

On the Contact Interfaces between the Driver and the Vehicle Seat

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ABSTRACT

In mathematical and mechanical modeling terms, automotive seating is characterized by boundary conditions at the nonlinear contact interfaces. These contact interfaces are subjected to vibro-impacts (slaps) and frictional slips. The slaps occur in contact interfaces at high amplitude vibrations, being characterized by very short duration, rapid dissipation of energy and large accelerations and decelerations. By considering friction in contact interface modeling, the simulation of the interaction between the driver and the vehicle seat becomes more realistic. Vibro-impacts and frictional slips can be simultaneously developed in a contact surface. The boundary conditions identification for a seat and a wide range of drivers' body types is performed using the concept of interference distance or penetration. The interference distance is introduced as an optimization problem. It is shown that the optimization problem provides robust solutions to minimum distance and interference problems.

CITATION: Munteanu, L., Dumitriu, D., Chiroiu, V. and Delsanto, P., "On the Contact Interfaces between the Driver and the Vehicle Seat," *SAE Int. J. Passeng. Cars - Mech. Syst.* 6(2):2013, doi:10.4271/2013-01-0455.

INTRODUCTION

The driver's comfort/discomfort evaluation depends on the interaction between seat properties, driver characteristics, environmental conditions and the driver-seat system. When the slip and vibro-impact mechanisms are simultaneously developed, the picture of normal forces at the contact interface is changed, as shown by Jalali et al. [1] when investigating the micro-vibro-impacts of a clamped Euler-Bernoulli beam at boundary conditions. Thus, the impact mechanism affects the frictional slip mechanism when they simultaneously develop in a contact interface. Karnopp [2] describes the friction as a function of the relative velocity, while Menq et al. [3] have introduced a modified micro-slip model in terms of an elasto-plastic shear layer. Comprehensive investigations of contact friction and vibro-impact mechanism developing in contact interfaces subjected to high amplitude vibrations have been performed by Ferri [4], Berger [5] and Gilardi and Sharf [6]. In automotive seating, the road and vehicle engine conditions are transferred into the body through the seat. Most car seats have fore-and-aft adjustment, as well as adjustable seat back inclination, ensuring an acceptable position for a range of drivers as wide as possible (Jonsson [7]). Such a seatback with seat pan

inclination is shown in [Figure 1](#) (Harrison et al. [8]). The position of the driver is essential to his/her driving performance and safety, e.g., neck injuries still pose serious problems in rear-end collisions.

So, this article concerns the design of car seats which must fit the drivers individually while covering a wide range of body types. A main issue in seat design is determining the contact forces and contact domains, as well as the propagation of these forces into the human body. Several research studies have been made to understand how impacts propagate in the contact domains (Emaci et al. [9], Moon. and Shawand [10] and Yang and Begeman [11]).

A continuous approach of the vibro-contact dynamics is developed in this paper by admitting there is an explicit relationship between contact force and deformation. In this continuous approach, no difference is made between impact and contact, therefore the methods of non-impact dynamics can be used to solve the problem. An advantage of the continuous approach over a discrete formulation is that it allows the application of the theory to multi-contact situations, as it is the case for the flexible human body (multi-body system). The use of Coulomb's law is consistent in the continuum approach and does not lead to multiple solutions

like the discrete approach. Moreover, the continuum theory can adopt any other friction model. The friction force is considered a combination of forces resisting motion, during various energy conversion processes (elastic/plastic contacts, viscous dissipation, fracture, adhesion).

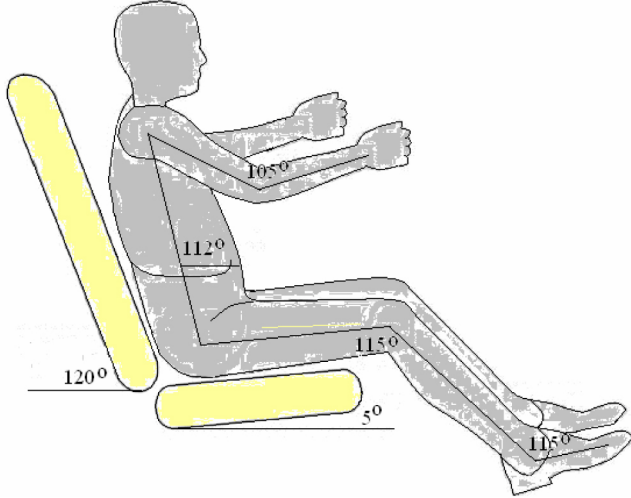


Figure 1. A generic seatback.

In what concerns the identification of the nonlinear boundary conditions, it can be performed based on the concept of interference distance or penetration. This concept defines the contact force, which in turn depends on the deformation at the contact interface. Impacts between bodies are generally defined by the condition of impenetrability (Kim [12]), because contact can be determined by checking the minimum distance between bodies. More precisely, the contact point is the point where the minimum distance is reached [6], as expressed by:

$$\min\left(\frac{1}{2}(p_1 - p_2)^T(p_1 - p_2)\right), \quad f_1(p_1) \leq 0, \quad f_2(p_2) \leq 0, \quad (1)$$

where p_1 and p_2 are the position vectors of two points on the two bodies and f_1 and f_2 are bounding surface constraints. To define the contact force, the interference distance can be computed as:

$$\min(-d), \quad f_1(p_1) \leq -\frac{d}{2}e_1, \quad f_2(p_2) \leq -\frac{d}{2}e_2, \quad (2)$$

where d is the interference distance and e_1 and e_2 are the unit vectors.

PROBLEM FORMULATION AND SOLUTION

The driver's back surface is modeled as a doubly curved thin shell of thickness h and the principal radii of curvature R_1 and R_2 , as shown in Figure 2. The reference surface area is

denoted by Ω . An inertial frame of reference is defined by three mutually orthogonal unit vectors i_1, i_2, i_3 . The position vector of one point of the shell can be expressed as:

$$R(\xi_1, \xi_2, \zeta) = r_0(\xi_1, \xi_2) + u(\xi_1, \xi_2) + \zeta E_3(\xi_1, \xi_2), \quad (3)$$

where ξ_1, ξ_2 are the material coordinates (the lines of curvatures of the shell reference surface), ζ is the material coordinate along the normal to the reference surface $n = e_3$, r_0 is the position vector of point P_0 on the reference surface of the shell, where the shell has a contact boundary condition, and u is the reference surface displacement vector. E_3 is a unit vector, E_1, E_2 and are the axial and transverse shearing strains developed during deformation.

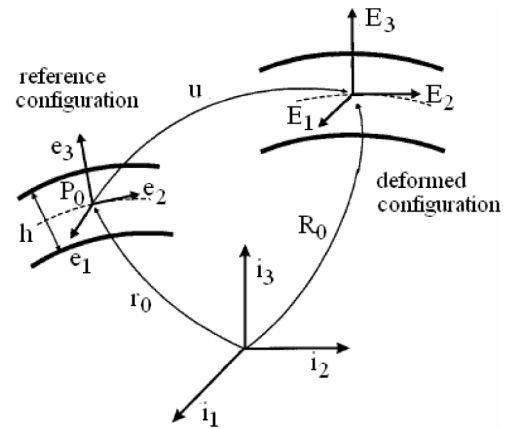


Figure 2. Reference and deformed configurations of the shell modeling the driver's back.

The unknown driver-seat contact domain D_c can be described by the Lamé curve:

$$\left(\frac{x}{a}\right)^n + \left(\frac{y}{b}\right)^n = 1, \quad n > 0, \quad (4)$$

where a and b are the radii of the oval shape. The parametric representation of (4) is:

$$x(\theta) = a \cos^{2/n} \theta, \quad y(\theta) = b \sin^{2/n} \theta. \quad (5)$$

The integral motion equation is obtained by applying the Hamilton principle (Bauchau and Choi [13]). It results:

$$\int_{t_1}^{t_2} \int_{\Omega} \left\{ \delta u (\dot{g}_1 - N_{1,1} - N_{2,2} + F_c) + \delta E (\dot{g}_2 - M_{1,1} - M_{2,2}) \right\} d\Omega dt = 0, \quad (6)$$

where g_1, g_2 are the linear and angular momentum vectors of the shell, N_1, N_2 are spatial in-plane forces, F_c is the contact force and M_1, M_2 are the bending moments. A constant normal force P is applied to the shell at contact point P_0 . The

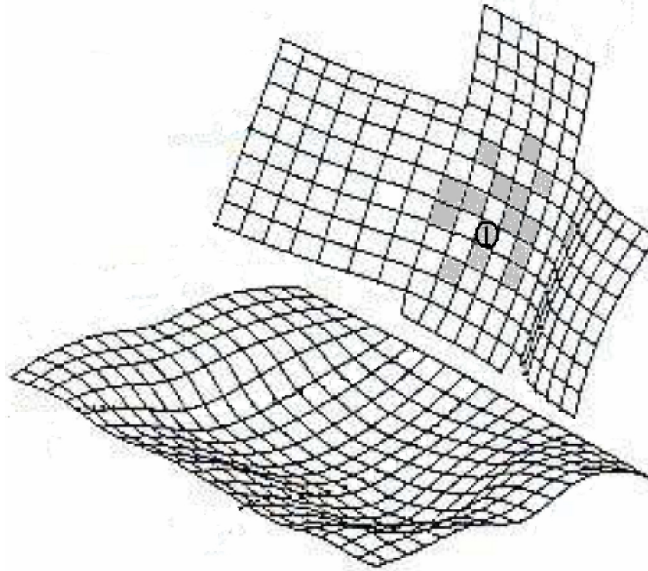


Figure 3. Contact domain D_c

shell is excited by the following forced vibrations $F(t) = f \sin(\omega t)$ with an arbitrary excitation point. Certain frequencies within the range of the resonance frequency of the human body, especially in the range of the resonance frequency of the spine, have been proven to cause low back pain. For this reason, the simulations described in this paper were performed for excitation frequencies closer to the resonance frequency of the spine, which is about 4.75-6.25 Hz (Matsumoto and Griffin [17]).

The nonlinear behavior can be spanned using its first n nonlinear normal modes. The hypothesis that each contact point allows small deflections is considered in this study. For large amplitudes of vibrations, micro-slip and micro-vibro-impact develop simultaneously in the contact interface of the shell. The associated contact force constrain F_c and the sticking constraint, respectively, are given by:

$$F_c = \varphi_c(\delta, \dot{\delta}), \quad \varphi_{st}(\xi_{1c}, \xi_{2c}, \zeta_c, F_t) = 0, \quad (7)$$

where $\delta(\xi_{1c}, \xi_{2c}, \zeta_c, \dot{\xi}_{1c}, \dot{\xi}_{2c}, \dot{\zeta}_c)$ is the local indentation function and $\xi_{1c}, \xi_{2c}, \zeta_c$ are the components of the position vector of a contact point. So, contact force F_c can be explicitly written as:

$$F_c = A\delta^n + B\delta^p\dot{\delta}^q, \quad (8)$$

where n, p, q are constants, coefficient A depends on the material and the geometric properties of the bodies in contact, and B is defined with respect to the coefficient of restitution e . These coefficients are calculated based on the viscoelastic theory. For example, $n = 3/2$ in the case of two spheres in central impact and k is defined in terms of Poisson's ratios, Young's moduli and the radii of the two spheres. The

standard values are $p = n$ and $q = 1$ [6]. In the case of central impact between two bodies, the coefficient of restitution is $e = 1 - 2B\dot{\delta}_0 / 3A$ [14]. Both coefficients also depend on the flexural and normal stiffness of the boundary condition. In the continuous model, the damping depends on indentation, since the contact area increases with deformation. The first term in (8) represents the contact constraint expressed as a functional between the contact force F_c at contact point coordinates $\xi_{1c}, \xi_{2c}, \zeta_c$ and their time derivatives. Therefore, the normal contact force F_c , given by (7)₁, depends on local indentation δ [14]. Friction F_t occurring at the contact point during sticking can be defined as (Stronge [15]):

$$F_t = C\delta_t + D\dot{\delta}_t, \quad (9)$$

where δ_t is the tangential component of displacement at the contact point, C is the tangential stiffness and D is defined with respect to the coefficient of restitution $0 \leq e \leq 1$. The energy W_r released during restitution at dynamical contact (impact) can be calculated as the negative work done by F_c during the collision:

$$W_r = - \int F_c \dot{\delta} dt. \quad (10)$$

The coefficient of restitution can be calculated as:

$$e = \sqrt{\frac{W_r}{-W_c}}, \quad (11)$$

where W_r is the energy released during restitution and W_c is the energy absorbed during compression. The unknowns of the problem are the contact vectors, the contact forces and the