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 & Yeadan, 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 attach ed 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 oscillations on XZ-plane and YZ-plane. The spear was also moved in Z-direction
(ϕ=0) to obseve oscillations. 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 \( \phi \) 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. \( T_1 = \frac{1}{2} \left( (m + m_B + M) \ddot{x} + ML \left[ \cos(\phi) \dot{\phi} - \sin(\phi) \dot{\phi}^2 \right] \right) \), \( T_2 = (m + m_B + M) \ddot{y} + ML \left[ \cos(\zeta) \ddot{z} - \sin(\zeta) \dot{z}^2 \right] \), and \( T_3 = (m_B + M) \left( g + \ddot{z} \right) - ML \left[ \sin(\phi) \dot{\phi} + \cos(\phi) \dot{\phi}^2 \right] \) are spring damper forces for -X, Y and Z directions respectively. \( \phi \) represents angular displacement of C at time \( t = t \) on YZ-plane. \( O_1 \) is a moveable point on the fixed sagital plane of the body without any friction.

Dynamic Equations: The Kene’s procedure (Kane & Levinson, 1985) was used to derive the system’s dynamical equations. The position vectors of \( m \), \( m_B \) and M masses: \( \text{OA} = x \mathbf{a}_1 \), \( \text{OB} = x \mathbf{a}_1 - z \mathbf{a}_3 \), and \( \text{OC} = [x + L \sin(\phi)] \mathbf{a}_1 - [z + L \cos(\phi)] \mathbf{a}_3 \). 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 \( Z \) respectively at \( t = t \) of an oscillation. Generalized active forces are \( F_1 = -2T_1 \) and \( F_3 = -T_3 + mBg + Mg \), \( g \) is acceleration of gravity. Genaralized initial forces are \( F_1^* = (m + m_B + M) \ddot{x} + ML \left[ \cos(\phi) \dot{\phi} - \sin(\phi) \dot{\phi}^2 \right] \) and \( F_3^* = m_B \ddot{z} + M \left( \ddot{z} - L \left[ \sin(\phi) \dot{\phi} + \cos(\phi) \dot{\phi}^2 \right] \right) \). Dynamic equations are \( T_1 = \frac{1}{2} \left( (m + m_B + M) \ddot{x} + ML \left[ \cos(\phi) \dot{\phi} - \sin(\phi) \dot{\phi}^2 \right] \right) \) and \( T_3 = (m_B + M) \left( g + \ddot{z} \right) - ML \left[ \sin(\phi) \dot{\phi} + \cos(\phi) \dot{\phi}^2 \right] \). Similarly, \( T_2 = (m + m_B + M) \ddot{y} + ML \left[ \cos(\zeta) \ddot{z} - \sin(\zeta) \dot{z}^2 \right] \) can be formulated by considering the movements on YZ-plane. Hence, three mathematical model can be defined as following equations (1),(2) and (3).

\[
\begin{align*}
T_{1M} &= K_x x + C_x x + F_x \\
T_{2M} &= K_y y + C_y y + F_y \\
T_{3M} &= K_z z + C_z z + F_z
\end{align*}
\]

\[
F_x, F_y \text{ and } F_z \text{ are constant values in each model of spring dampers.}
\]

RESULTS: The figure 4 shows velocities (dashed lines) in three X,Y and Z directions and their accelerations (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.
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 generation (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)

<table>
<thead>
<tr>
<th>Subject(M) [kg]</th>
<th>m[kg]</th>
<th>mB[kg]</th>
<th>KZ [N.m^{-1}]</th>
<th>C Z[N.s.m^{-1}]</th>
<th>RMS[N]</th>
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<td>31</td>
<td>1.00</td>
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<td>4.9920</td>
<td>0.00289</td>
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<td>5.001</td>
<td>19511.5</td>
<td>5.0121</td>
<td>0.00106</td>
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Table 2
Results of Parameter Identification(SD2=SD3)

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<th>Subject(M) [kg]</th>
<th>m[kg]</th>
<th>mB[kg]</th>
<th>KX [N.m^{-1}]</th>
<th>CX[N.s.m^{-1}]</th>
<th>RMS[N]</th>
</tr>
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<tbody>
<tr>
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<td>4.2446</td>
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<tr>
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<td>27633.15</td>
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Table 3
Results of Parameter Identification(SD4)

<table>
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<th>mB[kg]</th>
<th>KY[N.m^{-1}]</th>
<th>CY[N.s.m^{-1}]</th>
<th>RMS[N]</th>
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<td>5.01</td>
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<td>2.999</td>
<td>0.0006</td>
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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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