ACTIVE ADJUSTABLE SYSTEM OF CAR SEAT SUPPORT FOR CONTROLLED REDUCTION OF VIBRATIONS

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Abstract

For many years an effective design of car seat vibro-insulation has been an unsolved problem, which affects the feeling of security and quality of sitting. This problem is currently much more demanding, due to the requirements to use low-power recycled materials, and to reduce the seat weight. A dynamic system "driver – seat" has a very low resonant frequency, which makes it challenging to set the optimal vibro-insulation properties. Possible solutions of this complex problem consist of replacement of the current passive elastic support of seat by an actively controlled system with a visco-elastic composite support. For this purpose the design of an actively controlled system of reinforcements was carried out. To assess the load capacity, stability and distribution of major stresses in the active adjustable supports, FE model simulations were performed.

Introduction

The design of the existing car seat basically consists of three parts, i.e. the frame of the seat and backrest, its comfortable layers, headrest, and additional parts, such as plastic covers, gears, seat traces, etc. The current development of vehicles pushes car producers to reduce the weight, replace the polyurethane foam by other recycled material [1], [2], and also to reduce unwanted mechanical vibrations. The principle is in the weight reduction of all components and parts of the car, which in sum leads to a significant reduction of the whole car weight. The European Union's Directive 2000/53/EC from 1st January 2015 [3] requires for the automotive industry that reuse and recovery shall be increased to a minimum of 95% by an average weight per vehicle and year. Within the same time limit, the re-use and recycling shall be increased to a minimum of 85% by an average weight per vehicle and year. From the weight reduction of the existing seat with a passive elastic support it was found that a significant damping of mass cannot be achieved due to the current requirements of the car seat development. Therefore, it is necessary to use the active damping control of the seat [4], [5], [6] that would not only increase the seating comfort, but also the safety of passengers. Basically, only comfortable stuffing cannot dissipate the whole amount of the ingoing vibrations energy transformed by a seat frame, which is subsequently absorbed by the body mass. A possible solution to improve the vibro-insulation properties, with respect to the requirements of the Directive 2000/53/EC, may be an active system of the active adjustable seat reinforcement, which will be controlled with dependence on the load weight. The main aim of this work was to design and realize a controlled system consisting of visco-elastic composite textile [7], which will create a seat reinforcement, and also reduce the seat frame construction. To assess the capacity, stability and distribution of the principal stress in active adjustable reinforcement a dynamic simulation model in FEM was performed because functional prototypes can be evaluated and optimized by this method [8],[9].

1 Materials and methods

1.1 Theory

The application of an incorporation of the visco-elastic composite reinforcement in the construction of a car seat, which would ensure the loading function and possibility to place the comfortable cushion, is not so problematic [7]; it is much more difficult to find its control for the appropriate human load. For that purpose, three possible alternatives of the construction design of active adjustable visco-elastic reinforcement were suggested (Fig. 1).

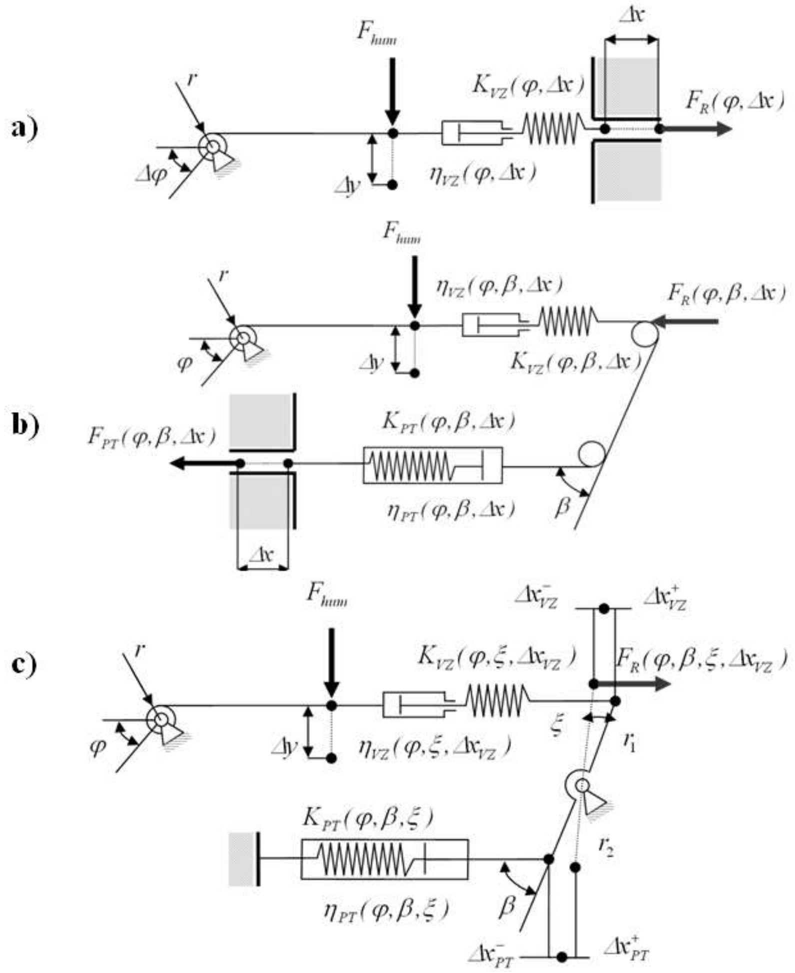

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Fig. 1: *Design of mechanical models of active adjustable regulation of seat reinforcing*

Fig. 1 a) shows the scheme of a mechanical model of the loaded visco-elastic reinforcement by the force F_{hum} corresponding to human body load. The reinforcement is expressed by the serial connection of the spring – dashpot, which corresponds to the rheological Maxwell model. The control is performed mechanically or electromechanically by the stretching of the reinforcement. The reinforcement is on one side controlled on the initial stiffness by a rotary or sliding member that preloaded spring about rotation angle φ. On the opposite side the spring is tensioned by a slide member about the value Δx. The required reaction control force F_R must be in equilibrium with the applied force F_{hum}, which compressed the reinforcement about the value Δy. This follows from the principle of virtual works (1)

$$\delta W = \sum_{i=1}^{n} \delta W_i = \sum_{i=1}^{n} F_i \cdot \Delta r_i = 0 \qquad (1)$$

where δW is virtual work, F_i is component of the applied force, and Δr_i is component of the resulting virtual displacement.

In Fig. 1 b) and 1 c) are given alternative solutions, which additional mechanisms use for regulation. It is the pulley (1 b) or crank mechanism (1 c) operated by the actuator. These systems of active reinforcement allow setting of the optimal seat stiffness in the low resonant frequencies. The results of proposed solutions affecting the total stiffness of the seat are shown in the graph (Figure 2). Optimal active control of the seat should allow adjusting the stiffness characteristics. From the courses in Figure 2 it is seen that these requirements are met when introducing the solution no. 3.

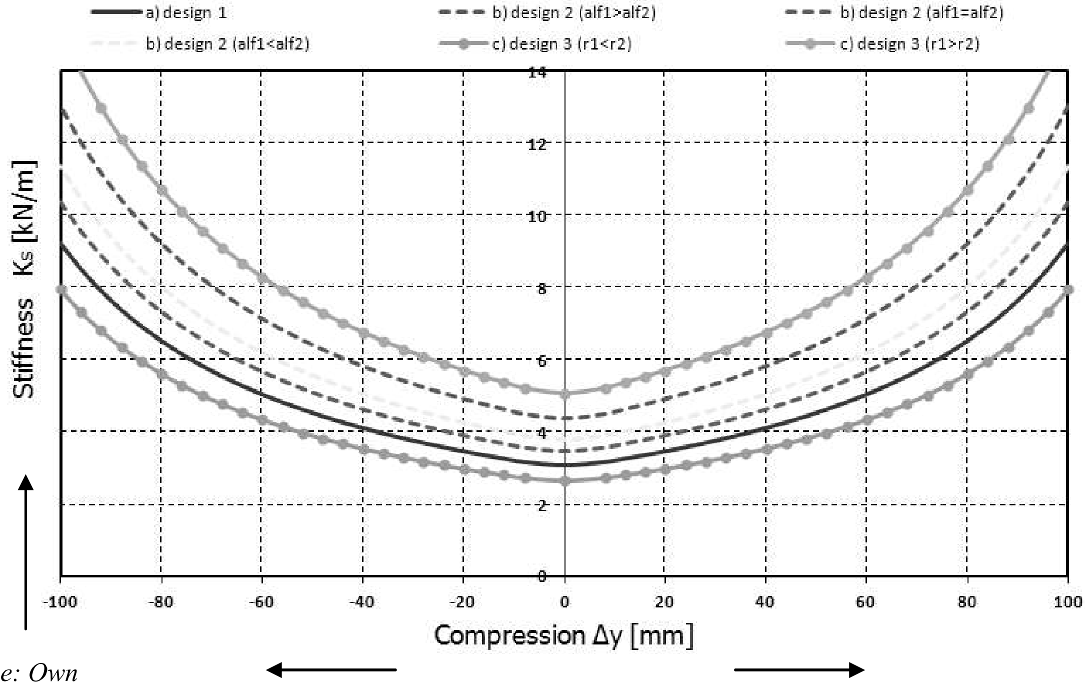

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Fig. 2: *Resulting courses of dependence of stiffness on compression*

It is important that the elasticity component of visco-elastic reinforcement is not significantly higher than the dumping ability because it can lead to vibrations similar to the tensioned string as reported in [10], which would be inappropriate for the final. Therefore it is necessary to include the elastic $\varepsilon_{Kvz}(t)$ and viscous component $\varepsilon_{\eta vz}(t)$ for the description of a variable strain rate of reinforcement ε_{KV}. By analogy, in the case of strain rate the situation can be described as (2).

$$\varepsilon_{VZ}(t) = \varepsilon_{Kvz}(t) + \varepsilon_{\eta vz}(t)\,,\ \dot{\varepsilon}_{VZ}(t) = \dot{\varepsilon}_{Kvz}(t) + \dot{\varepsilon}_{\eta vz}(t) \qquad (2)$$

Obviously, the elastic force of the reinforcement $F_{Kvz}(t, m) = K_{VZ} \cdot \Delta y(t)$, elastic stress in visco-elastic reinforcement $\sigma_{Kvz}(t, m) = E_{VZ} \cdot \varepsilon(t)$ and also damping force is $F_{\eta vz}(t, m) = \eta_{VZ} \cdot \Delta y(t)$ and therefore the damping stress in the visco-elastic reinforcement is $\sigma_{\eta vz}(t, m) = \eta_{VZ} \cdot \varepsilon(t)$, where E_{VZ} expresses the elasticity modulus. Then the rate of deformation of visco-elastic reinforcement $\dot{\varepsilon}_{VZ}(t)$ is expressed by the equation (3). If we introduce $\theta = 1$, $\theta_1 = 1/E_{VZ}$, $\theta_2 = 1/\eta_{VZ}$ then we can express the strain rate of the visco-elastic reinforcement by the following parametric equation (3).

$$\theta \cdot \dot{\varepsilon}_{VZ}(t) = \theta_1 \cdot \dot{\sigma}_{VZ}(t) + \theta_2 \cdot \sigma_{VZ}(t) \tag{3}$$

where $\sigma_{VZ}(t)$ is total stress in visco-elastic reinforcement, $\dot{\sigma}_{VZ}(t)$ is a total stress rate in visco-elastic reinforcement.

In accordance with the established relations (2) and (3) the principle of virtual work for a contribution of external and internal forces of the deformed body (4) can be extended

$$\delta W = \sum_{i=1}^{n} \delta W_{ext} + \sum_{i=1}^{n} \delta W_{\text{int}} = 0 \tag{4}$$

where δW_{ext} is the contribution of external forces, δW_{int} is the contribution of internal forces, while $\text{sgn}(\delta W_{int}) = -\text{sgn}(\delta W_{ext})$.

1.2 The Design

According to the proposed variant no. 3 the design of the adjustable active reinforcement which will replace an existing cushion support was prepared. The construction solution is shown in Figure 3.

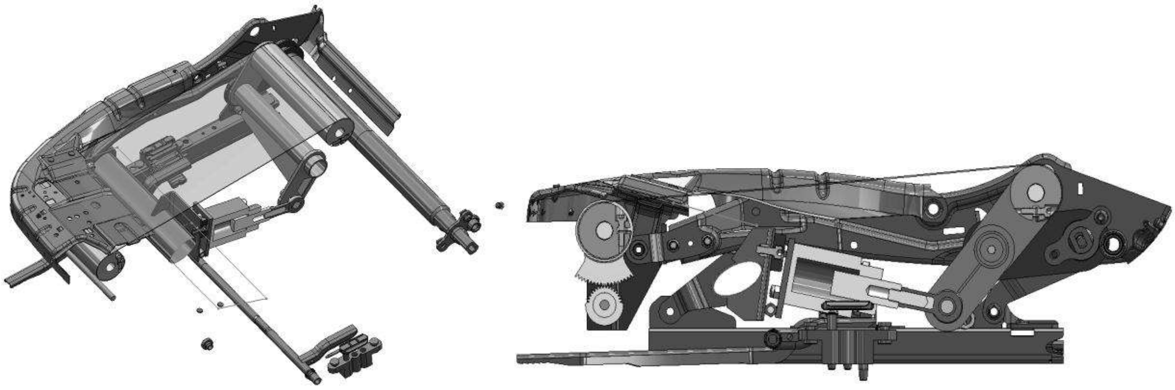

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Fig. 3: *Construction solution of active adjustable reinforcement*

1.3 FEM simulation

For the assessment of the stability and tension in the active adjustable reinforcement loaded by a human body, the FEM simulations were performed before the implementation of the prototype. In the model some parts of the seat frame and the regulation of visco-elastic reinforcement systems were left out (rotary and sliding members, flexible damping elements, etc.), as they are not important for the assessment of the tension in the reinforcement. It also results in the reduction of the calculation time. The FEM model is defined by the material properties, which were published in [7]. The initial and boundary conditions of the FEM model are based on the fact that visco-elastic of reinforcement is at first pre-stressed in the longitudinal direction on both sides by 8 mm. It corresponds with the stiffness for the optimal settlement of a virtual dummy of mass 80 kg (Fig.4).

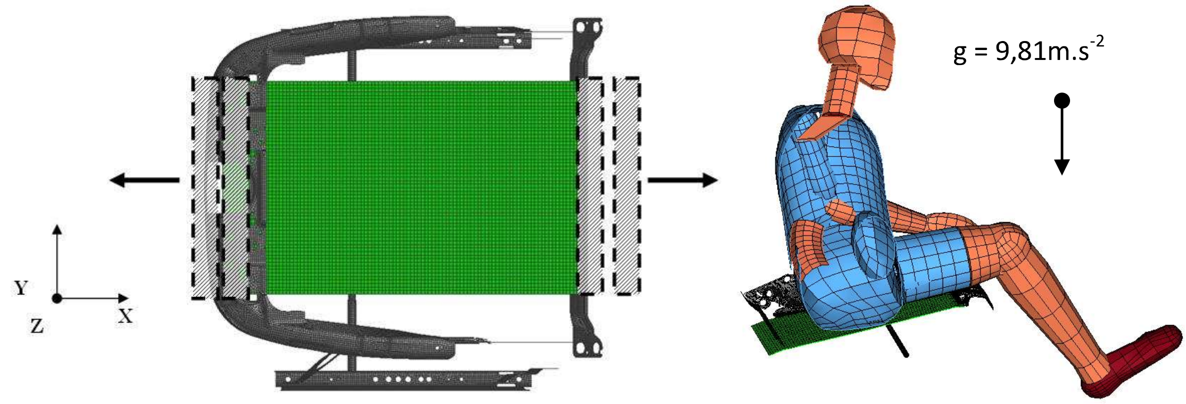

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Fig. 4: *Initial and boundary conditions of FEM model of active adjustable reinforcement*

Using the simulation it was determined that pre-stressed reinforcement with given stiffness will be elongated by 30 mm in the principal direction of the load, which is shown in Fig. 5, and the maximum principal stress value reached in the longitudinal direction is 2.715 N/mm and in perpendicular direction it is 0.576 N/mm.

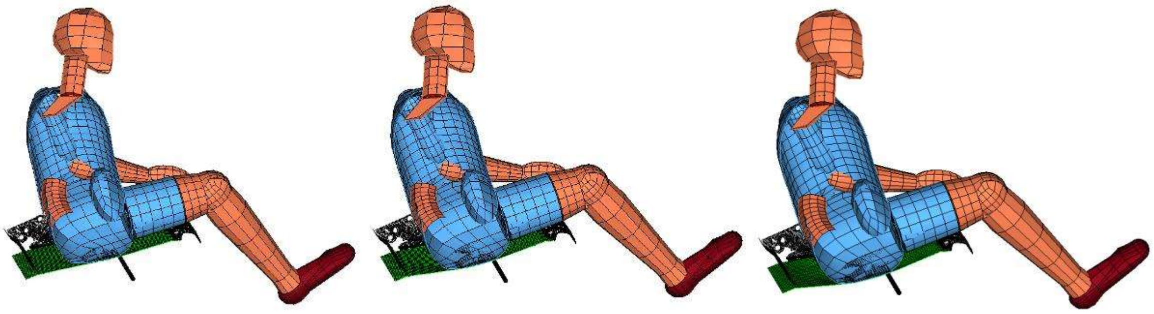

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Fig. 5: *Gradual loading of the active adjustable reinforcement*

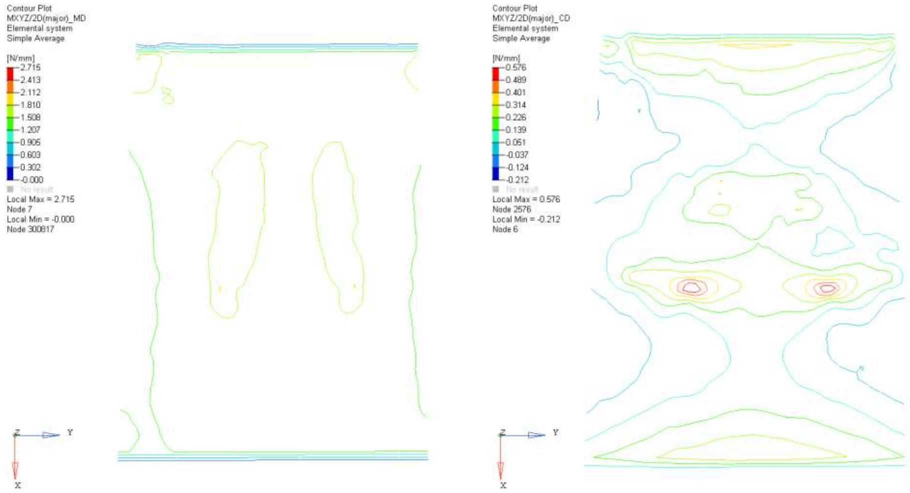

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Fig. 6: *Principal stresses in reinforcement: in longitudinal direction, in perpendicular direction*

2 Result and discussions

According to the design (Fig. 3) and the results of the model simulations, a functional model was realized for the subsequent experiments, testing and comparing with the currently produced car seat. The realization of the function model and a comparison with the currently produced car seat is shown in Fig. 7.

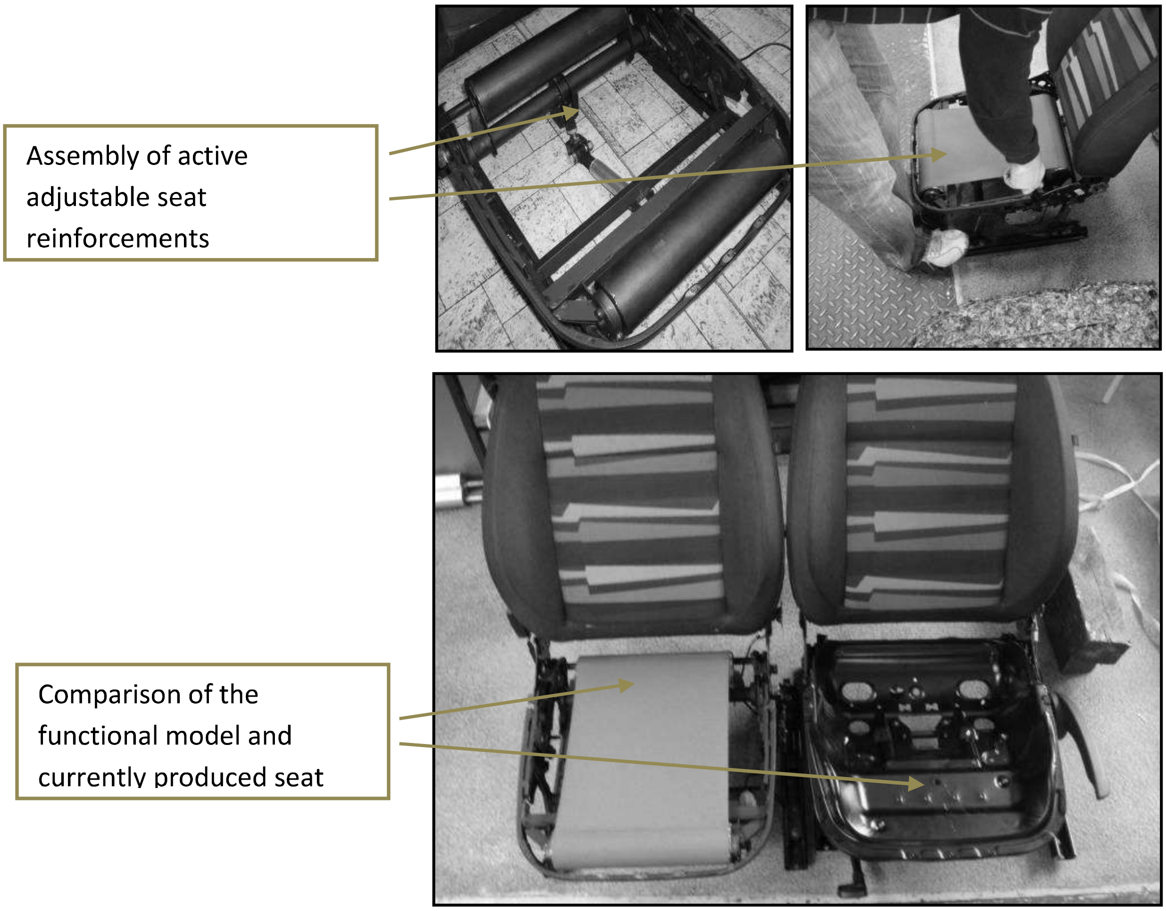

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Fig. 7: *Realization of function model of active adjustable reinforcement*

Conclusion

This article deals with the construction design of active adjustable reinforcement for controlled reduction of vibrations. Models of the regulation solution of viscoelastic reinforcement were designed (Fig. 1) that led to the selection of the suitable solution 1 c). This allows setting the desired stiffness of the visco-elastic reinforcement for a given load. Before the realization of the functional model, the FEM simulation of the adjustable active reinforcement of the seat was established. The applied load of a virtual dummy was 80 kg (Fig. 4). The results showed that under given pre-stressing the virtual dummy can sit and that the resulting maximal load of 2.715 N/mm (Fig. 6) was low enough with respect to the maximum strength of the reinforcement [6], [11]. These results led to the realization of the functional model of the new seat with adjustable active reinforcement (Fig. 7). In general, it can be concluded that the visco-elastic reinforcement might replace the metal sheet support of the seat. In addition, together with the regulation the setting of the stiffness for the corresponding load while driving could be achieved.

Acknowledgements

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KONSTRUKČNÍ SYSTÉM AKTIVNÍ REGULOVATELNÉ VÝZTUHY SEDÁKU AUTOSEDAČKY PRO ŘÍZENÉ SNIŽOVÁNÍ VIBRACÍ

Účinná vibroizolace konstrukce automobilové sedačky je po řadu let nedořešený konstrukční problém, který ovlivňuje pocit bezpečnosti a kvality sezení. Tento problém je v současné době výrazně ztížen požadavky na aplikaci energeticky nenáročných recyklovaných materiálů a snížení stávající hmotnosti. Dynamická soustava sedačka - řidič má velmi nízkou rezonanční frekvenci, která ztěžuje optimální vibroizolační vlastnosti. Možností řešení tohoto komplexního problému je konstrukční úprava stávajícího řešení konstrukce sedáku s pasivní elastickou výztuhou za konstrukční systém aktivní regulace výztuhy, která bude z kompozitní viskoelastické výztuhy. Byly provedeny návrhy systému aktivní regulace výztuhy konstrukce sedáku. Pro posouzení nosnosti, stability a rozložení hlavních napětí v aktivní regulovatelné výztuze byly provedeny modelové simulace v MKP.

KONSTRUKTIONSSYSTEM DER AKTIVEN REGULIERBAREN SITZSTREBE IN AUTOSITZEN FÜR EINE GELENKTE SENKUNG DER VIBRATION

Eine wirksame Vibrationsisolation der Konstruktion von Automobilsitzen ist seit einer Reihe von Jahren ein ungelöstes Konstruktionsproblem, welches das Gefühl von Sicherheit und Sitzqualität vermindert. Dieses Problem wird derzeit erheblich durch die Forderung nach Anwendung von energetisch anspruchslosen rezyklierten Materialien und nach Herabsetzung der bestehenden Masse erschwert. Der Fahrer hat eine sehr niedrige Resonanzfrequenz, welche die optimalen die Vibration isolierenden Eigenschaften belasten. Eine Möglichkeit der Lösung dieses komplexen Problems besteht in der Ausstattung der bestehenden Lösung der Sitzkonstruktion mit einer passiven elastischen Strebe anstelle des Konstruktionssystems der aktiven Regulierung der Strebe, welche aus kompositorischen viskoelastischen Streben zusammengesetzt ist. Es werden Vorschläge zu einem System aktiver Regulierung von Streben in der Sitzkonstruktion ausgeführt. Für die Beurteilung der Tragfähigkeit, der Stabilität und der Verteilung der Hauptspannungen in der aktiven regulierbaren Strebe wurden Modellsimulationen im MKB durchgeführt.

KONSTRUKCYJNY SYSTEM AKTYWNEGO MOŻLIWEGO DO REGULACJI WYPEŁNIENIA SIEDZISKA FOTELU SAMOCHODOWEGO W CELU KONTROLOWANEGO ZMNIEJSZENIA WIBRACJI

Skuteczna wibroizolacja konstrukcji fotelu samochodowego stanowi od wielu lat nierozwiązany w pełni problem konstrukcyjny, który wpływa na poczucie bezpieczeństwa i komfort siedzenia. Problem ten jest obecnie jeszcze poważniejszy w wyniku wymagań co do stosowania energetycznie niewymagających materiałów podlegających recyklingowi oraz zmniejszenia istniejącej masy. Dynamiczny zespół siedzisko – kierowca ma bardzo niską częstotliwość rezonansową, która utrudnia optymalne właściwości wibroizolacyjne. Możliwym rozwiązaniem tego kompleksowego problemu jest konstrukcyjna zamiana istniejącej konstrukcji siedziska z pasywnym elastycznym wypełnieniem na system konstrukcyjny aktywnej regulacji wypełnienia, które będzie z kompozytowych wiskoelastycznych materiałów. Zaprojektowano system aktywnej regulacji wypełnienia konstrukcji siedziska. W celu oceny nośności, stabilności i rozkładu głównych naprężeń w aktywnym, możliwym do regulacji, wypełnieniu przeprowadzono modelowe symulacje w MKP.