UNIVERSITI PUTRA MALAYSIA

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By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

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October 2012

Chairman: B.T. Hang Tuah Baharudin, PhD
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ABSTRACT

The aim of this study was to determine the optimum cutting condition for face milling when machining the nodular cast iron. The cutting conditions consist of the cutting speed, the feed per tooth and the depth of cut. The original problem arose in the crankshaft machining-line of the Proton engine shop where the face milling cutting tool frequently changed due to premature of tool life. As a result, the productivity of this production line was decreased. This problem occurred due to the enhancement of the raw-cast hardness, and no detail study was made on the cutting condition by the engine shop.

This study was carried in three experiments; the preliminary experiment, optimization experiment and confirmation experiment. All experiments used the same tool and the same material of the engine shop.The preliminary experiment aimed to determine and benchmark the performance of the cutting tool and surface roughness when machined in the laboratory environment. Taguchi optimization

method was applied for optimization experiment. This experiment aims to regulate the machining parameters of three parameters at three levels. A L_9 orthogonal array, signal-to-noise ratio and analysis of variance (ANOVA) were applied in order to determine and analyzed the optimal cutting condition. The confirmation experiment was conducted using the suggested cutting condition obtained from the optimization experiment in order to validate the result.

The result of the preliminary experiment showed that the volume of material removes using the current practice cutting condition was about two hundred and fifty cubic centimetres. The average surface roughness measured was about point six micrometers. The optimization result showed that the optimum cutting condition capable to remove the material more than four hundred cubic centimetres with the surface roughness measured about point six micrometers. Comparison between both experiments shows that the result was different for about forty percent. This indicated that the optimization experiment was successfully determined the optimal cutting condition. Results obtained by Taguchi method match closely with ANOVA and cutting speed is most influencing parameter. The confirmation experiment conducted also agreed on the optimization experiment result where the result of material removes volume and surface roughness was the same.

The results show that there is a proper way to determine the optimal cutting conditions other than trial-and-error method, which indirectly saves operating costs. It is recommended to the engine shop to adjust its current cutting conditions according to the findings of this study. Research on the same topic by using another grade inserts are recommended for further study.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

PENGOPTIMUMAN KONDISI PEMESINAN PADA HAYAT MATA ALAT DALAM PENGISARAN PERMUKAAN BESI TUANG BERGRAFIK BULAT MENGGUNAKAN KAEDAH TAGUCHI

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ABSTRAK

Tujuan kajian ini adalah untuk menentukan parameter pemotongan yang optimum untuk operasi mesin pengisar apabila memesin besi tuang bergrafik bulat. Parameter pemotongan terdiri daripada kelajuan pemotongan, suapan per gigi dan kedalaman pemotongan.Masalah ini asalnya berlaku di kilang pembuatan enjin Proton pada baris pemesinan aci engkol di mana mata alat mesin pengisar ini kerap kali ditukar disebabkan oleh hayat mata alat yang pramatang. Hasil dari kerapnya penukaran ini, produktiviti barisan pengeluaran ini telah menurun. Masalah ini berlaku disebabkan oleh peningkatan kekerasan bahan yang hendak di mesin, dan tiada kajian terperinci telah dibuat pada parameter pemotongan oleh pihak kilang.

Kajian ini telah dijalankan dalam tiga bentuk eksperimen; eksperimen permulaan, eksperimen pengoptimuman dan eksperimen pengesahan. Semua eksperimen telah menggunakan mata alat dan bahan yang sama seperti yang digunakan oleh kilang enjin. Eksperimen awal bertujuan untuk menentukan dan sebagai penanda aras

prestasi mata alat memotong dan kekasaran permukaan apabila dimesin dalam persekitaran makmal. Kaedah pengoptimuman Taguchi telah digunakan untuk eksperimen pengoptimuman. Eksperimen ini bertujuan untuk mengawalselia parameter pemesinan yang terdiri dari tiga parameter pada tiga peringkat. Tatasusn ortogon L_9, nisbah isyarat-kepada-hingar dan analisis variasi (ANOVA) telah digunakan untuk menentukan dan menganalisis keadaan pemotongan yang optimum. Eksperimen pengesahan telah dijalankan menggunakan keadaan pemotongan yang diperolehi dari eksperimen pengoptimuman untuk mengesahkan hasilnya.

Hasil eksperimen permulaan menunjukkan bahawa jumlah bahan terbuang adalah kira-kira dua ratus lima puluh sentimeter padu. Kekasaran permukaan purata yang diukur ialah sebanyak perpuluhan enam mikrometer. Hasil eksperimen pengoptimuman menunjukkan bahawa keadaan pemesinan optimum mampu memotong bahan lebih daripada empat ratus sentimeter padu dengan kekasaran permukaan diukur sebanyak perpuluhan enam mikrometer. Perbandingan antara eksperimen permulaan dan pengoptimuman menunjukkan bahawa isipadu bahan yang dibuang adalah berbeza sebanyak kira-kira empat puluh peratus. Ini menunjukkan bahawa eksperimen pengoptimuman berjaya menentukan keadaan pemotongan yang optimum. Keputusan yang diperolehi oleh kaedah Taguchi sepadan rapat dengan ANOVA dan kelajuan pemotongan adalah parameter paling mempengaruhi keputusan eksperimen. Eksperimen pengesahan dijalankan juga bersetuju pada hasil eksperimen pengoptimuman di mana hasil jumlah bahan terbuang dan kekasaran permukaan adalah sama.

Keputusan kajian ini menunjukkan bahawa terdapat satu cara yang betul untuk menentukan keadaan optimum pemotongan selain dari percubaan secara rawak, yang secara tidak langsung menjimatkan kos operasi. Adalah disyorkan kepada pihak kilang enjin untuk menyesuaikan keadaan paras semasa pemesinan menurut hasil dari kajian ini. Penyelidikan mengenai topik yang sama dengan menggunakan satu lagi gred sisipan adalah disyorkan untuk kajian seterusnya.

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Without my wife's encouragement, I would not have finished the degree.

I certify that a Thesis Examination Committee has met on 29 October 2012 to conduct the final examination of Mohamad Maaroff Bahurdin on his thesis entitled "Optimization of Cutting Conditions on Tool Life in Face Milling Spheroidal Graphite Cast Iron Using Taguchi Method" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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Date:

DECLARATION

I declare that the thesis is my original work except for quotation and citations, which have been duly acknowledged. I also declare that it has not been previously, and is not currently submitted for any other degree at Universiti Putra Malaysia or other institutions.

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MOHAMAD MAAROFF BAHURDIN

Date: 29th October 2012

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

κ	: Cutting tool edge angle
$\gamma 0$	: Cutting rake angle
γf	: Radial rake angle
γp	: Axial rake angle
a_e	: Axial depth of cut
Al_2O_3	: Aluminum Oxide
a_r	: Radial depth of cut
CF	: Catastrophic failure
CH	: Chipping
CNC	: Computer Numerical Control
Co	: Cobalt
CPS	: Cam Profile Switching
CR	: Cracks
CVD	: Chemical vapor deposition
D	: Milling cutter diameter (mm)
f_e	: Degree of error
FL	: Flaking
f_p	: Degree of freedom for parameter p
f_t	: Total degree of freedom
f_z	: Feed per tooth (mm)
HRC	: Rockwell hardness scale C
KT	: Face wear
MPR	: Monthly Performance Report
PD	: Plastic deformation
PVD	: Physical vapor deposition
R_a	: Arithmetic mean surface roughness
SS'P	: Corrected sum of square
SS_e	: Sum of square error
SSP	: Sum of square for parameter
SST	: Sum of square

TiC : Titanium Carbide

TiCN : Titanium Carbo-Nitride

TiN : Titanium Nitride

V_B :Flank wear

V_c : Cutting speed (m/min)

V_f : Feed velocity vector (mm/min)

V_p : Variance of the parameter

WC : Tungsten Carbide

z : Number of teeth

ρ : Parameter contribution

CHAPTER 1

INTRODUCTION

In metal machining industries, various methods and instruments are being used to acquire desired shape and dimensions. Until today, either conventional or modern machine tool, the exploration in machining technology is still in vast progress. These include new discoveries in various machining technologies such as in cutting tool technology, machine tool technology and tool management strategies.

The introduction of these new technologies is only been appreciated and utilized by some manufacturer. The main hurdle is the involvement of significant capital investment that reflects all economic perspective such as cost and time which most manufacture would not be interested. Majority of them prefers to carry out research that could improve or maximize manufacturing system performance using the existing available resources. Therefore, the research in determining the values of the process parameters that yield the high-quality product is the most desirable (Baskar et al., 2006; Benardos and Vosniakos, 2003).

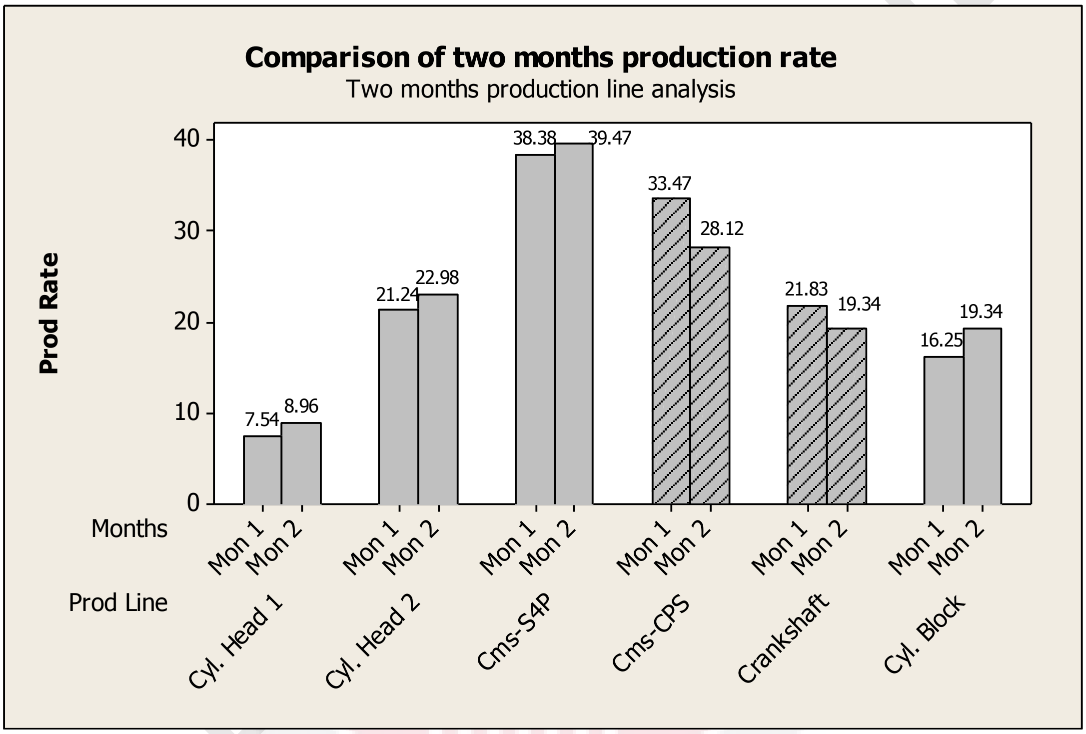
Face milling is frequently used process in industrial machining to machine large and flat surfaces in a very rapid and precise way. Normally, the cutter is equipped by multi-edge of indexable inserts that can easily be replaced whenever the inserts have reached its useful life. Many machining constraints should be considered as well as the selection of machining parameters. The selection of proper machining parameters using one self's experience or from the handbooks will not always give the best results. Conversely, this may lead to shorten the tool life and directly increased the production cost and ravage the production time.

1.1. Background of the Study

This study is based on the actual case condition originated from Proton Engine and Transmission Plant (Proton ETM) situated at Tanjung Malim, Perak. This engine shop is responsible to produce four main engine parts, namely cylinder head, cylinder block, crankshaft and camshaft. There are two varieties of part as the engine size is different, 1.3 and 1.6 liter engine, and the parts are produced in batches as a changeover in equipment programming is required between parts. The parts produce by this shop then shipped to another plant for assembly.

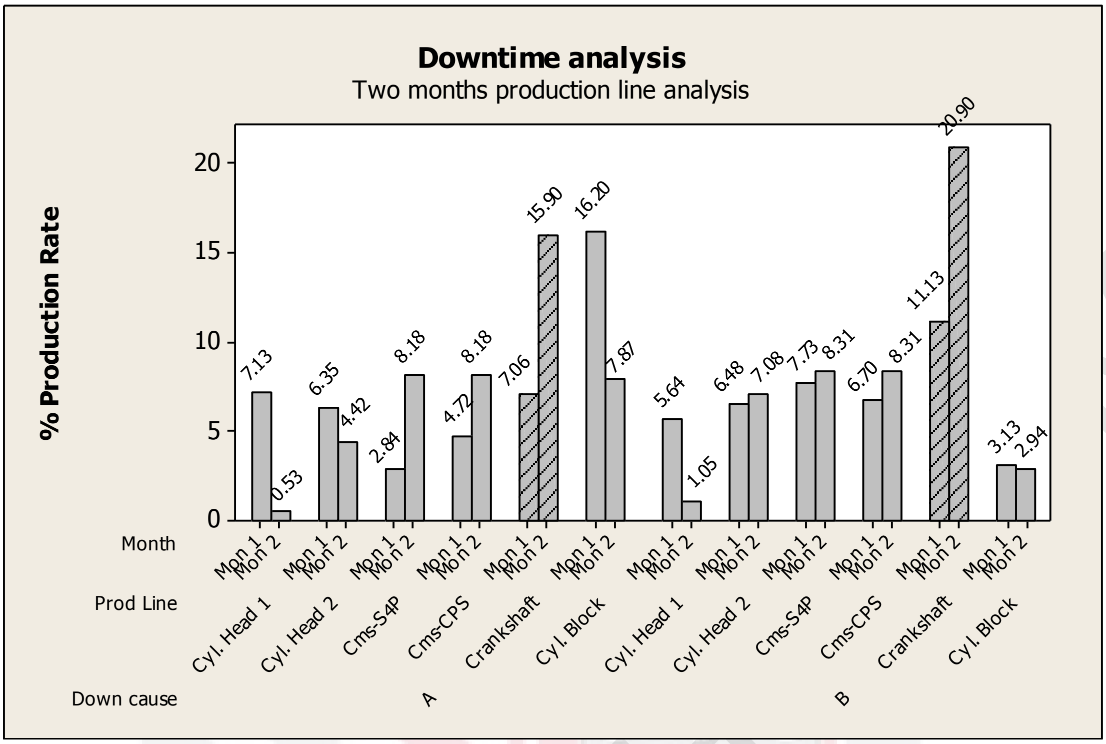
This shop floor consists of six machining process lines where two lines dedicated for cylinder head machining, another two lines for camshaft, and the rests are for crankshaft and cylinder block. The layout design for each line can be classified as a flexible manufacturing system (FMS) except for camshaft as the raw-casts were handled manually. As explained by (Groover, 2008), the FMS means a production system that has an ability to identify and distinguish between the different incoming part or product styles processed, quick changeover of physical setup and quick changeover of operating instruction. Each process line consists of a group of Computer Numerical Controls (CNC) machine tools, interconnected by an automated material handling system such as conveyor, gantry or robotic arm to move part between machines in the cell. All these systems are controlled by a distributed computer system.

Production analysis is conducted in order to evaluate the performance of each production line. The analysis is based on the engine shop's Monthly Performance Result (MPR) report as a variety of data was recorded on it, such as machining and assembly production status, process and material defects, downtime and etc. The two-month machining performance results were analyzed as shown in Figure 1.1 and Figure 1.2.



Cyl. Head 1: Cylinder head machining line 1
Cyl. Head 2: Cylinder head machining line 2
Cmc-S4P: Camshaft machining line for standard engine
Cmc-CPS: Camshaft machining line for CPS engine
Crankshaft: Crankshaft machining line
Cyl. Block: Cylinder block machining line

Figure 1.1: Comparison of two-month production rate



A: Inspection and quality adjustment B: Tool broke / changes

Figure 1.2: Downtime analysis

Figure 1.1 shows that the camshaft and the crankshaft production line have a decreased rate compared to previous month. This indicates the lack of productivity, which gives an immense impact to the monthly production target. According to (Wilson, 2011), the production rate analysis is a measurement of the typical amount of time it takes for a manufacturing operation to produce its goods, and this gives an understanding of the relative efficiency of each machining line's operation.

Further investigation was made by analyzing the downtime for each machining line for both months. The downtime or stoppage is classified into two highly related causes; one is because of the inspection and quality adjustment, and the other one is because of the tool deterioration. The analysis result was shown in Figure 1.2. Clearly, the percentage value between the two-month records of the crankshaft's machining line has shown a rapid increment of the downtime in both causes. The inspection and quality adjustment was 7.06% for month-one and rapidly increased to 15.90%. It goes the same for the other cause of the downtime; the tool broke and change stoppages, where in the first month was only 11.13% and suddenly increased to 20.90% in the second month. Compared with the other machining line, the crankshaft is regarded as the most problematic production line.

Based on these results and the discussion with crankshaft's production personnel, the main cause of the frequent tool broke is because the mechanical properties of the raw material have been improved. The improvement commenced mid 2009 as to fulfill the need of the new car model. According to (Ahmad Shahrir Halimi, Head of Department, Engine & Transmission Department, Proton Tanjung Malim Sdn Bhd, pers. comm. 16 December 2009), as the improvement in raw-cast is not too enormous, the management decided the part should be processed according to previous condition without any changes to the process parameters and further study.

Since then, the problem of the tool broke frequently appeared on almost the machining time which subsequently affecting the production target. Consequently, the crankshafts' production team has to adjust the machine setting to meet the need of newly improved raw-cast. The common method used is the trial-and-error, and this does not only involve in adjusting the machining parameter but also various other's adjustment such as changing the cutting tool dimension and the sequence of the machining process. This obviously led to a worst scenario as the production line has about 22 operations on 31 CNC machines.

1.2. Crankshaft Machining Line

The crankshaft machining line is designed to fabricate the crankshaft named *SP4H* (Figure 1.3), for 1.6 engine size and *S4PE*, for 1.3 engine size; both were produced in different batch, and the projected production target is 27 units per hour.

Figure 1.3: Crankshaft S4PH

The line have six manufacturing cells in which three cells for roughing process and the rest for finishing process. The layout is as illustrated in Figure 1.4. Every cell has more than four workstations and an operator. The operator is the person responsible to monitor and verify the quality of a processed work piece after every 20 pieces. If quality problems arise, the machine and cutting tool had to be inspected for error, correction being made and recorded. After the correction is made, the adjustment process then takes place where a single raw-cast will go through the entire machining process and inspected again afterwards. If the processed part meets the desired quality requirement, the subsequent process will continue in full capacity. This adjustment process also implemented after a replacement of cutting tool.

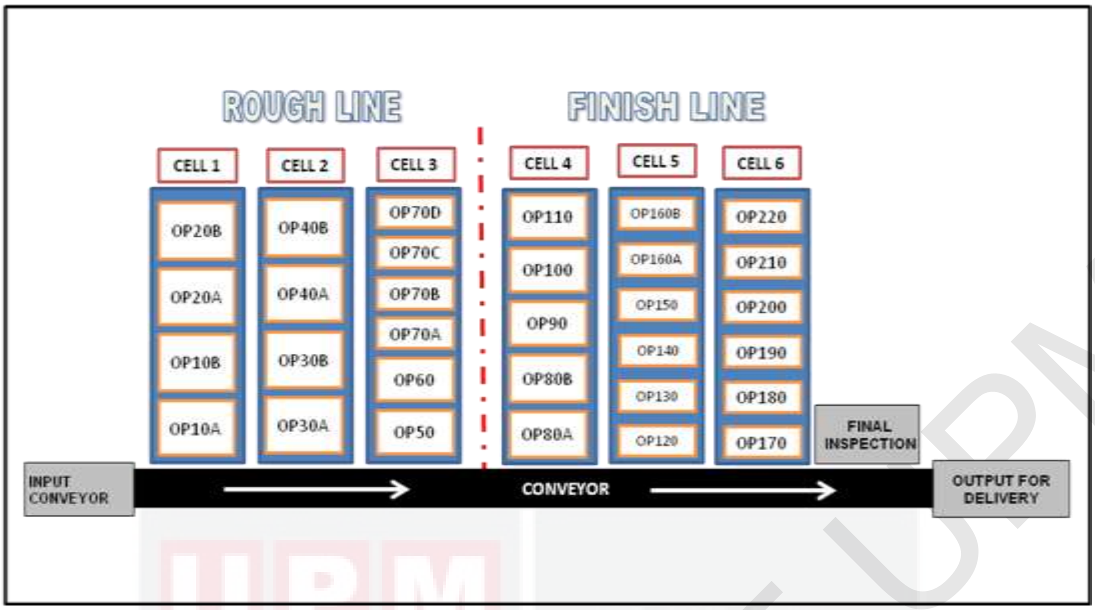


Figure 1.4: Crankshaft machining line layout

This machining line consists of 22 operations, and the entire systems are fully automated except for part loading at the beginning of the conveyor, unloading at the end of the production line and part inspection at every cell, which is done manually by an operator. The gantry system is used to transport the part between the conveyor and CNC machines.

The roughing line is intended to machine the part until it near net dimension. It consists of seven operations within three cells. Based on discussion and interview with the production personnel, this roughing line contributed higher downtime due to the tool change and the adjustment process.

1.2.1. The roughing cells

First cell consists of four CNC machine tools, named OP10A, OP10B, OP20A and OP20B. There are two operations involve in this cell; the primary OP10 operation is to face mill both end facing (Figure 1.5), centering and reference face milling. The

OP20 operation is to turn the front shaft and counter weight as illustrated in Figure 1.6.

According to observation and response from the operator, machine OP10 often has a downtime, mainly because of frequent cutting tool's changes due to premature end of tool life. It occupied nine different cutting tools, and the total cycle time projected is 97 seconds per part; the same cycle time for both part family.

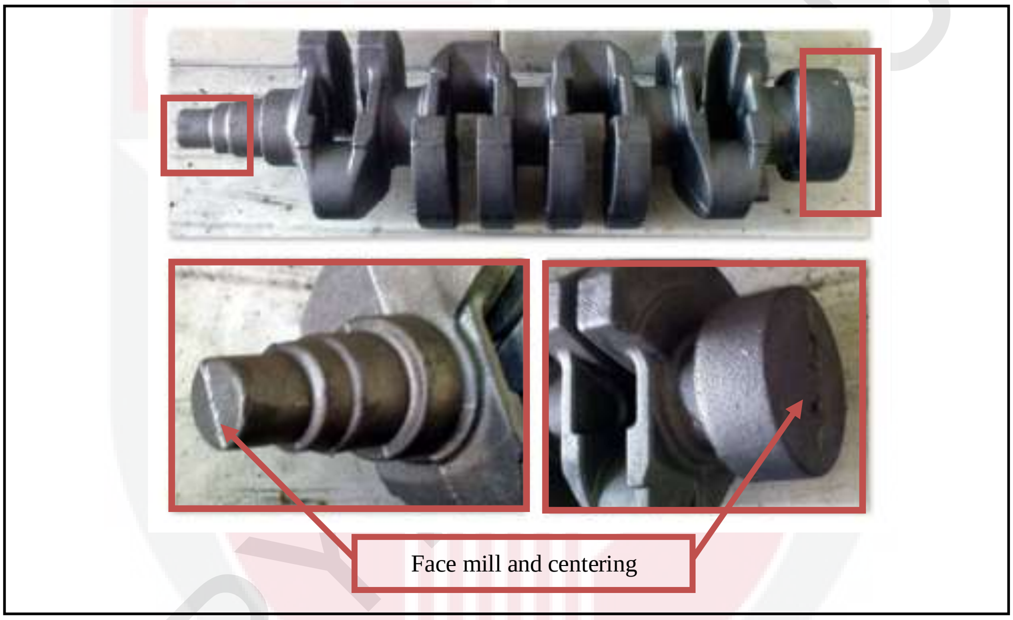


Figure 1.5: OP10 machining operation

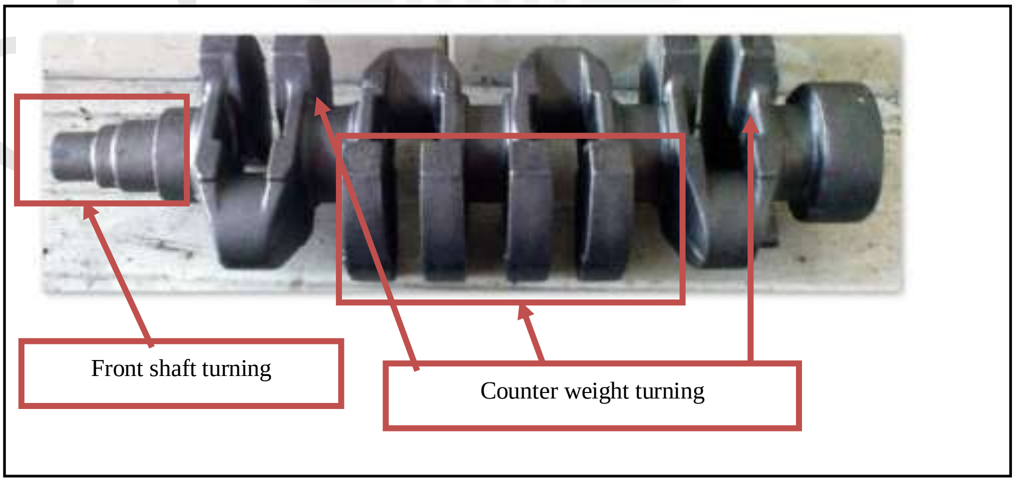


Figure 1.6: OP20 operation, to turn the front shaft and counter weight

1.2.2. The OP10 machining process

There are three major machining processes for OP10 with help of nine different cutting tools. The major machining processes are the face milling of both ends of the crankshaft, the centering for front and rear shaft and the reference face milling. Table 1.1 and Figure 1.7 show the details of the cutting tool used for each process and its time. The most employed tools were the tool-four (T4) with 22.9%, tool-one (T1) with 20.7% and tool-three (T3) with 14.8% of machining time.

Table 1.1: OP10 tool usage detail

Tool number	Process detail	Process time (sec/process)	Tool life set
Tool 1	Both end facing – milling	18.5	150
Tool 2	Rear centering – drill	7.5	250
Tool 3	Rear centering – drill	13.2	150
Tool 4	Rear turning – turning	20.5	150
Tool 5	Rear chamfering – turning	5.5	300
Tool 6	Reference face milling – milling	7.5	200
Tool 7	Front turning – turning	7.5	200
Tool 8	Front drilling – drill	5.5	500
Tool 9	Front centering – drill	3.5	500

Extracted from Proton ETM Crankshaft Process Sheet.

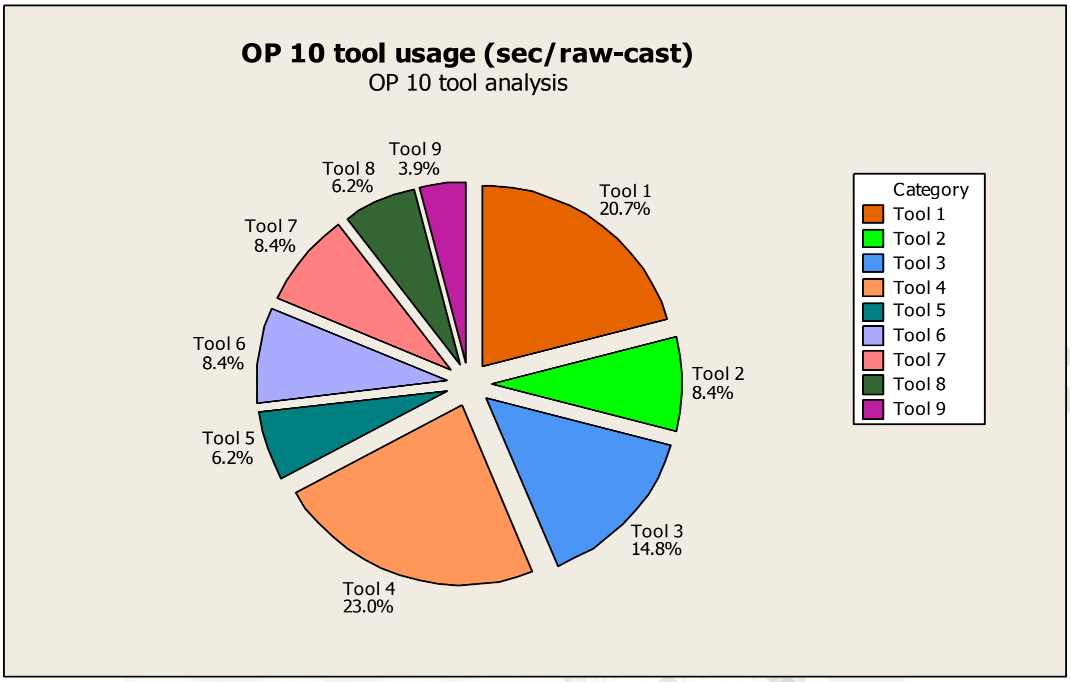


Figure 1.7: OP 10 tool usage

Therefore, an analysis of the frequent tool change was made. The three tools: T4, T1 and T3 are predicted to have frequent changes. The two-month tool change record of OP10 is analyzed and the result shows in Figure 1.8. As predicted, it clearly showed that the most frequent tool change is T1 with 77 times, T4 with 70 times and T3 with 58 times. However, these change frequencies are not only counted for tools that reach its service life but also for the tool that deteriorated before its end of life such as fracture and deform.

Figure 1.9 shows the frequency of tool change because of premature tool life. The highest frequent change because of this early tool life is T1 with 39 times, which is about 50% of the total tool change recorded. The T4 is the second highest recorded with 34 times of overall 70 times of tool change made. It is nearly 48% of the tool change due to the premature tool life.

The T1 tool lifespan set as in Table 1.1 is infrequently achieved. On average, the T1 lifespan is only capable to machine up to 94 raw-casts. It is about 60.27% from the total lifespan set. Obviously, any improvement on T1 will provide positive outcomes for the productivity.

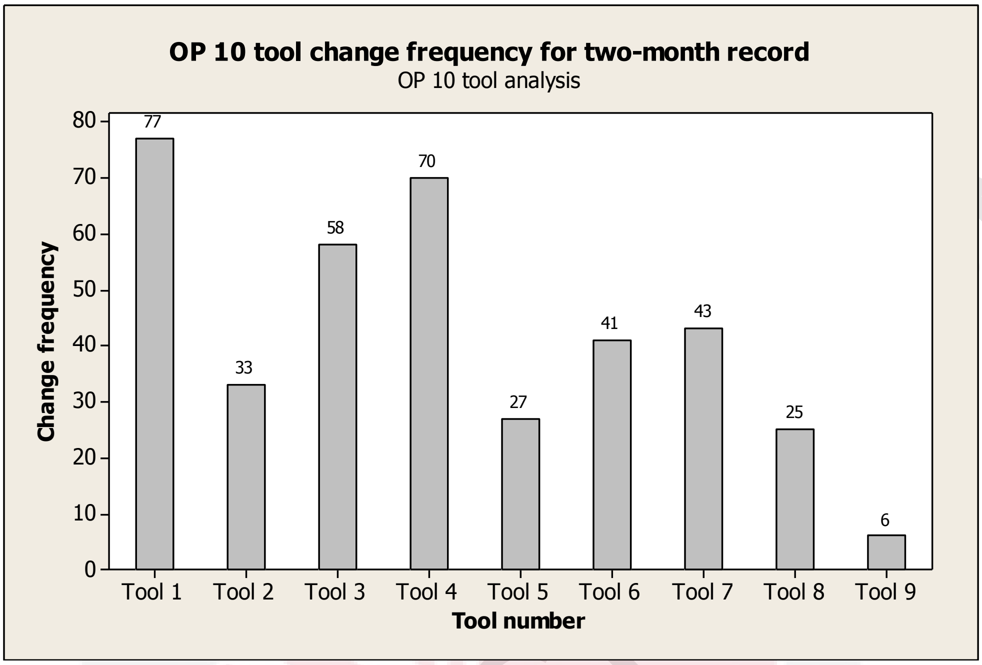


Figure 1.8: OP10 tool change frequency for two-month record

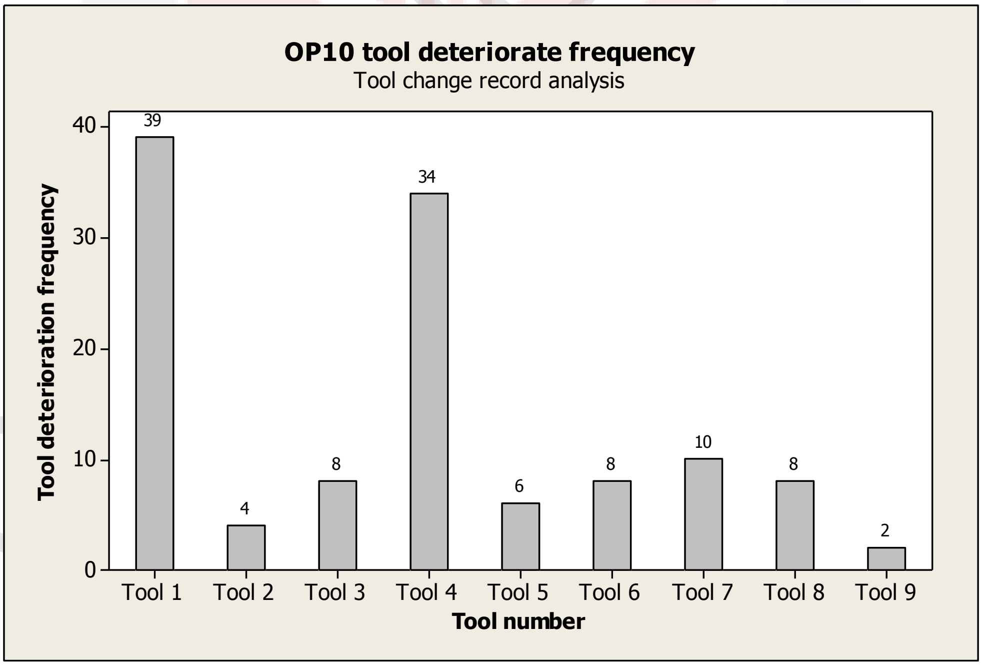


Figure 1.9: Tool deterioration frequency - not because of tool life

1.3. Problem Statement

The performance of the crankshaft machining line previously was very satisfying and often achieves the desired production target without many hassles. The production output target is 97 units per hour. However, the production performance declined drastically since mid-2009 due to increase of the production downtime such as the tool change, the adjustment and the inspection of quality. The frequent production downtime is because of the mechanical properties of the raw-cast has been improved where the hardness of the material was increased from averagely 230HB to 255HB. This material improvement is mandatory as to meet the requirement of the new engine specification.

An investigation was made to machine OP10 as it was the first machine of the production chain and reported as a liability to the entire machining line. The result found that some of the cutting tool had frequently failed prematurely. There are nine different cutting tools equipped within this OP10, but the most failed cutting tool was T1 which is responsible to face mill both-ends of the crankshaft. The tool life limit is design to cut about 150 raw-casts, but currently, the tool only able to cut on average 94 raw-cast. For a record, there is no preliminary study made to the lifespan of the cutting tool after the improvement of the raw-cast. Hence, this study will determine the T1 performance when face milling the newly improved raw-cast.

The need for T1 cutting tool replacement to the other grade or other specification is impractical as the current tool is still capable to withstand the material hardness up to 300HB (Sumitomo Electric, 2010). Moreover, if the conversion to other grades or brand of the cutting tool, it will consume huge cost and time. Therefore, this study also seeks the possibility to improve the T1 machining length. The proposed improvement was to determine the optimal cutting parameters in order to obtain the maximum T1 lifespan. However, the material removal rate should remain the same or higher than the current practices as any reduction in this rate will result in low productivity and definitely will not be accepted by the engine shop management.

Therefore, the need for evaluating the T1 performance with the new raw cast is essential as to be compared with previous performance. This performance evaluation will show the new T1 lifespan with the current machining parameters. It is expected that the T1 lifespan will be reduced. Since the T1 ability toward the new work piece is the still broad, hence, further study in seeking the maximum T1 utilization is a must. The optimal T1 cutting parameters should be determined for maximizing the tool life in terms of removed volume.

1.4. Research Objectives

The aim of this study is to evaluate and improve the T1 performance. The desired outcome of this study is to maximize the service life of T1 while maintaining the surface finish quality. Therefore, the specific objectives of this study are as follows:

i. To evaluate the performance of T1 insert in terms of removed volume and the average surface roughness when face mill the spheroidal graphite cast iron using the current engine shop cutting condition (the initial cutting condition) in the laboratory environment.

ii. To determine the optimal cutting condition for the tool lifespan (T1) in terms of materials removed volume when face milling the spheroidal cast iron by controlling three parameters at three levels using Taguchi optimization technique with the averaged machined surface response not exceeds 50 µm.

1.5. Scope of the Study

This study focuses on finding the optimal machining conditions namely cutting speed, feed rate and depth of cut for face milling operation to obtain the optimum material removed volume. At the same time, the quality of machined surface should be monitored as there is a tolerance limit where its R_a value should not exceed or equal to 50 µm.

The optimization method used in this study is the Taguchi method as it was proven to be the simplest yet efficient method by many researchers such as (Gopalsamy et al., 2009; Kacal and Gulesin, 2011; Khorasani et al., 2011; Lin, 2002a, 2002b; Tosun et al., 2004; Yang and Tarng, 1998; Zhang et al., 2007).

Only one type of milling insert and one type of material is employed during this whole study. For every experimental run, only one insert is used at a time. According to (Richetti et al., 2004), results from the milling test using lesser number of inserts than the cutter capacity can be used as comparison index of the machinability between two or more machining conditions. (Lin, 2002a, 2002b), mentioned that the uses only one insert during milling is acceptable in order to simplify the tool life analysis. Furthermore, it also reduces the experiment cost and time.

1.6. Significance of the Study

This study provided better understanding of various manufacturing aspects, and also method for process improvement. These include the machining tools' operation and its dynamism, cutting tool performance measurement, and method for quality improvement.

Furthermore, utilization of Taguchi technique in seeking the optimal value of machining parameters is presented in proper step according to (Khorasani et al., 2011; Lin, 2002a; Ross, 1995). The optimization technique proposed hopefully will benefits and help future researchers as guidance.

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