Development of Reach Envelopes for Optimum Location of Tractor Controls Based on Central Indian Male Agricultural Workers

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ABSTRACT

Tractor operator's comfort and safety have received considerable attention abroad particularly with respect to operator’s workplace, noise and vibration. It is necessary to design various controls and workplace on tractors with due consideration to the anthropometric data of Indian agricultural workers so as to achieve higher performance and efficiency with better comfort and safety of the operators. Therefore, the present study was aimed to develop the hand and leg reach envelopes based on anthropometric data of Central Indian male agricultural workers (N=825) to optimise the location of tractor control levers. The important anthropometric data of agricultural workers used for development of hand and leg reach envelopes were age, weight, stature, elbow grip length, shoulder grip length, elbow rest height, sitting acromial height, knee height sitting, popliteal height sitting, buttock popliteal length, buttock knee length, foot length etc. The mean, 5th percentile and 95th percentile data were used to develop the reach envelopes. The analysis of optimum hand reach envelope indicated that the workers hand could reach within the range of 431-636 mm forward and 252-405 mm above the seat reference point (SRP). Similarly, the 5th percentile leg reach envelope indicated that the workers leg could reach within the range of 460-894 mm forward and 374 mm below the SRP. Therefore, it may be concluded that the frequently operated controls in tractors like steering wheel, clutch pedal, brake pedal, accelerator pedal etc. should be placed in optimum hand and leg reach envelopes for the user population.

Key words: Leg reach, Hand reach, Tractor control, Anthropometric data, Central India

INTRODUCTION

Operating a tractor imposes a lot of physical and mental stress upon the operator. If the operator seat and controls are not properly located, his work performance may be poor and there is possibility of accident also in four wheel tractors and self-propelled machines. Proper design of controls is also important for comfortable and safe operation of the equipment. The design involves location of control as well as strength limits for operating these controls. At present, the data available for Indian operators on these aspects are very limited. Some case studies for workplace layout for operators of tractors/self-propelled equipment have been carried out in this country. However, the Bureau of Indian standards IS 12343 (1998) at present has adopted ISO standard. This standard is primarily based on anthropometric data of Western workers.

A survey of tractor drivers in the Central India indicated that about 36% operators felt uncomfortable while operating tractor controls (Anonymous, 2002). The placement of brake pedals, clutch pedal and hydraulic control lever was not conveniently in the tractors.
Morrison and Harrington (1962) reported that the steering wheel angle should be between 30-45° with horizontal, knee angle between 135-160° and foot at 28° above the horizontal plane for the operators in the stature range from 157.5 to 187.5 cm for 5th to 95th percentile of operator’s population.

The dimensions for optimum pedal area for British driver, when the controls were operated either by heel or toe were recommended and suggested that the vertical distance of pedal should vary with type of task and should not be more than 400 mm. The pedal should be displaced no farther than 75 to 125 mm from the midline (Matthews and Knight, 1971).

Some case studies on workplace layout of tractors were carried out for Indian operators. It was observed that nearly all locations of tractor controls met the requirements given in the Indian Standard (IS 12343, 1998). However, Indian operators were not able to reach all the locations and operate controls comfortably (Yadav, 1995; Tiwari, 2001; Mehta et al., 2007 and Kumar, 2009).

Arude et al. (1999) studied control locations in popular models of Indian tractors and tractor operators’ activities while performing the ploughing operation. They observed significant difference in the placement of clutch pedal, brake pedal, hydraulic control lever, steering wheel and footrest from seat reference point (SRP) in the workplace layouts of different models of tractors. The frequencies of operation of clutch, brake, hydraulic control lever and backward views were observed as 0.5, 1.55, 3.13 and 8.55 actions/min, respectively.

Tiwari (2001) conducted a study on ergonomical evaluation of tractor operator workplace and activities. He reported that nearly all locations of tractor controls met the requirements given in the Bureau of Indian Standards IS 12343 (1998). But the range of dimensions presented in the standard was very large.

Gite et al. (2009) compiled data on 79 anthropometric body dimensions and 16 strength parameters of 12525 (8025 male and 4500 female) agricultural workers from 12 states of India. Some studies on anthropometry have been carried out on Indian agricultural workers but few attempts were made to develop reach envelopes based on the anthropometric data of Indian agricultural workers for the design of workplace and location of tractor controls.

The optimal design of tractor workplace layout i.e. of seat and controls may be achieved by integrating anthropometric data with other technical feature of design. The placement of controls in the tractor operator’s workplace is a complex task for the designers. If the controls are not properly adapted to the anthropometric data of the operators, the performance demanded by the task may quickly reach and even exceed the limit of tolerance. As a result of excessive stress and premature fatigue, it will lead to impaired health and the possibility of accidents will also increase. The design of most of the tractor models available in India are based on the anthropometric data of agricultural workers of western countries.

The safety, comfort and convenience should be considered in the design, location and construction of the operator’s work place (Hansson et al., 1970). The work place should be located on a tractor so that visibility in the driving position is good without requiring the operator to work in an awkward and tiring posture. Levers, pedals and instruments should be conveniently and logically located and work place should fit both tall and short operators. In addition, the operator should be able to change his working position easily and the work area should be free of sharp edges and obstructions.

If the locations of controls are not properly designed as per the anthropometric data of the reference population, the performance is going to be reduced. As a result, it will cause poor work output and the possibility of accidents will also increase. To achieve enhanced performance and efficiency of man-machine system along with better comfort and safety of the operators, it is necessary to design various controls and work place on tractors with due considerations to the anthropometric data of Indian male agricultural workers. These data would be very useful for finding out the optimum location of workplace with respect to seat reference point as well as for providing guidelines to the Bureau of Indian Standards. Therefore, the study was aimed to develop the hand and leg reach envelopes based on anthropometric data of Central Indian
male agricultural workers to provide guidelines for workplace layout of tractors and self-propelled machinery.

**MATERIALS AND METHODS**

The anthropometric data of male agricultural workers of Madhya Pradesh with mean age of 29.9 years (N=825) were compiled and used in the study (Gite et al., 2009). The important anthropometric data of agricultural workers used for development of hand and leg reach envelopes were age, weight, stature, elbow grip length, shoulder grip length, elbow rest height, sitting acromial height, knee height sitting, popliteal height sitting, buttock popliteal length, buttock knee length and foot length. The definitions of anthropometric body dimensions used for developing hand and leg reach envelopes are given in Table 1. The mean, 5\textsuperscript{th} percentile and 95\textsuperscript{th} percentile values of anthropometric data of Central Indian male agricultural workers used to develop the reach envelopes are given in Table 2.

**Reach Envelope for Hand Controls**

The methodology given by Matthews and Knight

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**Table 1. Definitions of anthropometric body dimensions used for developing hand and leg reach envelopes (Gite et al., 2009)**

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Dimensions</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Weight</td>
<td>It is measured on a calibrated weighing scale</td>
</tr>
<tr>
<td>2</td>
<td>Stature</td>
<td>The vertical distance from the standing surface to the vertex of the head.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>The subject stands erect and looks straight forward</td>
</tr>
<tr>
<td>3</td>
<td>Elbow grip length</td>
<td>The distance from the tip of the bent elbow to the corner of the clenched fist</td>
</tr>
<tr>
<td>4</td>
<td>Shoulder grip length</td>
<td>The horizontal distance from a pointer held in the subjects’ fist to a wall against which he stands, measured with the arms extended horizontally</td>
</tr>
<tr>
<td>5</td>
<td>Elbow-rest height</td>
<td>The height of the bottom of the tip of the elbow above the sitting surface</td>
</tr>
<tr>
<td>6</td>
<td>Sitting acromial height</td>
<td>The height from the sitting surface to the top of the acromion. The subject sits erect and looks straight forward</td>
</tr>
<tr>
<td>7</td>
<td>Knee height sitting</td>
<td>The height from the footrest surface of the musculature just above the knee. The subject sits erect and looks straight forward</td>
</tr>
<tr>
<td>8</td>
<td>Popliteal height sitting</td>
<td>The height of the underside of the upper leg above the footrest surface. The subject sits erect and looks straight forward</td>
</tr>
<tr>
<td>9</td>
<td>Buttock popliteal length</td>
<td>The horizontal distance from the rear most surface of the buttock to the back of the lower cap.</td>
</tr>
<tr>
<td>10</td>
<td>Buttock knee length</td>
<td>The horizontal distance from the rear most surface of the buttock to the front of the knee cap</td>
</tr>
<tr>
<td>11</td>
<td>Foot length</td>
<td>The length of the foot measured parallel to its long axis</td>
</tr>
</tbody>
</table>

**Table 2. Mean, 5\textsuperscript{th} percentile and 95\textsuperscript{th} percentile values of anthropometric data of Central Indian male agricultural workers (Gite et al., 2009) (All dimensions are in mm unless mentioned)**

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Parameters</th>
<th>Mean (± SD)</th>
<th>5\textsuperscript{th} Percentile</th>
<th>95\textsuperscript{th} Percentile</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Weight, kg</td>
<td>50.8 (± 6.6)</td>
<td>40.0</td>
<td>61.6</td>
</tr>
<tr>
<td>2</td>
<td>Stature</td>
<td>1640 (± 65)</td>
<td>1532</td>
<td>1747</td>
</tr>
<tr>
<td>3</td>
<td>Elbow grip length</td>
<td>347 (± 19)</td>
<td>315</td>
<td>379</td>
</tr>
<tr>
<td>4</td>
<td>Shoulder grip length</td>
<td>710 (± 38)</td>
<td>648</td>
<td>772</td>
</tr>
<tr>
<td>5</td>
<td>Sitting acromion height</td>
<td>572 (± 31)</td>
<td>520</td>
<td>624</td>
</tr>
<tr>
<td>6</td>
<td>Elbow rest height</td>
<td>214 (± 23)</td>
<td>175</td>
<td>252</td>
</tr>
<tr>
<td>7</td>
<td>Knee height sitting</td>
<td>503 (± 28)</td>
<td>457</td>
<td>548</td>
</tr>
<tr>
<td>8</td>
<td>Popliteal height sitting</td>
<td>415 (± 25)</td>
<td>374</td>
<td>456</td>
</tr>
<tr>
<td>9</td>
<td>Buttock-knee length</td>
<td>544 (± 27)</td>
<td>499</td>
<td>589</td>
</tr>
<tr>
<td>10</td>
<td>Buttock-popliteal length</td>
<td>460 (± 23)</td>
<td>421</td>
<td>498</td>
</tr>
<tr>
<td>11</td>
<td>Foot length</td>
<td>251 (± 14)</td>
<td>228</td>
<td>274</td>
</tr>
<tr>
<td>12</td>
<td>Age, years</td>
<td>29.9 (± 9.1)</td>
<td>14.9</td>
<td>44.9</td>
</tr>
</tbody>
</table>
(1971) was followed for developing optimum hand reach envelopes. The optimum area of hand control is bounded by four points as explained below.

**Near low:** The operator’s elbow is next to the body and forearms horizontal. The dimension used is the 95th percentile value of elbow grip length to ensure that controls are not placed too close for most operators.

**Near high:** The operator’s elbows are next to the body and forearms flexed upwards about 15° from elbow.

**Far high:** The operator’s sitting erect and operators arm extended horizontally from the shoulder. The 5th percentile value of shoulder grip length (arm extended) is used to ensure that controls are not placed too far from most operators.

**Far low:** The operator’s arm extended and lowered until the hand is at the level of the elbow at the ‘rear low’ position.

The elbow pivot is the point having 95th percentile value of elbow rest height vertically above seat reference point (SRP) and half of 95th percentile value of wall to acromion distance forward of the SRP. The shoulder pivot point is the point having 5th percentile value of sitting acromion height vertically above SRP and wall to acromion distance forward of the SRP to ensure that controls are not placed too high for most operators.

**Reach Envelope for Leg Operated Controls**

The optimum pedal area is the most desirable for location of the foot controls both in their neutral position and when displaced in any direction. The separate areas for heel and toe operated controls are bounded by following four points:

**Near low:** Position of heel and retracted toe with upper leg raised 15° from seat surface and lower leg at 90° with upper leg.

**Near high:** Position of heel and retracted toe with upper leg raised 15° from the horizontal and toe level with the plane of the seat.

**Far high:** Position of heel and extended tow with upper leg horizontal and lower leg extended 60° from the vertical.

**Far low:** Position of heel and extended toe with upper leg horizontal and lower leg vertical.

The limiting maximum dimensions for the location of pedal controls for seated operator were bounded by these four points.

**Near low:** Position of the heel or extended toe with upper leg raised 25° from the seat surface and the lower leg at 95° with the upper leg.

**Near high:** Position of the heel or retracted toe with upper leg raised 25° from the seat surface and the lower leg horizontal.

**Far high:** The position of heel or extended toe with upper leg resting on seat surface and lower leg horizontal.

**Far low:** The position of heel or extended toe with upper leg resting on seat surface and the lower leg at 90° with upper leg.

Heel point is defined by the centre line of calf circumference. Similarly, toe point was on the tip of foot length.

**RESULTS AND DISCUSSION**

**Optimum Reach Envelope for Hand Controls**

The optimum hand reach envelope was developed to optimize the location of tractor control levers based on anthropometric data of Central Indian male agricultural workers (N=825). The 5th and 95th percentile values of anthropometric data of Central Indian male agricultural workers used to develop reach envelopes are given in Table 2.

Figure 1 shows the optimum area for hand control. The optimum reach envelope was drawn for 90% of user population. Near low point was drawn at 379 mm from elbow point as elbow grip length of 95th percentile population was taken to ensure that controls are not placed too close for most of the operators.

Similarly, far high point was drawn at 556 mm from shoulder point as shoulder grip length of 5th percentile population was taken to ensure that controls are not placed too far from most operators. It may be concluded that 90% of user population could operate controls if they were located within this envelope. The analysis of the developed optimum hand reach envelope (Fig.1) shows that the workers
hand could reach horizontally and vertically within
the range of 431-636 mm forward and 252-405 mm
above the SRP, respectively. Near high position
requires half of fore arm extension while far high
location requires full arm extension.

Limiting and Optimum Leg Reach Envelopes

The controls within the operator’s workplace need to
be placed considering the factors such as operator’s
comfort and safety. Figure 2 shows the optimum leg
reach envelopes for 5\textsuperscript{th} percentile seated central
Indian male agricultural workers developed on the
basis of the anthropometric data.

In Fig. 2, the points H1 and T1 show the lowest
positions where the heel and toe of the foot can
rest. Points H4 and T4 show the farthest locations
from SRP where the foot can reach. Line H1-T1
of leg reach envelope for 5\textsuperscript{th} percentile operator
shows that the position of the foot pedal should not
be below this line. Any foot pedal located at point
H1 can be operated by heel and that at the point T1
can be operated by the toe. Points H1 and T1 are
located at horizontal distance of 460 mm and 688
mm, respectively in front of SRP. Both the points
are at a vertical distance of 374 mm below SRP. Any pedal located below the line H1-T1 would be
difficult to reach for 5\textsuperscript{th} percentile operator without
excessive stretching of the leg muscles causing
compression of the thigh muscles with seat pan. A

foot pedal located above the line H1-T1 could be
easily operated by 95\% of the population.

Points H2-T2 show the nearest boundaries where
the foot can reach without excessive bending of the
leg at knee joint. The far high heel (H4) and far high
toe (T4) points are located at a horizontal distance
of 894 mm and 940 mm, respectively in front of
SRP. T4 is located at a vertical distance of 37 mm
above SRP. Any control pedal located at a horizontal
distance more than 894 mm would be difficult to
operate by the 5\textsuperscript{th} percentile operator, especially if
the control is to be operated by heel.

Points H4 and T4 represent the farthest location of
foot pedal in its depressed condition. Any foot pedal
located beyond this point would be difficult to reach
by the 5\textsuperscript{th} percentile operator. Even if the operator
reaches the foot pedal by stretching the legs he
may not get sufficient support from the backrest
to apply the required force. Any foot pedal located
within this envelope can be operated by 95\% of the
population. Points H2-T2 and H3-T3 represent the
near boundaries of the reach envelope. Operation of
the foot pedal located above the points H3-T3 would
be difficult to reach for the 5\textsuperscript{th} percentile operator,
as he would have to lean the leg at knee joint. The
5\textsuperscript{th} percentile operator’s reach value can be used
to make necessary recommendations for revising
the IS 12343 (1998) in respect of location of tractor
control pedal with respect to SRP.
The control location suitable for 95th percentile would be difficult to reach for a 5th percentile operator. Similarly, a control placed too close to the points H1-T1 of leg reach envelope for a 5th percentile operator would be uncomfortable for the 95th percentile operator. However, longitudinal and vertical adjustments in seat itself may solve this problem to a great extent.

CONCLUSIONS

The following conclusions can be drawn from the analysis of optimum hand reach and 5th percentile optimum leg reach envelopes for the Central Indian male agricultural workers:

1. The hand of male agricultural workers could reach within the range of 431-636 mm forward and 252-405 mm above the seat reference point (SRP).

2. The heel operated controls may be located with in an area of 460 - 894 mm forward of SRP and 374 mm below the SRP. The toe operated controls may be located with in an area of 940 mm forward of SRP and 37 mm above the SRP, and 688 mm forward of SRP and 374 mm below the SRP.

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