EVALUATION OF NOZZLE POSITIONING EFFECT ON AUTOMATED COOLANT SUPPLY SYSTEM PERFORMANCE USING A NEWLY DEVELOPED JIG

Submitted in accordance with the requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor Degree of Manufacturing Engineering (Hons.)

by

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APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of Universiti Teknikal Malaysia Melaka as a partial fulfilment of the requirement for Degree of Manufacturing Engineering (Hons). The member of the supervisory committee is as follow:

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ABSTRAK

Terdapat beberapa strategi bendalir pemotong telah dihasilkan, seperti pemotongan kering, penyejukan banjir, dan *Minimum Quantity Lubrication* (MQL). MQL terbukti dapat mencapai kualiti permukaan yang lebih baik dengan menggunakan jumlah bendalir pemotong yang kurang. Oleh itu, hakikat bahawa lebih banyak bendalir akan mencapai kualiti permukaan yang lebih baik boleh dipertikaikan dan telah menyumbang kepada perkembangan *Automated Coolant System* (ACS). ACS menggunakan *Programmable Logic Controller* (PLC) untuk mengawal bekalan bendalir pemotong mengikut selang masa. Oleh itu, jumlah bendalir pemotong boleh dikurangkan. ACS telah dikembangkan dalam karya penyelidikan sebelumnya dan terbukti mencapai kualiti permukaan yang lebih baik daripada penyejukan banjir. Semasa projek sebelumnya, parameter pemesinan optimum ACS sudah ditentukan. Parameter ini adalah kelajuan gelendong, kadar suapan, kedalaman pemotongan, dan selang waktu bekalan pemotongan bendalir pemotongan. Walau bagaimanapun, kedudukan muncung, yang juga merupakan salah satu parameter yang penting, masih belum dikaji. Dalam kes ini, projek ini bertujuan untuk mereka bentuk dan menghasilkan jig dengan fungsi pelarasan sudut untuk ACS dan melakukan analisis teori mengenai keputusan yang dijangkakan berdasarkan penemuan literatur. Reka bentuk jig dimulakan dengan penentuan *Degree of Freedom* (DOF) yang diinginkan, diikuti dengan lakaran jig. Pemodelan 3D dibuat di *Autodesk Inventor* dengan merujuk lakaran ACS jig. Prototaip jig kemudian dihasilkan dengan menggunakan pemprototaipan pantas. Sudut kedudukan muncung optimum mengenai arah suapan dijangkakan pada 120°, 150°, 180°, atau 210°. Sudut muncung optimum dijangka pada 45° atau 50°. 40 mm atau 50 mm dijangka jarak muncung optimum. Keputusan ini dijangkakan berdasarkan teori dan penemuan penyelidikan dan diyakini dapat meningkatkan kualiti permukaan aluminium pada proses pengisaran.

ABSTRACT

There are several cutting fluids strategies have been developed, such as dry cutting, flooded cooling, and Minimum Quantity Lubrication (MQL). MQL is proven to achieve a better surface quality while using a lesser amount of cutting fluids. Hence, the fact that more cutting fluid will achieve better surface quality is arguable and has contributed to the development of Automated Coolant System (ACS). ACS utilized Programmable Logic Controller (PLC) to control the supply of cutting fluid by time interval. Therefore, the amount of cutting fluid is reduced. ACS is already developed in previous research works and proven to have better surface quality than flooded cooling. During the previous project, the optimal machining parameters of ACS is already determined. These parameters are the spindle speed, feed rate, depth of cut, and the time interval of cutting fluid supply. However, the nozzle position, which is also one of the important parameters, has yet been studied. In this case, this project aimed to design and fabricate a jig with angle adjustment feature for the ACS and carry out theoretical analysis on the expected result based on literature findings. The design of jig began with the determination of desired Degree of Freedom (DOF), followed by the sketching of jig. 3D modelling is created in Autodesk Inventor by referring to the sketch of ACS jig. The prototype of jig is then produced by using rapid prototyping. The optimal nozzle position angle about the feed direction is predicted on 120°, 150°, 180°, or 210°.The optimal nozzle elevation is expected to be 45° or 50°. 40 mm or 50 mm is predicted to be the optimal nozzle distance. These results are predicted based on theory and research finding which is believed to improve the surface quality of aluminium in end milling.

DEDICATION

Special dedication to my loving family members, friends, classmates, and everyone who encouraged me during this entire project.

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TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ACS	-	Automated Coolant System
AISI	-	American Iron and Steel Institute
ANOVA	-	Analysis of variance
BUE	-	Built Up Edge
CAD	-	Computer Aided Drawing
CFD	-	Computational Fluid Dynamics
CNC	-	Computer Numerical Control
DOE	-	Design of Experiment
DOF	-	Degree of Freedom
FEA	-	Finite Element Analysis
MQL	-	Minimum Quantity Lubrication
NC	-	Numerical Control
NIOSH	-	National Institute of Occupational Safety and Health
PC	-	Personal computer
PDA	-	Phase Doppler Anemometry
PIV	-	Particle Image Velocimetry
PLC	-	Programmable Logic Controller
SEM	-	Scanning Electron Microscope
UTS	-	Ultimate Tensile Strength

LIST OF SYMBOLS

%	-	Percent
°	-	Degree
°C	-	Degree Celcius
ℓ/min	-	Litre per minute
mℓ/h	-	Millilitre per hour
mm	-	Millimetre
mm/min	-	Millimetre per minute
rpm	-	Revolution per minute
s	-	Seconds
MPa	-	Mega Pascal

CHAPTER 1
INTRODUCTION

1.1 Background of Study

Milling is a material removal process by feeding the workpiece towards the high-speed rotating cutting tool. It can produce complex shapes and detailed features such as holes, teeth, grooves, notches, etc. Milling is also capable of achieving a very high surface finish with high tolerance. As technology advances, the application of Computer Numerical Control (CNC) has been applied in the milling process. CNC milling offers a more convenient and accurate machining experience. With the support of coding, the cutting can be done more precisely and accurately by importing the Cartesian coordinates into the computer. The computer will interpret the coordinates and feed the workpiece to the cutting tool precisely.

During the milling process, heat is generated between the cutting zone and the workpiece. The generated heat will affect the tool life and surface quality. In some situations, it is vital to reduce the heat. In order to reduce the generated heat, cutting fluids is applied throughout the milling process. Generally, the machining process can be categorised into two categories, which are dry machining and wet machining. Dry cutting is defined as a cutting process without the presence of cutting fluids. For dry cutting, the lousy surface finish and high tool wear are apparent.

To overcome this issue, the application of cutting fluid has become common in the machining industry. With the presence of cutting fluid, the machining process is categorised as wet machining. The conventional cutting fluid supply strategy is continuous and steady throughout the cutting process and has been defined as flooded cooling. Due to various downside of flooded cooling, new strategies have been introduced, such as Minimum Quantity Lubricant (MQL), mist cooling, and so on. MQL uses lesser cutting fluid than flooded cooling, but it can achieve a higher surface quality and prolonged tool life.

Figure 1.1: Automated Coolant System in action

This is a continuous project from the previous research works. In the previous project, a new cutting fluid supply system was developed and named Automated Coolant System (ACS) as shown in Figure 1.1. The cutting fluid strategy can be defined as intermittent cooling, where the cutting fluid is not supplied continuously but at a specific time interval. Figure 1.2 showed the supply of cutting fluid based on time interval by ACS. This system is powered by Programmable Logic Controller (PLC) to control the open and close of the supply valve based on a timer. The time interval is adjustable in the ladder diagram. This method uses a slightly higher amount of cutting fluid compared to MQL but still less than flooded cooling. During the development of ACS, the performance of ACS has been investigated. The result showed that it could achieve a better surface finish than flooded cooling. The optimal parameters, such as the time interval, spindle speed, feed rate, and depth of cut had been discovered during the previous research works. Despite this, there are still some parameters that gives effect to the surface quality performance.

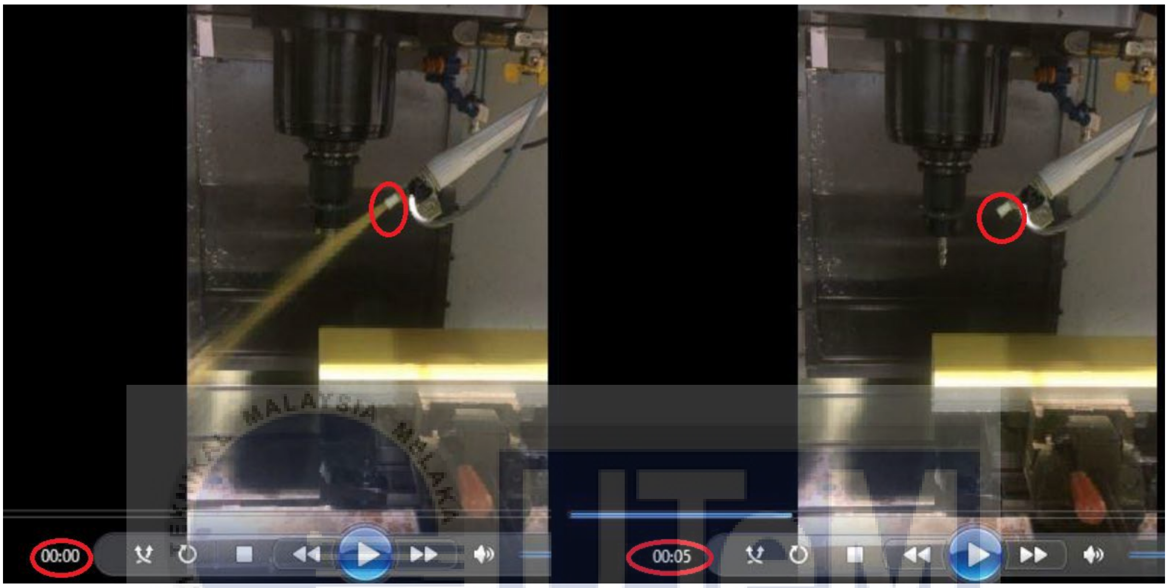

Figure 1.2: Cutting Fluids Supply with the Time Interval of 5s

The parameters that affect the performance of MQL is a lot, such as the cutting parameters that include the type of cutting fluid used, the types of the cutting tool, nozzle, and so on. The nozzle is also one of those parameters that will affect milling performance. For this project, the nozzle position angle about the feed direction, nozzle elevation angle, and nozzle distance to the cutting zone affect the surface roughness is mainly focused. In addition, the nozzle positioning effect has been proven in recent research that at a certain angle, position, and distance of nozzle, the end product’s surface roughness will be affected (Duan et al., 2020; Liu et al., 2011; Yan et al., 2012). As far as it concerns, the current stage of ACS is only capable of controlling the time interval to supply the cutting fluid. By referring to Figure 1.1 and Figure 1.2, there is no feature to adjust the position, elevation angle, and distance for ACS. A jig that can determine and adjust the nozzle position, elevation angle and distance between the nozzle’s tip to the workpiece’s surface is needed for ACS to improve the end product’s surface quality.

1.2 Problem Statement

In metal machining process, it involves the rubbing between the cutting tools and workpiece. During the CNC milling process, the sharp edge of high-speed rotating cutting tools will contact the surface of the workpiece at certain force. This will result in a change of shape of the cutting tools due to the high stress and heat produced during the cutting process, resulting in the cutting tool loss of material.

Surface quality is vital in metal machining for quality purpose. Limits for the surface roughness will be set to ensure a smooth finishing of machined products. The surface quality is often determined by measuring the surface roughness by using specific equipment. Radi (2010) studied that dry machining results in very high surface roughness on the workpiece's surface.

The effect of MQL is positive in improving surface quality and prolonged tool life. However, the position of the nozzle is also critical in order to benefit from MQL. Yan et al. (2012) determined that the nozzle positioning angle, nozzle elevation angle, and distance from the nozzle end to the machining zone will affect the surface roughness and tool life. From Figure 1.1, it can be noticed that the ACS does not have any nozzle positioning feature.

1.2.1 The Inaccurate Positioning Angle of the Nozzle

ACS does not come with an angle positioning feature. The position of nozzle about to the feed direction cannot be determined. The cutting fluid supplied might not be able to penetrate the zone between the cutting tool and the workpiece's surface. Furthermore, with the inaccurate angle, the cutting fluid supplied might become waste. During the process, the cutting tool is always rotating. If the cutting fluid is supplied in the wrong direction, the cutting fluid might be spun away by the rotation of the cutting tool. Based on Duan et al. (2020), the study showed the proper positioning of nozzle increase the surface quality of the workpiece, nozzle position at the angle of 35°, the distance of 30mm and the elevation angle at 60° has the best surface roughness. Accordingly, the performance of ACS is not at its optimum level. Thus, the surface quality might reduce, and the tool life will be shortened due to the high tool wear.

1.2.2 The Inaccurate Nozzle's Angle of Elevation

The elevation angle is the angle measured from the surface to be cut of the workpiece to the nozzle position. During the machining process, the adhesion of chip to the surface of the workpiece will occur. This will be resulting in the higher stress to the cutting tool because the built-up chip is usually harder than the workpiece. Thus, reducing the tool life and decrease the surface finish. If the angle of elevation is improper, the cutting fluid is unable to penetrate in the cutting zone effectively. For the current design of ACS, the angle of elevation is hardly to be determined. This will cause the chip hardly to be washed away by the cutting fluid. According to Yan et al. (2012), at the 60° angle of elevation, nozzle position at 120° and the distance of 20mm from the cutting zone, the tool wear is reduced and the surface finish is improved. This shows the importance of having the measurement of angle of elevation in the cutting fluid supply system.

1.2.3 Improper Distance from the Nozzle to the Cutting Zone

The distance between the nozzle end to the workpiece is crucial when the pressure of the cutting fluid is fixed. If the distance is too far or too short, the cutting fluid will not be acting properly. When the distance is too far, the pressure of the cutting fluid is not enough to wash away the chip and not provide lubrication properly. Meanwhile, if the distance is too close, the cutting zone cannot be fully lubricated. Only at the optimal distance that cutting fluid will be penetrating the cutting zone entirely and not being wasted. In other words, the distance will affect the surface finish and the tool life. The study of Liu et al. (2011) proved that when the nozzle position angle is at 135°, the distance of 25mm is the optimal distance.

Closer or further the distance will not improve the penetration of the cutting fluid. There is no distance measurement on the current stage of ACS. Because of that, the proper cutting fluid distance is hardly to be measured.

1.3 Objectives

The objectives are as follows:

(a) To design and analyse a suitable jig for the Automated Coolant System.

(b) To fabricate the ACS jig for the purpose of investigation of nozzle positioning effect.

(c) To analyse theoretically the expected result of the optimum nozzle positioning based on the literature findings.

1.4 Scopes of Study

The project is to design and fabricate a jig for the ACS's nozzle, and make theoretical assumption analyse regarding the optimum nozzle positioning setup theoretically through the literature study. The jig allows the nozzle to supply the fluids at the desired position. This jig's design is based on the CNC milling machine in UTeM FKP's workshop. This project focus on the three parameters, which are nozzle position, nozzle elevation angle, and distance of nozzle's tip from the surface of the workpiece.

The limitation of this project is that the jig design is not universal. This jig is only suitable for the CNC milling machine in UTeM FKP's workshop only. For the optimum nozzle positioning result in this project, it is analysed theoretically based on previous research works' achievement, which yet to be investigated and proven for the developed jig.

The design of the jig is based on the design principle of jigs and fixtures. The jig should fit the ACS nicely. The 3-2-1 Principle of Location for jig and fixture is applied but only provide accurate positioning for the nozzle. The design of jig is carried out using Autodesk Inventor. The fabrication of the prototype jig is at UTeM FKP's rapid prototype lab.

1.5 Significance of Study

There are some benefits that can be gained after the completion of this project. First of all, the usage of cutting fluid can be decreased. This will cause a significant effect in term of cost-saving. Other than that, the reduction of cutting fluid will also make a safer working environment and condition. The chance of worker getting skin disease and respiratory disease can be reduced. This will also help to save the cost to dispose of the waste cutting fluid. Not only saving cost, but it also reduces environmental pollution.

Secondly, the jig will bring ease in adjusting the position of the nozzle. With the help of the jig, the desired position of the nozzle can be determined and easily changed. By setting the nozzle at an optimum position, the surface roughness of the end-product can be decreased. This also helps to reduce the chance of a secondary process to smoothen the surface of end-product. In other words, the jig will increase the overall productivity.