THE PARALLEL BARS MOVEMENTS WITH STRAIN OF BARS

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The long swing movements of a national level gymnast (50.4kg) were used to observe time history of joint angles of body and the middle points of the parallel bars in different conditions. Parallel bars were modelled using four massless spring dampers and two point masses. Further, a 50kg metal spear was attached to the middle points of the parallel bars and their oscillations on different planes were observed. Parameters were calculated using a parallel bars model and were compared with the standard specifications of the Federation of International Gymnastics (FIG). Hence, the dynamic forces which are acting on the middle points of the parallel bars for a long swing movement were calculated.

KEY WORDS: gymnastic, long swing movement, parallel bars, strain,

INTRODUCTION: The International Gymnastic Federation has introduced different varieties of execution errors for long swing (in hang on parallel bars) movements (Code of Point, 2017). To minimise the execution errors of movement, gymnasts need to utilise bar strain in the correct manner. Therefore, gymnasts need to know how well they utilise not only the body dynamics but also the dynamic properties of exercise equipment/apparatus which interact with their bodies (Yamasaki, Yasuhiro & Gotoh, 2008). The bar strain of parallel bars significantly affects artistic completion of high difficulty long swing movements on bars. For this aspect, biomechanical models can provide with important factors which are based on performance (Hiley & Yeadon, 2005). Modelling of parallel bars is complicated due to the existence of many variables such as 3-dimentional (3D) movements of wooden parallel bars and tops of the four metal posts. Therefore, we used four massless spring dampers to model 3D movements of the middle point of the bars and the tops of the posts corresponding to gymnast's long swing movement (Linge, Hallingstad & Solberg, 2006). The elastic and viscous coefficients of three spring dampers were identified and those factors were used to find none-constrain forces acting on hand/grip. We observed the relationship between special vibration pattern of wooden parallel bars when player released the hands for rotations and natural frequency of wooden parallel bars. This indicated how gymnast performs a highly difficult movement while minimizing his execution errors.

METHODS:

Data Collection: In the first part of the research, reflective markers (14mm) were attached to the tops of the metal posts, the parallel bars and to a 50kg metal spear to observe oscillations around the middle point of the wooden parallel bars. This experiment was repeated for a mass 31kg spear in the same manner. In the second part, a national level player who had a high execution score of his best performance in National Games in China was selected as a subject of the experiment. Markers were attached to every joint of his body, the tops of the metal posts and to the middle point of the parallel bars. The long swing: "Forward giant swing backward double salto tucked to upper arm hang'' (Code of Point MAG, 2017) movement in the sagital plane was recorded using ten camaras (ViconT40s, 100Hz).

Data Anlaysis: The time history of all makers on the gymnast and the parallel bars in both parts of the research was measured using a digitizing software (Vicon Nexus 2.2). O is the initial position of one of the posts of the parallel bars before attaching the metal spear to the middle point of the wooden bar as shown in Figure 1. A spear was released smoothly to observe oscilations on XZ-plane and YZ-plane. The spear was also moved in Z-direction (ϕ=0) to obseve osclilations. Hence the coordinates of relevant markers throughout dynamic movements were observed and kinematic and kinetic values were calculated using Matlab R2014b software.

Model: Four massless spring dampers are connected to the point masses m and m_B as shown in Figure 2. Parameters (K_x,C_x,K_y,C_y,K_z and C_z) of the four massless spring dampers (SD1,SD2,SD3 and SD4) were identified using time history of ϕ angle, and the points B and C (center of mass M). SD2 and SD3 are identical and represents horizontal movement of the middle point of the bar. SD1 and SD4 represents the movement of the middle point of a bar in Z-direction and Y-direction respectively.$T_1 = \frac{1}{2}\{(m + m_B + M)\ddot{x} + ML\,[\cos(\phi)\ddot{\phi} - \sin(\phi)\dot{\phi}^2]\}$, $T_2 = (m + m_B + M)\,\ddot{y} + M\,L[\cos(\varsigma)\,\ddot{\varsigma} - \sin(\varsigma)\,\dot{\varsigma}^2]$, and $T_3 = (m_B + M)\,(g+\ddot{z}) - M\,L\,[\,\sin(\phi)\,\ddot{\phi} + \cos(\phi)\,\dot{\phi}^2]$ are spring damper forces for -X,Y and Z directions respectively. Angle ς represents angular displacement of C at time t=t on YZ-plane. O_1 is a movebale point on the fixed sagital plane of the body without any friction.

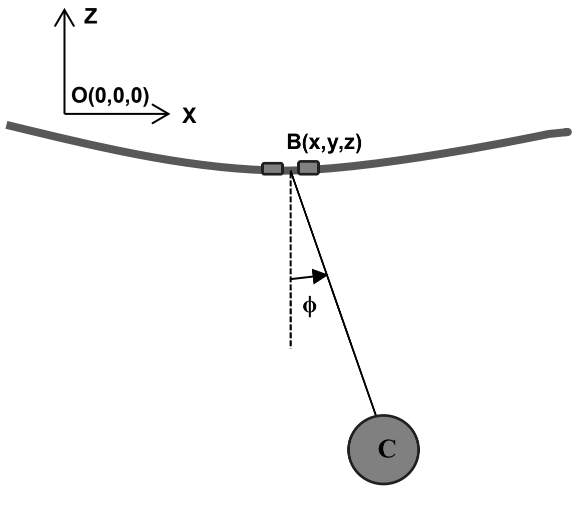

Figure 1: A 50kg Spear Ball Attached to the Middle Point of the Wooden Bar

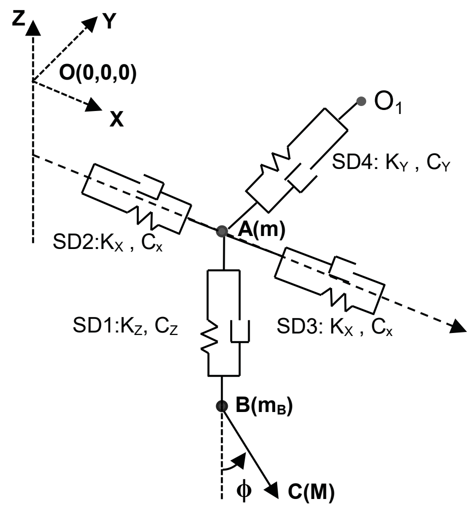

Figure 2: The Model of the Parallel Bars

Dynamic Equations: The Kene's procedure (Kane & Levinsion, 1985) was used to derive the system's dynamical equations. The position vectors of m, m_B and M masses: **OA** = x $\mathbf{a_1}$, **OB** = x $\mathbf{a_1}$ – z $\mathbf{a_3}$, and **OC** = [x + L sin(ϕ)] $\mathbf{a_1}$ – [z + L cos(ϕ)] $\mathbf{a_3}$. L is the length of BC. $\mathbf{a_1}$ and $\mathbf{a_3}$ are unit vectors of X and Z axis respectively. T_1, T_2 and T_3 are spring damper forces which are acting on mass m in the direction of –X,Y and Z respectivly at t=t of an oscilation. Generalized active forces are $F_1 = -2T_1$ and $F_3 = -T_3 + m_B g + Mg$, g is accelaration of gravity. Genaralized initial forces are $F_1^* = (m + m_B + M)\,\ddot{x} + M\,L\,[\cos(\phi)\,\ddot{\phi} - \sin(\phi)\,\dot{\phi}^2]$ and $F_3^* = m_B\,\ddot{z} + M\,\{\ddot{z} - L\,[\sin(\phi)\,\ddot{\phi} + \cos(\phi)\,\dot{\phi}^2]\}$. Dynamic equations are $T_1 = \frac{1}{2}\{(m + m_B + M)\ddot{x} + ML\,[\cos(\phi)\ddot{\phi} - \sin(\phi)\dot{\phi}^2]\}$ and $T_3 = (m_B + M)\,(g+\ddot{z}) - M\,L\,[\sin(\phi)\,\ddot{\phi} + \cos(\phi)\,\dot{\phi}^2]$. Similarly,

$T_2 = (m + m_B + M)\,\ddot{y} + M\,L[\cos(\varsigma)\,\ddot{\varsigma} - \sin(\varsigma)\,\dot{\varsigma}^2]$ can be formulated by considerining the movements on YZ-plane. Hence, three mathematical model can be defined as following equaions (1),(2) and (3).

$$T_{1M} = K_x\,x + C_x\,\dot{x} + F_x \qquad T_1 = \frac{1}{2}\,\{(m + m_B + M)\ddot{x} + ML\,[\cos(\phi)\ddot{\phi} - \sin(\phi)\dot{\phi}^2]\} \qquad (1)$$

$$T_{2M} = K_y\,y + C_y\,\dot{y} + F_y \qquad T_2 = (m + m_B + M)\,\ddot{y} + M\,L[\cos(\varsigma)\,\ddot{\varsigma} - \sin(\varsigma)\,\dot{\varsigma}^2] \qquad (2)$$

$$T_{3M} = K_z\,z + C_z\,\dot{z} + F_z \qquad T_3 = (m_B + M)\,(g+\ddot{z}) - M\,L\,[\sin(\phi)\,\ddot{\phi} + \cos(\phi)\,\dot{\phi}^2] \qquad (3)$$

F_x, F_y and F_z are constant values in each model of spring dampers.

RESULTS: The figure 4 shows velocities (dashed lines) in three X,Y and Z directions and their accelarations (solid lines) on a 50kg metal spear. The figure 5 shows spring damper forces (solid lines) and their model SD values (dashed lines). Height of the parallel bars from the mat is 185 cm.

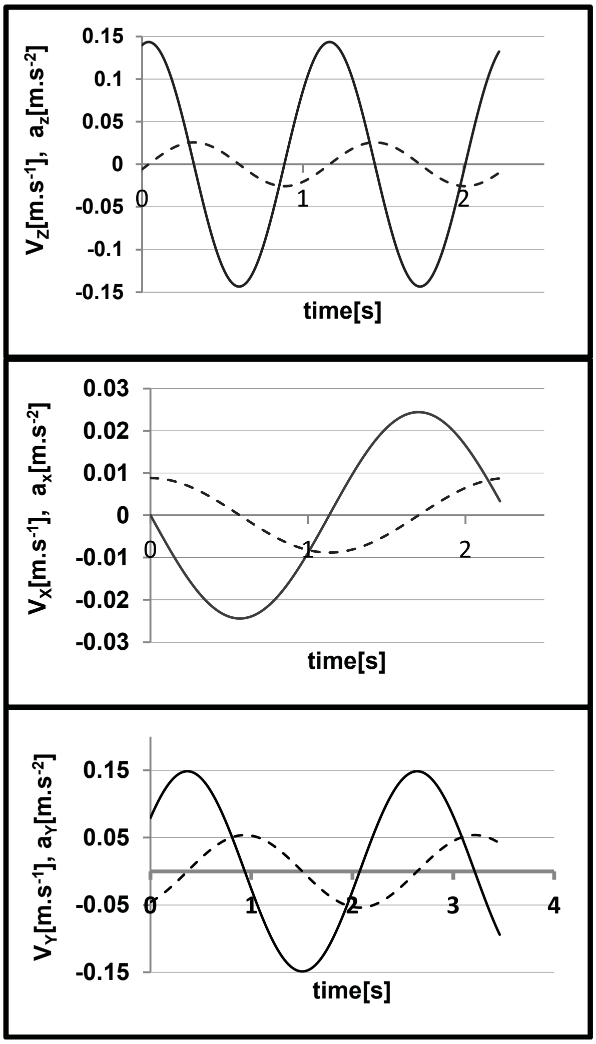

Figure 4: Velocity and Accelaration of Mass m_B in Three Directions

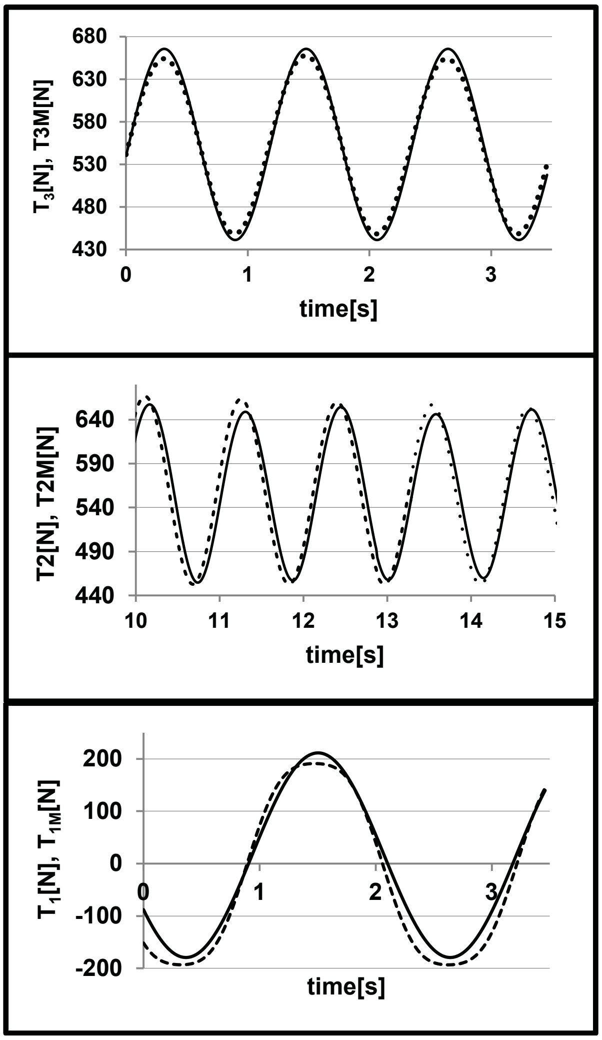

Figure 5: Spring Damper Forces (T_i) and Their Model's Values (T_{iM}), i = 1,2,3

DISCUSSION: The Tables 1 to 3 show the results of parameter fitting (minimizing RMS value related to T and T_M forces). The spring damper parameters (K_X and K_z) can be agreed with International Gymnastics Federation Norms (2016). The value of K_Y (less than the value of specification test of FIG) cannot be verified with a part of parallel bars verification test of FIG. K_Y value is a very important factor, specially for long swing movements under the bars to maintain correct movement pattern of the element. Therefore, players need to consider not only the elastic component in the Z-direction but also in the Y-direction specially for long swing movements (see figure 7). When the player reaches the exact vertical position (considered six joint angles) of body under the bars, the middle point of a bar moves about 15 mm towards the sagital plane of the body. This is a considerable amount of force genaration (150.2 N from a bar) for 50.4 kg mass player. Figure 6 shows the dynamic force (Z-component) which is acting on the point B while player (mass 50.4 kg) was performing "Forward giant swing backward double salto tucked to upper arm hang'' movement between the middle points of the parallel bars while keeping 185cm standard height (Code of Point 2017) of the wooden parallel bars from the mat. Player gains maximum amount of elastic energy of bars (F_z = 1226.4 N at the point D) when the body reaches the exact vertical position under the wooden parallel bars.The middle points of wooden bars oscillate in their natural frequency (16.66 Hz) when the player completely releases his hands from the bars at the point P (Figure 6). Under these conditions, the player completed the particular movement without any execution errors.

Table 1
Results of Parameter Identification(SD1)

Subject(M) [kg]	m[kg]	m_B[kg]	K_Z [N.m^{-1}]	C_Z[N.s.m^{-1}]	RMS[N]
31	1.00	5.300	20073.4	4.9920	0.00289
50	1.02	5.001	19511.5	5.0121	0.00106

Table 2
Results of Parameter Identification(SD2=SD3)

Subject(M) [kg]	m[kg]	m_B[kg]	K_X [N.m^{-1}]	C_X [N.s.m^{-1}]	RMS[N]
31	1.00	5.01	27800.91	4.2446	0.00438
50	1.00	5.31	27633.15	4.0009	0.00045

Table 3
Results of Parameter Identification(SD4)

Subject(M) [kg]	m[kg]	m_B[kg]	K_Y[N.m^{-1}]	C_Y [N.s.m^{-1}]	RMS[N]
31	1.07	5.08	10198.23	3.011	0.0007
50	1.00	5.01	10009.37	2.999	0.0006

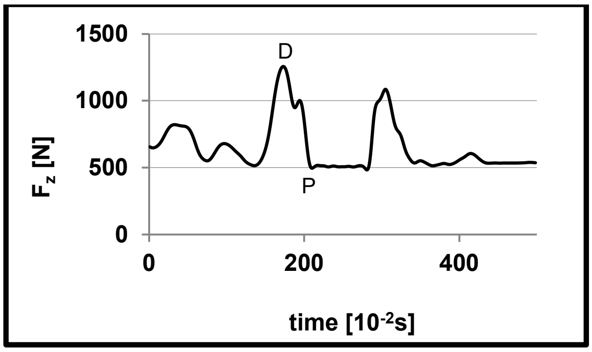

Figure 6: Dynamic Force (Z-component) Variation of Middle Point A of the Parallel Bars

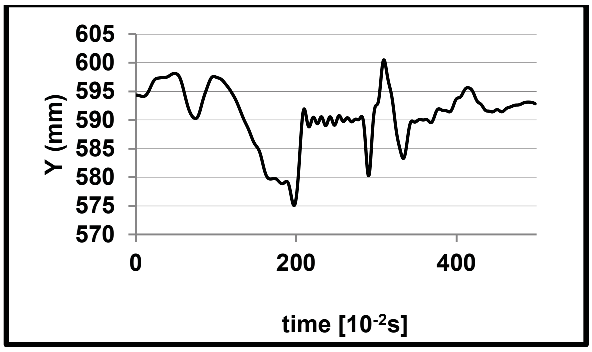

Figure 7: Displacement of Middle Point A in the Y-Direction

CONCLUSION: The simple parallel bars model with four spring dampers and two point masses clearly demonstrates that the dynamic strain of the bars vary with the long swing gymnastic movement under the parallel bars. In the phase PQ in Figure 6, the player is completing his rotations independent of the parallel bars. If player can apply the specific force at the releasing phase, we show that the middle points of the bars vibrate according to their natural frequency. These findings will provide further reviving of how injury involves with spring damper's parameters.

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