3. INDEX OF DIFFICULTY OF HEAVY PLATE ASSEMBLY TASKS

3.1 Overview and Research Objectives

The main objective of this chapter is to develop a formula to numerically measure the difficulties of heavy plate assembly tasks by referring to Fitts' index of difficulty as a guideline. Fitts' index of difficulty equation (Eq. 1) was derived from experiments that involve one-handed, axisymmetric assembly tasks. Therefore, it could not be directly applied to the plate assembly tasks that require both hands. Pilot test experiments have been conducted to show that Fitts' index of difficulty equation could also serve as a task difficulty indicator for two-handed assembly tasks. Chapter 3.5 explains the pilot test experiments in more detail.

In addition, Fitts' index of difficulty equation applies to tasks that are axisymmetric. To be specific, in Fitts' experiments the participants could freely rotate the part around the z-axis without increasing the task difficulty. On the other hand, the participants who perform the plate assembly tasks cannot freely rotate the part on the horizontal plane. Instead, the latter group has to locate both ends of the plate inside the target line. This increases the tasks' difficulties.

Based on the pilot test experiments, participants tended to perform the plate assembly tasks in two steps. The participants tried to position one end of the plate inside the target area first and then rotate the other end. This could be treated as a two-step task: transferring and rotating. From the pilot test experiments, the original Fitts' index of difficulty equation could be applied to measure the tasks' difficulty of the first step, the transferring. Since, Kondraske (1994) and Wong (1994) adapted Fitts' index of difficulty equation to create a new index of equation to measure the difficulty of angular-motion assembly tasks, the movement time of the second step then could be predicted. By combining both equations, a new index of difficulty equation was developed to measure the movement time for plate assembly tasks.

3.2 Experimental Hypotheses

The following hypotheses were formulated:

Hypothesis 1: Fitts' index of difficulty equation is applicable to a two-handed assembly task.

Hypothesis 2: A new index of difficulty equation for heavy plate assembly tasks can be derived from the original Fitts' and the angular-motion index of difficulty equations.

3.3 Participants

Four male volunteer participants, ranging in age from 24 to 28 were requested to perform 4 sets of the experiments. All were graduate students at Virginia Tech. Prior to the experiments, the participants were required to fill out the questionnaire to indicate their health status. If a person had or had previously experienced muscle or back injuries, he was not qualified as a participant for these experiments.

3.4 Apparatus

Three 10 Lbs. metal plates were used in this experiment set. They were 12"x12"x1/4", 12'x8"x3/8", and 12"x6"x1/2". Figure 3.1 shows some examples of the plates. Each of them was equipped at the bottom surface with a cylinder-shaped metal pin that has the same length of diameter as the thickness of the plates. These pins give the rotational freedom to the tasks.

Figure 3.1: Examples of the metal plates

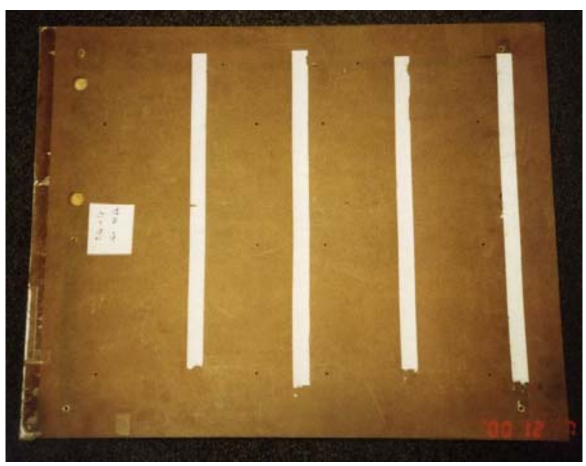

Figure 3.2: An example of target lines

Seven wooden boards contain seven sets of the target lines. Each set had four target lines located 6 inches away. The target lines were represented by white tapes, as shown in Figure 3.2. Since the thickness of the target lines indicates the clearance of the assembly tasks, each set of the target lines had different thickness: 5/16”, 6/16”, 7/16”, 8/16”, 9/16”, 10/16”, and 12/16”. The details of how these boards contribute to the experiment are explained in the next sections.

3.5 Experimental Design

As mentioned above, the purpose of this chapter is to develop a new index of difficulty equation for heavy plate assembly tasks, based on Fitts’ index of difficulty equation. Pilot test experiments were conducted to see whether Fitts’ index of difficulty equation could be used as a guideline.

Pilot Test Experiments:

The experiments were divided into two parts. The first part was to show how Fitts’ index of difficulty equation could be applied to the two-handed assembly tasks. The assembly tasks in this part used the pins at the bottom of the plates, which allowed the participants rotate the part without penalty, similar to those in Fitts’ experiment. The second part showed the increases in assembly time when the part cannot be rotated freely around z-axis. The same set of the participants was requested to perform the same set of tasks with the same plate without the pin.

Pilot Test Part I

Five male graduate students at Virginia Tech volunteered to be the participants. They were requested to perform tapping tasks (Figure 3.3) that represent the positioning tasks in the assembly process. The 10 Lbs. plate with the dimensions of 12”x12”x1/4” with a pin attached was used to represent a heavy plate. They were asked to hold a plate with two hands and tap the pin onto each of a pair of the target lines back and forth repeatedly as fast as possible within 20 seconds. However, this research emphasized accuracy rather than speed, thus the participants were required to locate the pin within the allowed space before tapping it to the other strip. The number of taps was recorded to indicate the speed of humans in performing a particular task. Prior to the experiments, each participant was asked to perform the tasks until he got used to the tasks, to eliminate the bias effect since the participant may perform the tasks faster in the later runs. During the experiments, the plate needed to be held vertically at all times. Between each run, the participants were given a sufficient resting period to relax their muscles to get rid of the fatigue-caused errors.

Figure 3.3: An example of a participant performing the tapping tasks

The experiment comprises nine different task difficulties. Each task had unique values of movement amplitude (6”, 12”, or 18”) and assembly clearance (1/16”, 1/8”, ¼”). Each participant was asked to perform all nine tasks. The sequences of the experimental scenarios were randomly selected. The numerical results are shown in appendix B.

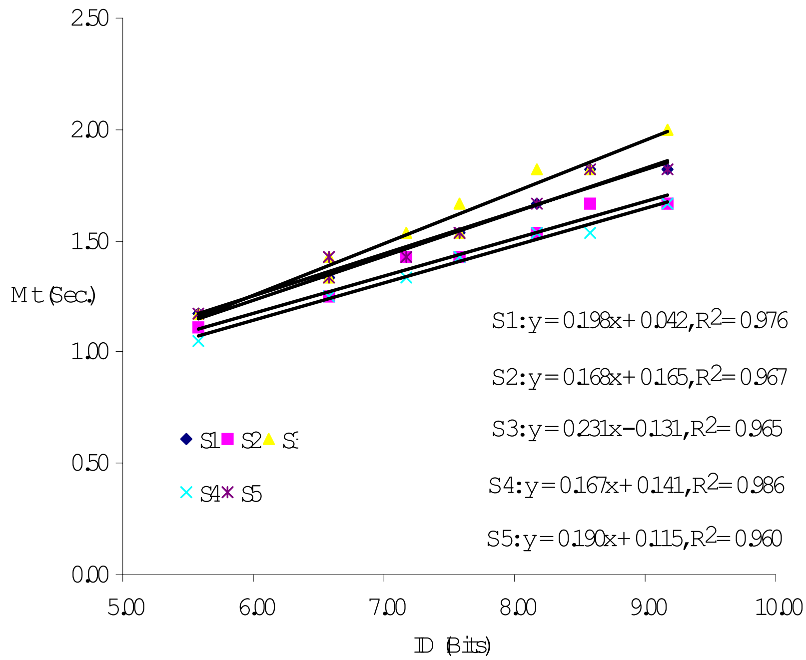

Figure 3.4: Fitts' ID & 2-Handed Assembly Tasks

Figure 3.4 shows a linear relationship between Fitts' ID and tapping or movement time (MT). The Linear Regression function in Microsoft Excel was employed to demonstrate the linear relationships. A linear equation and an R^2 value relating ID and MT of each participant are shown in the graph. The R^2 value can be interpreted as the proportion of the variance in y (MT) attributable to the variance in x (ID). Therefore, the R^2 value that is close to 1.0 would indicate a high dependency between the two factors. The R^2 values from every participant (figure 3.4) were very close to 1.0. This indicates a linear relationship between Fitts' index of difficulty and the movement time of two-handed assembly tasks. In other words, the movement times or positioning times can be estimated from the movement amplitude and the assembly clearance.

Pilot Test Part II

The pilot test part II was conducted to determine how much the task' difficulty increases when the allowance to move the part freely around the z-axis was eliminated. In this part, the participants were requested to perform the nine similar tasks as in part I, but without the pin. The experiments were recorded on videotape for analysis. The numerical results of the movement time were recorded in appendix C. Figure 3.5 shows the average value of movement times of the five participants performing the nine tasks both with and without a pin. The movement times from the tasks that did not use the pin were higher in every case. This indicates that without the pin, the task is more difficult to perform and required more time.

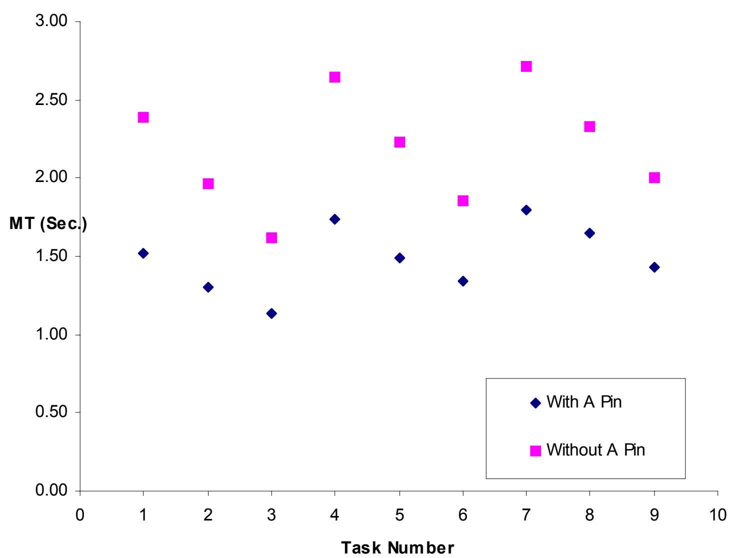

Figure 3.5: Comparison of Assembly Times: With and Without A Pin

The pilot tests have shown that Fitts' index of difficulty equation is applicable to the two-handed assembly task, and that it is more difficult to assemble parts such as plates that require accuracy around the z-axis. The observations from the videotape specified that the participants perform the plate (without a pin) assembly tasks in two steps as shown in figure 3.6. In the first step, the participants transferred the part to the target line with at least one end located on the target line and then rotated the other end onto the target line, if necessary. The increasing difficulty came from the second step, rotating the unaccepted end of the plate onto the target line.

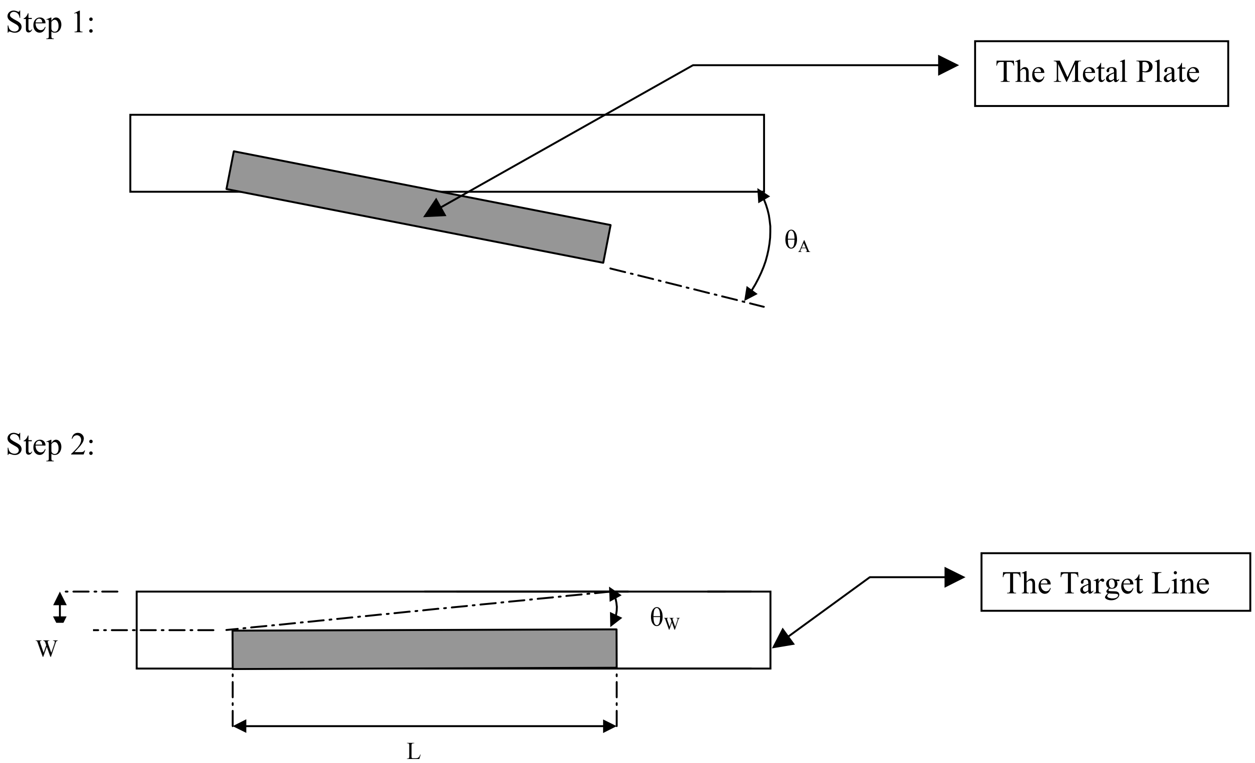

Figure 3.6: The two-step assembly task

A new index of difficulty equation for plate assembly tasks was developed based on the combination of the original Fitts' Index of difficulty equation (Eq.1) and the modified Index of difficulty equation (Eq.2) presented by Kondraske (1994) and Wong (1994) to estimate the increasing task's difficulty occurred in step 2.

$$Id = \log_2(\frac{2A}{W}) + \log_2(\frac{2\theta_A}{\theta_W}) \quad (12)$$

The variables A (amplitude) and W (clearance) could be measured directly from the actual plate and the target line. Since the θ_W is relatively small, it can be represented by W/L. Both W and L (plate's length) are pre-determined. Therefore, the new index of difficulty can be reformulated as:

$$Id = \log_2(\frac{4AL\theta_A}{W^2}) \quad (13)$$

From the equation, an index of difficulty for a plate assembly task can be calculated if θ_A is known. The θ_A is the average angle that the participants have to move the other end of the plate onto the target line, to complete the task. The following sets of experiments were designed to capture the value of θ_A. The participants were asked to perform four experimental sets. In the first set, the participants were asked to perform the tapping tasks similar to those in the pilot test part II but putting only one end of the plate on the target line was acceptable. In the other three sets, the participants were requested to do the tasks that require both ends of the plate to lie inside the target line. In each set, a pair of A, L, or W was varied. The results from these four experimental sets would indicate the value of the θ_A.

3.6 Experimental Procedures

The participants were asked to perform the 4 X 9 tapping tasks. To perform the tasks, the participants had to hold a plate with two hands and tap the plate onto each of a pair of the target lines back and forth repeatedly as fast as possible within 20 seconds (Figure 3.3). However, this research emphasized accuracy rather than speed, thus the participants were required to located the plate within the allowed space before tapping it to the other strip. The number of taps was recorded to indicate the performance of humans in performing a particular task. Prior to the experiments, each participant was asked to perform the tasks until they become familiar with it, to eliminate the biasing effect since the participant may perform the tasks faster in the later runs. During the experiment, the plate needed to be held vertically at all times. Between each run, the participants were given a sufficient resting period to relax their muscles to get rid of the fatigue-caused errors.

In the first and second sets, only one plate sized 12”x12”x1/4” was used and the task difficulties were varied by the increasing of clearance (1/4”, 1/8”, and 1/16”) and distance (6”, 12”, and 18”). In other words, the plate’s length was fixed while the distances and clearances were varied. In the first set, the participants performed the tapping by putting only one end of the plate on the target line. These tasks served as the basic tapping tasks similar to those in Fitts’ experiments. The freedom in rotating the plate around the z-axis was eliminated in the second set. The participants had to locate both ends of the plate on the target line.

The other two plates that have different lengths (8” and 6”) were added in for the third and forth sets. In the third set, the assembly distance was fixed at 12” while plates’ lengths and clearances were varied. The tasks in the forth set had a fixed clearance of 1/8” and had varied distances and plates’ lengths.

3.7 Results and Analyses

The purpose of these four experimental sets is to identify the θ_A. This can be done by using a sensitivity analyses technique. Several θ_A were generated to create new sets of the index of difficulty for each task scenario (table D5 in appendix D). By plotting the movements times of all participants from four experimental sets (appendix D, table D1 to D4) and the sets of the index of difficulty, the best value of θ_A was identified by the Microsoft Excel Linear Regression function (Figure 3.7)

The generated θ_A and the corresponding R-Squared values are summarized in table 3.1 and plotted in figure 3.8. It is clear that the estimated value of θ_A is a unique value since there is only one peak on the graph, at approximately 2.0 to 2.4 degrees. It means that after the participants had located one end of the plate on the target line, they had to rotate the plate at the average of 2.0 to 2.4 degrees to make the whole plate lie on the target line.

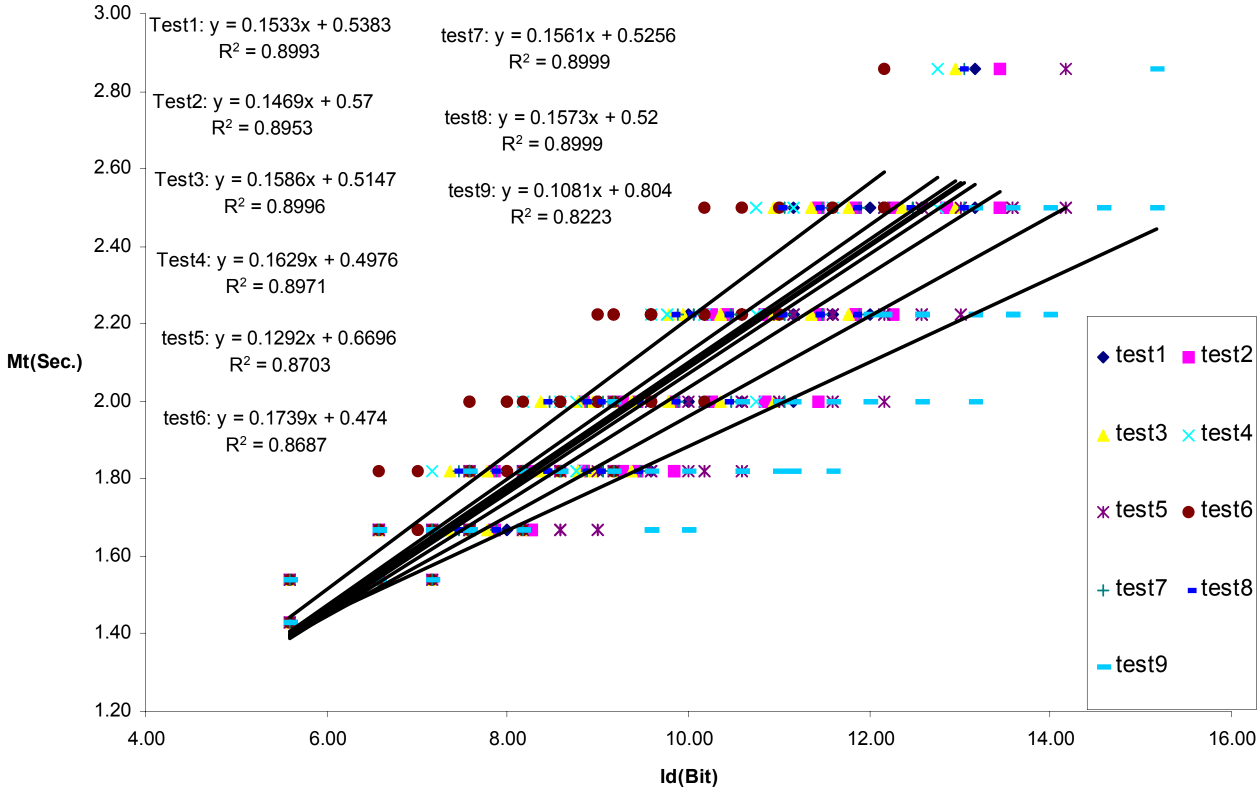

Figure 3.7:Identifing the best value of Theta A

No.	Theta A		R^2
	Rad.	Degree	
1	1/48	1.19	0.8687
2	1/32	1.79	0.8971
3	1/28	2.05	0.8996
4	1/27	2.12	0.8999
5	1/26	2.2	0.8999
6	1/24	2.39	0.8993
7	1/20	2.86	0.8953
8	1/12	4.77	0.8703
9	1/6	9.55	0.8223

Table 3.1: Theta A vs. R-Squared

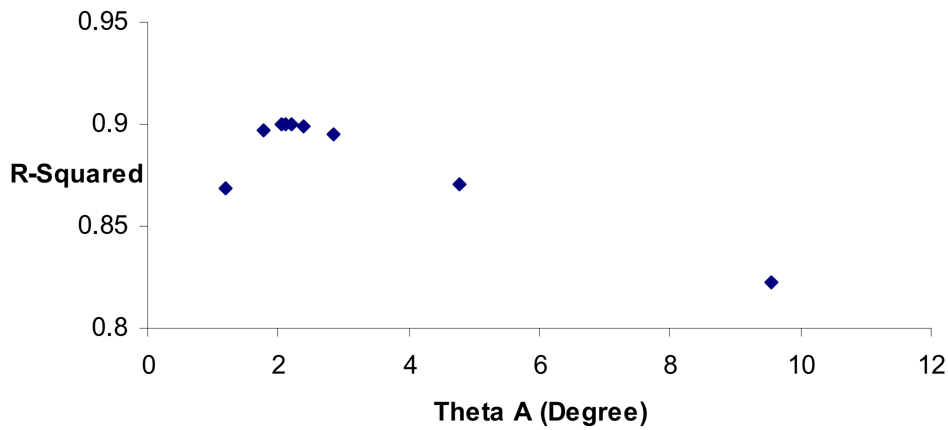

Figure 3.8: Plotting of Theta A and R-Squared values

To validate the new index of difficulty equation for plate assembly tasks (Eq.13), the movement times of each subject performing the plate assembly tasks in the experimental set number two to four and the index of difficulty generated by the new Index of difficulty (Eq.13) with the value of the θ_A equal 1/24 radius were plotted in figure D1 to D3 respectively. The R-Squared values ranging from 0.7922 to 0.9681 in the three graphs indicate high correlations between the index of difficulty and the movement times.

3.8 Discussion

The pilot test part I has shown that Fitts' index of difficulty equation is not only applicable to one-handed assembly tasks, but it also serves as a movement time predictor for two-handed assembly tasks. By observations from the videotape, the participants tended to perform the plate assembly task in two steps: transferring and rotating. Fitts' index of difficulty equation can predict the movement time spent in the first step. The rotating time could be well predicted by the modified index of difficulty equation proposed by Kondraske (1994) and Wong (1994). Therefore, this study combined the two index of difficulty equations to create a new index of difficulty equation for plate assembly tasks. The results showed that the new index of difficulty equation could provide a very good estimation of the movement time for plate assembly tasks.

In this study, the θ_A had been reliably estimated to be 2.0 to 2.4 degrees. However, this number could be varied depending on different abilities of the participants to perform the tasks.