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Fixture Design to Improve Manual Material Handling

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ABSTRACT

The purpose of this study is to propose a new design of the fixture for flange core assembly in order to reduce the manual material handling. Handling heavy loads under high temperature in repetitive motion daily, can give a significant impact on workers' performance. This manual material handling problem was identified and analyzed by using multisegment model. A new fixture for flange core assembly was designed to improve the existing fixture. SolidWorks software was used to design the new fixture. The prototype of this fixture was manufactured and trial run in production was conducted. The comparison calculations for existing fixture and new fixture were determined. The weight of fixture was reduced from 13.8kg to 3.46kg, which about 74.93% reduction. Fmuscle was reduced from 2212.8N to 1633.75N with 26.17% reduction. Fcompression was reduced from 2481.8N to 1709.22N which produce 31.13% reduction. Force per leg was reduced from 293.3N to 242.6N, about 17.3% reduction. From this study, the heavy load of the existing fixture was reduced after implemented the new fixture. By implementing the new fixture, the workers felt very happy as they are reduced back pain.
KEYWORDS: Ergonomic, Human Factor, Multisegment, Low Back Pain.

INTRODUCTION

Low back pain (LBP) is the leading cause of disability globally [1]. Exposure to physical risk factors at the workplace such as pushing, lifting, pulling and awkward trunk postures has been associated with LBP [2]. Manual material handing (MMH) involving bending, lifting, and twisting motions of the torso are a major cause of work-related low-back pain and disorders, both in the occurrence rate and the degree of severity [3, 4].

Over a long period, a history of LBP affects pelvis and trunk coordination during a sustained MMH task [5]. Moreover, female and older workers may be at a higher risk for developing LBP when completing similar MMH tasks compare to male and younger workers [6]. Because most of the workers at factory in Malaysia are female, MMH becomes the primary job situations in which the biomechanics of the back should be analysed.

The industries that already identified problem of MMH in their organization were mining industry [7, 8], construction site [9] and in warehouse [10].

This study is conducted to propose a new design of fixture for flange core assembly in order to reduce the heavy load at an electronic company in Malaysia.

LITERATURE REVIEW

The lower back is perhaps the most vulnerable link of the musculoskeletal system in material handling because it is most distant from the load handled by the hands as shown in Figure 1. Both the weight of the upper torso and the load create important stress at the low back, especially at the disc between the fifth lumbar and the first sacral vertebrae (called the L5/S1 lumbosacral disc).

A multisegment model is more accurate determination of the reactive forces and moments at the L5/S1 disc, as illustrated when forces and moments at the shoulder are estimated. The consideration of abdominal pressure, created by the diaphragm and abdominal wall muscles is also required [11]. However, a simplified single-segment model can be used to estimate the stress at the low back [12].

When a person with an upper-body weight of W_{torso} lifts a load with a weight of W_{load}, the load and the upper torso create a combined clockwise rotational moment that can be calculated as Equation (1):

$$M_{load-to-torso} = W_{load} \times h + W_{torso} \times b \quad (1)$$

where h is the horizontal distance from the load to the L5/S1 disc andb is the horizontal distance from the center of mass of the torso to the L5/S1 disc.

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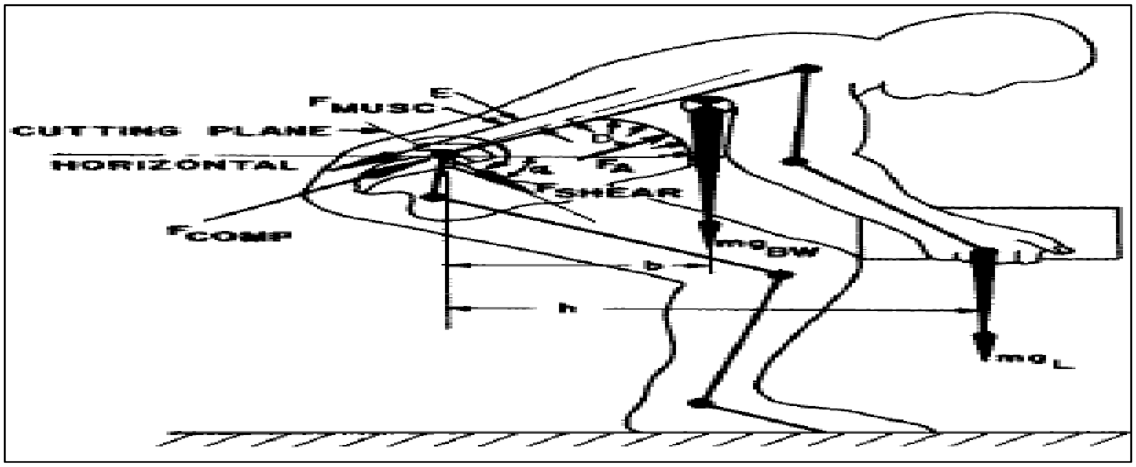


Figure 1: Simple cantilever low-back model of lifting for static coplanar lifting analyses with abdominal pressure [12]

Perceived this clockwise rotational moment must be counteracted by a clockwise rotational moment, which is produced by the back muscles with a moment arm of about 5 cm as Equation(2):

$$M_{\text{back-muscle}} = F_{\text{back-muscle}} \times 5 \text{ (N} - \text{cm)} \quad (2)$$

The second condition of static equilibrium stated that:

$$\sum \text{(moments at the L5/S1 disc)} = 0 \quad (3)$$

According to the Equation(1), Equation(2) and Equation(3), F_{muscle} is calculated as shown in Equation(4):

$$F_{\text{muscle}} \times 5 = W_{\text{load}} \times h + W_{\text{torso}} \times b$$
$$F_{\text{muscle}} = W_{\text{load}} \times h/5 + W_{\text{torso}} \times b/5 \quad (4)$$

In [13]estimated that2200 to 5500N is the normal range of strength capacity of the erector spinal muscle at the low back. Besides to the muscle strength considerations, we must also consider the compression force on the L5/S1 disc, which can be estimated with the Equation(5) on the basis of the first condition of equilibrium:

$$\sum \text{(forces at the L5/S1 disc)} = 0. \quad (5)$$

As a simple approximation, the abdominal force, f_a, can be ignored, and $F_{compression}$ is shown as Equation(6):

$$F_{\text{compression}} = W_{\text{load}} \times \cos\alpha + W_{\text{torso}} \times \cos\alpha + F_{\text{muscle}} \quad (6)$$

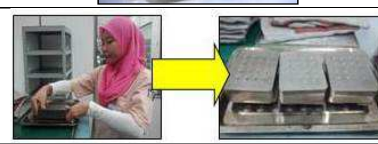
where α is shown in Figure 1 as the angle between the horizontal plane and sacral cutting plane, which is perpendicular to the disc compression force. Disc compression at this level can be hazardous to many workers. Several factors effect the load stress positioned on the spineduring carrying out a lifting task. The analysis considers explicitly two of the factors namely the weight and the position of the load relative to the center of the spine.

METHODOLOGY

Process Analysis

At flange core assembly process, worker has to place a 13.8kg tray into oven and withdraw it from the oven after 30 minutes cure time. In 7 hours, the production had produced 10 to 12 lots which in one lot is equal to 96 units, so the total quantity of product in 7 hours is 960 units to 1152 units. In one tray, that has 3 fixtures in which each fixture consist of 16 units and the total quantity in one tray is 48 units. We can conclude that the operator is inserting 20 to 24 times of tray into oven and withdrawing 20 to 24 times of tray from the oven. This kind of activity is not suitable for most of workers due to they are ladies and need to handle 13.8kg tray in repetitive motion. Besides, handling a hot 4kg heavy block which is 350°F will give a bad impact onto workers performance. This can cause of wrist pain, shoulder pain and low back pain among the workers. Table 1 shows the process sequence of flange core assembly.

Table 1: Process sequence of flange core assembly

Sequence	Job Description	Picture
1	Insert flange core into coil wire	
2	Place coil wire into fixture	
3	Place epoxy on flange core	
4	Place rod core into coil wire	
5	Three fixtures are placed on tray	
6	A weight block is placed on the fixture (1 weight block = 4 kg). Complete 1 tray = 13.8 kg	
7	Insert the tray into oven (350°F for 30 minutes)	
8	After 30 minutes, the trays will be removed from oven and place on table	
9	The weight blocks will be removed from the fixture	

Based on the process sequence, four processes will bring hazard to worker during handling of heavy block and tray. Table 2 shows several type of injury based on the sequence of the process.

Table 2: Process sequence of flange core assembly

No.	Process	Body Part Effected	Type of Injury
1.	Place heavy block on fixture	Wrist	Wrist pain
2.	Insert tray into oven	Wrist and shoulder	Wrist pain and shoulder pain
3.	Remove tray into oven after 30 minutes curing	Wrist, shoulder and low back	Wrist pain, shoulder pain and back pain
4.	Remove heavy block from fixture	Wrist	Wrist pain

Figure 2 shows a work posture while lifting and handling the tray and the force on operator body which are on shoulder, low back and legs. Both the load, which is tray and the weight of upper torso create important stress at the lower back, especially at the disc between the fifth lumbar and the first sacral vertebrae (L5/S1 or called lumbosacral disc).

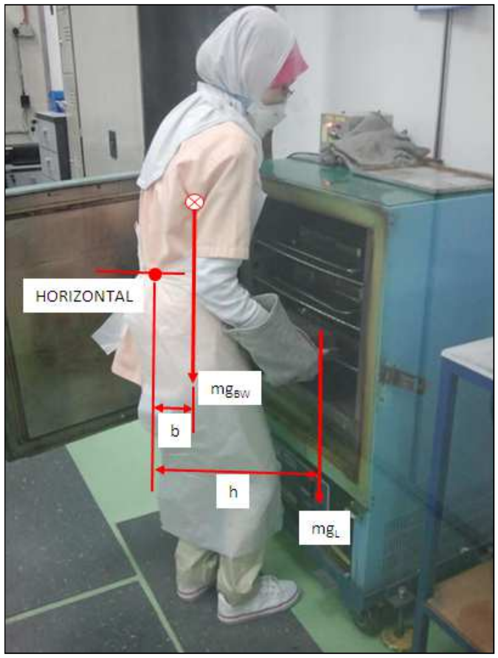


Figure2: A work posture while lifting and handling the tray and the force on operator body

Design the New Fixture

Solid modeling has become an essential tool for most companies that design mechanical structure and machines, and one of the solid modeling software is SolidWorks. SolidWorks software is used to design the new fixture. The prototype of this fixture is being manufactured and trial run in production is conducted. The existing fixture uses heavy block as a force to stick the rod core onto flange core. This proposed fixture also uses the same concept of force, but using two clamps to hold the top fixture and the base fixture. Figure 3 shows a 3D drawing of top fixture for flange core assembly. Figure 4 shows a 3D drawing of bottom fixture for flange core assembly. Figure 5 shows a prototype of flange core assembly fixture. Figure 6 shows a completed assembly of new fixture.

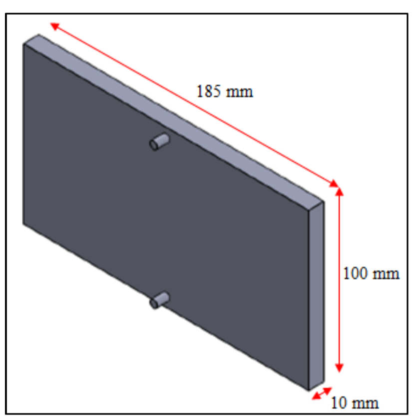


Figure 3: A 3D drawing of top fixture for flange core assembly

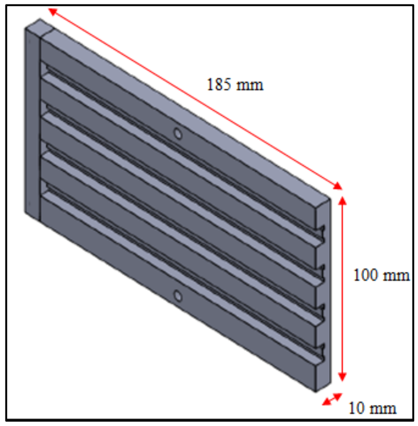


Figure 4: A 3D drawing of bottom fixture for flange core assembly

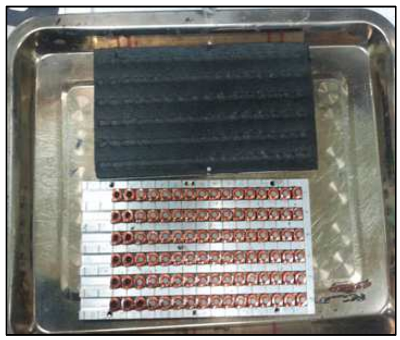


Figure 5: A prototype of flange core assembly fixture

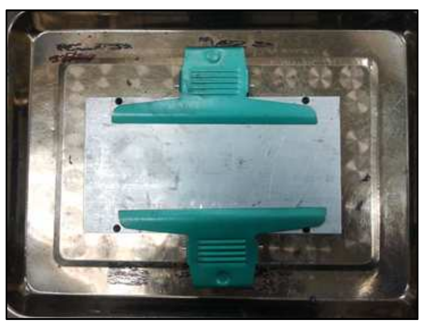


Figure 6: A completed assembly of new fixture

FINDINGS AND DISCUSSION

Findings of Existing Fixture

Referring the Figure 2, the upper body weight of W_{torso} lift the load (tray) with weight of W_{load} create combine clockwise rotational moment. F_{muscle} is calculated using Equation (4).

In this calculation, the assuming such as below:

a) Back muscle with the moment arm about 5 cm
b) Horizontal distance from load, h = 26 cm
c) Horizontal distance from the mass, b = 16 cm
d) Load (tray) = 138 N
e) Torso weight = 400 N
f) α= 60°

$$
\begin{aligned}
F_{muscle} &= W_{load} \times h/5 + W_{torso} \times b/5 \\
&= 138\text{N} \times 28/5 + 400\text{N} \times 18/5 \\
&= 2212.8\text{N}
\end{aligned}
$$

In [13] estimated that2200 to 5500N is the normal range of strength capacity of the erector spinal muscle at the low back. From the above calculation, the back muscle force would be 2212.8N. This result may exceed the capacity of some worker especially women worker. The compression force on L5/S1 disc is calculated as Equation(6).

$$F_{compression} = W_{load} \times \cos\alpha + W_{torso} \times \cos\alpha + F_{muscle}$$
$$= 138N \times \cos 60° + 400N \times \cos 60° + 2212.8N$$
$$= 2481.8N$$

At this level, the disc compression can be hazardous to the workers. In this analysis, the factor that influences the load stress is the weight and the position of the load relative to the centre of the spine. Besides, the size and shape of load, the degree of twisting of the torso, and the distance moved also factor that influences the load stress.

Other than that, the force on leg during handing the tray is calculated using Equation(7). The calculation is shown below:

$$\text{Force per leg, } F = mg \quad (7)$$
$$= 29.9 \times 9.81$$
$$= 293.3N$$

where operator weight = 46 kg, tray load = 13.8 kg and total load per leg, m = (46 + 13.8)/ 2 = 29.9 kg. From calculation above, 293.3N of force will effect on operator leg. This force increases if the operator weight increase.

Findings of New Fixture

The process of insert and withdraw the tray from oven using new fixture will be analyzed by using Multisegment Model. The weight of load is changed from 13.8kg to 3.46kg and α= 60° is changed to α= 80° due to operator no need to bend, while the others dimension remain the same. F_{muscle} for new fixture is calculated using Equation (4).

In this calculation, the assuming such as below:

a) Back muscle with the moment arm about 5 cm
b) Horizontal distance from load, h = 26 cm
c) Horizontal distance from the mass, b = 16 cm
d) Load (tray) = 34.6 N
e) Torso weight = 400 N
f) α= 80°

$$F_{muscle} = W_{load} \times h/5 + W_{torso} \times b/5$$
$$= 34.6N \times 28/5 + 400N \times 18/5$$
$$= 1633.75N$$

From the above calculation, the back muscle force is less than 2200N. Other than that, the back muscle force reduces from 2212.8N to 1633.75N. The compression force on L5/S1 disc for new fixture is calculated as Equation(6).

$$F_{compression} = W_{load} \times \cos\alpha + W_{torso} \times \cos\alpha + F_{muscle}$$
$$= 34.6N \times \cos 80° + 400N \times \cos 80° + 1633.75N$$
$$= 1709.22N$$

From the above calculation, the comparison force on L5/S1 disc is reduced from 2481.8N to 1709.22N. Other than that, the force on leg during handing the tray after using the new fixture is calculated using Equation (7). The calculation is shown below:

$$\text{Force per leg, } F = mg$$
$$= 24.73 \times 9.81$$
$$= 242.6N$$

where operator weight = 46 kg, tray load = 3.46 kg and total load per leg, m = (46 + 3.46)/ 2 = 24.73 kg. From calculation above, the force on operator leg was reduce from 293.3N to 242.6N. This force on leg reduces about 17.3%.

Table 3 shows the comparison analysis between existing fixture and new fixture. It concludes that the weight of fixture is reduced from 13.8kg to 3.46kg, about 74.93% reduction. F_{muscle} is reduced from 2212.8N to 1633.75N, about 26.17% reduction. $F_{compression}$ is reduced from 2481.8N to 1709.22N, about 31.13% reduction. Force per leg is reduced from 293.3N to 242.6N, about 17.3% reduction.

Table 3: The comparison analysis between existing fixture and new fixture

Analysis	Existing fixture	New fixture	Reduction
Fixture weight	13.8 kg	3.46 kg	74.93 %
F_{muscle}	2212.8 N	1633.75 N	26.17 %
$F_{compression}$	2481.8 N	1709.22 N	31.13 %
Force per leg	293.3 N	242.6 N	17.3 %

CONCLUSION

In conclusion, the proposed design of the fixture has been implemented at the company and the load also has been reduced, which is the weight of the fixture is reduced from 13.8kg to 3.46kg, about 74.93% reduction. By implementing the new design, the workers felt very happy and enjoy as they are reduced back pain and less fatigue.

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