

1. INTRODUCTION

1.1 Overview

In spite of advances in industrial automation, manual assembly tasks continue to be an important feature of many industrial operations. They contribute significantly to production costs in manufacturing assembled products. Manual assembly is a major factor that makes the indirect manufacturing cost vary since delays and defects are caused considerably by labor. However, these errors can be diminished by reduction in assembly difficulty, which consequently brings reduction of manufacturing cycle time.

In the heavy part assembly industry, automated material handling systems have widely replaced the manual systems since production cycle times and worker injuries can be greatly reduced, especially in mass production. However, in small batch size or one of a kind production, heavy parts are still mostly handled manually. In the case where the part is too heavy to be handled by an operator, manual material handling devices such as Jib cranes and overhead cranes are employed to help the operator work safer.

A single final product maybe composed of various kinds of components including finished raw material, machinery etc. Most of the raw material in heavy part manufacturing used in industry is fabricated and machined into a wide variety of sizes and shapes. However, the main structures mostly consist of metal sheets or plates in various thicknesses. Therefore, this research is focused on the assembly method of metal plates in various sizes and weights.

Heavy parts can be assembled or joined to form a final product in many ways such as welding, clamping, fastening, and insertion. Among these processes, the welding

process is one of the most commonly used and the strongest connecting process in heavy part manufacturing industry. Among these processes, welding is a very time-consuming one. In addition, it has been shown in this research that welding is the most time-consuming process and becomes the bottleneck. Therefore, reducing welding time would result in a shorter average manufacturing cycle time.

Normally, the welding process is divided into two main steps: tacking and solid welding. First, all of the parts are tacked together by experienced workers. Then, the framed product is sent to solid welding stations. By checking at the tacking stage, the company can reduce a great amount of time to fix the errors or mistakes that may occur during the welding process such as parts missing or misalignment.

Time spent in the tacking and the solid welding processes can be measured in different ways. The solid welding time is mostly dependent on the welding length. However, there is relatively little knowledge in determining the tacking time and how to perform this task efficiently.

A tacking task may be further divided into three subtasks: part transferring, approaching or positioning, and weld-tacking. First, the part is picked up from the WIP buffer and moved to the welding area. Then, it is placed onto an exact location and tacked by a welding gun at two or three spots to hold the parts together. This process continues until the last part is tacked to the frame. The final frame is then transferred to the solid welding process.

Time consumed in each step is varied depending on different factors. The part transferring time is principally dependent on the distance. The tacking time is primarily

based on number of welding spots. However, due to the mass, weight, and inertia of the heavy part and the tolerance, it takes considerably longer to put a heavy part onto an exact location at an exact angle. This research emphasizes studying humans' ability to perform this positioning process.

To accomplish efficient positioning, it is necessary to understand the human's ability to manipulate heavy parts both with and without the assistance of a material-handling device. Knowing the easiest and fastest way to handle and position a heavy part is likely to assist cycle time reduction. Therefore, this research focuses on the effects of the parts' heaviness and task difficulty on the performance of the assemblers.

To handle a very heavy part safely, in many cases, handling devices such as overhead cranes are required. However, the number of overhead cranes in each assembly row is limited, and in some cases not enough to support the assemblers' requirements. Therefore, options such as teams of humans or higher performance cranes are indicated.

There are many ways to make the crane work faster including increasing the controllability of overhead cranes. The obvious solution is to make the crane controller more responsive by using joysticks. The non-obvious solution is to put the control system back in the hand-eye loop of the user, as if weights were not an impediment. The later one would be the better choice since the human control loop runs with the body systems. Therefore, this study introduced an overhead crane with a spring equipped between the hook and the gripper. This spring would make the heavy plate liftable to the assembler and consequently shorten the assembly time.

Less assembly time might indicate an easier task. Leading Predetermined Time Standard Systems such as MTM, MOST, and MODAPTS provide estimated assembly times for most common tasks. However, none of them provide good models for heavy plate assembly with and without the aid of material handling devices. Hence, a more detailed model is needed.

As mentioned above, the positioning time varies depending on the task difficulty. One way to measure the task difficulty numerically, called the index of difficulty, was introduced by Fitts (1954). This measurement judges the difficulty of positioning tasks by taking 2 factors into account: the distance in between and the width of two targets. Fitts' research showed that the relationship between the positioning time and the index of difficulty is linear. Thus, the index of difficulty could serve as a positioning time predictor.

Unfortunately, Fitts used only light parts in his experiments, which means he did not consider the weight of the part. Besides, the participants had to use only one of their hands to perform Fitts' experiments. Furthermore, Fitts did the experiments concerning only axisymmetric objects, that is, the part could be freely rotated around the Z axis without affecting the result of the index of difficulty calculation. For these reasons, Fitts' index of difficulty might not be directly used to predict the assembly time in some tasks, especially the heavy plate assembly tasks. Thus, this study created a model using metal plates in order to find a new index of difficulty to predict the assembly times for metal plates.

In addition, the weight of the part also has an impact on assembly time. Thus, getting rid of or reducing the weight factor might help in decreasing of the assembly time. In industry, an overhead crane is not only employed to hold the part that is too heavy to be carried by the workers, but it also helps the workers transfer the heavy part faster. That is, the workers do not have to support the weight but have to only control the movement of the part by holding the part and pressing the control buttons.

However, using a crane to assist carrying a heavy part has some limitations in manipulating the part. Without the crane, the part can be located or positioned at a particular spot very quickly by the flexibility of humans' muscles. Since there are a lot of too-heavy parts to assemble, the assistance of a crane is needed. With a crane, it is not easy to manipulate the part onto an exact position. The worker might have to spend a substantial amount of time adjusting the part to the target location by repeatedly pressing the buttons on the controller. The worker has to lower the part onto the assembly level, which usually requires high accuracy. Then, the worker has to move the part horizontally by pressing the X-axis and Y-axis buttons on the controller. The part can be slightly moved in a horizontal direction by human force and it becomes more difficult for the heavy part to be moved as the lateral distance increases, due to the increasing lateral component of the part's weight.

To reduce the difficulty in manipulating the heavy part with the assistance of a crane, this study introduced a modification of an overhead crane by adding a spring between the hook and the gripper. This solution inexpensively provides vertical flexibility to the crane without investment in technology and modifications. A spring-equipped crane has less vertical and lateral stiffness, which would allow the workers to

move the parts more easily. Moreover, the workers do not need to spend time on controlling the vertical movement of the crane since the spring aids in supporting the weight of the parts. Therefore, the workers can maneuver the part in every direction manually.

1.2 Research Objectives

The main objectives of this research are to understand the effects of task difficulty and plates' heaviness on the assembly time and to study the efficiency in performing the tasks by using different methods. To achieve these, three sets of experiments are conducted: Index of difficulty of heavy plate assembly tasks, Impact of the index of difficulty and plates' heaviness on assembly time, and critical vertical force (weight) limits.

The index of difficulty of heavy plate assembly tasks experiments are conducted by imitating those of Fitts. This study employed Fitts' index of difficulty as a guideline to determine the task difficulty of two-handed heavy plate assembly tasks. Clearly, the original equation can not be applied directly. Therefore, a new index of difficulty was developed. Since the relationship between the index of difficulty and assembly time has been observed to be linear (Fitts 1954), if one is able to find the index of difficulty of a particular task, it should lead to a reliable estimation of the assembly time.

The objective of the second set is to formulate models to predict the assembly time of different handling methods when both parts' heaviness and the index of difficulty vary. The experiments were conducted in each of four experimental methods: One-person, Two-person team, One person with an overhead crane, and One person with a spring-equipped overhead crane. The results from this set would indicate the assembly performance of each method at different levels of heaviness and task difficulties.

The last set of experiments was created to determine the relationship between the vertical forces (weight) and the human's ability in performing the positioning tasks in

more detail and over wider range of heaviness. There might be a certain point where the assembly performance drops dramatically as the level of heaviness goes beyond that point. Without the assistance from an overhead crane, the lifting requirement to balance the vertical force (weight) varies directly as to the weight of the plate. On the other hand, with an overhead crane, the part's weight does not affect the force that the worker needs to lift the part. The vertical stiffness of an overhead crane is very high because the crane's cables support all of the vertical force. However, for the spring-equipped crane, varying the spring's stiffness directly changes the worker's vertical force requirement.

1.3 Organization of the Thesis

Chapter 1 provides the background of the design for assembly methods for large and heavy parts, and how this research can contribute to real-world manufacturing problems. Chapter 2 gives four of the literature reviews relevant to the research in order to lay fundamental knowledge about the fields of the study. Chapter 3 explains how the new index of difficulty for heavy plate assembly tasks was developed. Chapter 4 addresses the results and discusses the performances of the four methods (One-person, Two-person team, One person with an overhead crane, and One person with a spring-equipped overhead crane) at different levels of heaviness and task difficulties. Chapter 5 shows the performance-dropping points of the methods mentioned in the previous chapter. Conclusions and recommendations gained through the research are stated in Chapter 6. These conclusions and recommendations led to other topics for further research, which are stated in Chapter 7. References are listed in Chapter 8.