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THE DESIGN OF A WHEEL BALANCER BY THE LOAD HANDLING GUIDELINES

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Abstract

In the process of designing a wheel balancer, an ergonomic evaluation model has shown that manual tire handling on the machine was often the major problem. The root of the problem lay in the design of machine's shaft which is influenced by the operative handling task. Several methods were reviewed for determining the correct shaft' sizes, but the Revised NIOSH Equation and the Lifting Stress Calculator were found to be the only suitable models for this study. An application of these mathematical models has showed that the shaft length and the shaft height were the most critical measurement. By analyzing these conclusions, the correct shaft size parameters became clearly defined.

Key Words : Wheel Balancer, Ergonomic Evaluation, Load Handling, Back Injury, Lifting Stress Calculator, NIOSH Equation

INTRODUCTION

When any machine is designed, there should be a base of characteristics that will lead to an acceptable level of human performance.[1] Balancing the tires is a very important operation on any vehicle in order to provide a smoother ride and a greater stability. Garage mechanics are used to balancing wheels whenever mounting new tires, repairing a flat tire, or checking for abnormal tire wear, but before using a wheel balancer, operators have to handle tires on the machine's shaft. And the repetition of this physical task makes it especially tiring when user encounters heavy tires.

In the process of designing a wheel balancer, a French ergonomic evaluation model assessed 23 human factors and found that manual tire handling on the machine's shaft was the major problem. The major problem concerned the design of the machine's shaft which influenced manual handling of the tire. As a matter of facts, a number of pictures

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have established that when a mechanic handles the tire (Fig. 1), shaft length and shaft height have consequences on back injury risks. There is a potential hazard caused by the shaft's size. An explanation of this error is the main objective of the paper.

METHODOLOGY

The task of moving the tire onto the wheel balancer was classified into four steps (Fig. 1). They are:

1. Lifting the tire from the ground to the operator level
2. Loading the tire onto the machine's shaft
3. Unloading the tire from the machine's shaft
4. Lowering the tire back down to the ground level.

This detailed analysis pointed out that handling operations 1 and 4 were not connected with the machine and that the design of wheel balancer's shaft involved only steps 2 and 3. By breaking the job down into the four operations, the critical human postures became clearly defined. Several techniques for determining "safe" handling conditions were reviewed afterwards to investigate steps 1 and 2. There were:

- Acceptable Limits of Manual Handling Loads by One Person[2]
- Equation for Predicting Lifting Capabilities of People[3]
- Revised NIOSH Equation[4]
- Lifting Stress Calculator[5]

The "Acceptable Limits of Manual Handling Loads by One Person" were found to be non-adaptable for this application because of the greater emphasis on the transport distance than on the lifting distance. As to the "Equation for Predicting Lifting Capabilities of People," the height of lift

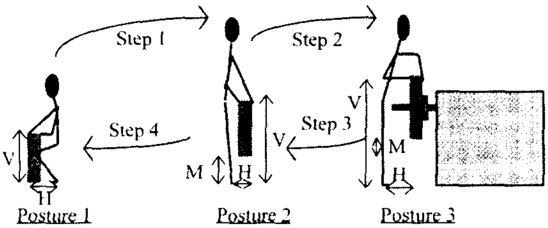

Fig. 1 Handling process on the wheel balancing machine

factor was not sensitive enough for the consideration of the shaft heights' differences. After further review, the Revised NIOSH Equation and the lifting Stress Calculator were found to be the only suitable models for determining the height and the length of the wheel balancer's shaft.

Revised NIOSH Equation

In 1981, the NIOSH equation was developed as an evaluation model, for a two-handed lift up movement when the operator is sessile, considering back injury as the prime risk.[6-8] The revised NIOSH equation permits one to determine the Maximum Safe Load of Lift (MSLL). The MSLL is such that provided the limit is not exceeded, then no administrative or engineering controls are necessary. It means that 99 % of the male and 75% of the female working population are able to carry a load of weight that is smaller than MSLL.

The MSLL is expressed algebraically by the equation:

$$MSLL=23*(25/H)*(1-0.003|V-75|)(0.82+4.5/M)*(1-0.0032A)*FF*IF$$

where

- H: horizontal location forward of the midpoint between the ankles at the origin of lift
- V: vertical location at the origin of the lift
- M: vertical movement distance between the origin and destination of the lift
- A: angle between the sagittal plane and the asymmetric plane
- FF: frequency factor depending on lift frequency, handling time, and posture, as determined by the NIOSH table
- IF: hand-object interface factor determined by the NIOSH table.

In this context, the Lift Load Index (LLI) permits one to explain results in relation to back injury risk:

LLI = Object weight / MSLL

If LLI is smaller than 1, then the task has a very low risk level.

Lifting Stress Calculator

The Lifting Stress Calculator[5] is a user friendly based upon a two-dimensional model of static lifting which recommends the optimum method of lifting given anthropometry, clinical symptoms and the physical characteristics of the load. This model predicts the knee (JK) and back (JB) joint reaction forces as a function of back joint and ankle joint angles, and anthropometrical measurements for a physical load condition (weight and height). Zoptimum, a coefficient of total joint forces, is given by the following equation:

Zoptimum = (JBm + JKm) / W

where JKm and JBm are the medians of the possible knee and back joint reaction forces, and W is the weight of the subject.

A regression equation (r^2=0.93), derived from the Zoptimum, summarizes the effects of vertical load location (V), weight (W) and horizontal distance (H) from the wheel:

$$\text{Zoptimum} = -5H + 0.001P + 17.9H^2 + 3V - 8.5V^2 + 4.14$$

A low Zoptimum indicates that joint forces are small.

RESULTS AND DISCUSSION

Observations in service stations showed that it took 20 minutes to balance the four wheels of a vehicle (0.2 tire/min). It was also recorded that the sizes of the tires that were balanced were usually 305 mm (12 inches) and 356 mm (14 inches) diameters. Thirty students were recruited from Chonbuk National University for a subjective test. The subjects who volunteered for the experiment were not on medication and had no physical ailments. Measures in Table 1 have been done on the 50^{th} percentile (stature=1.68m). The data used in this study were generated experimentally by lifting 305 mm and 356 mm diameter tires onto different heights of machine's shaft. Each subject performed the same task two times and the average value was taken into account. Moreover, three measures (A, B, C) were taken in order to compare shaft heights in order to predict the risk of back injury for different tire weights.

Table 1 Measures on different tires and shaft heights

Measure	A		B		C	
Shaft height	770 mm		710 mm		770 mm	
Wheel diameter	305 mm		305 mm		356 mm	
Tire weight	10.5 kg		10.5 kg		17 kg	
Step	S2	S3	S2	S3	S2	S3
H (mm)	250	340	250	340	250	340
V (mm)	750	920	750	860	750	940
M (mm)	170	170	110	110	190	190

Table 2 Maximum Safe Load of Lift and Lifting Load Index Measure

Measure	A		B		C	
Weight of tire-kg	10.5		10.5		17	
Step	S2	S3	S2	S3	S2	S3
Weight factor-kg	23	23	23	23	23	23
Horizontal factor	1	0.735	1	0.735	1	0.735
Vertical factor	1	0.949	1	0.967	1	0.943
Movement factor	1	1	1	1	1	1
Asymmetric factor	1	1	1	1	1	1
Frequency factor	0.95	0.95	0.95	0.95	0.95	0.95
Interface factor	1	1	1	1	1	1
Max. Safe Lift Load	21.85	15.24	21.85	15.53	21.85	15.14
Lift Load Index	0.48	0.69	0.48	0.68	0.78	1.12

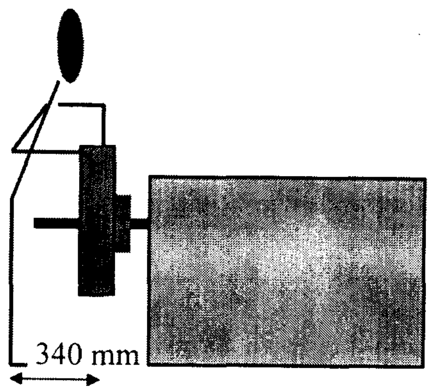

Fig. 2 Horizontal factor of step 3

Table 2 outlined the results obtained in calculating the Maximum Safe Load of Lift and the Lifting Load Index from Revised NIOSH Equation. This calculation pointed out that weakness occurred during step 3(MSLL≃15 kg) and that the LLI for measure C was in excess of the critical value of 1. It has been noted that the horizontal factor for situation 3 (HF3): H value was 340 mm. In fact, for this free posture (Fig. 2), the length of the wheel balancer's

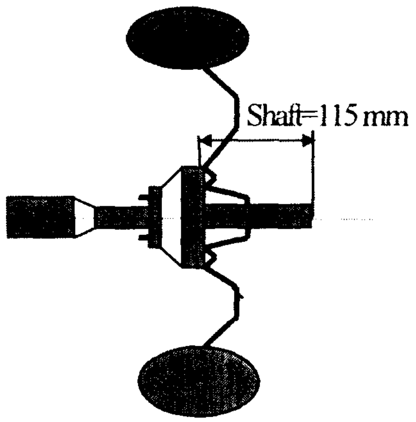

Fig. 3 Shaft length

Table 3 Zoptimum

Shaft Height mm	770	710	770
Measure	A	B	C
Step	S3	S3	S3
V (mm)	920*	860*	940*
Z optimum	0.18	0.91	0

* Values extracted from Table 1.

shaft was found to be the major reason for the mechanics back bending. Therefore reducing shaft length can be regarded as a solution. As step 3 in measure C shows the maximum Lifting Load Index, shaft length was recalculated to reduce back injury risk and to obtain the critical LLI of 1. As a result, the horizontal distance H should be 305 mm, which indicates a value of 35 mm less than the initial H value. Therefore the critical shaft length is 115 mm (150-35 mm) which will allow any operator to handle a 356 mm tire diameter ($\cong$17 kg) without excessive back injury risk (Fig. 3).

For the purposes of this comparison, three lifting conditions were chosen to represent a range of shaft heights when man handling a tire onto the wheel balancer (Table 3). The results from the Lifting Stress Calculator indicate that an increase in the height of the load lead to a corresponding decrease in the Zoptimum, along with further corresponding knee and back flexion angles. Nevertheless,

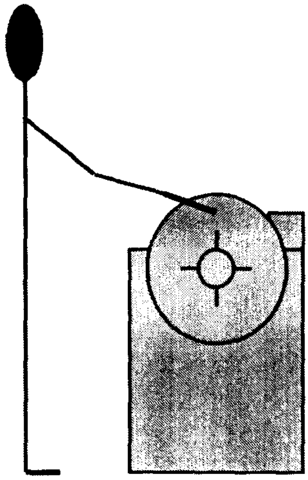

Fig. 4 Back straight stature

height had a relatively small influence on Zoptimum and NIOSH results in Table 2 confirmed this point. A 770 mm shaft height was chosen because a person of average height can still maintain a straight posture when adding the balancing weight(Fig. 4).

CONCLUSION

In the design of a wheel balancer, the emphasis of an ergonomic evaluation is on 23 human factors. Only the Lifting Stress Calculator and NIOSH Criteria permitted relevant calculations for determining the correct shaft length and height in order to reduce back injury risk. The final solution has been achieved to have a productive, comfortable and effective human use. These models to apply for any company mechanical system and the presented procedures provide a valuable tool for ergonomic specialists who work with mechanical systems.

REFERENCES

(1) SON, K. and Lee, H.T., A Computer-Aided-Design program of Man -in-Cab for Heavy Construction Vehicle, Trans. KSME Part A, Vol. 20, No.11, pp.3525~3537, 1996.

(2) AFNOR Association Francaise de Normalisation, Limites Acceptables de Port Manuel de Charges par une Personne : Renault Aide memoire d'ergonomie, 92080 Paris La Defense, France, French standard X35 109, 1983.
(3) MITAL, A., Equation for Predicting Lifting Capabilities of People, NIOSH National Institute for Occupational Safety and Health, 4676 Columbia Park Way, Cincinnati, Ohio, USA, NIOSH Grant No. 5-R01-OH-00545-02, 1985.
(4) WATERS, T. H., PUTZ-ANDERSON, V., GARG, A., and FINE, L. J., "Revised NIOSH Equation for the Design and Evaluation of Manual Lifting Task", Ergonomics, 36, 749-776, 1993.
(5) ARNIANPOUR, M., BEJJANI, F. J., PAVLIDIS, L., and BEJJANI, N., Lifting Stress Calculator, Hospital for Joint Diseases Orthopaedic Institute, New York University, New York, USA, 1985.
(6) NIOSH, Work Practices Guide for Manual Lifting, Department of Health and Human Services, Cincinnati, Ohio, USA, Publication No. 81 122, 1981.
(7) APTEL, M. , DRONSARD P., Charge Maximale Admissible de Lever de Charges (L' Equation Revisee du NIOSH), Institut National de Recherche et de Securite, 75680 Paris Cedex 14, France, 1995.
(8) National Technical Information Service. Scientific Support, Documentation for the revised 1991 NIOSH lifting equation, Springfield, US Department of Commerce, 1991.