Revista de Chimie
https://revistadechimie.ro
https://doi.org/10.37358/Rev. Chim.1949

Numerical Estimation of the Hand-Arm System Joints Reactions Caused by an Impact Based On Anthropometric Data

ADINA NEGREA*, IOANA IULIANA BUSUIOCEANU
Politehnica University of Bucharest, Department of Mechanics, 313 Splaiul Independentei, 060042, Romania

***Abstract**: This paper is concerned with the numerical analysis of the equations given by the mechanics of the impact of a ball and a hand-arm system for two potential subjects male and female. The influence of the mass of the ball and its velocity on the values of the hand-arm joints reactions is studied.*

***Keywords**: numerical estimation, elbow impact impulse, shoulder impact impulse*

1. Introduction

In the dedicated literature, numerous hand-arm studies concerning to the vibrations caused by the hand-held household and professional tools are realized, emphasizing the effects on the joints. In contrast, the weight of the studies regarding the loads and the effects on the wrist, the elbow and the shoulder joints generated by the hand intensive sports (basketball, tennis, volleyball, handball, rugby) is much lower.

Papers are focused on the effects produced by the throwing of the ball and by the ball repeatedly striking the hand in handball [1], the elbow loading and the biomechanical limits of the sportsmen in the case of specific sports as the throwing of some objects of different weights: spear, hammer, metallic balls [2]. King, Kental and Mitchell investigated the hand-arm system load by varying the position of the ball impact on the tennis racket [3].

There are not found any studies regarding the generated effects on the hand-arm joints by receiving the volleyball, more specifically, scientific works about the impact effects.

As a matter of fact, present paper follows up the theoretical study of the impact process of a hand-arm system bumped by a ball, presented intensively by the paper [4]. The impact system of equations is completed, all these relations are checked up carefully and then they are solved using computer software. On the other hand, the results below obtained may be a good set of values for the medical study in at least two directions: sports medical science and for the study and manufacture of materials (eg plastics) from which different prostheses of parts of the hand-arm system could be made. Regarding to above, there is research studying this issue in particular [5] and in general [6].

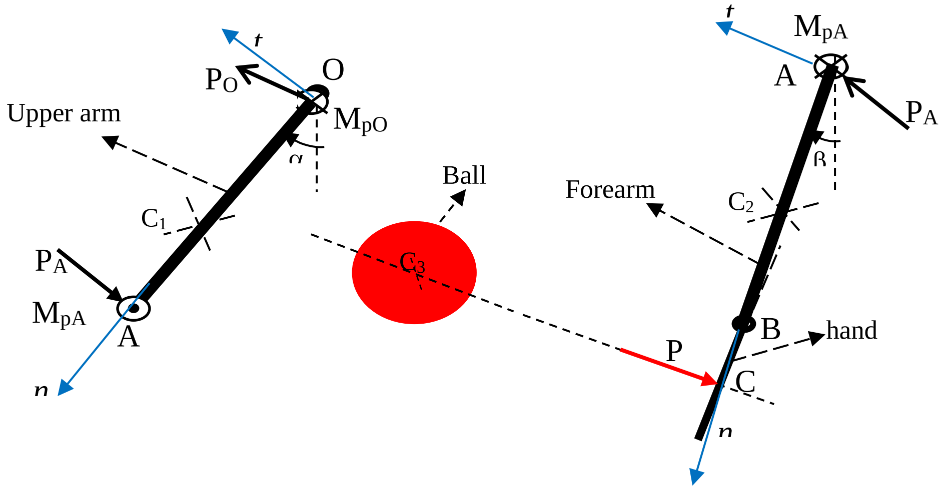
2. Materials and methods

Considerations on Mechanical Model of Studied Impact

It is appropriate to do firstly some considerations on the mechanical model widely presented in paper [4], especially for doing the welcome adjustments of this previous study. Before to remind the equations that describe the mechanics of impact, some words about the model are necessary: it is about a classical model of double pendulum representing upper arm, forearm and hand bumped by a ball, in a separate description as it can be seen in Figure 1(a and b). In this representation, the impact reactions in shoulder and elbow are clearly highlight.

**email: adina.negrea@upb.ro*

Revista de Chimie
https://revistadechimie.ro
https://doi.org/10.37358/Rev. Chim.1949



a. b.

Figure 1. Impact reactions in shoulder and elbow caused by impact. Upper arm (*a*) and Forearm bumped by a ball (*b*)

In Figure 1(*a* and *b*), impact reactions are the following: impact impulse ***P*** (very closed by the wrist joint) due to the ball hitting, elbow impact impulse $\boldsymbol{P_A}$, shoulder impact impulse $\boldsymbol{P_O}$, and the special impact moment caused by reaction of ligaments and muscles during impact process ([4]), respectively $\boldsymbol{M_{PA}}$, called elbow impact moment and $\boldsymbol{M_{PO}}$, shoulder impact moment.

It is also important to specify physical and geometric data according to the Figure 1(*a* and *b*) and to the equations given by the mechanics of the impact: m_1 and l_1 are the mass and the length of the upper arm, m_2 and l_2 are the mass and the length of the forearm, c_1 is the distance between the shoulder joint *O* and the arm mass center C_1, c_2 is the length AC_2 (where C_2 is the forearm mass center), *b* is considered the length between the wrist joint *B* (practically a rigid joint during impact) and the point of impact *C* (on the hand), J_O is the moment of inertia of the upper arm with respect to the perpendicular axis (*Oz*), J_A is the moment of inertia of the forearm with respect to the perpendicular axis (*Az*), J_{C_2} is the moment of inertia of the forearm with respect to the perpendicular axis (C_2z), m_3 is the mass of the ball and v_3 is its velocity, finally P_α and P_β being the generalized impact reactions (see [4]). It is important to mention that the subscripts *t* and *n* symbolize orthogonal axes, "*t*" perpendicular to each part of the system (upper arm and forearm respectively) and "*n*" along to each part (Figure 1*a* and *b*).

According to the reasoning of the impact mechanics ([4]), the impact equations are the next:

$$M_{P_A} = P_\beta + (l_2 + b)P \tag{1}$$
$$M_{PO} = P_\alpha + P_\beta + P[(l_2 + b) + l_1\cos(\alpha - \beta)] \tag{2}$$
$$P_\alpha = (J_O + m_2 l_1^2)(\dot{\alpha}_\tau - \dot{\alpha}_0) + m_2 l_1 c_2[\dot{\beta}_\tau \cos(\alpha_\tau - \beta_\tau) - \dot{\beta}_0 \cos(\alpha_0 - \beta_0)] \tag{3}$$
$$P_\beta = J_A(\dot{\beta}_\tau - \dot{\beta}_0) + m_2 l_1 c_2[\dot{\alpha}_\tau \cos(\alpha_\tau - \beta_\tau) - \dot{\alpha}_0 \cos(\alpha_0 - \beta_0)] \tag{4}$$
$$P_{At} = P + m_2 l_1(\dot{\alpha}_\tau - \dot{\alpha}_0)\cos(\alpha - \beta) + m_2 c_2(\dot{\beta}_\tau - \dot{\beta}_0) \tag{5}$$
$$P_{An} = m_2 l_1(\dot{\alpha}_\tau - \dot{\alpha}_0)\sin(\alpha - \beta) \tag{6}$$
$$P_{Ot} = P_{A_t} + m_1 c_1(\dot{\alpha}_\tau - \dot{\alpha}_0) \tag{7}$$
$$P_{O_n} = P_{A_t} \tag{8}$$

With regard to the previous paper [4], the following relations are supplemented, and for this reason they have to be presented one by one. These added relations are equations given by the theorem of the angular momentum applied in the impact mechanics ([7], but also [8, 9] mostly for a general perspective about the impact mechanics), on the subject "arm" and "forearm" respectively:

$$J_O(\dot{\alpha}_\tau - \dot{\alpha}_0) = M_{P_O} - P_{A_t} \cdot l_1 - M_{P_A} \tag{9}$$

$$J_{C_2}(\dot{\beta}_\tau - \dot{\beta}_0) = M_{P_A} - P_{A_t} \cdot c_2 - P[b + (l_2 - c_2)]cos^2 \beta - P[b + (l_2 - c_2)]sin^2 \beta \tag{10}$$

The last equation is the projection of the theorem of linear momentum applied to the ball bumping the hand along the impact line, using the symbol v_3 as resulted velocity of the ball between the velocity before impact (v_{30}) and the velocity after impact ($v_{3\tau}$):

$$m_3 \cdot v_3 = P \tag{11}$$

Some working assumptions available during impact are taking into account in this moment. Thus, the hand-arm system is initially (before impact) at rest, meaning $\dot{\alpha}_0 = \dot{\beta}_0 = 0$ (implying $\dot{\alpha}_\tau = \omega_1$ which is the angular velocity in the motion of the upper arm after impact and $\dot{\beta}_\tau = \omega_2$ which is the angular velocity in the motion of the forearm after impact as well) and the changes of the values of the angles α and β can be neglected ($\alpha_0 = \alpha_\tau = \alpha$, $\beta_0 = \beta_\tau = \beta$). Also, it is determined to consider that the variation of the velocity of the ball (denoted by v_3) is given and its mass m_3 is known as well.

Before to rewrite the system of the impact equations, it is welcome to specify that all above mentioned relations from (1) to (8) have been checked rigorously, all the small calculation errors from [4] being eliminated.

The unknowns of this impact process are delivered solving the following system of equations:

$$P_{A_t} = P + m_2 l_1 \omega_1 \cos(\alpha - \beta) + m_2 c_2 \omega_2 \tag{12}$$

$$P_{A_n} = m_2 l_1 \omega_1 \sin(\alpha - \beta) \tag{13}$$

$$P_{O_t} = P_{A_t} + m_1 c_1 \omega_1 \tag{14}$$

$$M_{P_A} = J_A \omega_2 + m_2 l_1 c_2 \omega_1 \cos(\alpha - \beta) + (l_2 + b)P \tag{15}$$

$$M_{P_O} = (J_O + m_2 l_1^2)\omega_1 + m_2 l_1 c_2 \omega_2 \cos(\alpha - \beta) + J_A \omega_2 + m_2 l_1 c_2 \omega_1 \cos(\alpha - \beta) + P[(l_2 + b) + l_1 \cos(\alpha - \beta)] \tag{16}$$

$$J_O \omega_1 = M_{P_O} - P_{A_t} \cdot l_1 - M_{P_A} \tag{17}$$

$$J_{C_2} \omega_2 = M_{P_A} - P_{A_t} \cdot c_2 - P[b + (l_2 - c_2)] \tag{18}$$

$$P_O = \sqrt{P_{O_t}^2 + P_{A_n}^2} \tag{19}$$

$$P_A = \sqrt{P_{A_t}^2 + P_{A_n}^2} \tag{20}$$

It is specified that all physical and geometric data are provided by paper [4], both for male and female.

3. Results and discussions

Numerical simulation of impact

The system of equations containing the relations from (12) to (20) has been solved keeping into account that the possible angles (corresponding to the real positions of the hand-arm system during the impact with the ball) α and β could have the subsequent values pinned on Table 1.

Revista de Chimie
https://revistadechimie.ro
https://doi.org/10.37358/Rev. Chim.1949

Table 1. Possible values of the angles α and β

Position I	***Position II***	***Position III***	***Position IV***
α=20^0 β=32^0	α=18^0 β=97^0	α=24^0 β=84^0	α=54^0 β=93^0

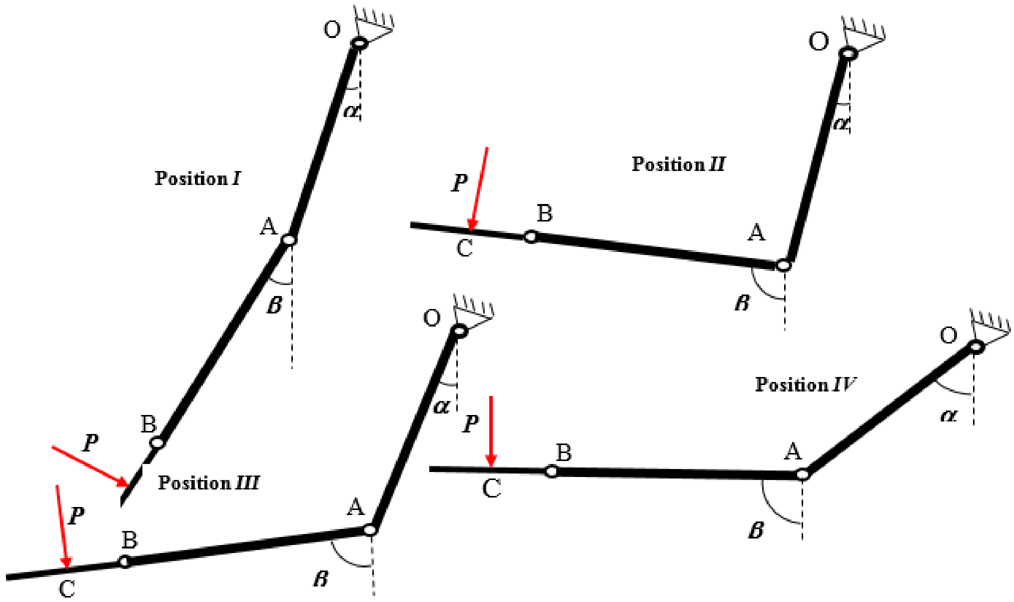


Figure 2. Configuration of the positions of the hand-arm system during impact

As it can seen, Figure 2 offers a suggestive picture of all these positions characterized by the angles α and β.

The numerical simulation has put into effect using a computer software based on [10], for six cases (illustrated by Figure 3 to Figure 8). These cases depend on different values of the mass and the velocity of the ball.

The target objective of this paper is to find the impact impulses. The results are caught in the diagrams bellow (Figures 3-8). The continuous line joints all computed male impact impulses according to the four positions (the red continuous line connects all computed male elbow impact impulses and the green continuous line connects all computed male shoulder impact impulses) and the broken line joints all computed female impact impulses (the red broken line connects all computed female elbow impact impulses and the green one connects all computed female shoulder impact impulses).

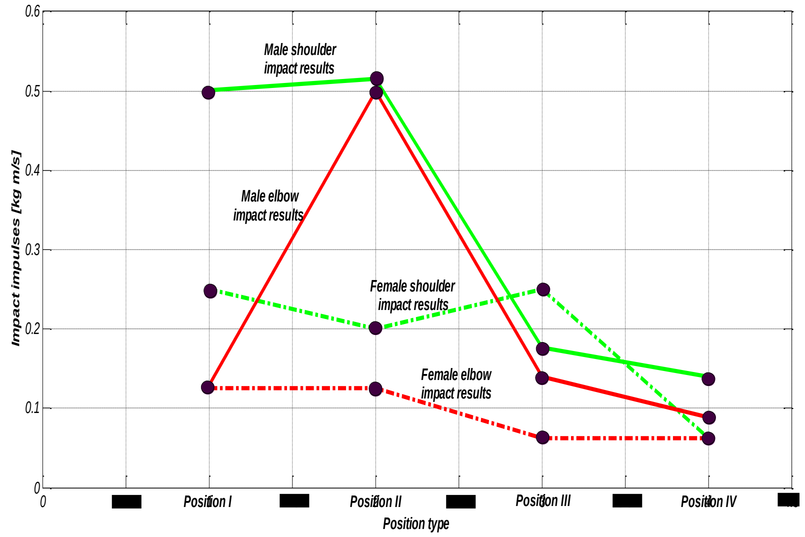


Figure 3. *Male* and *Female* Impact Impulses: *Case A* (m_3*=0.3* kg*;* v_3*=0.2* m/s)

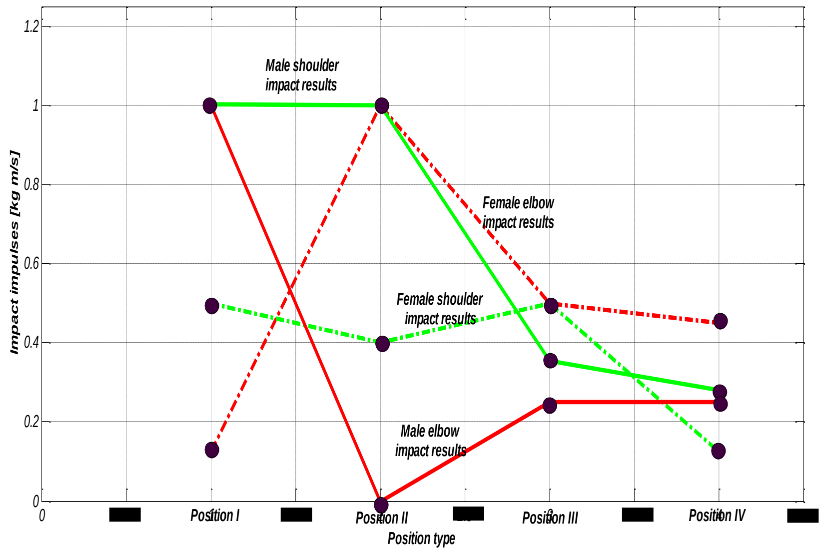


Figure 4. *Male* and *Female* Impact Impulses: *Case B* (*m*$_3$=0.3 *kg*; *v*$_3$=0.4 *m/s)*

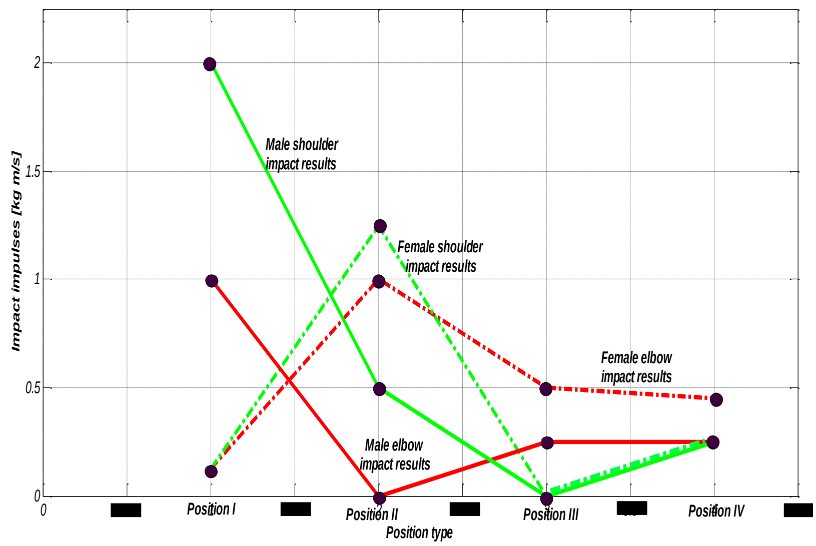


Figure 5. *Male* and *Female* Impact Impulses: *Case C* (*m*$_3$=0.3 *kg*; *v*$_3$=0.4 *m/s)*

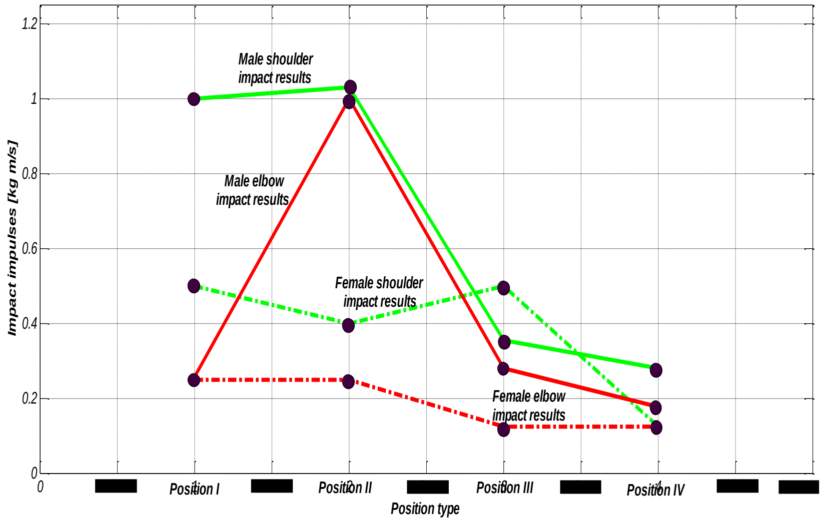


Figure 6. *Male* and *Female* Impact Impulses: Case *D* (m_3=0.6 *kg*; v_3=0.2 *m/s*)

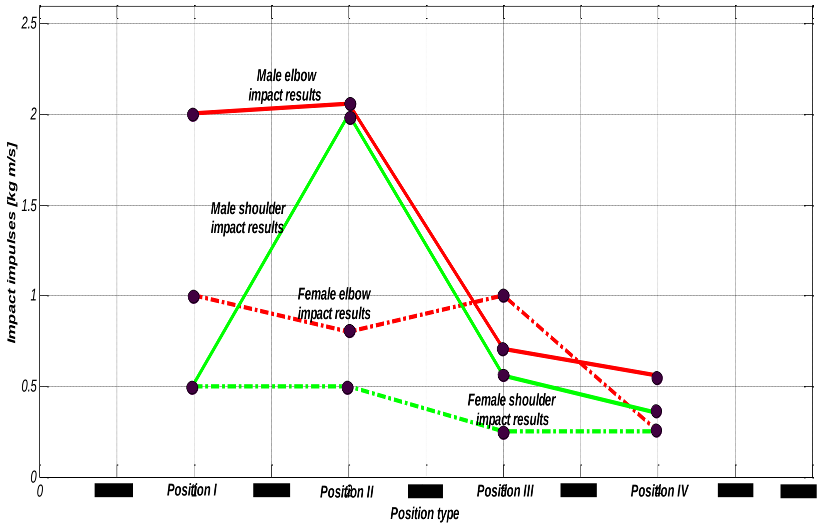


Figure 7. *Male* and *Female* Impact Impulses: Case *E* (m_3=0.6 *kg*; v_3=0.4 *m/s*)

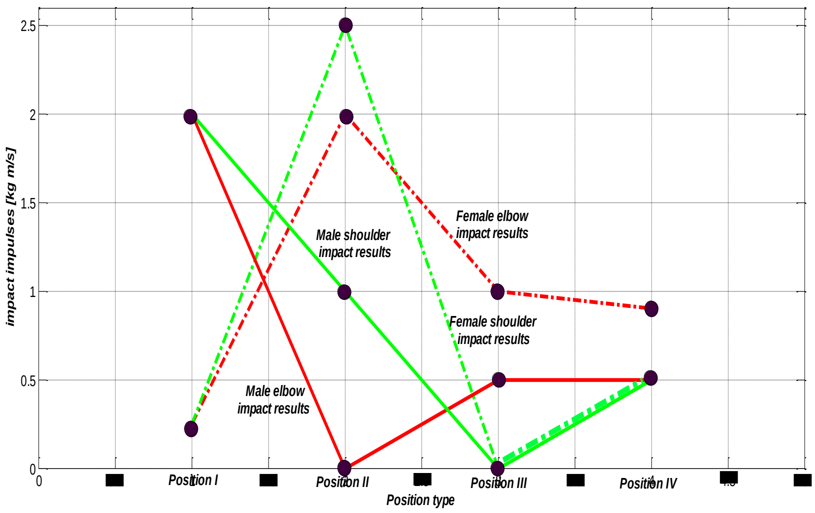


Figure 8. *Male* and *Female* Impact Impulses: Case *F* (m_3=0.6 *kg*; v_3=1 *m/s*)

Revista de Chimie
https://revistadechimie.ro
https://doi.org/10.37358/Rev. Chim.1949

4. Conclusions

The analysis of the above results causes the following commentaries. Before, it is necessary to explain that the numerical estimation of the shoulder and elbow impact impulses has a mathematical approach based on more or less realistic physical ball data (meaning the mass and velocity of the ball hitting the hand). For this reason, it is normal to reveal the qualitative aspects of the results and to not insist on the quantitative description of them.

The shoulder impact impulses are greater than the elbow impact impulses both for male and female according to the case ***A*** and the case ***D***, for the smallest velocity of ball (v_3=0.2 *m*/*s*), even if the mass varies from 0.3 *kg* to 0.6 *kg*. The elbow impact impulses are greater than the shoulder impact impulses, both for male and female, in case ***E*** (m_3=0.6 *kg*; v_3=0.4 *m*/*s*) and only for position ***III***, cases ***C*** (m_3=0.3 *kg*; v_3=1 *m*/*s*) and ***F*** (m_3=0.6 *kg*; v_3=1 *m*/*s*). For all cases it can notice that the first positions (position ***I*** and position ***II***) are the most "unsafe" situations providing surprising results either obvious differences between male and female impact impulses (from low to high values and vice-versa), or inside each gender impact results, where there are notable differences between the shoulder impact impulses and the elbow impact impulses (position ***I*** versus position ***II***). It is interesting to remark where the null values for impact impulses are obtained, for male there are five situations (elbow: case ***B***/position ***II***, case ***C***/position ***II***, case ***F***/position ***II***, and shoulder: case ***C***/position ***III*** and case ***F***/position ***III***) and for female there are only two situations (shoulder: case ***C***/position ***III*** and case ***F***/position ***III***) identical to those

A general view on the numerical estimation of the impact impulses leads to the conclusion that the "attack" angles α and β have a substantial contribution to the values of the impact impulses, as it can see, for all cases, both for male and female, positions ***III*** and ***IV*** have generated the smallest impact impulses, and of course the increasing values for the mass and the velocity of the ball are in charge of the increasing values of the impact impulses which is a logical consequence of the impact process.

References

1. PERIĆ, D., KUBUROCIĆ, D., NEŠIĆ, M., MAVRIĆ, F., MEĐEDOVIĆ, B., MILOSAVLJEVIĆ, S., Impact of Muscle Strength and Sport Technique on Throwing Distance of Balls of Various Weights with a Dominant Arm, Scientific and Academic Publishing, 2015.
2. LOFTICE, J., FLEISIG, G., S., ZHENG, N., N., ANDREWS, J., R., Biomechanics of the elbow in sports, Clin Sports Med, 2004.
3. KING, M., A., KENTEL, B., B., MITCHELL, S., R., The effects of ball impact location and grip tightness on the arm, racquet and ball for one-handed tennis backhand groundstrokes, Journal of Bio mechanics 45, 2012.
4. NEGREA, A., BUSUIOCEANU, I., I., Consequences of Impact on Arm (Elbow and Shoulder Joints) Caused by Ball Hitting, Theoretical Analysis, AIP Conference Proceedings, ICSSAM 2017, published 2018, WOS:000442818000011.
5. SCRIPCARU, A., BEREA G., COTRUTZ E., C., STAN, C., I., PUHA, B., Hemiorthoplasty in complex proximal humeral fractures in uncemented methaphysical comdemn blasted titanium humeral stem an afficient alternative ?, *Mater. Plast*., **55**(4), 2018, 679
6. NAUM, C., PRETA, I., POPESCU, C., EVA, L., TOMA, B., F., TOMA, S., L., The influence of the characteristics of plastic materials used in the performance of the thoraco-lumbar orthoses, *Mater. Plast.*, **55**(1), 2018, 85
7. STAICU Ş., Introducere in Mecanica Teoretica (Introduction in Theoretical Mechanics), Editura Ştiinţifică şi Enciclopedică Bucureşti, 1983, pp 346-350.
8. HIBBLELER., R., C., Mechanics for Engineers, Macmillian publishing Company New York,1985, pp 150-159.
9. VOINEA, R., VOICULESCU, D., CEAUSU, V., Mecanica (Mechanics), Editura Didactică şi Pedagogică Bucureşti, 1975, pp 410-412.
10. *** SCILAB, http/www.scilab.org

Manuscript received: 11.10.2019