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Actuating force for transmission controls in small farm tractor considering driver's comfort

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ABSTRACT

Tractor drivers are exposed to a lot of physical and mental stress during field operations. In small tractor, less space is available in workspace for tractor driver. Therefore, proper design of controls in workspace of small tractor is imperative. A study was carried out at ICAR-Indian Agricultural Research Institute during 2021 to compare the workspace configuration of small tractor with Indian Standard IS 12343:1998 and measure force requirements of selected transmission controls. Most of the frequently used controls in the workspace of the selected tractor are located at a range less than recommendations of the Indian Standard IS 12343:1998. Force measurements of selected transmission controls were performed in a field of size 30 × 15 m^2. Tractor was attached with three implements (i.e. rotary tiller, cultivator and planter) and operated by three different operators. It was observed that mean force requirement of brake and clutch pedals were high for small tractors due to difficulty in operator's sitting. However, the force requirements of accelerator, driving shift and range shift gear lever were close to the recommended values. The frequency of use of controls was also estimated to determine number of times tractor driver applied certain control in a defined area. The driving shift gear lever and range shift gear lever were observed as the most and least frequently used controls respectively in the tractor workspace during field operations. The measured forces will be used to design the automatic system for selected controls in small tractor.

Keywords: Controls, Force measurement, Low hp tractor, Tractor workspace

In India, small and marginal holding farmers cultivate around 46.94% of the area, and produce around 60% of the total food grain production and over half of the country's fruits and vegetables production (Agricultural census 2015–16). Therefore, it is imperative to use low hp tractor considering field size and economic condition of the farmers. Since most of the lands are small, tractor works involves repetitive operations within the limited boundary of fields. So, there is frequent need to use controls for changing direction of tractor. The repetitive uses of controls cause inconvenience to operators, and lower work efficiency. Improper design of workplace could lead to problems in health and risk the life of operator (Fathallah *et al*. 2009, Kumar *et al*. 2009, Monarca *et al*. 2009). The anthropometric characteristics of the target population have a great role in the proper placement of controls in the workplace of tractor (Bhatia and Rawal 1976, Gite and Yadav 1989, Tiwari *et al.* 2010, Shurrab *et al*. 2017, Maleki-Ghahfarokhi *et al*. 2019). Scientists have made attempt to study strength parameters of tractor operator (Kumar 1994, Fathallah *et al*. 2008, Agrawal *et al*. 2009, Yadav *et al*. 2010). Tiwari (2001) reported that location of all the controls in the tractor conformed to the Indian Standard IS 12343. However, the limits of dimensions given in IS 12343 were larger compared to his recommendations. Most of the ergonomic studies have conducted on higher hp tractor and very few attempts have made for lower hp tractor. In order to increase driver's comfort and safety while maintaining the performance of the operation, it is important to design workplace considering force requirement and frequency of application of controls during field operation. Considering the above facts, an attempt has made to compare the workspace configuration of small tractor with Indian Standard IS12343:1998 and measure the force requirement of selected transmission controls in a 15 hp tractor during field condition. Frequency of use of selected controls has also been recorded and results obtained are discussed in this paper.

MATERIALS AND METHODS

The present study was carried out at ICAR-Indian Agricultural Research Institute, New Delhi during 2021 with three tractor operators of different height and age group. The drivers were healthy and well experienced about driving. The force requirement of different controls was measured

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during field operations of three different implements i.e. rotary tiller, cultivator and planter.

A layout measuring device designed by Patel *et al*. (2000) was used to determine vertical and horizontal position of the different controls in the tractor workspace envelop for Indian male tractor operators. The basic design of the device was from Zander (1972) and again modified to incorporate the seat reference-measuring device (ISO 3462 1980). Tractor was placed on level surface. Installation procedure of ISO device for seat reference point (SRP) and layout measurement device on top of the seat were followed the method stated by Patel *et al*. (2000). The reference point of all the controls in the workplace was marked. The ISO device was placed on the seat as per ISO 3462-1980 to find out the seat reference point (SRP) for the tractor. Then the layout-measuring device was mounted on the ISO device to ensure 195 mm distance between the seat reference point (SRP) and center of the layout measurement device in longitudinal axis. The device was adjusted with the help of screw to ensure proper levelling in vertical and horizontal axis. A comparison was established between the Indian Standard IS 12343:1998 and workspace controls layout of selected tractor of tractor operator's seat with respect to Seat Index Point (SIP). The controls included are the steering wheel, clutch pedal, brake pedal, and throttle pedal.

Selection and calibration of load cell: Load cells were used to measure force applied by drivers to selected controls in the tractor workspace. The selection of load cells for brake and clutch pedals was based on maximum actuating forces as recommended by Mehta *et al*. (2011) for normal operation of frequently operated brake and clutch pedals of tractors. Two (50 kg capacity) half-bridge experiments body scale load cell sensors were selected for both clutch and brake pedals. Both the load cells were calibrated before using them for force measurement. The calibration set up consisted of a platform to hold load cell, Arduino UNO R3 microcontroller board, HX711 load cell amplifier module, weights and laptop. Two 90 mm × 90 mm × 3 mm MS sheet were joined with clamp so that it forms a hinge flap. A 25 mm × 25 mm size cut was made on one sheet to allow the space for load cell. The weights were placed on the top of the sheet and readings taken at an interval of 1 kg. A curve was plotted between actual weight and measured weight for both the load cells. The calibration result of both the load cells showed coefficient determination (R^2) of 0.998 and 0.99, indicating force measurement of clutch and brake pedals using 50 kg load cells is possible.

Two (20 kg capacity) load cells were selected for accelerator pedal and range shift gear (gear selection) lever. The calibration set up consisted of lower and upper platform, Z-shape flat, Arduino UNO R3 microcontroller board, HX711 load cell amplifier module, laptop and weights. The weights were placed above the upper platform at 1 kg intervals up to 10 kg. The coefficient determination (R^2) for both the load cell obtained as 0.98 and 0.99, indicating force measurement of accelerator pedal and range shift gear lever using 50 kg load cells is possible.

A 40 kg capacity beam type load cell was used to measure the force applied on the driving shift gear (speed selection) lever. The calibration set up for 40 kg load cell consisted of 3D printed platform, wooden platform, microcontroller, load cell amplifier, table and laptop. One end of load cell was fixed with 3D printed platform and other end with wooden platform. Similar graph was drawn between actual weight and measured weight and results showed coefficient of determination (R^2) as 0.998.

Set up for force measurement in the tractor workspace: All the calibrated load cells were fixed with the controls to measure force during field condition. Both the 50 kg load cells were fixed on the clutch and brake pedals with similar set up used for its calibration (Fig 1 a & b). The MS sheet was clamped to footrest of clutch and brake pedals to prevent it from loosening during field operation. The load cells were placed in 25 mm square formed at the center of MS sheet in a manner to inhibit its free movement. The 40 kg load cell was fixed with forward shift gear lever (Fig 1 c). Lower end of the load cell was clamped with gear lever while upper end was fixed with wooden lever. Force measurement of range shift gear lever was performed with 20 kg load cell (Fig 1 d). One end of load cell was fixed to the MS flat, which clamped to the range shift gear lever. The other end of the load cell was attached with MS pipe for operation (push/pull) purpose of operator. A 20 kg load cell was used to measure the force applied on accelerator pedal. The load cell was fixed between lower frame and upper platform (Fig 1e). The lower frame was clamped to footrest of accelerator pedal. The upper platform was provided to act as a footrest of accelerator pedal for the driver.

Measurement of force requirement for tractor controls during field operation: Force measurement of selected transmission controls was performed in a field of size 30 × 15 m^2. The electrical circuit for field measurement consisted of 5 calibrated load cells, 5 HX711 load cell amplifiers for each load cells, A Tmega2560 microcontroller and laptop. Tractor was attached with 3 implements i.e. rotary tiller, cultivator and planter and operated by 3 different selected operators. Readings were recorded on the laptop for each combination of operators and implements. Frequency of use of controls for each operations was counted as a spike from load cell output. he forces applied on the different controls by the selected operators were statistcally analysed to calculate the mean, standard deviation (SD), 5^{th} and 95^{th} percentile values. The percentile values were calculated as (Mehta *et al*. 2011):

$$5^{th} \text{ percentile value} = \text{mean} - (1.645 \times \text{SD}) \quad (1)$$

$$95^{th} \text{ percentile value} = \text{mean} - (1.645 \times \text{SD}) \quad (2)$$

RESULTS AND DISCUSSIONS

Comparison of selected tractor workplace configuration with BIS 12343:1998: The horizontal and vertical spacings and angles of differents controls in the workspace of selected tractor was measured with respect to seat reference point (SRP). Seat index point (SIP) was calculated for

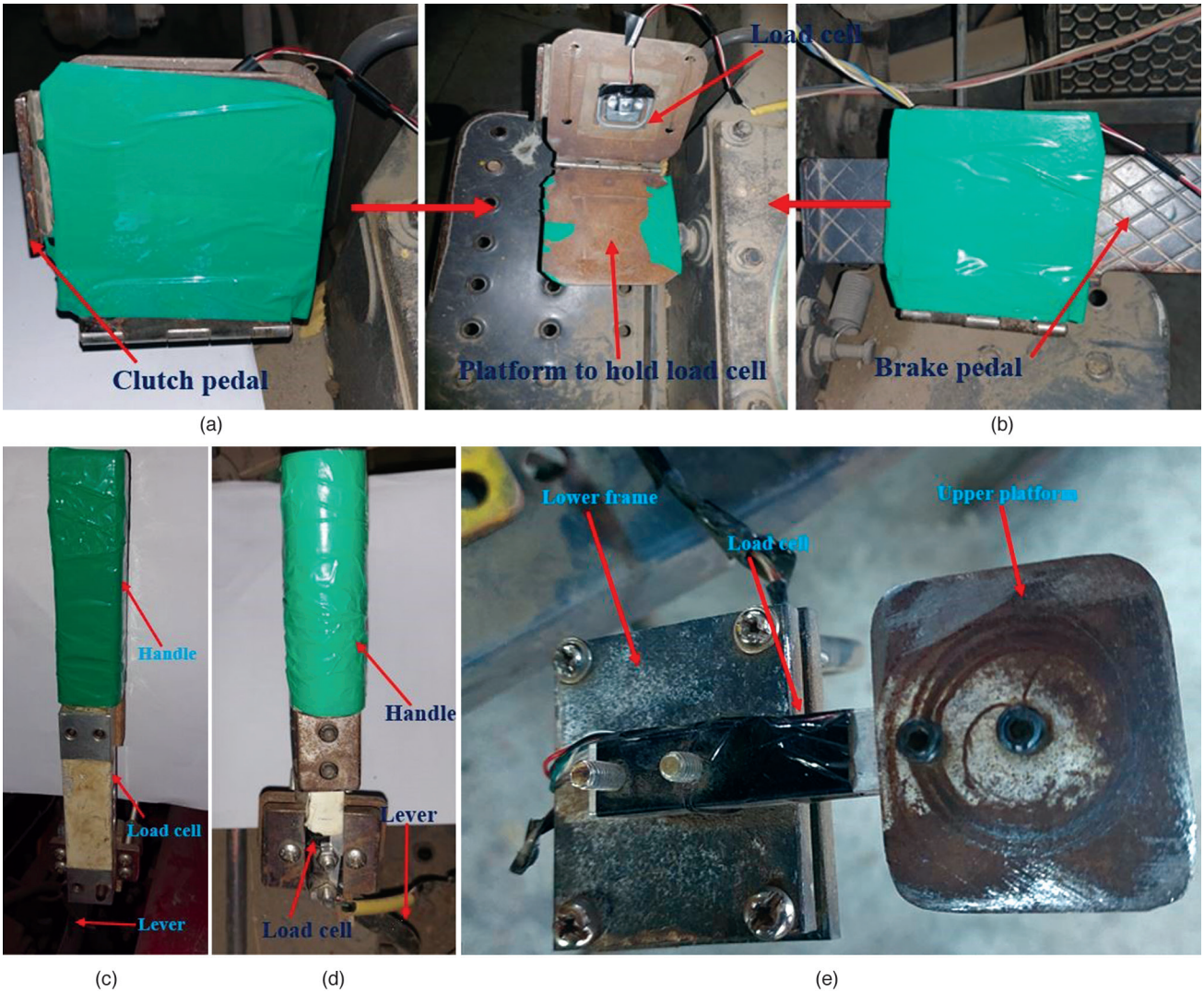

Fig 1 Force measurement set up for (a) clutch pedal, (b) brake pedal, (c) forward shifting gear lever, (d) range shift gear lever and (e) accelarator pedal.

comparision with Indian standard IS 12343:1998. The comparison of selected tractor workplace configurations with IS 12343:1998 is given in Fig 2. The horizontal position of steering-wheel relative to SIP (i.e. l_2) was 195 mm compared to IS 12343:1998 recommendation as 425–525 mm. The vertical position of steering wheel center from SIP (i.e. h_2) was 165 mm compared to standard value as 175–385 mm. Since, the measured value of l_2 and h_2 was much lower than the standard value, it may have impact on angle of the upper arms to the torso and the angle between the upper and lower arm. The steering wheel angle (α) was 50° for the selected tractor. This vaue is more as compared to standard value of 0 to 40°. Therefore, it may affect seating position and force required to turn the steering-wheel causing difficulty in turning of steering wheel. The horizontal position of pedal from SIP (i.e. l_1) was 310 mm, while the recommended value is 355–770 mm. The pedal was vertically positioned at 375 mm from SIP, less than the standard value 380–620 mm. This may result in sitting discomfort as these values affect the angle between the operator's upper and lower leg. Footrest height (575 mm) was within the range given in the standard. The rearward inclination and height of seat backrest were 15° from vertical and 405 mm respectively. These values were ranged within the BIS recommendation. The seat pan width was conformed to the standrd value 450 mm. The lateral position of clutch pedal, first brake pedal, second brake pedal and accelerator pedal were 307 mm, 275 mm, 325 mm and 401 mm, respectively. These values conformed to the standard values recommended by BIS. It is distinct that most of the frequently used controls in the workspace of the selected tractor were not within the recommeded range of the standard IS 12343:1998. These controls were loacated at a range less than the standard value. So, an operator has to adopt discomfortable posture while driving the tractor.

Force requirement of clutch, brake and accelerator pedal during field operation: The operation of clutch, brake and accelarator pedals requires the driver to apply force on footrest of the pedals so as to move it at a predefined distance along the axis of force application. The force

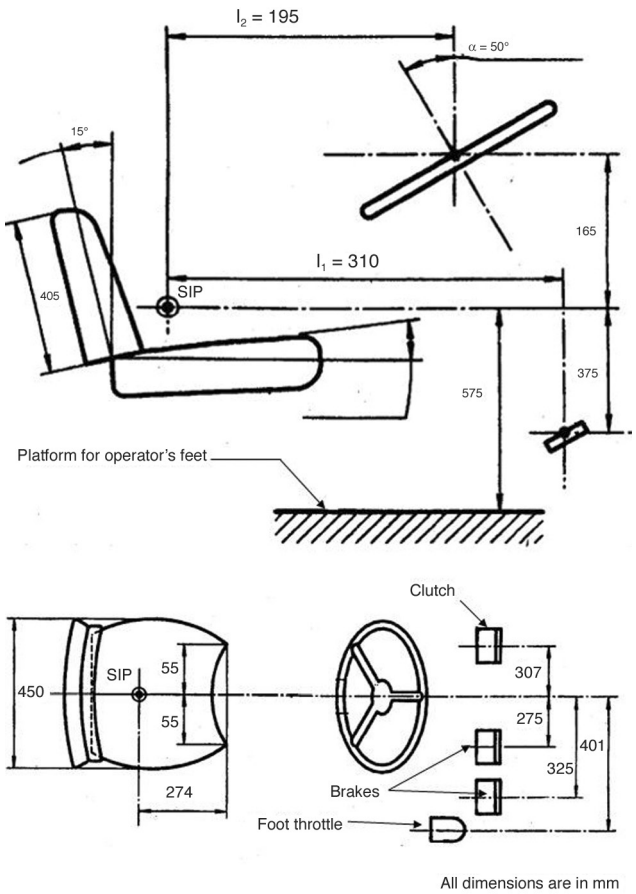

Fig 2 Location of controls in the workspace (IS 12343-1998).

requirements of leg operated controls were measured with 3 implements taken for study for selected operators. The descriptive statistics values i.e. mean, SD, 5th and 95th percentile values for cluth, brake and accelerator pedal in 3 selected implements operations are presented in Table 1. Highest mean value of force requirement for clutch pedal was observed as 153.2 N with cultivator. As per the Indian standard IS 10703, the maximum actuating force for tractor clutch pedal should not exceed 350 N. The measured value is less than the recommended value. But, this much amount of force should not be applied on leg for prolonged basis due to operator discomfort as the space is less in low hp tractor. Minimum 5th percentile force value of 131.7 N was observed with rotary tiller. In general practice, tractor brake pedals are right leg operated and forces requirement is quite high. Maximum mean value of 172.8 N was observed with planter for brake pedal. The Indian standard IS 10703 recommends that the maximum actuating force for brake pedal of tractor should not exceed 600 N. This limit is too high for Indian operators as Mehta *et al*. (2011) recommended that maximum actuating force for frequently operated brake pedals of Indian tractor should not exceed 260 N in normal operations. Minimum 5th percentile value of 113.8 N brake force was observed with rotary tiller. In lower hp tractor, the operator may feel discomfort with this much amount of force due to uncomfortable sitting position. Accelerator pedal is continously operated control of tractor. The maximum mean force requirement of accelerator pedal was measured as 28.6 N for rotary tiller. The minimum 5th percentile and maximum 95th percentile accelerator force requirement were observed as 24.9 N and 30.4 N with planter and rotary tiller respectively. These forces are within the limits suggested by Mehta *et al*. (2011) as the force requirement of accelerator pedal of a tractor should be in the range between 24 to 50 N.

Force requirement of driving shift and range shift gear lever during field operation: Driving shift gear lever is the most frequently used control lever in tractor. This control should be located close to operator in order to avoid excessive body movements. The mean values of force requirement were observed as 46.3 N, 47.7 N and 47.6 N for rotary tiller, cultivator and planter respectively (Table 1). The lowest 5th percentile force requirement value of 42.6 N was observed with cultivator. Similarly, the lowest 5th percentile force requirement for range shift gear lever was

Table 1 Actuating force requirement of different controls of tractor

Control	Descriptive statistics											
	Rotary tiller				Cultivator				Planter			
	Mean	SD	5th percentile	95th percentile	Mean	SD	5th percentile	95th percentile	Mean	SD	5th percentile	95th percentile
Clutch pedal (N)	150.4	11.4	131.7	169.1	153.2	6.6	142.2	164.1	150.0	8.4	136.1	163.9
Brake pedal (N)	170.3	34.3	113.8	226.7	156.6	24.6	116.3	197.0	172.8	20.1	139.7	205.8
Accelerator pedal(N)	28.6	1.1	26.9	30.4	27.9	1.3	25.7	30.1	27.1	1.4	24.9	29.3
Forward shift gear(N)	46.3	4.6	46.3	53.9	47.7	3.1	42.6	52.8	47.6	2.6	43.3	51.8
Range shift gear(N)	50.5	0.8	49.2	51.8	49.7	1.8	46.7	52.6	49.8	2.2	46.1	53.4

Table 2 Frequency of use of selected controls during field operation

Control	Mean frequency of use of controls per hectare		
	Rotary tiller	Cultivator	Planter
Clutch pedal	578	511	644
Brake pedal	622	577	689
Accelerator pedal	489	467	600
Forward shift gear lever	755	556	867
Range shift gear lever	356	266	378

46.1 N for cultivator. The highest mean force requirement for range shift gear (50.5 N) was obtained for rotary tiller. Mehta *et al*. (2011) suggested that the force required for operation of driving shift and range shift gear lever should not exceed 46 N for a tractor as the lowest 5th percentile hand strength value for male Indian agricultural workers was 46 N for push strength (left hand) on sitting position. The measured forces for both the gear levers were close to the recommendation values. This force may cause tiredness for the operator in prolonged use considering driver's sitting discomfort in lower hp tractors.

Frequency of use of selected transmission controls during field operations: Frequency of use of controls was estimated to determine number of times tractor driver apllied certain control in a defined area. The number of use of controls was equal to number of spikes in the output of load cells used for selected controls. The frequency of application of controls was calculted for 30 × 15 m^2 plot and estimated for one hectare area considering similar size test plots. For all the selected controls, higher frequency of use of controls were observed for forward shift gear lever with planting operation (Table 2). This may be due to more precise operation with planter as compared to rotary tiller and cultivator. The results showed that maximum requency of use was obtained for forward shift gear lever (867 times/ha) in planting operation. The least applied control was range shift gear lever with mean frequencies of use 356, 266 and 378 times/ha for rotary tiller, cultivator and planter respectively. In general practice, the range shift gear lever is operated at lower gear during field operation. Therefore, this contol is least used in field opeartion. The mean frequencies of use of accelerator pedal were less compared to clutch pedal, brake pedal and forward shift gear lever. Accelerator pedal is used in a continous manner during operation. As the frequency of use was estimated for spikes count of load cell output, the continous spikes counted as single use of accelerator pedal. Clutch and brake pedals were used 644 and 689 times per ha in maize planting operation. Force requirement of clutch and brake pedals were high as compared to other controls in lower hp tractor (Table 1). Therefore, the operator is exposed to high stress considering high frequency of use, more force requirement and uncomfortable sitting position in small tractor.

Workspace configurations of a low hp tractor was compared with Indian standard IS 12343:1998. There was a mismatch in vertical and horizontal position of steering wheel, and steering wheel angle with Indian standard. Most of the frequently used controls in the workspace of the selected tractor were located at a range less than recommendations of standard IS 12343:1998. So, an operator has to adopt discomfortable posture while driving the tractor. The force requirement of selected controls was measured in field condition. It was observed that mean force requirement of brake and clutch pedals were high for small tractors considering operator's sitting difficulty. Though, the force requirement of driving shift and range shift gear lever were close to the suggested values, but prolonged operation should be avoided considering the difficulty faced by the operator due to cramped workspace. During field operation, driving shift gear lever and range shift gear lever were observed as the most and least frequently used controls in the tractor workspace respectively.

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