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A study on the dynamic structural behavior of Olympic sabres

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Abstract

Sabres used in Olympic fencing are subject to severe elastic deformations during matches and training sessions. Even though strict rules for their manufacturing are prescribed by the international fencing federation, with requirements in terms of geometrical constraints and material (steel) properties, nonetheless frequent unexpected ruptures are observed. These may cause injuries to the fencers, and involve the replacement of the blade. In this study an experimental-numerical approach is adopted to investigate the underlying failure mechanisms. To this purpose, several attacks, “bouts” in fencing, were live filmed during actual practice with digital cameras and a trajectory tracking analysis was performed on the most critical of them, taking advantage of markers fixed on the blades at different positions. The post-processed data were subsequently used as boundary conditions of a 3D finite element model of the blade. Running a non-linear transient analysis, global and local quantities such as maximum stored elastic energy, stress and strain states, strain rates and possible permanent plastic strains were evaluated. A validation of the FE model with experiments was also carried out. From the critical analysis of experimental and numerical results it was possible to speculate about the influence of materials and dynamic related effects on the structural behavior of the blade. Eventually, hypotheses on fracture mechanisms were formulated.

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1. Introduction

Sabre is an Olympic sport since 1896, the equipment showing many peculiar engineering features during operation (blades are subject to very large elastic deformations and possibly plastic deformations). As a matter of fact, frequent unexpected ruptures are observed during trainings and matches, despite stringent specifications in terms of geometry and materials imposed by the International Association of Athletics Federations (IAAF Rules for Competition, 2016). Some of these ruptures may create sharp corners potentially dangerous for the athletes. Furthermore, these failures contribute to shorten the average sabre life (i.e. around two weeks) increasing the expenses for practicing the activity, since the cost for a good quality unit is quite high. It is worth noting how very few investigations on this topic are available in the literature, Chen et Al (2017). It has been observed in Coppola et Al (2016), that the sabre fracture behavior depends from a number of factors not fully quantified yet, and not directly related to the fracture type. Among them we can indicate the blade geometry and steel microstructure, mass, speed and fencing style of the athletes.
The present paper focuses on the analysis of the most critical kind of bouts, which has been identified partly relying on a previous study from Coppola et Al (2016), and partly on field observations during training with athletes performing actual bouts. The most severe condition for the sabres occurs when both athletes go in lunge at the same time: in this case the inertia of the two bodies moving one towards the other contributes to produce severe loads on the blades. Based on this challenging condition, an experimental-numerical dynamic study was performed to quantify the absorbed elastic and plastic energy, the state of stress and strain at critical points, and plastic deformations, if present. All results will be presented and discussed in the paper. The increased know-how on the mechanical behavior of the sabre will be useful to understand underlying failure mechanisms, improve the performance of such sporting tools, in terms of resistance, duration and safety, and might also lead to the identification of an equivalent laboratory test to be used as a certification for these sporting tools.

2. Experimental activities

The experimental activities were devised to measure the position and velocity of different points of the sabre during an actual bout. To this purpose many lunges were live filmed in a gym by using a digital camera to be successively post processed through a dedicated 2D analysis software. The acquired data will provide information on the structural dynamic behavior of the equipment and will serve as boundary conditions for a numerical structural simulation of the bout as well as for its validation. Capabilities and limits of single camera tracking in biomechanics are well documented in the literature, see for instance Pentenrieder et Al. (2006) and Yang et Al (2013).

A black uniform background was chosen for the scene, to maximize the contrast with performers, while two light sources were arranged to prevent cast shadows. The blades of the sabres were treated with an anti-reflective coating to limit reflection. In addition, several yellow and red markers were placed on the blade to be recognized by the video analysis software. They were spaced with an increasing density towards the tip, being the sabre stiffness non uniform because of its tapered geometry, which induces the largest deformations close to the tip itself. It is worth noting that failures are usually observed in this region of the blade. The camera distance from the athletes was chosen to frame the whole sabre shape during lunge movements and to have the action, and hence the contact between the athletes and the sabres, centered in the image. Several shooting session were performed, and the most significant lunges were successively identified. The performers, professional athletes, were asked to execute lunges as much as possible on a plane of motion perpendicular to the axis of the camera, to reduce perspective distortions. Each video was recorded at 240 fps with a consumer type digital camera.

The most severe lunges, presenting a residual plastic deformation on the blade, were analyzed with the free software Tracker (http://physlets.org/tracker). It offers a smart auto-tracking function, which seeks a target pattern of pixels defined in the first frame within a region of interest, in the subsequent frames, using digital correlation functions. After imposing the global coordinate system and scaling factors, positions and velocities of the markers over time could be obtained using the auto-tracker. The final result is visible in Fig. 1, showing some snapshots of the most critical lunge analyzed, that will be presented in this work (on the left), along with the deformation of the blade over time (on the right), relative to the handle.