

LOW COST ERGONOMICS SOLUTION FOR SAFE WORK POSTURE AT CONVENTIONAL MILLING MACHINE: A CASE STUDY

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ABSTRACT: Conventional milling machine has been recognized as one of the solutions for high productivity and economical machining processes. However, the existing design of conventional milling workstation leads to non-neutral work postures because of the machine operator has to bend downward his torso for better visualization in setting and machining the workpiece. The aim of this study is to redesign the existing milling workstation by focusing on operator's visualization and work posture. This study applied Rapid Upper Limb Assessment (RULA) to assess the work posture of the operator while performing milling operation. The existing milling workstation was redesigned by attaching a low cost LED light and a magnifying glass to improve operator's visualization in setting and machining the workpiece. Results of work posture analysis revealed that RULA score reduced from 7 to 3 due to application of these tools. This study concluded that low cost intervention is meaningful in improving work postures of conventional milling machine operators.

KEYWORDS: *Ergonomic; Conventional Milling Machine; Work Posture; Low Cost Solution*

1.0 INTRODUCTION

Milling operation is a machining process of removing excess material via force exerted through a cutting tool [1]. It is a versatile process which includes drilling, boring, machining slot, pocketing,

chamfering, facing, squaring and others. There are two types of milling machines: 1) semi-automated (computer Numerical Control (CNC)) and 2) manual control (conventional milling machine). Semi-automated CNC milling machine uses computerized coding to control the positions of cutting tools while the conventional milling machine is manually operated by human operators. Even though CNC milling machines show high efficiency in productivity and quality, conventional milling machines is still widely used in many industries. This is due to its flexibility and ability to perform rapid machining processes such as squaring and chamfering to reduce the lead time of the overall production.

Unfortunately in conventional milling workstation, the operators may be exposed to non-neutral work postures. Operators may need to frequently bend down their torso in order to adjust the machine cutting gauge located at the below machine bed. Additionally, the markings on the gauge may gradually fade due to wear which can further promote bending posture due to visibility issue. The frequent and prolonged adoption of awkward postures may lead to muscles strain, back pain, tension in the neck.

One of the ways to improve occupational health and productivity in industries is by applying ergonomics [2]. The International Ergonomics Association (IEA) defines ergonomics as the scientific discipline concerned with the understanding of interactions between humans and other elements of a system. It is an area that focuses on optimizing human well-being in its interaction with the system.

An ergonomically designed work process and workstation theoretically promotes good working environment, which may influence motivation, and ultimately workers' productivity [3-5]. In contrast, a poor ergonomically designed workstation promotes unnecessary physical demand as well as biomechanical disadvantage. As a consequence, workers may get fatigued at a faster rate, hence become more prone to make mistakes and errors. This will decrease quality and overall efficiency [6-7].

Workplace lighting has been shown to influence worker productivity [8-11]. The luminous environment in a workplace can influence job

performance and the psychological well-being of workers [8]. A famous phenomenon called the Hawthorne effect was documented in Western Electrical Company's Hawthorne Works in Chicago, where researchers reportedly experimented with lighting levels in the production facility which resulted in changing productivity levels of workers [12]. Previous studies on lighting have focused on the psychological effects of lighting on workers [8-9,11]. However, little is understood on the effects of low cost lighting ergonomics intervention in the Malaysian workplace, especially in conventional milling operation.

Therefore the aim of this study is to minimize the non-neutral work postures at the existing conventional milling workstations by utilizing a low cost lighting ergonomics intervention.

2.0 METHODOLOGY

A case study was performed in a medium sized metal machining company in Malaysia. This study has three stages as shown in Figure 1. It started with an ergonomics assessment at the existing conventional milling workstation. The second stage involved redesigning of existing workstation through a focus group. In the third stage, a 3D Computer Aided Design (CAD) simulation was performed to compare the work posture between the existing milling workstation and the redesigned milling workstation.

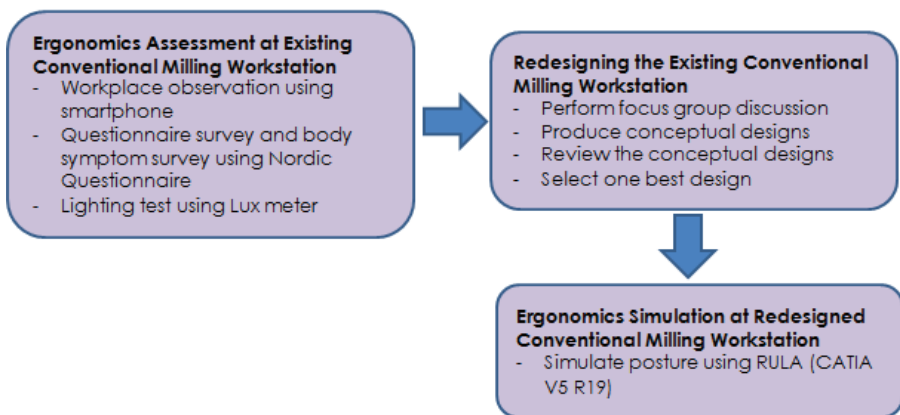


Figure 1: Process flow in conducting the study

2.1 Ergonomics Assessment at Existing Conventional Milling Workstation

In the first stage, ergonomics assessment was performed at existing conventional milling workstation to identify problems and the root causes that can affect productivity, product quality, and occupational health. The study applied workplace observation, questionnaire survey, lighting test as well as work posture assessment.

During workplace observation, videos and pictures of work postures during milling operation were captured. A questionnaire survey was also distributed to one production manager, two production supervisors and 17 machine operators (having more than one year work experience in conventional milling operation). The questionnaire consists of four sections. Section one highlights the demographic information of the respondents which consist of gender, age, nationality, body height, body mass, work designation, work experience and education level. Section two surveys the ergonomics risk factors exposed by the operators during operation of conventional milling machine. Section three identifies body discomfort level using Nordic Musculoskeletal Questionnaire (NMQ). The NMQ has been previously used to identify and analyze musculoskeletal symptoms [13].

Section four captures respondents' agreement on their workstation redesign ideas such as adjustable workstation height, extra lighting, and attachment of a magnifying glass on the reading gauge, and installation of vibration and noise insulator. In addition, they can also suggest additional ideas to improve existing conventional milling workstation.

The Canada Occupational Health and Safety Regulations (Part VI - 928-1-IPG-039) [14] was referred to determine the procedures in conducting the lighting test. A digital lux meter (Extech 407026) was used to measure lighting at the existing milling workstation. The lighting measurement points are shown in Figure 2. Three readings were taken at the same point within the interval of three minutes.

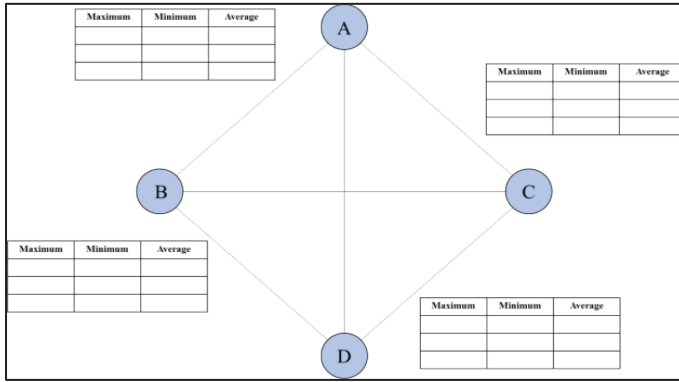


Figure 2: Lighting measurement points (A-B-C-D)

Anthropometric dimensions of the operators were measured using an anthropometer. The following body dimensions of operators were taken: stature, axilla, chest height (standing), waist height (standing), crotch height (standing), acromion-radiale length, radiale-styilion length, chest breadth, waist breadth, hip breadth, and elbow height (standing).

In CATIA V5 R19 software, a manikin was created based on the operators' anthropometric data. Consequently, the 3D drawing of existing milling workstation was created before being transferred into CATIA's human activity analysis module. The manikin was positioned similar to actual working condition using posture editor module. Work postures were then assessed using Rapid Upper Limb Assessment (RULA) method integrated within CATIA V5 R19 software. The RULA projected the risk of occupational injuries due to work postures [15]. A work posture is acceptable if the RULA scores are 1 or 2. Further investigation and changes required if the RULA scores are 3 or 4. Meanwhile, for the RULA scores of 5 or 6, prompt investigation and changes should be addressed to the cases. Immediate investigations and changes are required when the RULA score is 7 [15].

2.2 Redesigning the Existing Conventional Milling Workstation

A few focus group sessions were conducted to generate improvement concepts for the existing milling workstation. The focus group sessions involved production stakeholders such as production planner, machining supervisor, quality control manager, quality control supervisor and machine operators to ensure the concepts would not disrupt production, interfere with task, and affect product quality. Through involvement of stakeholders, potential solutions to minimize awkward postures at existing workstation can be explored while addressing practical constraints at the same time. The activity was also promotes teamwork and at the same time, provide a platform for stakeholders to come to collective agreement on workstation redesign specifications.

This study utilized information extracted from the focus group discussion to develop conceptual modification designs of a new milling workstation. Five sketches of conceptual designs were created based on criteria set during focus group sessions such as practicality, ease to implement, and cost. The five sketches of conceptual designs of the new milling workstation were then submitted to the stakeholders for their review.

2.3 Ergonomics Simulation at Redesigned Conventional Milling Workstation

In this stage, a computer simulation using CATIA was performed to assess the operators' work posture at the redesigned conventional workstation. This simulation provides visualizations on how the redesigned workstation can improve the work posture.

3.0 RESULTS AND DISCUSSION

3.1 Ergonomics Problems and Root Causes at Conventional Milling Workstation

Observations at the existing milling workstation revealed that in general, operators were adapting non-neutral postures where they had to flex their spines downward and maintain them to ensure the

workpieces are machined according to required dimensions. Moreover, the operators need to repeat these postures several times since the maximum feeding rate is only 2 mm per feed. The study also observed that the operators work in dim lighting which requires them to bend their body to check clamping of the workpieces, as well as feeding rate during machining operations.

Based on the questionnaire survey, most of the respondents strongly agreed that working height, workplace lighting and faded markings on the gauge are the root causes contributing to the non-neutral work posture. This finding shows a good agreement with Hassaine et al. [16] where incompatibility between worker height and table height can promote non-neutral torso angle and consequently muscular stress. Insufficient lighting at the workstation was also identified as a contributing factor to forward bending since the operator has to bend down to get visibility on the gauge. The advantages of working in adequate lighting environment have been documented, which include good occupational health and well-being, better work performance, fewer errors, better safety and lower absenteeism [17]. Meanwhile, 50 % of the respondents strongly agreed that the faded markings on the gauge also contributed to non-neutral work postures. Similar to poor lighting, the operators had to bend down to read the feed rate scale on the gauge.

The body discomfort using NMQ survey revealed that 50 % of the respondents reported persistent pain in their upper back and lower back, as well as shoulders. The pain may possibly be linked to their exposure to repetitive poor postures on current workstation set up. In terms of lighting, it was observed that existing fluorescent lamps were unable to provide adequate visibility for machining process at the existing workstation. The lighting level ranges between 56 to 114 Lux, which is significantly below the standard lighting level of 200 Lux as mentioned in ISO 8995-1:2002 [18]. Table 1 shows the lighting levels (measured in Lux) surrounding the existing conventional milling workstation.

Table 1: Lighting levels at the existing conventional milling workstation

Point	Minimum	Average	Maximum
A	56	57	59
B	112	113	114
C	109	111	113
D	76	77	80

Figure 3 and Figure 4 illustrate the operator’s work postures and RULA scores for left and right side respectively. The RULA score indicated that trunk, neck, legs and wrists required immediate improvement. This is due to operator is required to adjust the machining feed rate and holding the work piece simultaneously. To do that, his legs are in a static standing position. Furthermore, the torso obtained high RULA score because the operator needs to bend their body downwards to set the machining feed rate on the cutting gauge.

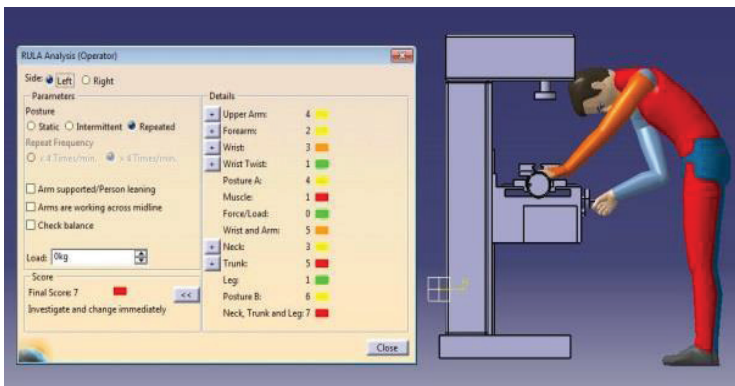


Figure 3: RULA score (left side) when working at the existing milling workstation

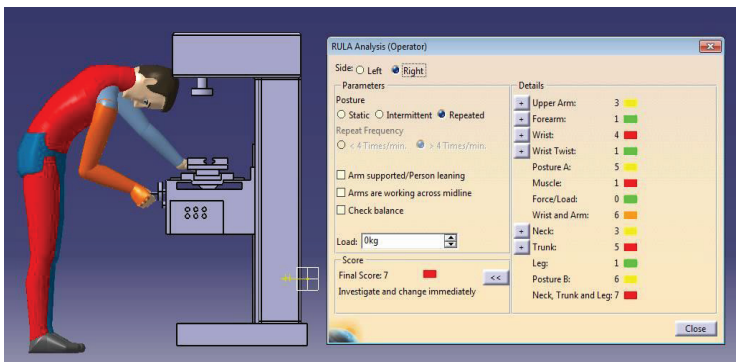


Figure 4: RULA score (right side) when working at the existing milling workstation

3.2 Redesign of Conventional Milling Workstation

This study has proposed five conceptual designs to improve the existing conventional milling workstation. Conceptual design 1, 2, 3, 4 and 5 are shown in Figure 5, Figure 6, Figure 7, Figure 8 and Figure 9 respectively. Concept 1 involves a customized cylindrical magnifying glass to assist visibility of the marking on the gauge in addition to the installation of double fluorescent lamps to improve lighting.

Concept 2 is proposing installation of a magnifying glass and LED lights. Two reuse magnetic bases are used to attach the magnifying glass and LED lights to the machine frame. Both concepts are envisioned to provide better visibility when working on the workpiece, consequently minimizing the need for operators to keep a close distance to the gauge. In turn, this will allow them to adopt more neutral postures.

Concept 3 involves a dual hydraulic system that provides adjustable function for machine and operator heights. A LED lamp is used to ensure the lighting in the workstation is sufficient. In Concept 4, a spotlight is installed to ensure the lighting is focused at the workstation. Additionally, an extendable flat magnifying glass is used to magnify the machine gauge and a standing platform is deployed to increase the height of operators. Concept 5 uses a flexible retractable lamp which is screwed on the machine frame. The purpose is to increase visibility when operator is setting up the machine gauge. Additionally, a stool is provided to enable operator to operate the machine in sitting. The benefit of this concept is can minimize operator's torso and neck from bending posture.

A series of discussions have been made with the stakeholders (production planner, machining supervisor, quality control manager, quality control supervisor and machine operators) to select one of the five concepts. Concept 2 was chosen as it meets contextual work requirements such as practicality, ease to implement, and cost saving. Figure 10 illustrates a 3D computer aided design (CAD) of concept 2 whereby the milling machine is attached with LED lights and a magnifying glass.

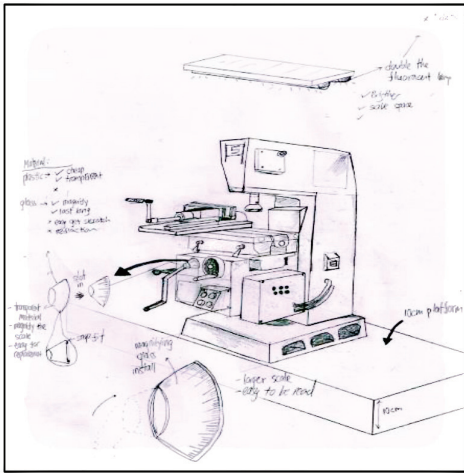


Figure 5: Conceptual design 1

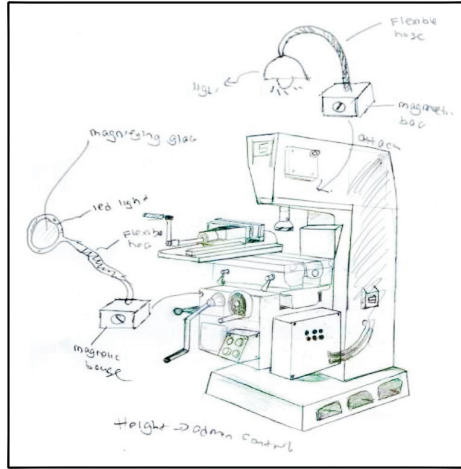


Figure 6: Conceptual design 2

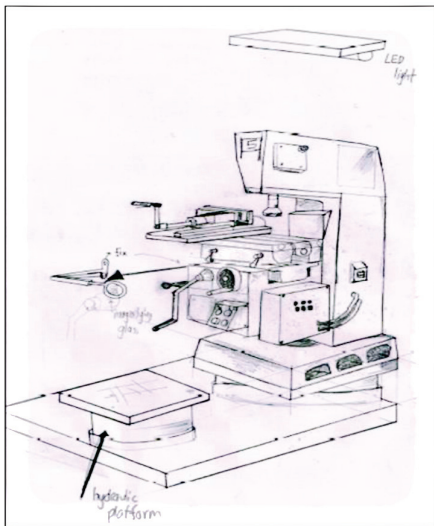


Figure 7: Conceptual design 3

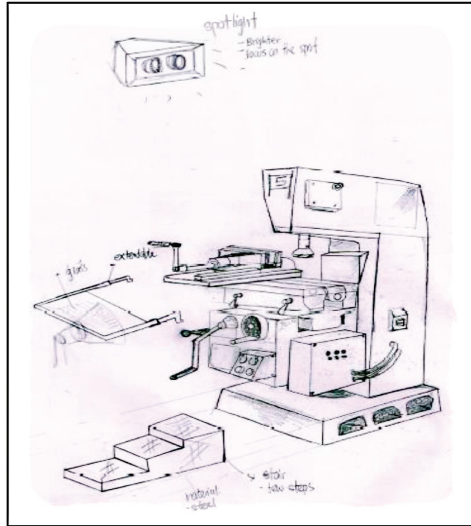


Figure 8: Conceptual design 4

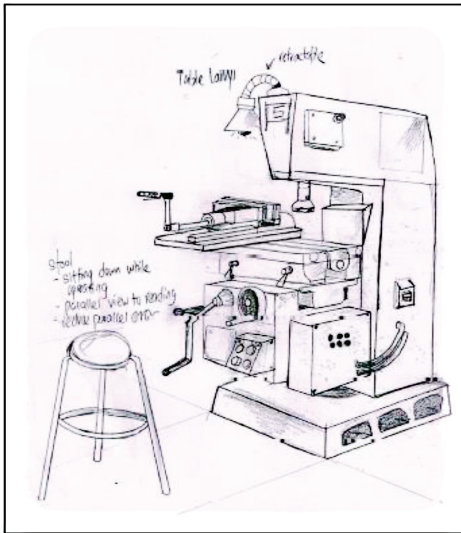


Figure 9: Conceptual design 5

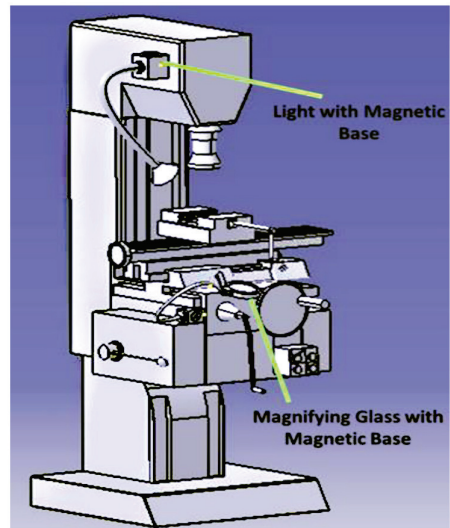


Figure 10: Concept 2 is designed in 3D CAD

3.3 Work Posture Assessment at Redesigned Workstation

Figure 11 and Figure 12 show the results of RULA analysis (through CATIA's human activity analysis module) of the selected workstation design concept. As tabulated in Table 2, the RULA scores have been reduced from 7 to 3 after the workstation had been redesigned conceptually. The reduction in the RULA score is due to the operators assuming a more neutral work posture.

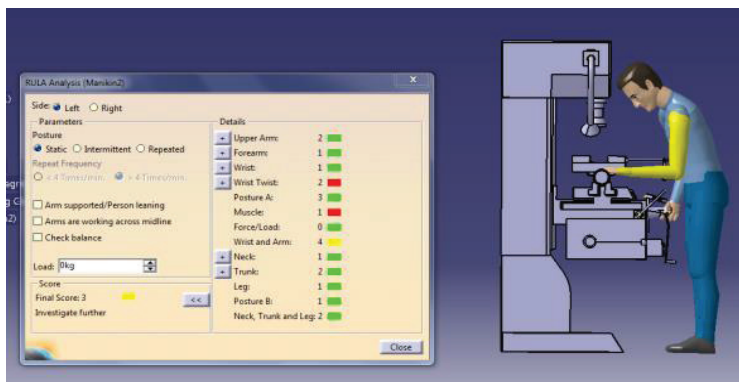


Figure 11: RULA score (left side) when working at the redesigned milling workstation

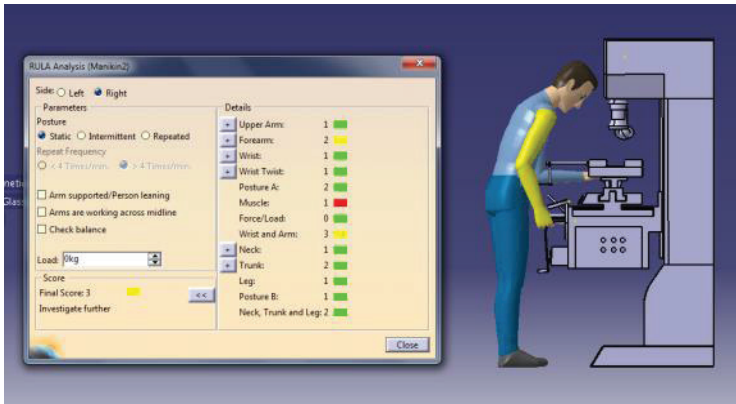


Figure 12: RULA score (right side) when working at the redesigned milling workstation

Table 2: RULA score for existing and redesigned milling workstations

Existing Workstation	Redesigned Workstation
7	3

3.4 Cost Impact

The total cost spent for improving the conventional milling workstation was RM 50.00 (magnifying glass: RM 30.00; LED lights: RM 20.00). This low cost concept can potentially improve work postures, and consequently reduce the risk of making errors, injuries, lost work time and compensation claims. Occupational injuries associated with ergonomics risk factors required significant amount of money for health medication, treatments and rehabilitation. The low cost concept generated in this specific case study may be a good investment to minimize the ergonomics risks due to existing workstation set up.

4.0 CONCLUSION

Based on the ergonomics assessment conducted in this case study of conventional milling operation, it can be concluded that inappropriate table height, insufficient lighting, and faded markings on gauge are the root causes to bending work posture. This condition leads to non-neutral work postures and potentially contributes to back pain and substandard machining quality.

This study has proposed low cost ergonomics solutions consist of a magnifying glass and LED lights. Both are attached to reused magnetic base to improve visibility and consequently promoting neutral working postures during machining operations. Results of work posture simulation in CATIA projected that the proposed concept may improve operators' work posture.

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