MODELING A SPRINGBOARD IN GYMNASTICS

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For development and optimization of elements in gymnastics` vault, the knowledge of the angular momentum, take-off velocity and thus the forces on the springboard are of interest. A multi-body model was developed for the determination of forces. The following article describes the creation of a springboard model and therefore the identification and evaluation of physical parameters acting during movements.

KEY WORDS: gymnastics, vault, springboard, modeling

INTRODUCTION: For the calculation of specific take-off parameters in gymnastics' vault, kinemetric methods have been used. Due to the short contact time on the springboard (Kasamatsu: 0.11 s (±0.02 s); (Farana, Uchytil, Zahradnik & Jandacka, 2015)) high frequency video is mainly used for determining the parameters. Since evaluation takes too long for practical application with direct feedback for trainer and athletes, a model should be used to determine forces acting on the springboard. With these forces and using minimally kinemetry, the angular momentum and the take-off velocity can be deduced.
With the assistance of a springboard model and acceleration sensors, it is possible to simulate the acting forces. Modeling of the springboard is based on the model approach (Eq. (1)) of Sano, Ikegami, Nunome, Apriantono und Sakurai (2007). This means that the board reaction force (BRF) is composed of the effective force below the springboard (GRF), minus the weight force of the board $(m \cdot g)$ and the sum of the forces accelerating individual segments modelled within the upper board $(m_{Segm} \cdot a_{Segm})$.

$$BRF = GRF - m \cdot g - \sum m_{Segm} \cdot a_{Segm} \quad (1)$$

In an iterative modeling process (Perl & Uthmann, 1997) the springboard should be generated in the interactive simulation environment software.
The aim of the present article is the presentation of the detection of mechanical board parameters and the modeling of the springboard.

METHODS: The springboard of the company Gymnova used at the Olympic Games 2012 in London was developed with the modeling and simulation environment software alaska (Institut für Mechatronik, 2014). This springboard also has the advantage that the lower board only consists of a simple frame. So it does not have to be considered in the modeling process.
The model was created based on technical joints (fixed, revolute), force elements and geometrically defined bodies. The upper board was devided into twelve segments. Each segment is linked with joint revolute elements with internal torsion springs (Lehmann, Naundorf, Schleichardt, Knoll, Seidel & Witte, 2015). With these it is possible to reflect the typical curvature of the board. The springboard springs were modeled with simple force elements. The coupling of the springboard model with environment was realized via a contact element.
The physical input parameters: modulus of elasticity, spring stiffness and rotational spring stiffness of the segments are determined experimentally. For this purpose, a test apparatus was used which detected the vertical displacement of the upper board of statically transmitted forces. The forces were determined with a calibrated force-measuring device on the board. The vertical displacement of the board was detected by a digital height gauge (Fig. 1). With this test setup, forces were gradually transfered from 0.4 to 3.6 kN (stepping up, step 0.4 kN) at measuring points (MP) measured from the fore edge (MP60: 0.6 m,

MP80: 0.8 m, MP95: 0.95 m). The vertical displacement of the upper board was detected at the outer edge of the board.

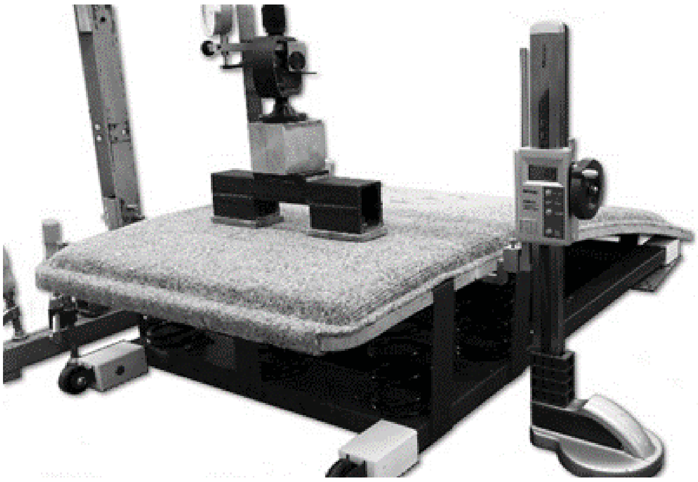

Figure 1: Test setup for the determination of the bending line.

The characteristics of the coil springs were determined by the same device.
For the reason that the structure of the upper board is made of plywood layer, plywood with a density of 0.65 g/cm³ was chosen as material for the springboard.
The model evaluation under static conditions was created by comparing the vertical displacement of the real and modeled upper board. For this purpose, static forces were applied to the MP (Fig. 2) using a force function (range 0.4-3.6 kN, step 0.4 kN, step time 0.5 s). The displacement was measured at the outer edge of the board. Subsequently, the percentage difference per load between the model and the original board was determined and the mean percentage difference across the load 0.8-3.6 kN was calculated as well.

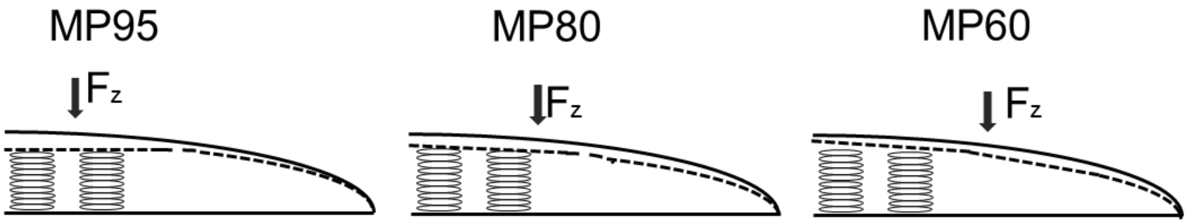

Figure 2: Test positions for static force transmission (MP95, MP80, MP60) and expected displacement of the upper board (dashed line).

RESULTS: The springboard model (Fig. 3) consists of an upper board devided into twelve segments (0.6 x 0.1 x 0.017 m). The segments are combined via torsion joints (torsion springs c = 17400 Nm/rad). The typical boarding curvature was realized by means of internal angle rules. The springs were modeled by one-dimensional single force elements (l_0 = 0.19 m, c = 10.7 N/mm) positioned according to the real board (Lehmann et al., 2015). The lower board frame was made of steel and consists of five separate parts. The model was coupled to the environment via contact elements with corresponding stiffness parameters.

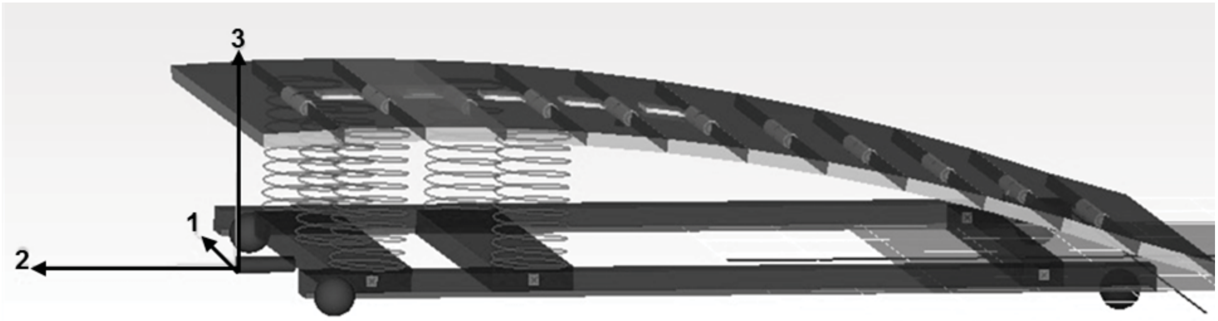

Figure 3: Model of the Gymnova springboard.

The static revision for the individual measuring points showed the percentage differences per load (Table 1). MP60 was expected to have the highest deflection value. Within this point, it was possible to measure the lowest percentage difference with 6.1 %. It is noticeable that there are strong deviations across all measuring points at the first load.

Table 1
Percentage differences in the vertical displacement of the individual load level

Load [kN]	MP60	MP80	MP95
0.4	253.0	1280.0	916.0
0.8	14.7	26.4	20.0
1.2	10.2	12.6	62.5
1.6	7.0	23.7	61.7
2.0	1.0	30.3	60.4
2.4	1.0	31.6	57.8
2.8	4.2	31.3	45.6
3.2	4.7	33.0	38.0
3.6	5.8	29.8	30.7
M (0.8-3.6 kN)	6.1	27.3	47.1
SD	4.6	6.7	16.2

DISCUSSION: By an iterative simulation a prototype model of the Gymnova springboard was developed with components available from alaska (Fig. 3). This prototype is based on a model of Sano et al. (2007). Individual board components were modeled separately and assembled into one model. The model input parameters modulus of elasticity, spring constant and board geometry were determined by experimental methods. The model evaluation was performed by comparing the vertical displacement of the real and modulated upper board. In this process, defined forces were introduced into the board and the displacement of the boards outer edges were captured. The simulated displacement of the board was realized with a force function, in which the corresponding force level was maintained for 0.5 s.

Subsequently, the percentage deviation between the real and simulated displacement of the upper panel was calculated for each load. Finally, the mean value and the standard deviation were calculated for each measuring point via the loads of 0.8 kN to 3.6 kN. It turns out that there is exceptionally high deviation in the first load step. This can be attributed to the influence of the damping foam layer on the upper board. This has not yet been included in the prototype model. For MP60, with an average deviation of 6.1 %, satisfying deviations could be realized. The differences in the other two measuring points result from the influence of the stiffness of the board springs. This must be taken into account in further evaluations.

The statically verified model will be adapted in further development steps also for dynamic applications. For future applications the main focus should be on the coupling with the environment, since the ground reaction forces will be calculated. Under standardized dynamic test conditions, the damping and stiffness of the contact elements must be optimized. This has to be realized with a fall mass test according to the guidelines of the international gymnastics association (Fédération Internationale de Gymnastique, 2006). Furthermore, the model evaluation under sport-specific loads and the remote controlled model will be focused on.

CONCLUSION: A springboard model has been developed which reflects the typical shape and functional characteristics of a board in gymnastics` vault. Modelling has successfully replicated displacement of the mid-portion of the board (MP60, main take off position for forward oriented jumps), but increasing levels of error were found when forces were applied to more distal points along the board.

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