Methodology

As shown in figure, all the steps are very critical, from selection of the machine tool to the machining of the hard to cut material. The flow states that the first step is to select the machine tool, machine can be selected from availability of machine speed and feed. The work holding on machine tool is very important step, as the heating setup can be placed according to the place of the machine tool. The pre heating of the workpiece can be carried out then, the temperature sensing is to be done simultaneously with the heating. The temperature monitoring will help to get the feedback about the temperature, on desired temperature, the heating can be stopped and the machining can be carried out. The actual setup and flow of work is explained in the next section.

III. EXPERIMENTAL SETUP

The experimental setup has been fixed on the listed criteria, the feasibility test was carried out before finalization of the experimental setup.

1. Selection of Machine Tool and Cutting Tool
2. Selection of Induction Heating Unit
3. Selection of Supporting Accessories

1. Selection of Machine Tool and Cutting Tool

The selection of the mechanical component includes the selection of the machine tool, selection of the cutting tool. The machine tools has been selected by the requirement of the cutting speed, feed and depth of cut i.e. cutting parameters. For hot turning, any lathe machine or CNC Turning centre can be selected. The selection of the cutting tool is a very crucial step. It has been selected on the requirement of the machining. The requirement can be the hardness of the cutting tool, the hardness of the workpiece material, the geometry of the cutting tool, type of cutting to be done during machining i.e. either facing or roughing, sometimes simultaneous operation are also done, for these factors the selection of the machining tool and cutting tool are very crucial. For this research, as per below given figures, the cutting tool and machining tools has been selected. The specification of the machining tool is given in the table 1.

Figure 3 Ceramic Cutting Tool with TNMG8135 grade

Figure 2 Lathe Machine at Pruthvi Engineers Pvt. Ltd. GIDC, Anand

Table 1 Specification of Machine

Specification of Machine Tool
Make: MaxCut *Drive: V Belt Drive* *Mode: Manual* *Length of Bed: 6'* *Spindle Range: 40 -950 RPM* *No. of feed: 19 (0.04 – 0.485 mm/rev)*

The cutting tool can be specified from its grade and its geometry, according to the industry expert the ceramic tools are generally used for the roughing operation and as desired by the experimental research, we have selected this cutting tool as shown in figure 2 [1].

2. Selection of Induction Heating Setup

The selection of Induction heating setup is very important in hot turning methodology, the induction heating setup generally includes, the heating coil, ZVS module (Zero Voltage Switching), power supply and other wirings. This research has done first feasibility checking for the setup and based on the results the final selection has been made.

2.1 Feasibility test of Induction Heating

Various combinations of induction module was tested with various design on the induction coil. The feasibility in keeping the induction coil design is as given below,

1. Round coil/Circular coil
2. C type coil.

The feasibility test of using coil is tested on both design. The coil winding has been carried out on the lathe machine. The coil turn and diameter has been calculated as per the size of the workpiece. The round coil and C type coil has been designed and wounded for the feasibility test. The coil has been designed to connect with the ZVS module. The details of the module is show in below figure.

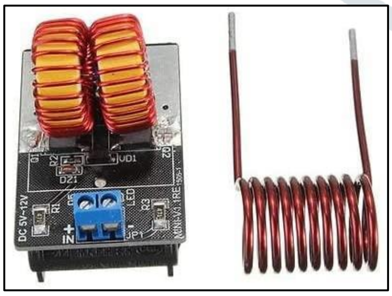

Figure 6 ZVS Module [4]

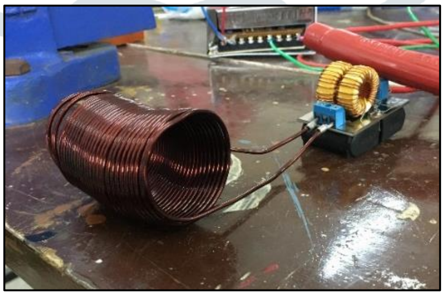

Figure 5 ZVS Module with Round Coil

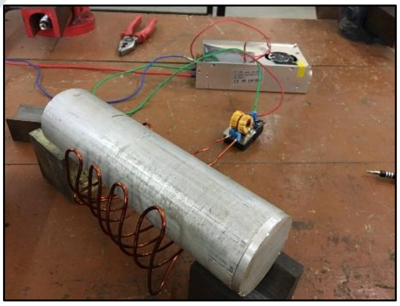

Figure 4 ZVS Module with C Type Coil

The specification of ZVS module was 5V~12V miniature low voltage module, which can be connected with the power supply with higher current capacity to increase the power drawing to the coil. For feasibility 12V and 25Amp power supply has been used which can draw power of around 300 W. As shown in figure the testing has been carried out on the below considered points,

1. Non rotating workpiece
2. Rotating workpiece
3. Coil Design
4. Diameter difference between workpiece and coil diameter
5. Power supply and power consumption testing
6. Temperature measurement testing

Based on the criteria the below conclusion has been carried out.

Table 2 Conclusion on Feasibility Test of Induction Heating

Feasibility Criteria	Observations
Non rotating workpiece	• Proper heating was observed. • Heating rate was low due to power supply selection. • It was taking 25 mins to reach 200 ºC temperature in a mild steel material, which is very low rate.
Rotating workpiece	• Heating rate was very low. • It was taking 25 mins to reach 140 ˚C which is very low rate. • One of the reason for low heating was power supply selection. • With the rotating workpiece, the back current was induced in the coil and that has been resulted into high heating at the ZVS module side. It damaged the module. • So this is one of the major criteria while selecting a rotating workpiece.
Coil Design	• 2 coil design had been analysed 1. Circular Coil – Proper heating was observed in the circular shaped coil. With non-rotating workpiece. 2. C-Shaped Coil – Coil heating was observed at the bending of the coil. Very low rate of heating.
Diameter difference between workpiece and coil diameter	• For +/- 10 mm diameter difference between the workpiece and coil, proper heating was observed. • For +/- 20 mm diameter difference the heating rate was reduced. • As per induction heating principle, the heating object should kept nearer to the coil to get the maximum output of the power supply.
Power supply and power consumption testing	• 300 Watt power supply module was taken here, which was very low and due to it the heating in the workpiece was also very much low. • A higher power of module was required to design.
Temperature measurement testing	• K type thermocouple was used for testing the temperature, it worked well during non-rotating condition. • At the time of rotating condition, the different type of non-touch type of sensor must be used to get the proper heating temperature measurement.

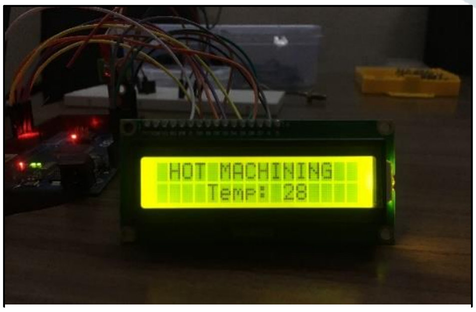

Figure 8 LCD Display for Temperature Sensing

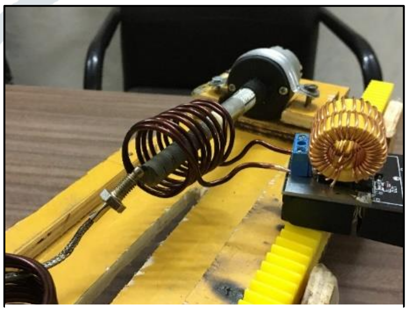

Figure 7 Feasibility with Circular Coil in Rotating workpiece

As per these observations, the more feasibility test was required for selection of induction heating as a primary heating unit. The major change identified were,

1. Power Supply
2. ZVS Module
3. Coil design to be fixed at circular coil
4. Temperature sensor must be of non-contact type.

2.2 Final Selection of the heating setup

1. Power Supply

The induction heating power supply requirement can be designed on the below parameters,

- Workpiece Material
- Heating Temperature requirement
- Heating time
- Inductor coil material
- Length of heating
- Diameter of workpiece

Based on this parameter the power supply requirement has been calculated as per shown in figure 3.24. The calculation was conducted on https://www.plustherm.com/power-calculation.html. [2]

The selection criteria were taken as given in table.

Table 3 Requirement for design of Power Supply

Sr No	Criteria	Requirement
1	Workpiece Material	Die Steel
2	Heating Temperature requirement	200˚C to 600˚C
3	Heating time	1-2 Minutes
4	Inductor coil material	Cu (Copper)
5	Length of heating	25 – 50 mm
6	Diameter of the Workpiece	ϕ 30 - 60

Calculation:

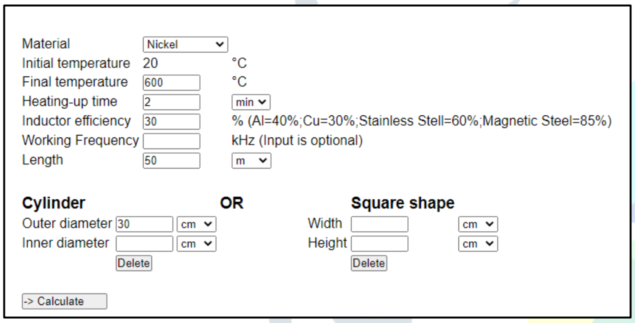

Figure 10 Calculation for Power Design [5]

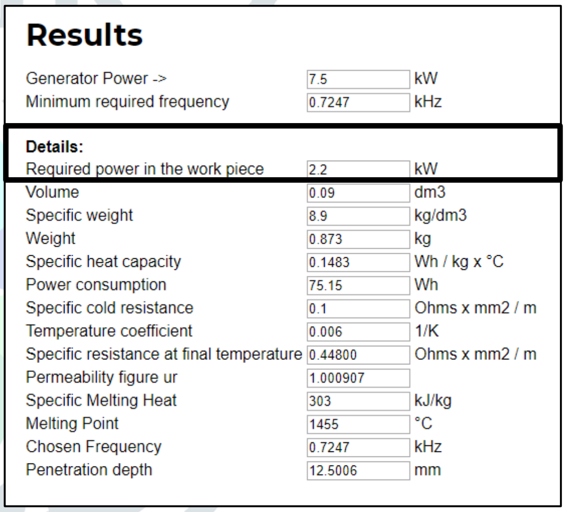

Figure 9 Result of the Calculation

So it resulted to the requirement of the workpiece power as 2.2 kW. Based on it, the induction power supply can be selected with rating of 2.2 kW. Based on this calculation, the ZVS module can be selected accordingly.

2. Induction Coil

The induction coil must be in round shape and with the φ 40-50 mm. Based on it the material diameter can be selected.

3. Temperature Sensor

For sensing temperature measurement the pyrometer/thermal gun IR sensor can be selected. The setup for continuous measurement of the temperature can be made by fixing the temperature gun location.

Based on the conclusion of the feasibility test, the final setup has been finalised as per below given components with their specifications.

Figure 11 ZVS Module [6]

Figure 12 Power Supply [6]

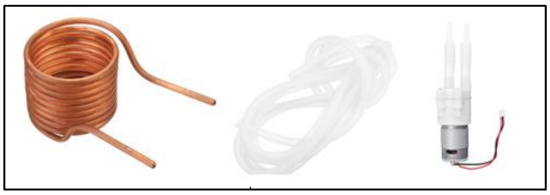

Figure 13 Copper Coil Setup - Round Coil, Cooling water pump and pipes

The use of ZVS Module is to carry the power supply to the induction coil for heat transfer to the desired object. This is the main unit for the induction heating which included different diodes, resistors, fuse, heat sink etc. The model is ready made available in the market that has been used for this experiment. The modules is further connected with the induction cu coil as shown in the next figure. The power supply used to connect the ZVS module is of rating 48 Voltages and 50 Amp which comes to the power of 2.4 kilo watt. Which is as per the requirement of the heating setup for this research. Such high power supply leads to high energy consumption and with it high rate of temperature generation due to heating the coil. Copper coil setup consist of 3 different parts, Copper coil with diameter of 45-50 mm. Cooling water pump, which is used to cool the heating coil. The water pump to deliver the coolant water in the coil during heating operation. The coil heats with the very high temperature and to avoid the cut off or the damage to the coil, the coil needs to be cooled during the heating, so the pipe and pumps are provided in the setup.

Figure 16 MCB Switch [6]

Figure 15 Final Parts for Induction Heating

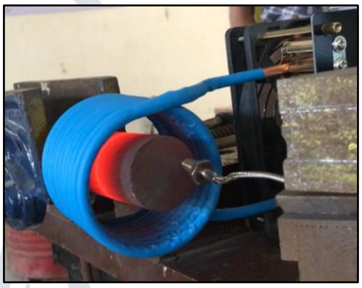

Figure 14 Heating check at 600ºC

Miniature Circuit Breaker switch is used to cut off the supply, if there is any disturbance in the circuit or at high temperature when the coil is not able to take further current, at that time this MCB breaks the circuits and disconnect the power supply from the ZVS module. Generally this MCB is connected with the Load and the Power Supply.

3. Selection of Supporting Accessories

The supporting accessories includes the heat sensing instruments, the heat sensing can be done by using either K-type thermocouple interfacing with the Arduino, or we can select IR non contact type thermometer / pyrometer. This section will discuss both the instruments.

3.1 K Type Thermocouple with Arduino Interface

Type K are the most widely used thermocouples in the Oil & Gas, and refining industries due to their wide range and low cost. They are occasionally referred to as Chromel-Alumel thermocouples. Note that above about 750°C oxidation leads to drift and the need for recalibration. K-type of thermocouple's temperature range is 0˚C to 1260˚C [3]. Max6675 module is compatible with Arduino Mega. The selection of Arduino Mega is required based on the requirement of I/O ports. This is used to interface between different sensors with the computer. We can get the output serially or parallel on the computer. For this experimental setup 3 analog and 3 digital I/O ports are required.

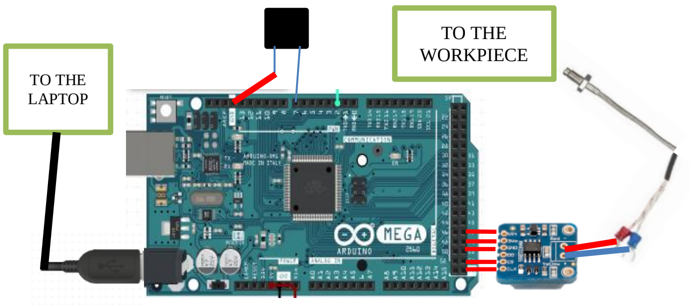

Figure 17 Block diagram for K-Type Thermocouple Connection

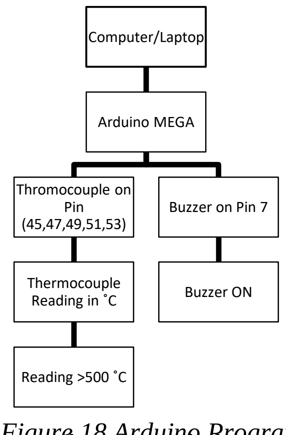

Figure 18 Arduino Programming Flow Chart

The interfacing of K-type thermocouple having range up to 1200 ˚C. In above circuit diagram the Arduino is connected with Laptop/Computer, thermocouple is connected with Arduino digital pin 45,47,49,51,53 where 45 is used for ground, 47 is used for VCC, 53 is used for SO, 51 is used for CS and 49 is used for CSK. The buzzer is connected with pin 06 of digital pin and it is used to indicate us when the temperature will go above the desired temperature. For this experiment we have set 500˚C. The display of the temperature can be taken by the LCD interface and also on Laptop screen. As shown in figure 13, we have used laptop screen to display the temperature.

3.2 IR Temperature Sensor

Figure 19 IR Temperature Sensor

For sensing the temperature during pre-heating as well as during cutting, IR Temperature gun also known as IR Laser infrared digital temperature thermometer has been selected. In figure the temperature thermometer range was from ~ -50ºC to 1240ºC. The temperature gun was provided by Metal Heat Treat situated at GIDC Anand. The thermometer used to check even the temperature of the cutting tool during and after the machining.

IV. WORKING SETUP

Figure 21 Final Setup on Machine at Pruthvi Engineers, GIDC Anand

Figure 20 Temperature Sensing During Pre Heat

Figure 24 Machining at High Temperature

Figure 23 Smooth Chip Formation during machining

Figure 22 Post machining Surface

As shown in the figures 20 to24, the final experimental setup with induction heating has been carried out at the Pruthvi Engineering pvt. Ltd. At GIDC, Anand. The heating setup worked efficiently and successful experimentation was carried out. The experiments were taken at 3 different level of heat 200ºC, 400ºC and 600ºC. The induction heating setup worked very well, the reaction time for heating was very good, to heat upto 600ºC the setup took only 1.5 minutes that is a very good response time.

IV. CONCLUSION

The idea of hot machining setup is feasible with the induction heating, the experiments by using this heat application turned out successfully. The induction heating is the fastest method of heating application and precise too. During machining with heating, a smooth cutting has been observed and the surface finish was also looked well. The future investigation can be made on surface roughness, cutting force measurement, tool life, material removal rate, power consumption, tool wear etc. This method is the best suitable for very hard to cut material, during experiment, the material considered for the machining was HCHC D3, die steel with hardness of 50-52 HRC. The selected cutting tool worked very well with such hard material. In future the same machining fundamentals can be applied on the milling machine operations. During the machining, the heat loss was calculated earlier so the extra heat has been given to the workpiece and accordingly the cutting has been carried out. In future, it’s a scope to develop an induction heating setup with continuous and controlled heat supply.

V. ACKNOWLEDGMENT

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