Factors to be considered when designing man machine interface element of machinery

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1 Introduction

1.1 Background of Ergonomic Design Criteria

The science of ergonomics, also known as human factors is one of the major aspects in modern engineering design methodology. Neglecting the effect of ergonomics and proceeding with the design while violating the rules of human factors could result in definite incompetence of the final outcome of a design. With the continuous and progressive development of engineering science and technologies, aiding user comfort from any design is now a major factor of systematic design approach. With that being said, the three main characteristics of ergonomics can be described as follows (Dul, et al., 2012).

- Ergonomic principles are utilized frequently in modern systematic design methodology
- Ergonomic is a design driven method, as it is mainly used as a design tool
- There are two correlated focuses of the ergonomics - Performance and well-being of the user. Any designer should take efforts on developing a design with high performance characteristics while assuring the compatibility of the design with ergonomic principles

1.2 Scope of the Report

This particular report is intended to describe the man machine interface of a radial drilling machine and analyze the ergonomic criteria of the traditional interfaces. After the ergonomic analysis, suggestions to improve the radial drill in terms of ergonomics will be provided.

2 Study on Radial Drills

2.1 General Radial Drilling Machine

A radial drill is a stationary machine which is used in heavy drilling tasks. The drill is consisted of a rotatable arm attached to a large column, which inherits radial coordination system.

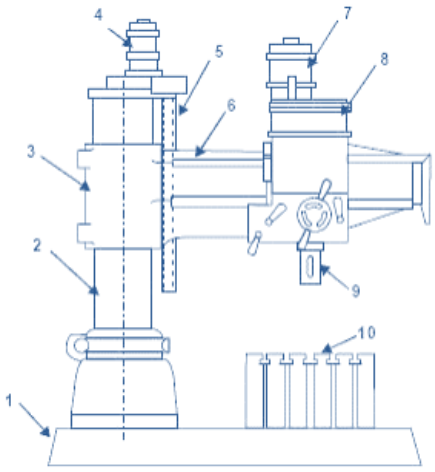


Figure 1. Nomenclature of a general radial drilling machine (Yuseman, 2011)

1. **Base** – Provides support for all the components
2. **Column** – Facilitate the rotational movement of arm while bearing arm and tool stock weight
3. **Radial arm** – Holds the radially moving tool stock. The arm can rotate with respect to the column. It's also able to move up and down along the column
4. **Motor of elevating arm** – Provide the lifting and declining motion for the arm to move up and down
5. **Elevating screw** – This is the lead screw which attaches to the arm, rotated by the motor of elevating arm
6. **Guide ways** – Provide guiding to the radial motion of the tool stock along the arm
7. **Spindle motor** – Powers the drill spindle
8. **Tool stock** – Mounted with all the handling wheels, buttons and drill spindle at the bottom
9. **Drill spindle** – Drill bit is fixed into the spindle
10. **Table** – The workpiece can be rigidly mounted on the table

2.2 Man-Machine Interface of a Radial Drill

There are many points of a radial drill which will be subjected to direct interaction with operators. In general, operator interactions with the machine can be categorized into (Patel, et al., 2015),

- Interactions with control devices such as levers, buttons, safety switches
- Interactions with drilling table when clamping the workpiece onto it
- Interactions with the tool stock when changing drill bits
- Interactions with tools stock and arm when positioning the tool at desired point
- Interactions with visual indicators such as colored lines, speed indicators, scales

In addition to the listed interactions, operators will experience vibrations and noises while operating the machine. Also, operator body size with controller positioning should also be considered. Proper ergonomic principles and standards should be effectively utilized when designing and manufacturing a machinery. In the general engineering design criterion, anthropometric dimensions are considered as key elements that aid in finalizing ergonomic dimensions, thus it can be assumed that once the machine has been manufactured in standard anthropometric measurements, most kinds of operators will be able to use it without any inconveniences (Karwowski, 2007).

3 Discussion

3.1 Anthropometry and Overall Dimensions

When it comes to the operator anthropometry and drilling machine dimensions, main point of concern lies on the handling wheel that controls the radial movement of tool stock and the vertical movement of the spindle (see Figure 2).

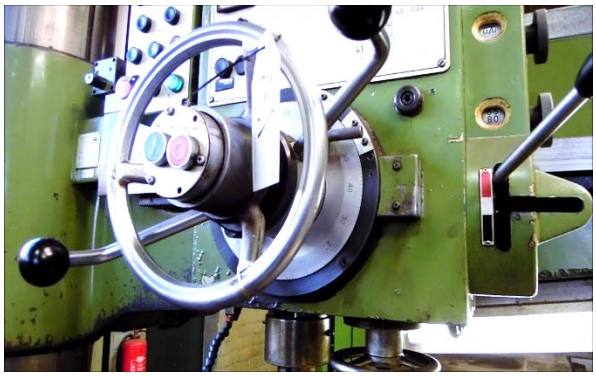


Figure 2. Main handling wheel of a radial drill

The wheel is directly connected to the tool stock itself, thus the operator has to move along with the tool stock in order to rotate it. Since the radial movement of the tool stock and the vertical movement of the spindle can be achieved from the same wheel, partially ergonomic design already can be seen in conventional handling wheels, but when it comes to the anthropometric measurements, the design is highly unfavorable (see Figure 3).

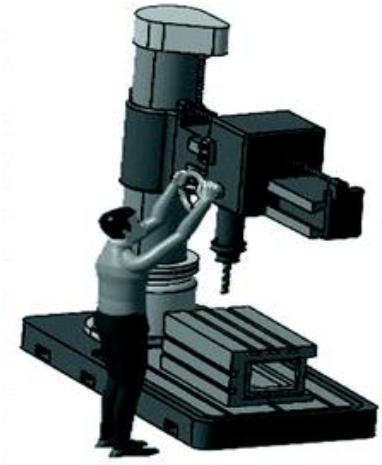
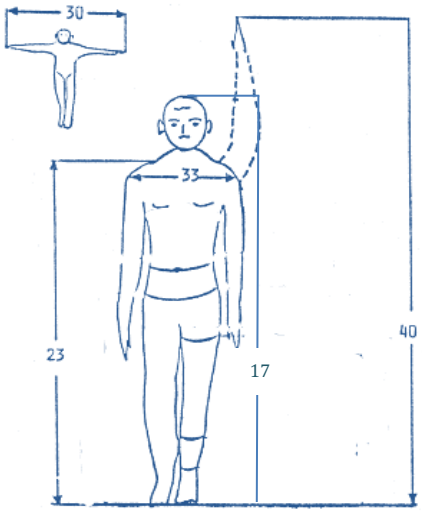


Figure 3. When the machining job is tall, excessive reaching to the handling wheel should be done

It is better to reevaluate the handling wheel position according to general anthropometric dimensions, in order to increase the ergonomic optimization of the design. When an operator is excessively reaching for the handling wheel, sternocleidomastoid (neck muscle), deltoid

(shoulder muscle), thoracolumbar (lower back muscle), and flexor carpi-radialis (forearm muscles) are simultaneously put under heavy strains and when the task is repetitive, this situation worsens. Sometimes, heavy strains of those muscles could lead to work related musculoskeletal disorders (Ashok, et al., 2018). As far as the handling wheel operation is concerned, standing anthropometric dimensions are taken into account (see Figure 4).



No	Measurement	5th Percentile	95th Percentile
17	Stature	60.6	66.1
23	Shoulder height	50	54.7
40	Upward reach	70.5	79.5
30	Span	58.7	66.5
33	Biacrominal breadth	13	16

Figure 4. Tabulations of most essential anthropometric data for Singaporeans (dimensions given in inches) (Huan et al, 2010)

Final drilling machine dimensions will be concluded after taken into consideration, the relevant anthropometric dimensions for certain kinds of body postures and evaluating the intended measuring platform dimensions just by critical analysis. There will be no mathematical means to calculate the dimensions, they will be solely concluded by eliminating nonsensical dimensional ranges. When evaluating the ergonomic dimensions, it is not practical to consider extreme populations with very short or very tall body dimensions. Generally, it is the standard method to design some system to fit 90% of the population, omitting both ends of extreme 5%s (Abeysekara, 1985), (Occupational Safety and Health Administration, 2000). It is more standardized if the handling wheel positions would not go beyond the shoulder height, if the radial drill is only intended for the local market. If the international market is targeted too, overall anthropometric dimensions of all the targeted nationalities should be taken into the consideration. Two main options are suggested when optimizing the handling wheel design.

1. Provide a height adjustable platform at the machine base for the operator to stand on
2. Arrange the hand wheel at the end of an extendable rod

3. Motorize the vertical movement of spindle and radial movement of the tool stock and replacing the hand wheel by a remote controller.

3.2 Body Movements and Muscle Loading

Working with any kind of machine involves with frequent movements of operators' body, unless the particular machine is highly automated. Automating a metal cutting machine would not be feasible in terms of cost since they are involved with heavy moving parts. Thus, it is vital to ergonomically optimize operator movements through the machine itself.

3.2.1 Muscle and Joint Dynamics

Muscle and joint dynamics are considered as the total movement and effort of all the muscles and joints in the body. This criterion comes as important because movement of a single muscle could affect other muscles adjacent to it, making operator body an object with series of biomechanical linkages. Ergonomic considerations of traditional radial drilling machines when it comes to muscle and joint dynamics and possible improvements are given below.

- There are many controls means provided for each and every movement of the radial drilling machine components, excepts for the rotational movement of the arm. The operator has to push or pull the heavy arm with an effort, in order to rotate it. Even when the pushing or pulling forces are released, high inertia of the rotating arm prevents it from coming to a quick stoppage. Hence, the operator has to exert extra resisting forces to stop the rotating arm. Carrying out the tasks repeatedly could exhaust the operator quickly. It is suggested for the new rill design to be mounted with moment stopping breaks on the rotating arm.
- Mounting drill bits to the spindle is done by tapered drill shanks. There are many advantages of tapered shanks such as self-centering and quick fitting abilities. The tapered shank feature can be considered as an already optimized ergonomic feature in radial drilling machines.

3.2.2 Body Segments and Effects of Trauma

When an operator of a radial drilling machine is concerned, his/ her body can be modelled into several segmentations. Head and neck, arms and hands and legs and foots are the major segments that can be identified in a radial drilling operation (National Research Council, 1988). Each and every segment is exposed to many safety hazards and each and every safety hazard should be countered through the drilling machine design itself.

- **Head and neck** – The rotating arm could come and hit the operators head if not stopped. Traditional drilling machines are not accompanied with any means to limit the movement of the rotational arm.
- **Arms and hands** – When the drilling action is completed through the whole workpiece, due to the fact that drill bit is acting as a screw, workpiece could go up along the drill bit if not properly clamped. Figure if the workpiece is a metal plate. The sudden rotational and vertically upward motion could heavily injure the operator. Thus, it is necessary to provide more effective clamping devices along with the drilling machine, which never are provided with traditional assemblies.

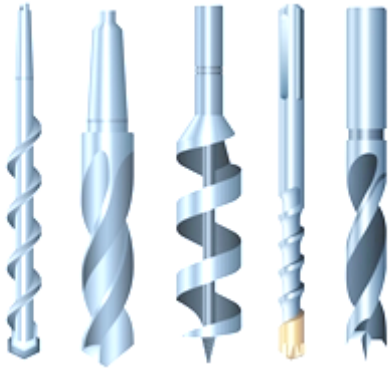


Figure 5. improperly clamped workpieces could travel upward along screw shapes of drill bits (Source - http://www.carbideprocessors.com/pages/technical-info/types-of-drill-bits.html)

- **Legs and foots** – In traditional radial drill assemblies, all the work is done by hand. There are no control means dedicated to legs and foots. If some control means were dedicated to the legs also; using step on buttons, leg operated pedals, over exhaustion of the hands will be reduced too, while increasing the controllability of the machine.

3.2.3 Bone and Link Dynamics

The bone structure of human body act as a series of mechanical linkages. Thus, ensuring the optimum operation of bones and relevant links depends on several; factors, such as extension length, folding angle and etc. When operations are provided such a way that, lowest of interferences of bones occur, operator would experience lesser discomforts.

- In traditional drilling machines, emergency stopping switch is located in the tool stock. If the drilling workpiece if tall, the tools stock would be at a higher position, making it harder for the operator to reach for the emergency switch. Hence, the emergency buttons of new drilling machine are recommended to move to a position where bone structure of the hand is

optimally aligned. It is recommended to mount the emergency switch on a fixed position, within the hand reach, at the stature anthropometric height.

3.3 Components and Subsystems

3.3.1 Spindle and Tool Stock

Most of the times, tools stock with the spindle will be placed at a more radially outward position, that is right hand side of the operator. Since all the controlling buttons and wheels are located on the tool stock itself, this situation is ergonomically favorable for the operator.

- But, as seen on below Figure 6, 2 handles on the guide wheel could interfere with other buttons at some positions. Shortening those 2 handles would also be not possible because the operator would lose the ability to quickly grasp onto them. It is better to carry out the design with handles replace by two buttons integrated into the handling wheel outer ring. Or, the whole handling wheel could be moved away from the tool stock, as suggested on chapter 3.1.

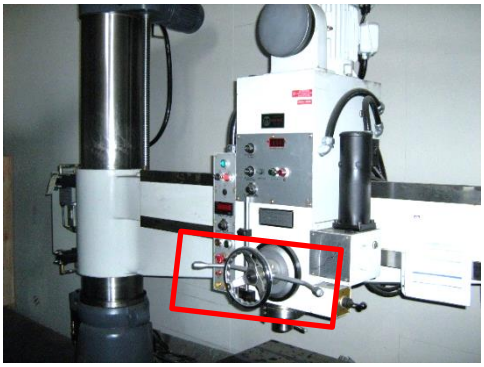


Figure 6. 2 handles situated on the guide wheel could interfere with other buttons

- Overall aesthetic appearance of the control panel is acceptable, but it should be further improved by adding LED indicators to essential buttons as most of the traditional machines comes with not LED indicators to convey the idea to the operator quickly.
- As for the spindle, there is an ergonomic flow when it come to the situation of tool mounting. Tapered shank drill bits do not need complex, increased effort mounting means. Just pushing the drill bit up the spindle would mount it tightly. But, pushing the naked drill bit up the spindle is a difficult task since sharp edges could injure the hand of the operator. Integrated clamping mechanism for the spindle is suggested.

Table 1. Evaluation of improvement suggested up to the point

Property	Weight	Score		
		Traditional Design	**Modified design 01** (Handling wheel levers replaced by buttons + LED indicators for most of the buttons + Integrated clamping mechanism for spindle)	**Modified design 02** (Handling wheel moved away from the tool stock + LED indicators for most of the buttons + Integrated clamping mechanism for spindle + Height adjustable platform provided for the operator)
Anthropometric compatibility	35%	0	1	2
Ergonomic shapes	10%	0	1	1
Safety	30%	0	1	1
Visual ergonomics	10%	0	1	1
Controllability	15%	0	1	2
Total Score		**0**	**1**	**1.3**

* Scores have been given within 0, 1, 2 range

Based on the total scores, it is obvious that level of ergonomic optimizations would progressively increase the quality of the product along with it.

4 Conclusion

The science of ergonomics, also known as human factors is one of the major aspects in modern engineering design methodology. Utilizing properly optimized ergonomic factors into a product could enhance its market value undeniably. Thus, machine manufacturing companies should pay their undivided attention to the task of ergonomically optimizing their end products. This particular report was intended to address ergonomic analysis of traditional radial drilling machines and suggest possible optimizations for the ergonomic factors for new designs. From the analysis, it was found out that there are many ergonomic related flaws in the traditional radial drill man-machine interfaces. Several such points were addressed within the report scope and possible optimizations were synthesized accordingly. After a weighted score evaluation, it was found out that increasing of ergonomic optimizations could increase the final value of machines progressively.

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