Arduino Uno-Based Tool Temperature Control Design Using A Cooling System In The Turning Process

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Abstract
The turning process generates heat due to the arrangement between the tool and the workpiece which can increase the temperature of the tool thereby accelerating tool wear and reducing the quality of machining results. This research aims to design an Arduino Uno-based tool temperature control system using a cooling system and determine its effectiveness in reducing the temperature of the tool in the turning process. The research method used was an experimental method by measuring test results without a cooling system and with a cooling system at a variation of feed rates of 0.10 mm/rev, 0.15 mm/rev, and 0.20 mm/rev as well as cutting depths of 0.4 mm, 0.8 mm, and 1.2 mm. Temperature data were analyzed using a comparative descriptive analysis method. The results showed that the average temperature without a cooling system was 41.79°C, 45.48°C, and 50.92°C, respectively, while with a cooling system it was 39.91°C, 40.02°C, and 41.28°C. The percentage of temperature reduction obtained was 4.50%, 12.01%, and 18.93%. These results show that the Arduino Uno-based cooling system is able to effectively control the chisel temperature, especially in cutting conditions with higher feed rates. Thus, the system designed can maintain a more stable tool temperature so that it has the potential to increase the life of the tool and the quality of the turning.
Keywords: *Arduino Uno, chisel temperature, cooling system and turning.*

I. INTRODUCTION

The manufacturing industry is one of the strategic sectors that contributes significantly to economic growth and increased national industrial competitiveness. This sector plays an important role in producing a wide range of mechanical components with high demands for precision, efficiency, and consistency. The machining process is still the backbone of modern manufacturing production systems. Among the various machining processes, turning occupies an important position in the manufacture of cylindrical components. The reliability of the turning process is greatly influenced by the stability of the cutting conditions during operation. Various studies state that the efficiency and quality of the turning process are largely determined by the stability of the cutting parameters and the condition of the tool (Demirpolat et al. 2023).

In the turning process, the interaction between the chisel and the workpiece causes intensive friction. This friction generates heat that accumulates in the cutting zone. The phenomenon of increasing the temperature of the tool is one of the main problems in the machining process. The temperature formed can reach hundreds of degrees Celsius, especially in high cutting speed conditions. The material of a particular workpiece also contributes to the amount of heat generated. Experimental research shows that the chisel temperature increases significantly as the cutting speed and feeding depth increase (Arifianti et al. 2025).

High tool temperatures have a direct impact on the performance of the turning process. One of the most significant impacts is the acceleration of tool wear. In addition, excess temperature also affects the surface quality of the workpiece produced. Degradation of surface quality can reduce the functional and aesthetic value of components. Quantitatively, an increase in the chisel temperature above optimal conditions is reported to increase flank wear by more than 30%. This condition also worsens surface roughness by up to 25% in the bearing steel turning process (Demirpolat et al. 2023).

Although the impact of tool temperature on the turning process is significant, monitoring practices in the industry still face various limitations. Most temperature monitoring systems are still done manually or periodically. The conventional method is not able to capture temperature fluctuations continuously. As a result, the information obtained often does not represent the actual conditions during the process. This condition causes process control to be reactive, not preventive. Taking action is generally carried out after damage to the tool or product defect occurs (Wallibai, 2020).

In addition to monitoring, chisel temperature control requires a cooling system that works effectively and adaptively. The cooling system plays an important role in keeping the cutting temperature in the optimal range. Proper cooling can reduce overheating and extend the life of the chisel. Some studies report that the use of a cooling system is able to significantly lower the temperature of the chisel. Cooling control integrated with actual temperature data provides potential for improved process performance. However, most cooling systems are still operated without direct integration with real-time temperature data (Manta et al. 2023).

Previous studies have extensively examined the relationship between cutting parameters and chisel temperature. Most studies are conducted through conventional experimental approaches. The main focus of such research is generally limited to the analysis of the effects of cutting speed, feed, and cutting depth. Integration between Arduino uno-based monitoring systems and automatic cooling systems is still rare. Research that combines these two aspects in one integrated system is still limited. This condition shows that there is a research gap that needs to be filled (Arifianti et al. 2025)(Laghari et al. 2023).

The turning process is one of the machining processes that are widely used in the manufacturing industry to produce components with a high level of precision. However, in practice in the field, there is often an increase in the temperature of the tool due to a fault between the tool and the workpiece during the cutting process. High temperatures can cause faster tool wear and reduce the quality of the finished turning. In general, monitoring the temperature of the chisel in the workshop is still done manually or even not done directly. In addition, the cooling system is still operating manually without accurate temperature data, making cooling less effective and inconsistent.

I took the title about Design of A Hammer Temperature Control Based On Arduino Uno Using A Cooling System In The Turning Process because along with the development of technology, the use of microcontrollers such as Arduino Uno allows real-time temperature monitoring and automatic control of the cooling system. With this system, the chisel temperature can be kept stable according to the predetermined limit. Based on these problems, this research was carried out to design an Arduino Uno-based tool temperature monitoring and control system with an automatic cooling system to improve the quality of the turning process and extend the life of the chisel.

This research is important because real-time chisel temperature control has a very significant role in the quality of turning results and the service life of the chisel. Uncontrolled tool temperatures can lead to faster wear, degrade the surface quality of the workpiece, and disrupt the stability of the machining process. In addition, without proper monitoring and cooling systems, the turning process risks decreased efficiency, increased production costs, and greater potential for tool damage. Therefore, a system that is able to control and control temperature automatically is needed so that the machining process can run more optimally and sustainably.

II. METHODS

Descriptive analysis is a data analysis method used to describe or describe the characteristics of research data without testing complex statistical hypotheses. In the research on monitoring and controlling the temperature of the tool in the turning process, descriptive analysis is used to present data in the form of tables, graphs, and simple statistical calculations.

The data analyzed descriptively include:

Average temperature (°C)

Maximum temperature (°C)

System response time (seconds)

Temperature stabilization time

Through this analysis, researchers can determine the pattern of temperature increase due to feed rate variations and see how the cooling system works in maintaining temperature stability. The results of the descriptive analysis provide an overview of the performance of the Arduino Uno-based monitoring system used in the study.

3.10.2 Comparative Analysis

Comparative analysis is a method used to compare two or more conditions to find out the difference or effect of a treatment. In this study, comparative analysis was used to compare:

Refrigeration conditions without refrigeration

Different feed rate variations (e.g. 0.10; 0.15; 0.20 mm/rev)

Cutting Depth (mm)

Comparison is carried out by calculating:

Temperature difference (ΔT)

Percentage of temperature decrease (%)

System response time difference

Through comparative analysis, it can be found out how effective the cooling system is in lowering the heat temperature. If there is a significant temperature difference between the two conditions, then it can be concluded that the cooling system has an effect on the temperature stability during the turning process.

Overall, descriptive and comparative combination analysis is very suitable for use in this experimental study. Descriptive analysis is used to describe the characteristics of temperature data, while comparative analysis is used to compare conditions before and after the application of a cooling system.

System Diagram Blocks

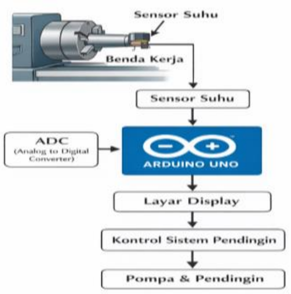
The system diagram block illustrates the workflow of monitoring and controlling the temperature of the tool in the Arduino Uno-based turning process. The system begins with the turning process, where the tool makes cuts on the workpiece so that it produces heat due to processing and applying the material.

Temperature sensors are installed near the tip of the tool to detect temperature changes during the turning process. This sensor converts the amount of temperature into an electrical signal that represents that value.

The output signal from the temperature sensor is then forwarded to the Arduino Uno through the signal conversion process. For analog sensors, the signal is converted from analog to digital signal by the ADC contained in the Arduino Uno so that it can be processed by a microcontroller.

Arduino Uno serves as a system processing and control center. The temperature data received is compared to the predetermined temperature limit value. The results of this processing are displayed on the display screen as information on the temperature of the chisel, as well as the basis for control decision-making.

If the temperature exceeds the set limit, the Arduino Uno will activate the cooling system via the cooling pump control. The cooling system works to lower the temperature of the tool until it returns to a safe state, so that the turning process can take place stably and the life of the tool can be extended.

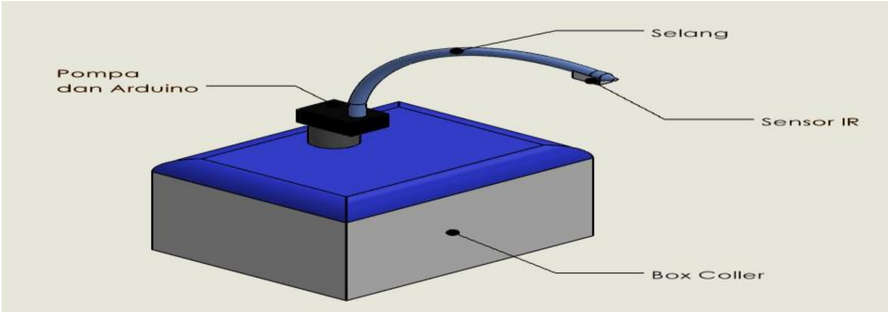


Pig 1. System Diagram

Hardware Design

The hardware design of the Arduino Uno-based tool temperature monitoring and control system is designed to monitor the temperature of the tool in real-time and control the cooling system automatically during the turning process. This system aims to keep the tool temperature at a safe limit so that it can reduce tool wear and improve the quality of turning results.

In the system design stage, tool modeling is carried out using SolidWorks software to visualize the shape and arrangement of components in three dimensions. This modeling aims to ensure the suitability of positions between components, such as infrared sensors, chisel stands, Arduino Uno-based control modules, and automatic cooling systems before the realization process is carried out. The results of the overall system design are shown in the following Figure.



Pig 2. 3D Hardware Design

Rancangan Software

The software design on the Arduino Uno-based tool temperature monitoring and control system functions to process temperature data obtained from sensors and control the cooling system automatically. The software is designed to be able to read sensor data in real-time, process that data, and display temperature and coolant status information during the turnaround process.

The program is developed using an Arduino IDE with the C/C++ programming language. The software begins with the process of initializing all devices, including temperature sensors, LCDs, and relay modules. At this stage, the temperature limit value (set point) used as a reference for controlling the cooling system is also determined.

In the data reading section, the software continuously reads the temperature value of the chisel temperature sensor. The temperature data obtained is then converted into degrees Celsius according to the characteristics of the sensor used. The reading process is carried out repeatedly so that changes in the temperature of the tool can be detected quickly and accurately.

The temperature data that has been obtained is then processed by Arduino Uno by comparing it to the set point value that has been determined. If the temperature exceeds this limit, the software will give a command to activate the relay so that the cooling system turns on. Conversely, if the temperature is below the safe limit, the relay will be disabled and the cooling system will stop working.

In addition to cooling control, the software also regulates the display of information on the LCD. The LCD displays the chisel temperature value in real-time as well as the status of the cooling system (ON or OFF). This information makes it easier for operators to maintain the working condition of the chisel without having to use additional measuring tools.

Overall, the design of this software is made with a simple and efficient program structure to make it easy to understand and develop. With this software, the chisel temperature monitoring and control system can work automatically, responsively, and reliably in supporting the turning process.

Pig 3. Software Design

Tool Working System in General

The work tool system in this study is designed to automatically monitor and control the temperature of the tool during the turning process. The system works with the principles of real-time temperature reading, data processing, and decision-making to activate or deactivate the cooling system based on the detected temperature value.

In general, the system starts when the turning process is carried out on a lathe. When the tool cuts through the workpiece, the processing and cooling of the plastic material occurs which generates heat energy in the cutting zone. The heat causes a rise in temperature at the tip of the tool which needs to be protected to prevent excessive wear.

A temperature sensor installed near the tip of the tool will detect temperature changes during the cutting process. This sensor converts the temperature into an electrical signal that is then sent to the Arduino Uno microcontroller as a data processing center. The temperature data received will be processed and compared to the predetermined temperature limit value (set point).

The chisel temperature is still below the set limit, the cooling system remains in a state of inactivity (OFF) and the turning process is normal. However, if the temperature exceeds the set point value, the Arduino Uno will send a signal to the relay module to automatically activate the cooling system.

The cooling system, which can be a coolant pump or a cooling fan, will work to lower the water temperature until it returns to a safe state. During the cooling process, the sensor continues to take continuous temperature readings. When the temperature has dropped below the specified limit, the cooling system will be switched off automatically.

In addition, the chisel temperature value and cooling system status are displayed on the LCD or serial monitor so that the operator can maintain the working condition of the tool directly. With this system, the temperature monitoring and control process is carried out automatically, responsively, and continuously.

Overall, the working system of this tool applies the concept of closed control (closed loop system), where the measured temperature data becomes the basis for decision-making to control the cooling system. Thus, the temperature stability of the tool can be maintained, the wear of the tool can be reduced, and the quality of the turning results can be improved.

Research Procedure

This research procedure is prepared to ensure that the implementation of research runs systematically and in accordance with the goals that have been set. The research is carried out through several stages, namely the preparation stage, system design, tool assembly, testing, data collection, and result analysis.

a. Preparation Stage

In the initial stage, a literature study was carried out related to the turning process, temperature chisel, cooling system, and the use of Arduino Uno microcontrollers in the temperature monitoring system. The literature study aims to obtain the basics of relevant theories as the foundation of system design.

In addition, tools and materials to be used in the research are prepared, such as lathes, temperature sensors (infrared (ir)), relay modules, cooling systems, lathe chisels, workpieces, and other supporting devices.

b. System Design Stages

This stage includes:

The role of hardware circuits (temperature sensors, Arduino, relays, cooling systems, LCDs).

Preparation of temperature control algorithms.

Determination of the temperature limit value (set point) as a reference for controlling the cooling system.

The design is carried out so that all components can work in an integrated manner in the chisel temperature monitoring and control system.

c. Tool Assembly Stage

After the system design is completed, all components are assembled according to the plan that has been made. The temperature sensor is installed as close to the tool tip as possible to obtain accurate temperature readings.

The program controls are then uploaded to the Arduino using the Arduino IDE. After that, the connection and function of each component are checked to ensure that the system works properly.

d.System Initial Test Stage

The temperature sensor can read the temperature well.

Temperature data is displayed on an LCD or serial monitor.

The cooling system is active when the temperature exceeds the set point.

The cooling system shuts down when the temperature returns to normal.

This stage aims to ensure that the system works according to the designed logic.

e. Data Collection Stage

Data collection is carried out during the turning process with a variety of conditions as follows:

1.Turning without automatic cooling system.

2.Turning with automatic cooling system.

3. Variation of feed rate (feeding motion) according to predetermined parameters.

4.Depth of cut

In each condition, the temperature is recorded in real-time. The data collected includes:

Maximum temperature

Minimum temperature

Average temperature

Temperature drop after the coolant is active

Data collection is carried out repeatedly to obtain more accurate and consistent results.

f. Data Analysis Stage

The data that has been obtained is then explained in the following ways:

Calculate the average value of temperature.

Compare temperatures before and after use of the cooling system.

Calculates the percentage of temperature drop.

Present data in the form of tables and graphs.

The analysis was carried out to determine the effectiveness of the precision monitoring and temperature control system that has been designed.

g. Conclusion Drawing Stage

The final stage is an interesting conclusion based on the results of data analysis. Conclusions are drawn to answer the formulation of the problem and to find out whether the designed system is capable of keeping the chisel temperature stable during the turning process.

Research Variables

Research variables are everything that is the object of observation in research and has a value that can be changed or measured. In the research on the Arduino Uno-based chisel temperature monitoring and control system, the research variables consist of independent variables, bound variables, and fixed variables.

a.Independent Variables

A free variable is a variable that is deliberately altered or manipulated in research to determine its effect on the chisel temperature during the turning process.

The independent variables in this study include:

1. Cooling System

The cooling system is varied in two conditions, namely:

Without refrigeration

With Arduino-based autocooler

The purpose of this variation is to determine the effectiveness of the cooling system in lowering and controlling the temperature during the machining process.

2. Variation of Feed Rate and Cutting Depth

The feed rate and cutting depth were varied to see the effect of changes in cutting load on the increase in chisel temperature. The greater the feed rate and cutting depth, the greater the cutting force and heat energy produced

b. Bound Variables

An attachment variable is a variable that is affected by an independent variable.

The attachment variables in this study are:

Tool Temperature (°C)

The temperature of the tool is measured using a MLX90614 sensor installed near the end of the hose. Temperature data is taken in real-time during the turning process.

The described parameters include:
Maximum temperature
Average temperature
Temperature drop after the coolant is active
Percentage temperature drop
c. Fixed Variables

Fixed variables are variables that are kept constant so as not to affect the results of the study. Fixed variables in this study include:
Types of lathes used
Tool type (HSS)
Workpiece material
Workpiece diameter
Spindle rotation speed (RPM)
Types of coolant
Temperature sensor mounting position

Fixed variables in this study include the type of lathe, type of HSS chisel, material and diameter of the workpiece, spindle rotation speed (RPM), type of temperature sensor, sensor mounting position, type of coolant, power supply voltage, test environmental conditions, and temperature set point value. These variables are kept constant so that the research results are more valid and the influence of free variables on the chisel temperature can be clearly observed.

III. RESULT AND DISCUSSION

Testing is performed on conventional lathes using the same cutting tool for each treatment. The material of the workpiece used is also made uniform so that it does not affect the results of temperature measurements. Before testing begins, all components of the Arduino Uno-based cooling system are checked to ensure that the temperature sensor, Arduino Uno, relay, cooling pump, and power supply are working properly.

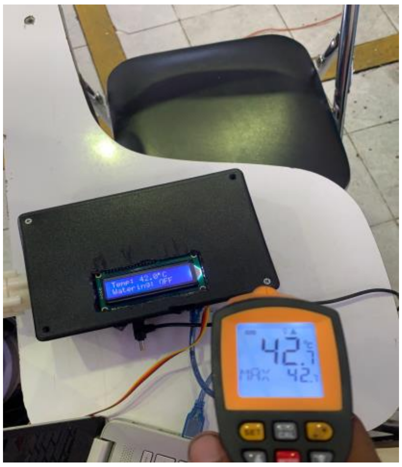
The variation of cutting parameters used in the study consisted of feed rates of 0.10 mm/rev, 0.15 mm/rev, and 0.20 mm/rev, and cutting depths of 0.4 mm, 0.8 mm, and 1.2 mm. In each combination of these parameters, two test conditions were carried out, namely without a cooling system and with a cooling system. Each condition was tested 9 times by taking chisel temperature data.

During the test, other parameters such as the type of chisel, workpiece material, spindle rotation (spindle speed), cutting length, and temperature measurement method were maintained so that the temperature difference that occurred was only influenced by the use of the cooling system as well as variations in feed rate and cutting depth.

Parameter	**Test Conditions**
Engine	Conventional lathes
System control	Arduino Uno
Sensor temperature	Temperature sensors used in the study
Cooling system	Arduino Uno based cooling pump
Variable feed rate	0,10; 0,15; 0.20 mm/rev
Variasi cutting depth	0,4; 0,8; 1.2 mm
Test conditions	Without cooler and with cooler
Total data collection	9 times on each variation
Observed data	Pahat Temperature (°C)

The following are the results of the design that has been built:

The following is a picture of the temperature data obtained:



System Test Results

The system test was carried out to determine the effect of the use of an Arduino Uno-based cooling system on the temperature of the tool in the turning process. The test was carried out under two conditions, namely without a cooling system and with a cooling system, using a variation of feed rates of 0.10 mm/rev, 0.15 mm/rev, and 0.20 mm/rev as well as cutting depths of 0.4 mm, 0.8 mm, and 1.2 mm. The temperature data obtained from each test was then analyzed using a comparative descriptive analysis method to determine the effectiveness of the cooling system in controlling hot temperatures. The results of the tests on each condition are presented in the following subchapter.

Table Test results without cooling system

No	Feed Rate (mm/ rev	Cutting Depth (mm)	P 1	P 2	P 3	P 4	P 5	P 6	P 7	P 8	P 9
1	0,10	0,4	33,8	34,5	37,1	38,9	41,6	45,3	47,4	48,1	49, 4
2	0,15	0,8	33,6	35,4	37,7	41,2	45,9	48,3	52,6	56,4	58, 2
3	0,20	1,2	34,5	38,2	42,4	47,0	52,2	56,4	59,9	62,4	65, 3

Based on the table above, the test results without a cooling system show that the chisel temperature increases at each measurement point. In the first condition with a *feed rate* of 0.10 mm/rev and *a cutting depth* of 0.4 mm, the initial temperature at point P1 was 33.8°C. Furthermore, the temperature gradually increased to 34.5°C, 37.1°C, 38.9°C, 41.6°C, 45.3°C, 47.4°C, 48.1°C, until it reached 49.4°C at point P9. The temperature difference between the starting point and the end point is 15.6°C. The increase in temperature indicates that the heat resulting from the accuracy between the tool and the workpiece continues to increase during the turning process. Without a cooling system, the heat generated cannot be released optimally so the chisel temperature continues to rise.

In the second condition with *a feed rate* of 0.15 mm/rev and *a cutting depth* of 0.8 mm, the temperature at point P1 is 33.6°C and increases to 58.2°C at point P9. During the testing process, the temperature gradually increases through values of 35.4°C, 37.7°C, 41.2°C, 45.9°C, 48.3°C, 52.6°C, and 56.4°C. The temperature difference between points P1 and P9 reaches 24.6°C. This value is greater than the first condition which was only 15.6°C. These results show that the increase *in feed rate* and *cutting depth* causes the heat generated during the turning process to be even greater. As a result, temperatures rise faster because there is no system capable of reducing heat accumulation.

In the third condition with *a feed rate* of 0.20 mm/rev and *a cutting depth* of 1.2 mm, the initial temperature at the P1 point was 34.5°C. The temperature then increased to 38.2°C, 42.4°C, 47.0°C, 52.2°C, 56.4°C, 59.9°C, 62.4°C, and reached 65.3°C at point P9. The temperature difference from the starting point to the end point was 30.8°C, which is the largest value compared to the previous two conditions. A sufficiently high temperature increase indicates that the larger the cutting parameters, the greater the heat generated at the end of the chisel. This condition occurs because the cutting force and accuracy between the tool and the workpiece increases as *the feeding rate* and *depth of the cut* increases. Without a cooling system, the heat that is formed continues to accumulate so that the chisel temperature increases significantly.

Overall, the test results without a cooling system showed that the tool temperature increased consistently at any variation of the cutting parameters. The average temperature obtained was 41.79°C, 45.48°C, and 50.92°C respectively for feed *rates* of 0.10 mm/rev, 0.15 mm/rev, and 0.20 mm/rev. The average values showed an increase of 3.69°C from the first condition to the second condition and 5.44°C from the second condition to the third condition. In addition, the maximum temperature also increased from 49.4°C to 58.2°C, then reached 65.3°C in the latter condition. The data proves that the increase in *feed rate* and *cutting depth* is directly proportional to the increase in the temperature of the chisel. This condition indicates that without a cooling system, the heat from turning continues to accumulate on the tool so that it has the potential to accelerate tool wear and reduce the quality of machining results. Therefore, a cooling system is needed to control the temperature so that the turning process can take place more stable and responsive.

Tabel Hasil pengujian dengan sistem pendingin.

No	**Feed Rate (mm/rev**	**Cutting Depth (mm)**	**P 1**	**P 2**	**P 3**	**P 4**	**P 5**	**P 6**	**P 7**	**P 8**	**P 9**
1	0,10	0,4	33,4	34,2	36,5	39,5	41,4	44,7	48,2	43,3	38,0
2	0,15	0,8	33,6	34,8	36,4	40,0	44,2	48,1	43,4	41,7	38,0
3	0,20	1,2	34,8	37,2	41,6	46,4	48,2	44,8	41,1	39,4	38,0

Based on the table above, the test results with a cooling system show that the chisel temperature changes at each measurement point, but the increase is more controllable than the test without a cooling system. In the first condition with a *feed rate* of 0.10 mm/rev and *a cutting depth* of 0.4 mm, the temperature at point P1 is 33.4°C. The temperature then increased to 34.2°C, 36.5°C, 39.5°C, 41.4°C, 44.7°C, and reached a high of 48.2°C at point P7. After that, the temperature decreases to 43.3°C at point P8 and 38.0°C at point P9. The temperature difference between the starting point and the highest point is 14.8°C. The temperature drop at the endpoint indicates that the cooling system is able to reduce the heat that has accumulated during the turning process.

In the second condition with *a feed rate* of 0.15 mm/rev and *a cutting depth* of 0.8 mm, the initial temperature at the P1 point was 33.6°C. The temperature gradually increased to 34.8°C, 36.4°C, 40.0°C, 44.2°C, 48.1°C, then decreased to 43.4°C, 41.7°C, and 38.0°C at point P9. The temperature difference between the starting point and the highest point is 14.5°C. Compared to the test without a cooling system that reached 58.2°C, the maximum temperature under this condition was only 48.1°C. This shows that the cooling system is able to withstand the increase in temperature even if the cutting parameters are improved.

Thus, the cooling process can reduce the accumulation of heat on the tool so that the temperature decreases again after reaching the maximum value.

In the third condition with *a feed rate* of 0.20 mm/rev and *a cutting depth* of 1.2 mm, the temperature at point P1 was 34.8°C and increased to 48.2°C at point P5. After reaching the highest temperature, the temperature decreases to 44.8°C, 41.1°C, 39.4°C, and 38.0°C at point P9. The temperature difference between the starting point and the highest point is 13.4°C. Although the cutting parameters are at the highest conditions, the maximum temperature remains in the range of 48°C. This shows that the cooling system works effectively in controlling the temperature of the tool during the turning process. The drop in temperature after the maximum point also indicates that the system is capable of accelerating the heat release from the cutting area.

Overall, the results of the test with the cooling system showed that the chisel temperature still increased during the turning process, but the increase did not occur as continuously as in the test without the cooling system. The maximum temperature in the third test variation was only in the range of 48.1–48.2°C, then decreased to 38.0°C at the end of the test. These conditions show that the cooling system is able to keep the chisel temperature stable even though the *feed rate* and *cutting depth* are increased. In contrast to tests without a cooling system that show a rise in temperature until the end of the test, the use of a cooling system results in a pattern of rise followed by a decrease in temperature. This proves that the Arduino Uno-based cooling system is able to effectively absorb and dissipate heat during the turning process. Thus, the chisel temperature can be maintained at a lower range, potentially increasing the life of the tool and the quality of the machining results. Therefore, the designed cooling system can be declared effective in controlling the chisel temperature at a wide variety of cutting parameters.

Data Processing Table

In this subchapter, the results of data processing obtained from the measurement of chisel temperature in conditions without a cooling system and with a cooling system are presented. The data is processed to find out the temperature difference in each variation of *feed rate* and *cutting depth,* as follows.

Tabel data tanpa system pendinginan

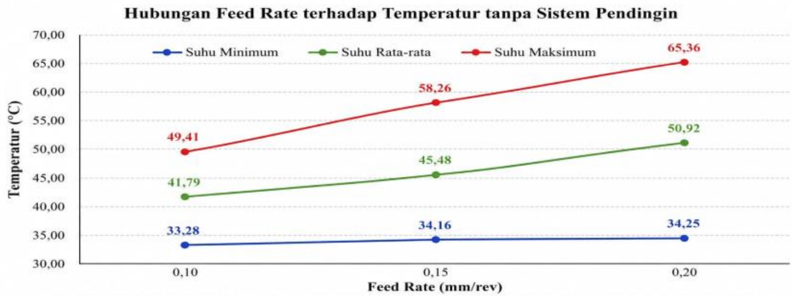
Feed Rate (mm/rev)	**Cutting Depth (mm)**	**Suhu Minimum Tanpa Sistem Pendingin (°C)**	**Suhu Maksimum Tanpa Sistem Pendingin (°C)**	**Rata-rata Tanpa (°C)**
0,10	0,4	33,28	49,41	41,79
0,15	0,8	34,16	58,26	45,48
0,20	1,2	34,25	65,36	50,92

Based on the table above, the test results without a cooling system show that the chisel temperature increases with each variation of the cutting parameters. In the first condition with *a feed rate* of 0.10 mm/rev and *a cutting depth* of 0.4 mm, the minimum temperature obtained is 33.28°C. The maximum temperature in these conditions reached 49.41°C, while the average temperature was 41.79°C. The difference between the minimum temperature and the maximum temperature of 16.13°C indicates an increase in temperature during the turning process. This increase in temperature is caused by ignition between the tool and the workpiece which produces heat energy. Without a cooling system, the heat generated cannot be released optimally so that the heat temperature continues to rise. These conditions indicate that the turning process without a cooling system causes heat accumulation in the chisel.

In the second condition, *the feed rate* is increased to 0.15 mm/rev and *the cutting depth* is 0.8 mm. The test results showed a minimum temperature of 34.16°C, a maximum temperature of 58.26°C, and an average temperature of 45.48°C. Compared to the first condition, the average temperature increased by 3.69°C. The maximum temperature also increased by 8.85°C, which is from 49.41°C to 58.26°C. The difference between the minimum temperature and the maximum temperature in the second condition is 24.10°C. The increase in temperature indicates that the increase in parameters causes the resulting heat cut to be even greater. This proves that the increase in *feed rate* and *cutting depth* affects the temperature of the chisel.

In the third condition, *the feed rate* of 0.20 mm/rev and *the cutting depth* of 1.2 mm produced a higher temperature than the previous condition. The minimum temperature obtained is 34.25°C, while the maximum temperature reaches 65.36°C. The average temperature in this condition is 50.92°C. Compared to the second condition, the average temperature increased by 5.44°C and the maximum temperature increased by 7.10°C. The difference between the minimum temperature and the maximum temperature reached 31.11°C, which was the largest value during the test. These results show that the larger the cutting parameters used, the higher the temperature produced on the chisel. This condition occurs because the cutting and installing force between the tool and the workpiece is increasing.

Overall, the results of tests without a cooling system showed a one-way relationship between the increase in cutting parameters and the increase in the temperature of the chisel. The average temperature increased from 41.79°C in the first condition to 45.48°C in the second condition, then reached 50.92°C in the third condition. The total average temperature increase from the first condition to the last condition was 9.13°C. In addition, the maximum temperature also increased from 49.41°C to 65.36°C, resulting in an increase of 15.95°C. The data shows that the heat from the cut continues to accumulate due to the absence of a cooling system. This heat accumulation can accelerate tool wear and reduce the quality of turning results. Therefore, the use of a cooling system is necessary to control the temperature of the tool so that the turning process takes place more stable and efficient.



Based on **Fig** 4. it can be seen that the increase *in feed rate* causes the chisel temperature to increase in conditions without a cooling system. At a *feed rate* of 0.10 mm/rev, the minimum temperature is 33.28°C, the average temperature is 41.79°C, and the maximum temperature is 49.41°C. When *the feed rate* is entered to 0.15 mm/rev, the minimum temperature increases to 34.16°C, the average temperature becomes 45.48°C, and the maximum temperature becomes 58.26°C. At a *feed rate* of 0.20 mm/rev, the minimum temperature again increased to 34.25°C, the average temperature reached 50.92°C, and the maximum temperature reached 65.36°C. The graph shows that the third temperature curve tends to increase as the *feed rate* increases. This indicates that an increase *in feed rate* generates greater heat during the turning process. Without a cooling system, the heat continues to accumulate so that the temperature of the tool increases.

The minimum temperature on the graph has a relatively small increase compared to the average temperature and maximum temperature. The minimum temperature value only increased from 33.28°C to 34.16°C, then to 34.25°C. The total minimum temperature increase is only 0.97°C. This shows that the initial temperature of the tool in each test did not experience a significant change. In contrast, the average temperature increased from 41.79°C to 45.48°C, then to 50.92°C. The overall average temperature rise reached 9.13°C, which indicates an increase in heat during the turning process. This condition shows that the heat generated during slaughter continues to increase as *the feed rate* increases.

The maximum temperature shows the greatest increase compared to other temperature parameters. The maximum temperature value increased from 49.41°C at *a feed rate* of 0.10 mm/rev to 58.26°C at a *feed rate* of 0.15 mm/rev, then reached 65.36°C at a *feed rate* of 0.20 mm/rev. The total maximum temperature increase was 15.95°C. The graph shows that the maximum temperature line has the sharpest slope compared to the minimum temperature line and the average temperature. This shows that the higher *the feed rate*, the greater the heat generated in the contact area between the tool and the workpiece. This condition causes increased cutting and rusting forces during the turning process. As a result, the engine temperature continues to rise when not using the cooling system.

Overall, the graph shows the unidirectional relationship between *feed rate* and tool temperature in tests without a cooling system. An increase in *the feed rate value* from 0.10 mm/rev to 0.20 mm/rev causes an increase in minimum temperature, average temperature, and maximum temperature. The greatest increase occurs at the maximum temperature, while the minimum temperature increase is relatively small. These results show that the heat from the turning process is greater when *the feed rate* is increased. In the absence of a cooling system, heat cannot be released effectively so that the temperature of the tool continues to increase during the cutting process. This condition can accelerate tool wear and reduce the quality of turning results. Therefore, a cooling system is needed to control the temperature of the tool so that the turning process takes place more stable and efficient.

Tabel data dengan system pendingin

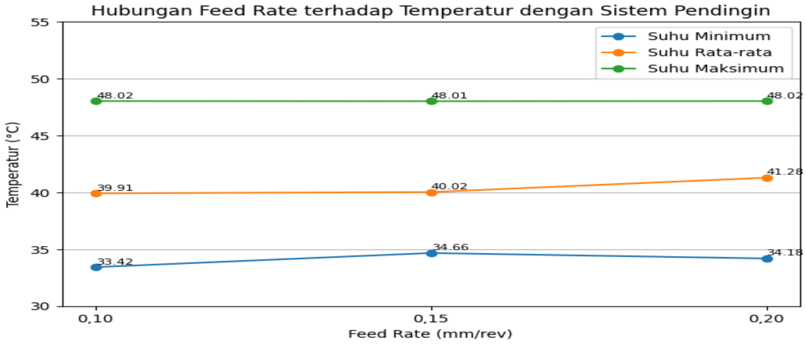
Feed Rate (mm/rev)	**Cutting Depth (mm)**	**Suhu Minimum Dengan Sistem Pendingin (°C)**	**Suhu Maksimum Dengan Sistem Pendingin(°C)**	**Rata-rata Dengan Sistem Pendingin (°C)**
0,10	0,4	33,42	48,02	39,91
0,15	0,8	34,66	48,01	40,02
0,20	1,2	34,18	48,02	41,28

Based on the table above, the test results with the cooling system show that the chisel temperature can be better controlled during the turning process. In the first condition with a feed rate of 0.10 mm/rev and a cutting depth of 0.4 mm, the minimum temperature obtained is 33.42°C. The maximum temperature in these conditions reached 48.02°C with an average temperature of 39.91°C. The difference between the minimum temperature and the maximum temperature of 14.60°C indicates that the temperature rise is still at a relatively controlled distance. The cooling system helps reduce the heat accumulation that occurs at the tip of the tool during the cutting process. With cooling, the heat from heating can be absorbed and expelled from the cutting area more effectively. These conditions show that the cooling system is able to maintain the temperature stability of the parts at low cutting parameters.

In the second condition, the feed rate is increased to 0.15 mm/rev and the cutting depth is 0.8 mm. The test results showed a minimum temperature of 34.66°C, a maximum temperature of 48.01°C, and an average temperature of 40.02°C. Compared to the first condition, the average temperature only increased by 0.11°C. The maximum temperature actually decreased slightly from 48.02°C to 48.01°C, so the difference was only 0.01°C. The difference between the minimum temperature and the maximum temperature in the second condition is 13.35°C. This value is smaller than the first condition, which indicates that the cooling system is still able to maintain temperature stability even though the cutting parameters are improved. This proves that system-controlled cooling is able to reduce temperature rise due to increased feed rate and cutting depth.

In the third condition, the feed rate becomes 0.20 mm/rev with a cutting depth of 1.2 mm. The test results showed a minimum temperature of 34.18°C, a maximum temperature of 48.02°C, and an average temperature of 41.28°C. Compared to the second condition, the average temperature increased by 1.26°C. Although the cutting parameters were at the highest value, the maximum temperature remained in the range of 48°C and did not experience a significant increase. The difference between the minimum temperature and the maximum temperature in this condition is 13.84°C. This value indicates that the cooling system is able to withstand the increase in temperature so that it does not spike drastically during the turning process. Thus, the cooling system remains effective in heavier cutting conditions.

Overall, the results of tests with the cooling system show that the chisel temperature is relatively stable across all variations of cutting parameters. The average temperature only changed from 39.91°C in the first condition to 40.02°C in the second condition, then to 41.28°C in the third condition. The total average temperature increase from the first condition to the last condition was only 1.37°C. Meanwhile, the maximum temperature remained in the range of 48.01–48.02°C although the feed rate and cutting depth continued to be improved. These results are different from tests without a cooling system which showed a maximum temperature rise of up to 65.36°C. This data proves that the designed cooling system is able to reduce heat accumulation and keep the chisel temperature stable during the turning process. Therefore, the use of an Arduino Uno-based cooling system has proven to be effective in controlling the temperature of the tool and has the potential to increase the life of the tool and the quality of turning.



Based on Fig 5. the relationship between *feed rate* and tool temperature with the cooling system showed a more stable pattern than the test without a cooling system. At a *feed rate* of 0.10 mm/rev, the minimum temperature is 33.42°C, the average temperature is 39.91°C, and the maximum temperature is 48.02°C. When *the feed rate* is set to 0.15 mm/rev, the minimum temperature increases to 34.66°C, the average temperature becomes 40.02°C, while the maximum temperature remains at 48.01°C. At a *feed rate* of 0.20 mm/rev, the minimum temperature is 34.18°C, the average temperature increases to 41.28°C, and the maximum temperature is back to 48.02°C. The graph shows that the average temperature line increases gradually as the *feed rate* increases. Meanwhile, the maximum temperature line tends to drop in the range of 48°C. This shows that the cooling system is able to control the temperature rise even though *the feed rate* increases.

The minimum temperature change at each *feed rate variation* is relatively small. The minimum temperature changes from 33.42°C to 34.66°C, then decreases slightly to 34.18°C. The minimum temperature difference between the first and last conditions is only 0.76°C. These conditions indicate that the initial temperature of the tool remained in almost the same range during the test. This shows that the cooling system is able to maintain temperature stability from the beginning of the turning process. Thus, the change in *feed rate* does not have a great influence on the minimum temperature when the cooling system is used. Minimum temperature stability is one of the indicators that the cooling process works consistently.

The average temperature increased from 39.91°C at a *feed rate* of 0.10 mm/rev to 40.02°C at a *feed rate* of 0.15 mm/rev, then to 41.28°C at a *feed rate* of 0.20 mm/rev. The total average temperature increase was only 1.37°C. In contrast to the average temperature, the maximum temperature remained in the range of 48.01–48.02°C throughout the test. The maximum temperature difference between feed *rate variations* is only about 0.01°C, so it can be considered relatively constant. This shows that the cooling system is able to reduce the maximum temperature of the increased load reduction. The cooling system absorbs the heat generated in the area between the tool and the workpiece so that the temperature does not experience a significant rise. As a result, the engine temperature remains at a more stable condition than without a cooling system.

Overall, the graph shows that the use of a cooling system is able to keep the temperature stable at any variation of *the feed rate*. The average temperature increase still occurs as *the feed rate* increases, but the increase is much smaller than testing without a cooling system. The maximum temperature that remains in the range of 48°C indicates that the cooling system is effective in inhibiting heat accumulation during the turning process. This result proves that Arduino Uno-based cooling systems are able to control heat temperatures better than conditions without a cooling system. More stable temperatures can reduce the risk of chisel wear, maintain the surface quality of the workpiece, and improve the efficiency of the turning process. Thus, the designed cooling system has met the research objective, which is to reduce the rise in tool temperature during the turning process. The results of this graph analysis also support the results of the temperature testing and calculation that have been discussed in the previous subchapter

Tool Temperature Comparison Table

A comparison of the chisel temperature was carried out to determine the effect of the use of a cooling system on the temperature produced during the turning process. Comparison results between tests without a cooling system and with a cooling system at each variation of *feed rate* and *cutting depth* are presented in the table below.

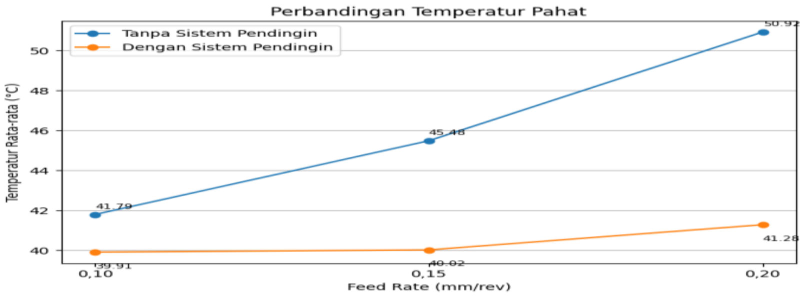
Feed Rate (mm/rev)	Cutting Depth (mm)	Average without Cooling System (°C)	Average With Cooling System (°C)	Difference (°C)	Reduction (%)
0,10	0,4	41,79	39,91	1,88	4,50
0,15	0,8	45,48	40,02	5,46	12,01
0,20	1,2	50,92	41,28	9,64	18,93

Based on the table above, there is a temperature difference between testing without a cooling system and testing with a cooling system. At a *feed rate* of 0.10 mm/rev and *a cutting depth* of 0.4 mm, the average temperature without a cooling system is 41.79°C, while with a cooling system it is 39.91°C. The temperature difference in these conditions is 1.88°C. The percentage of temperature reduction obtained is 4.50%. These results show that the cooling system is able to lower the temperature of the tool even under relatively low cutting conditions. The temperature drop occurs because the cooling system helps reduce the accumulation of heat generated during the turning process. Thus, the chisel temperature becomes more stable than the condition without a cooling system.

In the second condition with *a feed rate* of 0.15 mm/rev and *a cutting depth* of 0.8 mm, the average temperature without a cooling system is 45.48°C and with a cooling system is 40.02°C. The temperature difference in this condition increased to 5.46°C. The percentage of temperature reduction reached 12.01%, greater than the first condition. This shows that the effectiveness of the cooling system is increasingly noticeable when the cutting parameters are improved. The cooling system is able to reduce the heat generated by the increased cutting force and ignition between the tool and the workpiece. Therefore, the chisel temperature remains at a lower value than the turning process without a cooling system.

In the third condition with *a feed rate* of 0.20 mm/rev and *a cutting depth* of 1.2 mm, the average temperature without a cooling system reached 50.92°C, while with a cooling system it was 41.28°C. The temperature difference in this condition reached 9.64°C, which was the largest value of the entire test. The percentage of temperature reduction also reached 18.93%. These results show that the cooling system works more effectively in higher load cutting conditions. Despite the *increased feed rate* and *cutting depth*, the cooling system is still able to suppress the rise in tool temperature significantly. This condition proves that the cooling system can maintain temperature stability during the turning process.

Overall, the results of the comparison showed that the use of a cooling system had a positive effect on the reduction of the chisel temperature at any variation in the cutting parameters. The value of temperature reduction increased from 4.50% in the first condition to 12.01% in the second condition, then reached 18.93% in the third condition. The temperature difference also increased from 1.88°C to 5.46°C, then 9.64°C, which showed an increase in the effectiveness of the cooling system as *the feed rate* and *cutting depth* increased. The data proves that the Arduino Uno-based cooling system is able to reduce heat accumulation in the tool consistently. The temperature drop that occurs has the potential to reduce the wear of the chisel, maintain the stability of the cutting process, and improve the surface quality of the workpiece. Therefore, the designed cooling system can be declared to work well in controlling the temperature of the tool in the turning process. These results also support the research goal, which is to produce an effective system for lowering the temperature of the tool during the machining process.



Based on Fig 6 it can be seen that there is a difference in the average temperature of the tool between the test without a cooling system and with the cooling system at each feed rate variation. At a *feed rate* of 0.10 mm/rev, the average temperature without a cooling system is 41.79°C, while with a cooling system it is 39.91°C. The temperature difference in these conditions is 1.88°C. When *the feed rate* is set to 0.15 mm/rev, the average temperature without a cooling system increases to 45.48°C, while with a cooling system it is only 40.02°C. The temperature difference in this condition increases to 5.46°C. At a *feed rate* of 0.20 mm/rev, the average temperature without a cooling system reaches 50.92°C, while with a cooling system it is 41.28°C, so the difference is 9.64°C. These results show that the use of a cooling system is able to lower the chisel temperature at any variation of *the feed rate*.

The graph shows that the temperature line without a cooling system has a sharper slope than the temperature line with a cooling system. This suggests that the increase *in feed rate* has a greater influence on the chisel temperature when the cooling system is not in use. The average temperature without a cooling system increased by 9.13°C, from 41.79°C to 50.92°C. Meanwhile, the average temperature with the cooling system only increased by 1.37°C, from 39.91°C to 41.28°C. The difference in increase indicates that the cooling system is able to inhibit the increase in temperature during the turning process. The heat generated by printing between the chisel and the workpiece can be absorbed so that it does not accumulate excessively. Therefore, the chisel temperature remains more stable under each test condition.

In addition to lowering temperatures, the use of cooling systems also increases the effectiveness of heat control at higher cutting parameters. This can be seen from the increase in temperature difference between the two test conditions. The temperature difference increased from 1.88°C at *a feed rate* of 0.10 mm/rev to 5.46°C at a *feed rate* of 0.15 mm/rev, then reached 9.64°C at a *feed rate* of 0.20 mm/rev. The percentage of temperature reduction also increased from 4.50% to 12.01%, then reached 18.93%. The data shows that the higher *the feed rate*, the greater the influence of the cooling system in lowering the temperature of the chisel. Thus, the cooling system works more effectively when the turning process produces higher heat. This condition indicates that the cooling system is able to maintain temperature stability despite increased load reduction.

Overall, the temperature graph shows that using a cooling system gives better results than turning without a cooling system. The average temperature at each feed *rate* variation is always lower when the cooling system is used. The temperature difference is getting bigger as the *feed rate* increases, showing that the effectiveness of the cooling system is also increasing. Lower chisel temperatures can reduce the wear of the chisel, maintain the stability of the cutting process, and improve the surface quality of the workpiece. The results of this graph analysis are in line with the results of testing and data processing that have been discussed in the previous subchapter. Therefore, the Arduino Uno-based cooling system designed in this study is proven to be able to effectively control the heat temperature during the turning process. The results also show that the research goal of lowering the temperature of the tool using a cooling system has been successfully achieved.

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