

Force characterization of a rotary motion bottom drive type: linear type versus skewed type

Y.P. Chin, M.M. Ghazaly*, J.S. Keek, S.H. Chong, I.W. Jamaludin

Center for Robotics and Industrial Automation (CeRIA), Faculty of Electrical Engineering, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia

*Corresponding e-mail: mariam@utem.edu.my

Keywords: Rotary motion; electrostatic actuator; FEM analysis

ABSTRACT – Two types of rotary motion electrostatic actuator were designed and analyzed using Finite Element Method (FEM) analysis. This paper discussed the comparisons and detailed thrust force analysis of two types of electrostatic actuator; i.e. (i) bottom-driven (linear) and (ii) bottom-driven (skewed). In this paper, the parameter that was being varied is the air gap. From this research it is concluded that the bottom-driven (skewed) actuator produces the largest force, 5.95808mN in compared to the linear type.

1. INTRODUCTION

Development of Micro Electro Mechanical System (MEMS) is increasing rapidly throughout this year. MEMS consist of three (3) main components which are microstructure, microsensor, and microactuator. Microactuator is the only one of the subset of the MEMS that converts energy to create motion such as rotary or linear motion. The microactuator can be applied in many fields such as in micro-robotics, electronics, medicine, medical, biotechnology, communications and inertial sensing [1-4]. In the robotic field, the microactuator is required due to its light weight[1]. The main challenges in the micro-robot is related to the actuator used which must have the criteria such as providing the sufficient power for autonomous flight with wide variations in driving voltages and currents [1]. In additions, the microactuator can be utilized in the electronic field such as improving the performance of the hard-disk drives (HDD). This microactuator will act as the secondary drives in HDD by reducing the skew angle during the disk operation [2]. Furthermore, the microactuator also can be used in the surgery in medical field. The microactuator is using in the micro-mirror devices of the laser phononicrosurgery which acts as the manipulator of the laser source. It allows the micro-mirror operate in a high precision and low power consumption condition [3]. Therefore, this paper will analyse the optimized design of the rotary type electrostatic actuator on force profile by varying the actuators parameters. It is important to determine the relationship between the parameters with the force characteristics to ensure high thrust force.

2. METHODOLOGY

2.1 Initial Design of Electrostatic Actuator

In this research, two types of rotary bottom-driven type electrostatic actuator were designed which are (a) linear and (b) skewed, Figure 1 and 2 show the two designs, which consist of 16 rotor electrodes and 12 stator electrodes. The air gap between the rotor and the stator set to 2µm. The sizes of the actuators are 700 µm in radius and the thickness for the rotor and stator is 100µm. Figure 3 and 4 show the detail differences between the two designs. Eq. (1) shows the equation that is related to the electrostatic force. The equation shows the parameter that will affect the force characteristics, i.e: number of active electrodes per phase (*n*), permittivity of material (ϵ), electrode width (*w*), gap between the stator and rotor (*d*), and input voltage (*V*).

$$F = n \frac{1}{2} \epsilon \frac{w}{d} V^2 \quad (1)$$

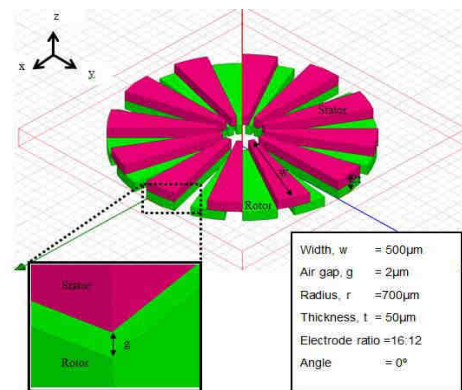


Figure 1 3D view of Design 1 (Bottom-Driven (Linear)) with initial dimension

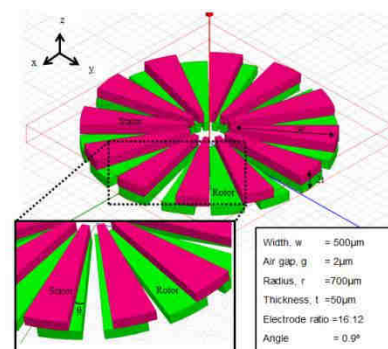


Figure 2 3D view of Design 2 (Bottom-Driven (Skewed)) with initial dimension

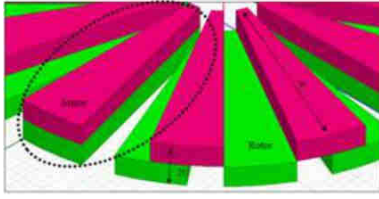


Figure 3 Zoom view of Design 1



Figure 4 Zoom view of Design 2

3. RESULT AND DISCUSSION

3.1 Varying Air Gap

In this section, the gap of the actuator was varied from $2\mu\text{m}$ to $5\mu\text{m}$ with the interval of $1\mu\text{m}$ whereas other parameters are fixed to $100\mu\text{m}$ of thickness, $700\mu\text{m}$ of size, and teeth ratio of 16:12. Based on Eq (1), the air gap will affect the force produced by the electrostatic actuator. As the gap between stator and rotor decreases, the force generated is greater as shown in Figure 5 and 6. From Figure 5 and 6, the electrostatic actuator with $2\mu\text{m}$ gap between stator and rotor produced the highest force compared to $3\mu\text{m}$, $4\mu\text{m}$, and $5\mu\text{m}$. This is because as the gap become smaller, the attractive force from the stator is bigger when the voltage is applied.

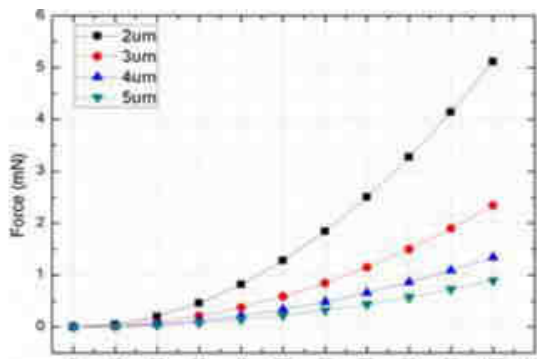


Figure 5 Force generated by Design 1 (Bottom-Driven (Linear))

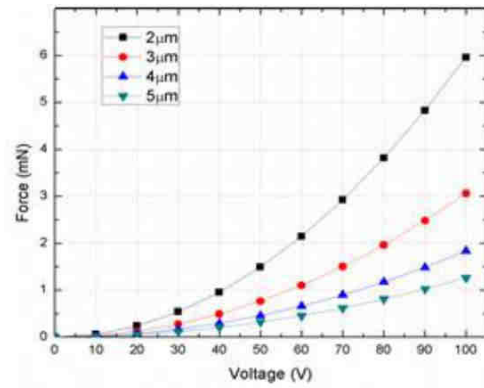


Figure 6 Force generated by Design 2 (Bottom-Driven (Skewed))

4. CONCLUSIONS

As a conclusion, Table 1 shows that the highest force was produced by Design 2 (Bottom-Driven (Skewed)) with 5.95808m N . This is due to the overlapping surface area is larger than Design 1 (Bottom-Driven (Linear)).

Table 1 Comparison of the passes and energy error for different thickness

| Parameter | Design | |
|-----------------------------|----------|----------|
| | 1 | 2 |
| Thickness (μm) | 100 | 100 |
| Size (μm) | 700 | 700 |
| Gap (μm) | 2 | 2 |
| R:S | 16:12 | 16:12 |
| Force(N) | 5.43046m | 5.95808m |

ACKNOWLEDGEMENT

Authors are grateful to Universiti Teknikal Malaysia Melaka for supporting the research. This research and its publication are supported by Fundamental Research Grant Scheme (FRGS) - FRGS/1/2016/TK04/FKE-CERIA/F00305

REFERENCES

- [1] M. Karpelson and R.J. Wood, "A review of actuation and power electronics options for flapping-wing robotic insects," *IEEE Int. Conf. Robot. Autom.*, pp. 779–786, 2008.
- [2] E. Sarajlic, C. Yamahata, M. Cordero, and H. Fujita, "Three-Phase Electrostatic Rotary Stepper Micromotor With a Flexural Pivot Bearing," *J. Microelectromechanical Syst.*, vol. 19(2), pp. 338–349, 2010.
- [3] E. Pengwang, K. Rabenorosoa, M. Rakotondrabe, and N. Andreff, "Characterization and micro-assembly of electrostatic actuators for 3-DOF micromanipulators in laser phonomicrosurgery," *IEEE/ASME 10th Int. Conf. Mechatron. Embed. Syst. Appl.*, pp. 1–6, 2014.
- [4] M.M. Ghazaly and K. Sato, "Basic characteristics of a multilayer thin electrostatic actuator supported by lubricating oil for a fine-motion stage," *Precision Engineering*, vol. 36(1), pp. 77–83, 2012.

Study on comparison of surface roughness when machining AISI 1045 under dry and wet conditions

T. Norfauzi², A.B.Hadzley¹, U.A.A. Azlan², W. Azahar¹

¹) Precision Machining Group, Advanced Manufacturing Centre, Faculty of Manufacturing Engineering, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia

²) Faculty of Engineering Technology, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia

*Corresponding e-mail: norfauzi@utem.edu.my

Keywords: Surface roughness; tool wear; carbon steel

ABSTRACT – This research presents the comparison of surface roughness when machining carbon steel under wet and dry conditions at low and high feed rates. The machining tests were held turning AISI 1045 steel at cutting speeds of 35 to 53 m/min, feed rates of 0.15-0.50 mm/rev and constant depth of cut of 1mm. From the analysis, it was found that surface roughness at wet conditions were better at lower feed rate of 0.15 mm/rev. Whereas, at higher feed rate of 0.5 mm/rev, surface roughness for dry cutting were better. Inconsistent penetration of cutting fluid is due to higher cutting speed and feed rate resulting limitations of cooling and lubrication at the cutting zone. Such conditions inhibited the advantage of the use of cutting fluid, resulting deteriorates surface finish. This study helps to understand the effect of cutting speed and feed rate on surface integrity when machining under dry and wet cutting conditions.

1. INTRODUCTION

In machining, dry and wet cutting were among basic preference for the new machinist to run initiate their machining activities [1]. Dry cutting is desirable as the process can promote of clean environment. Machinist often believe that making some operations dry will reduce the cost for coolant disposal, including eliminating coolant-management systems. For example, when machining cast iron, dry cutting is preferred to avoid difficulties in flushing the powdered-shape chip that could entrapped at the small area of machine components and machine drains systems. Whereas, wet cutting is desirable as it promote better cooling and lubrications, hence better wear performance and surface roughness. Without coolant, heat that remains in the cutting region could heat up the workpiece, tool and machine. Such situation would create unwanted heating effect to the workpiece such as work hardening, component distortions and surface flaws. In order to address the issue of dry and wet cutting for operational capability of machining process, two aspects of the machining have been presented in this study. First, investigation has been done on the capability of machining AISI 1045 with focus on obtaining finest surface roughness under wet condition. Wet machining using oil based lubricant has been used for this investigation. Secondly, the ability of the machining under dry condition. This is because dry machining is

common for short term machining that required minimum machining set up. The reason for choosing both processes is to identify the potential merit of each process at certain conditions.

2. METHODOLOGY

This study is an extension from previous research project [2]. Machining tests were held at both dry and wet conditions according to the cutting parameters as given in Table 1. AISI 1045 carbon steel was selected as the workpiece material. The type of carbide tools used in this work was made by SANDVICK-Coromant. The experiments were carried out by using a CNC Machine DMG- CTX 310. Pre-tech mineral oil was used as a coolant for wet condition. Figure 1 shows the experimental setup for the machining trials. As the machining process completed, surface roughness tester (Mitutoyo SJ-410) was used to evaluate the roughness value along the machined surface.



Figure 1 SANDVICK Coromant cutting tool setup inside CNC Machine DMG- CTX 310

Table 1 Cutting Condition for machining tests

| No. | Cutting speed (m/min) | Feed Rate (mm/rev) |
|-----|-----------------------|--------------------|
| 1 | 35 | 0.15 |
| 2 | 41 | 0.15 |
| 3 | 47 | 0.15 |
| 4 | 53 | 0.15 |
| 5 | 35 | 0.50 |
| 6 | 41 | 0.50 |
| 7 | 47 | 0.50 |
| 8 | 53 | 0.50 |

3. RESULTS AND DISCUSSION

Fig. 2 shows a plot of surface roughness (Ra) in wet and dry conditions with constant feed rate 0.15 mm/rev. The results show that the surface roughness at dry cutting condition was higher than wet cutting condition. This result contradict when the feed rate were applied at 0.5mm/rev where the surface roughness for wet cutting demonstrate higher surface roughness value as compared to the dry cutting as shown in Fig. 3. On the other hand, general observation of surface roughness trend demonstrated that the surface roughness considerably increased with an increase of cutting speed, for both wet and dry cutting.

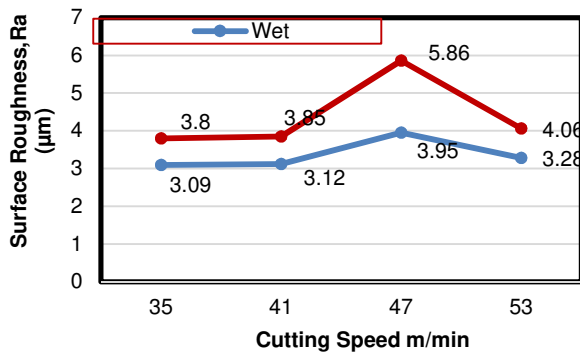


Figure 3 Surface roughness versus cutting speed in using feed rate 0.15 mm/rev

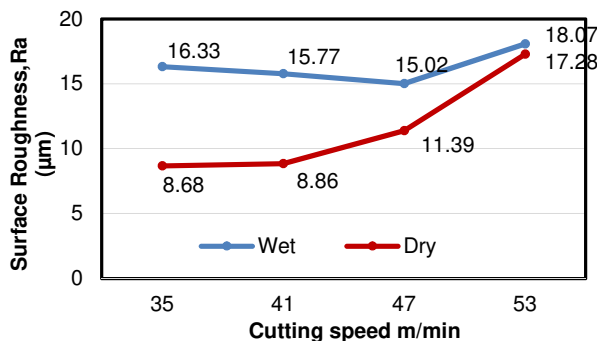


Figure 4 Surface roughness versus cutting speed in using feed rate 0.50 mm/rev

At the lower feed rate, slow movement between cutting tool and workpiece resulted easy penetration of cutting fluid [2]. During this stage, the temperature at the cutting zone is expected reduced, prolonged the stability of nose radius to resist wear, friction and eliminated built up edge formations. Hence the effect of cooling and lubrication can be appreciated, demonstrated by the lower surface roughness. On the other hand, at high feed rate of 0.5 mm/rev, the fast movement between cutting tool and workpiece, assisted by the higher pressure between cutting tool and chips at the primary shear zone restricted the penetration of cutting tool. As a result, the surface roughness at wet conditions demonstrated higher value, reflected the inability of cutting fluid to assess cutting zone. It can be interpreted that at this condition, the use of cutting fluid can be neglected.

The use of cutting fluid on the other hand, benefited

the machining to flush away the chip and to avoid further chip entangled at the cutting zone [1]. The results in this study, consistent with the finding from Isik (2010) where the author claimed that the use of wet machining did not give advantage on surface roughness especially when improper nose radius were applied [3]. On the other hand, the results from Hadzley (2016) also presented that the wet cutting did not give any advantage especially at the shorter machining time [1].

4. CONCLUSIONS

This paper presents the experimental of surface roughness of carbon Steel AISI 1045 by using dry and wet cutting CNC turning. From the machining data collected, there are several conclusions can be made.

- The use of wet cutting is preferable at a lower feed rate of 0.15 mm/rev, whereas the use of dry cutting is preferable at higher feed rate of 0.5 mm/rev.
- Surface roughness generally increased as the cutting speed increased for both dry and wet conditions.
- Higher feed and cutting speed reduced cutting time, increased pressure between cutting tool and chip and hence restricted the penetration of coolant.

ACKNOWLEDGEMENT

Authors are grateful to Universiti Teknikal Malaysia Melaka for the financial support through PJP High Impact Research Grant numbered S10483.

REFERENCES

- A.B. Mohd Hadzley, M.N. Farizan, M.O. Hairizal, T. Norfauzi, and A.A. Afuza, "Analysis of Surface Integrity and Formatio of Side Flow in Dry and Wet Machining of Aluminum Alloy", *International Conference on Design and Concurrent Engineering 2016*.
- N.F. Tamin, U.A.A. Azlan, M. Hadzley, N.S. Remle, M.H. Osman, M.R. Yusoff, and N.Z. Noriman, "Study on surface integrity of AISI 1045 carbon steel when machined by carbide cutting tool under wet conditions", *MATEC Web of Conferences*, 97, 01075, 2017.
- I. Yahya, "An Experimental Investigation on Effect of Cutting Fluids in Turning with Coated Carbides Tool." *Strojniški vestnik - Journal of Mechanical Engineering*, 56(3), 1-7, 2010.

Effect of cutting parameter on diameter accuracy in dry drilling of AISI D2 steel by using Taguchi Method

M.O. Hairizal^{1,3,*}, A.B. Hadzley^{2,3}, T. Norfauzi^{1,3}, S. Noorazizi^{2,3}

¹⁾ Faculty of Engineering Technology, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100, Durian Tunggal, Melaka, Malaysia

²⁾ Faculty of Manufacturing Engineering, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100, Durian Tunggal, Melaka, Malaysia

³⁾ Advanced Manufacturing Centre, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100, Durian Tunggal, Melaka, Malaysia

*Corresponding e-mail: hairizal@utem.edu.my

Keywords: Diameter accuracy; Taguchi Method; drilling

ABSTRACT – This paper presents the effect of cutting parameter on diameter accuracy in drilling of AISI D2 using Taguchi Method. HSS-TiN, HSS-TiCN and uncoated HSS drill tools were selected to drill AISI D2 within ranges of 680-970 rpm spindle speeds and 136-291 mm/min feed rates. The results show that the cutting tool appeared to be the most significant factor, followed by feed rate and spindle speed. Optimum parameters combination appeared to be HSS-TiCN, 136 mm/min feed rate and 825 rpm spindle speed. The use of HSS+TiCN showed higher fracture resistance to reduce friction and prolonged tool life during material removal.

1. INTRODUCTION

Drilling is a process to produce a cylindrical hole on a workpiece with using rotating drilling tools. This process strongly influenced by the drilling parameters, cutting tools as well as the properties of the workpiece material. The most important criterion is the strength and hardness of the workpiece material where it determines the requirement of suitable drilling tools to be engaged with. On the other hand, the used of suitable drilling tool must be accompanied with the right drilling parameters. Among important parameters, cutting speed and feed rate are dominant to control the shearing action during materials engagement as well as to evacuate the chips consistently [1].

Since the drilling process is important in producing hole inside components, this process considered significant in mould and die industry. Among materials that getting attention in die manufacturing is AISI D2. AISI D2 possess adequate strength and hardness that enable this material to be applied as a mold or die in automotive industry. The hardness of this material can be varied from 30 to 60 Hrc depended on the applications. Therefore, this material considered among difficult to drill since it has high sensitivity to the heat treatment [2]. In drilling process of AISI D2, diameter accuracy is one of the major criteria to represent the accuracy on the machined parts. Small change in drilling parameter could adversely affect the diameter accuracy. Therefore, in this project, the drilling process of AISI D2 tool steel has been under studied in order to evaluate the major factors that

contributed to the accuracy of drilling holes. Three type of drilling tools, which is HSS TiN, HSS TiCN and HSS uncoated with the diameter 10mm were used. Taguchi method experimental design was used to determine the optimum cutting parameter that contributed to the diameter accuracy in drilling AISI D2.

2. METHODOLOGY

2.1 Design of Experiment

The experimental layout for the machining parameters was set based on the L₉ orthogonal array. Three parameters with three levels were selected as experimental design as shown in Table 1. The experiments were carried out on 3 axis CNC milling machine, under dry condition, assisted by Catia V5 software for tool movement program. The workpiece were prepared according to the (100×100×10mm) size. Figure 1 shows the experimental result of AISI D2 steel after drilling process

Table 1 The parameter at three levels and three factors

| Factor | | Level | | |
|--------|---------------------------------|---------|----------|--------------|
| | | 1 | 2 | 3 |
| A | Feed rate (mm/min) | 136 | 206.25 | 291 |
| B | Spindle speed (rpm) | 680 | 825 | 970 |
| C | Drilling tools (10 mm diameter) | HSS+TiN | HSS+TiCN | HSS uncoated |



Figure 1 AISI D2 after drilling process

2.2 Hole Diameter Measurement

Then by using the Coordinate Measuring Machine (CMM) with four-point circle micro method, the accuracy of hole diameter has been measured. Assumed

that the most ideal diameter of hole should be 10 mm, the value that close to the minimum 10 mm have been determined as the optimum parameters. Confirmation test with the optimal level of machining parameters were carried out in order to illustrate the effectiveness of the Taguchi optimization method.

3. RESULTS AND DISCUSSION

Table 2 shows the result of the diameter accuracy and signal to noise ratio of nine holes that has been drilled according to selected parameters. By referring to the Table 3, the graph plotted shows that the minimum diameter recorded at 10.0427mm where the feed rate, spindle speed and drilling tools were set at Level 1 (136 mm/min), Level 2 (825 rpm) and Level 2 (HSS TiCN coated). In other words, the optimum parameter of this experiment is observed by the lowest value is by combination of A1B2C2 (136 mm/min, 825 RPM, HSS TiCN coated).

Table 2 The result of experiment

| No. | Designation | Mean |
|-----|-------------|---------|
| 1 | A1B1C1 | 10.1032 |
| 2 | A1B2C2 | 10.0427 |
| 3 | A1B3C3 | 10.0753 |
| 4 | A2B1C2 | 10.0556 |
| 5 | A2B2C3 | 10.0560 |
| 6 | A2B3C1 | 10.0977 |
| 7 | A3B1C3 | 10.0924 |
| 8 | A3B2C1 | 10.1143 |
| 9 | A3B3C2 | 10.0625 |

Figure 2 show the graph main effect plot for mean of hole diameter accuracy. Table 3 shows the analysis of variance based on the Figure 2. According to the analysis, the most significant factor the hole diameter accuracy is drilling tool. Then followed by feed rate factor and less significant is spindle speed factor. As the tool demonstrated the most dominant factor, it can be interpreted that the HSS-TiCN coated drill tool has superior abrasive performance which helps in shearing finer surface finish as compared to the other counterparts [2]. The use of HSS+TiCN showed much higher fracture resistance to reduce friction during material removal, prevent edge chipping and enhances wear resistance of the tool. When using softer drilling tools, such as uncoated or TiN coated, inaccuracies of drilling holes were evidence probably due to non-circular holes, resulted from early tool wear when the tool shear the metal. As a result, the rotating tool could be misaligned, promoting minor vibration that could shear the drilling holes inconsistently [3].

Table 3 Analysis of Variance for Means

| Source | Feed rate | Spindle speed | Drill Type | Residual error | Total |
|----------|-----------|---------------|------------|----------------|-------|
| Contri % | 13.33 | 4.89 | 79.95 | 1.83 | 100 |

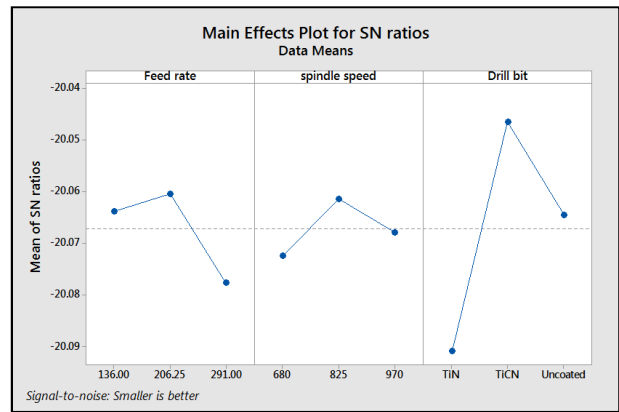


Figure 2 AISI D2 after drilling process

4. CONCLUSIONS

This paper has presented the effect of drilling tools and parameters to determine the main significant factors and optimum machining parameters for the diameter accuracy. The drilling tools contributed to the major significance factor to the diameter accuracy based on the highest percentage distribution, followed by the feed rate and spindle speed. The optimum parameter is observed by using HSS-TiCN drilling tools at 825 rpm spindle speed and 136 mm/min feed rate.

ACKNOWLEDGEMENT

Authors are grateful to Universiti Teknikal Malaysia Melaka for the financial support through PJP High Impact numbered PJP/2015/FTK(31B)/S01456.

REFERENCES

- [1] N.S. Arshad, A.K. Zahid, G.I. Pankul, K. Mukesh, A. Gaurav and Z.K. Noor, "Optimization of Deep Drilling Process Parameters of AISI 321 Steel Using Taguchi Method," *Procedia Materials Science*, Vol. 6, pp. 1217-1225, 2014.
- [2] M.H. Osman, M.H. Bakar, N.F. Tamin, M.N. Ahmad, S.H. Din, A.F. Azhar, "Effect of Cutting Parameters on Surface Roughness in Dry Drilling of AISI D2 Tool Steel by Using Taguchi Method," *International Conference on Design and Concurrent Engineering, 2016*.
- [3] M. Steinzig, D. Upshaw, and J. Rasty, "Influence of Drilling Parameters on the Accuracy of Hole-drilling Residual Stress Measurements," *Experimental Mechanics*, vol. 54(9), pp. 1537–1543, 2014.

Characterization of TiO₂ coating deposited on ceramic substrates

M.A. Musa¹, J.M. Juoi^{1,2,*}, M.R. Zulkifli^{1,2}, N.D. Johari¹

¹) Faculty of Manufacturing Engineering, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia.

²) SM4GT, Advanced Manufacturing Centre, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia

*Corresponding e-mail: jariah@utem.edu.my

Keywords: Ceramic substrates; TiO₂ coating; antimicrobial

ABSTRACT - The characteristics of titanium dioxide, TiO₂, coating on different ceramic substrates produced via sol-gel dip-coating technique was studied to take benefit of its antimicrobial properties. The coating morphologies and thickness deposited on unglazed ceramic tiles and Green Innovative Glass ceramic (GIG) with varied dipping time were analyzed using Scanning electron microscope (SEM), while the crystalline phases were characterized using Glancing angle, X-ray Diffraction (GAXRD). Results show that the coatings produced are with homogeneous morphology, thicker film and with the presence of anatase and rutile phases regardless of substrate's type. It was also observed that one dipping time is sufficient to produce a continuous coating with average thickness of ~ 12 μm on unglazed ceramic tile, while more dipping times is needed for GIG ceramics.

1. INTRODUCTION

To combat surface bio-contaminant, surface modification of ceramics materials with TiO₂ film has been carried out aiming to develop its antimicrobial property [1]. The sol-gel method is frequently employed in synthesizing TiO₂ films due to its advantages that allows for TiO₂ film deposition with good homogeneity on various substrates at low processing temperature and low equipment cost [2]. Although substrate's material and surface roughness have been shown to influence the microstructure of the TiO₂ films [3, 4], there hardly exist studies reported on the characteristic of TiO₂ coating on rough ceramic substrates (i.e. unglazed ceramic tile) as well as tiles made of glass ceramics. Moreover, most studies reported do not include the surface roughness values for comparison. Therefore, this study was conducted with the aims of characterizing the TiO₂ coating deposited on different ceramic substrates as an initial effort aiming on producing antimicrobial tiles. It is intended that the coating produced is continuously distributed and with a uniform thickness consisting TiO₂ crystalline phases (anatase, rutile and brookite). To optimize the cost involved and the time taken in producing the TiO₂ coatings, the study also assesses the correlation between the number of dipping times and coating thickness.

2. METHODOLOGY

TiO₂ sol was prepared via a sol-gel process using titanium (IV) isopropoxide, ethanol, hydrochloric acid and deionized water as described elsewhere [5]. However, in this study, 5 g of Degussa P25 (a commercial TiO₂ nanoparticles) was added to the TiO₂ sol and stirred before they were kept in dark. The pH was maintained at around 1.4 due to our earlier finding [5]. For the coating deposition, unglazed ceramics tiles (size: 20 mm × 10 mm × 5 mm; surface roughness: 5.5 ± 0.2 μm), and GIG (20 mm × 20 mm × 3 mm; surface roughness: 1.45 ± 0.02 μm) were utilized. The dip coating process is repeated for one, three and five times, employing 30 mm/min dipping speed and 5s dwelling time. The coating morphology was examined using Scanning electron microscope (JEOL model JSM-6010PLUS/LV). The GAXRD pattern of the coating crystallinity was recorded at a grazing angle of 4° by using the PANalytical X'PERT PRO MPD Model PW 3060/60 with Cu Kα of 1.54060Å.

3. RESULTS AND DISCUSSION

Figure 1 shows the surface morphology of one, three, and five dipping times of TiO₂ coatings on unglazed ceramics tiles and GIG ceramics. It can be seen that the continuous coatings are produced regardless of the substrate's type and dipping times. However, it is noticeable that coatings deposited on unglazed ceramic tiles start to show cracks as the dipping time increases (inset of Fig. 1a) ii and iii). This could be attributed to thicker coating formation as well as the differences in linear thermal expansion between the coating and the substrate [6]. The cross-sectional morphology of one, three, and five dipping times of TiO₂ coatings on unglazed ceramic tiles and GIG, together with its average thickness, are shown in Figure 2. The increase in dipping time increases the coating thickness, with unglazed ceramic tiles having thicker coating compared to GIG. The difference in thickness increment is attributed to the different in the substrate's surface roughness and wettability, which alter the quantities of TiO₂ sol that is retained on the substrates after each dipping process [6]. It is observed that the coating produced with one dipping time has an average thickness of ~12μm, higher than the surface roughness of the substrates (5.5 μm). Thus, it can be deduced that one dipping time is the optimum number of dipping to be used on the unglazed ceramic tiles in this study.

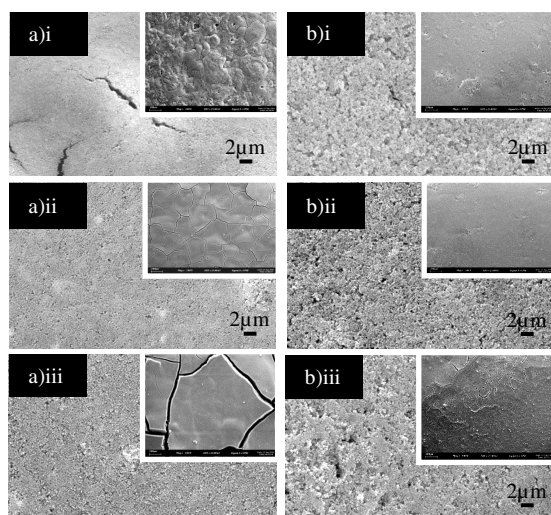


Figure 1 Surface morphology of TiO₂ coating deposited on unglazed ceramic tile (a) and GIG (b) at (i) 1, (ii) 3 and (iii) 5 dipping times

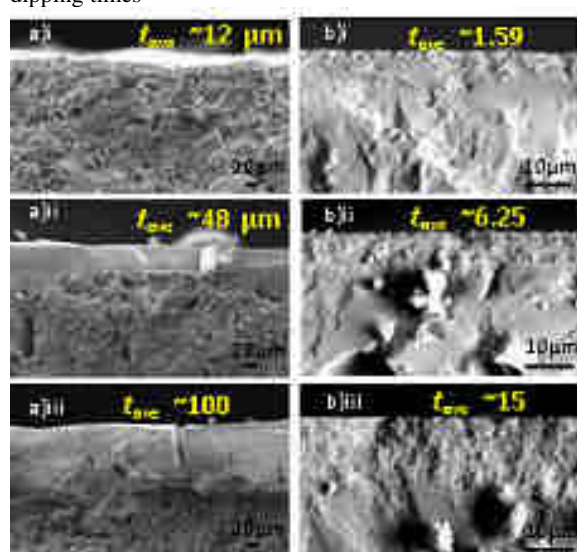


Figure 2 cross-section morphology of TiO₂ coating deposited on unglazed ceramic tile (a) and GIG (b) at (i) 1, (ii) 3, and (iii) 5 dipping times

Figure 3 summarizes the GAXRD diffractogram of the uncoated unglazed ceramic substrate, uncoated GIG as well as one, three, and five dipping times (labeled as 1L, 3L, and 5L) of TiO₂ coating, respectively. The uncoated ceramic substrates consist of many peaks assigned to the ceramic components, such as cristoballite, quartz, akermanite, anorthite, diopside, and gehlenite (labeled as C). It is apparent from Figure 3 that the coating exhibits the presence of crystal phases, regardless of the dipping time. Anatase peaks are detected at 2θ of 25.3°, 38°, and 48° (JCPDS No. 01-070-7348), and rutile peaks are centered at 27.5°, 36°, and 41° (JCPDS No. 01-072-4813). In addition, no traces of ceramic components are observed for one dipping of TiO₂ coating on unglazed ceramic tiles. However, a weak signal of ceramic component at around 21° is still visible at one dipping time of TiO₂ coating on GIG. This suggests that one dipping times is sufficient to continuously cover the unglazed ceramic tiles while more dipping times are needed for GIG substrates.

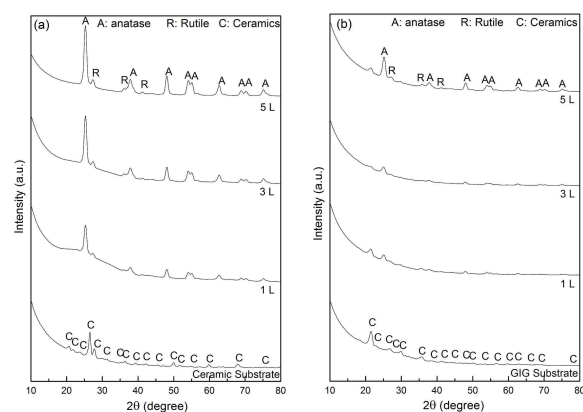


Figure 3 GAXRD diffractogram of TiO₂ coating coated at one, three, and five dipping times deposited on (a) unglazed ceramic tile; (b) GIG

4. CONCLUSION

TiO₂ films have been successfully deposited on two different ceramic substrates via sol-gel dip-coating technique. The coatings produced have good morphology and with crystallinity on both substrates. The coating thickness increases with the number of dipping and is dependent on the substrate's surface roughness. The study demonstrated that one dipping time is sufficient to continuously cover the unglazed ceramic tiles, while more dipping times is required for GIG ceramics.

ACKNOWLEDGEMENT

This work was supported by the Universiti Teknikal Malaysia Melaka through Grant FRGS/1/2014/TK04/FKP/02/F00215.

REFERENCES

- [1] S. de Niederhäusern, M. Bondi, F. Bondioli, "Self-Cleaning and Antibacterial Ceramic Tile Surface", *International Journal of Applied Technology*, vol. 10, no. 1, pp. 949 – 956, 2013.
- [2] M. Yao, J. Chen, C. Zhao, Y. Chen, "Photocatalytic Activities of Ion Doped TiO₂ Thin Films When Prepared on Different Substrates", *Thin Solid Films*, vol. 517, pp. 5994 – 5999, 2009.
- [3] Y. Ma, J. Qiu, Y. Cao, Z. Guan, J. Yao, "Photocatalytic Activity of TiO₂ Films Grown on Different Substrates", *Chemopere*, vol. 44, pp. 1087–1092, 2001.
- [4] M. R. Zulkifli, A. R. Nurhamidah, J. M. Juoi, "The Effect of Ceramic Substrates Surface Roughness on the Deposition of AgTiO₂ Coating", *Applied Mechanics and Materials*, vol. 699, pp. 9 – 14, 2015.
- [5] M. A. Musa, J. M. Juoi, M. R. Zulkifli, N. Masrom, "Influence of HCl Content and Ageing Time on TiO₂ Coating Formation in Acidic Sol-Gel Solutions", *Key Engineering Materials*, vol. 694, pp. 138-142, 2016.
- [6] L. Lopez, W. A. Daoud, D. Dutta, B. C. Panther, T. W. Turney, "Effect of Substrate on Surface Morphology and Photocatalysis of Large-scale TiO₂ Films", *Applied Surface Science*, vol. 265, pp. 162-168, 2013.

Analysis of an instrument to test reading and interpreting engineering drawing skills

Z. Abdullah*, H.H.Suhaimi, M.S.Tang, M.A.M. Ali, R.H. Hambali, S. Akmal

Faculty of Manufacturing Engineering, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia

*Corresponding e-mail: zulkeflee@utem.edu.my

Keywords: Instrument; reading; drawing skills

ABSTRACT – Engineering drawings required to ensure that designers and production engineers are able to convey information accurately and clearly. This study aimed to investigate the instrument that test reading and interpreting engineering drawing skills. The study design using quantitative and qualitative research methods. The result were analysed using IBM SPSS statistical software and qualitative data were resolved according to the themes that have been identified. Study data is described in terms of percentages, descriptions and transcripts. The results were analysed and three objectives were achieved and some suggestions are proposed for future work.

1. INTRODUCTION

Drawing skills is a must for the fresh graduate engineers to fully define requirements for engineering items. It is a graphical language that communicates ideas from one mind to another. Mostly, fresh graduate had poor graphical communication skills because they lack the knowledge in concept drawing and they are not exposed on how to read and interpret engineering drawings properly [1]. For example, (dashed) hidden line shows ambiguities which could be readily misinterpreted as shown in Figure 1. The build object cause an error when there is a problem on interpreting hidden line drawings.

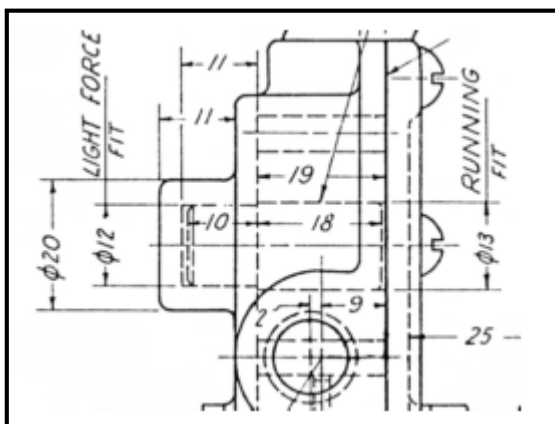


Figure 1 Showing how ambiguity can arise from the use of hidden lines [1]

In other example, novice engineers lack the ability on identifying the design faults through inspection of engineering drawings. As shown in Figure 2, this assembly drawing while looking fine is having lot problems and is impossible to manufacture due to these

problems.

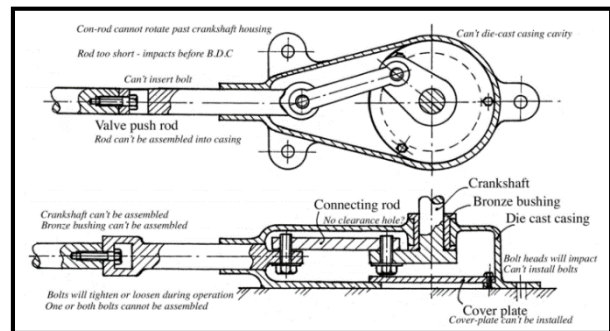


Figure 2 Showing assembly drawing that is impossible to manufacture and will not function as required (italicized text) [1].

The objectives of this research is to analyse the instrument [2] for analysing the skills of novice engineers in reading and interpreting engineering drawings. And to get validation for the instrument and to measure the undergraduate engineer skills in reading and interpreting engineering drawing using this instrument.

2. METHODOLOGIES

The methodology explains about the process of creating a validated test instrument to read and interpret engineering drawings (RIED). Flowchart is used to explain the achievement and procedure needed to make sure this research study achieved the specific requirement obtained from the collected data. Besides, the information about the study will be collected through various sources such as book, journal, internet and others. Project also start from the need of producing a test based on the feedback from the experience design engineers. A detailed study and survey form is prepared and the question which meet the criteria would help to measure the level of a novice engineer in the reading and interpreting engineering drawings [2].

3. RESULTS AND DISCUSSION

Two test were prepared to obtain the level of understanding of the fresh graduates. The first set was a pre-test, consist of 25 questions, while the second test called as post-test which consists of 20 questions. Figure 3 and Figure 4 show the 2D drawings for the test conducted on the fresh graduate. The image used for the test was an image of a sliding support which consists of

all elements that are essential for developing the questions. The sliding support are followed with the basics of the main representation system of the orthogonal cylindrical projection (multi-view) and how projections are created (from 3D to 2D) as well as the reason for visible and hidden lines [3].

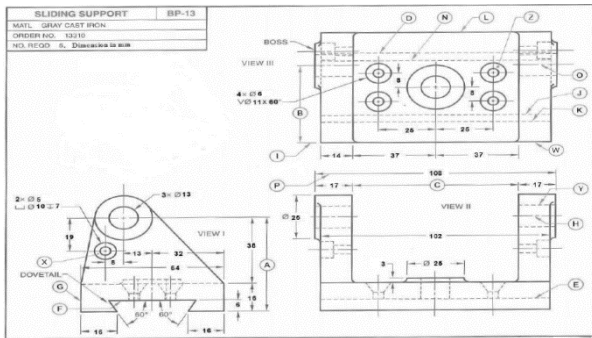


Figure 3 Pre-test drawing

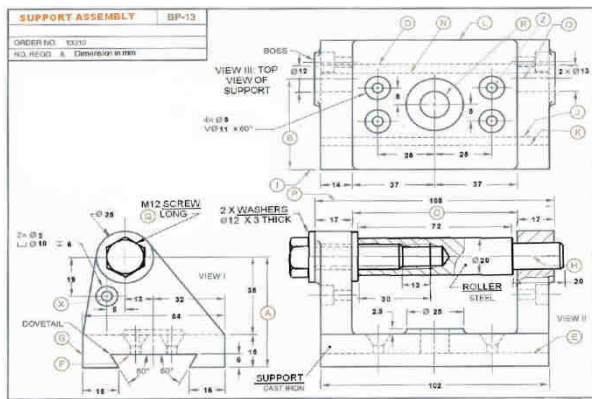


Figure 4 Post-test drawing

There are 15 same question asked in pre-test drawing and post-test drawing where both questions are same but in a different position to avoid familiarity of pre-test and post-test questions set (Figure 5).

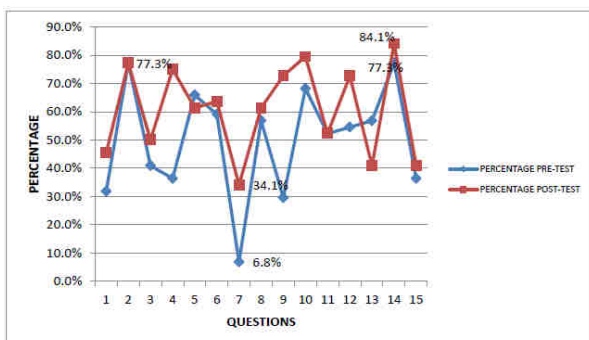


Figure 5 Graph line for the 15 same questions in both tests

Pre-test and Post-test reliability index were performed using SPSS software. For pre-test, and the results obtained were 0.788 out of the 25 questions. This means that the pre-test test was reliable since more than 0.7 points were obtained and considered to be as satisfactory or better. While for the post-test, the results obtained were 0.816 of 20 questions. This indicates that the post-test was more reliable because the reliability index is higher than the pre-test. Furthermore, it shows that post-test was highly reliable and can be considered as satisfactory

(Figure 6).



Figure 6 Reliability Statistics of Pre-test and Post-test

Besides, difficulty Index is used to calculate the proportion of students who answered the correct questions. This indicates the performance of a specific class in a questions. The formula is stated as below.

$$\frac{(N \text{ correct answers in top } 25\% + N \text{ correct answers in bottom } 25\%)}{(\text{Total number of students in top \& bottom groups} \times \text{Number marks})} \times 100\%$$

From the data and analysis that has made in both tests, it helps to measure the skills of students or fresh graduates in translating engineering drawing. This results are similar to previous study [1]. The results of the data analysis are able to give the impression in a given test that can be determined the effectiveness of the skills of a student in resolving engineering drawings. This could help with preparing students for the industry [2].

4. CONCLUSION

This study was conducted to measure the actual level of fresh graduates in translating engineering drawing and to get the validity and confirmation of the test method which could help to determine the actual level of fresh graduates. The instrument is suitable as a test of RIED. The objectives were achieved base on the discussion made on the results of the analysis of data obtained from this study..

REFERENCES

- [1] Z. Abdullah, B. Field, and C. Burvill, "Measuring Malaysian Undergraduate Skills in Reading and Interpreting Engineering Drawing," *Proc. Int. Conf. Eng. Des. ICED11, no. AUGUST, 2011*.
- [2] Z. Abdullah, C. Burvill, and B. Field, "Identifying and Quantifying Industry Perceptions of Engineering Drawing Skills in Novice Malaysian Engineers," *Proc. Int. Conf. Eng. Des. ICED11, no. AUGUST, 2011*.
- [3] E.S. Uria, M.G. Mugica, and J.M. Colindres, "Methodology for part visualization problem solving (reading mutiview technical drawing)," *Int. Conf. Eng. Des. ICED 09, pp. 1–12, 2009*.

Cutting forces data analysis of its spectrum for XY table ballscrew drive system

L.Abdullah*, M.J.Tan, M.A.A.Din

Faculty of Manufacturing Engineering, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia

*Corresponding e-mail: lokman@utem.edu.my

Keywords: Cutting forces; Fast Fourier Transform; spectral analysis

ABSTRACT – Spectral analysis is used to investigate the cutting force parameter. The cutting forces are analyzed at each frequency under a set of frequency content. Fast Fourier Transform (FFT) technique is applied to transform from the original form into cutting force data in frequency domain. The result shows the cutting force is directly proportional to the depth of cut and inversely proportional to the spindle speed of the end mill machine. The cutting force data will later be used as an input disturbance for XY table ball screw drive system during the simulation process in the MATLAB Simulink diagram.

1. INTRODUCTION

Group of researches widely use machining parameters in frequency domain in engineering field. The machining parameter involved in this case is the cutting force parameter and is identify by adapting spectral analysis to access in identifying specific cutting forces exerted to the surface of the work piece at each frequency under a set of frequency content. One of the factor which contribute in inaccurate machining is the elastic deformation of machine system, tool and workpiece from cutting forces and resistance [1] or the tracking performance of its drive system, which is greatly influenced by the cutting force and friction force [2]. Cutting force acts as an input disturbance on the motion control system during cutting processes done by end milling operation. Cutting force disturbance signal need to be identified, characterized and analysed so that it can be compensated and controlled later using any available motion controller [3]. Thus, leads to the main objective of this paper which is to perform spectral analysis of the collected forces to observe the actual cutting force behaviour within the range of frequency content.

2. METHODOLOGY

In this section, the research setup & procedures during research are discussed. The setup of equipment for cutting forces identification process is shown in Figure 1 and Figure 2. Based on Figure 1, cutting forces identification was performed by executing end milling cutting operation using conventional milling machine to collect the actual cutting force data. In this experiment, the collection of x and y directional cutting forces

components was done by mounting Kistler dynamometer on the milling table of milling machine. The cutting force signal was amplified by charge amplifier and the signal was sent to the personal computer equipped using Kistler Dynoware software. Spindle speed (S) and depth of cut (D) of the milling process are varied in order to establish different characteristics of the cutting forces.

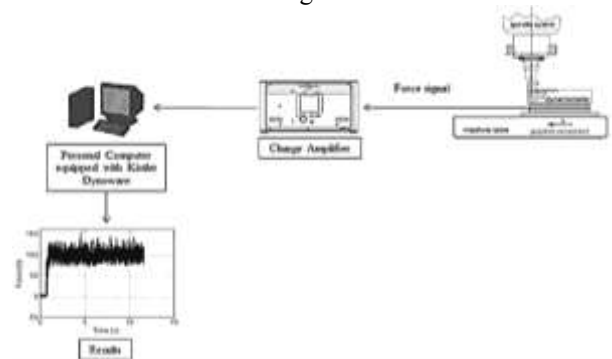


Figure 1 Process flow of cutting force identification [4]



Figure 2 Aluminium block during milling operation

Table 1 Milling parameters of cutting process characterization

| No. | Spindle Speed Test | | Depth of cut Test | |
|-----|--------------------|--------|-------------------|--------|
| | S (rpm) | D (mm) | S (rpm) | D (mm) |
| 1 | 1500 | 1.0 | 1000 | 1.0 |
| 2 | 2500 | 1.0 | 1000 | 1.5 |
| 3 | 3500 | 1.0 | 1000 | 2.0 |

For spindle speed test, it is varied while the depth of cut is constant whereas for depth of cut test, it is varied while the spindle speed is constant. These settings are due to the objective of observation of both tests based on their own variation settings with other parameters being set as constant. In both tests, the feed rate is constant. Up and down milling were carried out for both spindle speed test and depth of cut test each, producing a total of twelve sets of data.

3. RESULTS AND DISCUSSION

3.1 Spectral analysis of cutting forces

Identified cutting force data had been obtained according to their respective settings. FFT method is used to convert the time domain graph into frequency domain graph as shown in Figure 3. Spectral analysis or analysis of spectrum was carried out on data in frequency domain by identifying their maximum forces and their respective frequencies.

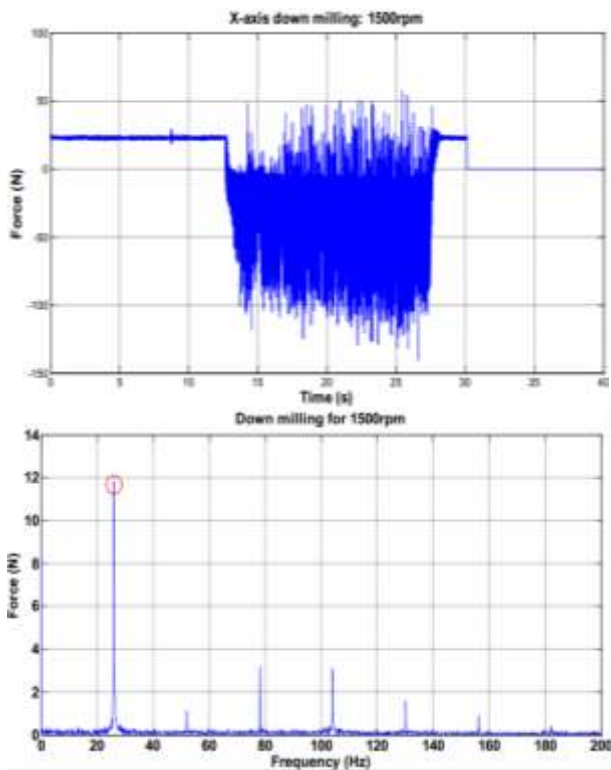


Figure 3 Results of down milling cutting force for 1500rpm in time and frequency domain

Table 2 show the forces at its respective frequency for up and down milling processes. Cutting forces obtained in time domain were moving towards the negative values for down milling and moving towards the positive values for up milling due to the different directions of cutting force applied to the workpiece. In Table 2, it was found that the increase in spindle speed decreases the cutting force when the depth of cut is constant whereas the increase in depth of cut increases the cutting force when the spindle speed is constant. This shows that the cutting forces are inversely proportional to the spindle speed and directly proportional to the depth of cut.

Table 2 Forces and its respective frequencies

| Down milling process | | | | |
|----------------------|--------------------|----------------|-------------------|----------------|
| No. | Spindle Speed Test | | Depth of cut Test | |
| | Force (N) | Frequency (Hz) | Force (N) | Frequency (Hz) |
| D1 | 11.84 | 26.10 | 6.97 | 16.20 |
| D2 | 15.94 | 38.50 | 30.81 | 16.20 |
| D3 | 13.58 | 0 | 38.81 | 16.20 |
| Up milling process | | | | |
| No. | Spindle Speed Test | | Depth of cut Test | |
| | Force (N) | Frequency (Hz) | Force (N) | Frequency (Hz) |
| U1 | 69.97 | 0 | 7.61 | 16.20 |
| U2 | 63.20 | 0 | 25.65 | 16.20 |
| U3 | 58.72 | 0 | 64.77 | 16.20 |

4. CONCLUSION

The objective of this paper which is to carry out spectral analysis to the cutting forces data from end milling operation has been successfully achieved. The cutting forces need to be identified and characterized accordingly to execute spectral analysis. The analysis is tabulated by transforming the cutting force data in time domain into the form of cutting forces data in frequency domain using FFT method. The result shows that the cutting forces are inversely proportional to the spindle speed and directly proportional to the depth of cut. The cutting forces obtained will be very useful in the future when comes the need to inject those data into the system of XY table during stimulation stage to closely replicate the real cutting operation and act as disturbances in the system.

REFERENCES

- [1] I. Kuric, M. Košinár, and M. Cisár, "Measurement and Analysis of CNC Machine Tool Accuracy in Different Location on Work Table", *Proceedings in Manufacturing Systems*, vol. 7(4), 2012.
- [2] Z. Jamaludin, "Disturbance Compensation for Machine Tools with Linear Motor Drives", *Published Doctor thesis*. Catholic University of Leuven, Belgium, 2008.
- [3] L. Abdullah, Z. Jamaludin, T.H. Chiew, N.A. Rafan, and M.Y. Yuhazri, "Systematic Method for Cutting Forces Characterization for XY Milling Table Ballscrew Drive System", *International Journal of Mechanical & Mechatronics Engineering*, vol. 12(6), 2015.

Analysis of simulated tracking performance of X-axis for ball screw drive system

N.A. Anang, L.Abdullah*, Z.Jamaludin, S.C.K Junoh, Z.Retas, R.I.A.R. Izam, T.H. Chiew

Advanced Manufacturing Centre, Faculty of Manufacturing Engineering, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia

*Corresponding e-mail: lokman@utem.edu.my

Keywords: FFT error; cascade P/PI; ball screw drive

ABSTRACT – Nowadays, accuracy in positioning machine tool for higher speed is demanding. This leads to the improvement of tracking performance of ball screw drive system. Therefore, Proportional-Integral-Derivative (PID) and Cascade P/PI controllers are designed and the tracking performances of the designed controllers are evaluated. The parameters of the simulation are set 10mm of amplitude for 0.7Hz of frequency. Spindle speed of 3500rpm is injected to the system as the cutting force disturbance. The performance is then analyzed based on Fast Fourier Transform (FFT) error in determining the harmonic frequencies of the controllers. After that, error reductions between two controllers are calculated.

1. INTRODUCTION

Precision of ball screw drive is important due to progressive growth in industry. Therefore, it is crucial to cater the tracking performance of ball screw drive system in improving the accuracy and precision of machine tool. As stated by Altintas [1], the performance of machine tool related to cutting operation such as milling. As the forces during milling operation affect the motor and leads to inaccuracy, higher precision at faster speeds are crucial in industry [2]. According to Altintas et al. [3], there are several factors that affect the positioning of machine tools such as mechanical drives, amplifiers, sensors, motors and control algorithm. Control algorithm is selected in order to boost the accuracy and precision where the modelling of the controllers is presented.

2. METHODOLOGY

Methodology for this research is divided into two parts before the controllers are designed. The components are system and cutting force identifications.

2.1 System Identification

System identification is the initial step in this research. The process of modeling is defined based on Frequency Response Function (FRF) estimated by H1 estimator [4]. The second order transfer function based on 0.0012sec time delay is shown below:

$$G_m = \frac{78020}{s^2 + 163s + 193.3} \quad (1)$$

2.2 Cutting Force Identification

This process is important to collect cutting force

data of 3500rpm. Figure 1 shows the structure of the cutting process. Spindle speed of 3500rpm is set during the process and the material used is aluminium. Kistler dynamometer is used in order to collect the cutting data of 3500rpm and injected into the designed controllers.

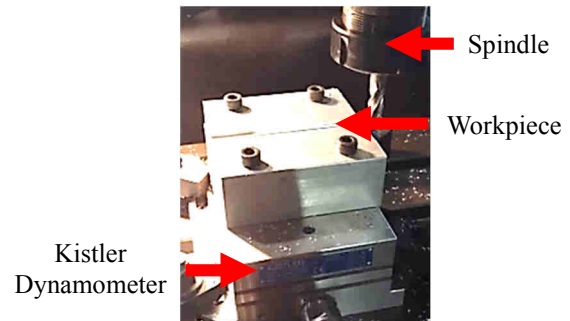


Figure 1 Cutting process of 3500 rpm

3. CONTROLLER DESIGN

There several properties that required designing PID and Cascade P/PI controllers. The components are open loop, closed loop and sensitivity.

3.1 PID Controller

$$\text{Open Loop} = G_{PID}(s) \times G_S(s) \quad (2)$$

$$\text{Closed Loop} = \frac{G_{PID}(s) \times G_S(s)}{1 + G_{PID}(s) \times G_S(s)} \quad (3)$$

$$\text{Sensitivity} = \frac{1}{1 + G_{PID}(s) \times G_S(s)} \quad (4)$$

The mathematical model of PID controller is

$$\text{PID} = 0.8998 + 0.005155s + \frac{0.0006077}{s} \quad (5)$$

3.2 Cascade P/PI Controller

Cascade P/PI consists of two loops; velocity and position loops which represents inner and outer loops respectively. The inner loop consists of Proportional-Integral (PI) controller while position loop consists of Proportional (P) controller. Firstly, the modeling for velocity loop is done as shown below:

$$\text{Open Loop, OL}_{VEL} = G_{PI}(s) \times G_S(s) \times \text{Vest} \quad (6)$$

$$\text{Closed Loop, CL}_{VEL} = \frac{G_{PI}(s) \times G_S(s) \times \text{Vest}}{1 + G_{PI}(s) \times G_S(s) \times \text{Vest}} \quad (7)$$

$$\text{Sensitivity, S}_{VEL} = \frac{1}{1 + G_{PI}(s) \times G_S(s) \times \text{Vest}} \quad (8)$$

After that, the outer loop is designed based on modeling of the velocity loop.

$$\text{Open Loop, OL}_{\text{POS}} = \frac{G_P(s) \times G_{PI}(s) \times G_S(s)}{1 + G_{PI}(s) \times G_S(s) \times V_{est}(s)} \quad (9)$$

$$\text{Closed Loop, CL}_{\text{POS}} = \frac{G_P(s) \times G_{PI}(s) \times G_S(s)}{1 + G_{PI}(s) \times G_S(s) \times V_{est}(s) + G_P(s) \times G_{PI}(s) \times G_S(s)} \quad (10)$$

$$\text{Sensitivity, S}_{\text{POS}} = \frac{1}{1 + G_{PI}(s) \times G_S(s) \times V_{est}(s) + G_P(s) \times G_{PI}(s) \times G_S(s)} \quad (11)$$

Therefore, the modeling for Cascade P/PI are shown as follows:

$$\begin{aligned} \text{Velocity loop} &= 0.005695 + \frac{0.05306}{s} \\ \text{Position loop} &= P = 540 \end{aligned} \quad (12)$$

4. RESULTS AND DISCUSSION

The performances of PID and Cascade P/PI controllers are evaluated based on standard analyses of analyzing tracking performance of controllers for frequency domain [5]. FFT error with cutting force disturbances of 3500rpm shows undesired frequency harmonics at varying amplitude during milling operation. The frequency is set 0.7Hz as the ball screw drive system started to vibrate when more than 0.7Hz is injected. Figure 2 shows the spectral analysis of Cascade P/PI controller during 3500rpm. The result shows undesired frequencies harmonics which resulting in existence of nonlinear characteristics [6] and time varying dynamics. Therefore, this will cause inaccuracy in positioning of the ball screw drive system.

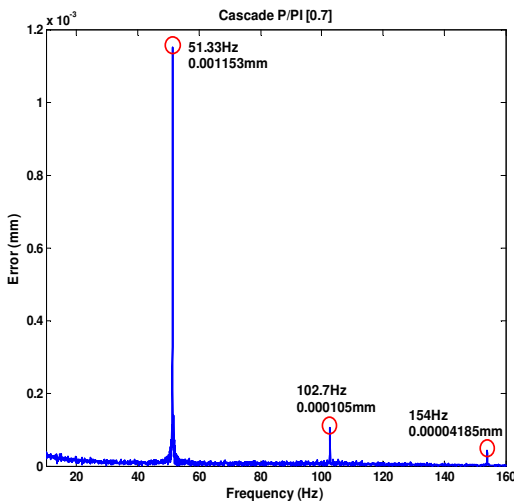


Figure 2 FFT errors for Cascade P/PI controller

Table 1 FFT error of PID and Cascade P/PI

| Peak Frequency (Hz) | Error (μm) | | Error Reduction (%) |
|---------------------|------------|--------------|---------------------|
| | PID | Cascade P/PI | |
| 51.33 | 22.79 | 1.153 | 94.94 |
| 102.7 | 0.6317 | 0.105 | 83.83 |
| 154 | 0.4679 | 0.04185 | 91.06 |

Table 1 shows the overall frequency harmonics for both controllers and the error reduction is calculated. Despite of the highest error is at 51.33Hz with 22.79mm and 1.153mm for PID and Cascade P/PI respectively, the frequency contributes the highest error reduction of 94.94%.

5. CONCLUSIONS

As the conclusion, the Cascade P/PI controller shows lower FFT error than PID controller. This proves that Cascade P/PI is better to be implemented in machine tool industry as the average error reduction up to 89.79%. Different spindle speed can be implemented in determining the best value of cutting force disturbances and add on module of the controllers can be implemented for future work.

ACKNOWLEDGEMENT

The authors would like to acknowledge the financial support by Universiti Teknikal Malaysia Melaka (UTeM) under the scholarship of ‘Skim Zamalah UTeM’, short term grant scheme (PJP) Universiti Teknikal Malaysia Melaka PJP/2014/FKPPROTOTAIP/S01379 and FRGS grant with reference number FRGS/1/2016/TK03/FKP-AMC/F00320.

REFERENCES

- [1] Y. Altintas. *Manufacturing Automation Metal Cutting Mechanics, Machine Tool Vibrations and CNC Design*, 2nd ed. New York: Cambridge University Press, 2012
- [2] J. Jamaludin, Z. Jamaludin, T.H. Chiew, and L. Abdullah. "Design and Analysis of Disturbance Force Observer for Machine Tools Application," *Applied Mechanics and Materials*. 761, pp. 148–152, 2015.
- [3] Y. Altintas, A. Verl, C. Brecher, L. Uriarte, and G. Pritschow, "Machine Tool Feed Drives," *CIRP Annals - Manufacturing Technology*. 60(2) pp. 779–796, 2011.
- [4] R. Pintelon and J. Schoukens. *System Identification: A Frequency Domain Approach*, Second Edi. John Wiley & Sons, Inc., 2012.
- [5] J. Jamaludin. *Cutting Forces Compensation using Disturbance Force Observer*, Master thesis, Faculty of Manufacturing Engineering, Universiti Teknikal Malaysia Melaka (UTeM), Malaysia, 2013.
- [6] F.C. Moon and T. Kamar-Nagy, "Nonlinear Model for Complex Dynamics in Cutting Materials," *Philosophical Transactions of the Royal Society of London*, 359(1781), pp. 695–711, 2001.

Selection of controller for machine tool application by using analytical hierarchy process

N.A.S Suhaimi, L. Abdullah*, M.Z. Mohamad Zaini

Faculty of Manufacturing Engineering, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia

Corresponding e-mail: lokman@utem.edu.my

Keywords: Analytical hierarchy process; control system environment; expert choice

ABSTRACT – This research basically discusses the selection of the controller for machine tool application by using Analytical Hierarchy Process (AHP) method. AHP is defined as a method of multi-attribute decision making that has been developing by Dr. Thomas L. Saaty in the year 1970. N. Bhushan and K. Rai [1] writes, the Analytic Hierarchy Process (AHP) is an efficient methodology created in late 1970 to structure the experience, instinct and heuristics-based decision making into well characterized approach by using the mathematical principles. Nowadays, there is a huge challenge in determining the most suitable controller to use in the system. The selection of controller involves many factors and requires careful attention to avoid the malfunction of the system. By using AHP method, a hierarchy framework model to arrange the best controller design decisions is made. Then, a few sets of sensitivity analysis were carried out by using Expert Choice software. The final result shows the best controller for machine tool application is Cascade controller with a score 39.1% of priority index, SMC controller is in second place with a score of 37.4% and PID controller with a score 23.5%.

1. INTRODUCTION

AHP is defined as a method of multi-attribute decision making that has been developing by Dr. Thomas L. Saaty in the year 1970. The purpose of this method is intended to adapt to both the rational and intuitive to choose the best from a variety of alternatives evaluated on several criteria [2]. In addition, the AHP is a tool which can utilize to build up an efficient approach for a single or group decision maker to solve decision-making problems [3] So, AHP can provide the accurate results right when faced with a problem to make right decisions, especially in the control system environment.

Nowadays, there are numerous controllers used in the industry to controlling machine and equipment. The control system is defined as a set of device that manage, instruct, coordinate and also adjust the behavior of the system or devices. Inside the control system theory, the reference or the output follows the desired control signal which may change the values or be fixed. To do this, a controller is designed to observe the output and compare it with reference. There are many controllers inside control system environment. PID controls include a Proportional controller (P), the Integral controller (I), and Derivative controller (D). Selecting the best controller is not easy because there are many factors that should be

considered. Thus, to overcome this situation, the powerful method to choose the controller is proposed in this research.

The AHP is used in the control system environment for controlling the quantitative and qualitative factors And sub-factors to choose the best controller. Although AHP hierarchical structure facilitates analysis, a much more important function of AHP can help measure and synthesize the huge number of a factor in a hierarchy [4]. AHP selection is based on the problem and deliberation of advantages and disadvantage of another method. Hence, the main point in this study is focused on developing a model of the AHP to select the most appropriate decisions on the control system environment.

2. METHODOLOGY

In this section, the research setup & procedures during research are discussed. The research was carried out based on the flow as follows:

- (1) Formulate research study: Gathering all the information on the problem statement, objective, and the scope of the project to narrow domain for the literature review.
- (2) Literature review: Data about control theory and AHP is collected from journal, conferences papers, online journals and textbooks.
- (3) Development of controller design criteria: Data is taken from various resources and illustrated in hierarchy framework before proceeding with AHP method.
- (4) Controller selection via AHP: AHP performed to select the best design controller for machine tools application.
- (5) Sensitivity analysis and conclusion: To verify the results of the decision and to study the effect of the different factors on deciding the best decision option. Expert Choice Software was used to execute the sensitivity analysis.

3. RESULT AND DISCUSSION

All the criteria, sub-criteria, and alternative are choose based on basic criteria to design the controller in control system environment. Hierarchy structure for analytic hierarchy process to select the best design of a

controller for machine tool application was constructed:

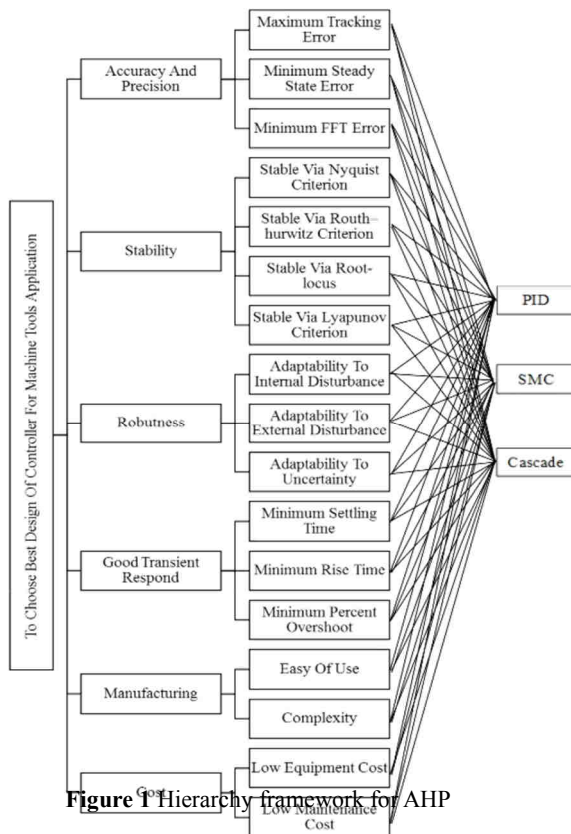


Figure 1 Hierarchy framework for AHP

The result has been drawn and based on that, the best design of a controller for machine tool application is Cascade controller with the score 39.1% of priority index if compared with another controller. The SMC controller is in second place with the score of 37.4% and the last controller is PID controller with the score of 23.5%. Therefore, it is proven that Cascade controller is the most suitable controller to use in machine tool application when compared with another controller such as SMC and PID. After sensitivity analysis are done by using Expert Choice Software, it shows the scenario tested, SMC controller is the most preferred alternative with respect to criteria and Cascade remain as the preferred alternative with respect to sub-criteria.

4. CONCLUSION

The study has shown that Cascade controller is the best design of a controller for machine tool application with a priority value of 39.1%. SMC controller followed on second ranking with a priority value of 37.4%. Finally, PID controller is the last ranking with a priority value of 23.5%. Due to numbers of calculation needed to be done, all calculation process was done by using a calculator and Expert Choice software. Sensitivity analysis was done by using Expert Choice 11 software. When compared, both results from calculating manually and Expert Choice have a small difference but the overall priority rank of the alternative remain the same. Priority vector for each selection criteria and sub-criteria were manipulated during sensitivity analysis to study their effect towards the alternative rank. At the end of the study, in most of

the scenario tested, SMC controller as the most preferred alternative with respect to criteria and Cascade remain as the preferred alternative with respect to sub-criteria. This study successfully addresses the implementation of Analytical Hierarchy Process (AHP) method into control system environment.

REFERENCES

- [1] N. Bhushan, and K. Rai. *Strategic Decision Making Applying the Analytic Hierarchy Process*, New York: Springer, 2004.
- [2] T.L. Saaty, and L.G. Vargas, *Models, Methods, Concepts & Applications of the Analytical Hierarchy Process*, Boston: Kluwer Academic Publishers, 2001.
- [3] C.F. Chen, "Applying the Analytical Hierarchy Process (AHP) Approach to Convention Site Selection," *Journal of Travelling Research*, vol. 45(2), pp. 167– 174, 2006.
- [4] E.H. Forman and S.I. Gass, "The Analytic Hierarchy Process – An Exposition". *Operations Research*. vol. 49(4), pp. 469-486, 2001.

Design and analysis on sitting posture in quality checking workstation of a manufacturing company

Z. Abdullah^{1*}, N.S. Norazman¹, C.S. Chew¹, M.M. Ghazaly², R. Jaafar¹, S. Maidin¹

¹) Faculty of Manufacturing Engineering, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia

²) Faculty of Electrical Engineering, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia

*Corresponding e-mail: zulkeflee@utem.edu.my

Keywords: QFD; RULA analysis; posture

ABSTRACT – This study focuses on sitting posture in quality checking workstation at manufacturing company. Workers must perform the quality checking processes in workloads, their repetitive sitting and standing posture in workplace could lead to ergonomics issue. The study aims to simulate the relation of sitting posture while performing workloads and apply RULA analysis as ergonomics tool assessment that came out with the redesign of the quality checking workstation to improve the sitting posture of the worker from score of RULA 3 and 4 to score of RULA 1. It concluded that the redesigned workstation has significant improvement on sitting posture.

1. INTRODUCTION

There are several ergonomic issues faced by the manufacturing industries especially the workers involved in the production line in a manufacturing company. Most people who worked in manufacturing sector will encounter a problem of pain or injuries and posture. It happens when they were asked to work for normally 8 to 12 hours per day without shifting in sitting position. Prolonged sitting posture could lead to discomfort feeling due to the factors of physical stress which means stress or pressure that were happened during working such as high demand of workload, repetitive motion and bad workstation area.

Moreover, ergonomics or human factors is, above anything else, a systems discipline and profession, applying a systems philosophy and systems approaches [1]. In Malaysia, studies on the ergonomics task analysis has been carried out among workers in two factories, the one producing electronics components and the other, audio electronic equipment said by [2]. From the journal research, mostly researcher found out that in industrialized countries sitting posture is the common position most frequent body posture took during job handling. The main reasons why seats were developed was to reduce physical strain on the body. Indeed, in the sitting position we relax the muscles in the feet, legs, and to some extent in the trunk according to [3]. Thus, the ergonomics is the scientific study of the relationship between human and their working environment. They also said that the term environment itself is taken to cover not only the surrounding environment or area in which they may work but also

their tools and materials, methods of work and the organization of work, either as individual or within working group.

All these are related to the nature of the man himself to his abilities, limitations and capacities. The goal of ergonomics is to find a best fit between worker and job environment. Therefore, the reasons identified include unnatural work postures, use of hazardous chemicals, unsafe working practices, long working hours and many risks of work accidents due to unsafe work environments. Table 1 shows the researches that were done in this research area.

Table 1 Related researches

| Authors | Focuses | Results/Findings |
|--|--|---|
| (Meena, Dangayach, & Bhardwaj, 2011) [2] | Ergonomic factors in handicraft industry. | Ergonomics intervention and ergonomic redesign of workstations to improve posture and working conditions. |
| (Zein, Halim, Azreen, Saptari, & Rahayu, n.d.) [4] | Working postures among Malaysian industrial workers. | Industrial workers should aware of injuries during job handling. |
| (Karakolis & Callaghan, 2014) [5] | Impact of sit-stand workstations lead to discomfort | Sit-stand gives pro and cons for itself |

2. METHODOLOGY

In this study, a survey was conducted to 3 respondents in a manufacturing company. This survey was conducted in face-to-face method, interviews and personal. They were asked about the work environment and give opinions while answering the questionnaire given. The purpose to conduct this survey is to collect data regarding to the factors for improving the work station ranging from the aspects of the location of work station, convenience stacked, convenience height, comfort posture and change layout.

Other option of method used was by searching journals through science direct and find any related topic to the study. Next, is by using QFD to redesign the workstation. Any improvements or design that wanted to be made, customer requirement is important to get a better result. QFD enables us to make decisions or to choose which design is suit to the requirements needed. In any design process, it must consider the cost, quality, satisfaction and build time.

In addition, to create or design a product that help in improving the sitting posture, CATIA (see Figure 2) were used to build a model and through analysis, RULA can be utilized for this ergonomics aspect. All this method helps in this study to design and analysed the problem encounter to achieve the objectives targeted.

3. RESULTS AND DISCUSSION

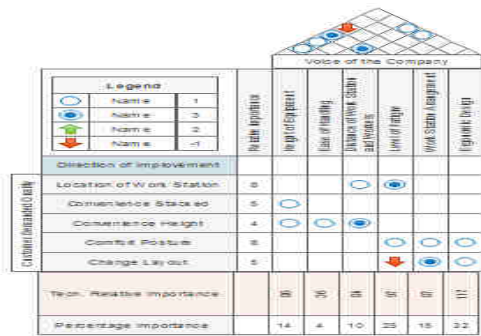


Figure 1 House of quality of the proposed design

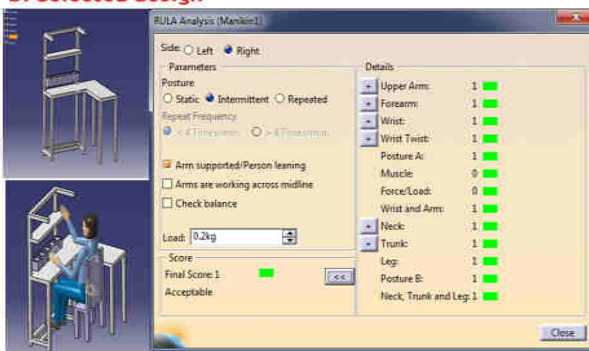
Based on the complete HOQ, from the figure itself it shows strong relationship between distance of workstation and equipment with the ease of handling. This is because upon the distance exceeding a standard height of worker with 180 cm makes the worker feel tired easily and furthermore it needs energy from one place to another. Short distance between the standard height of worker from 150 cm to 180 cm could save time of operation and reduce problem of fatigue. Moreover, in the figure 1, it shows how the technical relative importance gives results to the percentage importance. As can be seen from the figure 1, 32% comes from ergonomics workstation followed by 25% from level of fatigue. This indicates that an ergonomic workstation could improve their level of fatigue and as it is related to each other.

a. AHP Method on Proposed Designs

Overall D1 priority: 0.56 (0.582) + 0.33 (0.223) + 0.11 (0.131) = 0.414
 Overall D2 priority: 0.56 (0.316) + 0.33 (0.692) + 0.11 (0.677) = 0.480
 Overall D3 priority: 0.56 (0.102) + 0.33 (0.084) + 0.11 (0.192) = 0.110

Based on the results, D2 > D1 > D3. Therefore, since D2 has highest score of the results, D2 was chosen as the selected proposed design.

b. Selected design



Selected design with manikin Results of RULA analysis
 Figure 2 Results of AHP Method and RULA Analysis

After collected the data, QFD and AHP methods are conducted to select the best and optimum workstation design.

4. CONCLUSION

As the conclusion, in any industrial sector, posture is commonly used for job handling. Industrial workers should be more aware of their work environment where if take lightly, there will cause problems in future to health condition. A good workstation gives impact on work efficiency and the quality of work. Company management needs to give more consideration on the ergonomics aspect at the mean time of making profit in the manufacturing industry. As compared to existing workstation, it saves up to 33 % of time from 12 seconds short up to 8 seconds in manufacturing time.

Table 2 Comparison of existing and proposed workstation with CATIA and RULA analysis

| Existing workstation | Proposed workstation |
|--|--|
| | |
| | |
| -Posture: Intermittent -Load: 0.2kg -Score: 4 | -Posture: Intermittent -Load: 0.2kg -Score: 1 |
| -Comment/ Analysis: <ul style="list-style-type: none"> Packed workstation Non flexible movement Non ergonomics workstation Height distance from sitting place to the location of equipment is too high 90 degrees up to the hand. | -Comment/ Analysis: <ul style="list-style-type: none"> Free workspace workstation Flexible movement Ergonomics workstation based on RULA analysis Height distance from sitting place to the location of equipment is much nearer 45 degrees and easy for handling |

REFERENCES

- [1] J.R. Wilson, "Fundamentals of systems ergonomics/human factors," *Applied Ergonomics*, 45(1), pp. 5-13, 2014.
- [2] M.L. Meena, G.S. Dangayach, and A. Bhardwaj, "Impact of Ergonomic Factors in Handicraft Industries," *Proceedings of the International conference of Mechanical, production and Automobile Engineering*, pp. 247-249, 2011.
- [3] E. Grandjean, and W. Hünting, "Ergonomics of Posture-Review of various problems of standing and sitting posture," *Applied Ergonomics*, 8(3), pp. 135-140, 1977.
- [4] R. Zein, I. Halim, N. Azreen, A. Saptari, and S. Rahayu, "A Survey on Working Postures among Malaysian Industrial Workers," *Procedia Manufacturing*, 2, 450-459, 2015.
- [5] T. Karakolis, and J.P. Callaghan, "The impact of sit & stand of fire workstations on worker discomfort and productivity: A review," *Applied Ergonomics*, vol. 45(3), pp.799-806, 2014.

DFMA application on the development of products: a case study of consumer products

Z. Abdullah^{1*}, N. Zakaria, N. A. Zulkifli, S. Maidin¹, M. A. M. Ali¹, M. M. Ghazaly², M. K. M. Nor³

¹⁾ Faculty of Manufacturing Engineering, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia

²⁾ Faculty of Electrical Engineering, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia

³⁾ Faculty of Mechanical Engineering, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia

*Corresponding e-mail: zulkeflee@utem.edu.my

Keywords: DFMA; Boothroyd-Dewhurst Method; product design

ABSTRACT – This paper presents the result of case study of consumer product by using the Design for Manufacturing and Assembly (DFMA) application on the development of products. A kettle has been selected as a case study and had the potential to be redesigned by applying the DFMA methodology. In this project, the study of improvement of product designs is analyzed by using DFMA methodologies; namely the manual Boothroyd Dewhurst method, DFA software and DFM concurrent costing software. The evaluation of the original design efficiency over the new design efficiency has a great achievement with design efficiency improvement of 36%.

1. INTRODUCTION

In today's market industrial companies are struggling with fierce competitor in developing markets to optimize the production of products. Cost and quality are important during the design process for products in the early stages of the production process. By applying DFMA methodologies, it can reduce the part count; minimize the assembly costs and waste; therefore avoiding inefficiencies throughout the manufacturing process. DFMA is a systematic procedure that concerns all details of the design, improvement, number of parts, manufacturability, price, assembly time, and modularity [1]. DFMA is basically the combination of two methodologies which is Design for Manufacture (DFM) and Design for Assembly (DFA). DFM is the design help in ease of manufacturing parts that will develop a product. While, Design for Assembly (DFA) is designed to ease the assembly process. Basically, DFMA aims at product improvement to allow advancements in production, cost, quality, reliability, and time to sell [2].

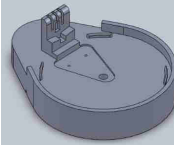
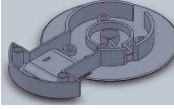
2. METHODOLOGY

The Boothroyd-Dewhurst DFA method and DFMA software is used in this case study. This methodology phased includes a reverse engineering process, producing CAD drawing (detail design), manual DFMA analysis approach, computer aided DFMA analysis approach (DFMA Software). Then the redesign phase was executed. After that the redesign product were reanalyze with DFMA approach again.

2.1 CAD drawing (detail design)

The parts and function of the product are studied, then the detail parts of products are drawn in a 3D CAD drawing by using the Solidworks software (Table 1). After completing the drawing of the original design of the product, the analysis is conducted by using DFMA method.

Table 1 Function of some part of original design of kettle

| Item No. | Name | Figure | Function |
|----------|--------|---|---------------------------------------|
| 1 | Base 1 |  | Base for the body of electric kettle. |
| 2 | Base 2 |  | Housing for electronic circuit |

2.2 Manual DFMA analysis approach

The analysis for the existing design is done by examining the products and filling in the recommended marks according to the DFMA analysis worksheet. This worksheet, consist of nine columns consisting of item number, part no, part name, number of items, handling code, manual handling, manual insertion code, manual insertion, operation time, operation cost and estimation for theoretical minimum parts. The estimated time is obtained from the table of manual handling and insertion estimated time by referring to the thickness and the size of each part. The total part number of the original design of kettle is 31 parts.

2.3 Computer aided DFMA analysis approach (DFMA Software)

Design for Manufacturing (DFM) Analysis:

DFM software is used to generate a fabrication cost estimate for each fabricated part in the system. In order to complete the Design for Manufacturing in DFM Concurrent Costing software, the suggested material and the processes were selected for each part in order to generate the total cost for the material and the processes

(Table 2). All dimensions of each part need to be given before insert for material and process step

Table 2 Material and process each part of original design

| No | Name | Material | Process |
|----|--------|--------------------|-------------------|
| 1 | Base 1 | Polypropylene (PP) | Injection molding |
| 2 | Base 2 | Polypropylene (PP) | Injection molding |

Design for Assembly (DFA) Analysis:

The DFA analysis is executed in the DFA software in order to determine the ease of assembly of product. Hence, through the DFA software the labor time, labor cost, total cost and DFA index.

2.4 Redesign phase

In redesign phase, the original design will be improved from the result of the analysis. The changes were made to reduce the number of parts and improve the design efficiency. Elimination and reduction of unnecessary parts is important to simplify the product structure to ease the assembly process. The redesign phase has variations of design rules [3]:

- i. Combine connected items in order to eliminate items whose function is solely to make a connection.
- ii. Reduce the number of items in the assembly by combining with others or eliminating the parts or subassemblies.
- iii. Reduce separate operation times where possible.
- iv. Consider redesigning the items to eliminate or reduce the handling difficulties.

3. RESULT AND DISCUSSION

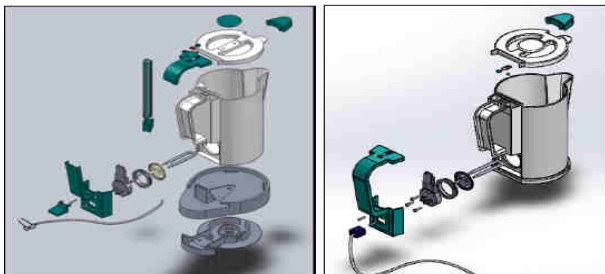


Figure 1 The original and redesign of kettle after applying DFMA methodologies

From Figure 1, the number of parts in the redesign of kettle can be seen to be significantly reduced with a simpler design. The numbers of part for the redesign of kettle were reduced from 31 parts to 14 parts. Some of the parts are reduced by combining two or three parts into a part only. For redesign kettle there was no subassembly during the assembly process. Redesign kettle consists of case, heater plate, screw heater element, standard screw, heater rod, long screw, small cap button, rubber bush, wire, socket, lip, handle, lid and switch. It is important to analyze and determined the parts of products that needs to be improved. The function of each redesign parts is still the same as the original and it is still functional as the original design. From the DFMA software analysis, nine reports of results were generated namely; executive summary of DFA, DFMA, structure chart, suggestion for redesign,

product worksheet, analysis total, environmental summary, notes and 57 pictures. The software suggested redesigning the product by eliminating the unessential parts by incorporating integral fastening elements into functional parts, or changing the securing methods, in order to eliminate as many as possible of the separate fastening elements.

Table 3 Comparison of DFMA software analyses between original and redesign of kettle

| Product | Existing product | Redesign product | Improvement (%) |
|--------------------------------------|------------------|------------------|-----------------|
| Product life volume | 10000 | 10000 | 0 |
| Number of parts | 31 | 14 | 45.16 |
| Theoretical minimum numbers of items | 5 | 4 | 20 |
| DFA index (%) | 52 | 88 | 36 |
| Total weight, kg | 0.52 | 0.73 | - |
| Total assembly labor time, s | 282.40 | 133.28 | 52.8 |
| Total cost per product, RM | 46.16 | 37.72 | 18.28 |

Table 3 shows the comparison of the result of the original and redesign kettle of the DFMA Software analysis. The result shows the increase of design efficiency (DFA index, %) from 52% to a whopping 88%. From Figure 2, it also shows the reduction of total number of parts with the improvement of 45.16%. Though, the total weight of the redesign kettle increase from 0.52kg to 0.73kg, the redesign of kettle managed to decrease the total assembly labour time with significance value of 133.28 sec from 282.40 sec. Finally, for the bottom line in the accounting terms (meaning the company can have greater profits), the total cost per product has a saving of 18.28%.

4. CONCLUSIONS

As a conclusion, DFMA is a tool of concurrent engineering in guidance design engineer to develop the product. DFMA helps in simplifying the tree structure of product, combining and eliminating unnecessary part in order to minimize the number of part at the same time reducing the manufacturing time as well as time of assembly and also the cost of the product. Though by using manual method there was no specific information used. Hence, to obtain accurate result, it is recommended to make prototypes to analyze the functionality and identify the improvement in handling and insertion difficulties.

REFERENCES

- [1] A.K. Chitale and R.C. Gupta. *Product Design and Manufacturing*, New Delhi: Prentice Hall of India, pp.18, 2006.
- [2] G. Boothroyd, P. Dewhurst, and W.A. Knight. *Product Design for Manufacture and Assembly*, United States: CRC press, pp. 1-26, 2011.
- [3] A. Kamrani, and E. Nasr. *Engineering design and rapid prototyping*, New York: Springer, pp. 142-143, 2010.