Discomfort, Pressure Distribution and Safety in Operator’s Seat – A Critical Review

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Abstract

Overall seating comfort is influenced by both static and dynamic characteristics of seat system. Therefore, the present study is an overview of work related to comfort in seat-operator interface affected by static and dynamic pressure distribution, and other related parameters involved in seat comfort, low back pain, seat design and safety in seats. A critical review has been presented on the subject, with a purpose to provide quick reference for the future researchers. The studies revealed that seat-human interface pressure on the soft seat is more evenly distributed on a larger effective contact area than on a rigid seat. The pressure distribution at human seat interface of a rigid seat is affected by seat height, posture, type of cushion and frequency and vibration. The dynamic pressure at interface is nearly sinusoidal in the vibration range of 1-10 Hz. Under vibration excitation, increase in excitation magnitude causes increased maximum ischium pressure and maximum effective contact area around resonant frequency of 4.5 to 5.0 Hz. Postural stress, whole body vibration and shocks are recognised as important factors, causing low back pain. This however, can be reduced by provision of lumbar support, side support and suitable cushion type.

Key words: tractor, seat, operator, discomfort, pressure, safety
1. Introduction

For over hundreds of years it has been recognized that our seated postures are of great importance to the maintenance of the health of our backs. Discomfort in sitting posture is the major cause of back pain in operators. Many a times it is assumed that comfort and discomfort are two opposites on a scale, ranging from extreme comfort to extreme discomfort. Formal definition of comfort is different but dictionary definition is “State or feeling of having relief, encouragement and enjoyment.” Or in scientific manner “a pleasant harmony between physiological, psychological and physical harmony between a human being and the environment”. It has also been referred to comfort as “absence of discomfort”. Many research studies indicate that “discomfort is primarily associated with the physiological and biomechanical factors.”

A kyphotic spinal curvature, typical for sitting cases increased disk pressure, stretched posterior ligaments and hampered supply of nutrients to the nerves. This eventually leads to low back pain and discomfort. Discomfort can also be attributable to seat pressure distribution. Long periods of static seating cause blood pooling and discomfort in the lower extremities. Seat temperature and humidity may also increase the discomfort. The study of human seat interface pressure distribution under vibration is quite critical to the comfort, work efficiency and health of operators, seat comfort rating can be determined with various methods viz. mechanical method, thermal and moisture test method, IFP test method. The standard method of determining firmness has been measuring the compressibility as functional load using a flat circular indenter.

The goal of this paper is to identify factors and their available solutions that play an important role in the discomfort caused to operators while performing different operations in a given seat comfort environment. A quantitative as well as qualitative approach, with regard to seat pressure distribution of seat pan, and seat comfort rating have been considered. The current attempt is basically aimed to review the scientific literature concerning seat discomfort parameters with a view to provide information to the future researchers that will eventually lead to the adoption in seat designing for the road and off road vehicles.

2. Seat Discomfort – A quantitative approach

Judgments of overall seat discomfort are influenced by both static seat characteristics (e.g. seat stiffness) and dynamic seat characteristics (e.g. vibration magnitude) Ebe and Griffin (2000a). The separate importance of static characteristics and dynamic characteristics each depend on the other variable. When the magnitude of vibration is low, discomfort evaluations are dominated by static seat characteristics. As the magnitude of vibration increases, the discomfort evaluation is influenced more by vibration. It is therefore important to take into account both the static and dynamic characteristics when predicting seat discomfort.

The root-mean-square (rms), the root-mean-quad (rmq) and the vibration dose value (VDV), of the frequency-weighted acceleration as defined in ISO 2631 (1997) and BS 6841 (1987), are the most common methods for evaluating vibration and predicting discomfort when subjects are
exposed to vibration. However, as Ebe and Griffin (1994) reported such measures will not always correlate with comfort evaluations, especially when the magnitude of vibration is low. With low magnitude vibration, seat stiffness can have dominant influence on the seat comfort Ebe and Griffin (2000).

2.3 Prediction of overall seat discomfort

Several relationships between the predicted magnitude estimates for the subjects, $\psi$, and physical magnitudes of the stimuli $\phi_s$ (static factor) and $\phi_v$ (dynamic factor) were obtained by multiple regression analysis, given as below Ebe and Griffin (2000).

Using the stiffness only:  
$$\psi = 6.32 + 3.72\phi_s^{1.18}$$  

Using the VDV only:  
$$\psi = 34.3 + 102\phi_v^{0.929}$$  

Using the stiffness and the VDV:  
$$\psi = -50.3 + 2.68\phi_s^{1.18} + 101\phi_v^{0.929}$$  

Using the stiffness, the VDV and an interaction variable:  
$$\psi = -19.1 + 1.71\phi_s^{1.18} + 65.9\phi_v^{0.929} + 1.08\phi_s^{1.18}\phi_v^{0.929}$$

The overall seat discomfort predicted by equations 1-4 and the median magnitude estimates of overall seat discomfort given by the 20 subjects sitting on the three foam seats. There were high correlations between the predicted overall seat discomfort and the median overall judgments of seat discomfort given by the subjects, except when using the stiffness only. Using the stiffness and the VDV (with or without and interaction variable) provided higher correlations than when using the VDV only, although the improvements were slight. Use of VDV only to predict overall seat discomfort appeared sufficient to predict overall seat discomfort for these data.

Useful predictions of seating comfort can be obtained using foam stiffness (when loaded to 490 N) and the vibration dose value (VDV) on the seat surface. Taking into account both static and dynamic factors (e.g. stiffness and VDV) improves prediction of overall seat discomfort, compared to predictions based on either factor alone. The combination is most useful when the differences in vibration magnitudes in seat are small.

3. Seat Discomfort – A qualitative approach

In the design of seat of vehicles contact of the seat with body is considered. Many factors may influence seat comfort, such as the postural support provided to the body, contact pressures with the body and the thermal and humidity properties of the seat Ebe and Griffin (2000). In dynamic conditions, when vehicle is driven over rough surface or there is vibration from an engine, the influence of the vibration transmitted through the seat (i.e. the dynamic seat comfort) is considered to be an important factor in seat design (e.g. Varterasian and Thompson 1977, Kamijo et al.1982).
Several methods of predicting discomfort caused by the whole body vibration have been proposed. The frequency-weighted root-mean-square (rms) acceleration, the frequency-weighted root-mean-quad (rmq) acceleration and the vibration dose value (VDV), as defined in ISO 2631 (1997) and BS 6841 (1987), are currently the most widely used methods of evaluating the vibration magnitude and predicting discomfort caused by vibration.

In static conditions a separate study, Ebe (1998) has found that seat comfort was correlated with cushion stiffness when loaded at 490 N. The results suggest that, in dynamic conditions, comfort evaluations can be influenced by both static and dynamic seat characteristics, and the effects of these seat characteristics vary according to the magnitude of vibration. During the study of seats it is important to study static seat factors when considering seat discomfort in dynamic conditions. Considering either the static seat factors alone or the dynamic seat factors alone may give a misleading evaluation of seat comfort. This is likely to be particularly important when comparing seats constructed of different types of cushion or when comparing different seats: in these cases, both the static seat characteristics and the dynamic seat characteristics can differ.

Since overall seat discomfort was influenced by both the static seat and dynamic seat factors, a method of predicting overall seat discomfort should take into account both factors. The overall seat discomfort, \( \psi \), could be expressed by a suitable summation of the separate discomforts caused by two stimuli \( \phi_s \) and \( \phi_v \), which represent the static and dynamic factors. In the context of the discomfort caused by combined noise and vibration, Howarth and Griffin (1990a, 1991) proposed:

\[
\psi = a + b \phi_s^n + c \phi_v^n
\]

It can be anticipated that when subjects are asked to judge a vehicle ride (i.e. the dynamic factors) their judgments may be influenced by their static comfort, the noise, and other physical environmental factors (such as temperature, humidity and glare). The discomfort could have been influenced by the sensation arising from vibration of their feet. Vibration at the feet can be a cause of discomfort and the vibration can be transmitted to the upper legs where relative motion between seat and feet may be felt in the area of the thighs. The prediction of discomfort in these situations is complex since it can depend on the phase between the seat and the feet Jang and Griffin (1999).

3.1 Seat pressure distribution

Tewari et al. (2000) developed a pressure measuring system. The pressure distribution on the seat – operator interface is related to the deflection of the cushion placed on the seat. It is further influenced by the type, property of the cushion material and nature of loading. The load deflection characteristics of a cushion may be determined using universal testing machine (UTM). This yields a pressure – deflection curve, which was used to determine the pressure distribution pattern in the present case. A suitably designed peg –system was incorporated to measure the cushion deflection.

3.1.1 Effect of seat pan design on pressure distribution

Stress concentration and high stress regions in a human buttock are of particular interest in the aetiology of decubitus ulcer since excessive compressive stresses can cause occultation of blood flow. It has been observed that compression and shear stress regimes tend to occur at two general locations in the buttock irrespective of the supporting cushion beneath the bone core along the axis, and the lateral to the core at an internal location in the buttock. Seat pan radius of curvature of 75 cm pressure contours were widely spaced in comparison with other curvatures. This feature indicates that pressure variation in the case of seat pan with 75 cm radius curvature is lesser as compared with others. This finding is also supported statistically for 75 cm radius of curvature seat pan.

3.1.2 Effect of back-rest design on pressure distribution

Comfortable tractor seats afford sufficient support to the lumbar region while uncomfortable seats do not do so and are therefore prone to cause a round shouldered driving posture. Therefore, the supporting pressure at the lumbar region can be regarded as one of the standards for evaluating the quality of seats. It is observed that with decrease in back rest radius of curvature, contact area increases on the sides along with widening of inter-contour spacing. The effect of the back rest inclination on pressure distribution for the subject at back-rest curvature 60 cm indicates that increase in back-rest inclination leads to increase in contact area in vertically downward direction.

3.2 Seat vibrational effects

Seating comfort in all vehicles (including off-road vehicles) is affected by the interactions of the vehicle with the rough terrain and by the power source. The level of ride vibrations, particularly on tractors during normal operations, is frequently in excess of internationally accepted levels (ISO 1985). Matthews (1966) has shown that the predominant vibrational motion of a wheel tractor is vertical and the seated operator is most sensitive to vertical vibration. Stayner et al. (1984) indicated that the effect of longitudinal and transverse modes depends on the type of task being performed by the tractor. The rotational modes of vibration however do not usually cause much discomfort (Griffin et al. 1982). But in certain cases, such as tractors going over rough terrain, the rolling and pitching or rolling motions of the seat may be more disturbing than those rectilinear vibrations.

Matthews (1966), Lines et al. (1995) and Prasad et al. (1995) presented extensive reviews of tractor ride vibrations experienced by drivers on the tractor. Lines et al.(1995) concluded that the majority of tasks exceed the level of the ISO 8-h exposure limit and some common tasks even exceed the level of ISO 4-h limit. The average daily dose of vibration from a sample of tractor driving days in fact reflected severe discomfort and increased risk of injury as compared with BS 6841. A considerable amount of energy is spent in counteracting the vibration. Suspended seats fitted to most tractors reduce the vertical component of vibration, but the levels are still undesirably high. Prasad et al. (1995) remarked that the effect of vibration has serious effect on the health of the operator and results in impaired performance ability of tractor drivers. They suggested that the vibrational level at the operator’s seat needs to be attenuated within acceptable limits. There is a need for a practical method to judge objectively the relative performance of
tractor seat pan and back-rest cushion materials with regard to reducing tissue stresses and stress gradient.

Kamijo et al. (1982) determined method for objectively evaluating seating comfort. Forty-three different front passenger car seats evaluated subjectively and objectively for comfort under static conditions. The seats were objectively evaluated for static pressure distribution characteristics, static load/deflection characteristics and vibration characteristics. Six seats were also subjectively evaluated for dynamic seating comfort on a servo hydraulic shaker. It was concluded that body pressure distribution and driving posture had a great influence on the overall evaluation of seats from static comfort evaluation. Kamijo et al. also concluded that the lower the static spring constant and natural frequency of the seat, the higher the evaluation of the sensation of being cushioned. A good seat must have a low natural frequency and transmission ratio at some hertz higher than the resonance frequency from dynamic comfort of seats. They had not indicated the time duration of the evaluation. However, the analyses were based on the patterns of pressure readings of only one subject being matched with the subjective evaluation of each seat by the 15 subjects.

3.2.1 Human-seat interface pressure distribution under vertical vibration

Pressure distribution at the human-seat interface has been found to be an important factor affecting the seating comfort and work efficiency of various workers. The study of human seat interface pressure distribution under vibration is specifically critical to the comfort, work efficiency and health of vehicle drivers, who are regularly exposed to vibration. The comfort of vehicle drivers is strongly related to various design factors, such as posture, range and ease of adjustments, and ride vibration environment, Wu, Rakheja and Boileau (1999). The driver comfort has been further related to the pressure distribution at the interface between human body and seat support surface.

Seat interface is known to cause soft tissue deformation leading to restricted blood and nutrient flows, and thus human discomfort Kumar et al. (1994). A number of studies performed on the human subjects seated in a static environment have concluded that inadequate pressure distribution can cause tissue anoxia and skin ulceration among the paralyzed patients with lack of sensitivity in the weight bearing areas, and discomfort and rapid fatigue among the healthy subjects Sember, (1994). The seated vehicle drivers are also subject to comprehensive magnitudes of low frequency terrain induced vibration, specifically when driving off-road or highway vehicles, which further contribute to their discomfort and fatigue. The design of driver seat interface pressure distribution under dynamic vibration environment.

Majority of the early studies on the pressure distribution at human seat interface were performed to minimize the risks of skin ulceration or the pressure sores among paralyzed patients (Treaster, 1987; Key et al., 1979; Lindan et al., 1965). These studies recommended that the risk of pressure sores can be reduced by uniformly distributing the body weight over the seating surface. Sanders and McCormick (1987) proposed that for healthy seated subjects, the body weight should be uniformly distributed over the buttocks area with minimal weight under the thighs, since the high pressure at the soft tissues of the thighs yields considerable discomfort and reduced working efficiency. A number of effective low natural frequency suspension seats have been

commercially developed to minimize the driver’s exposure to vehicular vibration. Ng et al. (1995) reported that an adequate driver seat support can reduce the stresses in muscles of the back, buttocks, and legs caused by prolonged seating during daily driving activities. The muscle experience increased static loading in an attempt to restore stability under poor seating posture, thereby contributing to increased driver discomfort and fatigue.

Swearingen et al. (1962) obtained a qualitative measure of the sitting pressure using an absorbent paper placed over inked corduroy cloth. The density of the ink transfer provided a measure of pressure intensity. Lindan et al. (1965) developed the “Bed of Nails and Springs”, comprising nails and springs placed at 1 cm intervals over a hard board, to quantify the interface pressure through measurement of spring deflection. Frisina (1970) developed a measurement system using the principle of pressure-controlled chemical reaction. The measurement method, however, was reported to be quite sensitive to temperature variations. Mooney et al. (1971) developed a flexible and pressurized pneumatic cell to measure the external pressure using the principle of differential pressure-based contact sensor. Optical sensors (Treaster, 1987), capacitive sensor (Bush, 1969) and strain-gauge (Drummond et al., 1982) based pressure transducers have also been employed to measure pressure distribution between human body and different surfaces. Piche et al. (1988) developed a flexible pressure sensing matrix using thin film force-sensing resistors to measure the dynamic pressure distribution at the man-machine interface. Most of the above studies reported the human-seat interface pressure under static seating conditions, with the exception of the study of dynamic grip pressure distribution reported by Gurram et al. (1995). The human-seat interface pressure vehicular vibration environment has not been reported.

4. Measurement of dynamic interface pressure distribution

The measurement of pressure distribution at the human-seat interface was performed by using the PLIANCE system developed by NOVEL Inc. The measurement system comprises a pressure sensing mat of 16 x 16 flexible capacitive sensors, the PLIANCE analyser with one analogue amplifier and a control/interface module, and a data acquisition system. The sensing matrix, comprising of 256 sensors arranged in 16 rows and 16 columns, is molded within a mat of flexible material with thickness less than 2 mm. The distance between the centres of two sensors in a row or column is 2.45 cm, and the surface area of each sensor is 1 cm².

The effects of seat height, subject posture, and magnitude and frequency of vibration on the pressure distribution were investigated on the basis of isochaim pressure and isochaim force. The study revealed that the maximum interface pressure occurs in the vicinity of the ischium tuberosities under both static and dynamic seating environments. The increased subject weight seems to induce decreased maximum pressure due to the fact that when subject weight doubles the effective contact area almost quadruples. The dynamic pressure at the human-seat interface was observed to be nearly sinusoidal in the 1-10Hz frequency range considered in the study, and the mean value of dynamic pressure at that location, irrespective of the excitation frequency and magnitude, posture and seat height. The dynamic components of both maximum ischium pressure and the ischium force at the vicinity of tuberosities, revealed peaks in the 4-5 Hz frequency band, which corresponds with the primary vertical mode resonance of the human body. An increase in the excitation magnitude resulted in a considerable increase in the dynamic pressure near the primary resonance of the whole body.

4.1 Distribution of interface pressure on a soft automotive seat under vertical vibration

Comfort performance of automotive seats necessitates considerations of the human-seat interface pressure distribution under dynamic vibration environment. The distribution of seating forces is considerably different for the vehicle seats, primarily due to confined space and vibratory environment, Wu.Rakheja and Boileau (1999). Extensive analytical and experimental studies performed on vehicle and driver vibration have established a relationship between the magnitude and frequencies of vehicle vibration and the driver discomfort (Griffin, 1990).

Distribution of contact pressure and forces between the seated human subjects and a visco-elastic seat is experimentally investigated under vertical vibration. The dynamic pressure on the elastic seat is measured under sinusoidal vertical vibration of different magnitudes in the 1-10 Hz frequency range, using a flexible grid of pressure sensors. The human-seat interface pressure data acquired with a total of six subjects is analyzed to illustrate the influence of magnitude and frequency of vibration excitations on the maximum ischium pressure, effective contact area and contact force distribution.

The study reveals that the interface pressure on the soft seat is more evenly distributed on a larger effective contact area than on rigid seats. Maximum pressure on a soft seat is reduced significantly compared with that on rigid seats. Under vibration excitation, the maximum variations of the ischium pressure and the effective contact area on the soft seat are observed around the resonant frequency of the human-seat system (2.5-3.0 Hz), compared to those maximum variations obtained around the resonance frequency of the human body (4.5-5.0 Hz) on the rigid seat. The large variation of effective contact area at human-seat interface necessitates the reconsideration of a proper seat cushion model. At high frequencies, the maximum pressure and effective contact force tend almost to be constant, irrespective of excitation magnitude and frequency.

5. Seat adjustment among drivers

A study by Merja & Hilka (1997) was made to clarify the ergonomics of forest tractor drivers’ sitting conditions, to study how well drivers had adjusted the seats of forest tractors and to study the short term effect of back rest adjustment and the use of accessory lumbar support on neck-shoulder and low-back symptoms of drivers,. The drivers were visited twice, and a two-week intervention on seat adjustment was carried out between the visits. The height and inclination of the seat, inclination of the backrest and the stiffness of the spring were measured; after the measurements, the technician adjusted the seat. Half of the drivers were given an accessory lumbar support (Camp 21025) and advice concerning its use. Pain stiffness and fatigue of the low-back and neck-shoulder at the end of the shift were reported to have diminished among nearly all drivers. There were no differences between the intervention groups regardless of whether the inclination of the back rest was adjusted or not or whether the drivers had used the lumbar support or not during two week intervention period.
The forest tractors drivers often suffer from pain in the back and neck-shoulder area Boshuizen et al, (1990b) and others. Long periods of sitting, poor ergonomics of the seat, whole body vibration, straining work postures in maintenance, and the accident prone access route to the cab are associated with musculoskeletal disorders Boshuizen et al., (1990b) and others. Also, the inadequate functional capacity of the back in relation to the demands of the work may be a cause of troubles. Anderson (1986), the lowest level of myoelectric activity and the lowest disc pressure were found when the angle of the backrest-seat was 120°, the lumbar support 5 cm thick, and the seat inclination 14°, based on the assumption that low myoelectric activity and low disc pressure are favorable, it was suggested that the backrest and the seat inclinations should aim at these values, taking the interrelations between body dimensions and workplace into consideration. The main purpose of the seat is to create good driving conditions. The field of vision and the reach of different controls are therefore the most important design criteria. As per the measurements, there were, some faults in the adjustment mechanisms and the attachment to the floor. These faults also showed up during the intervention. In seven out of 55 tractors the adjustment had changed even though no one had changed them. The adjustment of the seats should be checked several times during the working hours. The check should be carried out especially when the driver of the tractor changes after the work shift. Most of the drivers considered the condition, comfort and adjustment of the seats as good. The backrest inclination was changed in 55%of the seats. In 32 of them the adjustment had been maintained. The main reason for changing the adjustment was that the new position did not support the back. Nineteen drivers on the other hand said that the new position supported the back better than the old position. During harvesting, the optimal inclination of the backrest may be more upright than during driving. Besides, a stationary sitting position is not good. The adjustment of the seat should be made as early possible, half of the drivers who got the accessory lumbar support did not use it regularly during the intervention. The main reason for giving it up was that the support felt uncomfortable or did not stay in place.

6. Seat comfort rating measuring methods

The mechanical test method and equipment has been used for some years and has turned out to be a useful tool for determining the resilience of cushion and beds Sven et.al.(1996). The thermal and moisture test method has shown the importance of the surface material for obtaining a comfortable seating. The hardness of a seat or bed, more commonly expressed as its softness, is an important factor in reducing or preventing the pain or discomfort. A user relevant rating system for this system is very important. At IFP a new test method including a modular set of indentation devices has been developed, which provides more information about the mechanical and thermal comfort properties of the seat, bed or upholstery system well correlating to the subjective assessment of total comfort. The seat must give enough support to the body but must also contour itself in order to give an even distribution of contact pressure against the body. A more relevant test method has been developed at IFP (Dartman et al., 1988), which provides more user-relevant information about the mechanical properties of the bed system. An analogue prEn draft standard method for seats is not available but there are numerous methods used for testing the softness of car seats and wheel chair seats. ISO 3386/1-1979 is a standard method of determining firmness by measuring the compressibility as a function of load, using a flat circular indenter. This method has, however, been criticized for two reasons. The first being that it is the
contact pressure against the human body and not the compressibility due to a certain load that determines the sensation of firmness. The second point is that a flat circular plate pressed against a flexible medium, larger than the plate, will result in an uneven force distribution along the surface, thus making any calculation of contact pressure meaningless. It is necessary to determine the use-relevant compressional behavior not only for mechanical tests but also for the determination of heat flux, air permeability and moisture transport in a cushion. The thermal test method has been particularly useful in optimizing the location of the heating element for rapid initial heating. The moisture method has shown the importance of the surface material for obtaining comfortable seating pressure against the seat.

6.1 Biodynamic response of seated vehicle driver

Drivers of highway and off-highway vehicles can be exposed to considerable levels of low-frequency vibration originating primarily from the vehicle–terrain interactions, Boileau and Rkheja (1998). Appropriate design and proper tuning of vehicle and seat suspensions are highly desirable to provide increased driver protection against the ill-effects of vibration. Coermann (1962) demonstrated that the dynamic response of the human body deviates considerably from that of a rigid mass at frequencies above 2 Hz. Suggs et al. (1969) tested seats under the influence of vibration. These findings have also been supported by studies performed by Griffin (1990) on seat evaluation and by Rakheja et al. (1994) on the nonlinear driver-seat-suspension dynamics. Suspension seat performance is thus affected not only by the suspension design characteristics, but also by the dynamics of the seated driver. Several attempts have been made to characterize the dynamic response behavior of the human body by analytical means. Although a number of biodynamic models have been proposed in the literature, very few studies have focused on characterizing the dynamic response of the human body under typical conditions involved while driving vehicles (Suggs et al., 1970). The majority of human body models proposed in the literature is raised by the fact that these were derived to satisfy the magnitude and phase characteristics of either the driving-point mechanical impedance or the seat-to-head transmissibility. Such an approach has led to the definition of human body models which could provide a reasonable fit with the transfer function being considered but an uncertain match with the other.

6.2 Overview of bio-dynamic models

In literature a number of biodynamic models have been proposed to estimate the magnitude of forces transmitted to particular subsystems within the body (e.g. the spine), to establish potential damage mechanisms, and to assess the tolerance to vibration under exposure to intense vibration levels (Payne, 1978). For a seated human subject, driving-point mechanical impedance is determined by measuring the driving force and the resultant velocity at the point of entrance of vibration within the body. Seat-to-head transmissibility represents the ratio of head to seat acceleration, while the transmissibility of specific body segments may be obtained by dividing the accelerations measured at the extremities of the segment. The first group of models concerns those involving parameter identification based upon measured, or reported natural frequencies, or transmissibility characteristics of specific body segments.
The second group of models includes those involving parameter identification based upon magnitude and phase characteristics of the measured or reported whole-body driving-point mechanical impedance or apparent mass. The majority of the data used in deriving these models was obtained under sinusoidal excitations, and the seat-to-head transmissibility response characteristics of these models were either not reported or resulted in a poor fit with the data. Coermann (1962), Fairley and Griffin 1989) and Suggs et al. (1970) Tewari and Parsad defined one- and two-DOF models using this approach. The third class of models comprises those derived to satisfy the vibration transmissibility characteristics of certain specific segments of the body, while simultaneously matching the whole-body driving-point mechanical impedance or apparent mass response characteristics. Although a good agreement is observed with the vibration transmissibility of the body segments, the seat-to-head transmissibility response, in general, deviates considerably from the measured data.

Other group of models involves the determination of model parameters by matching the magnitude and phase characteristics of both the whole-body driving-point mechanical impedance and apparent mass and seat-to-head transmissibility functions. Although this approach enhances the uniqueness of the models, the complexities associated with curve-fitting the four different sets of data increase considerably. Only two of the models reported in the reviewed literature fall within the last category: Mertens (1978), and that proposed as part of an annex to a Draft International Standard ISO CD 5982 (1993) on the driving-point mechanical impedance and seat-to-head transmissibility of the human body.

Boileau and Rakheja (1998) proposed a four degree-of-freedom linear driver model and the parameters are estimated to represent a seated driver without backrest support, with feet supported on a vibrating platform, while the hands are in contact with a steering wheel, submitted to vibration in the 0.75–10 Hz frequency range for which the excitation levels are maintained below 4.0 m s$^{-2}$ W$^{-1}$ - frequency-weighted rms acceleration. These conditions are considered representative of those likely to prevail in a wide range of road and off-road vehicles. The model is further derived for a subject population with mean body mass of 75.4 kg, and 73.6% of their mass supported on the seat. The derived driver model, with the parameters chosen, provides a reasonable estimate of the driving-point mechanical impedance characteristics defined as applicable target values under the particular conditions considered. These values, however, differ considerably from those defined in a proposed ISO Committee Draft to represent the driving-point mechanical impedance of the seated human being in general.

The seat-to-head transmissibility characteristics derived from the model deviate more considerably from the derived target values, both response functions provide a whole-body resonant frequency estimate in good agreement. The methodology thus developed, while ensuring a unique set of model parameters under the conditions considered, could well be extended to derive new sets of parameters to better satisfy the driving point mechanical impedance and seat-to-head transmissibility characteristics.

7. Seat comfort to reduce low back pain

A significant health problem for professional vehicle drivers is low back pain, Hirshoi, et al. (1997). The rate of incidence of low back pain is higher than that of the general population (Troup, 1978; Ishibashi, 1988). Not only the complaint rate of low back pain but also the rate of degenerative changes of spine (osteoarthritis) for truck drivers is higher than for the general population (Gruber and Ziperman, 1974; Kristen et al., 1981). Therefore it is important to design to reduce low back pain. Postural stress, whole-body vibration and shock are recognized as important factors which cause low back pain (Troup, 1978). It is considered essential for desirable conditions to reduce low back pain: (1) lumbar support, (2) side support, (3) firmer cushion at the ischial tuberosity region, and (4) soft cushion at the femoral region (Andersson and Ortengren, 1974a,b; Anderson et al., 1974 a,b; Katuraki et al., 1993). From these viewpoints some improved prototypes of driver seat have been proposed. The low back pain of the seat was less due to provision of lumbar support, side supports, firmer seat at the ischial tuberosity region, adjustable head rest, and rubber mat.

8. Safety in seats

The accident rate in logging is high world wide. The number of fatal and serious injuries resulting from timber extraction machine rollovers is high. One method to reduce this number is through the use of a seat belt, Sullman (1998). Unfortunately, use of conventional seat belt is low. This high rate has also been seen in New Zealand (Cryer and Fleming, 1987). Ground-based timber extraction machinery operators’ operate the machinery from within a Roll Over Protective Structure (ROPS). The purpose of the ROPS is to protect the operator from being crushed in the advent of a machine rollover. As the majority of skidders do not have doors, the use of a seat belt is the most practical method of keeping the operator within the ROPS during a rollover. Unfortunately, the level of seat belt use in logging machinery has historically been low due to the absence of legislation requiring the use of a seat belt. No literature could be found to support the hypothesis that an improved seat belt design would increase seat belt usage. An exception to this is the use of automatic seat belts, where no action is required by the occupant (Williams et al., 1989).

9. Seat Design Considerations

Shao and Zhou (1990) described the design principles of tractors driver’s seat static comfort from an ergonomic viewpoint. They considered geometric parameters of the seat constructed from anthropometric data of Chinese population. The geometric parameters were lumbar support, back-rest slope angle, seat width, seat depth, seat height, seat pan angle etc. they concluded that the seat position could be adjusted vertically and longitudinally. It must allow the operator to change his/her position from time to time to relieve pressure and to rotate muscle groups under tension. The position of lumbar support should be vertically adjustable.

Several claims and counter claims are available for the best seat design. ISO 4253 (1993) is the recent International Standard specifying the optimum dimensions of seat for agricultural tractors. However, it is clear beyond doubt that no seat is the best for all seats of postures assumed by the tractor operator during any field operation and hence, leaves enough scope for improvement. The
operator during a field activity remains under dynamic state and keeps on assuming varying body postures as demanded while moving a lever in the operator work place.

The design of a seat with soft cushion on it must not only give enough support to the body, but also must contour itself to give an even distribution of contact pressure against the body. This decreases the incidence of ulcers and lengthens the tolerable period in a given posture (Chow and Odell 1978). In sitting for extended periods, normal individuals can relieve stresses that are potentially damaging to their tissues near the ischial tuberosities and sacrum region (Peterson 1976), where high stresses are sustained by the tissue during sitting.

10. Concluding Remarks

An overall seat discomfort is influenced by both static and dynamic seat factors. Influence of static discomfort on overall seat discomfort varies depending upon the magnitude of vibration. Hence the combination is most useful when the differences in vibration magnitudes on seat are small.

The pressure distribution at the human seat interface of a rigid seat is affected by the seat height, subject posture and magnitude and frequency of vibration maximum interface pressure occurs in the vicinity of ischium tuberosities under both static and dynamic seating environments. The dynamic pressure at the interface is nearly sinusoidal in the range of 1-10 Hz.

The interface pressure on the soft seat is more evenly distributed on a larger effective contact area than on a rigid seat. Maximum pressure on soft seta decreases significantly compared with that on rigid seats. Under vibration excitation, increase in excitation magnitude causes increased maximum ischium pressure and maximum effective contact area around resonant frequency (4.5 – 5.0 Hz). The seat pan curvature and subject’s weight significantly affects the pressure distribution on the seat pan-subject interface. The back-rest curvature and inclination significantly affect pressure distribution on back-rest.

References


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