Measurement of Transfer Function during Multi-axis Loading

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Abstract. The properties of car seats that determine seating comfort are defined by the transfer function in the direction of the Z axis (vertical direction) in the classical approach. This function describes the damping properties of the seat depending on the excitation frequency in the vertical direction. However, the seat is also excited by vibrations in other directions during the actual driving of the car. So, the question is whether the transfer function in the direction of the Z axis describes the characteristics of the seat accurately enough. This contribution describes a new perspective on the issue, i.e. determining the transfer function of the seat during multi-axis excitation. It is focused on defining the necessary HW and SW equipment for the implementation of the experiment. Using examples of real measured data, it shows the problem of signal measurement during multi-axis excitation.

Keywords: Car Seat, Transfer Function, Measurement, Multi-axis Loading.

1 Introduction

The comfort of the driver's seat on the car seat has a significant effect on the driver's fatigue and can thus directly affect driving safety. Seating comfort depends on the interaction of the car seat with the human body at the point of contact between the body and the seat. In order for seat tests to be comparable, the testing methodology is described by a number of standards [1, 2]. The classic methodology for testing the properties of a car seat consists in measuring the amplitude transfer function of the seat in the Z axis, i.e. the vertical direction. A free load (e.g. EuroSit III test dummy) is placed on the seat and the seat is excited by a harmonic signal with a variable frequency. The amplitude transfer function is determined from the course of excitation vibrations and load vibrations. Its course thus shows the dependence of the cushioning properties of the seat on the frequency of the excitation signal.

However, testing the seat only in the vertical direction does not correspond to the real use of the seat in a car, where the vibrations caused by driving are not only in the vertical direction. Therefore, current normative legislation requires testing in two axes, the vertical Z axis and the axis in the direction of travel, i.e. the X axis (see Fig. 1). This article is focused on the issue of multi-axis testing of car seats, on the necessary HW and SW

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equipment and the issue of measuring vibrations of a free weight on the seat during multi-axis excitation.

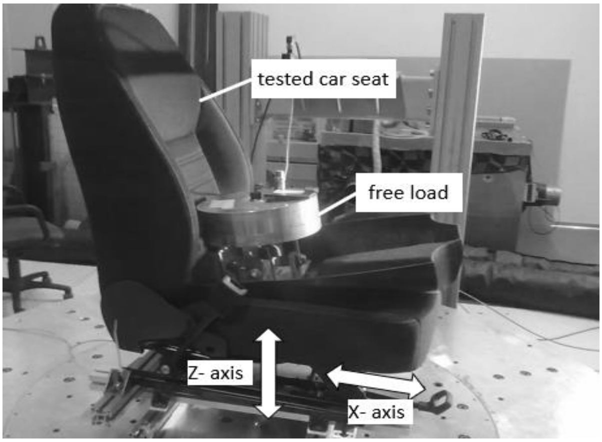

Fig. 1. The principle of a car seat testing.

2 Materials and methods

2.1 The theoretical basis of the experiment

The transfer function generally defines the relationship between the input and output functions of any device (see **Chyba! Nenalezen zdroj odkazů.**2).

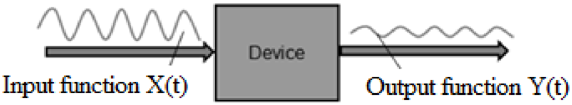

Fig. 2. A principle of the transfer function definition.

The transfer function is defined as the ratio of output function Y(t) to the input function X(t):

$$G(t) = \frac{Y(t)}{X(t)} \tag{1}$$

Expressing the transfer function from the time progress of functions is not very practical, therefore the ratio of images of the output and input functions obtained by Fourier transform is usually used for its expression [3]. This representation better describes the evolution of the transfer function depending on the frequency of the input signal:

$$G(j\omega) = \frac{Y(j\omega)}{X(j\omega)} \tag{2}$$

The transfer function is generally a complex function and its course is therefore represented in the complex plane (see Fig. 3 left). Displaying the frequency characteristic in the complex plane provides a self-contained summary of the progress of the transmission depending on the frequency of the signal. In many cases, however, for a more comprehensible presentation, the representation in the complex plane is omitted and the expression of the transmission function is divided into separate expression of amplitude and phase on frequency:

$$G(j\omega) = A(j\omega)e^{j\varphi(\omega)} = P(\omega) + jQ(\omega) \tag{3}$$

$$A(\omega) = \sqrt{P^2(\omega) + Q^2(\omega)} \qquad \varphi(\omega) = arctan\,\frac{Q(\omega)}{P(\omega)} \tag{4}$$

Thus, the amplitude frequency transfer function and the phase frequency transfer function are created. So, the amplitude characteristic determines how the ratio of the amplitude of the output and input signal changes depending on the frequency and the phase characteristic states which is the phase delay of the output signal to the input signal. Both can be expressed by a traditional graph (see Fig. 3 right).

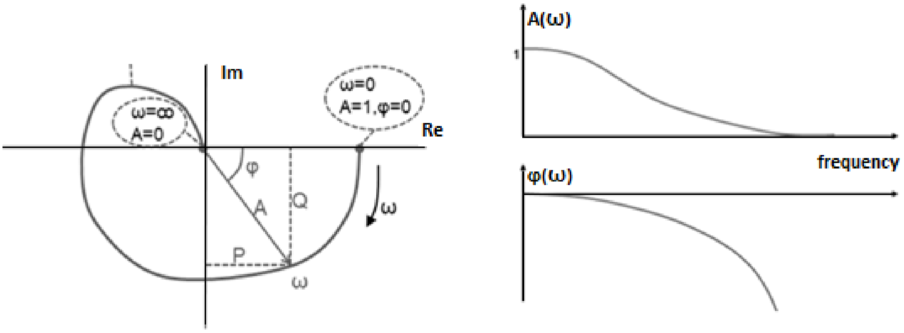

Fig. 3. Example of the transfer function in the complex plane - left and example of the amplitude and phase frequency transfer functions - right.

To describe the behavior of mechanical systems, it is often enough to show only the amplitude transfer function, because only the ratio of the amplitudes of the input and output signals is important for describing the properties of the system and the time delay does not matter. This is also the case with the testing of car seats, the standards prescribe the determination of the amplitude transfer function. The phase shift of output and input vibrations is not detected.

2.2 HW equipment for multiaxial testing of car seats

The multi-axis vibration excitation device is the basic equipment for multi-axis testing of car seats. Such a device can work on different principles, one possibility is, for example, a hexapod (see Fig. 4 left). Its excitation table has six degrees of freedom, displacement in three axes and rotation around these axes [4]. So, it is a very versatile device and the combination of Z and X axis vibrations needed for car seat testing is no problem for this device.

In order to calculate the amplitude transfer function, it is necessary to measure the amplitudes of the input and output vibrations. The Dewe 5000 measuring device was used for the experiments described in this paper. Vibrations were detected by two types of sensors, accelerometers and non-contact laser displacement sensors, in order to compare the results obtained by measuring accelerations and displacements. The Dewe 5000 measuring device enables synchronous data and image recording, so a camera was also connected to record the progress of the test. Synchronous image recording then enables better orientation in the measured data.

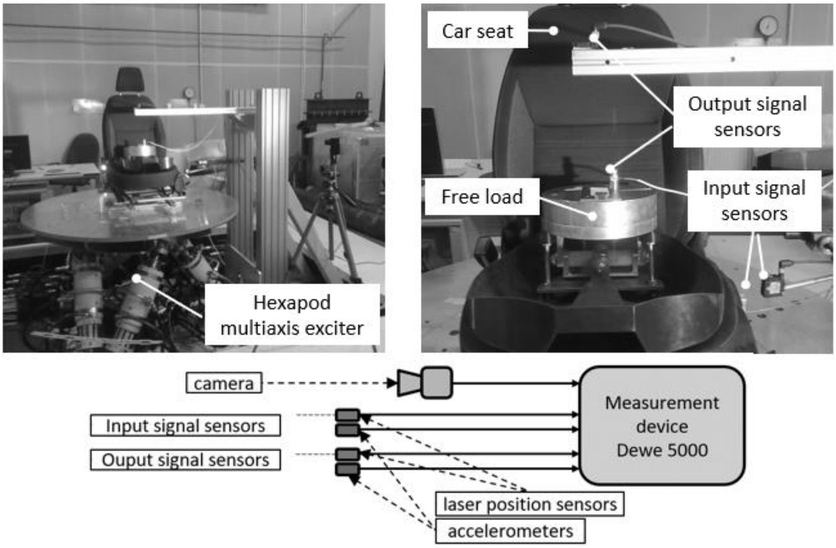

Fig. 4. The real experiment arrangement.

2.3 SW equipment for multiaxial testing of car seats

A multi-channel signal generator is the first piece of software equipment needed. The latter is usually part of the excitation device, and so is the case with the used hexapod. Its control software allows you to generate any composition of excitation signals.

For car seat testing, a signal with a constant acceleration value in the frequency range from 1 to 1 Hz is most often used in the Z axis. The magnitude of the constant acceleration value is chosen so that the free load does not bounce off the seat in the entire frequency band. A value of 1 ms^{-2} was used for these verification measurements. The same value was used for X-axis excitation, but the signal frequency was constant throughout. Several measurements with different vibration frequencies in the X-axis were performed to determine the effect of longitudinal vibration on the transfer function. The signal combinations used for the performed tests are in Table 1.

Table 1. Combination of signals used for tests.

Test number	Z-axis excitation	X-axis excitation
1	acc = 1ms^{-2}, frequency 1 – 16 Hz	0
2	acc = 1ms^{-2}, frequency 3 – 10 Hz	0
3	acc = 1ms^{-2}, frequency 3 – 10 Hz	acc = 1ms^{-2}, frequency 3 Hz
4	acc = 1ms^{-2}, frequency 3 – 10 Hz	acc = 1ms^{-2}, frequency 6 Hz
5	acc = 1ms^{-2}, frequency 3 – 10 Hz	acc = 1ms^{-2}, frequency 9 Hz

Before starting car seat testing, it was verified that the hexapod could generate the prescribed combination of signals with sufficient accuracy. Accelerometers in both axes were placed on the excitation table and real excitation was recorded in the entire frequency range. The inspection verified that the required acceleration amplitude level of 1ms^{-2} is observed in the all frequency range with sufficient accuracy (see Fig. 5).

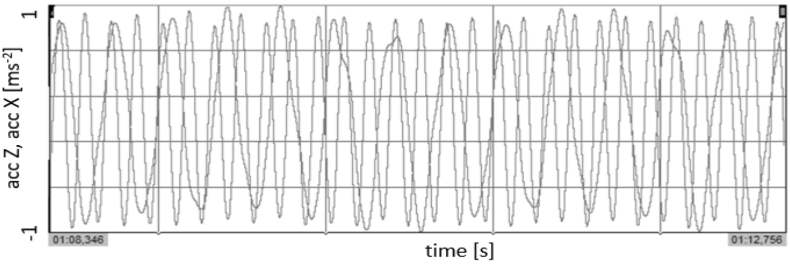

Fig. 5. The part of the record of the real hexapod acceleration in the X and Z axes.

Software for measurement and data storage is the second necessary equipment. It is then necessary to calculate the amplitude transfer function from the measured input and output data. This is possible manually, but the process is very tedious. Automatic calculation is a much more efficient solution. But it requires algorithms for automatic detection of the amplitude and frequency of the measured signals. The Dewesoft software, which is part of the Dewe 5000 measuring device, has such functions. Mathematical channels for detecting the amplitudes and frequencies of the measured signals were defined and the course of the amplitude transfer function was calculated and displayed in real time during the test. The progress of the transfer function is directly stored in the data files and no further processing is needed. This way of measuring and calculating is very efficient for many repetitive tests.

3 Result and discussion

In all measurements, two transfer functions were always calculated in the Z axis, one from the signals from the accelerometers and the other from the signals from non-contact displacement sensors. These two methods were chosen in order to be able to compare two possible methods of vibration measurement.

In the first measurement, only the Z axis was excited and the full frequency range of 1-16Hz was used.

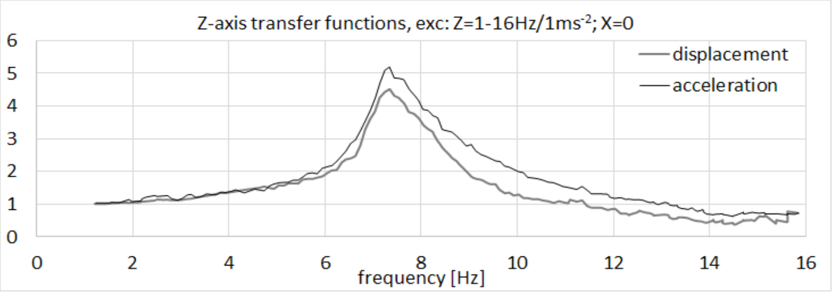

Fig. 6. Z-axis transfer functions, X_{exc}=0.

The course of the curves shows that the resonance frequency of the tested car seat is at 7.3 Hz, which is the expected value for this type of car seat. Both measurement methods showed the same resonant frequency, but the transmission value calculated from the accelerometers is slightly higher. The reason will be the different location of vibration sensors on the free load. The accelerometer and laser cannot be placed at one point, and the free load on the car seat does not have to vibrate only in the vertical direction. The amplitude of the vibrations at different points can thus vary. As will be shown later, the placement of the vibration sensors on the free mass is very important to obtain correct results in multi-axis excitation.

For multi-axis excitation, the Z-axis excitation frequency band was reduced to a range of 3 - 10 Hz to cover the resonance region and reduce test time and data file size. In the X-axis, the frequency was constant and the measurements were carried out according to the specifications in Table 1.

The course of the transfer function under X-axis excitation with an over resonance frequency of 9 Hz is shown as another example of the obtained results.

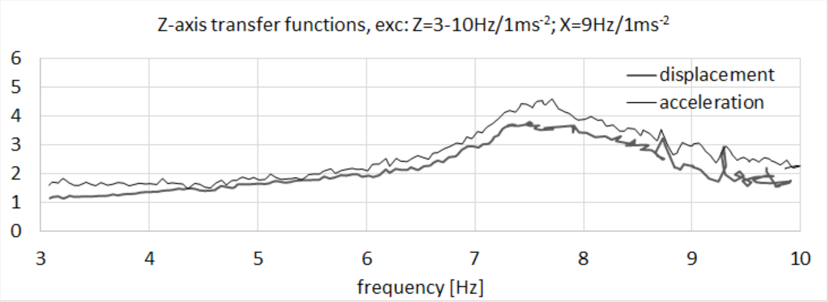

Fig. 7. Z-axis transfer functions, X_{exc}= 9Hz.

The progress of the transfer functions has the same trend as in the previous case. The resonant frequency has increased a bit to 7.6 Hz and the resonant peak has decreased. This shows the effect of vibration in the X-axis on the characteristics of the car seat. It is important from the point of view of the methodology of the experiment that the transfer function in the Z axis was correctly measured even with multi-axis excitation.

However, problems with vibration measurement became apparent during sub-resonant excitation in the X axis. The free load on the car seat began to waddle, and its vibration measurement in the Z axis was thus practically impossible (see Fig. 8).

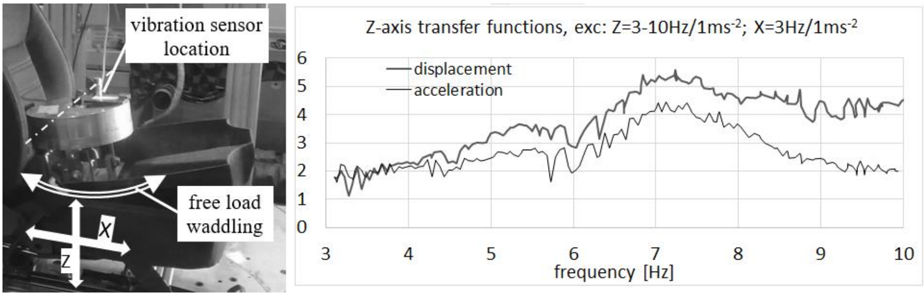

Fig. 8. The example of a poorly measured Z-axis transfer function.

If the free load waddles, the waddle amplitude is added to the Z-axis vibration amplitude. In this case, the position of the vibration sensor is very important. The more near the edge of the mass the sensor is located, the greater the distortion of the signal will occur. It would be ideal to place the sensor in the "waddling axis". Since the load is loosely placed on the car seat, it is very difficult to determine its. In addition, it is very likely that the “waddling axis” position changes depending on the vibration interference in both axes, because the excitation frequency in the Z axis changes with time. It turned out that measuring only the vertical direction of the load vibration during multi-axis excitation is insufficient to describe the movement of the load. In order to correctly measure the vibrations of a free load, it will be necessary to establish a new methodology for measuring its vibrations. Using multiple sensors at different locations, adding roll angle sensors, etc. can be a way to record comprehensive information about the movement of the free load on the car seat.

4 Conclusions

The conducted experiments showed that the multi-axis excitation of the car seat using the hexapod is well feasible in the required frequency range. The real excitation signals correspond to the prescribed specification with sufficient accuracy. Due to the six degrees of freedom of the hexapod, it is easy to carry out tests in a different combination of loads than the testing carried out so far in the combination of Z - X axes.

Dewe5000 measuring devices with Dewesoft software allow you to program automatic detection of amplitudes and frequencies of measured signals, calculate the amplitude transfer function in real time and save its course in data files. Data processing is very simple, no further adjustments to the measured data and additional calculations are needed.

A problematic part of the measurement with multi-axis excitation is the measurement of the vibrations of the free load, which during multi-axis excitation does not only oscillate in the vertical direction, but waddles in different ways. In order for the measurement to be correct even in this case, more sensors and other types of sensors will need to be used to perfectly record the movement of the free load on the car seat. Then it will be possible to correctly calculate the course of the transfer function. An important question is also whether, with multi-axial excitation, it is possible to define the damping properties of the car seat only by the transfer function in the Z axis direction, or whether the necessary definition should be expanded comprehensively in other directions as well.

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