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Development of a novel portable test device to measure the tribological behaviour of shoe interactions with tennis courts

Daniel Ura* and Matt Carré

Department of Mechcanical Engineering. The University of Sheffield, Mappin Street, Sheffield, S1 3JD, UK

Abstract

The interaction between tennis player and court is a complex problem determined by parameters that can be broken down as: the range of player movements and loading (e.g. push-off and sliding); a variety of surfaces (e.g. clay, acrylic and grass) and different shoe properties (e.g. sole material and tread geometry). These combinations generate different levels of friction that relate to both playing performance and safety. This paper presents the observations, findings and design methodology of a mechanical portable device to improve the understanding of tennis shoe-court interactions and allow courts to be measured and monitored.
Case studies of biomechanical player testing (kinetics and kinematics) and examination of how the tribological mechanisms change with different parameters (e.g. shoe orientation, contact area, roughness, shoe temperature), were considered in the design of a device capable of simulating the key aspects of the player-court interaction.
Eventually, this portable device will be an integral part of a standard test protocol for the International Tennis Federation, to quickly assess courts around the world and aid in the provision of high quality courts for elite use.

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Keywords: Tennis; shoe-surface; friction; tribology; mechanical test device

1. Introduction

Establishing the characteristics of player-court interaction in tennis is a key challenge. A crucial element in tennis is that it is played on different surfaces, where the main factor between the shoe and the surface is the level of friction [1]. The governing body of tennis (International Tennis Federation) is responsible for setting the rules and maintaining the standards of the sport, and therefore needs a system to quickly assess courts around the world and rate them according to expected performance during player interaction. This complex interaction is primarily determined by the player, surface and shoe. The interaction between these parameters can be broken down further as: the range of player movements (e.g. push-off and sliding), on a variety of surfaces (e.g. clay, acrylic and grass) and different shoes properties (e.g. material and tread geometry). These combinations generate different levels of friction that relate to both playing performance and safety.

The aim of this paper is to present the observations, findings and design methodology of a mechanical portable device to improve the understanding of tennis shoe-court interactions and allow courts to be measured and monitored.

Nomenclature

COF, COT	Coefficient of friction, coefficient of traction
CC, HC	Clay court, hard court
DCOF	Dynamic coefficient of friction

* Corresponding author. Tel.: +0-000-000-0000 ; fax: +0-000-000-0000.
E-mail address: author@institute.xxx

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DMTA	Dynamic mechanical thermal analysis
F_z	Vertical component of Ground Reaction Force (N)
ITF	International Tennis Federation
LVDT	Linear variable differential transformer
P_{peak}	Pressure peak (kPa)
Ra	Mean roughness value (μm)
SCOF	Static coefficient of friction
SD	Standard deviation
TS1, TS2	Test shoe slider 1 and 2
TSSTv1	Tennis shoe-surface test version 1

2. Biomechanical studies

In order to provide the boundary conditions for the mechanical test rig, a number of tennis biomechanical studies were analysed to collate relevant kinetics and kinematics data from tennis players performing typical tennis movements on different surfaces. Several lab and field studies [2-5], shown in Table 1, have reported human loading conditions during dynamic tennis movements on hard and clay courts. However, due to the magnitude of the forces, the challenge relies on replicating them on a tennis court with a light, portable device. However, knowledge in-shoe pressure data [6-8] opens the possibility to develop a field device that replicates levels of pressure, rather than force. Table 1 exhibits a summary of the reported values of different studies of foot peak pressures on clay and hard courts during running forehand, side jump, sliding, and baseline serve and volley movements.

Table 1. Summarised F_z and P_{peak} (SD) data of different movements on two surfaces (references cited for each).

	F_z		P_{peak}	
Movement	**HC**	**CC**	**HC**	**CC**
Forehand	1469 (583) [2] 1681 (484) [3] 1936 (484) [4]	1351 (379) [2] 1829 (393) [3]	417 (77) [6] 512 (85) [6]	379 (74) [6] 456 (112) [6]
Side Jump	1244 (100) [3]	1317 (82) [3]	428 (71) [6]	351 (73) [6]
Turn	1432 (593) [5]	1319 (500) [5]	-	-
Stop	1833 (646) [5]	1680 (713) [5]	-	-
Baseline play	-	-	381 (69) [7]	404 (137) [7]
Sliding	-	-	-	200 – 220 [8]

3. Tribological mechanisms

Tennis shoes outsoles are made from viscoelastic rubber. When this rubber is compressed against a hard tennis surface with some roughness, there is an interaction between their asperities, and hence a friction. There is some evidence of test methodologies utilised to measure the friction between a rubber foot and a tennis court. A pendulum test (Slip resistance test, ITF CS 02/01), and The Crab III devices have been previously used to examine translational surface friction on acrylic tennis courts [9].

Although translational friction has been measured with the equipment mentioned, there are various parameters that need to be considered during the design of new test methodologies. During typical dynamic tennis movements (e.g. push-off, running, sliding), the friction between the viscoelastic material and a hard substrate is ruled by different parameters such as the normal load, surface roughness, shoe orientation and temperature, and contact area [10-14]. These affect the contact between the asperities of the two materials, and hence, the adhesional and hysteretic components of the friction. Fundamental friction mechanisms were examined by two initial studies that formed the basis for further device development:

In the first study [10], the effect of a shoe normal force applied to a surface on friction was studied. Via a laboratory based test rig, it was found that friction is dependent on the normal force. As the normal force applied to a surface increases, the COF (referred to in this study as "coefficient of traction", COT) decreases and a power relationship can be fitted as shown in Figure 1(a).

The second study [11] showed that relationships between roughness and dynamic friction were found to be also dependent on the normal load. Under high normal loads (e.g. 1000 N), the friction decreases with roughness, reaches a minimum and then increases as the roughness increases. The opposite behaviour is observed under low normal loads (e.g. 500 N), and the trend is for friction force to increase with roughness, reach a maximum and then decrease as the roughness increases.

Another study, [12] examined the effect of shoe orientation on the friction generated by the shoe-surface interface. Friction tests were performed on an acrylic hard court tennis surface. A forefoot segment of a commercial tennis shoe was pressed and then made to slide, when mounted in four orientations, 0, 30, 60 and 90°, relative to the sliding direction. Strong and significant relationships were found between normal force and dynamic friction force showing differences between the orientations shown in Figure 1(b).