SIMULATION OF STATIC LOADING OF POLYURETHANE FOAM

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Abstract

Comfortable seat layers are in most cases filled with polyurethane foam. The equilibrium position of the automobile seat represents the static loading of polyurethane block. Thanks to simulations it is possible to predict the final position of the human body, which is important for passive safety features such as airbags. This article describes the measurement and simulation of static loading of the foam block by circular indentor, rigid dummy and compares two simulation environments. Analyses of static tests are determined by the force/displacement characteristic and pressure distribution in the contact zone. Material models of polyurethane foam can be used for the complete seat H-point achievement simulations by EHK17. It is possible to optimize the comfort layer of mechanical properties in the simulation environment and thus save the cost of prototyping seats.

Introduction

Polyurethane foam is a cellular material with specific mechanical characteristics with low density (generally around 55 kg/m^3 for seat cushions and mattresses). Foam is possible to characterize as a nonlinear visco-elastic material. Thanks to viscosity of the cellular structure this material has fatigue behavior. There are two main fatigue studies: relaxation and creep analysis. The methodology of static and quasi static analysis is necessary to adapt in terms of fatigue behavior. The viscous behavior brings also the ability of absorbing the strain energy. It is very useful for mechanical vibration dissipation. This contribution describes only the static loading of polyurethane blocks and the possibilities of simulations. In our case of static loading it is possible to use macroscopic approach instead of detailed microscopic cellular analysis such as shape cells, facets, etc. The macroscopic analysis considers the overall response of sample loading in order to estimate the macro-mechanical parameters. The polyurethane foam undergoing large deformation is assumed to be homogenous, isotropic with constant cross-section. The material model may be considered as generalized Kelvin model with nonlinear spring with hysteresis and linear dashpot. The elastic foam component is the nonlinear spring described by a stress-strain characteristic. It is a common approach to append Maxwell scheme with parallel spring and dashpot, which represent the viscous (fatigue) creep and relaxation. By using specific methodology for static analysis it is not necessary to include the relaxation and the creep behavior to material model. In static loading cases without relaxation and creep represents the dashpot viscous behavior and is optimized for stability during equilibrium achievement.

1 Static analysis of the polyurethane foam specimen

There are common approaches to get static characteristics. Cause of viscous behavior has the loaded specimen during cycling loading different force responses (Fig. 1).

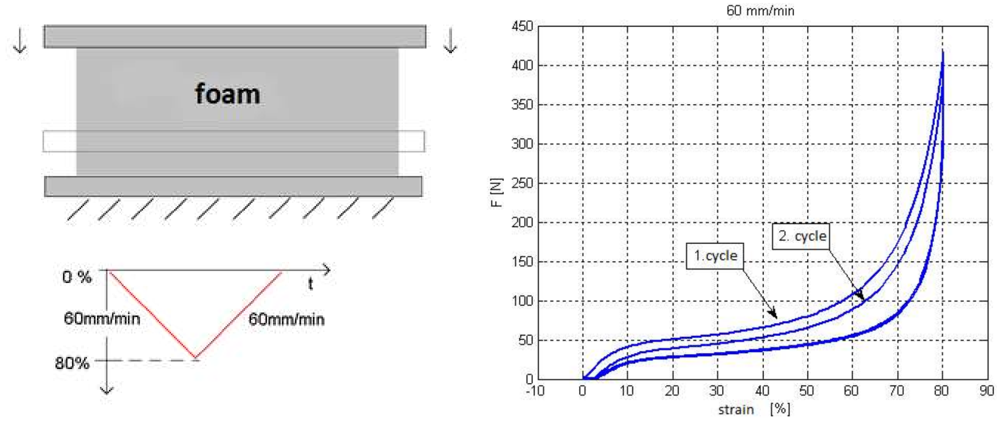

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Fig. 1: *Test Description, cycling loading of foam specimen*

There are two cases of loading - permanent strain and stress. Permanent strain evinces relaxation of the force response. Decreasing of the force is time dependent and the main difference is in first tens of a second. It is a very important phenomenon in terms of using automobile seats. It is assumed that the seat cushion is used as long term loading of the human body. The decreasing of the force response for different strain levels is described in Fig. 2.

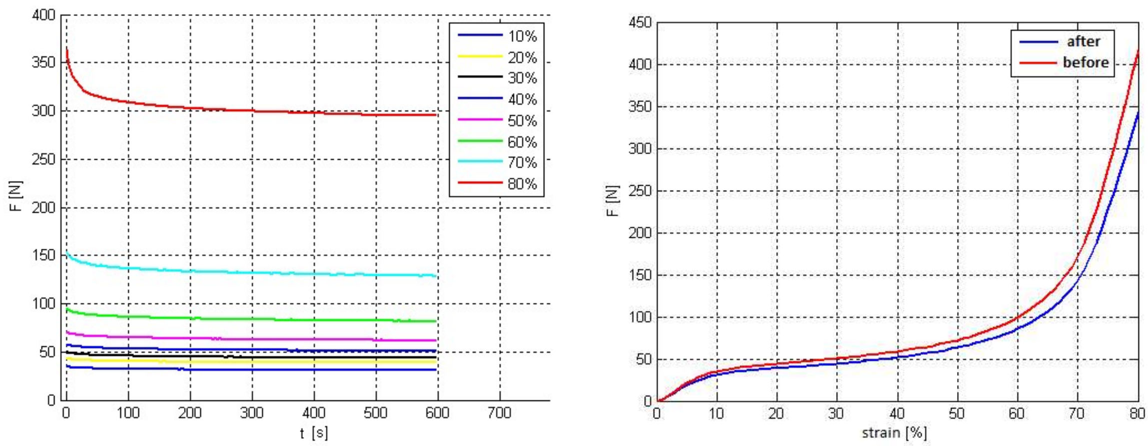

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Fig. 2: *Relaxation loading case, force response before and after relaxation interval*

There are differences between force response before and after relaxation interval. In long term point of view is more suitable and predicative the characteristic after relaxation interval.

Permanent stress means the permanent loading of the weight. It is closed to the real sitting of the human body on the seat cushion. The description of the testing is in Fig.3. The creep fatigue is important in terms of position of the weight on the foam block.

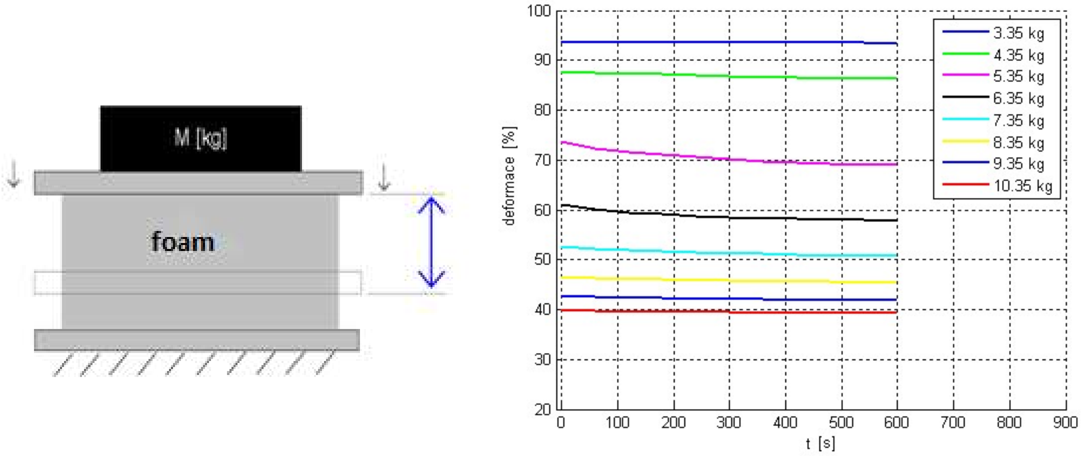

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Fig. 3: *Description of the permanent stress loading, creep results for different masses*

The comparison between permanent stress and strain loading is shown in Fig. 4. The differences are very low. It is possible to use both types of loading to get the static characteristic after relaxation and creep.

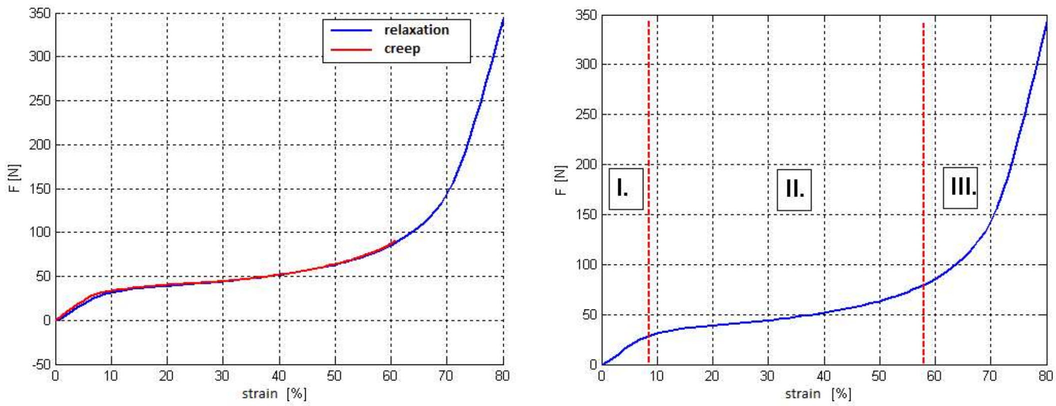

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Fig. 4: *Comparison between permanent stress and strain loading after relaxation interval, loading zones of the static characteristic of the polyurethane foam*

It is possible to divide the static characteristic after relaxation to three loading areas to describe the nonlinear behavior of the polyurethane foam. The cells of the foam are almost elastic in the first area. The stiffness is linear to strain around 10%. After this strain the cell structure begins to be destroyed and the stiffness is lower – it is area II in Fig. 4. During the destroying the cells are in contact with themselves and the friction between them is high – it represents the damping. The static loading of a sitting human body will be in the second area, cause of lower stiffness for contact pressure distribution and damping during mechanical vibration. The cells are completely destroyed in the third area. The stiffness is high with low damping.

The permanent strain loading with relaxation is more useful in terms of measurement simplicity and exact range of strain from 0 to 80%. For long term static loading analysis is used. The characteristic after relaxation interval and the fatigue analysis is not important in our case.

2 Simulation environment and material model

Simulations are made in PAM COMFORT (ESI GROUP) and ABAQUS (Dassault Systems). Both of them use the explicit integration scheme. Solver of PAM COMFORT is based on PAM CRASH explicit integration scheme and is optimized for comfort static simulations.

For static loading cases there is possible to use implicit integration scheme. For non-linear materials, difficult contact cases, the simulation of fatigue behavior, features with full physical approach the explicit scheme is more useful. The Kelvin rheological model is used for both solvers (Fig. 5)

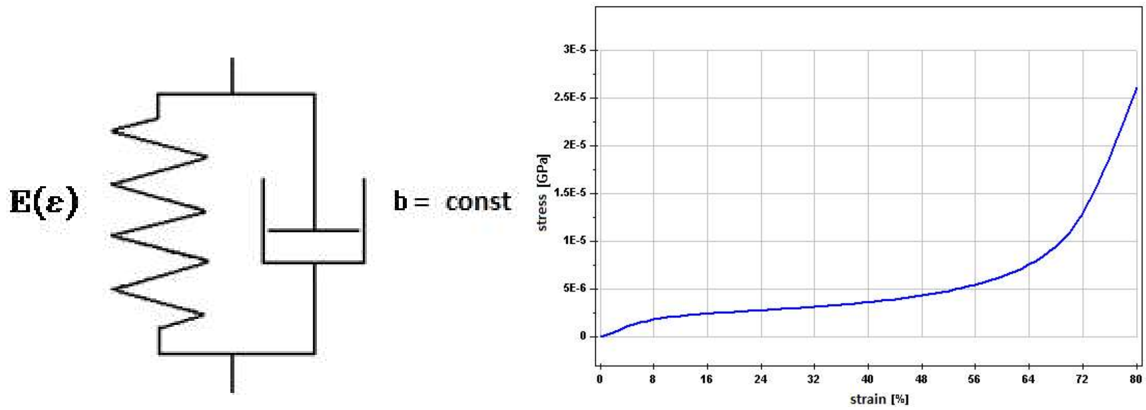

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Fig. 5: *Kelvin rheological model, input static characteristic for compression*

This material model contains non-linear spring with $E(\varepsilon)$ characteristic and linear constant dashpot b. Final response of the system is

$$\sigma = E(\varepsilon)\varepsilon + b\dot{\varepsilon} \tag{1}$$

The input static compression characteristic is the result of permanent strain loading after relaxation interval.

3 Simulation of the static loading with circular indentor

The standardized indentor with diameter 200 mm is used. The description of the test measurement is in Fig 6. The movement of the indentor is only in z axis and the maximum intrusion into the foam is 35 mm (Fig. 6).

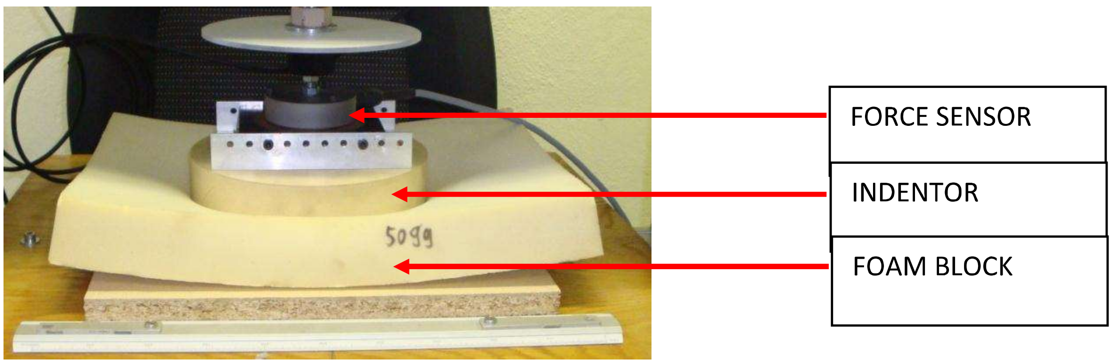

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Fig. 6: *Static loading case of the foam block with indentor*

There are two defined contacts (the first between indentor and foam skin, the second between foam skin and lower plate). The lower plate is fixed in all degrees of freedom. The movement of the indentor is only in z axis free, all other movements and rotations are locked. The lower plate and indentor are defined as the rigid body. There are the same initial and boundary conditions as in a real measurement. The results of the stages of simulations in ABAQUS and PAM COMFORT are shown in Fig. 7.

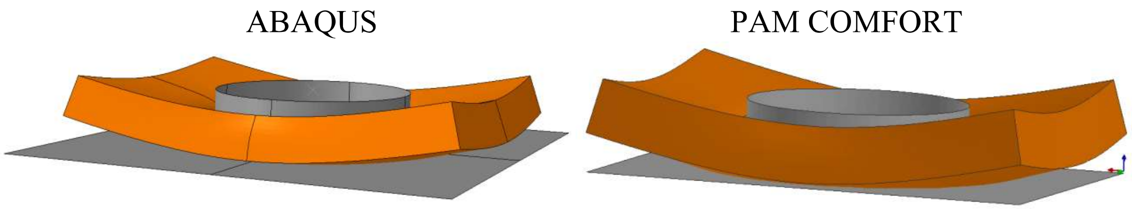

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Fig. 7: *ABAQUS and PAM COMFORT results stage with 35mm intrusion of the indentor*

The simulation results show a satisfied correlation with real measurement for both solvers (Fig. 8).

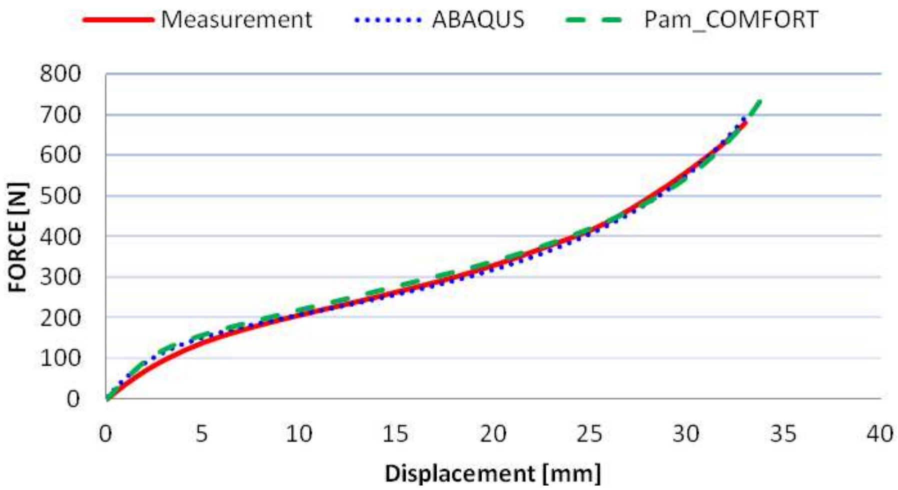

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Fig. 8: *Simulation results of ABAQUS and PAM COMFORT with indentor loading*

The differences between simulation and measurement results should be caused by discreteness of used mesh. The indentor has sharp edges, where during contact between indentor and foam block are generated peak of contact pressure. Those areas are subjected to contact perforation or penetration.

4 Simulation of the static loading with hard dummy

The hard dummy with standardized shape of pelvis and femur is used for static loading (Fig. 9, 10). The same foam block is used for loading with indentor (diameter 200 mm) and hard dummy. In this loading case a pressure distribution sensor was included into the contact area between hard dummy and foam block.

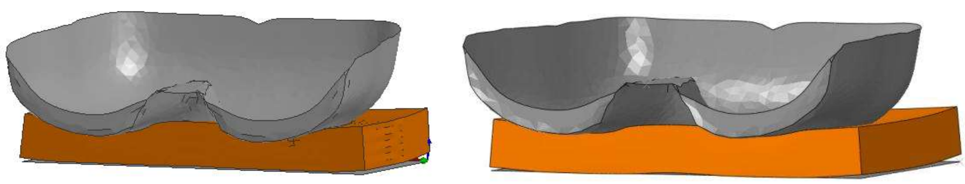

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Fig. 9: *ABAQUS and PAM COMFORT results stage with 35mm intrusion of the indentor*

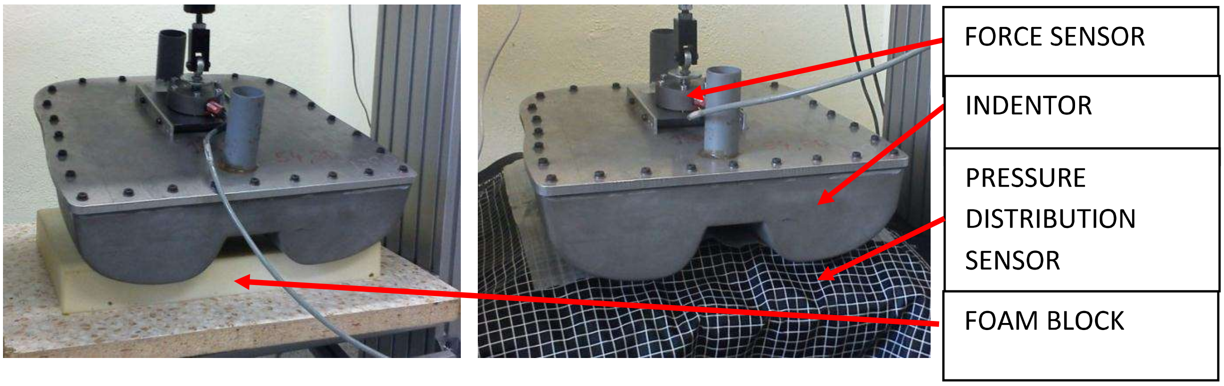

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***Fig. 10:** Static loading case with hard dummy, pressure distribution sensor included*

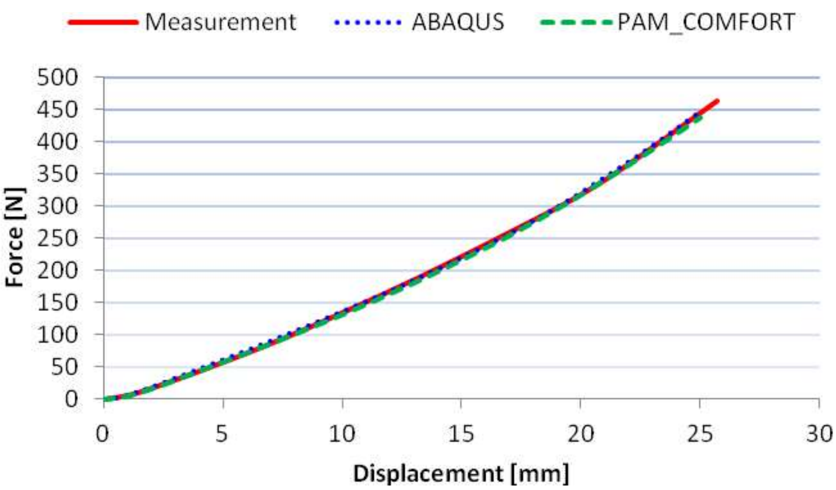

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***Fig. 11:** Simulation results of ABAQUS and PAM COMFORT with hard dummy loading*

The simulation results (Fig. 11) show a satisfactory correlation with real measurement for both solvers. The hard dummy has no sharp edge; the results are much closer to the reality (measurement curve). The pressure distribution in the contact area between hard dummy and foam block shows Fig. 12. The first pressure map is the measurement in maximum intrusion (25 mm). The second represents the Pam Comfort result. There is a special feature in Pam Comfort to simulate the sensor measurement cause of interpolation of the active areas on the sensor. The third picture is contact pressure contour directly on foam block in Abaqus. The results from Pam Comfort are closer the measurement.

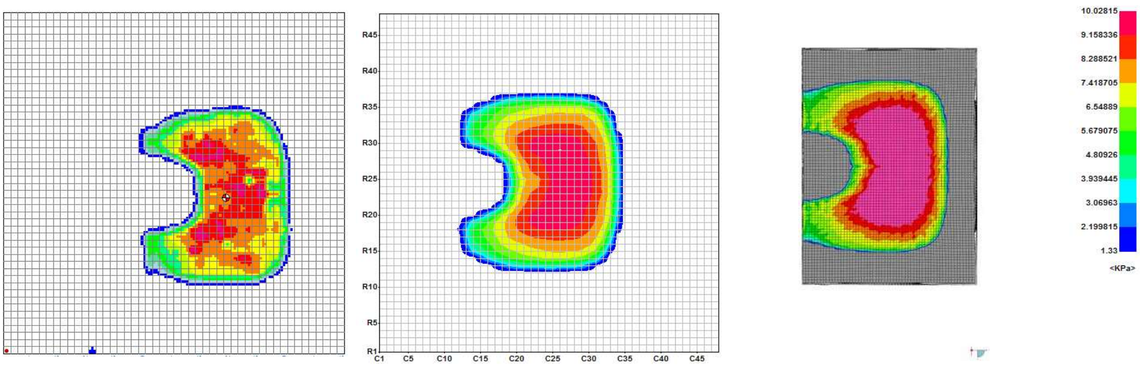

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***Fig. 12:** Pressure distribution of measurement, PAM COMFORT and ABAQUS simulations*

Conclusion

The nonlinear static characteristic is very suitable for a sitting human body. The first elastic zone of the static characteristic represents the high stiffness and the second is suitable for low peaks in terms of pressure distribution peaks. It is possible to simulate the static loading by using the specific methodologies of material model configuration. The simulation results show the possibility of static loading and pressure distribution prediction. It is possible to simulate static loading of polyurethane foam block in both simulation environment. Pam Comfort will be more suitable for full physical approach in complete seat simulations. It is possible to include pre-stressed covering material, use the standardized dummy to H-point position simulation (Fig. 13).

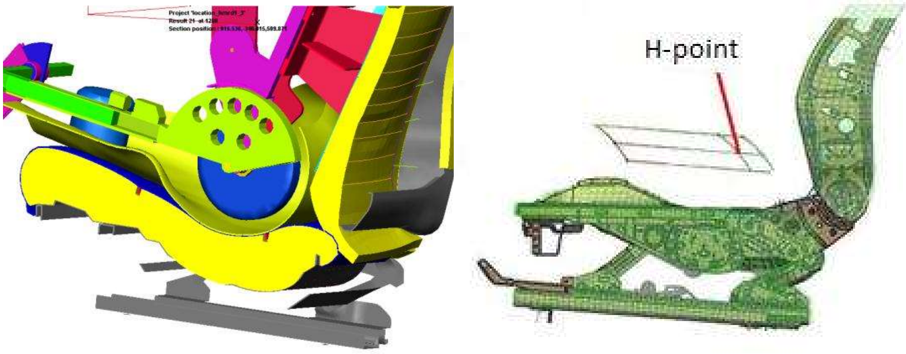

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Fig. 13: *PAM COMFORT possibilities of simulation of H-point achievement*

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SIMULACE STATICKÉHO ZATĚŽOVÁNÍ POLYURETANOVÉ PĚNY

Komfortní vrstva sedaček je ve většině případů vyplněna polyuretanovou pěnou. Rovnovážná poloha lidského těla na automobilové sedačce představuje statické namáhání polyuretanového bloku. Díky simulacím lze predikovat výslednou polohu lidského těla, která je důležitá kvůli prvkům pasivní bezpečnosti, jako jsou např. airbagy. Tento článek popisuje měření a simulaci statického namáhání bloku pěny kruhovým indentorem, tuhou figurínou a porovnává dvě simulační prostředí. Analýza statických zkoušek je určena průběhem zdvihu na síle a rozložením tlaku v kontaktní zóně. Materiálové modely polyuretanové pěny lze následně použít pro model kompletní sedačky a simulaci dosažení H-bodu podle EHK17. Velkou část optimalizace mechanických vlastností komfortní vrstvy lze provést v simulačním prostředí a tím ušetřit náklady na výrobu prototypů sedaček.

SIMULATION EINER STATISCHEN BELASTUNG VON POLYURETHANSCHAUM

Die Komfortschichten der Sitze sind in den meisten Fällen mit Polyurethanschaum gefüllt. Die Gleichgewichtslage des Körpers auf dem Sitz bedeutet eine statische Belastung für den Polyurethan-Block. Mit Simulationen kann man die endgültige Position des menschlichen Körpers vorhersagen, welche für die passiven Sicherheitsfeatures wie z.B. Airbags wichtig ist. Dieser Artikel beschreibt die Messung und Simulation der statischen Belastung des Blockschaums durch einen kreisförmigen Eindringkörper sowie durch einen Hart Dummy und vergleicht zwei Simulationsumgebungen. Die Analyse der statischen Tests wird durch den Hub auf der Kraft- und Druckverteilung in der Kontaktzone bestimmt. Polyurethan-Schaumstoff-Modelle können dann zur Modellierung und Simulation des kompletten Sitzes sowie zur H-Punkt-Leistung gemäß EHK17 verwendet werden. Ein großer Teil der Optimierung der mechanischen Eigenschaften der Komfortschicht kann in der Simulationsumgebung durchgeführt werden und damit können Kosten für Prototypensitze eingespart werden.

SYMULACJA STATYCZNEGO NACISKU NA PIANKĘ POLIURETANOWĄ

Warstwa poduszki siedziska jest w większości przypadków wypełniona pianką poliuretanową. Równowagowa pozycja ciała człowieka na fotelu samochodowym wywiera statyczny nacisk na część poliuretanową siedziska.. Dzięki symulacjom można przewidywać ostateczną pozycję ciała człowieka, która jest ważna pod względem elementów bezpieczeństwa pasywnego, takich jak np. poduszki powietrzne. W niniejszym artykule opisano pomiary i symulacje statycznych nacisków na część siedziska wypełnioną pianką, przeprowadzone przy pomocy okrągłego wgłębnika i sztywnego manekina, oraz jednocześnie porównano te dwa środowiska symulacyjne. Analiza badań statycznych przeprowadzana jest pod kątem przebiegu działania siły oraz rozmieszczenia nacisku w strefie kontaktu. Modele z pianki poliuretanowej mogą być następnie wykorzystane do projektowania całego fotela samochodowego i symulacji osiągnięcia punktu H według normy EHK17. Optymalizację właściwości mechanicznych warstwy poduszki siedziska można w dużym stopniu przeprowadzać w środowisku symulacyjnym, oszczędzając tym samym wydatki na produkcję siedzisk prototypowych.