

An ergonomic approach to design hand tool for agricultural production

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Abstract. Hand tool mechanisms designed to reduce the risk factors have rarely been studied. In this paper it is analyze trowel firstly designing in CATIA and then its Finite Element Analysis has been carried out by ABAQUS. The main emphasis is on finding stresses by using this software, then removing them by suitable mechanical working on tool & ergonomic change in the design of handle to make it more comfortable. Body part discomfort score and overall discomfort rating experienced by the subjects had also been estimated. During the muscular activity workers physiological responses i.e. energy expenditure rate, oxygen consumption rate and heart rate increases. This increase in physiological responses is related to the type, intensity and duration of work and thus sets limits to the performance of heavy work. In this paper oxygen consumption rate and heart rate was used for physiological cost estimation. These parameters were measured by Computerized Ambulatory Metabolic Measurement System K4b₂.

Keywords: Trowel, Ergonomics, Productivity, CATIA, ABAQUS

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1. Introduction

Design and structural analysis can assist by using design software like Abaqus and CATIA, but ergonomics must be considered for better productivity. Ergonomics has many aspects, one of which is anthropometry, which addresses posture analysis to reduce worker stress, fatigue and injuries. At the same time, attention to details such as these has the potential to increase worker performance and productivity. Hand tool constitutes a significant number in farm injuries, Improper handle dimensions can lead to lower force application, therefore requiring higher impact velocities for cutting, loose grip, slippage and inaccurate direction of applied force. Based on the above information and factors associated with hand tool injuries, in this Paper attempt is made to developed trowel less tool injury and improvement in productivity.

2. Method:

Evaluation studies of existing and developed trowel have been conducted with Objective measurements & Subjective experiences of the subjects (to measure comfort or discomfort Corlett and Bishop Technique is adopted). As comfort and discomfort are subjective feelings. To achieve goal, a designed hand tool evaluation study was also conducted and Comfort Questionnaire for hand tools (CQH) is used and evaluated the modified trowel.

To grade posture, the body parts focused on is back, neck, shoulder, elbow, hand/fingers, hip joint, knee and ankle. When grading force, the users have a table for assistance where measurements in kilos and newton are represented. The following aspects are assessed:

- Weight, lifted in standing or sitting position;
- Assembly force, exerted by fingers or hand;
- Grip opportunities and other heavy load handling.

3. Experimental Designs

3.1 Objective measurements:

Physiological cost assessment of operator: In the present research Oxygen consumption rate, Energy Expenditure Rate (kJ/min) and heart rate was used

for physiological cost assessment. These parameters were measured by Computerized Ambulatory Metabolic Measurement System K4B₂. Field experiments were carried out to assess the oxygen consumption rate and heart rate responses during weeding by Trowel operation. Ten subjects were used for this experiment.

3.2 Subjective measurements:

The subjects were asked to dig a hole of 1 feet depth and area of 1 square feet with conventional Trowel. The soil was made moist by sprinkling water about 3 or 4 hours before the start of experiment. The subjects were asked to dig holes in the soil as quickly as possible without any rest breaks. After the subjects finished digging holes, the descriptors of the Comfort Questionnaire for Hand tools (CQH) were rated and—if necessary—the meaning of the descriptors was explained. At last, the subjects rated overall comfort. After a rest break of at least 5 min, the next digging-task started. This procedure was repeated for both Trowels existing and developed one.

Overall discomfort rating gives the capacity of the worker or subject to work and it is defined on a scale with a sliding pointer with graduations marked. The rate is important because with its help a workers body's overall capacity can be known during working and proper intervals during working can be given for rest.

3.3 Determining overall discomfort

Overall discomfort rating was taken on a ten point psychophysical scale (0=totally disagree with given CQH statement, 6= totally agree with given CQH statement) which is an adoption of Corlett and Bishop (1976) technique. A chart namely CQH was prepared including comfort descriptors. At the end of 35 minutes period the subject was asked to indicate the overall discomfort rating on this chart. The overall discomfort ratings given by each subject were added and scaled from one to six

3.4 Physiological cost measurement of workers

Objective analyses: Physiological Cost of the Workers during the Manual Weeding with traditional Trowel.

Experiments were carried out to assess the physiological cost of the subjects in terms of heart rate (HR), oxygen consumption rate (OCR), and energy

expenditure rate (EER) for both spades means traditional and developed one, with help of $K4B_2$ and relations between these tools on increase in oxygen consumption rate and heart rate were evaluated statistically. The increase in heart rate (ΔHR) and oxygen consumption rate (ΔOCR) is expressed as difference in working heart rate and resting heart rate, as working oxygen consumption rate and resting oxygen consumption rate respectively.

Heart rate (HR) and oxygen consumption rate (OCR) of all selected subjects were measured during manual weeding with Trowel. As the experiment was spread over 20 working days, the mean values of HR and OCR were used for comparison of different trials to eliminate the effect of different days as well as the time. the mean HR (beats/min) during resting is 79.7, and mean work pulse (ΔHR) of the subjects during operations is 40.2, the mean HR of the subjects during operation is 119.6 beats/min.

Mean work pulse (ΔHR) for weeding with Trowel of all subjects are ranged from 29 to 51 beats/min.

3.5 Work plan:

- I. Modeling in CATIA of existing hand trowel
- II. Analysis of existing hand trowel in ABAQUS
- III. Testing the existing trowel in the field & evaluation of comfort questionnaire
- IV. Modifying the existing tool ergonomically according to CQH
- V. Testing again in the field with modified trowel

4. Tool design in Catia & analysis in Abaqus

After modeling part is saved in IGES format to import in ABAQUS.

Analysis steps in ABAQUS

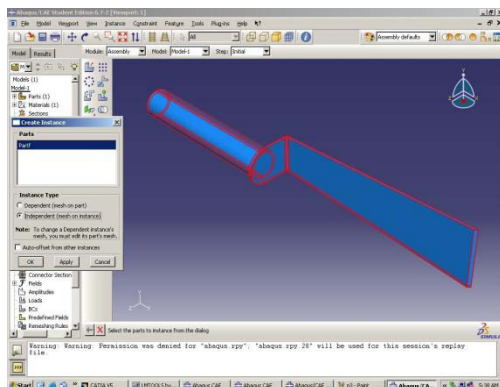


Figure 1: Steps of analysis trowel in Abaqus

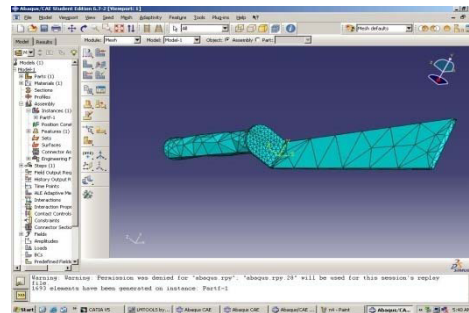


Figure 2: Steps of analysis trowel in Abaqus

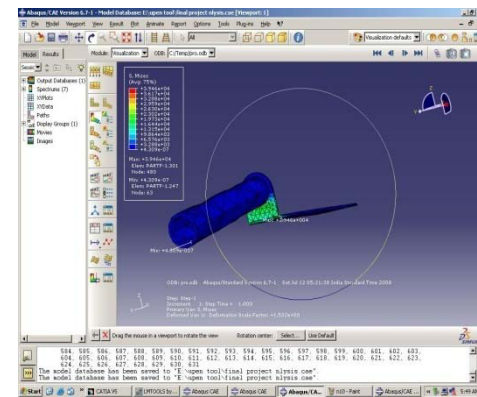


Figure 3: Steps of analysis trowel in Abaqus

4.1 Testing on the improved trowel

The following procedure was used to test the new trowel:

After this improved trowel was issued to the subjects and they had to work 35 minutes work followed by rest of 10 minutes. For measuring ODR they were asked to indicate a number on CQH.

A good working posture is one, which requires a minimum of static muscular effort. Hence the work performance will be better and the body discomfort will be less. If a work can be done in a standing posture instead of bending or squatting posture, it should be preferred for long duration jobs. Postural discomfort is the discomfort experienced by the subject because of muscular discomfort to maintain the body posture during the work. Discomfort is the body pain arising as a result of the working posture and/or the excessive stress on muscles due to the effort involved in the activity. In many situations, though the work may be well within the physiological limits, the body discomfort may restrict the duration of work depending upon the static load compo-

ment involved in it and this is the case for most of the agricultural activities. For evaluating Comfort, CQH was used. In this technique the body was divided into 27 regions. The subject was asked to indicate the number on CQH for his work experience with tool. Having noted these, then modifications in the tool handle were made.

5. Comparison of CQH of an old and new tool (Subjective Analysis)

Table 1

Analysis of existing and modified trowel.

Analysis for trowel	Existing tool	Modified tool	Percentage improvement
Sum	181	231	27.6%

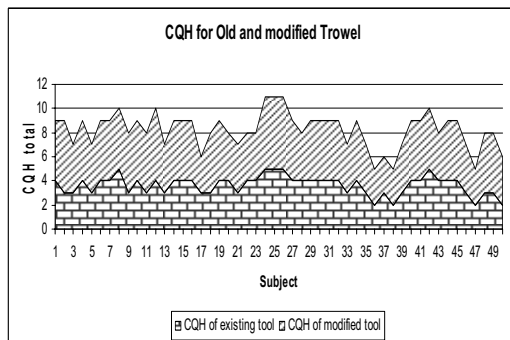


Figure 4: comparison of CQH of an old and new tool

6. Physiological cost measurement of operator

6.1 Objective analysis (physiological cost measurement of operator)

Experiments were carried out to assess the physiological cost of the subjects in terms of heart rate (HR), oxygen consumption rate (OCR), and energy expenditure rate (EER) for both spades means traditional and developed one, with help of $K4B_2$ and relations between these tools on increase in oxygen consumption rate and heart rate were evaluated statistically. The increase in heart rate (ΔHR) and oxygen consumption rate (ΔOCR) is expressed as difference in working heart rate and resting heart rate, as working oxygen consumption rate and resting oxygen consumption rate respectively.

Heart rate (HR) and oxygen consumption rate (OCR) of all selected subjects were measured during manual weeding with spade. As the experiment was

spread over working 30 days, the mean values of HR and OCR were used for comparison of different trials to eliminate the effect of different days as well as the time. The experiment was conducted from 9 AM to 5 PM during a day.

Heart rate response of the subjects

Table shows that the mean HR (beats/min) during resting is 78.3, and mean work pulse (ΔHR) of the subjects during operations is 40.2, the mean HR of the subjects during operation is 119.6 beats/min.

Mean work pulse (ΔHR) for weeding with spade of all subjects is ranged from 27 to 33 beats/min.

The mean dry bulb temperature, wet bulb temperature, relative humidity and wind velocity varied between 8.2 to 24.5°C, 7.6 to 18.6°C, 32 to 81 per cent and 1.8 to 4.1 km/h respectively during the experiments.

7. Energy expenditure rate (EER) of subjects during weeding operation.

Since oxygen consumption rate (OCR) is a better parameter than heart rate, the energy expenditure rate was estimated by multiplying the OCR work with the calorific value of oxygen (20.88 kJ/l) (Nag and Dutt, 1980). Mean Energy expenditure rate in weeding operation ranged from 12.07 to 13.74 kJ/min for weeding with trowel operation.

7.1 Mean Energy expenditure rate in weeding operation.

The mean energy expenditure rate for all subjects is presented in The energy expenditure rate was highest for Trowel (13.18 kJ/min) followed by Spade (12.82 kJ/min), and Maize sheller (6.52 kJ/min). The energy expenditure rate for weeding spade and trowel was almost same which implies that work load for both the tools is nearly same.

Chart for comparative study of traditional and developed Trowel in terms of Heart rate:

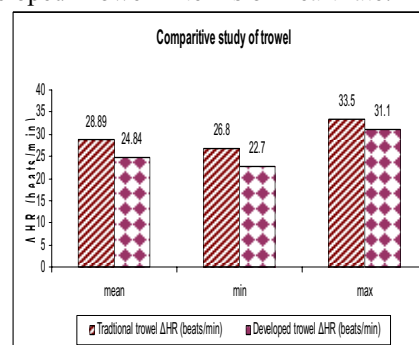


Figure 5. Mean minimum & maximum ΔHR for weeding operation with trowel

From observation it is seen that the mean work pulse (ΔHR) of the subjects during manual weeding operations with developed trowel is 24.84 in comparison of 28.89 beats/min with traditional trowel.

Minimum value for work pulse (ΔHR) for traditional tool is 26.8 and maximum is 33.5 comparative to 22.7 & 31.1 respectively for the developed tool.

Chart for comparative study of traditional and developed Trowel in terms of oxygen consumption rate (ΔOCR):

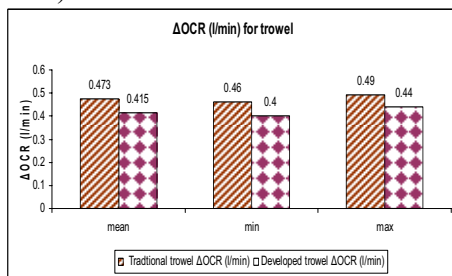


Figure 6: Mean minimum & maximum ΔOCR for weeding operation with trowel

From observation it is seen that the mean oxygen consumption rate (ΔOCR) of the subjects during manual weeding operations with developed trowel is 0.415 in comparison of 0.473 lit/min with traditional trowel.

Minimum value for oxygen consumption rate (ΔOCR) for traditional tool is 0.46 and maximum is 0.49 comparative to 0.4 & 0.44 respectively for the developed tool.

Chart for comparative study of traditional and developed Trowel in terms of Energy Expenditure Rate (ΔEER):

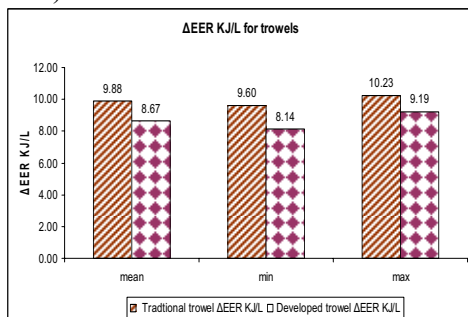


Figure 7: Mean minimum & maximum ΔEER for weeding operation with trowel

From observation it is seen that the mean Energy Expenditure Rate (ΔEER) of the subjects during manual weeding operations with developed trowel is 8.67 in comparison of 9.88 KJ/l with traditional trowel.

Minimum value for Energy Expenditure Rate (ΔEER) for traditional tool is 9.605 and maximum is 10.23 comparative to 8.14 & 9.19 respectively for the developed tool.

8. Results

In the above analysis it is observed that the maximum stress is developed at intersection of the planes of blades. Therefore to remove those stresses we have added fillet at intersection point in new improved tool. This imparts more strength & increases its durability.

From the ergonomic point of view it is observed from field study that working with existing available hand tool is not comfortable. To provide comfort handle of hand trowel in bent in particular profile and a better quality of non slipping grip is used. Hand grip equipped with existing trowel was made of hard rubber which causes blisters on palm while working. This grip felt slippery on handle while working.

But in improved tool the grip provided which is made of durable & high quality rubber. This handle grip does not cause any blisters on palm while working. The grip surface is not slippery either.

The handle bar of previous tool was straight it causing wrist strain due to bending of wrist. This reduced the workers comfort during long hour operations, therefore causing more fatigue.

In improved trowel, handle bar was bent to ensure that wrist remains straight while working. This increased worker's comfort while working. With new tool it is observed that an average worker can work 35 minutes without resting in spite of 27 minutes with traditional tool. If per day work is calculated than it is found that he covers 1628 square feet of area comparative to 1341 square feet with traditional trowel.

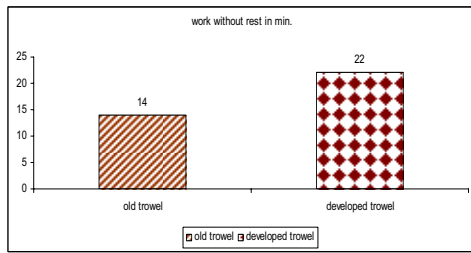


Figure 8: Continuous works with trowels in Minutes.

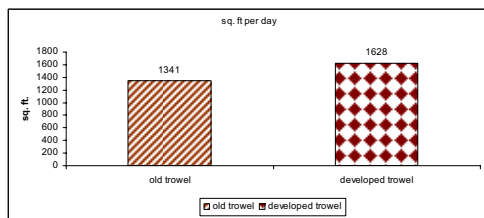


Figure 9: weeding in square ft. per day

The first decision is based on the task (low or high intensity). The second decision is based on the force direction on the hand (shear forces or normal forces). This flow chart is based on findings of the current study and the differences between the studied hand tools. Therefore, it has to be validated with other kinds of hand tools and for different groups of end-users (Subjects and professionals) in the future. Moreover, it has to be validated for occupational situations in which hand tools are used under different circumstances. In addition, designers should evaluate this flow chart, in order to get insight into the usability of this flow chart for addressing comfort in the hand tool design process.

Table 2
Increase in Heart Rate/m² of the Subjects during different Weeding operations

Method of operation	Increase in heart rate of the area covered HR/m ²	Area covered m ² /h
Trowel	37	43

Table show the effect of using different methods on heart rate response of the selected subjects during weeding operation. The increase in HR/m² of area covered while, weeding with Trowel.

Gite *et al.*, (1999) reported mean values of heart rate during weeding work as 101.6 beats/min for Spade The corresponding work pulse (Δ HR) was 21.1 beats/min.

8.1 Statistical analysis for mean working HR and Δ HR for manual weeding

Table 3
Oxygen consumption rate of the subjects during weeding operation

Tools	Trowel	
	OCR (L/Min)	Δ OCR (L/Min)
S ₁	0.62	0.47
S ₂	0.63	0.47
S ₃	0.62	0.47
S ₄	0.64	0.48
S ₅	0.62	0.47
S ₆	0.66	0.49
S ₇	0.62	0.46
S ₈	0.66	0.49
S ₉	0.63	0.47
S ₁₀	0.61	0.46

The mean OCR of the subjects during weeding operation range from 0.15 to 0.63 l/min and 0.6139l/min to 0.631/min for spade and trowel respectively. The mean OCR of the subjects for maize sheller operation range from 0.193 to 0. 237 l/min. (Table 4.14).

Tools	Trowel	
	OCR (L/Min)	Δ OCR (L/Min)
Subjects		
Mean	0.631	0.473

Table 4: Mean oxygen consumption rate of the subjects during weeding operation

8.2 Mean working OCR and Δ OCR of manual weeding

Mean OCR of subjects during weeding operation was found to be 0.631 l/min for trowel operation. Mean working OCR was highest for trowel because it required more physical effort than other weeding methods. Similar results have been reported by Nag and Dutt (1979).

The mean Δ OCR of subjects during weeding operation was found to be 0.473 l/min for trowel operation.

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