Design and Ergonomics Analysis of Cutter Machine Locking Device in Aerospace Industry

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Abstract: Ergonomics has been used since 1850s and the application is widely used in aerospace industry, health care institution, information technology company, product design, transportation agency, training institution, nuclear engineering, virtual environmental and many more. Ergonomics is a science of designing the job, equipment and workplace to fit the workers environmental for more comfortable during the working duration. Since it related to the industry, this study is focused more to the mechanical device that is used at heavy aerospace engineering industry which is locking device design. This device is important to this industry because it is more related to safety procedure for workers during operation of certain machines. This study is aimed to improve the design of locking device for aerospace industry in term of ergonomics evaluation. Six conceptual designs were proposed and evaluated using scoring matrix technique. All of these designs were developed using computer aided design software and the highest score from the scoring matrix was proposed to replace the current device. Ergonomics analysis which is rapid upper limb assessment (RULA) is performed to evaluate the ergonomics design. From the analysis, it shows that the result of proposed design is better than existing design with highest score of 8 were reduced to score of 1 and 2. This means that the design is acceptable due to body posture of human parts from ergonomics evaluation.

Key words: Locking device, aerospace industry, rapid upper limb assessment (RULA), finite element analysis (FEA).

1. Introduction

Mechanical is one of the important divisions over the past few centuries. Until today, many new technologies such as machine, mechanical devices and modern mechanical process exist around the world to generate and manufacture parts instantaneously and better than ever before. An existing of the mechanical devices is such as lock, clamp, jig, fixture and many more have changed the world scenario of safety and securing. Security systems require a locking mechanism which is to avoid sliding movement between two surfaces. Safety of locking device could not be doubted and there has several design of locking device not really giving well functioning whether it is for human or machine.

Locking device is generally defined as a mechanical fastening device which could be used on a door, vehicle, container, restricting access to area or enclosed property [1]. The locking device is consisting of a lock bolt and a lock catch which avoids the lock bolt from falling out after install at the chosen area. Consisting of lock bolt and lock catch is especially for the moving machine such as excavating machines, mechanical diggers, mechanical loader and dredger. The locking devices include a lock releasing handle slid able relative to the operating handle, wherein the locking pin is secured to the lock releasing handle [2]. These devices have a special contribution for stretcher that carries of wounded or sick person to the inside of an ambulance. According to L. Johansson, multipurpose locking device, designed to avoid thefts of trailers, heavy tows and

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called as dollies and for the example it is having coupling elements with a pull rod and a turn table, designed to haul a trailer by means of a truck and all of which are provided with coupling devices designed to effect a connection with traction vehicle [3].

A lock which secures a first member to a second member has been stated by R.G. Loren and it is described that locking device must have two parts which is male (first locking element) and female (second locking element) [4]. Moreover, the present invention relates generally to a lock, and more particularly, to a lock used to secure a pair of members together. The use of locking device at machine is important according to the situation and frequently it is involving many parts to become one. A locking device for a plane machine includes a handle, an actuating rod, two side bases, an urging block respectively provided at two sides of each side base [5]. Each item in the locking device has the own function concurrence to the needed of the locking device to the machine itself.

Most of machine in heavy industries used a locking device to make them easy to do their job and it also made more safety during the operation. Besides, the locking device is designed to avoid vandalism to the enclosure. More over when it involving hazardous machine such as cutter machine that need a precise and accurate cutting and this device can avoid this situation happen.

In industry, locking device is a mechanical device that used as a safety device to avoid any unwanted thing happened while worker done their job. These devices are provided with addition for lock, support and safety. The ideal locking device can be worked properly agreement to their circumstances without involving any danger to human or machine itself during operation. Locking device is one of the important parts to easy worker done their job without any injury and make the machine well functioning. In order to comply with the need of locking device of cutter machine at kitting workstation in aerospace industry, the device needs to be redesigned with safety and healthy consideration for worker to make the job properly without any difficulty. The function of this device at cutter machine is made to lock the movement between machine carrier and cutter bed so that the cutter machine could cut a material without slip from the rail.

In this study, it was carried out to make the improvement of locking device for kitting machine in aerospace industry. To do so, the designation of locking device must be accurately and precisely performed because it is involving machine. The existing of modern software such as Computer Aided Design (CAD) is a tool to assist this improvement which can be finished successful. By using this CAD, most of the part can be simulated and optimized to optimum performance and furthermore it can be operated more efficient.

2. Types of Locking Device

There are many types of locking devices which are generally defined as a mechanical device for using on a door, vehicle, container and many more. The simple meaning of locking device is some mechanical device which is used to prevent any unwanted obsession approaching in with no any permission. Locks could be entirely mechanical or electromechanical. They could be operated by turning or moving some form or removable key, by keying or dialing in a combination which directly or via electromechanical means operates the lock or by moving part on a safety lock intended to prevent accidental operation rather that to avert unauthorized admittance specially by involving machine in aerospace industries. The functional of locking device could be reduced the operation time for lock and unlock procedure, it is easy to use and install, and it is small and suitable to any location and safety for use. The types of locking device are shown in Table 1.

3. Ergonomics and Anthropometry

3.1 Introduction of Ergonomics

Ergonomics is concerned with the fit between people
Table 1  Types of locking device.

| No. | Types               | Figure | Description                                                                                                                                 |
|-----|---------------------|--------|---------------------------------------------------------------------------------------------------------------------------------------------|
| 1   | U-Lock or D-Locks   | ![U-Lock or D-Locks](image) | U-lock also known as a D-lock because the shape of the device. This type are more secure and safer than other types because it more resistance to cut by any cutter [6]. |
| 2   | Cam lock            | ![Cam lock](image) | This type is more like latch which it has a base and cam. The functional of base is to rotate the cam. Cams can be multi-motion where it can be rotate clockwise or vice versa [7]. |
| 3   | Combination lock    | ![Combination lock](image) | The functional of this type is using a sequence combination numbers to lock and unlock operation. This sequence number can be generating by rotating the number in clockwise or counterclockwise direction [8]. |
| 4   | Cylinder lock       | ![Cylinder lock](image) | It functions based on constructing with several of cylinder and it may contains a variety of locking mechanisms, including the pin tumbler lock, the wafer tumbler and the disc tuber lock [9]. |
| 5   | Deadbolt            | ![Deadbolt](image) | This type usually use for door house and the functional are by rotating the lock cylinder at the key position. It known as a deadlock because it mechanism is separate from spring-bolt and it could not be opened except rotate the lock cylinder [10]. |
| 6   | Padlock             | ![Padlock](image) | It is familiar and portable lock that used for protects against theft, vandalism, sabotage, unauthorized use and harm [11]. |
| 7   | Pin tumbler lock    | ![Pin tumbler lock](image) | It is uses long pins to avoid the lock from opening without the correct key used. It is simple type of locking device and it most commonly employed in cylinder lock [12]. |
| 8   | Disc tumbler lock   | ![Disc tumbler lock](image) | It is also called as an Abloy Disclock. The main mechanism of this type is lock composed of slotted that rotating the detainer disc. Then, it also known as a Solex locking mechanism and it require a special cut key that rotates the disc like tumblers of a safe to align with the slot [13]. |

and their work station. It will take account of the worker capabilities and limitations in seeing to ensure the work tasks, equipment, information and environment suit for each worker. This ergonomics commonly is the effect of the body or muscle to human when they are making a job. Job or work is related musculoskeletal disorder constitute a major problem in many industrialized countries [14]. In industry area, the ergonomics is always being a key problem because it is consisted a hard work prepared by the workers.

Worker posture at work is important because erroneous postures can give muscle pain. The general concept of human posture refers to the carriage of the body as a whole, the attitude of the body or the position of the limbs. An awkward posture happened when used repetitively of for prolonged periods result in increased risk of fatigue, pain or injury. The repeating job finished has a potential to make the muscle pain. When
work is non-cyclical or the work cycles are long and irregular, the work needs to be observed over an extended period time in order to accurately qualify the proportion of time a worker could be exposed to a specified risk factor [15].

If the worker posture is in a proper way, the muscle will not feel any pain. The ergonomics interventions for improved mechanical exposure are based on ergonomics guidelines, describing proper exposure variables to achieve good musculoskeletal health [16]. If one of mechanical device needs to be designed, the ergonomic guideline could be applied so the users can use it without any problem to the muscle. The ergonomics guideline could be offered the recommendations regarding the several aspects which are dimensions, location and visibility for push button in an instrument panel [17]. The implementation of ergonomic in the working field is important because it could avoid any injury and muscle pain to workers.

3.2 Introduction of Anthropometry

Anthropometry plays an important role in industrial design, clothing design, ergonomics and architecture where statistical data concerning the distribution of body dimensions in the population are used to optimize products. Changes in life styles, nutrition and ethnic composition of populations lead to changes in the distribution of the body dimensions and require regular updating of anthropometric data collections. Anthropometry is one of the measurements on human physical shape and size [18]. E. Nowak has mentioned that anthropometry as a set of research method used in anthropology such as the science about man (anthropos-the man, logos-science) in a Greek language [19]. Anthropometries are one of the ergonomic method to measure body dimensions. According to S. Brown, this anthropometry is a branch of ergonomics concerned specially with the physical characteristics of people like size, shape and strength [20].

An anthropometric data can be used to design a machine or device effectively by referring to human body dimension. Mebarki et al. have stated that anthropometric data are one of essential factors in designing machines and devices [21]. The research in this area is important to determine the size and shape of human in designing machine because it can eliminate all the unwanted performance and accident while using the machine. The lack of properly machines and equipment may lead to power work performance and higher incidence of work-related injuries [22]. According to Feathers et al., anthropometric measurement is simply a construction of an observation or recording of an attributes, which can be effected by measure characteristics, where it is a method used in measurement and the environment [23]. This method is not only by using for measurement tools but also can be gained by observation or record the movement and reaction.

Mismatches between human anthropometric dimensions and equipment dimensions are known to be a contributing factor in decreased productivity, discomfort, accidents, biomechanical stress, fatigue, injuries and cumulative traumas [24]. In designing machines and devices, the accuracy of the information and data influence the result of design that made. Accuracy in anthropometric data is required in some man-machine system.

4. Research Methodology

4.1 Generating Idea

Working with moving machine generated more dangerous situation which is operation of the machine can give a problem to the workers itself. The existing of mechanical device performs give better results to the operation and handling work in workstation. In Kitting workstation at aerospace industry in Malaysia, there has one cutter machine and two beds where the raw material will be cut on the beds. The machine basically needs to be transferred from bed 1 to bed 2 because it is only one cutter machine at that workstation.

The transfer process required worker to use a carrier and locking device to perform the operation. Workers
need to lock and unlock the locking device manually before the machine transferred to its location. The location and design of locking devices make the worker feel uncomfortable. The existing locking device generates problem to worker when handling the machine. The current locking device needs worker to get inside the danger area to lock and vice versa it.

Workers need to go at different location to perform operation because there has two locking devices that hold the machine. Although there has no accident and back pain happened at the Kitting workstation while handling the locking device, it has a possibility to happen when workers are not carefully perform their job.

Based on the observation at the Kitting workstation, the problem requires a new design of locking device at cutter machine. The design procedure will be explained in the flow chart shown in Fig. 1.

4.2 Study on the Existing Design

According to the existing locking device currently used at cutter machine, the study can be performed to gather any information and data needed to do ergonomics analysis. The data needed is the shape, geometry and design criteria of the locking device which is detail dimension and characterization of it. The data of the worker also need to be taken to perform ergonomic analysis which is to obtain how they feel when handling the locking device. The data are needed from worker such as waist breadth, axilla height, acromion-radiale length, bilalleolar breadthcroft height standing, waist height omphalion and chest height standing.

4.3 Design of Current Locking Device

Figs. 2 and 3 have showed the actual current locking device and current locking device drawing, respectively. The existing locking device is drawn from the actual locking device at Kitting workstation where all dimensions are taken by using measurement tools. The dimension is implemented in the CAD software so that it can be drawn in detail where it is in same scale with the actual dimension.

5. Result and Analysis

5.1 Existing Design

The analysis that is used to measure workers posture is RULA. RULA stands for Rapid Upper Limb Assessment analysis. The RULA analysis is used to investigate the exposure of workers to the risk of upper limb disorders. RULA provides a record of each workers general posture with particularly references to the trunk, neck and upper limbs. RULA examines several risk factors associated with the body posture, loads, muscle use and compiles these factors into a posture score. This analysis is also a screening tool that assesses biomechanical and postural loading on the whole body with particular attention to the neck, trunk and upper limb.
These neck, trunk and upper limb is the part where the force always exert because workers usually do their job by using hand and if the work done is heavy, it will affect worker body especially at that body part. The grand score that provided by RULA is proportional to the risk involved in performing the task, so that the highest scores indicate a greater risk of muscular-skeletal injuries. The method divides the grand scores into action levels which guide the decisions that the observer has to make after the assessment. The small score is better rather than higher score. The scale of the score is as follows:

Level 1: Score of 1 or 2 – acceptable posture if not maintained or repeated for long periods.
Level 2: Score of 3 or 4 – Further investigation needed, may require changes.
Level 3: Score of 5 or 6 – Investigation, changes required soon.
Level 4: Score of 7 or above – investigation, changes required immediately.

In this analysis, the medium to analyze the RULA is by using numerical software. With this software, it will tell whether the posture is good or not by refer to the color of the result. The posture is considered good if the color turns to green and has a problem if the color turns to red. Fig. 4 shows the analysis by RULA on an existing device and Table 2 shows the result using the RULA analysis.

According to the analysis for the existing design, it shows that, when workers handle the first locking devices like posture shown, the worker is in danger. The posture is danger because it will cause back pain and muscle pain to worker. The load that produces by that locking device is very heavy where the load is approximate to 8 kg to unlock it. Based to this statement, the worker needs to use energy that equally or more to operate the locking device. It will cause injury to worker especially to their back muscle.

| Human part            | Score | Color |
|-----------------------|-------|-------|
| Upper arm             | 5     | Red   |
| Forearm               | 3     | Red   |
| Wrist                 | 3     | Brown |
| Wrist twist           | 1     | Green |
| Posture A             | 7     | Red   |
| Muscle                | 0     | Green |
| Force/load            | 1     | Yellow|
| Wrist and arm         | 8     | Red   |
| Neck                  | 5     | Red   |
| Trunk                 | 4     | Yellow|
| Leg                   | 1     | Green |
| Posture B             | 5     | Yellow|
| Neck, trunk and leg   | 6     | Brown |
or spine. Although, worker operates the locking device with intermittent, it still brings danger to worker.

The result in Table 2 shows that the human part that turn to red color has five which is upper arm, forearm, posture A, wrist and arm, and neck. The red color shows that the workers have a serious problem with their posture and it is needed to be changed immediately. Furthermore, the workers need to operate the locking device several times in one day and this will cause back pain and injury to their muscle.

From the results, posture A shows the critical part where it has score of 7. The detail of posture A is divided into several human body parts which is the highest score is wrist and arm with score of 8. Wrist and arm get the highest score because the locking device is operated by using hand. The worker needs to bend their body to reach to the desire location to operate the locking device. The location of locking device has a problem especially with height where it is not suitable to operate by worker. Fig. 5 shows the clear posture, locking device and the way for operating it by workers.

5.2 Proposed Design

One of the parts of proposes locking device is torsion spring. Torsion spring usually close-wound, as is a helical coil extension spring, but with negligible initial tension. The torsion spring that used is similar with other basic torsion spring where it works by torsion or twisting: a flexible elastic object that stores mechanical energy when it is twisted. Torsion spring are familiar used in clothespins, windows shades and animal traps where they may be seen around the house and out of sight in counterbalance mechanisms, ratchets and a variety of other machine components.

Torsion spring is very suitable to implement at cutter machine because it is used to push the propose locking device to the unlocking position. The torsion spring that used has a bending induced in the coils when the brake lever is pulled by workers. Choose the suitable torsion spring is important to determine the force or load that produce by the torsion spring and make workers comfortable while operate it. The force or load can be determined from the bending stress the produce by torsion spring.

In Table 3, it has shown the material choose and the detail description for each criteria of the material for the proposed design.

For music wire, the ultimate tensile strength can be calculated by using Eq. (1).

\[
S_u = \frac{A}{d^2} \times \frac{2211}{145} = 1999.58 \text{MPa}
\]  

By using equation of yield strength, the below data was identified.

\[
s_y = 0.78 S_u = \text{Static strength for music wire (2)}
\]

\[
s_y = 0.78 \times (1999.58) = 1559.67 \text{MPa}
\]

The coil helix diameter is \( D = 14 \text{ mm} - 2 \text{ mm} = 12 \text{ mm} \). The spring index \( C = D/d = 14 \text{ mm} / 2 \text{ mm} = 7 \text{ mm} \). The stress bending stress correction factor \( K_i \):

\[
K_i = \frac{4C^2 - C - 1}{4(C - 1)}
\]

\[
K_i = \frac{4 \times (7)^2 - 7 - 1}{4 \times (7 - 1)} = \frac{188}{168} = 1.119
\]

The maximum torque can be defined by using formula in Eq. (4).

\[
(Fr)_{max} = \frac{\pi/2 S_u}{32K_i}
\]

\[
(Fr)_{max} = \frac{\pi (2)^3 \times (1559.67)}{32 \times (1.119)} = 1094.7 \text{Nmm}
\]
Table 3  Material description for proposed design.

| No. | Description | Criteria |
|-----|-------------|----------|
| 1   | Material    | Music wire |
| 2   | Behavior    | Music wire is the best, toughest and most widely used of all spring materials for small springs. It has the highest tensile strength and can withstand higher stresses under repeated loading that any other spring material. |
| 3   | ASTM No.    | A228     |
| 4   | Exponent, m | 0.145    |
| 5   | Diameter    | 2 mm     |
| 6   | Constant A  | 2211 MPa |

From the maximum torque, the force exert by torsion spring can be defined by using formula in Eq. (5).

\[
T = Fr
\]

\[
F = \frac{1094.7 \text{ N/mm}}{50 \text{mm}} = 21.89 \text{ N}
\]  

(5)

The load that produces by torsion spring can be defined by using formula in Eq. (6).

\[
m = \frac{F}{a} = \frac{21.89 \text{ N}}{9.81 \text{ m/s}^2} = 2.23 \text{ kg}
\]  

(6)

From the calculation that has been done, the load that produces by torsion spring is 2.23 kg where it can be applied at RULA analysis. When workers pull the brake lever by using 2.23 kg load, there has no problem regarding to the muscle and their human parts. The torsion spring that has been selected according to its material and dimension is suitable to install at propose locking device because it produced less force compared to current design of locking device.

The type of spring that choose is music wire because it has the best in term of toughest and the spring material are the most widely used in term of small spring. Music wire has high tensile strength and can withstand higher stresses under repeated loading compared to others spring material. Material of music wire are available in diameter of 0.12 to 3 mm which is suitable with the design of torsion spring for proposed design because the torsion spring has a diameter of 2 mm. Fig. 6 and Table 4 show the analysis on proposed locking device using RULA analysis and the result of proposed device, respectively.

According to the results that analysis by RULA, it can be assumed that propose locking device is successful to eliminate all the danger that faced by worker. But, this result is success in term of the posture only. Based on the result in Table 4, it has shown that no human part turn into red color. The color just only green and yellow, respectively, which shows that worker does not feel any back pain and muscle stretch. The highest score is only 4 where only at the wrist and arm. It gets score of 4 because propose locking device is operated
by pulling the brake lever at the handle of machine carrier. The score does not give any problem to the worker because it is at the safe range. The workers do not need to use so much energy to pull the brake lever because it just needs 2.23 kg to pull it. The load is produced by the torsion spring at the locking device where it is only use small amount of load. A worker also does not need to go to different place to operate the locking device. It is just pulled the brake lever and the locking device will unlock by itself. According to the results, the proposed locking device is produced so much better result compared to the current locking device.

The location of the locking device does not change and it stays at the current location because workers do not need to go to the location anymore because it can be operated at the handle of machine carrier. This will reduce the percentage of injury caused by the cutter machine. Fig. 7 has shown the clear posture, locking device and the way to operate it by worker.

6. Comparison between Existing Design and Proposed Design

This section will explain the differences between existing and proposed design of locking device in aerospace industry and focused on the Kitting workstation. This analysis is done using RULA analysis from numerical software. The comparison is based on the results of scoring that produce by both existing and proposed design. The comparison is based on the results about posture of how the workers operate the locking device. The comparison done by refers to the score and color that produce from the results. If the score is small and the color is green, the posture does not have any problem. Otherwise, if the score is high and the color is red, the posture has a problem and need to investigate and change immediately. Hence the best score will be assumed at the best design. According to the posture of existing design, the worker needs to bend their body to reach the desire location to operate the locking device. Meanwhile, the posture from proposed design, the worker just forms a normal posture and does not need to bend their body to operate the locking device. There will be differences between existing and proposed design in term of workers’ posture.

7. Conclusions

Based on the research that had been done, it can be concluded that the posture of workers at work place is important to avoid any injury and danger situation. Human cannot stay at one posture for a long period because this might present some risk of injury from their work posture. The ergonomics analysis is the
analyses that use to evaluate whether the posture applied is good or worst. Specifically, the analysis is done by using RULA analysis. RULA analysis is designed to assess workers who may be exposed to the muscle problem which is known to contribute to upper limb disorder. RULA analysis is done to get the results of ergonomics posture from the worker posture while operate the existing and proposed locking device.

By using RULA analysis, the results from the analysis can notify whether the existing locking device can be replaced with proposed locking device or not. The results of proposed locking device show that, it is better that result from existing locking device after RULA analysis is applied. From the analysis that have been done for existing locking device, the results show that the posture has a problem and might bring injury to the workers who operate it. It is because the posture provides negative results which are the high score and red color displays when the RULA analysis is running. When the implementation of propose locking design, it shows the positive results where the score reduces from 7 to 3 while the color turns from red to yellow. From the results that get, the objective of this report is achieved where the improved design show that the workers did not have any posture problem while handling and operating the locking device. Hence, existing locking device can be replaced with proposed locking device because it can make workers feel comfortable when operating the locking device.

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