

The drivers spine movement equation in the coronal plane

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Abstract—The paper presents the determination of the movement equation of the drivers spine in the coronal plane, during the drive. Using the movement equation, the spines movements in the coronal plane were simulate by using the MathCAD and CATIA software.

On this line was proposed a methodology to approach the interaction between driver and the vehicle to allow accurate conclusions for the driving activity.

Keywords—Ergonomics, spine, vehicle, simulation.

I. INTRODUCTION

RECENT years have brought the current general trend in the design, construction and operation of motor vehicles (research centers of companies producing curricula of universities / departments field, masters that include ergonomics and comfort of road vehicles, European legislation, etc.), namely the transformation of the interior components of passive elements with uncontrolled reaction to changing human factor elements able to adapt continuously.

In the current scientific and technological conditions is required reconsideration of the research, analysis and design optics of the working places by applying outstanding results obtained recently in some new areas of human activity such as systems theory, cybernetics, information theory, operational research, computer science and ergonomics.

It should be noted that if the configuration of the safety, ventilation, lighting, heating, etc..., interior equipment is analyzed and properly carried out, in terms of scientific evidence (evidence based) on the behavior of the driver's body, especially the spine with associated muscles, still requires further study which continually preoccupied car manufacturing companies.

II. DETERMINING THE MOVEMENT EQUATION OF THE SPINAL COLUMN IN THE CORONAL PLANE

Using the coordinate system shown in figure 1 it is considered that the center of each vertebra is moving along the arch of circle with center the origin of the coordinate system, and radius equal to the height above the x-axis, the seat surface. The length of each arc of circle is depending on the vehicle traveling speed and the radius of the trajectory.

In the coordinate system shown in figure 1, the sinusoidal functions are variations on the x-axis:

$$XC1_i = acp \cdot \cos(f_{\Delta t} \cdot i \cdot \pi) \quad (1)$$

$$XT4_i = aum \cdot \cos(f_{\Delta t} \cdot i \cdot \pi) \quad (2)$$

$$XL1_i = alb \cdot \cos(f_{\Delta t} \cdot i \cdot \pi) \quad (3)$$



Fig. 1. – The spine in the coronal plane related to the coordinate system xOy.

The equations of the arch on what the C1, T4 and L1 vertebrae are moving are given by the relations:

$$YC1_i = \sqrt{r_c^2 - XC1_i^2} \tag{4}$$

$$YT4_i = \sqrt{r_T^2 - XT4_i^2} \tag{5}$$

$$YL1_i = \sqrt{r_L^2 - XL1_i^2} \tag{6}$$

In the coronal plane and the coordinate system (fig. 1), the spine shape is a curved line given by the following equation:

$$y(x) = a_i \cdot x^3 + b_i \cdot x^2 + c_i \cdot x + d_i \tag{7}$$

In this equation the unknowns are: a_i , b_i , c_i , and d_i . Knowing the coordinates of four points, the unknowns a_i , b_i , c_i , and d_i are determined with the *Cramer* method:

$$\begin{cases} YC1_i = a_i \cdot XC1_i^3 + b_i \cdot XC1_i^2 + c_i \cdot XC1_i + d_i \\ YT4_i = a_i \cdot XT4_i^3 + b_i \cdot XT4_i^2 + c_i \cdot XT4_i + d_i \\ YL1_i = a_i \cdot XL1_i^3 + b_i \cdot XL1_i^2 + c_i \cdot XL1_i + d_i \\ d_i = 0 \end{cases} \tag{8}$$

Due to the fact that the origin is one of the four points results that d_i is equal to 0. So the system of equations (8) is transformed into a system of three equations with three unknowns:

$$\begin{cases} YC1_i = a_i \cdot XC1_i^3 + b_i \cdot XC1_i^2 + c_i \cdot XC1_i \\ YT4_i = a_i \cdot XT4_i^3 + b_i \cdot XT4_i^2 + c_i \cdot XT4_i \\ YL1_i = a_i \cdot XL1_i^3 + b_i \cdot XL1_i^2 + c_i \cdot XL1_i \end{cases} \tag{9}$$

$$\Delta_i = \begin{bmatrix} XC1_i^3 & XC1_i^2 & XC1_i \\ XT4_i^3 & XT4_i^2 & XT4_i \\ XL1_i^3 & XL1_i^2 & XL1_i \end{bmatrix}$$

$$\Delta a_i = \begin{bmatrix} YC1_i & XC1_i^2 & XC1_i \\ YT4_i & XT4_i^2 & XT4_i \\ YL1_i & XL1_i^2 & XL1_i \end{bmatrix}$$

$$\Delta b_i = \begin{bmatrix} XC1_i^3 & YC1_i & XC1_i \\ XT4_i^3 & YT4_i & XT4_i \\ XL1_i^3 & YL1_i & XL1_i \end{bmatrix}$$

$$\Delta c_i = \begin{bmatrix} XC1_i^3 & XC1_i^2 & YC1_i \\ XT4_i^3 & XT4_i^2 & YT4_i \\ XL1_i^3 & XL1_i^2 & YL1_i \end{bmatrix}$$

$$a_i = \frac{\Delta_i}{\Delta a_i}; b_i = \frac{\Delta_i}{\Delta b_i}; c_i = \frac{\Delta_i}{\Delta c_i}$$

Using the Mathcad software has created a program sequence which limits the curve given by the equation (7), that describes the shape of the spine in the coronal plane, between the origin and the center of C1 vertebra. The program sequence is:

$$y(x) = \begin{cases} (a_i \cdot x^3 + b_i \cdot x^2 + c_i \cdot x + d_i) & \text{if } 0 \leq \\ \leq (a_i \cdot x^3 + b_i \cdot x^2 + c_i \cdot x + d_i) \leq YC1_i & \\ (\text{break}) & \text{otherwise} \end{cases}$$

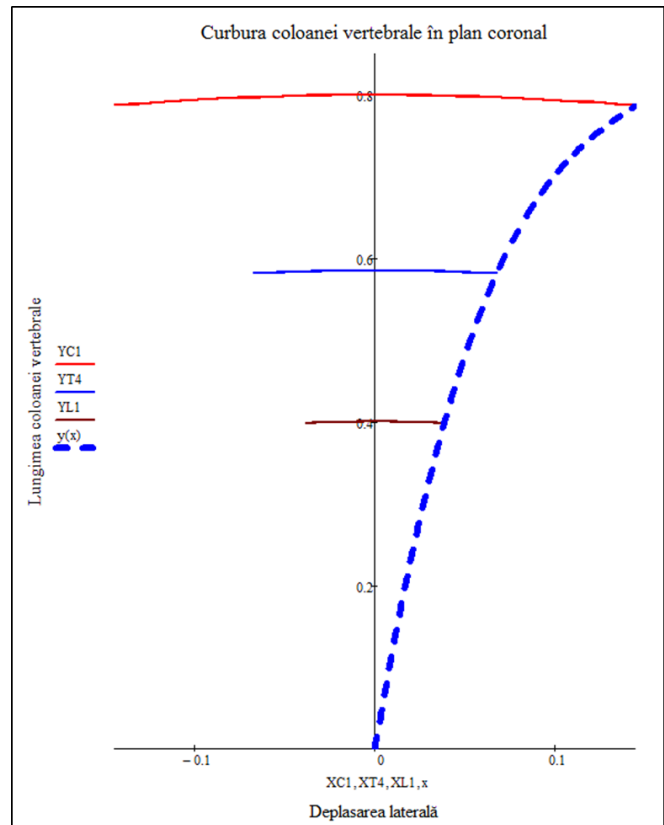


Fig. 2– The shape of spinal colume in coronal plane at the maximum right lateral tilt.

In figure 2 is shown the graph obtained with the Mathcad software in which is represented the shape of the spinal column in coronal plane at the maximum right lateral tilt, given by the equation (7). Also in this graph are the corresponding trajectory arch centers of the C1, T4, and L1 vertebrae.

III. SPINE MOTION SIMULATION USING MATHCAD SOFTWARE

Through Animation function, Mathcad software allows changes to a graphic animation using software integrated FRAME variable.

Starting from the equation (7), which describes the shape of the spine in the coronal plane between the origin and the center of C1 vertebra, was created the following sequence of program that animates the graph in figure 2.

$$y(x) = \begin{cases} (a_{FRAME} \cdot x^3 + b_{FRAME} \cdot x^2 + c_{FRAME} \cdot x + d_{FRAME}) & \text{if } 0 \leq \\ \leq (a_{FRAME} \cdot x^3 + b_{FRAME} \cdot x^2 + c_{FRAME} \cdot x + d_{FRAME}) \leq YC1_{FRAME} & \\ (\text{break}) & \text{otherwise} \end{cases}$$

In figure 3 are shown some frames from the created animation in Mathcad software.

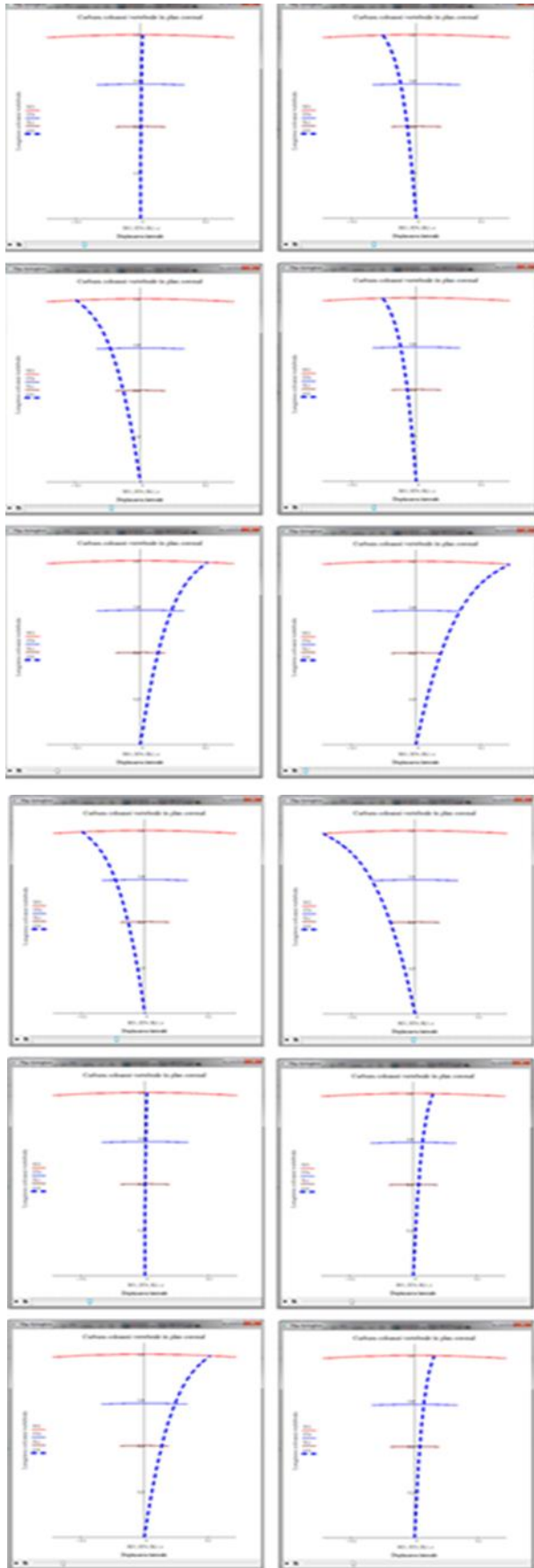


Fig. 3 – Extracted frames from Mathcad simulation.

IV. SPINE MOTION SIMULATION USING CAD SOFTWARE CATIA

Vertebrae 3D model was realized using the ATOS IIe optical high-end 3D Digitizer by 3D scanning the vertebrae from a human corpse. The digitizer uses the spatial triangulation and generates a cloud of points on the object surface. It has been obtained a cloud of points with the shape of the vertebra 3D model. The 3D model was generated by transforming the cloud in NURBS surfaces using the Geomagic Studio 3D software. Final design of the vertebrae was realized by importing these surfaces in CAD software CATIA V5.

The steps of the 3D design of vertebrae are shown in figures 4, 5 and 6.

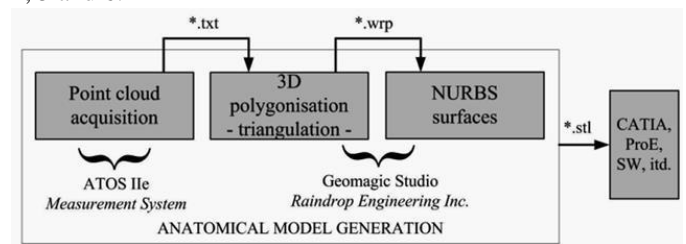


Fig. 4 – Generating anatomical model.

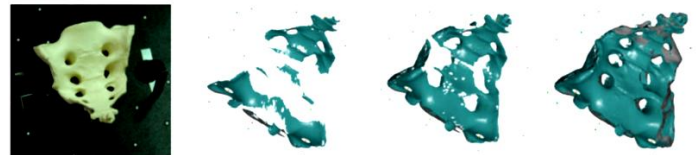


Fig. 5 – The vertebra scanning.

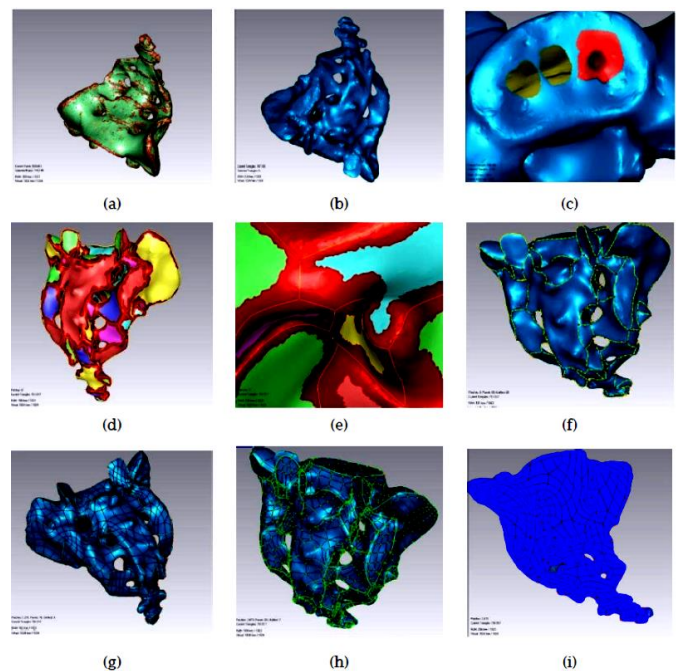


Fig. 6 – The vertebra reconstruction.



Fig. 7 – The 3D model of the spine by using CATIA.

To achieve spine motion simulation with CAD software CATIA, the DMU Kinematics module is selected. Because the simulation of the spine movement is only in the coronal plane, spine assembly is such that the motion of each vertebra is restricted in the rotation joint at the center of rotation.

Using DMU Kinematics module, the simulation is done with the function Simulation with Laws. The laws of motion are given by the time variation of angle α_i .

The angle α_i is determined by the difference between the two slopes to the curve given by equation (7) in the centers of two consecutive vertebrae. To determine the slope in the center of the vertebrae we should know that center of coordinates must be reported to the reference system. From the 3D model of the whole spine created in CAD software CATIA V5, we extract the values of the distances between the centers of the vertebrae. The values of the distances between the centers of the vertebrae are given in Table 1.

Table. 1 – Distances between the centers of the vertebrae.

Nr. crt.	Vertebrae	Distance [mm]
1.	C2 – C3	15,7
2.	C3 – C4	14
3.	C4 – C5	14,9
4.	C5 – C6	14,5
5.	C6 – C7	15
6.	C7 – T1	16
7.	T1 – T2	18,48
8.	T2 – T3	21
9.	T3 – T4	21,5
10.	T4 – T5	21,5
11.	T5 – T6	22,46
12.	T6 – T7	23,46
13.	T7 – T8	24,47
14.	T8 – T9	25,49

15.	T9 – T10	27
16.	T10 – T11	28
17.	T11 – T12	29,5
18.	T12 – L1	30,98
19.	L1 – L2	31,49
20.	L2 – L3	31,92
21.	L3 – L4	32,45
22.	L4 – L5	32,47

These values will be introduced in Mathcad software under the string of numbers with the note dv . Knowing the center of each vertebra is moving in an arc of a circle with its center at the origin of the coordinate system, we determine the radius of these arcs with the relationship:

$$r_u = r_c - \left(\sum_{j=0}^u dv_j \right) \cdot 10^{-3}$$

Where u is a counter for determining the number of orders according to Table 1.

Each of the vertebrae is moving under a center of an arc of a circle with a time variation given by the sinusoidal function similar to those given by the relations (1), (2) and (3). The amplitude of movement is determined by the intersection of the arc corresponding to each center of the vertebrae, and the curve that describes the shape of the spine extreme point side slope.

To determine the coordinates of these points, the following sequence was created using the software program Mathcad:

$$xiv_{u,k} = \begin{cases} h_k \text{ if } trunc \left[\left(\sqrt{r_u^2 - h_k^2} \right) \cdot 10^4 \right] = \\ = trunc \left[(a_0 h_k^3 + b_0 h_k^2 + c_0 h_k) \cdot 10^4 \right] \\ 0 \text{ otherwise} \end{cases}$$

$$xv_u = \max(xiv_{u,k})$$

$$\text{Where } k = 0 \dots 145 \cdot 10^6, h_k = k \cdot 10^{-6}$$

$$yv_u = \sqrt{r_u^2 - xv_u^2}$$

Knowing the coordinates of the center vertebrae in the coronal plane, the shape of the spine side slope extreme point, can be determined from the slopes of the curve (7) in these points with the following relationship:

$$\gamma_u = \arctg \left(\frac{y(xv_u + 10^{-6}) - y(xv_u - 10^{-6})}{(xv_u + 10^{-6}) - y(xv_u - 10^{-6})} \right)$$

Thus the angle α will be:

$$\alpha amp_u = (\gamma_{u+1} - \gamma_u)$$

The values of the angles αamp and γ are returned in radians

by the Mathcad calculation software. The values of the angle α_{amp} represent the amplitude of the sinusoidal function given by the following relationship (10). The functions describing the variation in time of the angle between the vertebrae.

$$\alpha_u = [\alpha_{amp_u} \cdot \sin(f_{\Delta t} \cdot i \cdot \pi)] \cdot \frac{180}{\pi} \quad (10)$$

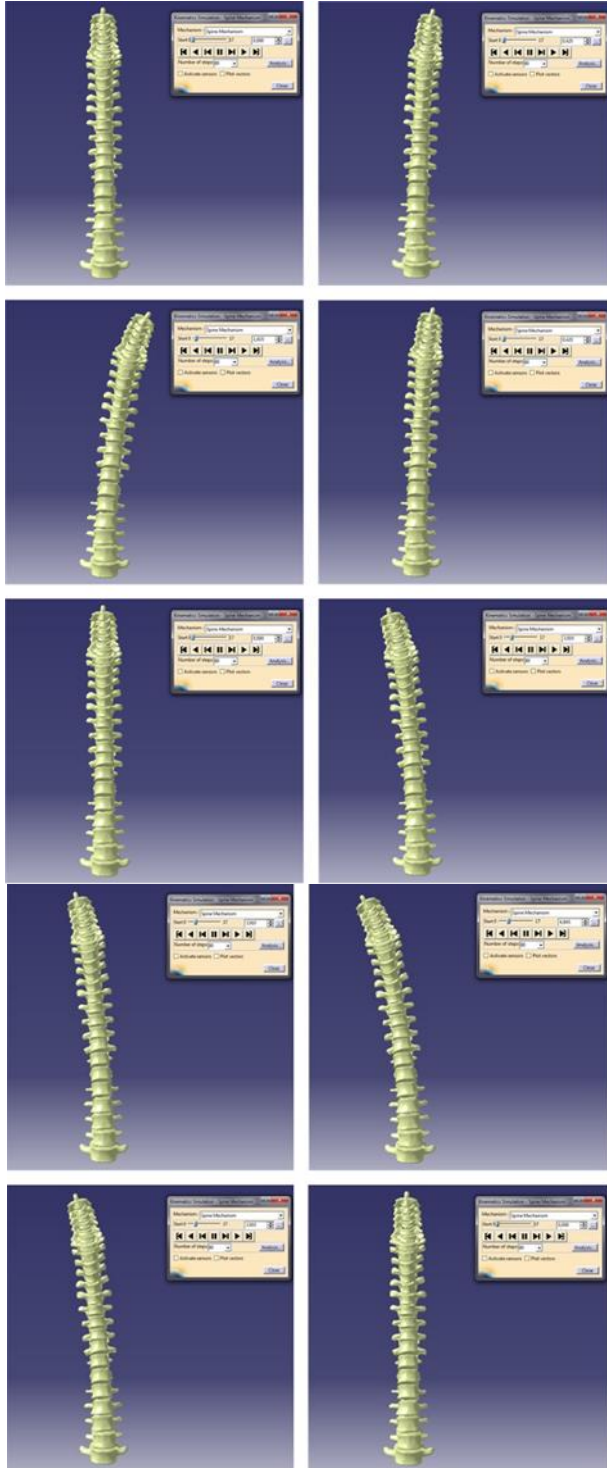


Fig. 8 – Extracted frames realized with CAD software CATIA V5.

V. CONCLUSION

The amplitude values of the sinusoidal functions describing the variation in time of angles between vertebrae gives an insight into the degree of deformation of intervertebral discs.

According to the literature the maximum tilt in the coronal plane of the lumbar vertebrae are 5 ° for L1-L2; 5 ° for L2-L3; 4.5 ° for L3-L4; 2.2 ° for L4-L5; 1 degrees for L1-S1.

This sort of ergonomic analysis over the driver spine involves a study of the effects of vibration on the human body.

As reported above it is evident that we have a maximum interest for understanding the pathogenesis of diseases caused by vibration, to determine the hygienic conditions of operation of vehicles. Such research should focus on framing all operation of machinery, especially motor vehicles, in parameters corresponding to operator health insurance, in this analysis of driver and passengers.

On this line was proposed a methodology to approach the interaction between driver and the vehicle to allow accurate conclusions for the driving activity.

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