# Improving of a Steering System for walking tractor - Trailer Combination to Increase Operator's Comfort and Ease of Control

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## ABSTRACT

The aim of present study was develop the performance of walking tractor-trailer combination, increase the ability of control and steering, maneuverability, reduce the hand transmitted vibration (HTV), discomfort, stress and probability of accident for walking tractor operators. The location of controls in existing walking tractor with respect to anthropometric suitability of operators and rearrangement for improved operator's ergonomics was analyzed. To compare existing system with improved system, and find the affects of improved workplace layout over the existing one in terms of physiological cost and discomfort of the walking tractor operator, turning radius, operator hart rate, energy cost and HTV were measured. The energy cost of riding walking tractor -trailer with improved workplace layout is 9.2% lesser than that of riding unmodified walking tractor -trailer. The over all discomfort and body part discomfort of operator riding walking tractor-trailer with improved workplace layout were reduced by 38.5 and 17.9 % walking tractor -trailer with and without improved work space layout. The HTV was measured and analyzed as per the guidelines of International Standards ISO 5349 (1986 Vibration was measured using the portable four-channel multi-analyzer system The data collection included frequency-unweighted and frequency-weighted vibration in RMS acceleration, frequency response of the vibration. The HTV reduction of the walking tractor with trailer at the handles for steering system was improved from 10.1 to 11.6 % and from 11.9 to 17.3 % on farm road and Concrete road respectively at selected levels of forward speed of operation. The turning radius decrease from 6.2 to 2.7, 6.7 to 2.8 and 7 to 3 meter for unmodified and modified walking tractor respectively at speed of 3, 4 and 5 km/h. Average operator hart rate has reduction at the rate of 20% for modified compare to unmodified walking tractor. Reduction in operator heart rate was because of fixing the handle steering and convenience during the operating.

**Keywords:** walking tractor, steering, workplace layout, vibration, heart rate, turning radius.

## 1. INTRODUCTION

The walking tractors are used in very many areas as well as rice and sugarcane producing areas. The operators of hand tractors experience high levels of vibration in the hand and arm, which cause early fatigue and result in shorter work hours. So the operator of a walking tractor has to endure various environments and stresses. Agricultural workers have different anthropometric dimensions, perception of comfort, strength, sensory capabilities, mental or cognitive capabilities for storing and training. So their processing information, making decisions, experiences, motivation, cultural background, perception of risks etc are different from the industrial workers. Nowadays researchers are placing attention to ergonomic aspects of the farm workers and this proposed research work to be carried out is also another step towards changing to betterment of walking tractor operators. The ergonomic aspects of walking tractors are of great importance as working with walking tractor involves considerable physical strain to the operator. The working performance of a walking tractor depends not only on the machine but also on the operator. If ergonomic aspects are not given due consideration, the performance of the man-machine system will be poor and effective working time will be reduced. The man-machine environment system of walking tractor operation indicates that the operator of a walking tractor has to endure various environments and stresses. Among these factors, environment is more important because it significantly accelerates fatigue and affects sensitivity and reaction heart rates of the operator. Controlling the walking tractor with trailer while turning causes considerable fatigue to the operator.

## 2. REVIEW OF LITERATURE

The operators of walking tractors experience high levels of vibration in the hand and arm, which cause early fatigue and result in shorter work hours. The operator of a walking tractor has to endure various environments and stresses. The various disorders associated with exposure to vibration are vascular, neurological, musculoskeletal, and other effects. The term ‘hand–arm’ vibration syndrome (HAVS) is used collectively for the different symptoms of the disorder (Mishoe and Suggs, 1977; Reynolds and Keith, 1977; Wasserman and Taylor, 1991). Frequency-weighted vibration acceleration of a moving component either reciprocating or rotating causes vibration depending on its own degree-of-freedom and the natural frequency. A machine consists of many such moving components which contribute to the further vibration of the whole system. This interference of vibration makes the vibration of the whole system rather complex. Thus machines produce a most dominant frequency of vibration and subsequent frequencies of vibration are observed at a periodic interval. However, human response to hand–arm vibration varies enormously for frequencies between 6.3 and 1250 Hz. At low frequency lesser than 100 Hz, the vibration is transmitted from the handle to the hands, arms and shoulders without attenuation and therefore the perception is high. The perception greatly decreases with increasing the frequency and reduction of vibration transmissibility throughout the hand–arm system (Broyde et al., 1989; Giacomina et al., 2004).The international standard ISO 5349 (ISO, 2001) recommends the use of frequency-weighted acceleration. To establish the stress potential of particular work, it may also be necessary to consider the working posture and environmental parameters such as temperature, humidity, noise and dust levels. Grandjean (1988) has suggested that the measurement of stress at work must focus on the individual’s psychological state. Psychophysical methods are one of the methods used to determine acceptable workloads (Snook and Ciriello, 1991; Garg et al., 2006). Psychophysical self-rating based on Borg scale, CR-10 (Borg, 1982) has been used for measurement of perceived stress. Wos et al. (1988) have found that self-rating based on

Borg's scale can be used to assess vibration intensity. The pictorial representations, where discomfort is plotted on a human figure, have been used for studies of vibration tolerance and discomfort and also for studies of back pain (Kuorinka, 1983).

## 3. MATERIALS AND METHOD

The field experiment and the ergonomics refinement was carried out in the steering system include:

As it has illustrated in figure (3.1) the two handle bars attached to the body of a 7 Hp diesel walking tractor are removed and rigidly fitted in front of the toe bar of the trailer with a bracket. The handle bars are supported with fixtures from the toe bar of the trailer. The main clutch and brake lever from the handle bar of the walking tractor is connected to the clutch assembly through a rod and cable supported by clamps mounted on the left side handle bar. The two steering cables were extended in linear mode through a coupling mounted on the two sides of the bracket mounted on toe bar of the trailer. The steering cable consists of two portion *i.e.*, one is connected between the steering clutch and the coupling and the other connected between the coupling and steering lever in the body of he walking tractor.

Fig 3.1- 7Hp diesel walking tractor with removed handles from body and rigidly fitted in front of the toe bar of the trailer with a bracket

Assessment of ergonomic parameters and physical work load for comparing modified walking tractor with the unmodified HR was taken as a reliable index. Selected subject was given enough of rest and then their resting heart was measured with the heart rate monitor. After the complete rest, the subjects were asked to perform operating the walking tractor. During the operating the heart rate was recorded every 10 second. To evaluate total physiological expenditure, physiological reaction, both during the work load (activity) and during the recovery period are considered. Heart rate was recorded using Mounting Polar Electro Oy Pacer heart rate monitor on the body firstly at rest, during the activity and recovery. From the value of HR, total cardiac cost of work (TCCW) and physiological (PCW) for walking tractor operation was calculated.

### 3.2 Ergonomic evaluation

Ergonomic evaluation of walking tractor with improved work place layout was conducted with selected 12 male subjects. The subjects were screened for normal health through medical investigations. The age, mass and height of the selected male subjects were 29.9±3.6 years, 60.9±3.4kg and 160.4 ±6.3 cm respectively. The selected twelve subjects were calibrated in the laboratory by indirect assessment of oxygen uptake. The maximum aerobic capacity of the selected twelve male varied from 1.90 to 2.26 l $min^{-1}$. The ergonomic evaluation was conducted to ascertain the improved comfort, safety and ease of operation. The trials were conducted between 10.00 AM to 5.00 PM during the October 2009. The temperature and relative humidity varied from 24 to 28°C and 69 to 76 % respectively during the period of evaluation. The evaluation was carried out in terms of hand transmitted vibration, heart rate (HR), oxygen consumption rate (OCR), energy cost of operation (ECR), acceptable work load (AWL), limit of continuous performance (LCP), over all discomfort rating (ODR), over all safety rating (OSR), over all rating of ease of operation (OER), body part discomfort score (BPDS) and vibration transmitted to the operator. The mean values of discomfort, safety and ease of operation rating of the subjects are furnished in table 3.2.1. as below

| walking tractor operation | Rating | ODR Scale |
|---|---|---|
| A. Overall discomfort rate (ODR) | | |
| walking tractor -trailer without improved work place layout | 6.5 | < More than discomfort. < 5 |
| walking tractor -trailer with improved work place layout | 4.0 | < Moderate discomfort 3.5 to 5 |
| B. Overall safety rating (OSR) | | |
| walking tractor -trailer without improved work place layout | 5.5 | < Less inconvenient and less unsafe. < 5 |
| walking tractor -trailer with improved work place layout | 4.5 | > Less convenient and less safe. 4 to 5 |
| C. Overall ease of operation rating (OER) | | |
| walking tractor -trailer without improved work place layout | 5.8 | Less inconvenient and less unsafe. < 5 |
| walking tractor -trailer with improved work place layout | 3.1 | > Moderately convenient and moderately safe. > 3.5 |

The cost of riding walking tractor -trailer with improved work place layout is 9.2 % lesser than that of riding walking tractor -trailer without improvement. The mean values of oxygen consumption rate (OCR) in terms of $VO_2$ max and the work pulse values were much higher than that of the AWL limit of 35 % of $VO_2$ max and higher than the LCP value of 40 beats $min^{-1}$, which is clear indicative of the fact that the walking tractor -trailer operation could not be performed for longer duration without adequate rest. Mean values of body part discomfort score of the subjects for walking tractor -trailer operation are furnished in table 3.2.2.

Table 3.2.2 Body part discomfort for walking tractor -trailer operation

| | BPDS | Score |
|---|---|---|
| Modified walking tractor -trailer | **Heavy pain** in left and right shoulders, mid back and neck. **Moderate pain in lower back and neck** | 39 |
| Unmodified walking tractor -trailer | **Moderate pain** in left and right shoulders, mid back and neck. **less pain in lower back and neck** | 32 |

The over all discomfort and body part discomfort of operator riding walking tractor -trailer with improved work place layout is reduced by 38.5 and 17.9 % respectively when compared with walking tractor -trailer without improvement. The walking tractor -trailer with improvement resulted in 18.2 and 46.6 % increase in safety and ease of operation when compared with riding walking tractor -trailer without improvement. The modified steering system in modified walking tractor -trailer arrested the relative motion of the operator between the trailer seat and steering handle and the up and down swing motion of the handle bar. Controls *viz.(such as),* steering clutch, main clutch lever, brake lever, main gear shift lever and rotary gear shift lever are well within the reach of the operator. The mean values of physiological response of the subjects for walking tractor –trailer operation are furnished in table 3.2.3

Table 3.2.3 Mean values of physiological response for walking tractor operation

| walking tractors | Heart rate beats $min^{-1}$ | Energy cost, kJ $min^{-1}$ | AWL (35% VO2 max) | LCP beat $min^{-1}$ |
|---|---|---|---|---|
| walking tractor-trailer without improved work place layout | 136.1 | 27.1(Heavy) | 61.7 (> AWL) | 48.2 (>LCP) |
| walking tractor -trailer with improved work place layout | 125.6 | 24.6 (Heavy) | 56.1 (>AWL) | 43.8 (>LCP) |

### 3.3 Steering system for walking tractor trailer

The steering wheel serves two purposes: *viz.* To transmit steering forces and To support the body of the operator. The steering handles position allows the operator's back to be braced against the lower backrest at all times. The arm each encourages grasping the sides of the steering handles for maximum stabilization. The elbow should remain partly flexed permitting the upper arms position to hang freely close to the side. If the plane of steering handle is between approximately 30° to 45° from the horizontal the operator's forearm rests on the steering handle for relaxation without pulling the shoulder girdles forward into a round shouldered position. The elbow and shoulder joints are, capable' of extreme mobility. However an excessive reach to the steering handle places burden on the muscles, which hold the arm up against gravity. The location of controls in walking tractor with and without improved work place layout for walking and riding type walking tractor with reference to the seat rest are measured and the values are furnished in table 3.3.1

Table 3.3.1 Location of controls in walking tractor with and without improvement

| Serial No. | Locations of controls | walking tractor with trailer | |
|---|---|---|---|
| | | Without replaced | With improved |
| i | Distance between seat rest and handle, mm | 710 | 500 |
| ii | Minimum distance between seat rest and clutch lever, mm | 980 | 870 |
| iii | Distance between seat rest and clutch lever, mm | 1220 | 1100 |
| iv | Distance between seat rest and main gear shift lever, mm | 1200 | 1280 |
| v | Distance between seat rest and rotary gear shift lever, mm | 1300 to 953 | 1300 |
| vi | Distance between seat rest and throttle lever, mm | 805 to 546 | 630 |
| vii | Distance of brake pedal form trailer seat | 730 | 670 |

**3.4 Vibration characteristics in stationary mode**

Machine vibration at the root of handle bar and handle grip in stationary mode was measured for the walking tractor with and without improved work space layout using portable pulse multi-analyzer system (Brüel & Kjaer Type 3560 C). The machine vibration was measured using the ENDEVCO Istron model 751-10 accelerometer of the B&K instrument. Vibration signals in the vertical mode were recorded by employing Fast Fourier Transform (FFT) technique using the FFT analyzer built in the PULSE multi-analyzer system. FFT is a powerful analytical tool which transforms the random time domain data into highly descriptive frequency data. The trial was conducted at selected levels of engine rpm as (1500, 1750 and 2000 rpm). Each trial was repeated for three times with an acquisition period of 30s, and the peak value arrived from the spectrum was averaged for each selected level of upper speed. The vibration from the handle of the walking tractor is transmitted to the hand and arm of the worker through the palm of his hand. The hand transmitted vibration was measured at handle-grip level as per the guide lines issued in ISO 5349 (1986). The transducer (B&K, Type 4392) mounted to be inserted between the fingers grip and the handles. The transducer is inserted between the middle and index fingers of left hand and between the middle and ring fingers for right hand. The orientation of the measurement axes of the accelerometer is as per the guide line stipulated in ISO 5349 (1986). The hand transmitted vibration was measured for both modified and unmodified walking tractor-trailer in stationary and riding mode. Measurements were carried out at selected levels of engine speed of walking tractor. The pulse Programmer was activated after the walking tractor was started and the measurement was recorded with an acquisition period of 60 seconds. Each trial was repeated five times at selected levels of engine speed in stationary mode. The vibration characteristics of walking tractor handle is different while riding a walking tractor with an empty trailer. So vibration levels were measured on handle for walking tractor with and without improved system during transport on farm and bitumen road in same path but in virginal place. The measurement was taken at all selected levels of forward speed of operation in riding mode. Each trail was repeated for three times with an acquisition period of 30s and the peak value arrived from the spectrum was averaged for each selected levels of forward speed. The exposure guideline was followed as per ISO 5349 (1986). The values of HTV of 5 runs were averaged at corresponding frequency for one subject in each rpm engine. The procedure was repeated for all the subjects and the mean value for each selected levels of engine was computed. The exposure time limit is then predicted by superimposing the mean measured values of 12 subjects at each frequency on the exposure guide line.

## 4. RESULTS AND DISCUSSION

### 4.1 Location of controls

In the existing design, the trailer is attached with the walking tractor through a single point hitch. The handle bar attached with the body of the walking tractor moves up and down while riding with the trailer. Accordingly, the height of the handle which varies from 610 to 950 mm of ground level (because of exchanging the position of handles during the riding mode) and this causes discomfort to the operator. In the walking tractor with improved work place layout, the handle bars are attached to the toe bar of the trailer and hence the height remains constant. In the existing design to negotiate turns, the operator has to lean side ways to hold the handle which swings to right or left as the turn may be. The handle swings out of reach (Location of handle grip from the seat rest of trailer is 1700 mm and the handle is inclined at 46º from the axis of trailer at extreme tuning condition). The operator jumps out of the seat and steers the walking tractor by holding the handle in standing posture from ground level improved steering system. The lateral swing of the handle is arrested and the operator can steer the walking tractor with trailer from the seat of the trailer when negotiating turns. The specifications of the new steering system for walking tractor -trailer has illustrated in table 4.1.1

Table 4.1.1 Specifications of with improved steering system for walking tractor - trailer

| S. No. | Details | Value mm |
|---|---|---|
| i | Over all dimensions of the bracket fixed in toe bar of the trailer (Lx B x H), | 120 x 100 x 90 |
| ii | Over all dimensions of the clamps fixed in bracket (L x B x H) | 100 x 40 x 40 |
| iii | Length of steering cable from steering clutch to the coupling | 950 |

| | | |
|---|---|---|
| iv | Length of steering cable from the coupling to steering lever in the body of he walking tractor | 1300 |
| v | Over all dimensions of the frame connecting the lower end of the handle bar with trailer toe bar(L x B x H) | 250 x 140 x70 |
| vi | Length of clutch rod | 750 |

In the modified walking tractor location of controls *viz.*, steering clutch, main clutch lever, brake lever, main gear shift lever and rotary gear shift lever with reference to the seat of the operator is nearer when compared with the existing design. Hence the operator finds easy to reach the controls and operate the tractor trailer.

### 4.2 Machine vibrations of walking tractor with trailer in stationary and transporting mode

Machine vibration at root of handle bar and handle grip in stationary mode was measured for the walking tractor with trailer and the peak value arrived from the spectrum was averaged for selected levels of engine speed and the values are furnished in table 4.2.1.

Table 4.2.1 Machine vibrations of walking tractor with trailer in stationary mode

| Engine rpm | Peak acceleration, $ms^{-2}$ modified&(unmodified) | |
|---|---|---|
| | Root of handle bar | Handle |
| 1600 | 4.24 (5.28) | 8.35 (12.05) |
| 1900 | 6.36 (7.40) | 11.79 (15.49) |
| 2200 | 7.55 (8.59) | 13.24 (16.94) |
| 2500 | 8.68 (9.72) | 14.24 (17.94) |
| 2700 | 10.03 (11.07) | 17.39 (21.09) |
| 3000 | 11.36 (12.40) | 19.59 (23.29) |
| 3200 | 12.35 (13.03) | 21.37 (24.81) |

It is observed that as the engine speed increased, the peak acceleration also increased at root of handle bar and handle grip of walking tractor with trailer. The increase in engine rpm from 1600 to 3200 rpm resulted in three times increase in peak acceleration at root of the handlebar and more than two fold increases at handle grip of walking tractor. The peak acceleration observed at the root of the handle bar and handle grip with walking tractor with improved steering system was lower than that of walking tractor – trailer without workplace layout. The magnitude of reduction varied from 5.2 to 19.7 % and 13.9 to 30.7 % at the root of the handle bar and handle grip respectively. The peak values of acceleration arrived from the vibration spectrum for walking tractor with and without improvement at selected forward speeds on farm road and bitumen road are shown in table 4.2.2

Table 4.2.2 Machine vibration of walking tractor with trailer on transport mode

| km/h | Peak acceleration, $ms^{-2}$ modified&(unmodified) | | | | | |
|---|---|---|---|---|---|---|
| | Farm road | | | Bitumen road | | |
| | Root of handle bar | Handle grip | Seat | Root of handle bar | Handle | Seat |

| | | | | | | |
|---|---|---|---|---|---|---|
| 3.5 | 3.96 (4.31) | 4.41 (4.76) | 1.38 (1.73) | 3.77 (4.12) | 3.41 (3.76) | 1.01 (1.36) |
| 4.0 | 4.61 (4.95) | 5.15 (5.52) | 1.39 (1.74) | 4.38 (4.73) | 4.93 (5.28) | 1.07 (1.42) |
| 4.5 | 4.98 (5.33) | 6.51 (6.86) | 1.47 (1.82) | 4.72 (5.07) | 5.37 (5.72) | 1.33 (1.68) |
| 5.0 | 5.12 (5.47) | 6.72 (7.05) | 2.56 (2.91) | 4.77 (5.12) | 5.39 (5.74) | 1.45 (1.81) |

The reduction of machine vibration at handle grip of the walking tractor with trailer having improved steering system was from 5.2 to 7.4 % and from 6.1 to 9.3 % on farm road and bitumen road respectively at selected levels of forward speed of operation.
The peak value of HTV in bitumen road was lower than that of farm road. This may probably due to the fact that unevenness and surface roughness of farm road induced more terrain vibrations compared to the relatively smooth level in bitumen road. The mean value of r.m.s weighted acceleration HTV of all subjects at selected levels of forward speed for walking tractor with and without improved workplace layout during transport on farm road is presented in table 4.2.3 as below:

| speed (km/h) | Mean value of root mean square acceleration (HTV) ($ms^{-2}$) | Exposure time (h) | Probability of white finger syndrome (years) |
|---|---|---|---|
| A | Farm road | | |
| 3.5 | 2.31 (2.58) | 2 - 4 (1-2) | 9.45 (8.85) |
| 4.0 | 2.67 (3.02) | 1 - 2 ( 1-2) | 8.19 (7.61) |
| 4.5 | 3.09 (3.45) | 1 - 2 (1/2 -1) | 6.89 (6.17) |
| 5.0 | 3.58 (3.98) | 1/2 -1 (1/2-1) | 5.88 (5.46) |
| B | Bitumen road | | |
| 3.5 | 1.79 (2.02) | 2 – 4 (2-4) | 12.73 (10.50) |
| 4.0 | 1.96 (2.35) | 2 – 4 (2-4) | 10.62 (9.27) |
| 4.5 | 2.26 (2.64) | 2 – 4 (1-2) | 9.59 (8.48) |
| 5.0 | 2.75 (3.12) | 1 – 2 (1-2) | 7.66 (6.85) |

The value of hand transmitted vibration increased with the increase in forward speed on farm road and bitumen road respectively.

**4.3 Turning radius**

The measured values of turning radius for walking tractor -trailer with and without improved workplace layout are furnished in table 4.3.1

Table4.3.1. Turning radius for walking tractor -trailer in different condition

| Serial No. | Forward speed, $kmh^{-1}$ | Turning radius, m | |
|---|---|---|---|
| | | walking tractor -trailer without improvement | walking tractor -trailer with improvement |
| i | 4 | 6.20 | 2.7 |

| | | | |
|---|---|---|---|
| ii | 5 | 6.74 | 2.8 |
| iii | 6 | 7.32 | 3.0 |

The turning radius for the modified walking tractor -trailer is smaller by 62.5 to 64.0 %.

## 5. CONCLUSION:

The core is for omitting the vibrations it is better to slash the relation between the source of vibration and user part (handles).The ergonomic aspects of walking tractors are of great importance as working with walking tractor involves considerable physical strain to the operator. If ergonomic aspects are not given due consideration, the performance of the man-machine system will be poor and effective working time will be reduced. On the other hand, due to heavy demand on the worker's biological systems, the walking tractor operation results in clinical and anatomical disorders and in long run, will affect the workers health. The man-machine environment system of walking tractor operation indicates that the operator of a walking tractor has to endure various environments and stresses. The environment includes all the factors in the surroundings which have an effect on man-machine system. Among these factors, environment is more important because it significantly accelerates fatigue and affects sensitivity and reaction rates of the operator. Physical efforts required for the operation of the machine combined with exposure to varying degrees of solar radiation, dusty environment, monotonous nature of the job and the severe hand vibrations cause a lot of stress on the operator resulting in physiological and psychological fatigue after the daylong operation. The main clutch and brake lever form the handle bar of the walking tractor are connected to the clutch assembly through a rod and cable supported by clamps mounted on the left side handle bar. The two steering cables were extended in linear mode through a coupling mounted on the two sides of the bracket mounted on toe bar of the trailer. In the s with improvement the two handle bars are attached to the toe bar of the trailer. The vertical movement of the handle (from 610 to 950 mm) from ground level as observed in the existing design is arrested and this enables the operator to exercise firm grip of the handle. In the existing design to negotiate turns, the operator had to lean side ways to hold the handle which swings to right or left as the turn may be. The handle swings out of reach (Location of handle grip from the seat rest of trailer is 1700 mm and the handle is inclined at 46º from the axis of trailer at extreme tuning condition) and the operator jumps out of the seat and steers the walking tractor by holding the handle in standing posture from ground level. With improved steering system, the lateral swing of the handle is arrested and the operator can steer the walking tractor with trailer from the seat of the trailer when negotiating turns. The reduction of HTV at handle of the walking tractor with trailer having improved steering system was from 10.1 to 11.6 % and from 11.9 to 17.3 % on farm road and bitumen road respectively at selected levels of forward speed of operation. There was no variation in the safe exposure time of the operator with improved work space layout. However the probability of occurrence of finger blanching was increased from 6.4 to and 10.5 and 10.6 to 20.1 % during transport on farm and bitumen road respectively with improved workplace layout. The turning radius for the walking tractor-trailer with improvement is smaller by 62.5 to 64.0 % than that of walking tractor-trailer without improvement.

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