A system to measure seat-human interaction parameters which might be comfort relevant

Wegner, M.; Martic, R.; Franz, M.; Vink, P.

DOI
10.1016/j.apergo.2019.103008

Publication date
2020

Document Version
Final published version

Published in
Applied Ergonomics

Citation (APA)
Wegner, M., Martic, R., Franz, M., & Vink, P. (2020). A system to measure seat-human interaction parameters which might be comfort relevant. *Applied Ergonomics*, *84*, Article 103008. https://doi.org/10.1016/j.apergo.2019.103008

Applied Ergonomics 84 (2020) 103008

Contents lists available at ScienceDirect

Applied Ergonomics

journal homepage: http://www.elsevier.com/locate/apergo

A system to measure seat-human interaction parameters which might be comfort relevant

M. Wegner [a,b,*], R. Martic [b], M. Franz [b], P. Vink [a]

[a] Faculty of Industrial Design Engineering, Delft University of Technology, Landbergstraat 15, 2628, CE Delft, Netherlands
[b] BMW GROUP Research and Innovation Centre (FIZ), BMW Group, Knorrstraße 147, 80937, München, Germany

ARTICLE INFO

Keywords:
Measurement method
Objective seat comfort
Seat characterization
Comfort relevant parameter

ABSTRACT

In this paper a measurement tool is described and tested to evaluate the characteristics of different elements of a seat. Many studies report a relationship between discomfort and pressure distribution, but it is unknown what exactly is happening in the interaction. The purpose of this study is to present a measuring device, which records the comfort relevant seat parameters pressure and elongation while loading a seat. The results of the study, including the repeatability, reproducibility and detectability show that the measurement method is appropriate for our purpose, although the reproducibility has to be improved by operator experience or by a more intuitive assembling of the measurement setup. An application example illustrates that the interaction of the seat components highly affect the resulting comfort relevant parameters. The question is whether this objectively recorded differences are also experienced by seat occupants, which is interesting to study in future research.

1. Introduction

The European Union and the European Free Trading Association-States together have a population of 520.582.413 (Eurostat, 2017; European Free Trading Association, 2015) individuals and about 259.834.000 (Jurado, 2014) vehicles in use. Statistically, nearly one out of two persons own a vehicle irrespective of whether they have a driver's license or not. Therefore, it is obvious that the automobile is an essential part of our everyday life. The results of the Market Research Institute: Consumer Science & Analytics with the title "OUR LIVES INSIDE CARS" underlines the rising importance of vehicles as a daily companion. On average, a person spends four years and one month in a vehicle during their lifetime (CSA Research, 2017), most of the time sitting causing a static load on the musculoskeletal system. In the future, autonomous driving opens opportunities to use this travel time in a more efficient way and facilitate variation in postures. Hence, it is important for the car manufacturers to emphasize the role of a comfortable, adaptable and pleasant car interior with a special focus on the seat as the main interface between human and vehicle. The challenge for seat design is to develop an ergonomic and comfortable product, avoiding discomfort in the seat interaction zone and facilitate a variety of postures.

The interaction between the human and the seat is influenced by the indentation process and the way the occupant behaves after indentation. There is a lot of literature on the subjective experience of this interaction zone (De Looze et al., 2003). The objective seat comfort evaluation is more complex as comfort experience is in principle a subjective experience (Vink and Hallbeck, 2012) and the meaning of objective recorded parameters for the comfort experience is often unclear. However, there could be seat characteristics which have a strong relationship with the subjective experience of comfort and more knowledge on the seat characteristics could be helpful in designing and testing seats. The complexity is caused by the fact that there are many seat characteristics and only one comfort or discomfort experience. The specific properties of the seated individual, the seat and the changes over time increase the complexity even further. To simplify the time aspect, some authors divide the evaluation of the seat into three time dependent subcategories: the initial, the short-term and the long-term comfort. Mergl (2006) defined the initial comfort as the first 3 min, the short term comfort up to 30 min and long term comfort starts after 30 min. Sammonds (2017) stated that in a static situation, in 140 min the number of seat-movements rise as well as the discomfort scores. Furthermore, Adler (2007) found that the long-term seating comfort is directly related to system stress by measuring the stress-induced postural modifications of the sitting person. Likewise, Hartung (2006) investigated the time-dependency of the subjective seat comfort evaluation. The discomfort feeling was significantly higher ($p < 0.05$) after 135 min

* Corresponding author. BMW GROUP Research and Innovation Centre (FIZ), BMW Group, Knorrstraße 147, 80937, München, Germany.
E-mail address: Maximilian.Wegner@bmw.de (M. Wegner).

https://doi.org/10.1016/j.apergo.2019.103008
Received 7 December 2017; Received in revised form 13 October 2019; Accepted 21 November 2019
Available online 10 January 2020
0003-6870/

compared to an evaluation after 15 min. Other authors also illustrated the time-dependency of the interaction zone (Smulders et al., 2016).

The seat usually consists of different components influencing the interaction zone. It is assumed that car manufacturers usually specify the components separately, though an overall specification of the seat describing the interaction of the combination of components is much more relevant as this is what the end user will experience. A seat can consist of the seat-frame, the adjustment systems of the seat, the foam hardness and dimensions, the cover materials with different tensions and friction coefficients as well as the different layers, the lamination, the heating system, the resistant layers and the cushion-suspension. These systems are often well tested individually, like the foam, which is characterized objectively with a test defined in DIN 53579 (2005). The factor making it complex is the non-linear behavior of certain components, such as the viscoelasticity of the foam (Gibson and Ashby, 2001). Additionally, it is unknown how the subsystems interact with each other and subsequently influences the total comfort perception.

The perceived comfort is not only influenced by the seat characteristics, but also by psychological factors such as the expectations, physical state and physical factors of the human body (Vink and Hallbeck, 2012). The human body influences the seat interaction by its individual weight, shape, anthropometric dimensions, gender and sitting position (Kilincsoy et al., 2014; van Veen, 2014; Vink, 2012). The reaction of the seat components during the indentation could deform the human skin and the underlying tissue, also affecting the blood flow, musculoskeletal system and tissues. Systems in the human body could react and amongst these the mechanoreceptors in the skin record the changes in the stressed surface and send the information to the brain (Diesing, 2006) influencing interpretation and evaluation of the seat comfort. Other systems, like propriocepsis could be influenced as well. The literature mentions four receptors in the skin (Schmidt and Thews, 1980), the Merkel disks for the pressure, the Ruffini corpuscles for the stretch and shear stresses, the Pacinian corpuscles for vibration and the Meissner's corpuscles, primarily providing information about tactile and sensitive changes. The Merkel disks and the Ruffini corpuscles are slowly adapting cutaneous mechanoreceptors. The Meissner corpuscles and the Pacinian corpuscles adapt comparatively in a slow manner (Klinke and Brenner, 2014). The sensors in ligaments and muscles gather information and form the proprioceptive input. For the comfort evaluation the slowly adapting mechanoreceptors are probably more critical than the fast adapting mechanoreceptors (Goossens et al., 2005). Therefore, the parameters in the interaction zone, which might be very relevant are the pressure, the elongation, the shear stress and the friction coefficient. Depending on the age or gender, the sensitivity and the signal power changes. In addition, Hartung (2006) described that gender has a big influence on the comfort evaluation and Venkatesan et al. (2015) mentioned that the physical structure in the skin changes with age affecting the skin sensitivity. Furthermore, the location in the human body shows variation in sensitivity (Vink and Lips, 2017).

Most of the seat comfort studies focus on the foam characteristics, the seat dimensions or seat-adjustments and the correlation to the subjective seat discomfort evaluation as well as to the seat pressure distribution (probably related to Meissner corpuscles). The studies of Ebe and Griffin (2000, 2001) use various cushions with different foam heights (50 mm, 70 mm, 100 mm, and 120 mm), hardness and densities to investigate the difference between the static and the dynamic seat comfort. Additionally, Kamp (2012) uses the contour and foam hardness in her experiment to describe how the geometrical characteristics of the seat influence the perception of a seat (sporty, luxurious and practical) and Kolich (2003) focuses on the contour and the geometrical parameter of a cushion. All the studies are based on subjective evaluations. Moreover, De Looze et al. (2003) discussed different studies and pointed out that most of them described a correlation between pressure and discomfort, predominantly with a limitation on special body parts. Zenk et al. (2006) and Kilinscoy et al. (2016) worked out general guidelines for an ideal seat pressure distribution. Zenk et al. (2006) presents guidelines recommending a pressure distribution in the cushion of 49%–57% in the buttock, <28% in femur area next to the buttock and <6% on the front femur area. Mergl (2006) also reported that the pressure distribution in the cushion influence the pressure distribution in the backrest and vice versa. Vink and Lips (2017) confirmed the results of the previous studies by studying sensitivity and described a higher sensitivity in the shoulders and at the front of the seat cushion. Less sensitivity was found in the middle area of the back close to the spine. All in all, the methodology to objectifying the seat characteristics is reduced to the evaluation of various foam properties, seat contours and the relation to individual pressure distributions. The interaction of the seat components and remaining mechanoreceptors of the skin are not taken into account. The individual pressure distribution is recorded with a pressure mat, which influences the seat properties itself (e.g. surface and stiffness of a seat) and thus, the results of the pressure measurement. A reproducible recording of the seat pressure distribution is only possible with an anthropometric test device and a pressure distribution mat.

To our knowledge no study considers the interaction of the various seat components and the changing properties while loading the seat. The cover characteristics and the cushion suspension caused by the foam might cause of a different effect than predicted by the foam alone. For instance, in most cases the cover is connected to the foam and the seat-frame. If the cover is stretchable and loosely connected, the foam characteristics could be more predominant as the foam is able to perform in a wide scope. In contrast, a stiff cover tightly connected to the foam could limit the foam deformation influencing its performance. Additionally, the comfort of a seat might not only be dependent on the foam and the cover, but also by the seat dimensions, seat adjustment and other seat components such as the seat suspension.

There are indications that shear force could influence comfort perception. In the field of decubitus (Diesing, 2006), especially in the wheelchair development (Goossens, 2001) studies show that shear stress on the human body influenced seat comfort. In the past, the effects of pressure and shear stress on the human body were studied in-depth. Bennet and Worthen (1980) investigated in the palm of the hand that only half of the initial pressure is necessary to stop the blood flow if high shear forces are included. Additionally, Goossens (1994) measured a cut-off pressure of 11.6 kPa in the absence of shear stress. With a shear stress of 3.1 kPa he showed the cut-off pressure was significantly reduced to 8.7 kPa. Previous studies showed both stresses, the shear force and the pressure, influence the deformation of the anatomical structure, like the tissue and skin of a sitting person. Chow and Odell (1978) described the interface shear force has a significant effect on pressure distribution. It is underlined by the statement that the frictionless interface produces much lower pressure. Furthermore, Zhang and Roberts (1994) mentioned that the externally applied stresses to the skin alter the internal stress distribution. The shear forces externally applied to skin surface roughly have the same effects on underlying tissues as normal forces (pressure). Also, the skin blood flow reduces with the increase of shear force (Goossens, 2000).

Most of the studies use a small variety of seats and do not study the different seat components. To advise on the seat components or test the effect of these components in this paper it is assumed that the elongation (shear stress and friction coefficient) could be useful to study as well to make linkages with the seat components. Therefore, the elongation (shear force, friction coefficient) could be an important part in the evaluation of the seat comfort. *The objective of this paper is to describe a measurement method, which records reproducible comfort relevant parameters of a seat during the indentation process and during a static situation*. This work outlines the advantages and the limitations of the applied method.

First, the "Method" section presents in detail the measurement method, which measures parameters which might be relevant to comfort while loading a seat. Subsequently, to study its possibilities an application example of the measurement method is described as well. Followed by the declaration of the results which are analyzed and related to current studies in the "Discussion" part. At the end the findings are concluded in a short summary.

2. Methods

2.1. Measurement method

To explore the effects in the interaction zone between human and seat, a measurement method is developed. Fig. 1 shows the measurement tool consisting of a material testing machine with a controllable spindle, a stamp with sensors and an adaptable measurement setup. The stamp is connected to a certified material testing machine, a Z005, made by the Zwick/Roell Company. The spindle of the machine allows an upward and downward movement of the stamp. A Zwick/Roell Software named testXpert II allows to define sequences of the test cycles. Typical parameters are the indentation velocity, the rest time, the force control and time control. The stamp simulates the initiated stress of the human body on the seat and the associated sensors simulate the recording of the skin-mechanoreceptors. On the fixing plate of the testing machine different seat elements and combination of seat elements can be mounted, such as different foams, covers or suspensions (shown in Fig. 2). The testXpert II Software controls the specified testing procedure getting information from the force sensor and the position of the spindle. During the increase of the load the stamp records the pressure and elongation signals, whereas the testing machine records the applied force and distance of the indentation.

2.1.1. Stamp

The shape of the stamp is a half sphere with a diameter of 75 mm. It follows the requirements of the Standard DIN 53579 (2005), which measures the foam hardness. The stamp, shown in Fig. 3, is equipped with four elongation sensors (hereafter denoted with I, II, III, IV, V) and five pressure sensors (hereafter denoted with 1, 2, 3, 4, 5). A micro-controller processes the recorded sensor signals and LabView visualizes these signals. For the synchronization of the sensor signals, the micro-controller processes the Zwick/Roell signals (force and the position information of the spindle) via an I/0-module.

2.1.2. Measurement setup

The measurement setup represents various combinations of the seat structure. The setup allows to use various foams with different degrees of hardness and heights, different cover materials with adjustable cover tensions as well as various seat suspensions (see Fig. 2). Furthermore, it is possible to integrate different laminations, layers or interfering contours. The seat suspension is replaceable by a plate, which follows the

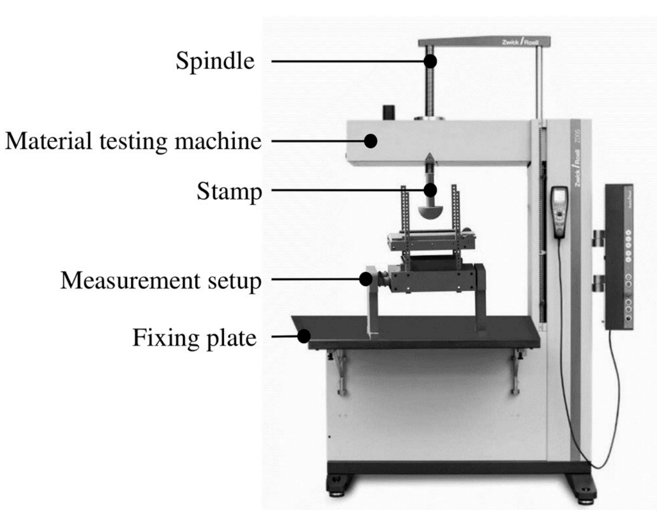

Fig. 1. Elements of the measurement tool.

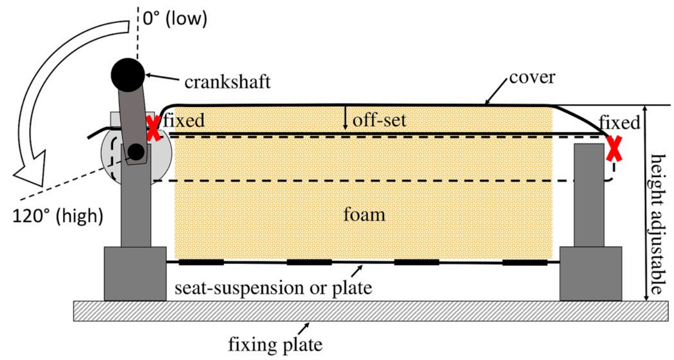

Fig. 2. Schematical measurement setup, including the cover fixation, the foam, the seat suspension or plate as well as the cover height adjustment for various foams.

requirements of the *DIN EN ISO3386-1* (2009). The holes of the plate have a diameter of 6 mm and a distance of 20 mm.

2.1.3. Guidelines for the cover fixation

The fixation of the cover is critical because the initial tension of the same cover type (same material, new fixation) has to be equal for each new fixation. During the increase of the load the fixation has to avoid any cover movements. Fig. 4 shows the guidelines for each cover sample. The cover has a marked field to align the right position in the measurement setup. The marked fields 1 to 4 in Fig. 4 are for the fixation of the cover. Field 1 is connected to a crankshaft to adjust the cover tension in 20° steps. The minimum cover tension is at the 0°-Position of the crankshaft and the maximum cover tension is at 120° crankshaft position. Field 2 to 4 are fixed with cover clamp devices. The surfaces of the devices have a high roughness in order to be able to keep the fixation pressure constant.

2.1.4. Measurement procedure

The measurement procedure is based on the DIN 53579 (2005) and DIN EN ISO3386-1 (2009). The validity of the DIN requirements are restricted to foams and not to the overall seat layout. Therefore some parameters of the DIN requirements had to be adapted. The environmental conditions of the specifications are unchanged with a humidity of (50 ± 5) % and the temperature of (20 ± 2) C°. Other process parameter of the DINs like the indentation velocity, the time of the holding phase and the maximum force are adjusted to ensure a suitable process reliability. The original specification for the measurement procedure (DIN 53579 (2005) and DIN EN ISO3386-1 (2009)) has four cycles consisting of three pre-cycles and one measurement cycle. Fig. 5 shows an exemplary curve of the specified measurement force. It is the same for each measurement. The curve specification is divided in three sectors: T_1 = stress-phase (stamp stresses the seat layout), T_{hold} = 30 s holding phase (maximum stress) and T_2 = relief-phase (stamp reliefs the seat layout). The indentation velocity for the pre-cycle is for the stress-phase as well as for the relief-phase 300 mm/min. For the measurement cycle the stress- and relief-velocity is 100 mm/min. Preliminary investigations with a pressure mat (XSensor X3 LX210) on a 4 kPa hard foam have shown that the stamp reaches the maximum measurable pressure of 10.34 N/cm^2 at a force of 350 N. Therefore the predefined measurement range is 0 N–350 N and 0 N/cm^2 - 10.34 N/cm^2. To avoid lasting damages in the cover materials the maximum force for this research is defined to 200 N.

2.2. Capability study of the measurement method

2.2.1. Raw data processing

All sensors were develop by the Fraunhofer Institute (Boese et al., 2015) recording capacities in the range of pF (picofarad). The evaluation

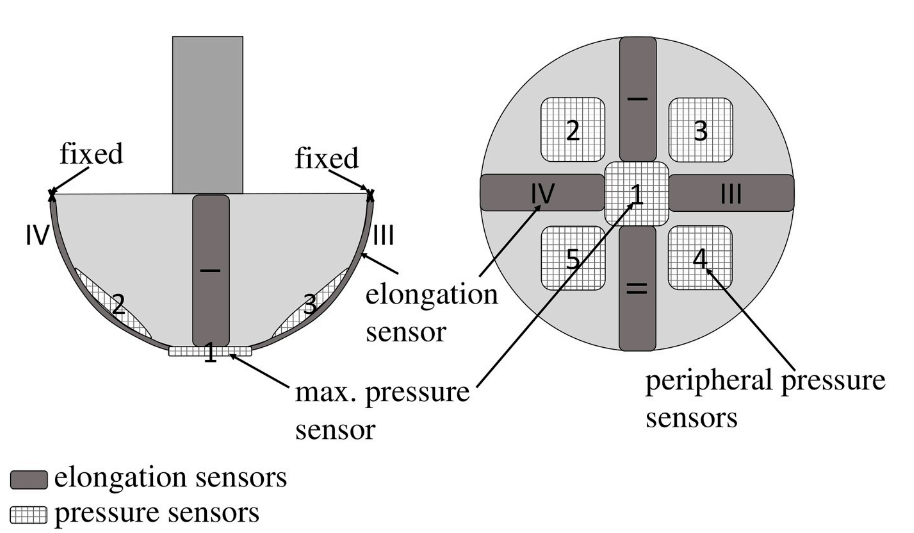

Fig. 3. Overview of the pressure and elongation sensors location.

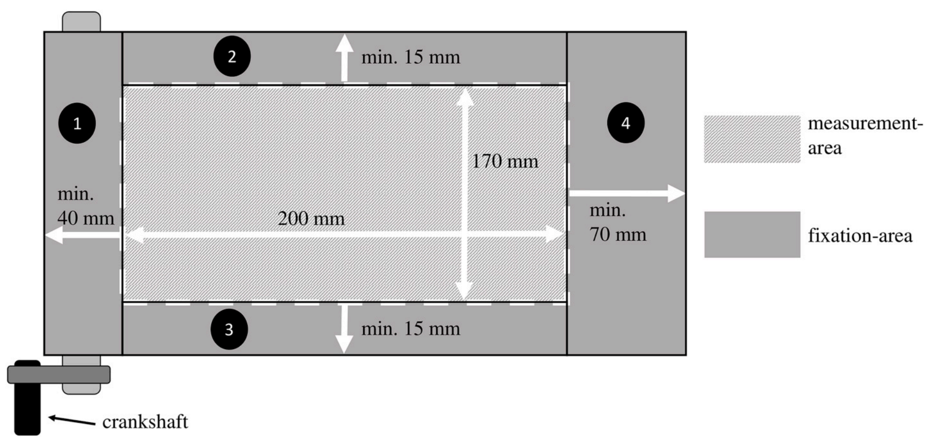

Fig. 4. Geometrical guidelines for the cover sample.

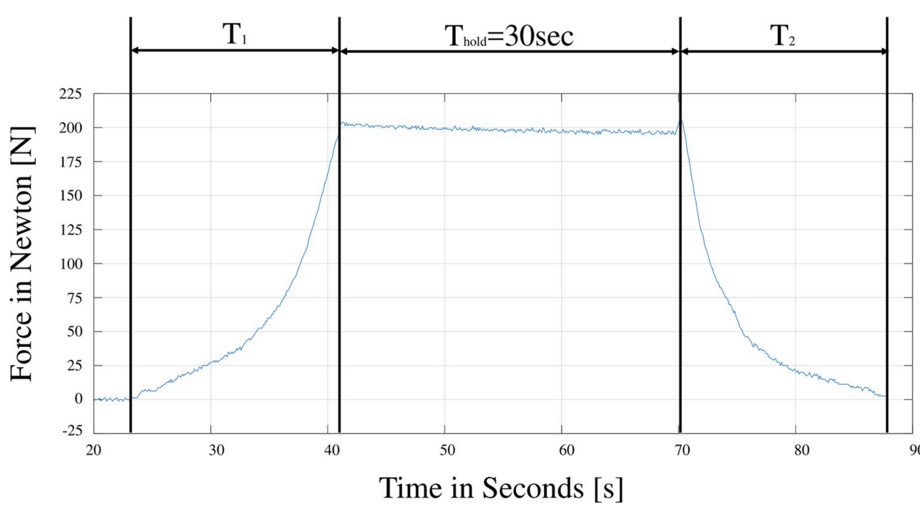

Fig. 5. Prescribed force curve for the measurement cycles (without pre-cycles).

of repeatability, reproducibility and detectability is based on the recorded data during the holding phase (T_{hold}, see Fig. 5) due to the fixed position of the stamp (maximum indentation). The data set content for each sensor and each measurement is 815–850 measurement values. To analyze the stress-dependency of the sensor noise floor due to the mechanical interaction of the integrated sensors into the stamp, the signal-to-noise-ratio (SNR) is calculated for each sensor in a stressed and an unstressed condition using the signal mean (μ) and the standard deviation of the noise (σ):

$$SNR = \mu / \sigma. \quad (1)$$

Each sensor has a basic capacity (unstressed capacity of the sensor in pF), which rises while pressing or stretching the sensors. The capacity of the pressure sensors converts into a pressure information by using a calibration curve (capacity-pressure-diagram) for each sensor. The capacity of each elongation sensors converts into an elongation information while calculating the percentage increase of the sensor based on the basic capacity and the capacity measured during the load (measured capacity in pF). All elongation sensors have in the initial position the same basic capacity within the sensor specification (Boese et al., 2015):

$$Elongation\ [\%] = Measured\ Capacity\ \ [pF] \,/\, Basic\ Capacity\ \ [pF]*100\%. \quad (2)$$

For further analysis the average elongation and pressure is calculated for each sensor using the 815 to 850 measurement values obtain during the holding phase.

2.2.2. Repeatability

The repeatability is the ability of a measuring instrument to provide the closeness of the agreement between independent results on the same item under identical conditions (NIST TN 1297, 1994). This means that the measurements are made by the same operator, with the same measurement procedure using the same measurement instruments over a short period of time (ISO 5725-1, 1994).

In this experiment 12 measurements are performed under the same conditions, following the definition of repeatability. The stressed item is a seat layout consisting of a commercial suspension, a foam with a height of 100 mm and a hardness of 4 kPa with a fabric cover stretched to the maximum crankshaft-position of 120°. For each of the five pressure sensors (1–5) and the four elongations sensors (I-IV) the mean value ($\overline{x}_{sensor,\ 1-12}$), the maximum deviation ($x_{max} - x_{min}$), the standard deviation ($s_{sensor,\ 1-12}$) and the relative standard deviation ($RSD = s_{sensor,1-12}/\overline{x}_{sensor,1-12}$) of the 12 measurements (n = 12) are calculated. For the calculation of the confidence interval (CI) the significance level is set to 5% ($t_c = 1.96$):

$$CI = \overline{x} \pm t_c * s / \sqrt{n}. \quad (3)$$

2.2.3. Reproducibility

Reproducibility is the closeness of the agreement between the results of measurements obtained with the same method on identical test item under changed conditions (NIST TN 1297, 1994). The changing conditions may be due to different measurement methods, miscellaneous instruments being used, different operators or measurements made over a certain period of time (ISO 5725-1, 1994).

For the presented measurement method the reproducibility is ensured by assembling the measurement setup three times over a certain period of time with the same method, on the same item under the same conditions. The measurements are repeated three times (n = 3) for each assembled setup. The assembled setup includes the positioning of the measurement setup aligned to the material testing machine and the stamp as well as the positioning and fixation of the seat layout components. The seat suspension and the foam is adjusted by a mechanical stop and the cover is re-fixed following the guidelines described in section 2.1.3. The stressed item is identical to the seat layout of the repeatability test. Out of the three recorded measurements for each pressure (1–5) and elongation (I-IV) sensor the maximum and percentage deviation is calculated as well as the mean value ($\overline{x}$) and the standard deviation (s). Based on the results of the first assembling a confidence interval with a significance level 5% ($t_c = 1.96$) is calculated according to equation (3).

2.2.4. Detectability

The section "Detectability" investigates if the elongation and the pressure sensors detect obvious changes of the seat layout. The initial layout is identical to the layout applied for the repeatability and reproducibility test. The second seat layout is nearly the same except of the cover tension, which is reduced by changing the crankshaft position from 120° to 0°. The third layout has a leather cover material with a crankshaft position of 120°. All other components remain unchanged.

2.3. Application example: the influence of seat cover and seat suspension on seat characteristics

Referring to the introduction, the seat cover and the seat suspension could affect the seat comfort as well as foam characteristics. In order to study the effect the stamp is used to investigate the influence of the different seat components. For an analysis of the seat-layouts the foam hardness (4 kPa and 12 kPa), the foam height (30 mm and 100 mm), the cover tension (0°- crankshaft-position: "low/loosely", 120°- crankshaft-position: "high/tight") and seat suspension (plate and suspension) were varied (see Table 1). The foam has a constant raw density of 70 kg/m^3. The cover is a smooth leather which is integrated in high class automotive seats. The seat suspension is a standard product used in all common automotive seats. It is a spring steel wire (Ø 5 mm) with a meander shape (two wires with 3 meander). The only difference to the above presented method is that the maximum force for the measurement cycle (section 2.1.3) is set to 100 N. This is to prevent exceeding the elastic range of the leather material during the deformation of the various seat layouts. The processing of the raw data follows the procedure of section 2.2.1. Furthermore, the sensor information is processed on specific demands of the study. The pressure information of all sensors are combined to a maximum pressure, measured by the pressure sensor 1, and a pressure distribution, calculating the ratio of the maximum pressure (pressure sensor 1) to the peripheral pressure (sensor 2 – sensor 4). This study focuses on the summed elongation information of the sensor I and sensor II. This direction of the elongation sensors recognizes changes in the crankshaft-position of the measurement setup.

3. Results

3.1. Sensor noise floor

Table 2 shows the average values of the unstressed and stressed capacity of each elongation sensor (see Fig. 3). These values are the base for the determination of the elongation by calculating the percentage increase of the capacity (elongation). All sensors show nearly the same magnitude in an unstressed condition (basic capacity). Only sensor IV shows a smaller standard deviation. In the stressed condition sensor I

Table 1
Overview of the tested seat layouts.

Foam hardness	Foam height	Cover tension	Suspension	Test-No.
4 kPa	30 mm	0° (low)	plate	1
			suspension	2
		120° (high)	plate	3
			suspension	4
	100 mm	0° (low)	plate	5
			suspension	6
		120° (high)	plate	7
			suspension	8
12 kPa	30 mm	0° (low)	plate	9
			suspension	10
		120° (high)	plate	11
			suspension	12
	100 mm	0° (low)	plate	13
			suspension	14
		120° (high)	plate	15
			suspension	16

and sensor II (located in the direction of the same axes, see Fig. 3) have nearly the same value with a four hundredth deviation in the standard deviation. The capacities of sensor III and sensor IV deviate for the stressed sensors due to the properties of the cover tension and the cover material. Still, the standard deviation of the signals are comparable. In conclusion, all SNR-values indicate a very low influence of the noise floor. The noise floor of the pressure sensors is metrological negligible.

3.2. Repeatability

Table 3 considers the repeatability of the stressed elongation sensor signals based on 12 measurements. The pressure sensors have no measurable deviations. The elongation sensors I and II have the same absolute maximum deviation of 0.24%. The sensor signals III and IV have a higher absolute maximum deviation up to 0.77%. In general, the maximum deviation of all signal is less than 1%, the relative standard deviation (RSD) for all sensors is between 1.2% −3.1%. The average elongation of the four elongation sensors for each of the 12 measurements are constantly in the calculated sensor specific confidence interval (CI).

3.3. Reproducibility

Table 4 shows the exemplary results of the reproducibility test for the elongation sensor I. The results of the second and third assembling are compared to the reference results of the first assembling. The results of the first assembling are also used to calculate the confidence interval (CI). The range is calculated from 6.96% to 7.22%. All measurements results are in the confidence interval except one measurement of the first assembling and one measurement of the second assembling, both values are bold in Table 4. An addition, a noteworthy information is, the maximum deviation (percentage and absolute deviation) decreases with an increasing number of repeated assembling.

3.4. Detectability

The results of Table 5 show that the measurement system recognizes changes in the cover tension and the cover material, beyond that also the anisotropy of the surface materials. The exemplary results of elongation sensors I and II show that for the fabric material the difference between sensor I and II (one axis, see Fig. 3) is significantly smaller compared to the recorded elongation difference (between elongation sensor I and II) of the leather material. The results are compared for the same cover tension (120° crankshaft position). Additionally, the results of Table 5 point out the anisotropy of the cover material increases with a lower cover tension due to the higher difference of the elongation sensor I and II for a lower cover tensions.

Table 2
Results of the unstressed and stressed elongation sensors.

	Elongation Sensor I	Elongation Sensor II	Elongation Sensor III	Elongations Sensor IV
Average value (unstressed)	240.24 pF	240.24 pF	240.24 pF	240.23 pF
Std. deviation (unstressed)	0.15 pF	0.15 pF	0.15 pF	0.11 pF
SNR (unstressed)	1620	1620	1620	2107
Average value (stressed)	257.42 pF	257.08 pF	260.35 pF	256.18 pF
Std. deviation (stressed)	0.15 pF	0.11 pF	0.15 pF	0.15 pF
SNR (stressed)	1776	2347	1797	1768

Table 3
Investigation of the repeatability of the sensor signal comparing the elongation sensor I-IV with the average elongation (in %), the absolute maximum deviation (in %), the standard deviation (in %) and the relative standard deviation (−).

	Elongation Sensor I	Elongation Sensor II	Elongation Sensor III	Elongations Sensor IV
Average Elongation	7.19%	6.89%	8.31%	6.47%
Max. Deviation (absolute)	0.24%	0.24%	0.77%	0.41%
Standard Deviation	0.14%	0.09%	0.20%	0.20%
RSD (relative standard deviation)	0.019 (1.9%)	0.012 (1.2%)	0.024 (2.4%)	0.031 (3.1%)
Confidence Interval	7.05%–7.32%	6.83%–6.95%	8.16%–8.46%	6.32%–6.62%

3.5. Results of the application example

This section presents the results of the application example defined in section 2.3. Table 6 shows the indications that the measurement system can discover differences in the behavior of the seat components and materials. The table compares the maximum pressure, the pressure distribution, the elongation and the indentation depth for different seat layouts at a maximum load of approximately 100 N.

The seat suspension affects the maximum pressure only for the thin and soft foams. Test No. 1 and No. 3 without seat suspension show for thin and soft foams around 1 N/cm^2 higher maximum pressure values than for Test No. 2 and No. 4 with a seat suspension. This may be due to the total compression of the foam itself. The harder and thinner the foams, the higher the effects of the seat suspension on the pressure distribution (Table 6: compare pressure distribution of Test No. 9 and No. 10). High and soft foams in combination with a seat suspension influence an even pressure distribution in a negative way (Table 6: compare the pressure distribution of Test No. 5 and No. 6). The suspension results in all seat layouts in a higher indentation depth which also provokes a higher elongation, except for the seat layout with the 12 kPa hard and 100 mm high foam with a high cover tension. In this case the elongation decreases. An increasing cover tension increases predominantly the maximum pressure, generates higher pressure peaks in pressure distribution and decreases the elongation as well as the indentation depth. It stands out as for the maximum pressure, the pressure distribution, the elongation and the indentations depth differ for different seat layouts with a soft foam showing a higher range of values than seat layouts with a hard foam.

4. Discussion

4.1. Capability study

The raw data of this study show that all of the sensors have a small noise floor, which means the sensors are nearly independent of the load state. The results of the repeatability test show, that the repeated accuracy of the sensors is sufficient, while all sensor values are in the confidence interval (CI). Thus, no measurable interaction of the sensors influence the results of the measurement. The results of the reproducibility test have shown, that not all measurement values, especially the elongation data, are in the range of the confidence interval. Simultaneously, the maximum deviation reduces by the amount of assemblies, which indicates, the operator of the measurement method needs experience in assembling the measurement setup. A more precise and intuitive fixation of the cover would probably decrease the maximum deviation to <1%. The study also has shown that the measurement method recognizes changes in the cover material and cover tension. In conclusion, based on this study the measurement method seems sufficient for an objective recording of the comfort relevant parameters while

Table 4
Results of the reproducibility test exemplary for the elongation sensor I.

Assembling	Elongation	Max. Percentage Deviation	Max. Absolute Deviation	Average Elongation	Standard Deviation	Confidence Interval Min.	Max.
1	7.21% 7.11% **6.95%**	3.74%	0.26%	7.09%	0,11%	6.96%	7.22%
2	**6.91%** 6.97% 7.00%	1.26%	0.09%	6.96%	0.04%		
3	7.17% 7.22% 7.21%	0.70%	0.05%	7.20%	0.03%		

Table 5
This table shows the three measurement results of the elongation sensor I and the elongation sensor II for three different cover versions defined in Table 1. For the anisotropy evaluation the difference between elongation sensor 1 and the elongation sensor 2 is calculated. Additionally, it is shown the indentation depth and the force.

Test-No.	Elongation Sensor I	Elongation Sensor II	Difference Between Elongation Sensor I and Elongation Sensor II	Indentation Depth	Force
	in %	in %	in %	in mm	in N
Fabric High Cover Tension (120°-crankshaft-position)	7.22 7.11 6.95	7.11 6.88 6.80	0.11 0.23 0.15	26.68 26.88 26.90	199.07 199.13 198.12
Fabric Low Cover Tension (0°-crankshaft-position)	10.45 10.09 9.97	9.90 9.44 10.37	0.55 0.65 0.40	30.00 28.35 29.43	198.54 198.67 198.80
Leather High Cover Tension (120°-crankshaft-position)	7.66 7.66 8.06	6.70 6.46 6.85	0.96 1.20 1.21	28.03 27.65 27.52	198.77 198.78 198.79

Table 6
Result overview of the various seat layouts defined in Table 1.

Test-No	Max pressure	Pressure Distribution	Elongation	Indentation Depth
	N/cm^2	Ratio	sensor I[%] +sensor II[%]	mm
1	9.20	71.3/28.7	1.3	25.2
2	8.00	66.5/33.5	2.2	33.9
3	9.10	77.8/22.2	0.9	24.6
4	8.10	74.5/25.5	2.0	32.4
5	5.40	51.4/48.6	3.4	40.0
6	5.30	55.5/44.5	5.6	39.9
7	6.00	65.5/34.5	1.9	36.4
8	6.10	68.3/31.7	2.1	35.6
9	6.20	59.9/40.1	1.8	18.2
10	6.20	49.8/50.2	2.2	27.6
11	7.60	85.8/14.2	1.3	16
12	6.90	67.1/32.9	2.0	25.0
13	6.50	58.4/41.6	1.9	22.1
14	6.20	52.1/47.9	3.1	25.3
15	7.70	77.3/22.7	1.5	20.4
16	8.00	70.2/29.8	1.2	23.2

loading a seat. An investigation of various seat components related to the comfort relevant parameters is viable with the described measurement method. Compared to the common method, taking measurements with a pressure mat, the presented method enables to measure additionally to pressure also the elongation, which is based on wheel chair research a relevant comfort parameter (Goossens, 2001). Moreover, the additional information of elongation in combination with the pressure information allows to recognize changes of the seat layout. The most current applied pressure mats are not able to detect these changes sufficiently.

4.2. *The influence of seat cover and seat suspension on seat characteristics*

Studies described above indicate that not only the pressure (maximum pressure and pressure distribution) but also the elongation, the shear stress and the friction coefficient might be comfort relevant parameters for the seat comfort. However, these parameters are difficult to measure. The results of Table 6 show that with the system developed in this study the elongation (the shear and friction coefficient is in this application example not explicit considered) can be recorded and it is influenced by the selection of the seat components. The exemplary test layout No.5 and No. 10 (see Table 6) determines two completely different seat layouts (see Fig. 6) with almost the same pressure distribution and a similar maximum pressure but nearly with a 1.5-fold difference in the elongation, measured by our device. This means, the human skin in contact with the seat in the seat layout of test layout No. 5 probably stretches more, which could affect the blood flow, the musculoskeletal system and the tissue as well might influence the perceived seat comfort perception. The studies of Diesing (2006), Bennet and Worthen (1980) and Goossens (1994, 2001) stress the importance of shear forces. More studies are necessary to investigate whether this effect is noticed and experienced by subjects in a subjective comfort experiment. Previous seat comfort studies of Ebe and Griffin (2000, 2001), Kamp (2012) or Kolich (2003) focus mostly on the foam characteristics, the seat contour, the seat dimensions and seat adjustments. The result of Table 6 illustrates that the seat components do affect each other. The main question is whether this objectively recorded differences are also experienced by seat occupants, which needs to be studied in future research.

5. Conclusion

In this study a system (a stamp) is developed to measure the effects of combinations of different seat elements. The reproducibility and

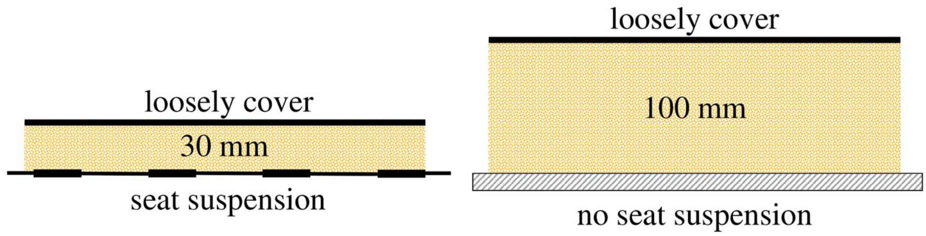

Fig. 6. Two different seat layouts (No. 5 and No. 10) are shown with nearly the same pressure distribution and maximum pressure but with a 1.5-fold higher elongation for the seat-layout with 100 mm foam. The left seat layout (No. 10) has a loosely cover, a 30 mm high and 12 kPa hard foam and contains a seat suspension. The right seat layout (No. 5) has a loosely cover, 100 mm high and 4 kPa soft foam without a seat suspension.

repeatability of the stamp sensors are appropriate for our purpose to study pressure and elongation (shear force and friction coefficient) of different components and component interactions. Nevertheless, the assembling procedure of the measurement setup and especially the fixation of the cover materials could be optimized in order to reach a better reproducibility of the measurement results. The new measurement procedure should be able to break down the effects of the surface (cover materials and layer) up to the anisotropy of the cover materials.

The application examples have shown that the measurement approach is able to determine differences between various seat elements. The results of the comparison demonstrates that the seat suspension and cover tension influence the behavior of the loaded seat. Furthermore, specifically the assumed comfort relevant parameters maximum pressure, pressure distribution and elongation could be recorded by this system. The technical protection of the system and the application example have confirmed that this measurement approach is suitable for a more extended investigation of the various seat components which could affect the seat comfort. Additionally, examining the characterization of the components with appropriate coefficients. However, it would be interesting to discover whether the recorded differences in seat characteristics and combinations of elements have a relationship with the experienced comfort.

Acknowledgement

This research was supported by the Fraunhofer Institut ISC. We are thankful to our colleagues Sven Ritter, Wolfgang Grüner, Rolf Lechner, Florian Fitzen, Tobias Englmaier and Mario Buljan who provided expertise that greatly assisted the research. We are also grateful to Erich Zerhoch for assistance organizing the measuring instruments.

References

Adler, S., 2007. Zusammenhang von Langzeitsitzkomfort und Fahrerbewegungen. Dissertation. Friedrich-Schiller-Universität Jena.
Bennet, T., Worthen, E.F., 1980. Shear vs. pressure as causative factors in skin blood flow occlusion. Plast. Reconstr. Surg. 66 (1), 180.
Boese, H., Fuß, E., Ehrlich, J., 2015. Capacitive sensors mats for pressure detection with high sensitivity. In: Fraunhofer-Institut für Silicatforschung, AMA Conference 2015.
Chow, W.W., Odell, E.I., 1978. Deformations and Stresses in Soft Body Tissues of a Sitting Person, 1978.
CSA Research, 2017. OUR LIVES INSIDE OUR CARS. EUROPEAN SURVEY.
De Looze, M. P. de, Kuijt-Evers, L.F.M., van Dieen, J., 2003. Sitting comfort and discomfort and the relationships with objective measures. Ergonomics 46 (10), 985–997.
Diesing, P., 2006. Prüf- und Bewertungsmethoden für Antidekubitus-Systeme. Dissertation. Technische Universität Berlin.
DIN 53579, 2005. Testing of Flexible Cellular Materials –Indentation Test on Finished Parts. DIN-Normenausschuss Materialprüfung (NMP).
DIN EN ISO 3386-1, 2009. Polymeric Materials, Cellular Flexible –Determination of Stress-Strain Characteristics in Compression –Part 1: Low-Density Materials. DIN-Normenausschuss Materialprüfung (NMP).
Ebe, K., Griffin, M.J., 2000. Quantitative prediction of overall seat discomfort. Ergonomics 43 (6), 791–806.
Ebe, K., Griffin, M.J., 2001. Factors affecting static seat cushion comfort. Ergonomics 44 (10), 901–921.
EUROPEAN FREE TRADE ASSOCIATION, 2015. This Is EFTA.
Eurostat, 2017. Population of the European Union 2014. http://ec.europa.eu/eurostat. (Accessed 3 April 2017).
Gibson, L.J., Ashby, M.F., 2001. Cellular Solids. Structure and Properties. Cambridge Solid State Science Series. Cambridge Univ. Press, Cambridge u.a.
Goossens, R.H.M., 1994. BIOMECHANICS of BODY SUPPORT. A Study of Load Distribution, Shear, Decubitus Riskand Form of the Spine.
Goossens, R.H.M., Teeuw, R., Snijders, C.J., 2000. Decubitus risk: is shear more important than pressure?. In: Proceedings of the lEA 2000 lHFES 2000 Congress.
Goossens, R.H.M., 2001. Shear Stress Measured on Three Different Cushioning Materials. Delft University of Technology.
Goossens, R.H.M., Teeuw, R., Snijders, C.J., 2005. Sensitivity for pressure difference on the ischial tuberosity. Ergonomics 48 (7), 895–902.
Hartung, J., 2006. Objektivierung des statischen Sitzkomforts auf Fahrzeugsitzen durch die Kontaktkräfte zwischen Mensch und Sitz. Dissertation, Technischen Universität München.
ISO 5725-1, 1994a. Accuracy (Trueness and Precision) of Measurement Method and Results - Part 2: General Principles and Definitions. International Organization for Standardization.
ISO 5725-2, 1994b. Accuracy (Trueness and Precision) of Measurement Method and Results - Part 2: Basic Method for the Determination of the Repeatability and Reproducibility of a Standard Measurement Method. International Organization for Standardization.
Jurado, A., 2014. EUROPEAN MOTOR VEHICLE PARC. VEHICLES IN USE(2009-2014). Anfac.
Kamp, I., 2012. Comfortable Car Interiors. Experiments as a Basis of Car Interior Design Contributing to the Pleasure of the Driver and Passenger, pp. 88–105.
Kilincsoy, Ü., Wagner, A.-S., Bengler, K., Bubb, H., Vink, P., 2014. Comfortable rear seat postures preferred by car passengers. In: Proceedings of the 5th International Conference on Applied Human Factors and Ergonomics AHFE 2014.
Kilincsoy, Ü., Wagner, A.-S., Vink, P., Bubb, H., 2016. The Ideal Pressure Distribution for SUV and Sedan Rear Seats.
Klinke, R., Brenner, B., 2014. Physiologie. Thieme, Stuttgart, pp. 624–675.
Kolich, M., 2003. Automobile seat comfort. Occupant preferences vs. anthropometric accommodation. Appl. Ergon. 34 (2), 177–184.
Mergl, C., 2006. Entwicklung eines Verfahrens zur Optimierung des Sitzkomforts auf Automobilsitzen. Dissertation. Technischen Universität München.
NIST TN 1297, 1994. Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results. United States Department of Commerce Technology Administration, National Institute of Standards and Technology.
Sammonds, G.M., Fray, M., Mansfield, N.J., 2017. Effect of long term driving on driver discomfort and its relationship with seat fidgets and movements (SFMs). Appl. Ergon. 58, 119–127.
Smulders, M., Berghman, K., Koenraads, M., Kane, J.A., Krishna, K., Carter, T.K., Schultheis, U., 2016. Comfort and pressure distribution in a human contour shaped aircraft seat (developed with 3D scans of the human body). Work 54 (4), 925–940.
Schmidt, R.F., Thews, G., 1980. Physiologie des Menschen. Springer Verlag; Springer, Berlin u.a.
van Veen, S.A.T., Hiemstra-van Mastrigt, S., Kamp, I., Vink, P., 2014. Improving car passengers' comfort and experience by supporting the use of handheld devices. Work 49 (2), 215–223.
Venkatesan, L., Barlow, S.M., Kieweg, D., 2015. Age- and sex-related changes in vibrotactile sensitivity of hand and face in neurotypical adults. Somatosens. Mot. Res. 32 (1), 44–50.
Vink, P., 2012. Advances in social and organizational factors. In: Advances in Human Factors and Ergonomics Series. CRC Press, Hoboken.
Vink, P., Lips, D., 2017. Sensitivity of the human back and buttocks: the missing link in comfort seat design. Appl. Ergon. 58, 287–292.
Zenk, R., Mergl, C., Hartung, J., Sabbah, O., Bubb, H., 2006. Objectifying the comfort of car seats. SAE International.
Zhang, M., Roberts, V.C., 1994. The effect of shear forces externally applied to skin surface on underlying tissues. J. Biomed. Eng. 15 (6), 451–456.