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Design Improvement of a Polishing Machine Work Station in Industrial Environment to Minimize Health Risk

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Abstract

The application of ergonomics in the industry has become significantly important nowadays, especially for designing a workstation. The purpose of ergonomics application in industry is to make the workplace best fit for the workers to ensure their comfort and safety. It impacts the workers' satisfaction, reduces the number of injuries and production rate. To maximize the safety and productivity of a working environment, an ergonomic approach must evaluate every aspect of the workplace and appropriately implement rules, guidelines, and plans. This paper addressed an injury risk in the manufacturing industry and proposed multiple solutions to resolve injury and musculoskeletal disorder (MSD) risk. The injury risks include bare skin exposure to sparks while grinding, poor back posture, and hand injury while performing the operation. Keeping the worker in mind and the need for precision and specific tolerances, the difficulties are significant. The proposed design modification of the polishing/grinding machine was challenging because of the type of job performed here and the space limitations. The improvement of the workstation was made by incorporating an economic and ergonomic design approach. The result was verified by the ergonomic risk factor assessment tool Rapid Upper Limp Assessment (RULA) before and after the design modification.

1. Introduction

Work related musculoskeletal disorders (MSD) is a considerable concern in the manufacturing industry. According to the U.S. Bureau of Labor Statistics (BLS), the incidence rate of MSD cases reported in 2011 was 35.4 per 10,000 full-time workers and 27.2 in 2018 [1]. MSD injury includes the muscles, joints, tendons, cartilage, and spinal discs [2]. This disorder affects the employer with less production rate, product quality, absenteeism, administrative cost, high medical cost, and worker compensation. Among all the reported cases of MSD injury, service in the manufacturing industry is accounted for half of all cases [3][4]. Recently, the manufacturing industry has raised awareness of MSD injury as the workers in this environment are prone to injury. To fit in with the competitive world market, companies are going through organizational transformations. Many of the companies, big or small, take initiatives to downplay the MSD risk. However, ergonomic solutions' implementation and adaption process is a slow process and encounters huge barriers [5].

Ergonomics is a scientific discipline concerned with human factors and steadily works to optimize the systems' function. In particular, it is a systems-oriented discipline, which practices continuous improvement processes between the workers and the work environment [6]. Aftereffect of the adaption in this systematic principle reduces the risk of MSD in the workplace. In this context, the current study reported a design modification of an existing polishing machine to address MSD injury risk in the manufacturing industry. The primary rationale of this work includes the need for industrial reliability and taking care of MSD related complaints reported by the workers where they were exposed to awkward postures.

It's been rigorously established that the students learning with hands-on projects escalate their interest and motivation to lead a successful career in the industry upon graduation. Students' learning performance curve alleviates while using the project-based learning (PBL) technique, as they experience the process in real-time [7], [8]. They apply their theoretical knowledge acquired in class within the defined context. An engineering technology level-4 course named "Ergonomics and Process Optimization" had been instructed following the PBL technique in Fall 2019. A total of 18 students were divided into nine groups assigned a real industrial problem and asked to find out prospective solutions to the problem. Students were encouraged to administer their theoretical knowledge in the class and look for the appropriate solutions to address the concern. By the end of the semester, most groups had successfully developed multiple excellent strategies to fulfill the assignment. Their proposed design was validated by recalculating the risk assessment using ergonomics risk assessment tools.

2. Industry Sponsored Project

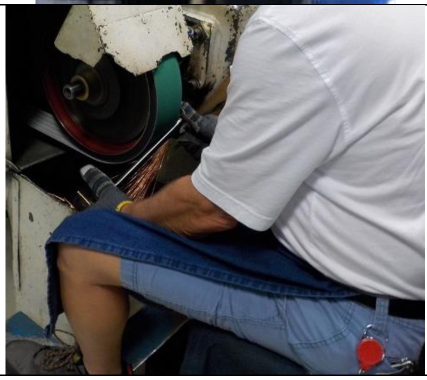
A multinational manufacturing industry approached the East Tennessee State University Technology department with a severe safety issue they were experiencing in their hand-wrench polishing process facility. This company is one of the pioneer manufacturers that produces high-end tools and equipment for professional and home use. They are well known for their quality and consistency. They used a belt polisher to polish various sized wrench surfaces. The safety issue came from the fact that the machine had very little guarded, and workers needed to hold their hands close to the abrasive belt while the belts spin at high rpm [Figure 1]. Another concern was a large portion of the belt was exposed to the workers; the sparks from the polishing face landed on their skin and burned the surface area at the micro-level. Nine employees were injured while operating the polishing machine by accidental contact with the grinding belt. They wanted their workers' safety to be the top priority, but they also couldn't risk the precision that the company currently has in achieving this safety.

The long-term solution would be more automated, possibly robotic. However, the company did mention that their attempts to use robots for this process have been challenging to be done effectively due to the complex shapes and lack of ability for the robots to tell how effectively a grind has been applied. It appears to be working well for a few of their larger wrenches but not the small ones. Therefore, they are seeking a solution with the existing manual polishing machine with a tool attachment that could downsize the risk factor, hence assure the workers' safety.

Figure 1: Exposed belt to the operators while in operation

A postural analysis has been done to identify the risk factor by number. The ergonomic assessment tool Rapid Upper Limb Assessment (RULA) was used to calculate the MSD risk on operators while in operation. Table I describes the postural analysis of wrist, trunk, and total RULA score. Pictures in table-I also showed the at-risk body part to machine injury.

Table I: Worker identified injury risk tasks and postural assessment score:

Injury risk area	Existing design	Ergonomic risk assessment score
Hand close to high rpm abrasive belt are at risk of machine injury		Rapid Upper Limb Assessment (RULA) score: 7
Awkward wrist posture prone to MSD risk		Wrist score: 4
Fire sparks from grinding surface landed on workers' exposed skin area		Trunk score: 3

4. Methods for Integrating Ergonomic Solutions to Minimize Risk Factor

After a preliminary ergonomic risk assessment of the task, the coexistence of high postural and injury risk was confirmed. The upper body part, more precisely the wrist and exposed skin area, threatened long-term MSD risk and permanent skin damage. Several incidents reported due to slip of tools ended with severe machine injury. The absenteeism and frequent medical visit were reported as a fact of this safety issue.

A total of 18 students of 9 groups (2 students in each group) were assigned to find a potential solution to curtail the risk related to this safety concern. Each group came up with multiple designs, which seemed to be promising solutions to the existing problem. The manufacturer decided not to add automated machining, but their preference was to modify the current machine with some added features. Students were instructed to follow the guideline, and design criteria should meet the ergonomic goal to lower the risk. After completing the task, students' work was presented to the manufacturer company, verified by their engineering department. Finally, they categorized the designs into three different types based on its' use and time necessary to implement. The proposed designs are discussed in detail in the design approach section.

5. Design Approach

Design 1: Keeping the worker in mind, students designed the top part of the machine guard to be closer to the grinding wheel on both sides. Therefore, the worker(s) could still use the wheel in the same manner, achieve the same quality of finish, and still polish wrenches in the same amount of time. Another feature they added to their design was a bottom plate so that the bottom of the grinding belt could not be accessed during operation. The plate includes a series of square holes and a piece of wire mesh so the dust could still settle at the bottom of the grinder and no objects could enter (figure 2a). The shaft and the nut that is on the side of the grinding wheel are both now guarded, and the worker can no longer come in contact with them. The bottom of the grinding belt can no longer be accessed while the machine is in operation.

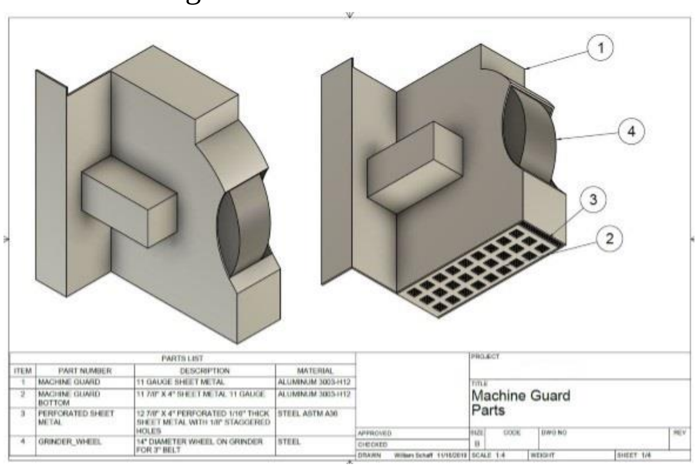


Figure 2a: Machine guard with mesh sieve at the bottom

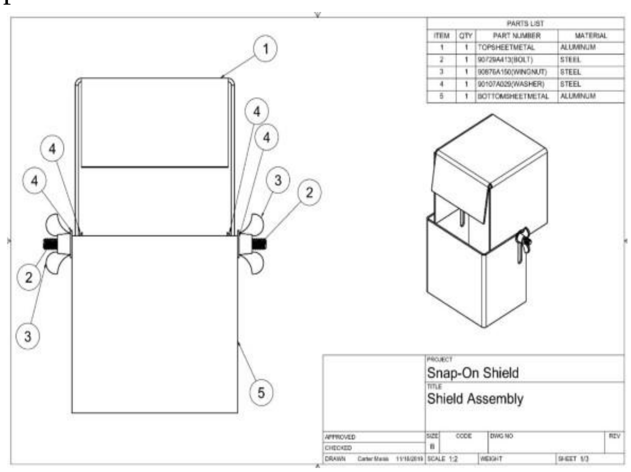


Figure 2 b: Machine guard with adjustable frame

Another group proposed a similar concept, which they considered ergonomic. It includes an adjustable frame adjusted by wing nuts and one bolt for securing the machine (figure 2b). Making the guard adaptable allows the operator to set the exact amount of belt he or she needs to be exposed, ultimately reducing the work envelope and reducing the contact with the belt. Using wingnuts allows the operator to make quick adjustments without any tools within minimal downtime.

Design 2: Robotic arms inspired this group's design structure. The arm component is the basis, and it is fully adjustable, independent of the size of the workers, and most importantly, versatile to all polishing machines regardless of belt diameter. The design contains the three-axis adjustable arm with a plate on top that can rotate up and down, which conforms around the grinder belt (figure 3). This will allow employees to adjust the plate to access the minimal amount of belt needed to perform each task to minimize injury risk. The adjustable plate will also allow the worker to lay the tool on the plate and still achieve the polishing process, which will reduce fatigue in the arm and wrist.

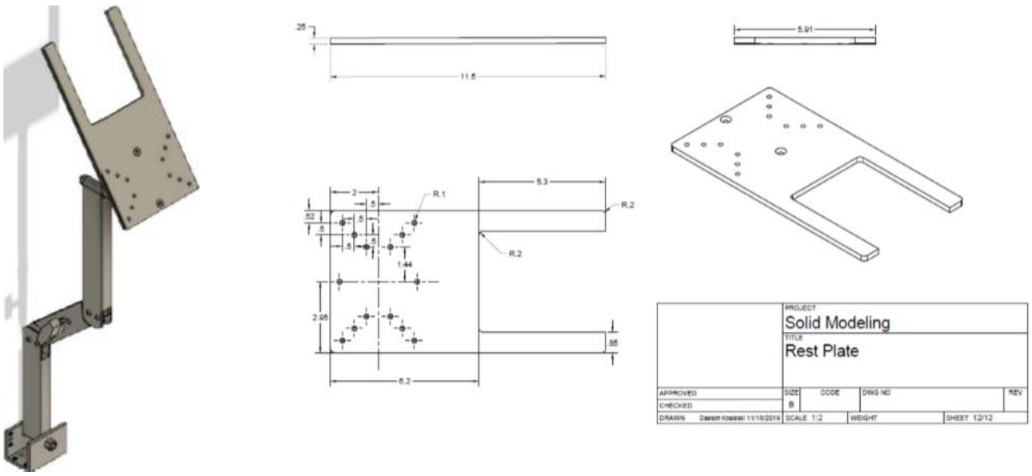


Figure 3: Schematic diagram of adjustable rest plate

Design 3: In this category, students' groups were focused on designing clamp-type fixtures fitted to any size of wrenches, big or small. The first group decided that the best course of action was to design an apparatus that would move the workers' hands further away from the belt itself while still allowing the workers to maintain the high level of precision required for this process. However, the clamp would limit how the wrench could be held due to size variance, thus hindering the workers' ability to polish corners and edges. The team took the initial design of an apparatus that would hold the wrench itself and modified it to suit the needs of the workers better. This involved scrapping the clamp-style head for a much more reliable and ergonomic magnetic head. The ergonomic handle would then have a hinge system that would allow the head of the handle to move to three different angles, giving the user much more control while grinding the wrench (figure 4a). The hinge angle would be determined by the user and held in place by a pin system. This magnet would then be covered by a material that would give the wrench a sturdy place to sit yet soft enough not to damage the wrench's finish. These pucks would be mounted to the end of the apparatus via a screw-in system. This will allow the ability to quickly switch out magnetic pucks if they are damaged in any way. This feature also allows the apparatus to be much more adaptable depending on the size of the wrench being ground.

Figure 4a: Schematic diagram of magnetic clamp

Figure 4b: Schematic diagram of 360° rotation clamp

Figure 4c: Schematic diagram of Pliers-Activated Spring Clamp

The following group wanted to design a solution that would decrease the injury rate and make the task more comfortable and more enjoyable for the workers. They modeled a type of mechanical clamp mount that would hold the tool in place to be ground by the machine. The clamp mount is attached to both sides of the polishing machine's belt guard. Each clamp would hold the tool in unison by a screw mechanism. The clamps would also have 360° rotation freedom so that the device could be held in various positions. The workers would control the clamp by handles with ergonomic grips attached to each side (figure 4b).

The third option into this category design proposed a Pliers-Activated Spring Clamp. The pliers will remove the operator's hands from being so close to the belt on the polishing machine. These would enable the workers to polish the tools and complete control of the tool in multiple directions (figure 4c). However, this seems to be a simple solution but effective in an economical way.

6. Risk Analysis

The main risk factors were identified from the initial ergonomic risk assessment (Table I). Investigation showed that primarily the operators were at high risk of machine injury and skin burn out of sparks since a decent part of the abrasive belt were exposed to the operators while at work. The ergonomic assessment tool for the upper body part also indicated poor posture with a risk of injury and recommended further investigation and immediate actions to prevent future injury [9]. Precisely, the wrist and the trunk score lead to confirm MSD risk if this awkward posture would consistent.

At the first visit on the operation floor, students measured the postural positions of the operators and found the initial RULA score of 6, which means at medium risk. Students then did further investigation and took account of all possible reasons of immediate risk. Following their query, they started their research on modifying the existing machines ergonomically and turning down the RULA score into the safe zone. The design approach discussed in previous sections demonstrated their plan and was validated by the final RULA score they measured. The last measurement was taken with an actual polishing machine provided by the company. Because of the time limitations, students could not build the infrastructure; instead, they made a prototype with cheap materials and measured the final RULA score. Table II provides the risk analysis of the initial and final RULA score for the six solutions supplied by the student groups.

Table II: Risk Assessment after design modification

Ergonomic Solutions	Initial RULA Score	Final RULA Score
Machine guard with mesh sieve	6	4
Machine guard with adjustable frame	6	4
Adjustable rest plate	6	3
Magnetic clamp	6	4
360^o rotation clamp	6	3
Pliers-Activated Spring Clamp	6	3

From the table, it can be concluded that a clamp fixture could be an excellent solution to minimize the MSD risk in the wrist and trunk area. It also allowed the operators to maintain a safe distance from the rotating abrasive belt and, this way, address the machine injury risk. A heat protective cover could protect the surface skin from flame sparks, as this design did not consider the machine guard. This design cost ranges from \$30 ~ \$150 to add these features to the existing machine. This meant to be a minimal cost compare to the risk associated with this job definition. Moreover, these features can diminish potential accidents. The problem with the machine guard design is that it could not maintain the preciseness at the manufacturer level for small size wrenches. Besides, it would be more costly and time-consuming during the loading-unloading process than the clamp fixtures (design 3).

7. Conclusion

The student groups proposed nine different solutions to reduce the risk factor experienced by one of the leading hand tools manufacturing companies. Among them, six solutions are more likely to be adopted in the future. The solutions were verified and compared by the ergonomic risk assessment RULA score. However, even if these six designs seemed to be promising, some solutions could not fully satisfy the criteria defined by the manufacturer company. A solution with ergonomic characteristics and compatibility was more likely to be adopted, which was clamp fixtures design. Besides, this design could be easily tested, witnessed the result in practice, and could be considered for further development without hindering the current production process.

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