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Research Article

Ergonomic Assessment of Self-Propelled Machinery Seats for Agricultural Workers

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ABSTRACT

Excessive vibrations in self-propelled machinery engaged in agricultural farm operations cause mechanical failures and subject the operators to discomfort. Laboratory tests were carried out in a completely randomized design in a factorial arrangement (type of seat×engine, speeds×subject) with a view to evaluate the self-propelled machinery seat ergonomically. Various performance parameters like 1/3rd octave band vibration acceleration, Working Heart Rate (WHR), Oxygen Consumption Rate (OCR), Energy Expenditure Rate (EER) were measured during the operation of self-propelled machinery with different types of seats (SM-1 to SM-5) and statistically analyzed. The 1/3rd octave band vibration acceleration of self-propelled machinery was found to be lowest with SM-5 seat i.e. 0.983, 0.646, 1.019 m/sec^2 and highest with SM-1 seat i.e. 4.21, 2.77 and 9.819 m/sec^2 in X, Y and Z direction, respectively. It was observed that the vibration acceleration in Z direction is higher as compared to X and Y direction and vibration acceleration has a linear correlation with engine speed. The vibration acceleration and physiological parameters viz. working heart rate, oxygen consumption rate and energy expenditure rate of the subjects were found lesser for SM-5 as compared to other four seats at different engine speed for the self-propelled machinery. Different types of seat, engine speed and subject has statistically significant effect on 1/3rd octave band vibration acceleration, WHR, OCR and EER at 1% level.

Keywords: 1/3rd octave band vibration acceleration; Self-propelled machinery seat; Working heart rate; Oxygen consumption rate

INTRODUCTION

Self-propelled machinery are the most commonly used on-farm power source for small land holding throughout the year, unlike other agricultural machinery having specific and seasonal use. Self-propelled machinery i.e., power tiller; the main means of transportation and agricultural operations in rural areas. In India, the self-propelled machinery had been introduced during the seventies of the last century and recently the number of self-propelled machinery used in India has reached up to 5000 approx [1]. Evolution of the self-propelled machinery has accompanied changes in farm technology and enhancement of farm mechanization. Depending upon the local and domestic conditions, various types and sizes of self-propelled machinery have been developed and used worldwide. The self-propelled machinery has progressed from its original primary use as a substitute for animal power to present units designed for multiple uses [2].

The design of modern tractor includes consideration of human factors because the ultimate objective of ergonomic studies is to optimize the man-machine-environment system to harness greater system efficiency. Generally, new tractors have relatively higher safety and ergonomically designed components. However, some features, such as operator access to the cab and access for servicing or maintenance, have improved very little over time, and therefore scope remains for improvement in safety features of new models of tractors. This improvement leads to well-designed human–tractor interfaces, such as well-accommodated tractor operator enclosures (i.e. cabs, hand and foot controls, and protection frames) can enhance worker productivity, comfort, and safety [3]. The pedal position was identified as the 12.5% of stature below Seat Reference Point (SRP) and 47.5% in front of SRP to have the appropriate operating posture and optimum force application [4]. For example, if the operator's seat is not comfortable, his work performance may be poor and there is also a possibility of accidents. The optimal design of a tractor seat may be achieved by integrating anthropometric data with other technical features of the design [5]. Reviewed the existing information on the tractor seat design, which considers anthropometry and biomechanical factors and gives an approach for seat design based on anthropometry in physical anthropology, refers to the measurement of the human individual for the purposes of understanding human physical variation [6]. Anthropometric dimensions are the initial data used to design the seat and tractor workplace parameters and these data should be only considered in terms of the user population [7]. The placement

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of controls is a complex task for the designer who must take into account the anthropometric characteristics of his target population. The anthropometric dimensions, i.e. popliteal height sitting (5th percentile), hip breadth sitting (95th percentile), buttock popliteal length (5th percentile), interscye breadth (5th and 95th percentile) and sitting acromion height (5th percentile) of agricultural workers need to be taken into consideration for design of seat height, seat pan width, seat pan length, seat backrest width and seat backrest height, respectively, of a tractor.

The most genuine problems faced by operators in the heavy-duty machines; trucks, tractors, etc. are vibrations of low frequency due to non-uniform road roughness, unbalanced rotating engine elements, vehicle components in combination and so on. These vibrations affect the entire body of the operator leading to quick fatigue, inefficient working along with diminished working performance and temporary or permanent damage to driver's health. Tried different combination of cushion materials for the tractor seat, since seat appeared to be the simplest, economic and best location for vibration isolation. They attempted a static and dynamic characterization of three radial tractor tires with four different vertical throttles at four inflation pressures and found that the ratio between static and dynamic stiffness was substantially independent of throttle and inflation pressure. The mechanical vibrations in agricultural equipment are caused by the moving components of the machine, variable environmental terrain and changing speed [8]. Also, these vibrations not only pose a health risk to the operator but make the operator uncomfortable leading to fatigue, injury and high medical expenditures. The average reduction in the tractor seat vibration is 40% with the installation of piezo-metric based seat suspension system with a custom designed isolator in it. The highest value of vibration acceleration was experienced along the vertical direction [9,10]. Tractor induced shock and vibration, currently known as "whole-body vibration" is a major health and safety concern for all the operators [11]. Exposure to whole-body vibration causes a complex distribution of oscillatory motion and forces within the body ISO, 1997 [12]. An electromechanically coupled Finite Element (FE) plate model was developed for predicting the electrical power output of piezoelectric energy harvester plates. In view of above, an investigation was carried out to design and analyze the piezoelectric material based seat suspension system in order to reduce the vibration experienced while the tractor is in operation on various tarmacadam surfaces and field conditions [13].

This paper describes the ergonomic assessment of commonly available self-propelled machinery in Indian farms which includes measurement of 1/3rd octave band vibration acceleration and physiological parameters during the operation of self-propelled machinery with different types of operator's seat.

MATERIALS AND METHODS

In this study, the most popular self-propelled machinery seats and developed seats as SM-1, SM- 2 SM-3 SM-4, and SM-5 were selected for the experiment in laboratory condition with a view to analyze the comfort ability and safety of the subjects during the operation. A developed simulator was used for the experiment in which actual field conditions can be simulated. 1/3rd octave band vibration acceleration and physiological parameters like Working Heart Rate (WHR), Oxygen Consumption Rate (OCR) and Energy Expenditure Rate (EER) of the selected subjects were measured during the experiment. Details of self-propelled machinery seat type are given in (Table 1).

Selection of subjects

The subjects were selected considering the driving knowledge of self-propelled machinery to operate it safely and efficiently. Other major parameters for the selection of subjects included the representation of anthropometric dimensions, physical fitness, and willingness to participate in the experiments and their availability during the entire period of the study.

Measurement of 1/3rd octave band vibration acceleration

For the whole body vibration acceleration, frequency weighting was directly employed through the in-built filters provided in SWAN Pic software, which are in tune with ISO 2631/1, 1997. The spectrum of vibration acceleration was thus obtained for each 1/3rd octave band in the range of 1-80 Hz [14-16]. The measurement procedure of vibration acceleration is presented in the Figure 1.

Computation and data analysis

Fast Fourier Transform (FFT) analysis was performed on the observed data using the SWAN Pic software (Window, USA). Frequency-weighted vibration acceleration (RMS) for the whole body transmitted vibration was calculated for each axis using the filter suggested by ISO 5349 (1986). The sum of the three axes vibration was calculated according to Griffin (1990). The spectrum of vibration acceleration (RMS) was obtained for each 1/3rd octave band in the range between 6.3 and 85 Hz. For the whole body acceleration, frequency weighting was directly employed through the in-built filters provided in SWAN Pic software, which are in tune with ISO 2631/1 (1997). The spectrum of vibration acceleration was thus obtained for each 1/3rd octave band in the range of 1-80 Hz. ANOVA was also created to compare the various parameters considering the details presented in Table 2.

Measurement of physiological parameters (WHR, OCR & EER)

Calibration of the subjects were conducted prior to the experiment in laboratory condition. The calibration was conducted on the

Table 1: Type of seat self-propelled machinery

Name of the machine
SM-1- Self-propelled Rice Transplanter seat
SM-2- Self-propelled Reaper binder seat
SM-3- Mini combine Harvester seat
SM-4- Developed seat without Isolator
SM-5- Developed seat with Isolator

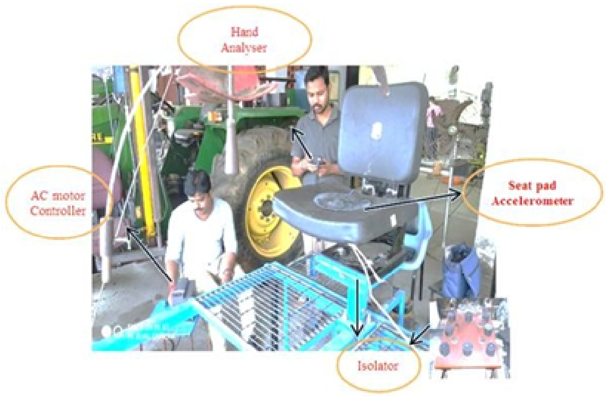

Figure 1: Setup for measuring vibration in the X, Y, Z, direction.

treadmill at natural environmental condition after the training of the subjects for a month in the treadmill. At each selected level of walking speed, heart rate was recorded with the help of polar heart rate monitor. The corresponding oxygen consumption rates were recorded by using the $K4b^2$ human energy measurement system. Considering the maximum heart rate limits suggested by Nag (1981), maximum oxygen consumption rate (VO_2) value was calculated for the subject. A calibration chart was prepared by considering the heart rate and corresponding oxygen consumption rate of the subjects and it was identified that heart rate of the subjects are linearly related to the oxygen consumption rate.

The WHR of the selected subjects during the experiment with all the seats were recorded by using Polar heart rate monitor. The recorded heart rate values from the heart rate monitor were transferred to the computer through the interface in all the above cases. From the downloaded data, the values of heart rate at the resting level and 6^{th} to the 15^{th} min of operation were considered for the calculation of physiological responses of the subjects. The heart rate increases rapidly at the beginning of an exercise and reaches a steady state by the end of the sixth min (Davis and Harris, 1964). The stabilized values of heart rate for each subject from 6^{th} to 15^{th} min of operation were used to calculate the working heart rate of the selected subjects.

The WHR values recorded during the experiments were used to calculate the corresponding values of OCR of the subjects for all the selected self-propelled machinery operating conditions. The oxygen consumption rate values of the subjects were predicated from the calibration chart of the corresponding subjects which was prepared earlier prior to the experiments by recording the heart rate and oxygen consumption rate in laboratory conditions (Figures 2 and 3).

The EER of subjects during the operation of selected self-propelled machinery at all the operating conditions were computed by multiplying the oxygen consumed by the subject during the experiment with the calorific value of oxygen as, 20.88 kJ/min (Nag et al., 1980). The values of WHR, OCR and EER for all the subjects were averaged to get the mean values for all the selected operating conditions.

The Energy Expenditure Rate (EER) of all the subjects for each experimental trial was calculated using the relationship developed for Indian subjects by Nag et al. (1980).

$$EER = 20.88 ^{*} VO_2 \quad (1)$$

Where,

EER=Energy expenditure rate, kJ/min;

OCR=Oxygen consumption rate, l/min.

Experimental design

The experiment was conducted considering factorial randomized design where different self- propelled machinery seats, different speed of operation, $1/3^{rd}$ octave band vibration measurement are the inputs and physiological parameters (WHR, OCR &EER) are the outputs. Three trials were conducted with each subject for each of the above conditions and the mean value of these trials was taken as the representative value for that replication. At a time, $1/3^{rd}$ octave band vibration acceleration in x, y, and z-direction and physiological parameters were measured considering all the type of seats, engine speed and subjects [17,18]. Details of experimental variables are given in (Table 2).

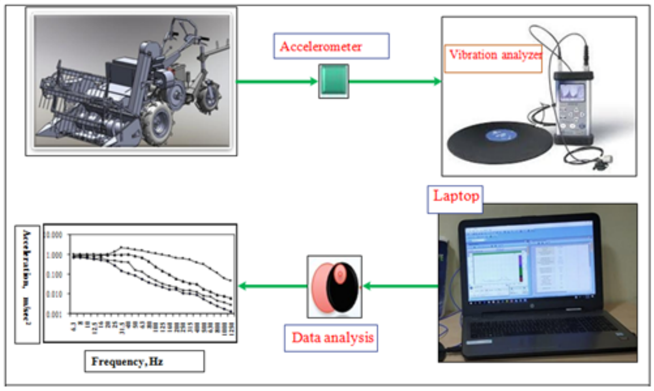

Figure 2: Experimental process of vibration analysis.

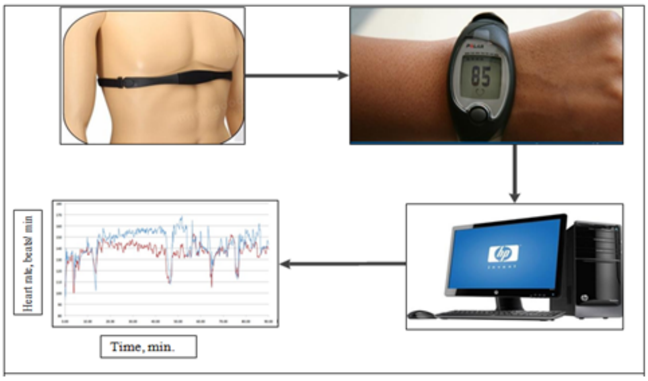

Figure 3: Schematic diagram of the working heart rate measurement setup.

Statistical analysis

Two-way Analysis of Variance (ANOVA) was created to determine the significance level of the influence of the type of seat, engine speeds and subjects to the corresponding $1/3^{rd}$ octave band vibration acceleration in all the directions, working heart rate, oxygen consumption rate, and energy expenditure rate. The statistical analysis was performed using design expert software (version 7.0). A statistically significant difference among the data was considered at $p>0.01$ level of significance [19,20].

RESULTS AND DISCUSSION

Ergonomic evaluation of different types self-propelled machinery seats

The ergonomic evaluation of different self-propelled machinery seats were carried out in terms of $1/3^{rd}$ octave band vibration acceleration (X, Y, Z direction), Working Heart Rate (WHR) (beats/min), Oxygen Consumption Rate (OCR) (l/min), and Energy Expenditure Rate (EER) (kJ/min) of the subject during the operation at selected speeds.

Measurement of $1/3^{rd}$ octave band vibration acceleration at rated speed

The experiment was conducted for different self-propelled machinery seats operated at different speed of the engine to study the comfort ability of the operator. During the operation $1/3^{rd}$ octave band vibration acceleration of different seats were measured. Hand accelerometer was used to record the $1/3^{rd}$ octave band vibration acceleration of different seats in all three directions at different operating speeds.

Table 2: Experimental design for selected seat

Parameters	Level	Description
Independent parameter		
Self-propelled machine seat	05	SM-1, SM-2, SM-3 SM-4 SM-5
Engine speed, rpm	02	Rated speed and higher speed
Subject	03	S-1, S-2, S-3
Dependent parameter		
Vibration acceleration, X,Y & Z direction, m/sec^2		
Maximum heart rate, beats/min		
Oxygen consumption rate, l/min ,		
Energy expenditure rate, kJ/min		

The most dominant frequency during the operation was found to be 25, 31.5, 20, 8 and 16 Hz in x-axis, where the corresponding 1/3rd octave band vibration acceleration was found to be 1.48, 1.72, 1.748, 1.192 and 1.643 m/sec^2 for SM-1, SM-2, SM-3, SM-4, and SM-5, respectively as shown in (Figure 4).

Also, most dominant frequency during the operation was found to be 25, 31.5, 20, 8 and 25 Hz in y-axis, where the corresponding 1/3rd octave band vibration acceleration was found to be 1.99, 2.03, 1.377, 0.836 and 0.888 m/sec^2 for the selected seats, respectively. It was concluded that vibration acceleration was highest in the dominant axis of 1/3rd octave band vibration (z-axis) and there was an amplification of vibration during the operation at rated speed as shown in Figure 5.

Also, most dominant frequency during the operation was found to be 25, 31.5, 80, 8 and 40 Hz in z-axis, where the corresponding 1/3rd octave band vibration acceleration was found to be 2.28, 7.39, 2.388, 1.237 and 1.646 m/sec^2 for the selected seats, respectively. It was concluded that vibration acceleration was highest in the dominant axis of 1/3rd octave band vibration (z-axis) and there was an amplification of vibration during the operation at rated speed as shown in Figure 6.

Measurement of 1/3rd octave band vibration acceleration at high speed

The most dominant frequency during the operation was found to be 40, 63, 16, 6.3 and 6.3 Hz in x-axis, where the corresponding 1/3rd octave band vibration acceleration was found to be 4.10, 2.46, 2.99, 1.053 and 1.583 for SM-1, SM-2, SM-3, SM-4, and SM-5 seats, respectively as shown in Figure 7.

Also, most dominant frequency during the operation was found to be 80, 63, 6, 12.5 And 12.5 Hz in y-axis, where the corresponding 1/3rd octave band vibration acceleration was found to be 1.05, 2.77, 2.881, 0.646 and 0.818 m/sec^2 for the selected seats, respectively as shown in Figure 8.

Also, most dominant frequency during the operation was found to be 40, 63, 63, 63 and 40 Hz in z-axis, where the corresponding 1/3rd octave band vibration acceleration was found to be 4.10, 4.68, 9.817, 2.08 and 3.192 m/sec^2 for the selected seats, respectively. It was concluded that vibration acceleration was highest in the dominant axis of 1/3rd octave band vibration (z-axis) and there was an amplification of 1/3rd octave band vibration during the operation at high speed as shown in Figure 9.

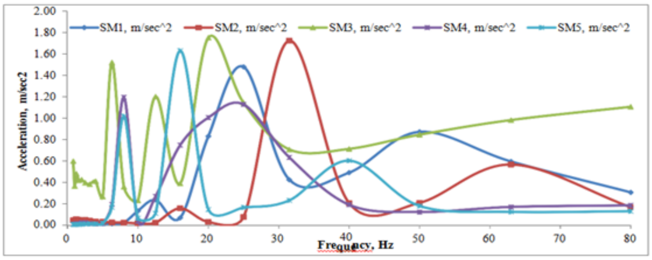

Figure 4: 1/3rd octave band vibration acceleration during the experiment in laboratory condition for selected seats in X direction at rated speed.

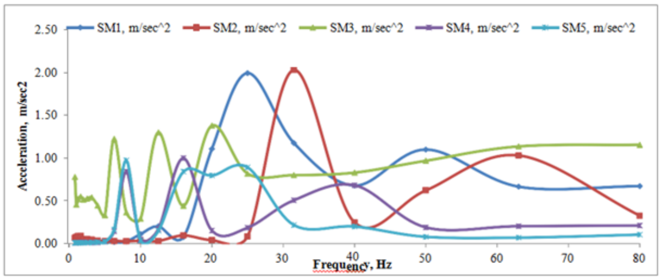

Figure 5: 1/3rd octave band vibration acceleration during the experiment in laboratory condition for selected seats in Y direction at rated speed.

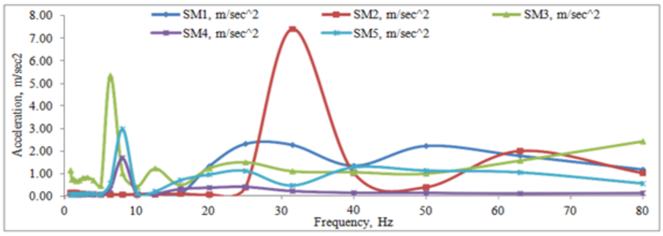

Figure 6: 1/3rd octave band vibration acceleration during the experiment in laboratory condition for selected seats in Z direction at rated speed.

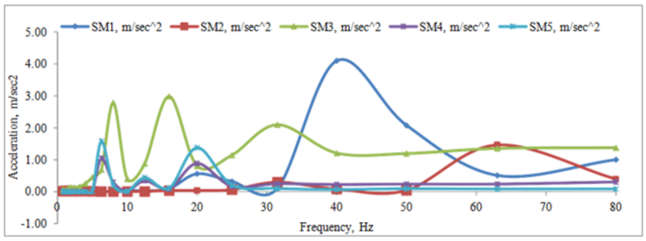

Figure 7: 1/3rd octave band vibration acceleration during the experiment in laboratory condition for selected seats in X direction at high speed.

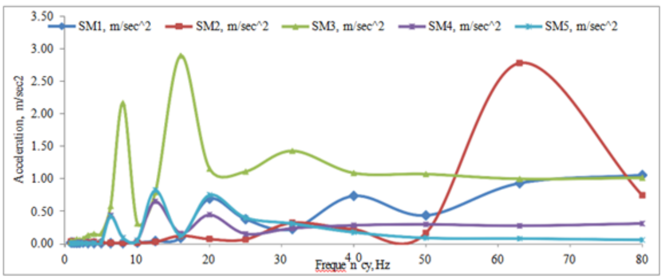

Figure 8: 1/3rd octave band vibration acceleration during the experiment in laboratory condition for selected seats in Y direction at high speed.

Measurement of physiological parameters of selected subjects during the operation of self-propelled machinery at rated speed

It was observed that working heart rate of the subjects is linearly related to the corresponding oxygen consumption rate during the operation with all the seats at rated speed. The graphical representation of working heart rate and oxygen consumption rate showed that WHR and OCR of the selected subjects were lowest with SM-5 and highest with SM-3 during the operation at rated speed. The working heart rate and corresponding oxygen consumption values are shown in Figures 10 and 11. The working heart rate values of selected subjects during the experiment with SM- 1 SM-2, SM-3, SM-4 and SM-5 lie between 98 to 106, 94 to 116, 87 to 120, 89 to 102 and 83 to 98 beats/min, respectively. Similarly, oxygen consumption rate values of the subjects during the experiment with SM-1 SM-2, SM-3, SM-4 and SM-5 were found to be within the range of 0.473 to 0.591, 0.495 to 0.751, 0.581 to 0.977, 0.499 to 0.598 and 0.455 to 0.917 l/min, respectively. It was found that the working heart rate and oxygen consumption rate of subjects were lesser for SM-5 as compared to other four seats during the operation of self-propelled machinery at rated speed.

Also, it was observed that the energy expenditure rate was found lowest for all the subjects with SM-5 as compared to SM-1, SM-2, SM-3, and SM-4 at rated speed. The mean values of energy expenditure rate are shown in the Figure 12. The energy expenditure rate of the subjects during the operation with seats SM-1, SM-2, and SM-3 are categorized under heavy work as per the classification given by Ramanathan and Nag, for different agricultural operations and that of SM-4 and SM-5 in moderate work. It was observed that there is a significant difference between the energy expenditure rates of subjects for all the seats but there is no interaction significant difference between all types of seats.

Measurement of physiological parameters of selected subjects during the operation of self-propelled machinery

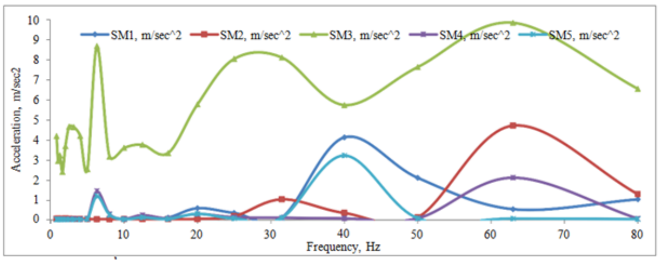

Figure 9: 1/3rd octave band vibration acceleration during the experiment in laboratory condition for selected seats in Z direction at high speed.

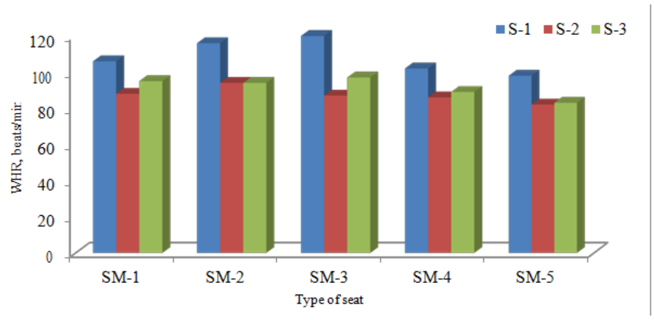

Figure 10: Working heart rate of subjects with different self-propelled machinery seats at rated speed.

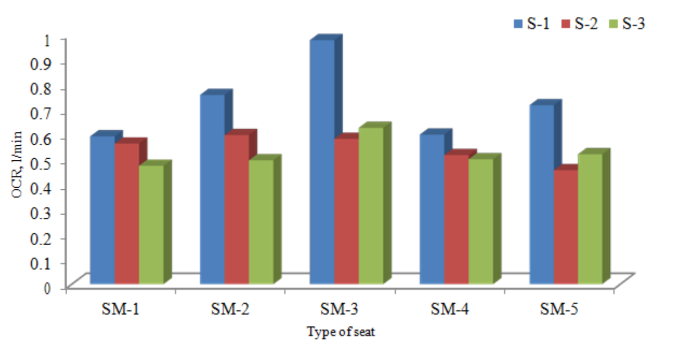

Figure 11: Oxygen consumption rate of subjects with self-propelled machinery seats at rated speed.

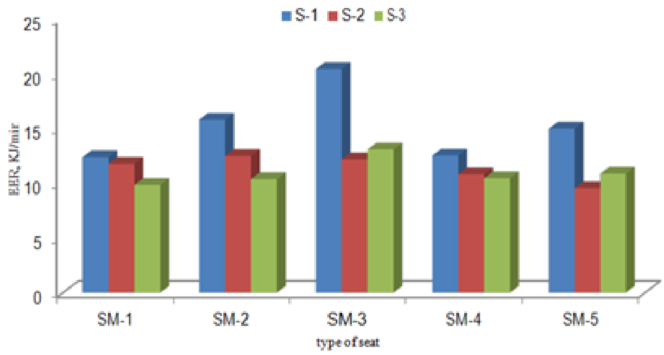

Figure 12: Energy expenditure rate of subjects with self-propelled machinery seats at rated speed.

at higher speed

It was observed that working heart rate of the subjects is linearly related to the corresponding oxygen consumption rate during the experiment with all the seats. The graphical representation of working heart rate and oxygen consumption rate shows that WHR and OCR was found lowest for SM-5 and highest for SM-3 at higher speed. The mean value of working heart rate and corresponding oxygen consumption rate are shown in Figures 13 and 14. The mean value of working heart rate and oxygen consumption rate were found highest for SM-2 for all the subjects. The working heart rate of the subjects during the operation with SM-1, SM-2, SM-3, SM-4, and SM-5 seats were found to be within the range of 96 to 122, 96 to 126, 95 to 119, 90 to 113 and 86 to 110 beats/minutes, respectively. Similarly, mean value of oxygen consumption rate of the subjects during the operation was found to be within the range of 0.495 to 0.824, 0.622 to 0.937, 0.666 to 0.813, 0.551 to 0.854 and 0.522 to 0.674 l/min. It was found that the working heart rate and oxygen consumption rate of the subjects were lesser for SM-5 as compared to other four seats at higher speed.

Also, it was observed that the energy expenditure rate was found lowest for subjects during the operation of self-propelled machinery with SM-5 as compared to SM-1, SM-2, SM-3 and SM-4 at higher speed. The mean values of energy expenditure rate are presented in the Figure 15. The energy expenditure rate of subjects during the operation with SM-1, SM-2, and SM-3, SM-4 seats is categorized under heavy work and with SM-5 seat the operation is categorized under moderate work. It was observed that there is a significant difference between the energy expenditure rate of the subjects with all the seats but there is no interaction significant difference with all the seats.

Statistical analysis of data collected during the operation

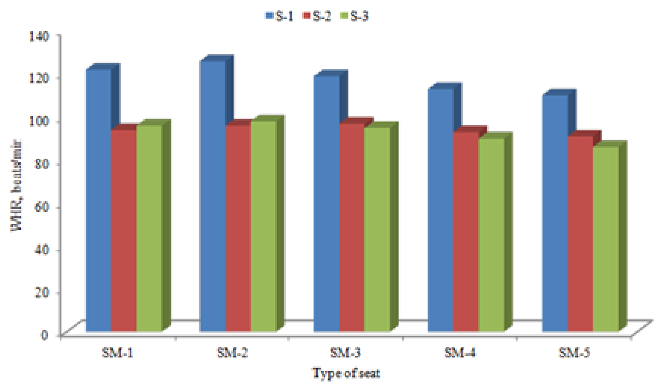

Figure 13: Working heart rate of subjects with self-propelled machinery seats at higher speed.

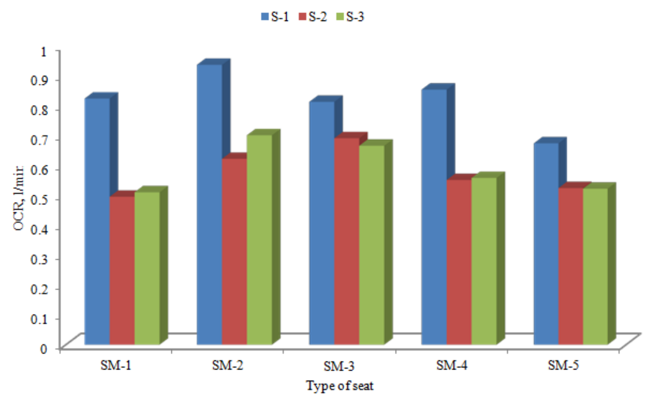

Figure 14: Oxygen consumption rate of subjects with self-propelled machinery seats at higher speed.

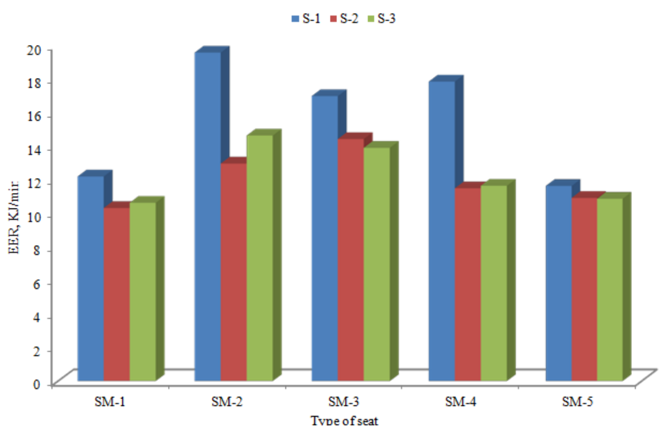

Figure 15: Energy expenditure rate of subjects with self-propelled machinery seats at higher speed.

of self-propelled machinery with different seats

The statistical analysis of vibration acceleration in X, Y, and Z direction, working heart rate, oxygen consumption rate, and energy expenditure rate collected during the operation of self- propelled machinery with different seats were conducted. The effect of type of seat, engine speed and subjects on vibration acceleration in X, Y, and Z direction, working heart rate, oxygen consumption rate and energy expenditure rate of all the subjects are presented below.

Effect of type of seat, engine speed and subjects on 1/3rd octave band vibration acceleration in X direction

The signal to noise ratio was found to be 8.67 which states a highly satisfactory signal indicating that the above model could be used to navigate the 1/3rd octave band vibration acceleration in X direction. The relationship between the actual and predicted value of power was found to be in a straight line, with a high R^2 value of 0.70 shown in Figure 16. The statistical analysis of the observations obtained from the experiment was conducted by two- way full factorial randomized design. It has revealed that 1/3rd octave band vibration acceleration in X direction was affected by the type of seat, engine speed, and subjects significantly with 1% significance level ($p<0.0001$) while the effect of the combination on vibration acceleration X subjects was found not significant.

Effect of the type of seat, engine speed, and subjects on 1/3rd octave band vibration acceleration Y direction

The signal to noise ratio was found to be 8.84 which states a satisfactory signal indicating the above model could be used to navigate the 1/3rd octave band vibration acceleration in Y direction. The relationship between the actual and predicted value of 1/3rd octave band vibration acceleration in Y direction was found to be linear with an R^2 value of 0.71 shown in Figure 17.

The 1/3rd octave band vibration acceleration in Y direction is significantly affected by the type of seat, engine speed and subject at 1% significance level ($p<0.0001$).

Effect of type of seat, engine speed and subjects on 1/3rd octave band vibration acceleration in Z direction

The signal to noise ratio was found to be 5.79 which states a satisfactory signal indicating that the above model could be used to navigate the 1/3rd octave band vibration acceleration in Z direction. The relationship between the actual and predicted value of 1/3rd octave band vibration acceleration was found to be in a straight line, with an R^2 value of 0.50 as shown in Figure 18.

The 1/3rd octave band vibration acceleration was found to be significantly affected by the type of seat, engine speed and subject at a 1% significance level ($p<0.0001$). It was also observed that the interaction effect of the type of seat, engine speed and subjects is not significant for the 1/3rd octave band vibration acceleration in Z direction.

Effect of type of seat, engine speed, and subjects on working heart rate

The signal to noise ratio was found to be 21.36 which states a satisfactory signal indicating the above model could be used to navigate the working heart rate design. The relationship between the actual and predicted value of working heart rate was found to be

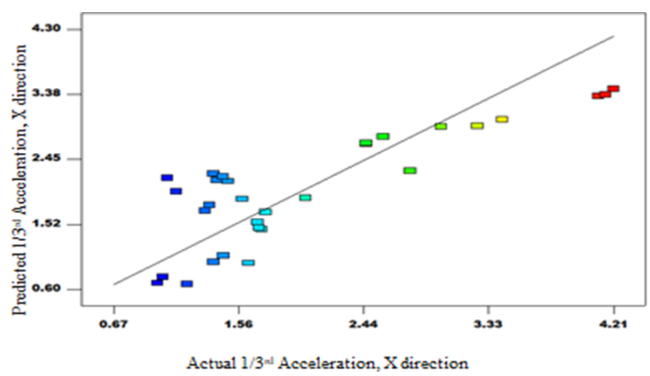

Figure 16: The relationship between the actual and predicted value of 1/3rd octave band vibration acceleration in X direction.

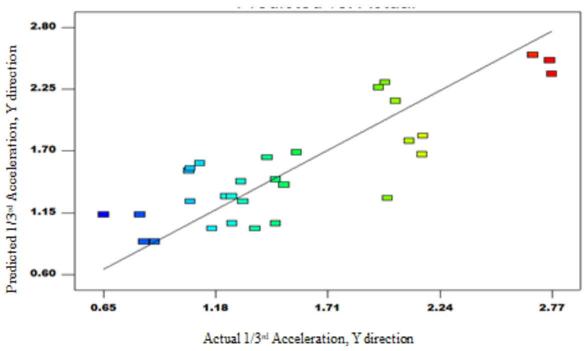

Figure 17: The relationship between the actual and predicted value of 1/3rd octave band vibration acceleration in Y direction.

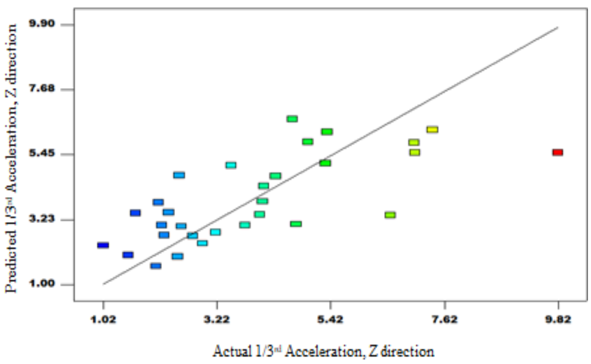

Figure 18: The relationship between the actual and predicted value of 1/3rd octave band vibration acceleration in Z direction.

linear with an R^2 value of 0.9309 shown in Figure 19. The working heart rate is significantly affected by the type of seat, engine speed and subjects at 1% significance level ($p<0.0001$).

Effect of type of seat, engine speed and subjects on the oxygen consumption rate

The signal to noise ratio was found to be 11.71 which states a satisfactory signal indicating the above model could be used to navigate the oxygen consumption rate. The relationship between the actual and predicted value of oxygen consumption rate was found to be linear with an R^2 value of 0.80 as shown in Figure 20. The oxygen consumption rate is significantly affected by the type of seat, engine speed and subjects at 1% significance level ($p<0.0001$). It was also observed that the effect of the engine speed is not significant for the oxygen consumption rate at 1% significance level ($p<0.0001$).

Effect of the type of seat, engine speed and subjects on energy expenditure rate

The signal to noise ratio was found to be 10.81 which states a satisfactory signal indicating the above model could be used to navigate the energy expenditure rate. The relationship between the actual and predicted value of energy expenditure rate was found to be linear with an R^2 value of 0.79 as shown in Figure 21. The energy expenditure rate is significantly affected by the type of seat, engine speed and subjects at 1% significance level ($p<0.0001$). It was also observed that the effect of the engine speed is not significant for the energy expenditure rate at 1% significance level ($p<0.0001$).

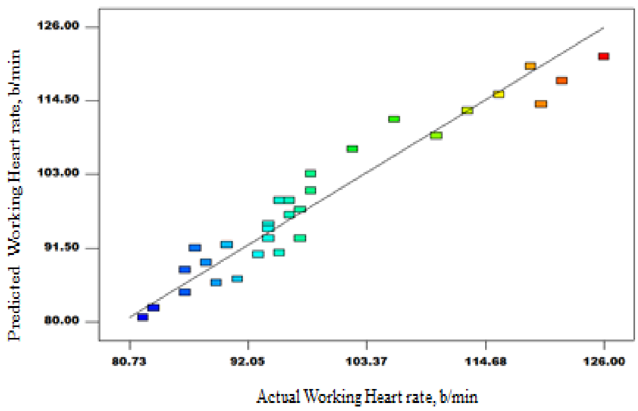

Figure 19: The relationship between the actual and predicted value of working heart rate.

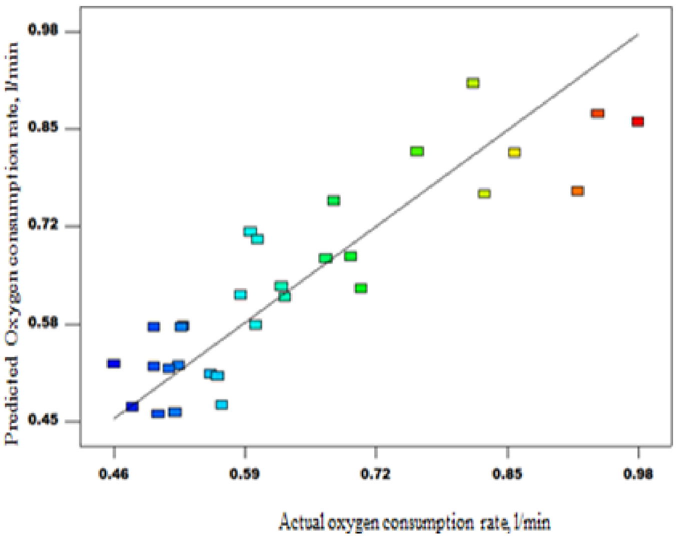

Figure 20: The relationship between the actual and predicted value of OCR.

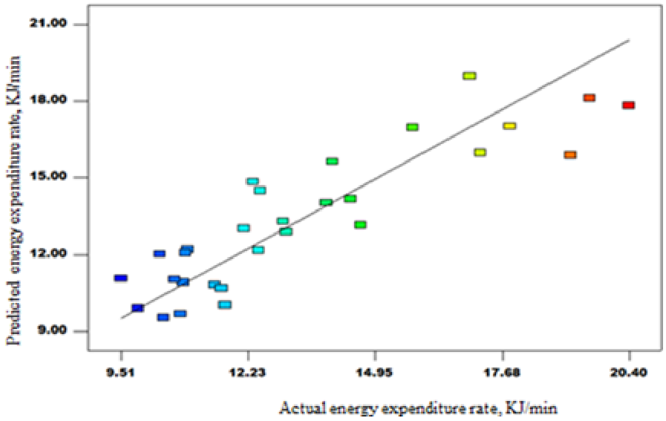

Figure 21: The relationship between the actual and predicted value of EE.

Numerical optimization of type of seat, engine speed and subjects on WHR, OCR, and EER

The input values given to model for the optimization process is given in Table 3. The allotted limits are within the values as accepted in the experiment. The whole criteria were finalized by setting the goal and their importance (grading out of 5) on the basis of the desirability of the response the reduced models were obtained by eliminating the non-significant term from the model. The reduced model and its statistical data obtained from the ANOVA are given

Table 3: Numerical optimizations of the type of seat, engine speed, and subjects

Name of variable	Lower limit	Upper limit	Weight	Criteria		Predicated value
				Target	Importance	
Independent						
Type of seat	SM-5	SM-1	1	Range	3	SM-4
Engine speed	Rated	High	1	Range	3	Rated speed
Subject	S-1	S-3	1	Range	3	S-3
Dependent						
Acceleration X	0.983	4.21	1	Minimize	5	0.9914
Acceleration Y	0.646	2.77	1	Minimize	5	1.00863
Acceleration Z	1.019	9.819	1	Minimize	5	2.6637
WHR	82	126	1	Minimize	5	86.0667
OCR	0.455	0.977	1	Minimize	5	0.46
EER	9.51	20.4	1	Minimize	5	9.54909

Table 4: Reduced response and statistical data obtained from the ANOVA.

Response	Reduce model in terms of the actual factor	R^2	Std. dev.
Acceleration X	+2.04+0.75×A+0.067×A+0.31×A+0.41×A+0.61×B0.040 ×C+0.063×C	0.70	0.62
Acceleration Y	+1.54-0.046×A+0.82×A+0.10×A-0.44×A+0.12×B-0.095× C+0.071×C	0.71	0.36
Acceleration Z	+3.940.68×A+2.14×A+1.00×A0.71×A+0.19×B+0.41×C -0.036×C	0.50	1.69
WHR	+98.77+1.40×A+5.23×A+3.73×A3.27×A+2.97×B+14.43 ×C -7.97×C	0.93	3.69
OCR	+0.640.061×A+0.048×A+0.089×A0.071×A+0.026×B+0.16×C-0.077×C	0.80	0.078
EER	+13.321.16×A+0.97×A+1.83×A1.51×A+0.57×B+3.25× C -1.56×C	0.79	1.66

in Table 4.

The values of the coefficient of determination are greater than 0.70, 0.71, 0.50, 0.93, 0.80 and 0.79. It shows that the model is well fitted in the order of the polynomial equation. The models were found to be within 1% level of significance.

CONCLUSION

Ergonomic evaluation of self-propelled machinery with five different seats were conducted and physiological parameters (working heart rate, oxygen consumption rate and energy expenditure rate) and 1/3rd octave band vibration acceleration at different engine speeds were collected. The effect of engine speed and types of seat on vibration acceleration in all the directions, working heart rate, oxygen consumption rate and energy expenditure rate of the subjects was studied.

The 1/3rd octave band vibration acceleration was found to be increased with the increase of engine speed. The vibration acceleration during the experiment was found to be 0.983, 0.646, 1.019 m/sec^2 and 4.21, 2.77 and 9.819 m/sec^2 in X, Y and Z direction with SM-5 and SM-1, respectively. Different types of seat and engine speed have statistically significant effect on vibration acceleration in all the direction at 1% level but there is no significant effect on the interaction at a 1% level of significance.

It was found that the working heart rate, oxygen consumption rate and energy expenditure rate of subjects was lesser for SM-5 as compared to other four seats at rated speed for self-propelled machinery. Working heart rate and oxygen consumption rate were found to be increased with the increase of engine speed. Different types of seat and engine speed have statistically significant effect on WHR, OCR, and EER at 1% level.

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