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On the Development of an Upholstery Database for Simulating the Human-Seat Interaction in Automotive Interiors

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Abstract. A corner stone in digital ergonomics is the positioning of digital human models into occupant configurations. Since seats play a major role for interiors, the human-seat interaction has to be considered for simulating postures. In most applications the classical H-Point model has been used. Since this approach is limited, the prediction has been refined by considering seat parameters like kinematics, upholstery surfaces and stiffness. But the necessity of stiffness parameters often hinders applying this method, since it requires extensive measurements based on a special indenter. To reduce this bottleneck, two improvements have been introduced. First, the measurement has been enhanced to be more generic and easier to perform. The process has been standardized in line with SAE J2896 and supports user-defined indenters. Second, an upholstery database has been implemented as alternative to measure the stiffness. The database is based on a sample of German vehicle seats and a statistical analysis of their measured force-deflection curves. A GUI supports the definition of characteristic curves. This can be done by selecting a referential curve, by setting individual parameters or by predicting a curve from the cushion stiffness. The final curves are suited for predicting the manikin or seat positions in interior designs.

Keywords. Posture Simulation, Human-Seat Interaction, Upholstery Database, Upholstery Stiffness Measurement

1. Introduction

A crucial feature of digital vehicle ergonomics tools is the realistic and automatic task-specific positioning of a digital human model into a given occupant configuration. Since the seat has a major influence on the occupant behavior in vehicle interiors, the human-seat interaction has to be considered properly by a digital human model for the simulation and evaluation of occupant postures [1].

In most applications the classical and pragmatic H-Point model has been used to predict sitting postures. This model addresses the offset between the seating reference point and the occupant's hip center and dates back to the start of using human models in automotive applications [2]. Since the quality and evaluation potential of this approach is limited, the prediction has been refined by an advanced human-seat simulation method [3]. This method can be used to predict a manikin posture in a given seat or the seat position for a given sitting manikin. It takes into account several user-defined seat

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parameters like kinematics, cushion and back rest surfaces, attachments, H-Point travel field and upholstery stiffness.

However, poor availability of stiffness parameters impedes the application of this method in ergonomic vehicle design, because extensive seat stiffness measurement has to be conducted by moving a special indenter device into the upholstery and measuring the corresponding forces and deflections [4]. Such procedures are commonly used to evaluate the dynamic seat comfort concerning vibrations caused by driving dynamics [5]. This global approach is a simplification of measuring local foam characteristics for the simulation of seat foam structures in complex FEM models [6] and of measuring local seat pressure distributions for the prediction of static seat comfort ratings [7,8].

This bottleneck was defused by a measurement procedure that is more generic and easier to perform. In addition, a seat upholstery database has been implemented as a functional alternative for explicitly measuring the seat stiffness. These two improvements will be described in the following sections.

2. Method

2.1. Seat measurement

The measurement of upholstery stiffness is an extension of a procedure which essentially is based on the determination of the force-dependent deformation of the complete seat surface [4]. A machine moves an indenter into the seat surface at specific locations with varying forces and constant speed, while taking its travel length to measure the upholstery deflection. The measurement appliance and the rigid indenter (shaped like human buttocks) are displayed in Figure 1.

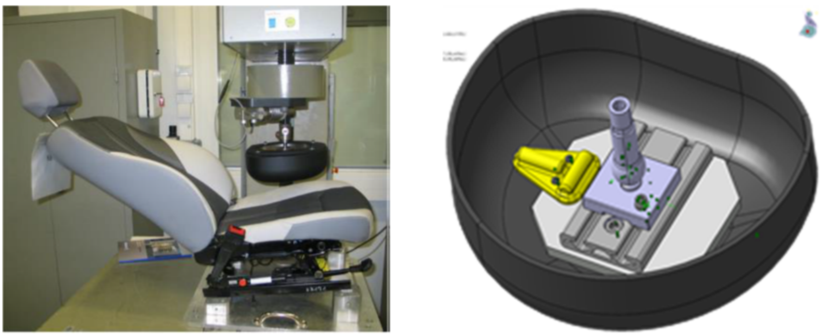


Figure 1. Measurement appliance and indenter.

In order to cover the entire upholstery area, the procedure is applied to various locations on the seat. The cushion and back rest are fixed and aligned such that the indenter subsides orthogonally into the upholstery surface. The forces are measured perpendicular to the indenter. The four measurement locations and directions are illustrated in Figure 2 and Figure 3.

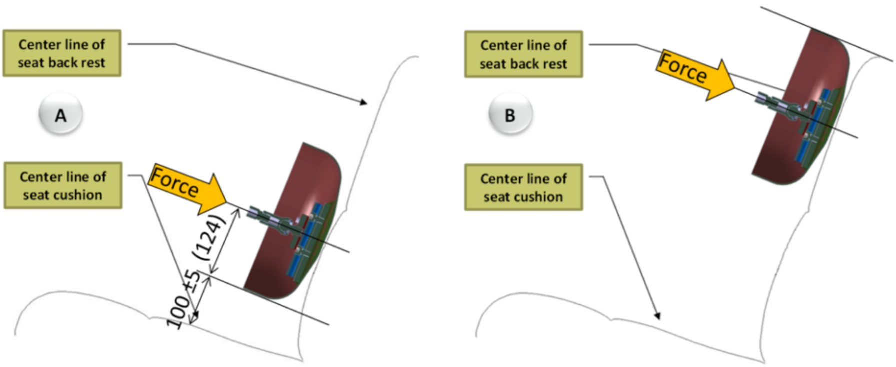


Figure 2. Measurement locations on back rest: bottom and top.

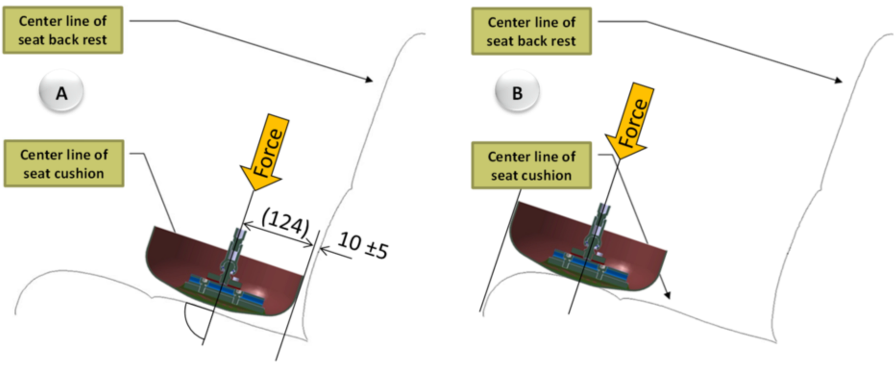


Figure 3. Measurement locations on cushion: rear and front.

The measurement forces are uniformly increased up to 750 N (cushion) and 250 N (back) at a constant speed of 50 mm/min (loading) and decreased to 0 N under the same conditions (unloading) without time delay. This procedure is repeated four times with 5 minutes break between the takes. Finally, the last trial is used for further processing. The measured force-deflection pairs build the characteristic load-deflection curve at the specific location (Figure 4).

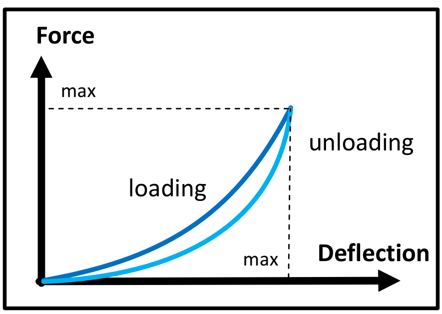


Figure 4. Characteristic force-deflection curve.

This procedure is essentially compatible with the standard SAE J2896 "Motor Vehicle Seat Comfort Performance Measures" [9]. Selective differences with regard to recommendations such as maximum applied forces and measurement direction are neglected, because their application in the presented method has already been approved [4]. Basically, the principal procedure and results of the standard correspond to our approach.

The scope of SAE J2896 is a recommendation for test procedures applied to complete seat systems in manufacturing quality. The specified test methods stipulate a range of indenter shapes (buttform, disk or oval). This open indenter specification is addressed in the measurement processing software presented in Section 2.3.

A representative set of 24 automotive and light truck seats from German vehicle manufacturers were measured using the method described above. The resulting force-deflection curves (loading) show quite homogenous trends (Figure 5).

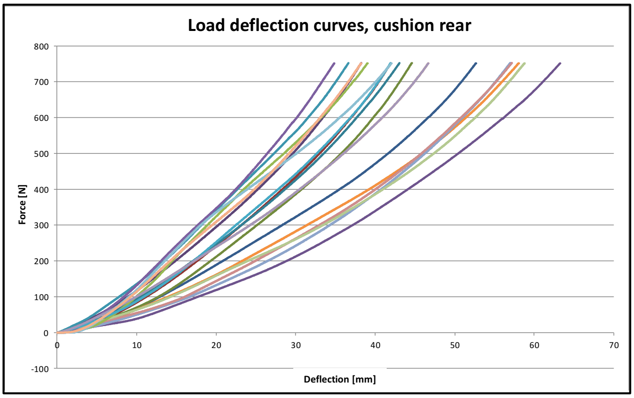


Figure 5. Load-deflection curves of all seats (cushion-rear).

The analysis of repeated measurements showed that all trial curves are similar with exception of the first take (Figure 6, left). The diagram in Figure 6 (right) shows small deviations between the maximal forces and deflections over all locations and seats for trial 2-4 and large deviations between trial 1 and the averages of trial 2-4. This confirms the guideline instructions given in Section 2.1 to use the last measurement in further practice.

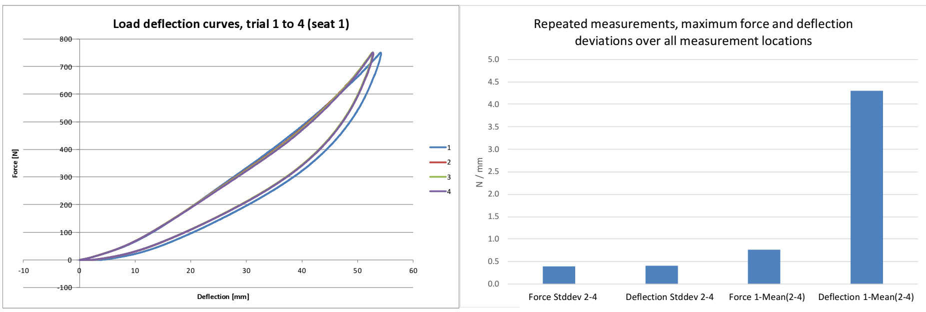


Figure 6. Deviations between maximal forces and deflections over all locations and seats for repeated trials.

2.2. Seat curve analysis and modeling

The goal is the creation of a database from a representative set of seats providing the two main features:

1. Representation of upholstery load-deflection curves by percentiles
2. Selection, adjustment or prediction of user-defined load-deflection curves

Since the trend of these curves (loading part) is quite similar over all seats (Figure 5), the principal idea of the database model is to represent each curve by two characteristic parameters: Absolute deflection d_{max} under maximal force and deflection $d_{50\%}$ (relative to d_{max}) under half of maximal force (Figure 7, left). For these two parameters the percentiles are calculated over all elements of the data pool at each of the four seat locations (Figure 7, right).

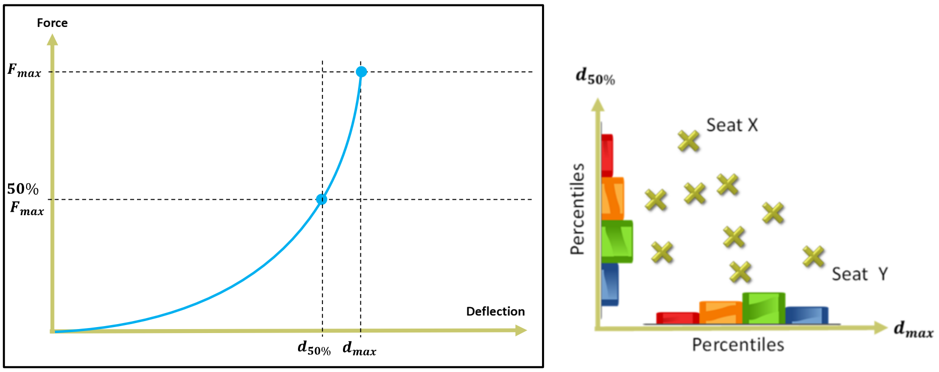


Figure 7. Two characteristic parameters (left) and percentiles in 2-dimensional parameter space (right).

In addition, the correlations between these parameters for different locations are studied as a basis for a regression model predicting a curve at a certain location from the data of the other seat locations (Figure 8). Since the cushion-rear measurement is most important for posture prediction, all further locations should be predictable from there. This enables users to model the upholstery properties of the entire seat by just providing the cushion-rear measurement.

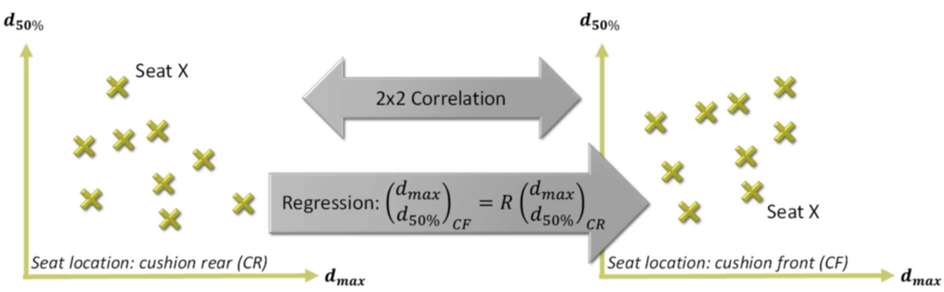


Figure 8. Correlation analysis between parameters of different seat locations.

Finally, the model for deriving a curve from the two characteristic parameters is generated by normalizing measured curves (with respect to maximal force and deflection) and clustering them in three groups at each seat location. The group "mean" contains 60% of curves around the average d_{max} over all seats. The groups "min" and "max" contain the remaining curves below (hard) and above (soft) the average d_{max}. In each group the average curve is pointwise calculated as a representative of the group.

These three curves provide the trends which are locally interpolated to create a user defined curve (Figure 9).

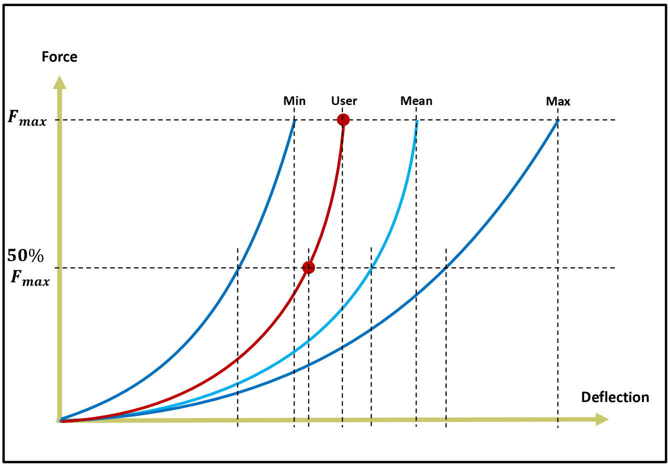


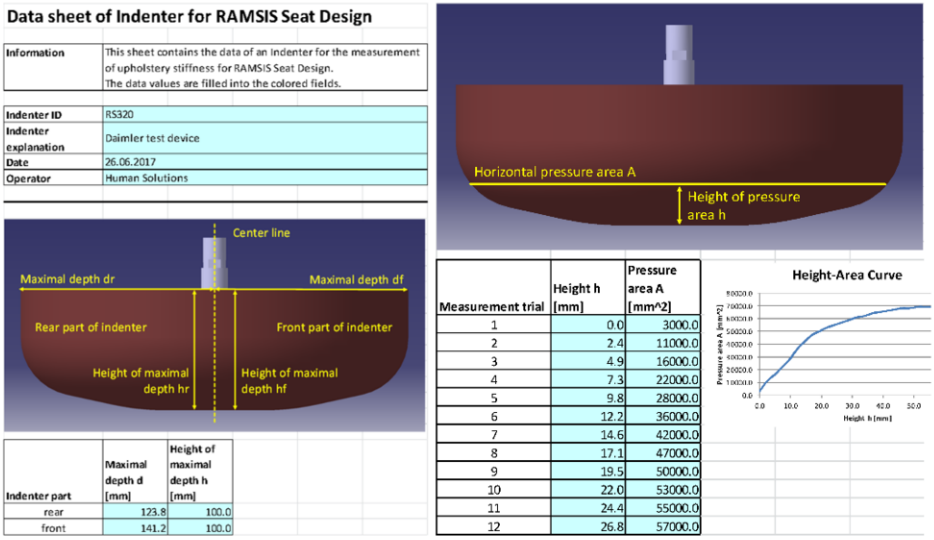
Figure 9. Representative trends for hard (min), mean and soft (max) seat curves interpolated for user curve.

2.3. Measurement processing

The load-deflection curves exemplified above deliver force data that have to be converted to pressure data using the indenter dimensions, thus facilitating the posture simulation to account for various manikin dimensions. In order to handle user-defined indenter shapes in the seat measurement, the processing tool provides a parameterization of the shape with respect to crucial properties.

Modelling the measurement locations on the virtual seat requires the main geometric indenter dimensions, namely the maximal depth and the height at the location of the maximal depth can be defined for each of the rear and the front part (Figure 10, left). The generation of the pressure data requires the effective pressure areas of the indenter during the measurement. Therefore, the pressure area values of horizontal intersections at various heights above the bottom can be defined (Figure 10, right).

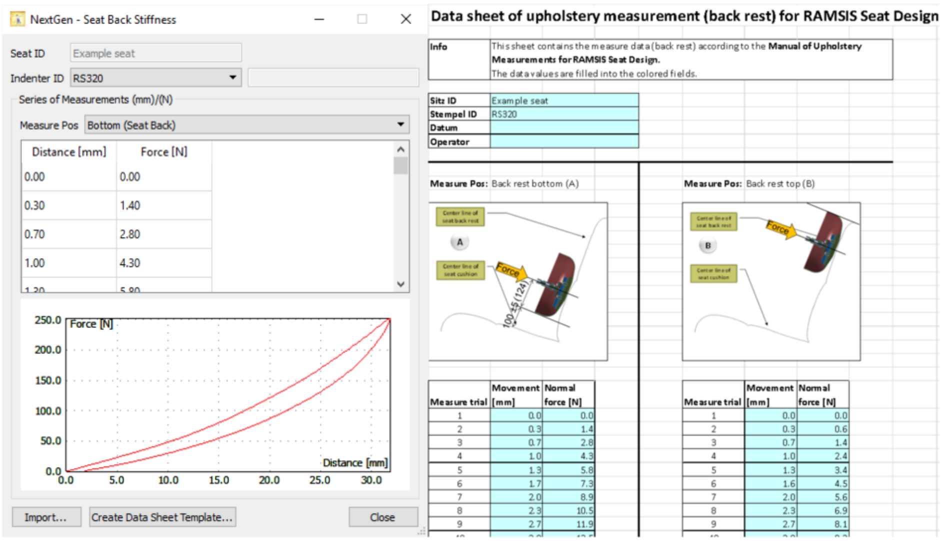
To process the seat measurement results, the values of the characteristic load-deflection curves (Figure 4) are stored in a specific protocol. This EXCEL data sheet provides two table fields for the trial pairs of movement and normal force at both measurement locations on each of cushion and back (Figure 11, right).



Indenter part	Maximal depth d [mm]	Height of maximal depth h [mm]
rear	123.8	100.0
front	141.2	100.0

Measurement trial	Height h [mm]	Pressure area A [mm^2]
1	0.0	3000.0
2	2.4	11000.0
3	4.9	16000.0
4	7.3	22000.0
5	9.8	28000.0
6	12.2	36000.0
7	14.6	42000.0
8	17.1	47000.0
9	19.5	50000.0
10	22.0	53000.0
11	24.4	55000.0
12	26.8	57000.0

Figure 10. Protocols for indenter dimensions (left) and height specific pressure areas (right).



Measure trial	Movement [mm]	Normal force [N]
1	0.0	0.0
2	0.3	1.4
3	0.7	2.8
4	1.0	4.3
5	1.3	5.8
6	1.7	7.3
7	2.0	8.9
8	2.3	10.5
9	2.7	11.9

Measure trial	Movement [mm]	Normal force [N]
1	0.0	0.0
2	0.3	0.6
3	0.7	1.4
4	1.0	2.4
5	1.3	3.4
6	1.6	4.5
7	2.0	5.6
8	2.3	6.9
9	2.7	8.1

Figure 11. GUI (left) and protocol for load-deflection curve (right).

These sheets can be imported by the processing software which displays the load-deflection curves for each location as well as the indenter positions on the virtual seat and transfers the force data to pressure data using the specified indenter (Figure 11, left). Since the posture simulation addresses the sinking into the seat of a manikin, it refers only to the loading part of the load-deflection curves.

3. Results

The methods introduced in Section 2.2 were applied to the German seat measurements to create an upholstery database predicated on the extracted 2-dimensional parameters from which the percentiles were calculated (Figure 12).

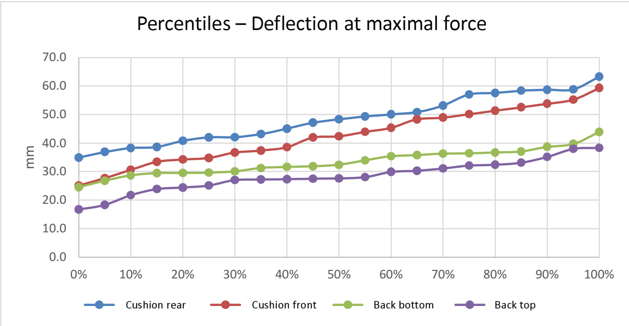


Figure 12. Percentiles for parameter: deflection at maximal force ($\boldsymbol{d_{max}}$).

The clustering process was applied on the normalized raw curve data to get the three representative curve trends for a hard, mean and soft upholstery (Figure 13).

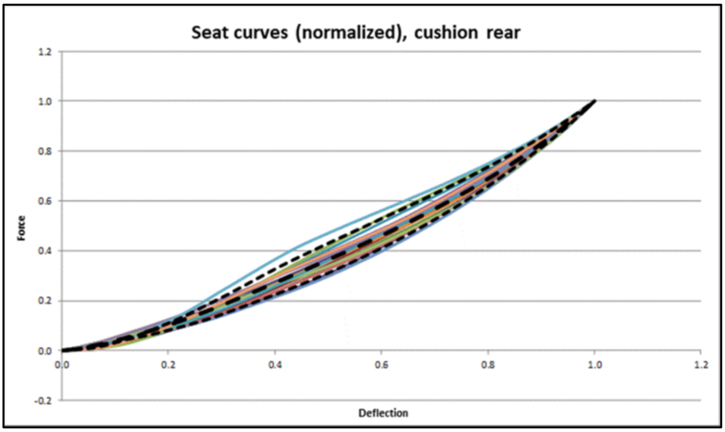


Figure 13. Representative curve trends for hard, mean and soft upholstery.

The correlations of the 2-dimensional parameters between the seat locations cushion-rear and -front, back-top and -bottom were calculated. Additionally, the determination coefficients between the locations were calculated to check the significance of predicting curves from the cushion-rear parameters by regression. According to the results in Figure 14, the prediction of cushion-front and back-bottom from the cushion-rear parameters is satisfying. Back-top parameters should rather be predicted from the back-bottom data if provided. All in all, the prediction order cushion-rear to -front and to back-bottom as well as back-bottom to -top was implemented.

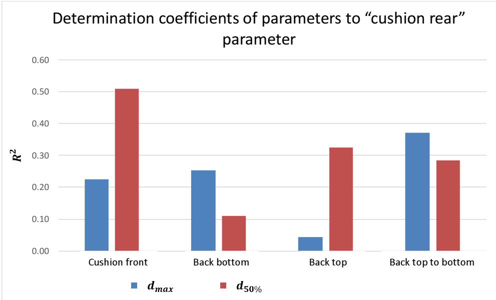


Figure 14. Determination coefficients between parameters and "cushion rear" parameters & prediction order.

All statistical figures were integrated into an upholstery database. The corresponding software interface provides several possibilities to create individual load-deflection curves from the database (Figure 15). In the diagram referential curves such as "very hard", "medium" or "very soft" are plotted (blue) together with the current user defined curve (red). This curve can be defined directly by selecting a referential curve from the database, or by setting the individual characteristic parameters (d_{max}, $d_{50\%}$), or by predicting them from the cushion rear stiffness data. Both parameters can be provided within a reasonable range observed in the measurements. The corresponding pressure and percentile values are automatically displayed.

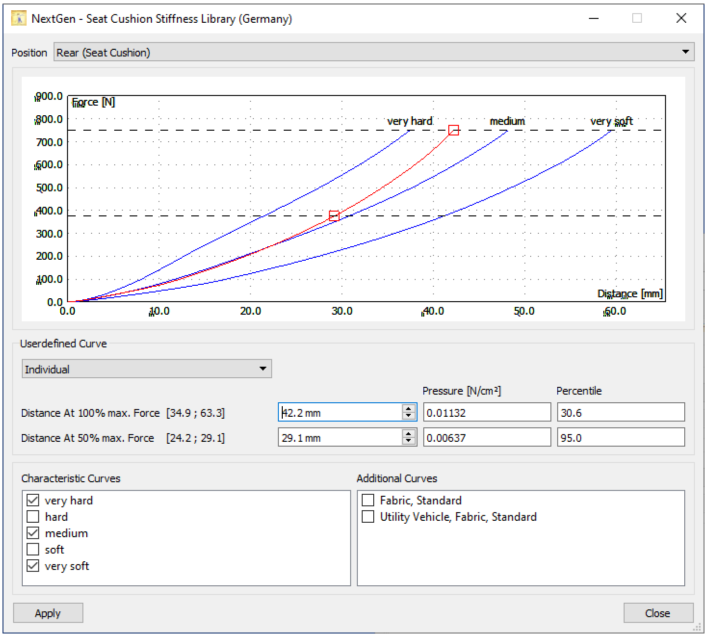


Figure 15. Software interface to upholstery database.

The final curves are ready for direct use in the human seat interaction predicting the manikin or seat positions. For this purpose, the force-deflection curves are transferred into pressure-deflection curves by the processing tools described in Section 2.3. The simulation calculates the position of the manikin or seat such that the manikin body weights are compensated along the manikin-seat collision areas by the reaction pressure from these seat curves [3].

4. Discussion

The presented measurement procedure is less complex and easier to perform than earlier instructions. In addition, it is more generic and in line with the international standard SAE J2896. All this makes individual upholstery measurements more acceptable for users.

The measurement has been extensively performed using a buttock-like indenter. For practical reasons, the same indenter is used for all seat locations. In future, the usage of additional indenter types, especially for the back rest, should be validated.

The usage of horizontal indenter intersections to transfer force to pressure data is a simplification of the indenter pressure distribution in the upholstery. This is a pragmatic compromise, since real pressure areas are difficult to determine during the measurement process and the vertical force component is the most essential one for the prediction of manikin postures.

The current upholstery database is based on a representative set of seats available in German cars and light trucks. The question remains if it can be applied to seats manufactured in additional regions like France, America or Asia. This certainly depends on the international manufacturing differences of vehicle seats and should be elaborated in future. Anyway, the proposed procedure is suited to create further international upholstery databases.

The software interface to the database has been successfully validated by users. It is a proper compromise between a pragmatic reduction of complexity and a range of possibilities to parameterize individual seats.

Acknowledgement

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