3 DECADES OF FORCE MEASUREMENT ON VAULT IN GYMNASTICS

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Force measurement on gymnastics apparatuses can give useful knowledge about technique of gymnasts, but also on injury prevention and stress on the human body. Since 1986 direct force measurements on vault horse and tables were applied by our researchers. Aim of this paper is to publish information about the technology we used for direct force measurements. All measuring systems were customized to the apparatuses from different manufacturers. Most measures were arranged in training sessions, but we report also about data collection in official competitions. Examples of force patterns give an idea of peak forces and impulse during different vault groups (handspring, Kasamatsu).

KEY WORDS: Artistic Gymnastics, Force Sensors, Measuring Technology.

INTRODUCTION: Vault is among the gymnastics apparatuses a special one. While on other apparatus a variety of elements must be demonstrated, gymnasts achieve comparable scores on vault by a single element. The horizontal energy generated in the run-up has to be converted on the springboard and the horse (or from 2001 the table) through the jump and the push-off within a short time into vertical velocity and angular momentum. Through the objectification of the push-off can be gained basic knowledge and contribute to the optimization of technique in artistic gymnastics. Here, an optimal relationship between height of flight (vertical velocity) and angular momentum is to go for the somersault or longitudinal axis. Due to the short support periods and the insufficient accuracy of the inverse kinematics of kinematic measurement methods dynamometric methods must be used.
There is only one group of researchers who published methods and data about force measurement on vault. Penitente, Sands, McNeal, Smith & Kimmel (2010; also published at ISBS 2011: Penitente, Sands & McNeal, 2011) used two portable force platforms (0.37 x 0.37 m) on a gymnastics vault table. Twelve American National Champion Junior Olympic Levels 9 and 10 female gymnasts performed their forward handspring vault on this instrumented table. They published force reaction time patterns separated for the left and the right hand. The results of this study provided a first look at directly measured hand contact forces on the vault table of female gymnasts performing a handspring vault. Their data showed that upper extremities are subjected to impact forces very close to what is considered the fracture load.
The purpose of this abstract is to show variations of technology for a direct force measuring in vault (horse and table) during the last three decades.

METHODS: First push-off force measurements have been realized in 1986 by the Research Institute “Forschungsstelle für Körperkultur und Sport” (FKS) in Leipzig. For measurement of force we applied force sensors on the upper part of the vault horse and fixed it in a special base construction (Figure 1; Knoll, 1999). The original lower part of the horse was not stable enough. The force sensors were also installed in 3-component force platforms (Härting, Zschocke, Alvermann, Wecker & Schattke, 1982). This measuring device was only used in training sessions for East German national gymnastics team.
The first measurements during an official competition with an instrumented vault horse was realized in 1998, together with the manufacturer Spieth at the DTB-Pokal in Stuttgart. At this Spieth-horse two patented special sensors (deformation elements with strain gauges, measurement range: vertical: 7,0 kN; horizontal:4,0 kN) of Drunk (1987) were used.

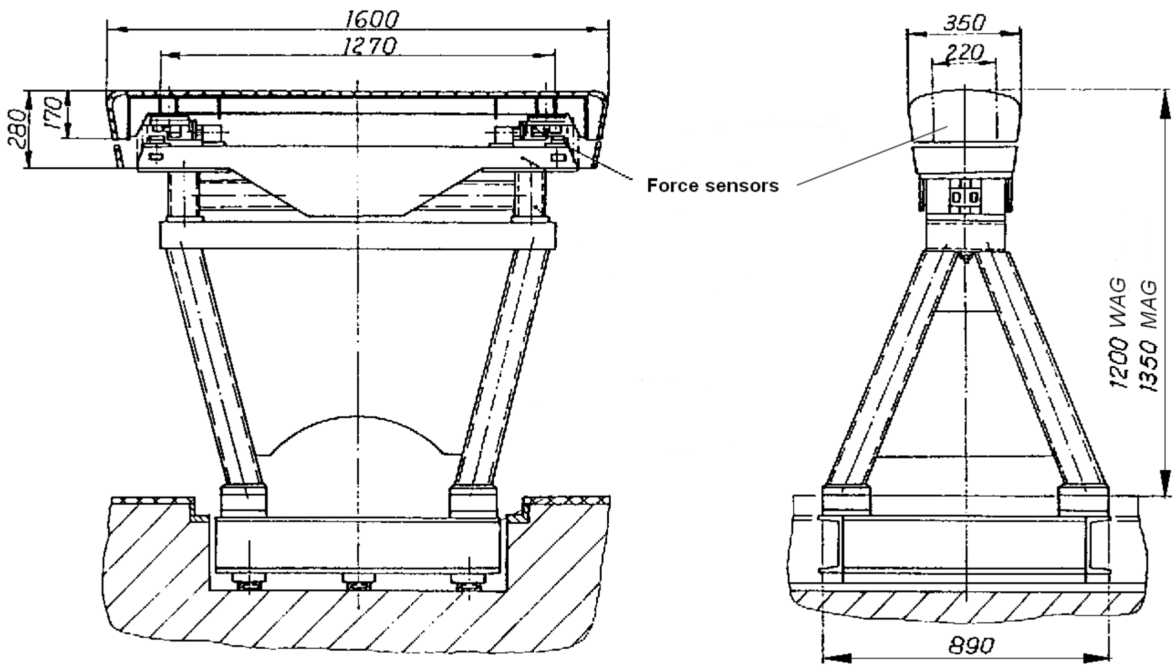

Figure 1: First force measurement device from 1986 on a vault horse

The introduction of the vault table by the International Gymnastics Federation (Fédération Internationale de Gymnastique [FIG]) in 2001 represents a challenge for the measurement of the supporting force and the measurement technology had to be revised fundamentally to the new vault apparatus. The force measurement at the vault table is now carried out by a measuring device, which is mounted between the table body and the upper part of the table (Figure 2). This consists of four force sensors (deformation elements with strain gauges of Drunk, 1987; measurement range: vertical: 3,5 kN; horizontal: 2,0 kN), which are installed between two steel plates in defined intervals. The components of the force sensors are connected such that the number of amplifiers can be reduced.

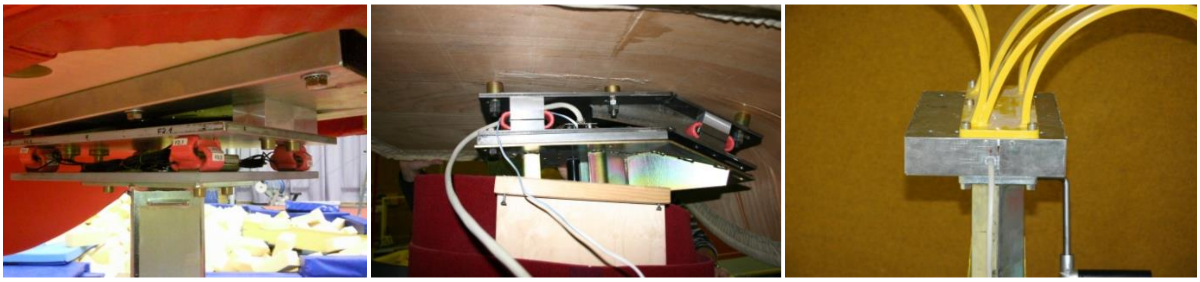

Figure 2: Force measurement device for vault table from different manufactures (left: Gymnova, center: Janssen-Fritsen right: Spieth)

The requirement of the gymnasts and coaches is to always train with the current devices of the supplier of the primary competitions. Due to the different structure of the vault tables from different manufacturers (Spieth: supplier World Championships 2007, European Championships 2011; Janssen-Fritsen: Olympic Games 2008; Gymnova: Olympic Games 2012), all corresponding to the FIG standards, specific measurement devices have been developed (Figure 2). Due to the small width in vault direction of the connecting of table body and base at the Spieth-table the measuring device had to be increased (Fig. 2, right). So we had enough distance between the sensors in vertical direction. The angled design of the substructure of the Janssen-Fritsen vault table (Fig. 2, center) requires a tilt of the front part of the measuring unit. Therefore, a separate calculation of measurement signals is necessary for two of the four sensors. In 2011 we developed a dynamometer for the vault

table from Gymnova (Figure 2, left). With this table we used wireless signal transfer for transmitting the measured data for the first time. This consists of a transmitter with integrated amplifiers and battery for the transmitter and the force sensors on the vaulting table.
For all instrumented apparatuses a static calibration was carried out for the whole measuring device and not with the individual sensors. However, the horizontal calibration was initiated at the same height difference as the original vault table dynamometer. The measurement properties of linearity, repeatability and crosstalk were determined.
A verification of the dynamic measurement properties was also applied at the vault table dynamometer. Due to the elastic foam surface of the table body, differences in signal amplitude (damping) and phase difference between the measured forces and reaction forces acting directly on the table surface were expected. Therefore experiments with falling masses were utilized to compare the force-time curves of the dynamometer with the acceleration-time histories of the falling mass.

RESULTS: Using the measured force data differences in vault groups and techniques of the same vault can be observed.
Force-time-patterns from the measuring vault horse from 1986 (Figure 3) shows different vertical peak forces depending on the technique. A gymnast with near vertical arm position at horse impact during the handspring shows about half peak force (technique 2) than a gymnast with near diagonal arm position (technique 1). This result is not only interesting for performance development, it is also important for injury prevention and overuse in vault training.

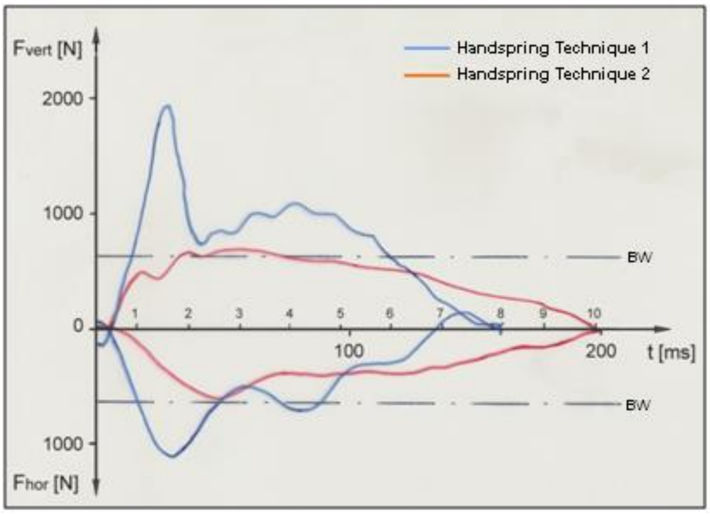

Figure 3: Force-time pattern of different techniques from handspring vaults (F_{vert}: vertical absolute force; F_{hor}: horizontal absolute; BW: body weight)

Because of its heavy, but stable construction the table from Janssen-Fritsen for the Olympic Games in Beijing 2008 have the best measuring properties. Force data from the Janssen-Fritsen table from German national Olympic qualification 2008 were shown in Figure 4. The two force-time patterns are from the same gymnast, but left from his handspring vault (Handspring and double somersault forward tucked) and right from his Kasamatsu vault (Kasamatsu layout with 1/1 turn).

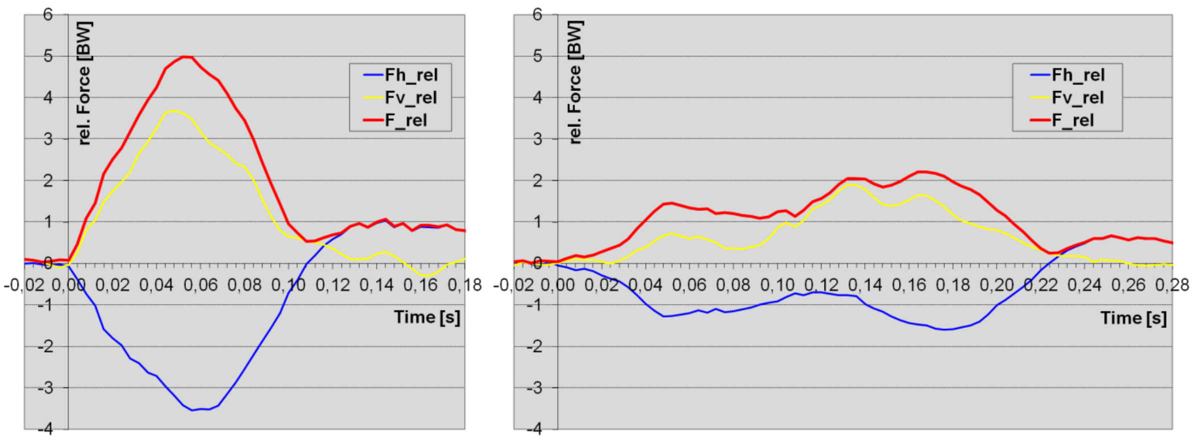

Figure 4: Force-time pattern from handspring (left) and Kasamatsu (right) of the same gymnast in one competition (Fh_rel: horizontal relative force; Fv_rel: vertical relative force; F_rel: resultant relative force; BW: body weight)

Because of the simultaneous hand support at the handspring vault and the successive hand support during the Kasamatsu vault there are differences in peak force and in contact time. The peak force for the handspring is 5x body weight (BW), for the Kasamatsu only about 2x BW. The support phase for handspring is about half time from the Kasamatsu vault. Additionally for the Kasamatsu you can see the successive hand support and the higher importance of the second part of the support phase.

DISCUSSION: Our force data were not comparable with data from Penitente, et al. (2010) because we report force date from men's artistic gymnastics. But also the measuring systems were not comparable. Penitente, et al. (2010) placed force plates on the table, our group build force sensors into the vault table/horse. Nevertheless it would be interesting to compare data from same sex, level of performance and the same vault with the different measuring systems. Results from the time of the support phase were comparable to Bradshaw, Hume, Calton & Aisbett (2010). These researchers use a contact mat on the vault table in every day training.

CONCLUSION: The vault horse or vault table dynamometer can be used up to the first construction with the special base construction in training and also in competition. The vaulting horse dynamometer was first used at the 1998 "DTB-Pokal" in Stuttgart and the measuring vault table at the "Tournament of Masters" in 2002 in Cottbus. More competition highlights with force measuring were the German World Championship Qualification in 2007, the International Tournament Euro Stars 2008 in Dessau and the German Championships (National Olympic Qualification) 2008 in Chemnitz. In squads training camps of the German Gymnastics Federation, the dynamometer can be used with software for immediate information to the Gymnasts and coaches. Information on the main biomechanical parameters of the force measurement (maximum forces and impulses) and synchronized video recordings, supplemented by the run-up velocity, will help in the optimization of sporting equipment.

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