MAIN AMBIENT FACTORS INFLUENCING PASSENGER VEHICLE COMFORT

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Summary: Higher level of comfort experienced by passengers in vehicles is the objective of numerous researches. The expectations and demand for higher ride comfort of the customers (driver and passengers) have been dramatically increased over past few years. Therefore new vehicle models launched on the market have to have not only better performance and design-wise appealing, but also ride comfort has to be increasingly better then its predecessor. Humans classify experienced comfort subjectively as there are considerably different response and assessment to the same situation. The factors on which people base their opinions on comfort level are physical variables characterizing the surroundings such as temperature, air velocity, acceleration, and light intensity. The main ambient factors of vehicle comfort are: vibration, noise, thermal comfort (temperature), air quality, light and ergonomics.
Keywords: vehicle comfort**,** vibration, noise, thermal comfort, air quality.

1. INTRODUCTION

In a trend of general mobility, increasing level of comfort in private and public transportation plays a significant role as people nowadays spend a significant proportion of their time traveling. Improving riding comfort is triggered off by numerous reasons; the performance of the driver will be better in pleasant ambience, safety will also be improved while the tiredness of the passengers will be significantly reduced. From the automotive industry point of view, the image of the brand depends largely on the passenger comfort, among many other factors. It may be that vehicle comfort plays the key role on the market, in case when different brands have similar performance cars.
Comfort implies a conscious well-being. Discomfort implies a consciousness of unwell-being, corresponding to feelings such as annoyance or irritation.
When analyzing traveling comfort, three classes of factors should be considered: organizational, local, and riding. This thesis will be focused only on those relating riding factors.
According to a classification **[1]** riding comfort can be analyzed in three different respects: dynamic factors (vibrations, shocks, and accelerations); ambient factors (thermal comfort, air quality, noise, pressure gradients...) and factors dealing with the ergonomics of the passenger's position.

The new index weighting the influences of different stimuli in a very specific environment such as passenger cabin should be considered.

2. AMBIENT FACTORS

2.1 Vibration

The human body is exposed to various whole-body vibrations from different sources. Whole-body vibrations occur when the human body (standing, laying or sitting) is in contact with vibration surface. Oscillations in the frequency range from 1 – 80 Hz (and sometimes higher) are called vibrations in existing standards. For higher frequencies the human body becomes less and less sensitive. In **[2]**, the limits on time of exposure of the human body to a given vibration condition are defined, taking into account three criteria: preservation of comfort, preservation of work efficiency, and preservation of health and safety.
For vehicle occupants, two frequency ranges are considered: 0,5–80 Hz for health, comfort, and perception; and less then 1,0 Hz for motion sickness. Research of the vibration effects on the human body should take into consideration that it is built of different parts and reacts differently. Fig. 1 shows a biomechanical model of the human body in which each part is of equivalent mass, elastic and damping elements, **[3]**. Also the natural frequencies of the different parts are indicated.

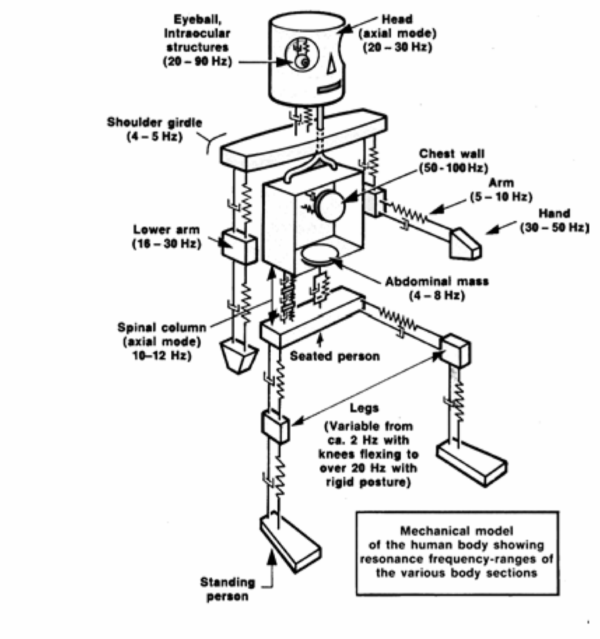

Figure 1. A biomechanical model of the human body

The overall sensations of vibration discomfort depend upon the sensing as well as the frequency content of the stimulus producing them. The basic axes of the human body are defined for three different positions (seated, standing, and laying) on the evaluation of human exposure to whole-body vibration, as well as the frequency and weighting factors used to adjust the calculated values of equivalent acceleration [a_{eq}] to human perception. The sensitivity of the human body to vibration differs in the three spatial directions and this is considered in the calculation of the a_{SUM} [m/s^{-2}], an overall vibration descriptor:

$$a_{SUM} = \sqrt{(1{,}4 \cdot a_x)^2 + (1{,}4 \cdot a_y)^2 + (a_z)^2} \qquad (1)$$

In a vehicle, various systems can be engineered to contribute to minimization of the discomfort perception of vibration by occupants, e.g. the tyres, main suspension, engine suspension, car body, seat... The behavior of the components and systems have been substantially improved to advance their capability of reducing the vibrations transmitted to passengers.

At the same time it should be born in mind that driving performances of the vehicle have to be improved. These two generally opposed requirements should be balanced. By increasing maximum speed of the vehicle, requirements of breaking performances should also be improved. Better breaking force is the result of larger diameter of discs and larger wheels consequently. Simultaneously the profile of the tire has to be decreased, and as the result vertical vibrations are increased. The suspension has to be harder in order to ensure adequate maneuverability of the vehicle. All these factors is reflected on the riding comfort of the driver and passengers. Higher level of comfort is the objective of active and semi-active main vehicle suspension researches, as well as improved ergonomics of the seats in a vehicle.

An index, named "*SEAT*", that evaluates the performance of vehicle seats is introduced in **[4]**. It is the ratio of disturbance perceived by the passenger on the seat in a vehicle not moving and the disturbance that would have been felt if the seat was rigid, in the vibration frequency range.

$$SEAT = 100 \cdot \sqrt{\frac{\int G_{ss} \cdot W^2 \cdot d\omega}{\int G_{ff} \cdot W^2 \cdot d\omega}} \, [\%] \qquad (2)$$

where: G_{ss} [ω] .. the acceleration power spectral density measured at the seat,
G_{ff} [ω] .. the acceleration power spectral density measured at the floor,
W [ω] .. the human perceived disturbance weighting for the relative vibration axis.

The index value contains information about the input vibration spectrum, human perception filters, and the behavior of the seat itself.

One of the automotive industries **[5]** makes a vehicle vibration simulator that can make the reproduction in laboratory facilities of the profiles recorded on the road (subjective

opinions of passengers). In the simulator facility, a set of computer-controlled actuators creates vibrations in the seat (six degrees of freedom), the steering wheel (four degrees of freedom), the vehicle floor pan (one degree of freedom), and the brake and accelerator pedals (one degree of freedom) and all the contact points or interfaces between the driver/passenger and the car cell are monitored. The seat shaker is now commercially available and has been used in studies.
The use of these simulation techniques improves the consistency and repeatability of the tests, allows comparison between vibration profiles and eliminates most of causes of bias in subjective evaluations, e.g. other environmental factors and brand-name effects.

2.2 Noise

By definition noise is unwanted sound. Sound wave - frequencies typically between 20 Hz and 20 kHz - presents an air pressure fluctuation, over time, around a mean value corresponding to the local atmospheric pressure to the ears of a person in a fixed position. In the automotive industry, sound level plays a significant role as the cars are subjectively evaluated by the public considering sound characteristics of the product. Level of the sound, its duration, spectral contribution, temporal structure, quantity, spatial distribution, subjective attitude, and signal information are the factors that must be taken into consideration when classifying the sound event.
A moving vehicle is the sources of numerous types of noise and the objective of designers and engineers is to reduce the effect of the sound or to change its nature to a more pleasant one. Depending on what produces the noise and how it is transmitted, we deal with two main types of noise: airborne noise and structural noise. The source of airborne noise is aerodynamic noise, which is the result of car body moving through the surrounding air volume. The structural noise results from transmission and suspension resonances, body structural resonances and interior acoustic resonances. There is also a combination of these two noises e.g. noise coming from the exhaust system, the air inlets and cooling fans of the engine.
As it is impossible to produce a completely silent vehicle, it is necessary to convert the various annoying sounds into more pleasant and appealing to the passengers exposed to those sounds. The target is to produce a car with the good ‘acoustic image’ (e.g. engine noise, and sound of the door locking*)* with types of sounds that match the expectations for the particular market destination of the product.
To reduce the new model development time, the noise issue is not only handled during prototype testing, but different simulation techniques are intensively used. In order to simplify and speed up the simulation process, the vehicle is divided into five subsystems (frame, doors, dashboard, seats, and other internal parts). These subsystems are separately analyzed and their interactive influence on the noise level of the vehicle. *Active control techniques* are also studied (using the loudspeakers mounted in the passenger area to add to the noise signal an artificially generated noise with the same amplitude but in phase opposition; the results are better with the lower part of the frequency spectrum, while there are limits for the high frequency signal).

2.3 Thermal comfort

Thermal comfort is by definition 'that condition of mind that expresses satisfaction with the thermal environment' **[7].** The human beings evaluate environmental conditions through their senses and this type of comfort is a subjective concept. The energy harmony between the human body and the surrounding environment is influenced by different phenomena.
The thermoregulatory system in the human body keeps the body temperature within safe limits, avoiding hyperthermia or hypothermia that can cause different health problems. The centre that controls various physiological processes is located in the hypothalamus, and it maintains the temperature around a value defined as a function of the metabolic rate (typically 36,8 ºC to 37,9 ºC for a highly active person).
The air temperature, the radiant temperature, the air velocity, and the relative humidity are the physical parameters characterizing the environment and influencing the heat exchange from a person's body. The metabolic rate and the clothes thermal insulation are also important for the subjective sensation of thermal comfort.
The passenger area in a vehicle is a very specific type of thermal environment. The external climatic conditions have a strong influence on the vehicle interior. The issues playing very important role are: size and position of glass surfaces, the number of passengers per volume or per area, the limited amount of insulation material, weight restrictions, and asymmetries in air velocity, air temperature, and radiant temperature. Car manufacturers put a considerable effort into producing vehicles with excellent thermal climate systems because they have strong influence on health, safety and comfort. Also poor climate conditions may affect the driver performance, decreasing the ability to concentrate and the driver reaction time. Therefore, air-conditioning systems are to be presumed as a part of safety rather than comfort extra equipment.
Different evaluation methods are used to analyze the thermal environment in the vehicle interior. There are the following sections of these methods: individual measurement of the physical variables, measurements done with sensors responding to the combined influence of various environmental parameters, and thermal mannequins. It is quite complicated to measure individually each parameter influencing the sensation of thermal comfort, because numerous instruments would be required, which are not easy to accommodate in the narrow space inside a car. Also, there is a loss of accuracy, because it is not possible to place all the sensors at the same measuring point. Therefore a thermal mannequin was developed which is capable of evaluating simultaneously the effects of local air temperature, radiant heat exchanges with surrounding surfaces and bodies, air velocities, and solar heat gains. Thermal mannequin measures these effects in a small space as well as the effect of other passengers in the vehicle; the body blockage effect, the induced self-convection streams, the air breathing flows, and the heat exchanges with other bodies and even between body parts. A thermal mannequin should have the shape and size of a human person, be capable of sitting and wearing clothes, and allows the measurement of the influence of relevant physical parameters along the entire body surface, with the possibility of separating out the body parts.
The thermal mannequins used in the automotive industry have a heating system based on electrical resistances coiled around their different sections, immediately under the

external skin layer, to guarantee a temperature distribution over the surface that is as even as possible. They looks like shop-window mannequins, constructed from resin or plastic, and are light and with moderate thermal capacity, allowing a short time of response to transients. The number of sections into which the mannequin is divided varies: to 36 for the mannequins used by European vehicle producers.

2.4 Air quality

If the vehicle interior is not sufficiently ventilated, the presence of people may result in a degradation of the indoor air quality. This loss of quality is mainly caused by gases resulting from breathing and other organic functions. Also the presence of moisture, combustion products, particles can also decrease air quality in the interior.
There are different ways to improve the indoor air quality; the use of filters, and the dilution of or substitution for the pollutants with a large volume of fresh air. Various method based on sensors are utilized to provide complementary evaluations of the indoor air quality. Sensors usually used to measure physical variables (e.g. air velocity, temperature, humidity) can provide some information about the air quality, because relationships between the sensory evaluation of the indoor air quality and those variables are known.
The effect of the air inside a vehicle on fatigue and accident prevention is the focus of numerous studies. The main goals are the development of the monitoring system, the identification of driving conditions that can result in poor air quality in the vehicle and the establishing of threshold and sensation algorithms for the air quality monitor. The idea is to have an automatic regulation system that continuously monitors different types of gases in order to avoid health risks to car occupants. Therefore, the air quality monitor system may be presumed as the part of the equipment providing safety, and not only comfort.

2.5 Other factors

Also some other factors can contribute to the sensation of comfort of vehicle occupants; such as the “seat/human” body interaction, in its multiple aspects. It has an important role in the ‘pleasantness’ felt by drivers and passengers. Considerable number of scientific studies focus on the pressure distribution in the seat, the seat deflection, and the thermal sensation due to the covers used or special heating or ventilation devices used on the seats. All these aspects largely influence on the comfort level.
Car seat manufacturers have also participated in researches with the objective of creating ingress/egress robots to test the performance of seats. Other aspects related to seats, e.g. the thermal comfort due to the cover laminate **[7],** the influence of seats on interior noise absorption, and the use of heating or ventilation devices in the seat to improve the thermal sensation (particularly in the transient phases) have also been investigated. Other studies dealing with the enhancement of riding comfort (in addition to those already mentioned) can be found. Some ‘driveability’ indices have resulted from correlations established between the assessment of jury panels composed of

driveability experts and objective measurements performed during road tests or simulation trials in the laboratory.

2.6 Multiple stressors

The available literature gives little information about the discomfort due to different causes acting simultaneously. The *ride comfort index*, based on both vibration and noise, was introduced **[8]** and developed to evaluate the traveling conditions of pilots and astronauts. A user-friendly computational model of the index calculation was presented recently. An electronic equipment measuring this ride comfort index is also described in literature.
The model capable of analysing the influence of multiple factors in the comfort evaluation of vehicles has been developed, identifying the possible causes of annoyance, and defining a way to create a weighted index. **[9].**
Thermal comfort, air quality, noise, vibration, and global comfort were evaluated in the study on the comfort conditions in public transportation buses [**10**]. The physical data necessary for computing the indices representative for each discomfort stimulus were recorded and the index values were compared with subjective opinion of the passengers.

3. CONCLUSION

Comfort level is obviously a subjective value experienced in a given environment and circumstances, as different people can react and assess differently to the same situation. The main factors on which human beings base their opinion and feelings on comfort level are physiological variables characterizing their environment such as the temperature feeling, feeling of air speed in the cabin, the feeling of vertical acceleration, the feeling of light type and intensity in the interior and of course ergonomics. Besides *discretely* measured variables, relevant physical parameters, the comfort level is also assessed by human sensitivity to complex influences of different ambient factors.
In order to introduce the *comfort index* new analyses of comfort level should be performed under more controlled conditions to define how different discomfort stimuli interact. The *comfort index* will take into account the influence of multiple stressors, improving ride comfort level in vehicles.

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