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Actuating Forces of Frequently Operated Controls on Indian Agricultural Tractors

PRABHAKAR SHUKLA*, R R POTDAR AND BIKRAM JYOTI

ABSTRACT

India is the world's largest operator and manufacturer of agricultural tractors. The ergonomic concerns and incorporating the physical and strength capabilities of the Indian operators were neglected while designing and developing the tractors in India. As a result, there was a substantial mismatch between the operators' capabilities and the forces required to operate the tractors' controls. Therefore, this study was planned to determine the actuation forces of frequently operated controls on popular Indian tractors. Ten agricultural tractors of different makes and models in the power range of 23 to 50 kW were selected for the study. The Sushma steering torque measurement system, Novatech pedal force load cell, and gear effort transducer were used to measure the actuation force of the controls, steering wheel, clutch, brake pedal, and gear shifter lever, respectively. The actuation forces required to operate the clutch pedal on selected tractors ranged from 130 to 250 N, well below the IS 10703 (1992) limit of 350 N. Except for one tractor, the brake pedal actuation forces observed for the selected tractors varied from 390 to 670 N, well below the recommended limit of 600 N given by IS 10703 (1992). In static conditions, most tractors' steering wheel actuation forces ranged from 210 to 340 N, exceeding or approaching the 250 N limit set by AIS-042 (2004). In dynamic conditions, when tractors were operated at 3 km/h, the actuating forces for the selected tractors ranged from 90 to 220 N and were well within the AIS-042 limit.

KEYWORDS

tractor, actuating forces, frequently operated controls, mismatch

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INTRODUCTION

In India, agricultural tractors are extensively used to carry out different operations on farms. Tractors are used on farms to operate various types of mounted, semi-mounted, and trailed type farm equipment. Tractors are also used for transporting agricultural commodities in rural areas. In terms of production and sales of agricultural tractors, India leads the world. India presently produces one third of the world's tractors, with 16 domestic and four multinational manufacturers. Tractor sales in India increased from 3,877 units in 1961-62 to 633,656 units in 2018-19. Haryana (96), Punjab (79), Uttar Pradesh (58), Bihar (54), Tamil Nadu (46), Andhra Pradesh (48), and Gujarat (44) have higher tractor densities than the national average of 43 tractors per 1000 ha of net sown land. About 6.35 million tractors are now in use in India for various purposes (Mehta *et al*, 2019).

Growing tractorization of Indian farms has resulted in tractor related incidences and injuries, owing to a lack of understanding of ergonomics principles and practises when designing a tractor. Ergonomics is the scientific study of a person's relationship with his or her working environment. Its goal is to boost workers' productivity and efficiency without putting their health and safety at risk (Potdar *et al*, 2021). Disregard of ergonomics principles and practises results in reduced man-machine system efficiency, worker health issues, and a rise in the number of accidents resulting in fatalities and injuries.

In the developing countries, the tractors used are not designed based on ergonomics (Victor *et al*, 2002); the majority of the tractors manufactured in India are based on tractor designs developed for western countries (Potdar *et al*, 2018). Furthermore, the Indian standards adopted international standards related to ergonomic considerations in tractor design as such. The international standards were developed with both the physical characteristics and strength capabilities of western tractor operators in mind. Between the populations of India and Western countries, there are substantial variations in physical characteristics and strength capabilities (Shukla *et al*, 2021; Potdar *et al*, 2018). This difference resulted in a mismatch between the capabilities of Indian tractor operators and the tractors designed and developed according to western standards. The significant mismatch between their capacity and the tractor design was observed for the operators' workplace design and the design values of the actuation forces of various controls.

The tractor driving involved the operation of a number of controls operated simultaneously. If the most frequently operated controls, viz., the steering wheel, gear shifter lever, and clutch and brake foot pedals, were not designed as per the operators' strength capabilities, the possibility of accidents may increase (Shukla *et al*, 2021). It was found that sometimes the tractor operator has to be in an awkward position to be able to use the control. Even so, it was found that the operator

[1] ICAR-Central Institute of Agricultural Engineering, Bhopal 462 038, Madhya Pradesh, India
*Corresponding author email: prabhakarshukla05@gmail.com

has to stand on the pedal controls to actuate them to control the tractor. A comparison between the determined actuating forces based on the measured muscular strengths of tractor operators and the recommended values in international and national associated standards indicated that the tractor control tools designed based on these standards were improper and would culminate in overexertion (Feyzi *et al*, 2019). Such situations mainly occur due to the higher actuating forces and improper design considerations of the controls. Therefore, keeping these facts in view, a study was planned to measure the actuating forces of the frequently operated controls on the popular tractors that are used on Indian farms.

MATERIALS AND METHODS

Selection of tractors

The agricultural tractors used in the study were selected based on the horsepower range that is most commonly sold in the Indian market. Tractors with power ratings ranging from 23 to 50 kW accounted for approximately 79% of domestic tractor sales (Senthilkumar *et al*, 2017). As a basis, ten distinct tractor models from various manufacturers, all of which are manufactured and widely used on Indian farms and have a power range of 23 to 50 kW, were selected at random for the measurement of actuation forces of frequently operated controls. The selected tractor models were represented as TR-A, TR-B, TR-C, TR-D, TR-E, TR-F, TR-G, TR-H, TR-I, and TR-J.

Measurement of actuating forces of clutch and brake pedals of selected tractors

The actuation force of the clutch and brake pedals on the selected tractors was measured using a NOVATECH load cell (F304) and load metre (TR200). The load cell is built compactly and robustly, and it has a high level of precision. The maximum force range of the load cell is 2.5 kN. The load cell has several holes that allow it to be attached to any type of pedal with screws or cable ties (Figure 1). The pedal force load cell and load meter were used to measure the initial force necessary for actuation of the clutch and brake pedals of the selected tractors. The pedal force load cell was bolted to an attachment that was secured to the pedals. The load meter was connected to the load cell with the cables and displayed the force data. The displayed data was recorded and saved on an Android smartphone wirelessly through a Bluetooth device and an Android application. The operators of the selected tractors were instructed to press the load cell on the pedals until they could no longer be pressed during the measurement of actuation force data. For each tractor model, actuation force measurements were repeated five times.

Measurement of steering toque/ effort of selected tractors

On tractors, automotive four-wheelers, cars, buses, trucks, and other vehicles, the SUSHMA steering torque measurement system is used to measure steering torque, angle, and effort (Figure 2). The torque that the driver applies to the steering wheel is measured by this device. This instrument is suitable for use both in the field and in the laboratory. This setup can also be used to test steering systems, steering geometry, tyre interactions, and safety factors. This setup is simple and easy to set up. It is made up of a steering torque sensor and a steering wheel. With this instrument, we can measure the torque and angle at the same time on selected tractors.

A 3-point clamp arrangement can be used to attach it to an existing steering wheel. It fits steering diameters ranging from 300 to 380 mm. It can be used in both clockwise and counter-clockwise directions.

On the steering wheels of selected tractors, the digital SUSHMA steering torque measurement system was mounted. The signal recorder-cum-printer was linked to the mounted wheel of the instrument. The instrument was powered by the tractor's battery. The steering torque was measured in the laboratory and on a concrete track, using the procedure given in AIS-042 (2004). The Automotive Research Association of India (ARAI) created AIS-042 (2004), which was adopted for testing Indian tractors by the Ministry of Road Transport and Highways, Government of India. A 50 m straight track was established on the concrete surface, followed by a circular track of a 12 m radius, as per the technique given in AIS-42 (2004). The operators of the selected tractors were briefed on the methodology and purpose of the experiment. The operator was instructed to control the tractor only with the steering wheel of torque measuring setup and follow the specified line. The tractor was started at the beginning of the track, and the time it took to complete the standard track was recorded using a stop watch. The experimental technique was explained to the operator. The PTO rpm was also recorded, so that five replications could be done at the same speed. The torque applied to the steering wheels of ten tractors was measured on the test track.

Measurement of actuating forces of gear-shifter lever of selected tractors

A MONAD gear effort sensor and a digitizer-cum-data logger were used to measure and record the actuating force of the gear-shifter lever on the selected tractors. The actuating force applied by a human hand actuator is measured by an ergonomically shaped gear knob. Axial force transducers are used in the gear effort sensor to provide calibrated values. It is quick and simple to mount with a simple attachment that can be adjusted to fit different settings with a screw. The actuating force readings were recorded using the digitizer-cum-data logger. It displays the subject's maximum force on the gear-shifter lever. The digitizer-cum-data logger was calibrated according to the recommendations in the operators' manual. With the help of an attachment, the gear effort sensor was mounted on the gear shifter lever on the selected tractors. The operators were given an overview of the gear shifting method. The digitizer-cum-data logger was used to record the actuating forces of the gear shifter lever. The recorded data was downloaded on a computer and analyzed.

Fig. 1: Measurement of actuating force of (a) clutch pedal and (b) brake pedal

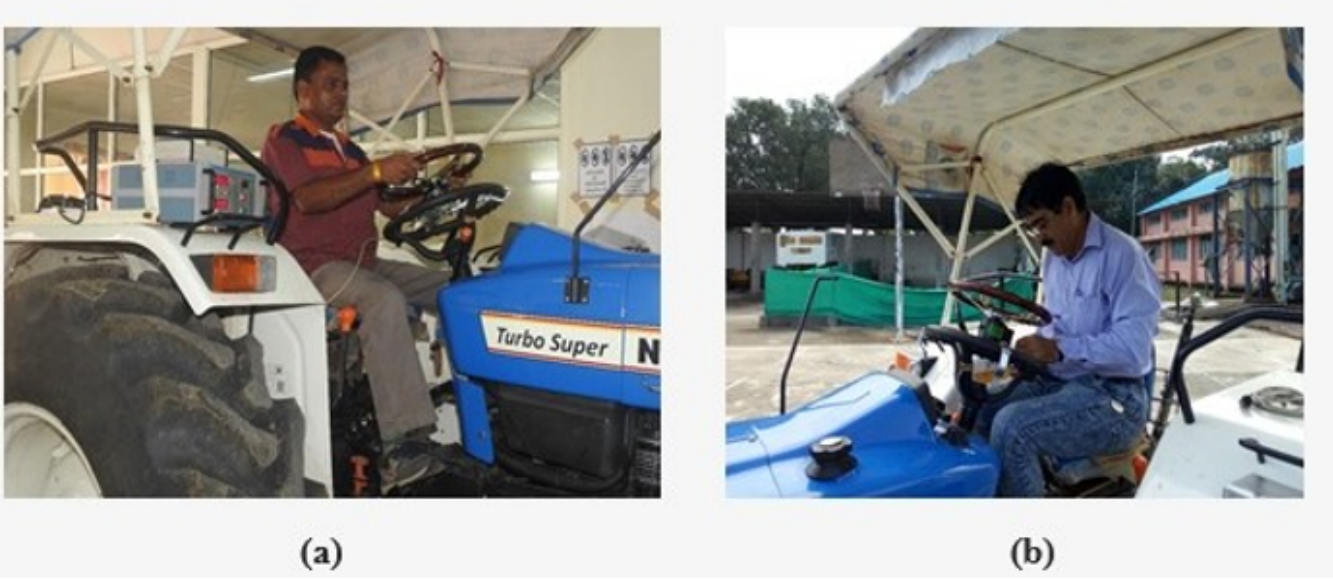

Fig. 2: Measurement of steering torque in (a) laboratory and (b) test track

Fig. 3: Measurement of actuating force of gear shifter lever using gear effort sensor

The measured and recorded actuating forces data of the frequently operated controls, viz., the clutch and brake pedal, steering wheel and gear shifter lever on the selected tractors, were compared with the recommendations given in the standards as well as the actuating forces recommended in various studies for Indian operators.

RESULTS AND DISCUSSION

Actuating force of clutch and brake pedal

The actuating forces for the clutch pedal and brake pedal on the selected tractors were measured and are presented in Figure 4 . The actuating forces for the clutch pedal and brake pedal for the selected tractor ranged from 130 to 250 N and 390

to 670 N, respectively. The maximum force for the operation of the clutch pedal was observed for tractor C, while the minimum force was observed for tractor A. In the case of brake pedal force, the maximum force value was observed for tractor C and minimum force value was observed for tractor F. The clutch pedal actuating forces observed for selected tractors were well within the limit of 350 N recommended by BIS (1992) . In addition, except for tractor C, the brake pedal actuating forces observed were well within the limit of 600 N recommended by IS 10703 (1992). Though, the actuation forces for both clutch pedal and brake pedal on selected tractors were in agreement with the limits set by IS 10703 (1992), those were much higher than the limits of actuation forces recommended by Mehta *et al* (2011). They reported that the maximum actuating forces for normal operation of frequently operated brake and clutch pedals of tractors should be less than 260 and 125 N based on the 5th percentile values of the right and left leg strength of Indian male agricultural workers, respectively. The limits given in IS 10703 (1992) were adopted as such by the international standard. For this reason, many operators found difficulty in the effective operation of both the foot pedals. In addition, the limits recommended by Mehta *et al* (2011), not yet incorporated into the Indian standard. In the case of females as tractor operators, as females have lower leg strength as compared with their male counterparts, the smaller female operator could not operate the pedal controls on these tractors. Therefore, in the case of a gender-neutral tractor, these limits of actuation forces for the brake and clutch pedal will be further reduced and will be based on the 5th percentile values of right and left leg strength of Indian female agricultural workers, respectively.

Actuating force of steering wheel

The actuating forces for the steering wheel on the selected tractors in static and dynamic conditions were measured and are presented in Figure 5. The actuating forces for the steering wheel in static and dynamic conditions for selected tractors ranged from 210–340 N and 90–220 N, respectively. In static conditions, steering wheel actuating forces for most of the tractors were exceeding the limit or close to the limit of maximum actuating force of 250 N to operate tractor steering wheel systems given by AIS-042 (2004).

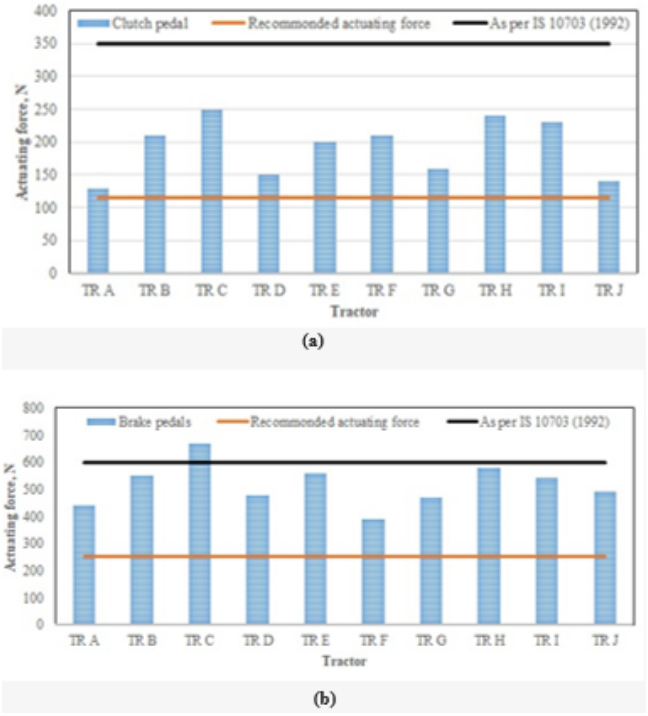

Fig. 4: Actuation forces of a)Clutch pedal and b) brake pedal for selected tractors

In dynamic conditions, when tractors were operated at 3 km/h, actuating force values for all tractors were reduced, which was well within the limit provided by AIS-042 (2004). As per Mehta *et al* (2011), the maximum actuating forces required in steering wheel operation should not exceed 171 N based on the 5th percentile value of sitting torque strength (both hands) of Indian male agricultural workers. The actuation force of the steering wheel on all tractors exceeded the limit of 51 N recommended by Mehta *et al* (2011). The recommended limit of actuation force for the steering wheel is much lower than the limit given in AIS-042 (2004). The actuating force recorded in the static condition was found to be higher than the limit recommended by Mehta *et al* (2011) for all the selected tractors. In the case of dynamic conditions, the actuating force values decreased below the recommended force limit, except for the tractor C, H and I. If the tractor will be operated by a female operator, this limit will be further reduced as females have lower torque strength values than males. This limit will be based on the 5th percentile value of sitting torque strength (both hands) of Indian female agricultural workers.

Actuating force of gear shifter lever

The actuating force for the gear shifter lever on the selected tractors was measured and is presented in Figure 6. The actuating force for the gear shifter lever for the selected tractor ranged from 38 to 57 N. The values of actuating force for most of the tractors were found to be close to the actuating force value of 46 N recommended by Mehta *et al* (2011) and Gite *et al* (2020). For a few tractors, the actuation force value of the

gear shifter lever was observed to be higher than the recommended value. This might be due to the improper linkages and inappropriate location. For female operators, this limit will be further reduced as females have lower push-

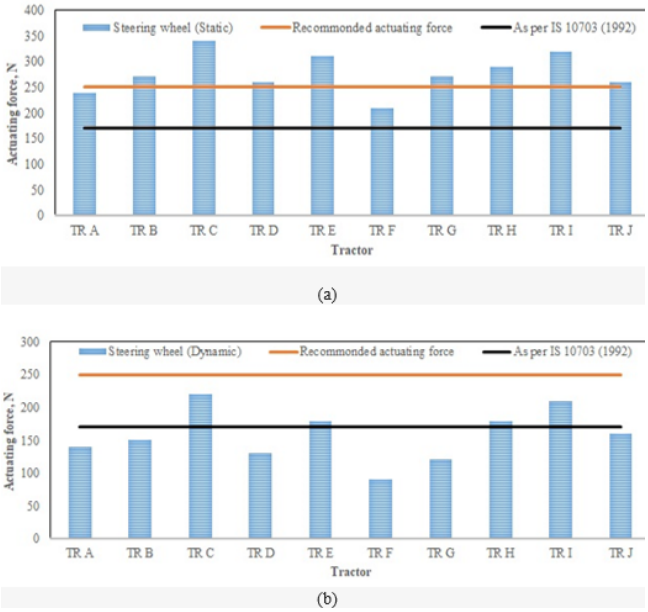

Fig. 5: Actuation forces of steering wheel for selectedtractors in a) static and b) dynamic condition

pull strength values than males. This limit will be based on the 5th percentile value of right hand push and pull forces in the sitting position of Indian female agricultural workers.

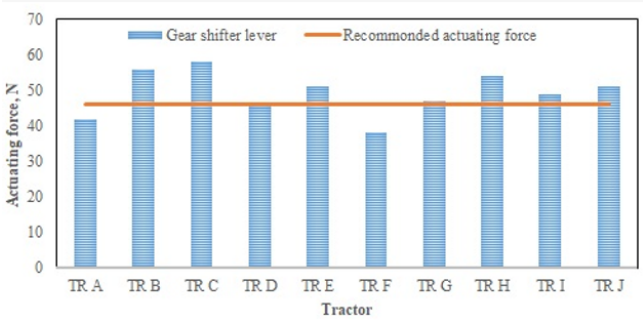

Fig. 6: Actuation forces of gear shifter lever for selected tractors in dynamic condition

CONCLUSION

The actuation force of the controls, viz., steering wheel, clutch, brake pedal, and gear shifter lever, on ten selected tractors was measured, respectively. The actuation forces required to operate the clutch pedal on selected tractors ranged from 130 to 250 N, well below the BIS 10703 (1992) limit of 350 N. The brake pedal actuation forces observed for the selected tractors varied from 390 to 670 N, well below the recommended limit of 600 N given by BIS 10703 (1992). But, the limits given in Indian standards are on the higher side and are not suitable for Indian tractor operators. In static conditions, most tractors' steering wheel actuation forces ranged from 210 to 340 N, exceeding or approaching the 250 N limit set by AIS-042 (2004). In dynamic conditions, the actuating forces for the selected tractors ranged from 90–220 N and were well within the AIS-042 limit. The actuating force for the gear shifter lever for the selected tractor ranged from 38 to 57 N.

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