Design and Analysis of Pneumatic Drilling Fixture Using A Microcontroller-Based Control System

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Abstract. Drilling is a machining process intended for the formation of holes in the workpiece. The gripper in the drilling process is generally still driven manually. This causes the machining process to take a long time. The purpose of making pneumatic drill chucks using a microcontroller-based control system is expected to be able to produce products effectively and efficiently. The data analysis method used in this study is a quantitative method with real experimental techniques. The data studied is the result of data processing that occurs in the pneumatic drill chuck controller microcontroller. The drill chuck is driven by a pneumatic drive system sourced from the compressor. The pneumatic drill chuck is controlled by a microcontroller control system in the form of an Arduino Uno. The results obtained are the design and pneumatic drill chuck using a microcontroller-based control system. In addition, it produces the drilling time on cylinder B, the feed speed that occurs and the total time that occurs during one cycle. The resulting drilling time from cylinder B is 9 seconds, the feeding speed is 5.4 mm/second, and the total time for one cycle is 33,544 seconds. All parts of pneumatic drill chucks have been designed according to the calculated safety limits.

Keywords: Drilling, Fixture, Pneumatic, Microcontroller

1 Introduction

In today's era of globalization, human work is supported by various kinds of machines in the machining process. The drilling process on the workpiece is an important process in forming holes to meet the daily needs of both household and industry. This drilling process is intended as a process of forming holes in the workpiece using a drill bit. On an industrial scale, the drilling process has many benefits, including housing for fasteners such as bolts and rivets. The seated drill is one of many drilling machines where the work is done on a table and produces relatively small holes. The use of drilling tools mostly uses manual drilling tools that utilize the physical power of the operator. However, this method takes a long time, drains energy and is prone to work accidents because there are no safety equipment available.

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In modern times, all human actions are endeavored to achieve maximum results in a relatively short time, including drilling large quantities of workpieces. Mass production should strive to produce products that have many holes in a short time to achieve efficient performance. Therefore, the drilling fixture as a guide for the workpiece is required to maintain the position of the workpiece during the machining process which produces a uniform and accurate product. As for the fixture drive, it is required to be able to pull and push using a pneumatic drive automatically.

The application of automation systems in large companies is mostly controlled by a Programmable Logic Controller (PLC) which has advantages in the aspect of control resilience. However, an automated system using a Programmable Logic Controller (PLC) requires no small amount of funds in its manufacture, so that some companies, especially small companies, shift control of the Programmable Logic Controller (PLC) to Arduino. This is done to reduce manufacturing costs and provide maximum results.

From the description above, this research aims to develop a microcontroller-based automatic drilling machine that functions as a pneumatic drill chuck controller in order to simplify and speed up machining time. Therefore, a pneumatic drilling fixture is designed using a microcontroller-based control system for continuous hole making in order to get more effective and efficient results. The Arduino microcontroller used is Arduino Uno which provides convenience in terms of programming and a relatively cheap price.

1.1 Jig and Fixture

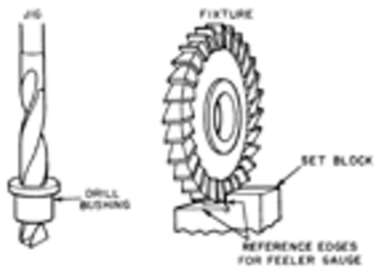

Fig. 1. Jig and Fixture [1]

The jig and fixture in Figure 1 is a production workpiece holder that helps in the machining process to make accurate duplicating components or parts. Correct alignment and alignment between the cutting tool or other auxiliary tool and the workpiece must be maintained. To do this, a jig or fixture is needed that is designed to hold, support and position each part. Jig (placer) is a special tool that holds, supports or places tools on the component to be worked on. These tools are production aids designed to not only place and hold the workpiece but also direct the cutting tool. Jigs are usually equipped with hardened steel bushings to guide the drill bit. Basically, the small jig is not bolted or fixed to the press table of the drilling machine. However, for drilling diameters above 6 mm, the jig usually needs to be securely fixed to the table [2]. Fixtures are production equipment that places, holds and supports the workpiece firmly so that the required machining work can be carried out. A gauge block or feeler gauge is used in the fixture for reference or setting of the cutting tool to the workpiece. The fixture must be fixed to the machine table where the workpiece is placed.[3]

1.2 Theoretical Review

In the drilling and clamping process to determine the size of the cylinder used, it is necessary to pay attention to several forces that will occur during the drilling process. The force that occurs can be calculated using the following formula.

1. Cutting Force

The cutting force that occurs in the drilling process can be calculated using the formula below [4].

$$\frac{F_{cut}}{A} > \text{occuring } \tau g \tag{1}$$

2. Gripping Force

The gripping force is generated by the cylinder to grip the workpiece during the drilling process. The gripping force can be calculated using the following formula.[4]

$$F = A \times P \text{ or } F = D2 \times \frac{\pi}{4} \times P \tag{2}$$

3. Shear Stress

Shear stress is the stress caused by a force acting parallel to or in the direction of the force resisting plane. Shear stress is denoted by the Greek letter τ [4]

$$\tau g = \frac{F}{A} \tag{3}$$

description:

τg = Average shear stress (N/mm2)

F = Shear force (N)

A = cross-sectional area of the retainer (mm2)

4. Bending Stress

The bending stress is the stress caused by a force acting in the opposite direction to the force resisting plane. The bending stress is denoted by σ (Greek letter sigma). [4]

$$\sigma b = \frac{Mb}{Wb} \tag{4}$$

description:

σb = bending stress (N/mm2)

Mb = bending moment (N.mm)

Wb = bending load (mm2)

1.3 Safety Factor

The safety factor is a quantity or factor obtained from the comparison between the maximum stress of the machine component material and the working stress. Mathematically it can be formulated as follows. [5]

$$safety\ factor = \frac{maximum\ stress}{working\ or\ design\ stress} \quad (5)$$

For ductile raw materials such as mild steel, the yield point is strictly defined. Then the factor of safety is based on the yield stress, namely:

$$safety\ factor = \frac{yield\ point\ stress}{working\ or\ design\ stress} \quad (6)$$

For brittle materials such as cast iron, the yield stress is not clearly defined. Then the factor of safety for the material is based on the ultimate stress, so that:

$$safety\ factor = \frac{ultimate\ stress}{working\ or\ design\ stress} \quad (7)$$

The above value can be used for the factor of safety for both loading, static and dynamic loading. The high factor results in a large, heavy shelter. This means that there is a waste of material. While a small safety factor results in a risk of failure.

Table 1. Safety Factor

Material	Steady Load	Dinamic Load	Shock Load
Cast Iron	5 - 6	8 - 12	16 - 20
Wrought Iron	4	7	10 - 15
Steel	4	8	12 - 16
Soft Material and Alloy	6	9	15
Leather	9	12	15
Timber	7	10 - 15	20

1.4 Microcontroller

Simply put, a microcontroller is a small computer. Microcontroller is a microcomputer chip that looks physically in the form of an Integrated Circuit (IC). Microcontrollers are widely used in systems that are relatively smaller, inexpensive and do not require complex calculations when compared to the use of Programmable Logic Controllers (PLC). Microcontrollers are very much found in electronic equipment which contains several main components, namely the Central Processing Unit (CPU), Random Access Memory (RAM) and Input/Output Ports (PORT I/O). In addition to these main parts, there are several hardware devices that can be used for various purposes, such as enumeration, serial communication and interrupts. Certain microcontrollers even include an Analog to Digital Converter (ADC), Universal Serial Bus (USB) Controller and Controller Area Network (CAN).[6]

Microcontroller works based on the program (software) embedded in it. The program is made according to the application that the user wants. Microcontroller applications are generally related to reading data from outside and controlling external equipment. Examples of simple applications are for running text, temperature sensors, lights on smartwatches, turning on and off Light Emitting Diodes (LEDs). [7]

2 Experimental Setup

2.1 Research Flow Chart

The research flow chart as shown in Figure 2 analysis of the design and manufacture of pneumatic drilling fixtures using a microcontroller-based control system.

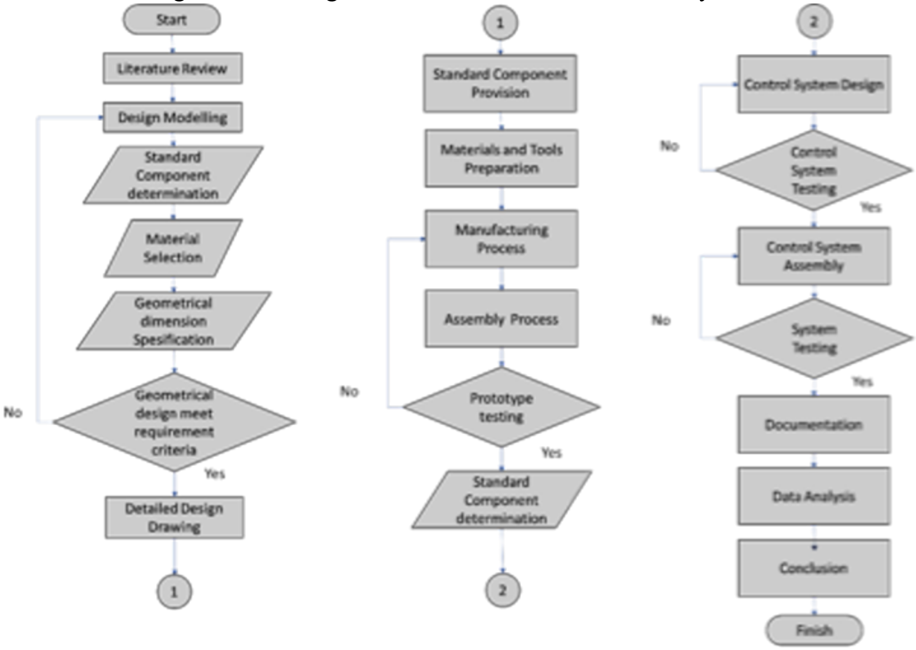

Fig. 2. Research flow process diagram

2.2 Final Design

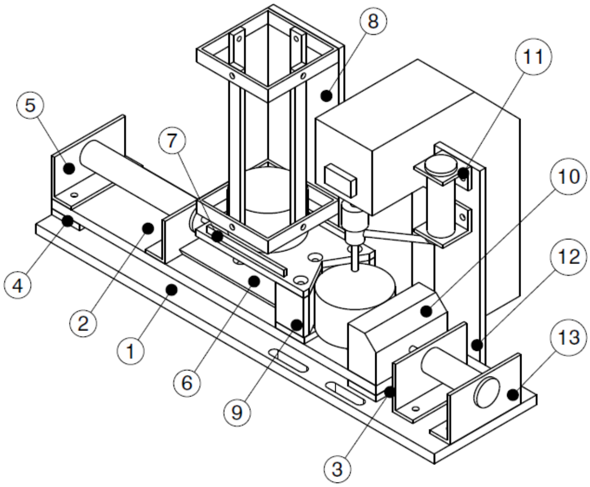

Fig. 3. Pneumatic Drilling Fixture system

Based on the literature study, the sketch of the pneumatic drilling fixture as shown in Figure 3. The things that are shown are: 1. Bottom Platform; 2. Top Platform; 3. The Tail of the Grounding Bird; 4. Bird's Tail Groove; 5. Cylinder A Support; 6. Bird's Tail; 7. Workpiece Support; 8. Magazines; 9. Jaw Movement; 10. Fixed Jaws; 11. Cylinder B Support; 12. Mast Cylinder B; 13. Mast Cylinder C.

2.3 Drilling Fixture

Drilling fixture is a drilling tool used to make two holes with the same depth and diameter. Existing drilling fixtures are driven by three driving methods, namely: mechanical drive, pneumatic drive and hydraulic drive. Drilling fixtures with pneumatic drives carry out the movement process from cleaning, drilling and setting drills using the help of pneumatic cylinders [7]. The working step of the drilling fixture is that the object is taken by cylinder A from the fall magazine, then pushed and clamped at the drilling site. Drilling is carried out by cylinder B and the drilling depth can be determined by setting the limit switch. Setting the second drilling distance with the first hole is done by adjusting the sliding table driven by cylinder C. Cylinder A, cylinder B, and cylinder C use a double acting cylinder (DAC).

2.4 Conceptual Framework

The research concept framework is a relationship or link between one concept to another concept of the problem to be studied. The research concept in this study can be seen in Figure 4.

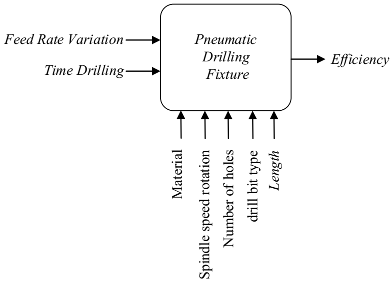

Fig. 4. Pneumatic Drilling Fixture system

- Controlled Variable
  The use of the Arduino Uno microcontroller and the spindle rotation speed whose value is not changed and must be constant throughout the research process.
- Independent Variable
  The independent variable used in this study is the variation of the feed rate speed which is influenced by the flow control setting. The feeding speed and feeding time are variable because feeding time depends on the feed speed for the length traveled (or cut), so the feeding time is dependent on the ingestion speed.
- Processes
  An arduino microcontroller as the brain of the operation that gets power from the power supply.
- Dependent Variable
  The resulting value towards the solenoid in the form of the distance between the two holes, the drilling depth and the actual time is an output whose value can change based on the Arduino Uno programming results.

3 Result And Discussion

After the initial design is made, the next step is to calculate the strength of each component that receives the force. This is done so that the tools to be used are not damaged and can be used for a long time. The load calculation is calculated based on the force that occurs during the drilling process which is shown in Figure 5

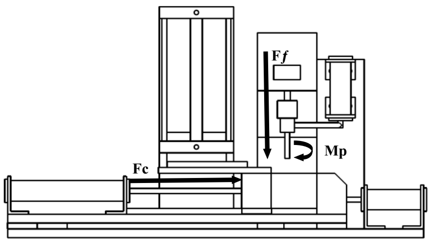

Fig. 5. Force Diagram

3.1 Cutting Force Calculation

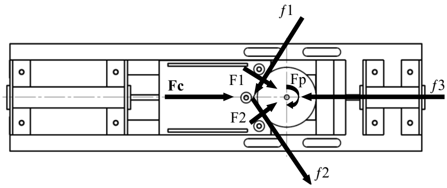

Fig. 6. Gripping mechanism

In the drilling process, it can be seen that the drill bit used for drilling is Ø8mm with an angle of 1180 and ST37 steel. In order for the cutting process to occur (Fcut), the stress that occurs

τs material < τs actual

$$0.8 \text{ x } 370 \text{ N/mm2} < \frac{F.Cut}{\frac{4}{0.866mm} x\ 2\ mm\ x\ 1}$$

F. cut > 296N/mm2 x 9236mm2

F. cut >2733.856N ≈ 2734N

3.2 Cutting Moment Calculation

The cutting moment due to the cutting force generated during the drilling process can be calculated using the following formula.

Cut Moment = F.Cut x Diameter of Drill

Cut Moment = 2734 N x 8mm

Cut Moment = 21872 N/mm

3.3 Cutting Moment Calculation

The gripping force that occurs during the gripping process can be calculated using the following formula.

Cut Moment < Squeezing Moment

21872N/mm < F. chuck xDiameter of the workpiece

21872N/mm < F. chuck x100mm

F. chuck > 21872/100mm

F. chuck > 218.72N

3.4 Calculation Of Gripping Force

The gripping force that occurs during the gripping process can be calculated using the following formula.

Cut Moment < Squeezing Moment

21872N/mm < F. chuck xDiameter of the workpiece

21872N/mm < F. chuck x100mm
F. chuck > 21872/100mm
F. chuck > 218.72N

3.5 Piston Dimension Design

The design of the piston diameter to be used in the manufacture of the pneumatic drilling fixture can be calculated using the following formula.
F. chuck = Fn. forward
F. chuck = AxP
218.72N = d2mm x 0.8 N/mm2
218.72N = 0.628N/mm x d2
= d2
d2 = 348.280mm
d2 =
d = Ø18.662mm ≈ Ø20mm

From the analysis carried out that the minimum gripping force required when drilling the workpiece is 218.72N and using a piston of at least Ø20mm. As a safety factor and for the sake of success, the compiler uses a piston measuring Ø32mm

3.6 Control System Design

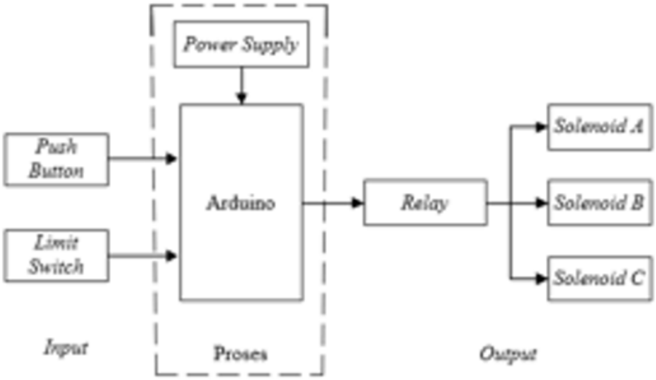

Fig. 7. Control System Schematics

Figure 7 explains that the input comes from the push button and limit switch, while the Arduino Uno is powered by the power supply for controlling it. Arduino Uno is used to activate the relay, where the relay drives solenoid A, solenoid B and solenoid C.

3.7 Pneumatic Drilling Fixture Motion Data

Motion data from the pneumatic control system on the drilling fixture is adjusted to the existing cylinder movement. The data of the pneumatic cylinder motion stroke on the drilling fixture is obtained. The number of pneumatic cylinders used in pneumatic drilling fixtures using a microcontroller-based control system is 3. These cylinders drive the drilling fixture. The cylinders used are given the notation cylinder A, cylinder B and cylinder C. The working process of the 3 cylinders is given the names and notations in table 2 as follows.

Table 2. Cylinder Notation

Cylinder Name	Notation	Feedback Signal
Cylinder A Forward	A+	a1
Cylinder A Backward	A-	a0
Cylinder B Forward	B+	b1
Cylinder B Backward	B-	b0
Cylinder C Forward	C+	c1
Cylinder C Backward	C-	c0

The sequence of working steps of the three cylinders in a pneumatic drilling fixture using a microcontroller-based control system is as follows.

A+ B+ B- C+ B+ B- C- A-

The work steps are illustrated with a state diagram. The state diagram of the pneumatic dilling fixture process for making two holes using a microcontroller-based system is shown in Figure 8 below.

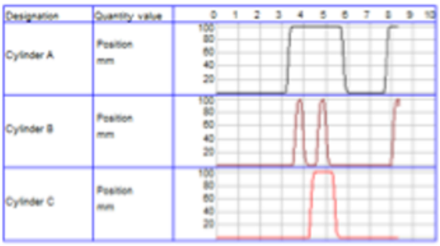

Fig. 8. State Diagram

From the state diagram above, the feedback signal step can be described in Figure 9.

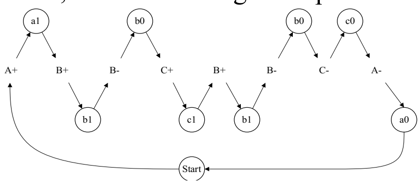

Fig. 9. Feedback Signal

Limit switches with the notation a0, a1, b0, b1, c0 and c1 are installed in the initial and final positions of the piston movement of cylinder A, cylinder B and cylinder C. The function of the limit switch is to provide a feedback signal.
The way the 3 cylinder works is as follows.
1. Signals a0, b0 and c0 are depressed.
2. In the first step, cylinder A moves forward until it suppresses signal A1.
3. Signal a1 is depressed, then cylinder B moves forward until it suppresses signal b1.
4. Signal b1 is depressed, cylinder B moves backwards until it suppresses signal b0.
5. Signal b0 is depressed, then cylinder C moves forward until it suppresses signal c1.
6. Signal c1 is depressed, cylinder B moves forward until it suppresses signal b1.
7. Signal b1 is depressed, cylinder B moves backwards until it suppresses signal b0.
8. Signal b0 is depressed, cylinder C moves backwards until it suppresses signal c0.
9. Signal c0 is depressed, cylinder A moves backwards until it suppresses signal a0.
10. All cylinders are in initial position.

The first series of pure pneumatic manufacture is less efficient so that it is converted into an electro pneumatic circuit, in order to simplify the electrical circuit on the Arduino for programming or coding on the Arduino Integrated Development Environment (IDE) application.
The series of trials have been carried out carefully in stages. The trial has been successful and the tool is ready and feasible to operate. The following table 3, table 4, and table 5 are data exposures on testing pneumatic drilling fixtures using a microcontroller-based control system obtained after running automatically. The results obtained directly run automatically on the Arduino Uno program and immediately transferred to Microsoft Excel.

Table 3. The Effect Flow Control Valve Opening Towards The Drilling Time

Distance of Cylinder B (mm)	Flow Control Valve op.	Drilling time (T) (s)
50mm	100%	9,259
	90%	10,417
	80%	11,574
	70%	12,731
	60%	13,889
	50%	15,046
	40%	16,204
	30%	17,361
	20%	18,519
	10%	19,676

Table 4. Effect Of Drilling Time Towards Feed Rate

Drilling time (T) (s)	Feed Rate (V) (mm/s)
9,259	5,400
10,417	4,800
11,574	4,320
12,731	3,927
13,8896	3,600
15,046	3,323
16,204	3,086
17,361	2,880
18,519	2,700
19,676	2,541

Table 5. Feed Rate Towards Total Time

Feed Rate (V) (mm/detik)	Waktu Total (detik)
5,400	33,544
4,800	34,694
4,320	36,362
3,927	39,801
3,600	42,868
3,323	44,818
3,086	47,323
2,880	48,487
2,700	50,702
2,541	55,206

The data processing method in this research is the result of automatic drilling on a pneumatic drilling fixture using a microcontroller-based control system in actual fact. Data analysis used quantitative methods. The results obtained are the drilling time on cylinder B, the feeding time that occurs and the total time that occurs in one cycle.

In Figure 10 there is a relationship between the flow control valve setting and the drilling time. The more the flow control valve is closed, the longer it will take to drill the workpiece. Vice versa, the more the flow control valve is opened, the faster the workpiece drilling process will be.

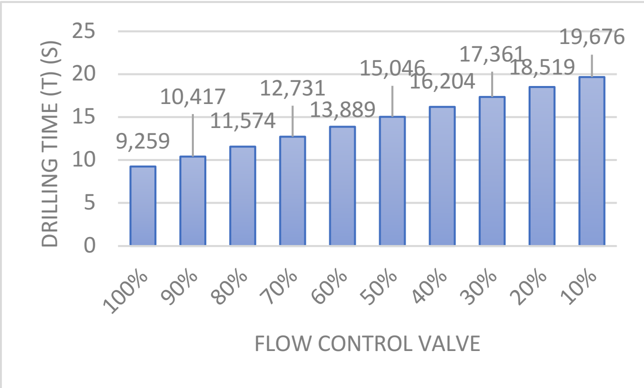

Fig. 10. Relationship of Flow Control Valve to Drilling Time

In Figure 11 there is a relationship between drilling time and feed rate. The faster the drilling time of the workpiece, the greater the feed rate that occurs. And vice versa, the longer the time of drilling the workpiece, the smaller the feed rate that occurs.

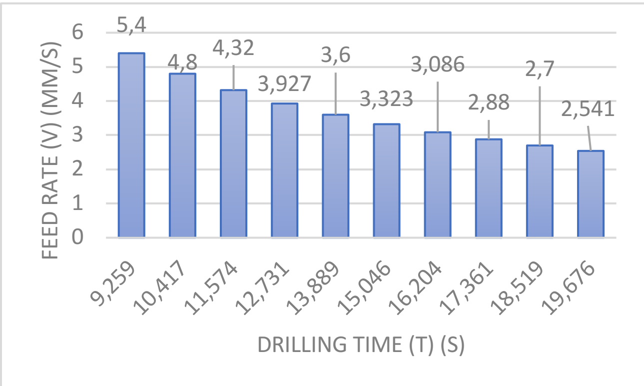

Fig. 11. Relationship between Drilling Time and Feed Rate

In Figure 12 there is a relationship between the feed speed and the total time that occurs in the pneumatic drilling fixture using a microcontroller-based control system. The higher the feed rate used, the faster the drilling time for one cycle. Vice versa, the lower the feed rate used, the longer the drilling time for one cycle

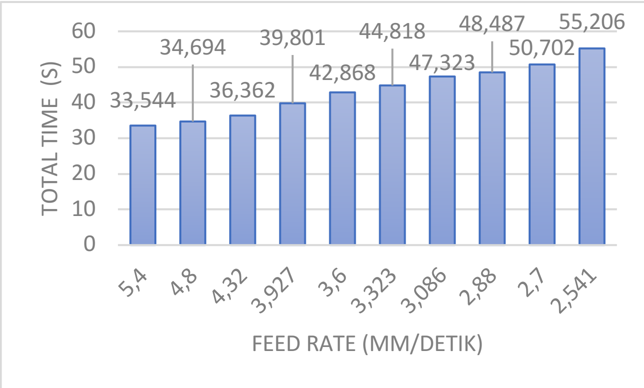

Fig. 12. Relationship between Drilling Time and Feed Rate

4 Conclusion

Based on the results and discussion in Chapter III, the conclusions that the authors can take are as follows.

1. The calculation of the strength analysis of pneumatic drilling fixture construction using a control system based on a microcontroller is as follows.

a. Weight: 42.8kg

b. Dimensions: 700mm x 180mm x 455mm

c. Cut Style: 2733,856N

d. Cut Moment: 21872N/mm

e. Piston Diameter: 32mm

f. Drilling Machine Power: 375Watt

2. All parts of the pneumatic drilling fixture have been designed or designed according to calculated safety limits.

3. All component parts of the pneumatic drilling fixture have been made and can be moved manually before the automatic testing process is carried out using a microcontroller-based control system.

4. The results of the control system test are as follows:

a. All components of the limit switches a0, a1, b0, b1, c0 and c1 are connected correctly.

b. The output signal on the Arduino Uno has been connected to the 5/2 solenoid valve which controls cylinder A forward, the 5/2 solenoid valve which controls cylinder A backwards, the 5/2 solenoid valve which controls cylinder B forward, and the 5/2 solenoid valve which controls cylinder B is reversed, a 5/2 solenoid valve which controls cylinder C forward and a 5/2 solenoid valve which properly controls cylinder C backwards.

c. A properly simulated Arduino Uno program.

5. There is a relationship between the flow control valve setting and the drilling time. The more the flow control valve is closed, the longer it will take to drill the work-

piece. Vice versa, the more the flow control valve is opened, the faster the workpiece drilling process will be.
6. There is a relationship between drilling time and feed rate. The faster the drilling time of the workpiece, the greater the feed rate that occurs. And vice versa, the longer the time of drilling the workpiece, the smaller the feed rate that occurs.
7. There is a relationship between the feed speed and the total time that occurs in pneumatic drilling fixtures using a microcontroller-based control system. The higher the feed rate used, the faster the drilling time for one cycle. Vice versa, the lower the feed rate used, the longer the drilling time for one cycle.

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