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Comfort conditions of a tractor driver in Indian Context : A Review

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Abstract: Seated drivers are exposed to vibrations effects; which are very harmful and in some cases lead to permanent pains, i.e . back pain etc. The source of the vibration is usually a dedicated work-related vehicle such as a dump truck, forklift truck or agricultural tractor. The vibrations are transferred to drivers who are constantly engaging and disengaging the accelerator, brakes and clutches. Even if driver is idle, but vehicle moving, the tractor drivers are exposed to pain because they interact with vibration more than other people. The restricting and awkward postures contribute more to this problem. The vibrations in vertical direction has more influential effect than vibrations in other directions. The frequency range of 2–6 Hz has been observed to be the most harmful for the human operator because resonance occurs within this frequency range.

In this paper, a review of the work done in this area, particularly WBV vibrations to which tractor drivers are exposed, has been presented and discussed. The paper also summarises the literature for study of various other comfort factors particularly thermal comfort. It also discusses if there can be any combined method where one factor contribute to the other factor for further study, investigation and experimentation purpose.

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Keywords: WBV, Tractor driver, sitting posture, FEM

1. Introduction

1.1 Whole Body vibrations:

Whole-body vibration (WBV) is vibration transmitted to the whole body by the surface supporting it (i.e. via a seat or floor). It is commonly experienced by drivers, operators and passengers in vehicles when travelling over uneven surfaces. The vibration can normally be caused by events such as: wheels moving across uneven paved surfaces; wheels moving over obstructions or into potholes. WBV can also be produced by specific work activities such as compaction techniques and tillage operation etc.

The study of WBV in past have been carried out for the vehicle occupant, automobile drivers, players and for getting medical physical exercise result too. An ISO standard 2631-1 (1997) has been made out as a guideline for the safe exposure limits to WBV. The transmission of vibration to the body is dependent on body posture. Human, as a mechanical system, is extremely complex and its mechanical properties readily undergo change. So, the effects of vibration are complex. Exposure to WBV causes motions and forces within the human body affecting cardiovascular, respiratory, digestive problems and discomfort that could lead to accidents[1].

To study the effect of Vibrations on human body and the most affected area, can be the area of interest for mechanical engineers as well as medical expertise. A tractor driver by default is subjected to vibrations from seat, back, feet and even the steering wheel.

1.2 Thermal Factor:

It is generally observed that ride comfort is effected by a number of factors such as temperature, noise, vibration, seat design, seated posture, use of backrest, etc. Out of these factor, **the thermal environment** affect tractor driver's health, performance and comfort. Even in moderate outdoor conditions, tractor is subjected to various heat loads such as direct and reflected solar radiation, heat transfer through the cab walls, and heat gain from the powertrain [2].

According to the ANSI/ASHRAE Standard 55-2010, thermal comfort, or human comfort, is defined as "**that condition of mind which expresses satisfaction with the thermal environment and is assessed by subjective evaluation**". The heat transfer occurs between the environment and the human body, which has a surface area of 19 ft^2 (1.81 m^2)

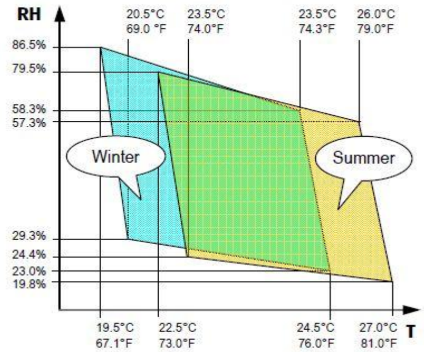

Figure 1. Thermal Comfort Zone: Temp 23.5^{0}C & RH 29.3% to 57.3% [Ohio University, Study Material**]**

Human comfort inside the tractor cab depends upon the factors like Air temperature, interior surfaces radiant temperature, air velocity and relative humidity, which *combined coupled with the effect of WBVs* should obtain the absence of discomfort, for given operator's activity.

Thermal environment for tractor drivers differs from typical working places in buildings and is highly non-uniform and asymmetric due to : cab interior volume being small, rapid changing of microclimate parameters due to changing orientation of tractor w.r.t. sun, glazing area is large in comparison to the cab surface area, operator unable to change position within the cab, limited changes of body posture etc. Due to these reasons, obtaining the uniform and comfortable conditions for a tractor driver with homogeneous steady environment of thermal and WBV comfort is difficult; for a long duration of stay of him on driving seat.

2. Methods to simulate vibration and thermal effects:

To simulate the changes on the human body due to various factors, a virtual 3-D model of the human body operator can be created that mimics the dynamics of the human body, and at the same time efficiency can be assessed by comparison of heat losses from the operator's body segments, in order to study the vibrations as well as thermal stresses, on the tractor driver/human subject in sitting posture. Then the results of data from literature can be compared to the results obtained from the simulated mechanical system of the human body by using simulation software.

The human body is a complex non-uniform, nonlinear and anisotropic structure. Finite Element Analysis (FEA) assumes that human body consists of numerous finite elements whose element properties, can be defined from experiments on corpses. Modal analysis(a part of FEA) is a tool for the study of dynamics properties of the any object/body under the action of vibrations. Modal parameters such as damping ratio, natural frequencies and mode shape are determined in order to describe dynamics behaviour of the system.

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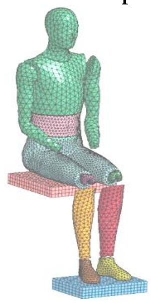
The computerised modeling of the human body can be Finite Element Modeling (FEM).



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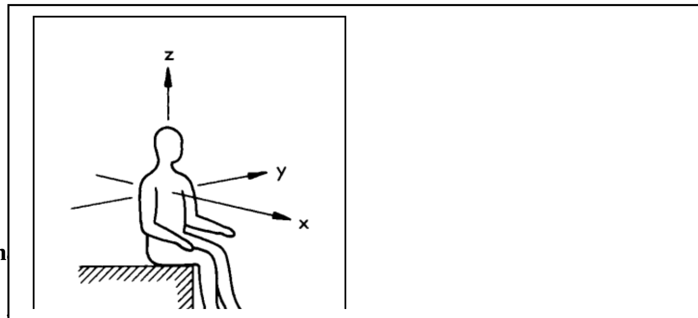
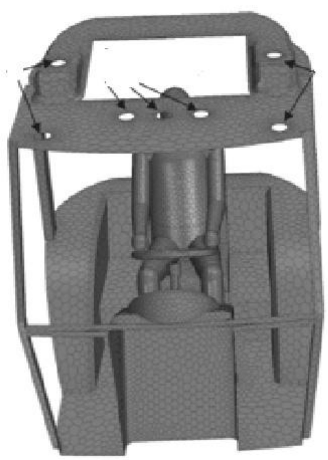


et al.]

Figure 2(b). Co-ordin ... n ISO 2631[N. Mansfield, 2005]

Due to significant ... an body has provided deep insight into the "suitability" of a certain environment or task to the human performing this task.

Computational Fluid Dynamics(CFD) is carried out for thermal analysis by computer simulations, since CFD software capture the effects of heat in the form of fluid flow. It helps to identify hot spots and learn where cold air is being wasted or air is mixing. By changing variables, one can visualize how air will flow through the tractor cabs under a number of different circumstances, to optimize and predict the effectiveness of a particular layout.



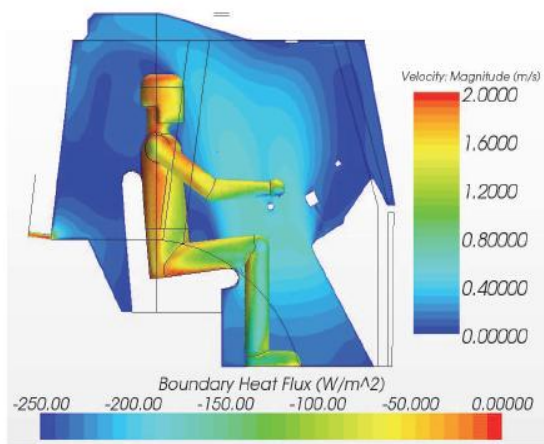


Fig 3 (a) Arrangement of Air distribution designs on meshed model of tractor cabin
Fig 3(b) CFD analysis process showing Convective heat loss [Ruzic et al., 2014]

However, as the tractor driver is also subjected to the vibrations, so the comfort analysis of tractor driver should not be thought of without the inclusion of vibration analysis.

3. Studies related to Vibrations:

Various studies carried out on automobiles, were relevant for the physical problems experienced by auto driver. The studies were made in: X, Y and Z directions as defined in figure 2(b).

However, a few research findings related to vibration comfort of tractor driver are given below:

1. Village et al. (1989) [3], made 22 measurement of WBV at seat level for 11 Long-Haul-Dump(LHD) vehicles and found that 20 measurements exceeded recommended limits of ISO 2631-1(1985) for vertical (z-direction).
2. Anderson et al. (1992) [4] concluded from the study that 67% of the drivers had Lower Back Pain(LBP) symptoms, which were mostly due to postural problems and not due to some mechanical disorders.

3. Bovenzi & Betta (1994) [5] undertook a similar study on agricultural tractor drivers. The study quantified the two factors: Vibration dose in years and Postural load on Lickerts scale. It was found that increase in total driving hours had increased LBP.
4. Kumar et al. (2001) [6] took Magneto Resonance Image (MRI) of Lumbar Spine for tractor driving farmer(TDF) to be compared with non-TDF. However, the objective difference between the two groups could not be established significantly, whereas the TDF complained of back pain more oftenly.
5. Johanning et al. (2006) [7] studied US locomotive operator with seat design factor's influence on WBV exposure and effects. It was found that seat ratio indicated that the seat magnified the floor input vibration particularly in horizontal direction.
6. Mohsen Fereydoomi et al. (2012) [8] analysed the vibrations of operator in Universal 650, Massey Ferguson 285, MF 299 models and found that in addition to WBV, vibration difference in Hands Arm Vibration(HAV) and engine rotation were significant too,.
7. Boban Cvetanovic et al. (2017) [9], found that old tractor models had high intensity of vibrations, above permitted limits, at driver seats. Cushions lowered the vibration levels.
8. Mourizio Cutini et al. (2017) [10] presented a review of creating a simplified procedure for determination of agricultural tractor vibrations. It presented a number of factors affecting the vibration comfort like soil profile, tractor speed and nature of operations.
9. S. Karthik Niranjan et al. (2017) [11] , studied the human response to the WBV generated by tractors by mathematical modelling and analysis of an occupant tractor system in Wolfram System Modeler software. The results were compared with ISO standards, safe vibration exposure was found. For simplification, the profile of the road was considered sinusoidal, of amplitude 5cm.
10. Ishbir Singh *et al.*(2016) [12], conducted experimental investigations to assess the subjective response of 12 seated human male subjects under vertical harmonic vibrations of amplitudes of excitation (0.5, 1.0 and 1.5 m/s^2 rms) and frequencies of 5, 8, 12, 16 and 20 Hz. Backrest inclination was varied for inclination angle of 0°, 15° and 30°. It was concluded that the varying of frequency and amplitude had a definite effect on various parts of the body, concentrating at the feet and increasing the inclination increased the comfort. However, the effect of cushioned seat was not studied in the investigation.
11. K.N. Dewangan et al. (2015) [13], calculated apparent mass (AM) responses of the body seated with and without a back support on three seats (polyurethane foam (PUF), air cushion and a rigid seat) measured under three levels of vertical vibration (rms acceleration: 0.25, 0.50 and 0.75 m/s^2) in the 0.5 to 20 Hz range. The peak magnitude decreased by changing the sitting condition from no back support to a vertical support; and more with the air seat. AM responses of the seated body were dependent on visco-elastic properties and contouring of the seat. Variation in anthropometric parameters and visco-elastic properties of seats was desirable.
12. G. Alfaro Degan et al. (2015) [14], evaluated the relationship between the WBV exposure values of loader vehicle drivers and their anthropometric characteristics, like height and weight. In this case study, sampling campaigns were used to analyse, the responses of drivers to vibrations from the same vehicle. A correlation study was proposed to quantify the observed differences and to predict exposure values from anthropometric data.
13. In a study by B. Cvetanovic and D. Zlatkovic (2013) [9], for a short-term work of 1 hour, acceleration and daily exposure A(8), vibration values in lower power (IMT 533) tractors were almost negligible and harmless. In IMT 558, for two-hour work, the values of daily exposure A(8) were 1.93 m/s^2 which was significantly higher above ELV was unacceptable risk. The highest vibration level in all models was along z axis.
14. In a modal analysis study, Roger Scholza *et al.*(2013) [15], the measurement of vibrations in older models of IMT tractors showed that more than one-hour work with these models regularly,

caused a risk of intense daily vibration exposure. Frequencies of vertical oscillations of human body parts were assumed with approximations, e.g. : head≈25 Hz, shoulders≈ 4-5 Hz, chest ≈60 Hz, spine ≈10-12 Hz, abdomen ≈4-8 Hz, hips ≈50-200 Hz, elbows ≈16-30 Hz, eye socket ≈30-80 Hz, etc. There were both short-termed vibrations related disorders and long-term influence disorders.

15. Chak Yin Tang, Wai Chan and Chi Pont Tsui (2010) **[**16**]**, made FEM analysis of the seat cushion, to design seat to reduce vibrations at a certain frequency range.
16. M.M. Verver *et al.* (2007) [17], observed that a FEM of the human buttocks could be developed for prediction of seat pressure distributions at the contact interface between human and seat. A parameter study showed that seat pressure distributions were sensitive for variations in seat properties, human soft tissue properties and posture
17. Anisa, Geeta and Vishal Kumar (2013) [18]conducted experiments with five dependent variables viz., body temperature, blood pressure, heart rate, noise and vibration level, and three independent variables viz., tillage implement, operator age group and field conditions. The tractor operator having age group of 21-30 years had minimum physiological changes as compared to 31-40 and 41-50 years age in all tillage operations. as well for wet field conditions as compared to dry field conditions.

4. Studies related to thermal comfort of driver:

18. Ibrahim Reda et al.(2017) [19], carried out the study of the air flow regimes and thermal comfort in vehicle cabin using CFD software, FLUENT 17.2 on embedded s2s (surface to surface). The air flow regimes with rectangular shape had a temperature 2-4°C lower than circular shape, whereas the velocity in circular shape was lower. Both the two cases had a bad agreement between the average air velocity, temperature with the ASHRAE comfort conditions. Inside the cabin gave too hot discomfort and dissatisfaction.
19. Md. Shaha Nur Kabir *et al.* (2014) [20], reviewed comfort conditions of agricultural tractor and it was found that, the outdoor thermal environment conditions, operator's activity and clothings effect operator's health, performance and comfort. Vehicle is subjected to heat loads such as direct and reflected solar radiation, heat radiation through cab walls due to temperature difference and heat gain from the power train. Also, WBV levels were found to be dependent upon the nature of field operation performed.
20. D. Ruzic *et al.*(2010) [21], developed CFD model of the human-cabin-environment system, using computer simulated person (CSP) to observe, heat losses from body part, without solar radiation. In two groups of simulations, one was isothermal and in other the initial conditions were the hot cab ambient temperature of 30°C. Solar characteristics of glass was found to be a direct way to reduce the operator's thermal load. Whereas the use of roof overhangs, adjustable sun visors, less inclined glass and thermally reflective heat shield placed beneath the cab floor, were other improvements suggested.
21. Martin Helander, *A guide to human factors and ergonomics*, (2006) [22], gave a simplified version of thermal balance equation given by Barnard, 2002 (in W/m^2):

$$M - W = C + R + E + S$$

where M is the metabolic power, W is the effective mechanical power, C is the heat exchange by convection, R is the heat flow by radiation at the skin surface, E is the heat flow by evaporation at the skin surface, and S is the heat storage.

22. V.K. Tiwari and P.K. Bhoi et al.(2007) [23], designed and fabricated a collapsible tractor operator enclosure (CTOE) for comfort to the operators during all seasons of the year. The open condition

with all sides closed provided comfort 87.5% in cold condition, whereas the open condition with front, back and window open provided comfort of 77.5% in hot condition. No conclusion was drawn, for dusty condition.

23. G. Karimi, E. C. Chan and J. R. Culham (2003) [24], developed experimental physical model to simulate the thermal interactions between passenger-cabin-heated/ventilated seat. The low-power electric heating pads and ventilation installed on the seat cushion and backrest quickly attained thermal comfort to the passenger in the contact areas.

5. How to combine the effect of Thermal Comfort and Vibration?

24. Anelise Sonza et al.(2015) [25], measured cutaneous/skin temperature to study the effect of WBV. A study with thermography showed an increase in temperature of the medial head of the gastrocnemius. However, different BMI and platform setting could have different results.
25. A study by D. J. Cochrane et al.(2015) [26], found that effects of WBV were more equivalent effective warm up than that of stationary cycling and passive warm-up(hot water). The study showed the increased rate of muscle temperature (Tm) during acute WBV.
26. Aderito Seixas et al. (2014) [27], exposed 12 volunteers to WBV of 35 Hz , 40 Hz and 5-6mm amplitude. Infrared thermography of lower limbs revealed decrease in skin temperature.

6. CONCLUSION:

"Comfort" identifies a sense an overall well-being, both physical and psychological, influenced by factors such as vibrations, temperature, humidity, noise etc. All the WBV work is focused on the low frequency ride comfort, related to mechanical vibrations between 0 and 40 Hz. This frequency range involves the natural frequencies of most of the human body organs [1, 2, 3, 4]. For sake of brevity, we will refer to comfort, meaning actually ride comfort. Exposure to mechanical vibrations has negative consequences on the driver's health and discomfort; in particular the low frequency vibrations generated during ride. Some studies have been undertaken with the aim to measure the level of vibrations at which farm tractor operators are exposed [6, 7, 8, 10, 11]. Moreover in the literature there are some contributions that provide the guidelines to objectively evaluate comfort [6, 7, 8, 10, 11]. While these studies confirmed that tractor WBV emission levels were found to be very dependent upon the nature of the operation performed, they have shown that changing soil profiles and tractor speeds give rise to similar spectral trends of the accelerations resulting from ground input.

As of farm tractors, experimental tests are performed in order to measure the vibration level in the cabin and at the seat [6, 7, 8, 10, 11, 23]. The experimental tests also simulated different working conditions [21]. The main purpose of such tests is to measure the vibration level felt by the operator in order to predict the vibration exposure level [6, 7, 8, 9, 10, 11]. Simulation models are often used to evaluate the vibration level at the driver seat [12, 13]. High values of vibration exposure levels can lead not only to operator discomfort but to early fatigue and even to health problems.

In order to compare the results of different thermal stress studies, information on three items had to be found for each study: temperature, the duration of exposure, and the type of task. Across the studies, these three factors provided sufficient information to recognize trends in thermal effects on mental and performance despite an expected amount of variability.

Discomfort is a personal response to hot conditions based on one's own perception of air temperature, humidity, air movement, and the degree of insulation afforded by clothing. When workers are uncomfortable they may remove clothing, alter work patterns, or withdraw to cooler environments. Because it is not always possible for a tractor driver to withdraw from excess heat. The ASHRAE comfort zones have been extended to accommodate more prevalent Indian working conditions. The original comfort limits are only applicable to seated work, such as that performed by some operators in control rooms. The additions estimate comfort levels for active workers, assume average air movement, and account for clothing insulation levels.

The literature presented in this review indicates the possibility, of developing virtual laboratory procedure for measuring the exposure of agricultural tractor operators to WBV combined with thermal environment so that the outcome of the simplified procedure can be used to compare different conditions—or a given tractor with different equipment like seats etc. Such simplified testing procedures can be considered suitable for determining operators' daily exposure to vibration and thermal environment in open field operating conditions.

A few papers (25, 26, 27) gave an indication that an effect of WBV can be measured by change in cutaneuos/skin temperature. It also contributed to increase in muscle temperature. This clearly showed that there is an alternate equivalent method which can be experimented and calibrated for further study purpose.

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