# Development of a System to Control Flow of Coolant in Turning Operation

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ABSTRACT

*Automation of cooling system in machine tools is an effective method for achieving higher productivity and increased tool life. A cooling system* is *designed to control the operating temperature on the cutting tool tip by circulating coolant through a reservoir built on the top of the machine tool. This arrangement maintains the coolant flow rate as per variation of cutting tool tip temperature sensed by LM-35 temperature sensor which is located 1 cm away* (*calibrated distance) from the cutting tool tip and whose output voltage is linearly proportional to the temperature. Coolant flow rate is varied in such a manner that the temperature of the cutting tool tip remains within fixed value of temperature. The aim of present work is to develop a cooling control panel system to provide coolant on cutting tool tip in turning operation of mild steel. The coolant flow rate can be increased or decreased as per the variation of sensor temperature during turning of mild steel with high speed steel (HSS) cutting tool at different depth of cut, and spindle speed ,keeping feed rate constant which results in effective cooling of the cutting tool tip. The experiments were carried out with and without use of coolant. It supplies the coolant as per instructions of cooling control panel system which results in saving of coolant as well as power. The mechatronics application of designed cooling control panel system enabled the reduction in cutting tool tip temperature in more robust way as compare to conventional cooling system.*

**Keywords:** *Centre Lathe; Cutting Tool, Cooling Control Panel System; Coolant; Temperature Sensor*

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## Introduction

The challenges in machining are to achieve high dimensional accuracy of work part, surface finish, high production rate, less environmental effect as well as cost saving. These responses are strongly influenced by various machining factors such as tool geometry and work-piece material, turning process parameters, cutting tool material, coolant etc [1]. Hasib et al. [2] have observed that the main functions of coolant in machining are to reduce the friction at the interface of tool –chip and tool workpiece, cool both chip and tool as well as to remove the chip.

In turning operation, high temperature is generated which causes various problems like high tool wear in high heat affected zone, change in hardness, as well as work-piece microstructure, burning and micro-cracks. The problems of temperature raised could be reduced through the application of cutting fluid by conventional methods. But in conventional method, it can reduce in some extent through cooling in cutting zone because cooling rate is very low. Thus, for increasing the cooling rate the researchers have focus on alternative method instead of traditional flood cooling. The alternative technique referred as mist application of cutting fluid also known near dry machining.

This method can reduce the use of coolant which leads to environment friendly as well as economic benefits. The turning operation has been carried out in dry, flood and mist condition of cutting fluids. It has been seen that the mist application reduced 40% more tool-chip interface temperature than the conventional cooling methods. Benedicto et al. [3] have observed the application of coolants in machining process which is a matter of serious concern in terms of cost, environment and health issue. The alternative use of cutting fluid such as solid lubricants, cryogenic cooling, gaseous cooling, use of vegetables oil for cooling and Minimum Quantity Lubrication (MQL) in which oil is mixed with compressed air and uses in the form of drops or spray in the cutting zone which can reduce the environment and health issue.

In Oda et al. [4], the aim of this paper is to reduce power consumption by improving the machining process. Here it has been described that in machining process about 54% of total energy is consumed due to coolant related equipment. To reduce the energy consumption efforts are totally concentrated on coolant related equipments which caused the saving of energy approximately by 26%. Nandgaonkar et al. [5] explained the concept of water oil mist spray (WOMS) for cooling in machining as compare to MQL in which air is mixed with oil. It has been found that the use of (WOMS) causes better cooling as well as better tool life. Attanasio et al. [6] found that the use of MQL causes reduction in cutting fluid. When it is applied on rake face of tool, it does not produce the reduction of wear and same as in case of dry machining. When it is applied on flank surface it shows the appropriate reduction in tool wear as compare to dry condition.

Dhar et al. [7] paper deals with the use of MQL as coolant for turning of AISI-4340 steel at different speed-feed combination. Use of this technique causes a significant reduction in cutting temperature, tool wear and surface roughness as compare to the conventional cooling and dry conditions. Dhar et al. [8] have observed that in high production machining the application of conventional cooling is not suitable in terms of cooling, tool wear, and surface finish. The use of MQL shows significant results over the mentioned responses. Dhar et al. [9] work deals with the use of cryogenic cooling by liquid nitrogen jet in turning of AISI-4037 steel.

There are several benefits of using cryogenic as a coolant in turning zone as compare to the conventional flooded cooling and dry conditions. It has been seen that the use of liquid nitrogen jet on turning zone cause good reduction in cutting temperature, tool wear. It also provides good surface finish and better dimensional accuracy. The use of cryogenic cooling is harmless as it is also called as environment friendly and clean technology. N.R. Dhar et al. [10] have found the application of minimum quantity of lubrication (MQL) as a coolant while turning the AISI-1040 steel at different speed-feed combination shows a favourable condition as compared to the dry and conventional cooling conditions. Cutting temperature, dimensional inaccuracy and surface roughness get reduced to a great extent by using the MQL. Not only these, the use of MQL are environment friendly as well as enhance the machinability characteristic.

Shane et al. [11] investigates the use of cryogenic as a coolant in a new economical approach so that it can reduce the tool–work piece interface temperature and tool wear. Since machining of Titanium alloy Ti-6Al-4V is very difficult because of its high hardness, thus the tool life is extremely short in this condition of machining. Therefore, the use of cryogenic as a coolant in machining increases the tool life. In M.M.A. Khan et al. [12], the applications of MQL based on the vegetable oil as coolant in the turning of low alloys steel AISI 9310 have been observed more favourable as compared with dry and wet conditions. In this system the vegetable oil is sprayed with the help of air in heat affected zone which reduce the cutting temperature, tool wear, surface roughness, as well as environment pollution a great extent as compared with dry and wet condition.

Maurya et al. [13] have focuses on methodology presented by various researchers to investigate the mechanical properties of EN-36C alloy steel. The objective of this work is to control the flow rate of the coolant as per variation in the tool tip temperature so that appropriate cooling could be done without loss of coolant as well as power consumption. The cooling control panel system has been developed to response the supply of coolant as per the variation of tool tip temperature to obtain better surface finish and tool life. It is responsible for the saving of coolant and power consumption at any appropriate cutting process parameters.

## Methodology

In the present work, the turning operation has been performed on mild steel bars of same diameters with High Speed Steel (HSS) cutting tool at various process parameters keeping feed rate constant throughout the experiments in the Flat Bed Lathe machine (CA6161). The experiments were conducted with and without use of water-soluble oil coolant. The cutting conditions used in the experiments are given in Table 1. The complete flow chart of methodology is shown in Figure 1.

Table 1: Cutting Conditions for experiments

| Spindle speed(RPM) | 112 | 180 | 280 | 450 | 710 |
|---|---|---|---|---|---|
| Depth of cut (mm) | 0.4 | 0.6 | 0.8 | 1.2 | 1.4 |
| Length of cut (m) | | | 0.6 | | |
| Feed rate (mm/rev.) | | | 0.1 | | |

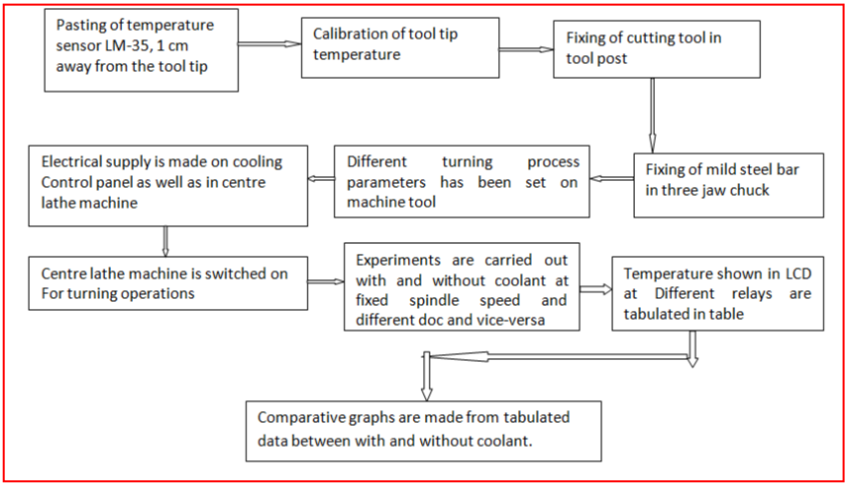


Figure 1: Methodology flow chart

## Development of Cooling Control Panel System

An important mechatronics cooling control panel system is based on the use of temperature sensor i.e. LM-35 and microcontroller ATmega-16 which has high-performance, low-power AVR® 8-bit microcontroller having operating voltages 2.7 - 5.5 V and speed grades 0 - 8 MHz. Sensor gives the temperature of the tool tip in centigrade which is displayed on the LCD. There is number of relays which give the signals at different set of temperatures as per the program of the microcontroller. The flow rate of coolant is controlled by switching off the relays step by step. Higher position of the relay gives the higher flow rate.

The proposed cooling control panel system has been developed to reduce the cutting tool tip temperature in more robust way as compare to conventional cooling system and measure the flow rate of coolant as per the variation of cutting tool tip temperature which is sensed by the sensor i.e. -35 Precision Centigrade Temperature Sensors and automatic on and off of the coolant flow as per the temperature variation of the tool tip. Cooling control panel system consists of number of components which is shown in Figure 2.

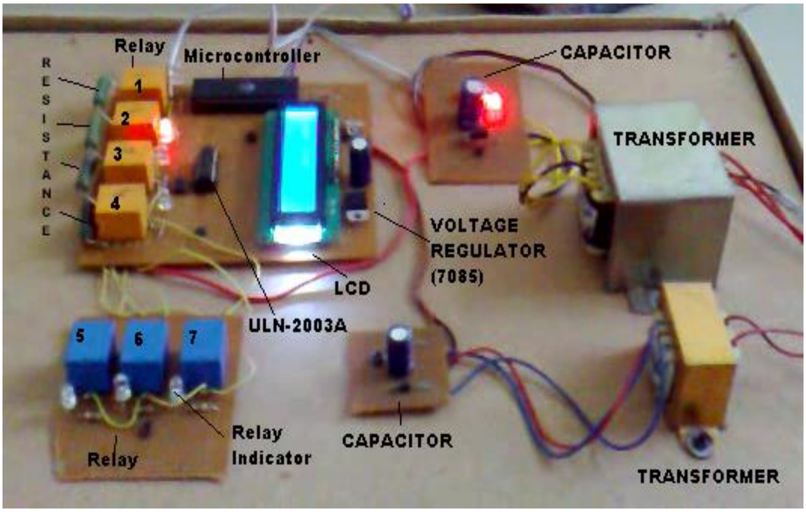


Figure 2**:** Cooling control panel system

## Calibration of Experimental Data

The following procedure has been adopted to perform the experiment on the cooling control panel system for the calibration of tool tip temperature vs. sensor temperature (LM-35) which is located 1 cm away from the cutting tool tip.

First, the cutting tool and thermometer has fixed in the burette stand in such a way that the tool tip as well as thermometer is dipped in the oil contained in glass beaker and placed it on stand. The oil glass is heated with sprit lamp continuously till the experiment is completed. The electrical supply is made to the cooling control panel system for running the circuit in response the LCD gets on and showing the normal temperature. Oil and tool tip temperature is displayed by the thermometer dipped in oil bath. LCD temperature is the temperature of sensor location which is fixed 1 cm away from the tool tip. The reading of tool tip temperature and sensor are recorded time to time.

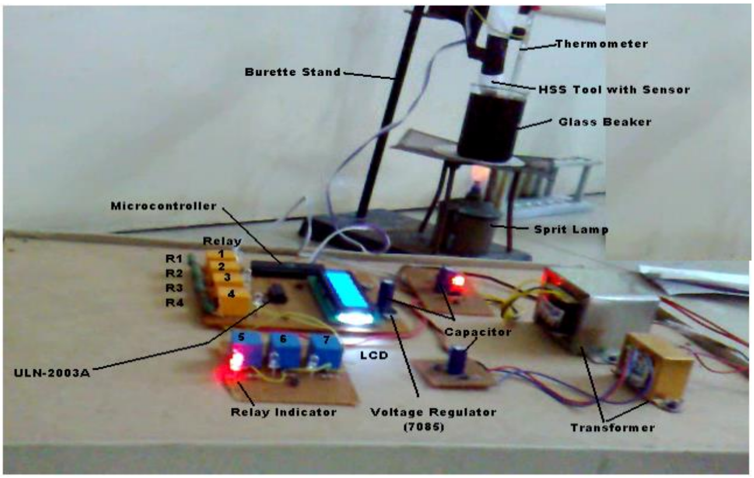


Figure 3: Experimental setup for calibration of tool tip temperature

Table 2: Calibration of tool tip temperature

| S.N. | Sensor temperature in °C | Tool tip temperature in °C |
|---|---|---|
| 1 | 37 | 80 |
| 2 | 40 | 90 |
| 3 | 46 | 97 |
| 4 | 50 | 102 |
| 5 | 56 | 108 |
| 6 | 61 | 113 |
| 7 | 66 | 118 |
| 8 | 71 | 124 |
| 9 | 73 | 126 |
| 10 | 78 | 130 |
| 11 | 81 | 131 |
| 12 | 83 | 132 |
| 13 | 85 | 134 |
| 14 | 90 | 139 |
| 15 | 91 | 140 |
| 16 | 95 | 142 |
| 17 | 101 | 144 |
| 18 | 104 | 150 |
| 19 | 107 | 153 |
| 20 | 111 | 157 |
| 21 | 113 | 159 |

As the LCD temperature reached 51 ºC, the first relay switched on as per the program of microcontroller. At this instant, the pump starts, and flow of coolant takes place, Noted down the reading of LCD and thermometer temperatures. As the temperature of LCD is reached 61 ºC, the second relay switched on and pump speed is increased in response to increase the flow rate of coolant. Again, noted down the readings of LCD and thermometer temperatures. The process is continued till the last relay is switched on at 121 ºC. Again, noted down the readings of LCD and thermometer temperatures. This is all about the calibration of tool tip temperature vs. sensor location temperature as shown in Figure 3. The sensor temperatures corresponding to tool tip temperature are observed through the LCD readings which are given in Table 2.

## Experimental work

After performing the calibration of tool tip temperature, the cooling control panel system is used to perform the turning operations on centre lathe machine at different depth of cut and spindle speed with and without coolant.

First, the cutting tool has been fixed in tool post, which contains the temperature sensor i.e. LM-35, 1 cm away from the tool tip and the tool tip made the contact with work piece i.e. mild steel bar which is fixed in three jaw chuck. The electrical supply is made on cooling control panel system for running the circuit in response; the LCD gets on and showing the normal temperature.

The different parameters has been set in centre lathe machine such as spindle speed, depth of cut, feed rate and the centre lathe machine is switched on, as the turning operation starts, the tool tip temperature starts increasing and the sensor temperature is displayed on the LCD which is fixed 1 cm away from the tool tip. As the LCD temperature reached 51 ºC the first relay switch on as per the programmed of microcontroller. At this instant the pump start and in response flow of coolant takes place. In similar way when the temperature of LCD is reached on 61 ºC the second relay switched on and the pump speed is increased in response the flow rate increased. This process is continued till the last relay is switched on at 121 °C. This experiment is carried out at fixed spindle speed such as 180, 280 and 450 rpm at different depth of cut such as 2 mm, 0.4 mm, 0.6 mm, 0.8 mm, 1 mm, 1.2 mm, and 1.4 mm with and without coolant flow. This experiment is also carried out at different value of fixed depth of cut such as 0.2 mm, 0.4 mm, 0.6 mm, 0.8 mm, 1 mm, 1.2 mm, and 1.4 mm at various spindle speed such as 112 rpm, 180 rpm, 280 rpm, 450 rpm, and 710 rpm with and without coolant flow. The experimental observation has been shown in Table 3 and Table 4.

Figure 4: Cooling control panel setup on center lathe machine

Flow rate of the coolant is measured with the help of measuring beaker and stop watch at the onset of different relay having different temperature such as 51 °C, 61 °C, 71 °C, 81 °C, 91 °C, 101 °C, 111 °C, and 121 °C which is shown in Table 5.

Table 3: Observation table at different speed

| Exp. No | DOC | N1 (180 rpm) | | N2 (280 rpm) | | N3 (450 rpm) | |
|---|---|---|---|---|---|---|---|
| | | Without coolant | With coolant | Without Coolant | With Coolant | Without Coolant | With Coolant |
| 1 | 0.2 | 40 | 40 | 38 | 24 | 40 | 24 |
| 2 | 0.4 | 45 | 45 | 62 | 26 | 75 | 27 |
| 3 | 0.6 | 55 | 55 | 85 | 28 | 100 | 32 |
| 4 | 0.8 | 75 | 75 | 100 | 30 | 125 | 34 |
| 5 | 1.0 | 85 | 85 | 110 | 43 | 135 | 36 |
| 6 | 1.2 | 100 | 100 | 120 | 36 | 165 | 38 |
| 7 | 1.4 | 110 | 110 | 145 | 40 | 185 | 44 |
| 8 | 1.6 | 122 | 122 | 160 | 45 | 220 | 48 |

Table 4: Observation table at different DOC

| Exp. No | Speed | D1=0.4 | | D2=0.6 | | D3=1.2 | | D4=1.4 | |
|---|---|---|---|---|---|---|---|---|---|
| | | Without coolant | With coolant | Without Coolant | With Coolant | Without Coolant | With Coolant | Without Coolant | With Coolant |
| 1 | 112 | 35 | 22 | 36 | 22 | 45 | 20 | 55 | 22 |
| 2 | 180 | 45 | 24 | 50 | 24 | 100 | 24 | 110 | 26 |
| 3 | 280 | 65 | 28 | 80 | 36 | 125 | 36 | 150 | 38 |
| 4 | 450 | 78 | 30 | 110 | 40 | 160 | 44 | 200 | 46 |
| 5 | 710 | 95 | 32 | 124 | 44 | 230 | 50 | 240 | 51 |

Table 5: Observation table for coolant flow rate

| S.N. | Tool tip temperature (°C) | Coolant flowrate (L/min) |
|---|---|---|
| 1 | 102 | 1.132 |
| 2 | 113 | 1.249 |
| 3 | 118 | 1.428 |
| 4 | 130 | 1.578 |
| 5 | 139 | 1.764 |
| 6 | 147 | 1.999 |
| 7 | 157 | 2.307 |
| 8 | 165 | 3.000 |

## Results and Discussions

Calibration data of tool tip which are obtained from experimentation have been listed in Table 2. It has been seen that there was a steep increase in the curve which has been obtained from the calibration data. Thus the graph shows that the data obtained from the experiments is quiet successful and correct which is shown in Figure 5.

The curve obtained from observations data at fixed spindle speed and different depth of cut is listed in Table 3 have been shown in Figure 6 (a), (b) and (c).The curve is drawn with tool tip temperature vs depth of cut in Figure 6 (a) without and with coolant at speed of 180 rpm. It is clearly seen that the curve obtained without coolant has gradual increase in slope because of less development of tool tip temperature at slow speed (180 rpm). Whereas the curve at the same speed with coolant has steep down slope as compared to without coolant which is favorable condition in turning operations. Similarly it could be seen in Figure 6 (b) and (c), but curve at the speed of 450 rpm has steep increase in slope without coolant as compare to curve obtained at speed of 180 rpm and 280 rpm. It is due to the higher development of tool tip temperature at high speed. Thus from graph, it is clear that the mechatronics application of designed cooling control panel system enabled the reduction in cutting tool tip temperature in more robust way as compare to conventional cooling system.

The curve obtained from observations data at fixed depth of cut and different spindle speed is listed in Table 4 have been shown in Figure 7(a), (b), (c) and (d). In Figure 7 (a), the curve is drawn with tool tip temperature vs spindle speed without and with coolant at fixed depth of cut of 0.4 mm, 0.6 mm, 1.2 mm and 1.6 mm. It is clearly seen that the curve obtained without coolant has gradual increase in slope because of less development of tool tip temperature at low depth of cut. Whereas the curve at the same depth of cut with coolant has steep down slope as compared to without coolant which shows favorable condition in turning operations. Similarly it could be seen in figure 7 (b), (c) and (d) but curve at the depth of cut of 1.2

mm and 1.4 mm has steep increase in slope without coolant as compare to curve obtained at depth of cut 0.4 mm and 0.6 mm. It is due to the higher development of tool tip temperature at high depth. Thus, from graph it is clear that the mechatronics application of designed cooling control panel system enabled the reduction in cutting tool tip temperature in more robust way as compare to conventional cooling system.

The curve of flow rate vs. tool tip temperature which is obtained from the experimental data listed in Table 5 is shown in Figure 7. The flow rate of coolant has been measured at variable tool tip temperature in liter/minute. It has been observed that the coolant flow rate increased with increase in temperature. The coolant flow rate has been found 1.13 liter/minute at tool tip temperature of 102 °C and 3 liter/minute at the tool tip temperature of 165 °C.

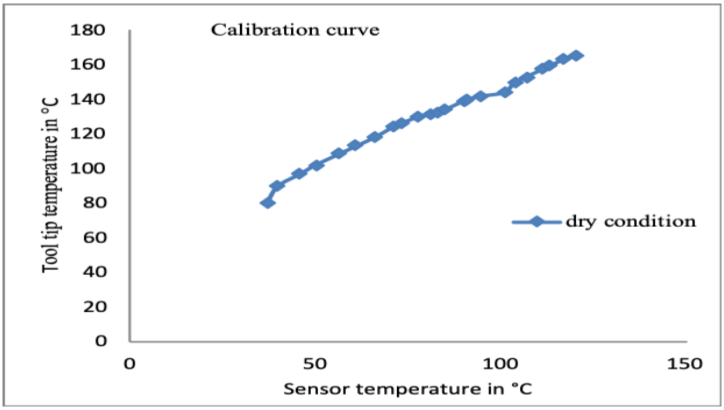


Figure 5: Calibration of tool tip temperature vs. sensor temperature

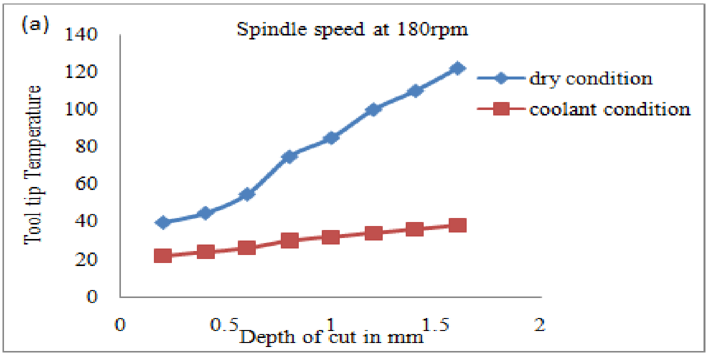


Figure 6 (a): Curve for tool tip temperature vs. depth of cut

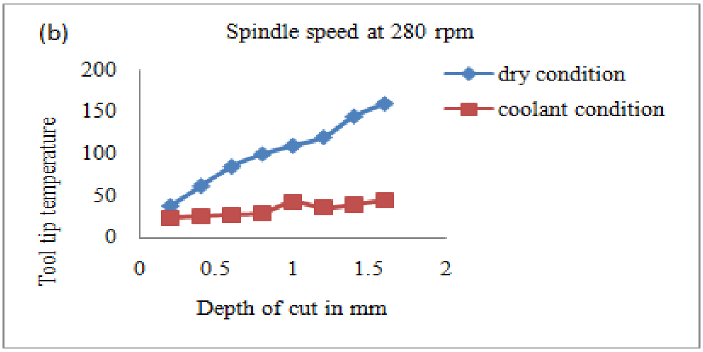


Figure 6 (b): Curve for tool tip temperature vs. depth of cut

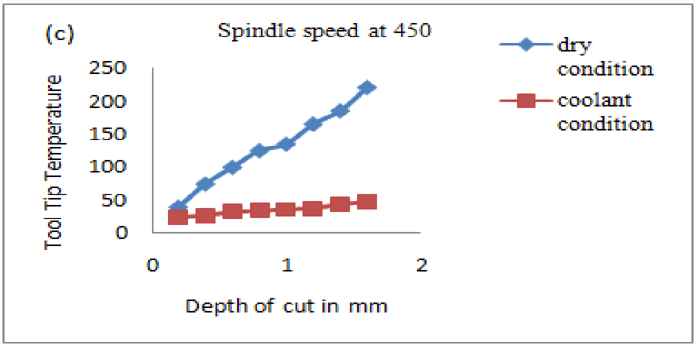


Figure 6 (c): Curve for tool tip temperature vs. depth of cut

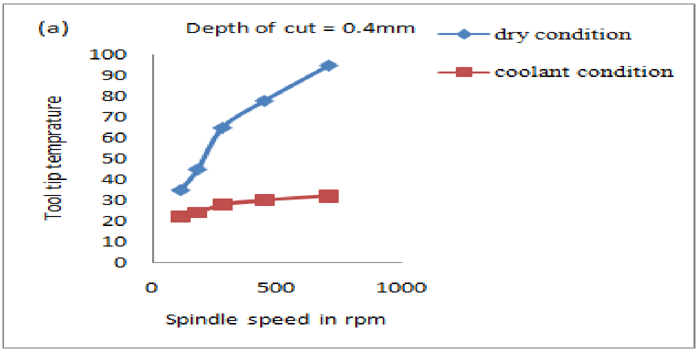


Figure 7 (a): Curve for tool tip temperature vs. spindle speed

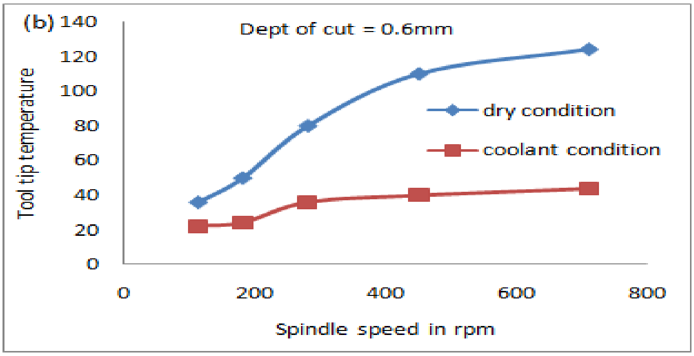


Figure 7 (b): Curve for tool tip temperature vs. spindle speed

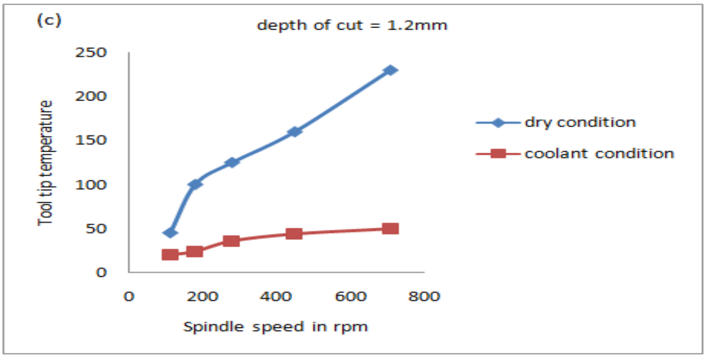


Figure 7 (c): Curve for tool tip temperature vs. spindle speed

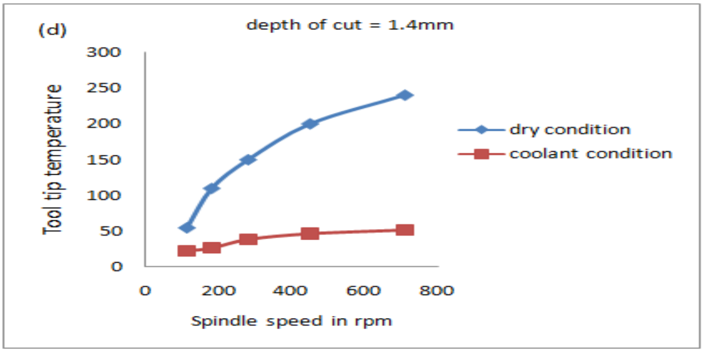


Figure 7 (d): Curve for tool tip temperature vs. spindle speed

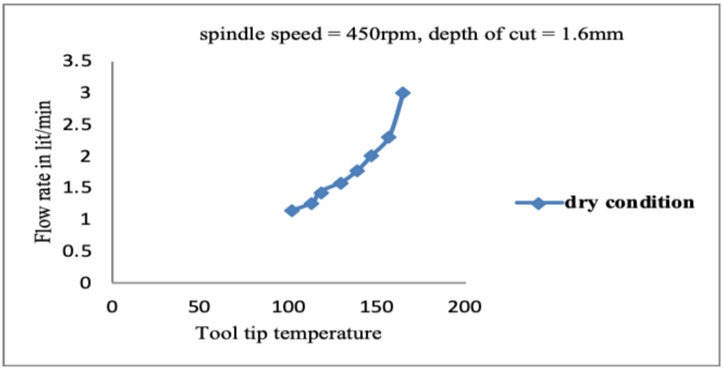


Figure 8: Curve for flow rate vs. tool tip temperature

## Conclusions

Based on the present experimental study, the following conclusions are drawn:

- Cooling control panel for the measurement of cutting tool tip temperature has been successfully designed and used to measure the tip temperature during turning operation.
- The coolant is supplied only when the sensor temperature has been reached at fixed value of 51 °C during turning operation which shows the tool tip temperature is about 94 °C. Below this sensor temperature of 51 °C, the coolant pump will always in off position which save the energy and coolant wastage. In case of conventional method, the coolant flow is continued which consume more power and wastage of coolant.
- Cooling control panel system can be used in any machining operation with changing the sensor location as per the position of the cutting tool in the machine tool.
- The cutting tool tip temperature has been found reduced drastically at various cutting speeds and depth of cut with the use of cooling control panel system.
- The coolant flow rate has been found increased in the given tool tip temperature range under dry machining at spindle speed of 450 rpm and depth of cut of 1.6 mm.

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