

5. CRITICAL VERTICAL FORCE (WEIGHT) LIMITS

5.1 Overview and Research Objectives

This chapter discusses further the critical point of human performance as the weights or the vertical forces that the assemblers have to support increase. As discovered in the previous chapter, a single person's assembly speed tends to decrease once the weights of the plates start getting heavier than 20 Lbs. The main objective of this chapter is to observe these critical points of methods presented in the previous chapter.

5.2 Experimental Hypotheses

Hypothesis 1: In all the assembly methods discussed so far, there is a certain point where the assembly speeds are constant and the speeds will drop as the vertical force that the assembler has to support increase beyond that critical point.

Hypothesis 2: Setting the operator's expected force in x, y, and z directions to be nearly equal should minimize assembly time.

5.3 Participants

Five male volunteer participants, ranging in age from 24 to 32 were requested to perform three sets of 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.

5.4 Apparatus

Eight 12"x12" metal plates were used for the One-person method. They weigh from 5Lbs to 40Lbs and have a thicknesses of ¼" to 1". Each of them has four holes as shown in figure 3.1 to make combination plates that weight 50, 60, and 70Lbs, for the Two-person team method experiments. The same seven springs were used in the One person with a spring-equipped overhead crane method experiments. Several sets of target lines have a thicknesses equal to the widths of the plates and the experimental clearances.

5.5 Experimental Design

Prior to the experiment, each participant and each pair of the participants who were requested to attend the One-person and Two-person team experiments were asked to specify the maximum weights that they were willing to work with. The maximum safe weights of lift approach (MSWL), introduced by Karwowski (1996) were used as a guideline. They were asked to picture themselves as a worker who works eight hours a day and determine the maximum weight they could safely lift without raising the risk of low back pain or muscular overexertion. The answers were 40, 40, 45, 40, and 40Lbs from each participant and 70, 70, and 70Lbs from each pair of the participants, respectively. Therefore, the maximum weights used in the first two experimental sets were 40 and 70Lbs.

In the One-person method experiments, the results from the previous chapter predict that the assembly speed decreases linearly along with the increasing of heaviness

once the plate is heavier than 20 Lbs. However, the weight differences between each plate were 10Lbs, which could be considered a wide range. Therefore, this chapter used more plates with a tighter range of 5Lbs. The outcomes would specify a more accurate critical point as well as the relationships between movement times and increasing weights.

With the plates that weigh 40Lbs or less, the Two-person team method showed no point where the assembly speeds decreased. The critical point might appear at a higher weight. Therefore, this chapter investigated the assembly speeds of the Two-person team method with plates that weigh up to 70Lbs.

Without a spring, the weights of the plates are mainly supported by the crane's cables. However, by increasing the stiffness of the springs, the assemblers would have to use more muscle force in moving the plate up and down. Therefore, the last experimental set was created to investigate the assembly speed at different levels of springs' stiffness.

5.6 Experimental Procedures

For the One-person method, the amplitude and the clearance were fixed at 6" and 1/8", respectively. The eight plates were assigned randomly throughout the experiments. The tasks were done in a similar way as in the previous chapter.

For the Two-person team method, seven plates ranging from 10 to 70 were randomly assigned while the index of difficulty was fixed at the distance of 12" and the clearance of 1/8".

In the last experimental set, only the 20Lbs plate was used and the springs were randomly picked. The participants performed the tapping tasks in the similar ways as in the previous chapter. The amplitude and the clearance were fixed at 12” and 1/8”, respectively.

5.7 Results and Analyses

The numerical results are recorded in table F1 to F3 in appendix F. The data from each experimental set are plotted in Figure 5.1, 5.2, and 5.3, respectively.

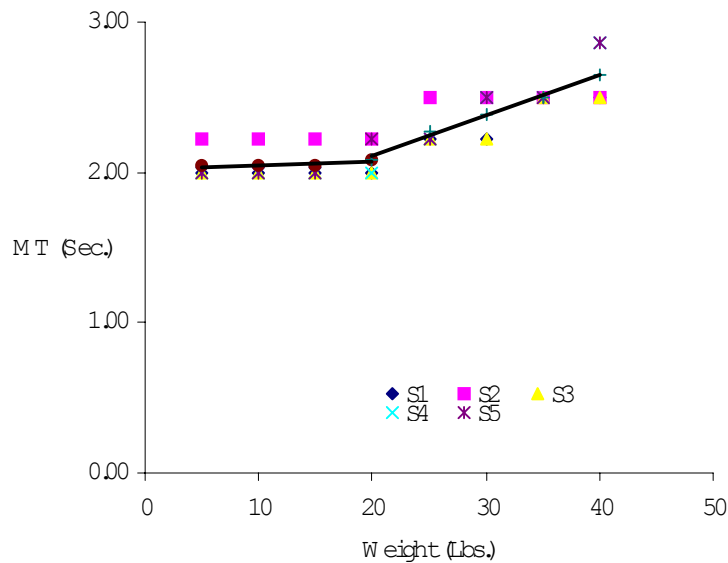


Figure5.1: One Person: MT & Weight Relationships

The slope in figures 5.1 strengthens the results from the previous experiments that the critical point is located at 20Lbs and the movement times start to increase linearly as

the weights go beyond this point. These results confirm Eq14 and Eq15 proposed in the previous chapter.

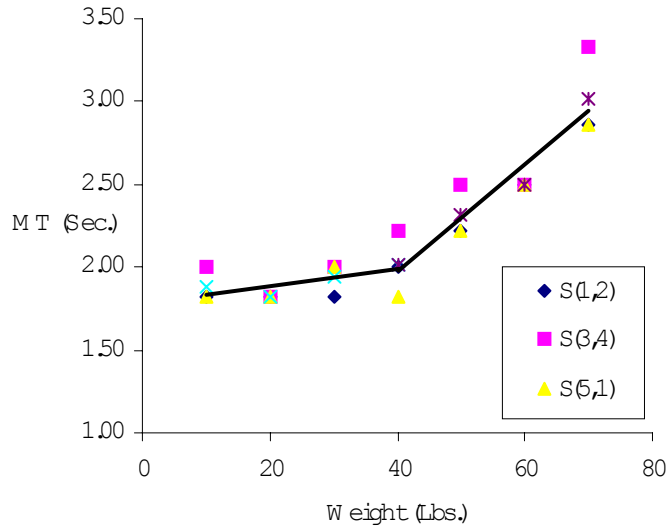


Figure 5.2: Two-person team: MT & Weight Relationships

Figure 5.2 displays the critical point of the Two-person team method. As the weights go beyond 40Lbs, the assembly times start to increase linearly along with the increasing weights at the rate approximately 0.25 Sec/Lb. Therefore, by modifying equation 16, a movement time of the Two-person team method with a plate that weight 40Lbs or greater could be formulated as:

$$MT = -1.5 + 0.3 ID + 0.25 (Weight - 40) \quad (19)$$

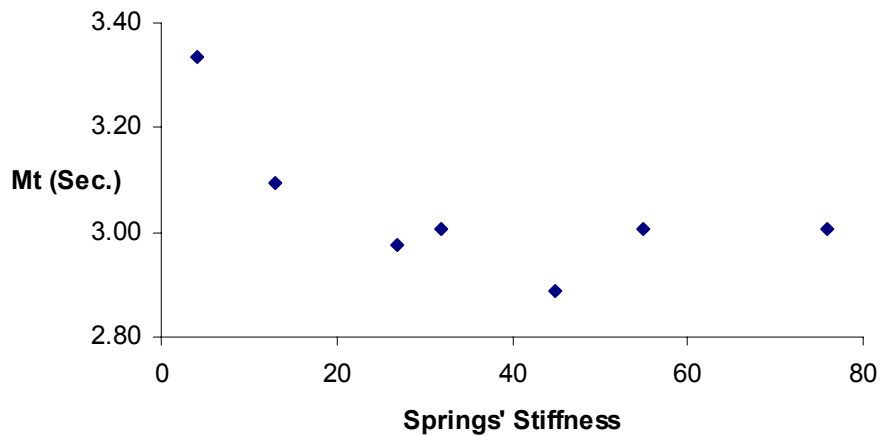


Figure 5.3: One person with a spring-equipped overhead crane: The relationships between springs' stiffness and the average movement times

With the 4 Lb./Inch spring, the participants require more time to assemble the plate. From the observations, the extra times were the waiting time for the 20Lbs hook to stop swinging after tapping the plate on a target line. This is because the spring is extended from approximately 2 inches to 12.4 inches. Since springs do not provide lateral stiffness, once the spring is extended long enough, it creates a parasitic oscillation of the hook to interfere with the assembler's efforts (Figure 5.4). However, this effect doesn't seem to affect the assembly time with other stiffer springs that are not greatly extended. The assembly times start to get stable once the stiffness goes beyond 27 Lb./Inch where the measured extensions range from 0.5 to 1.3 inches. The springs are not extended long enough to create a large delay swing of the hook. This indicates the optimum range of springs for the 20Lbs plate assembly.

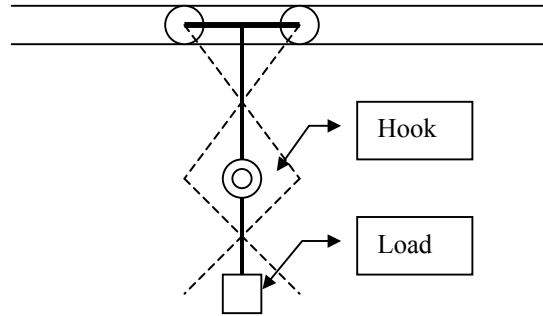


Figure 5.4 Compound pendulum formed by the hook and the load

The latter forces required to move the plates in the z-axis were measured to be in the range of 0.8 to 1.2 Lb./Inch. Therefore, setting the operator's expected force in x, y, and x directions to be nearly equal, in this case 4Lb./Inch for z direction, may create a compound pendulum and increase the assembly time.

The graph also shows that there is no critical point in this method. It may be because the participants do not have to heavily exert their muscle to control the plate. From the observations, the participants have to lift the plate approximately a quarter of an inch during the tapping. Even with the stiffest 76Lb. /Inch spring, the participants have to push or pull only 19Lbs, which is lower than the critical point of a person to perform the task. Therefore, the most suitable spring for each task would be the one that provides good support and doesn't create a large parasitic oscillation.

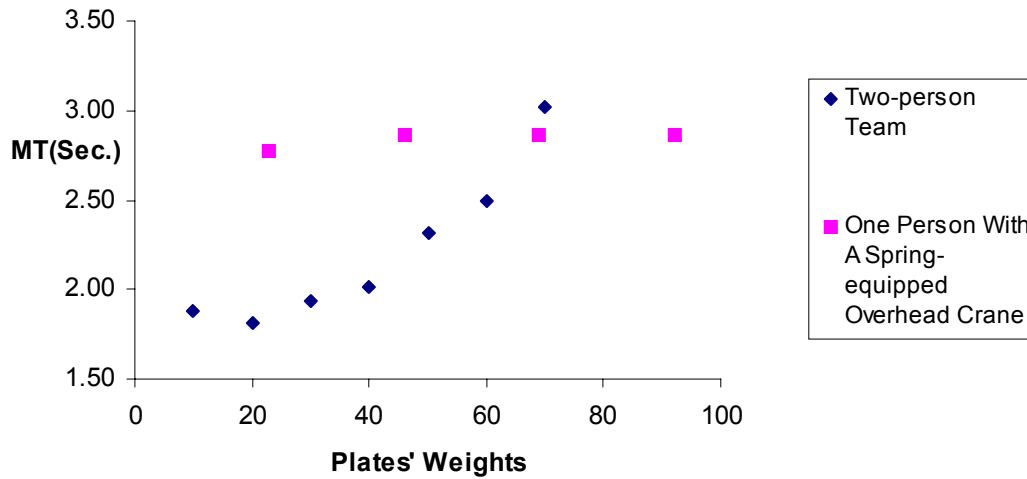


Figure 5.5: Movement times comparison between the Two-person team and One person with a spring-equipped overhead crane methods at different levels of the plates' weights

As described in the previous chapter, the Two-person team method is the fastest way to assemble a plate that weighs up to 40Lbs. Figure 5.5 shows the movement time comparison between the Two-person team method and One person with a spring-equipped overhead crane method at a similar level of tasks' difficulty. The graph shows that the latter method has a constant assembly speed across all the levels of heaviness and becomes attractive once the weights go beyond 70Lbs.

5.8 Discussion

The results reveal the hidden critical points of the One-person and Two-person team methods. This explains that at the lower level of weight, the assemblers can perform the task comfortably, without the effect from the heaviness of the plate. Once the heaviness level goes beyond this point, the assembly times tend to increase linearly to the

increasing weights. Since the participants are all graduate students, the critical points and the maximum safe weights to lift could be higher for experienced workers.

The results of the last experimental set indicate that using soft springs creates a disturbing motion at the hook, which leads to longer assembly time. However, very stiff springs might not provide sufficient flexibility for moving the part up and down. To deal with a variety plate weights without changing the springs, variable-stiffness springs or other ways to increase the flexibility of the crane should be investigated.