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ScienceDirect

Procedia Engineering 147 (2016) 407 – 412

Procedia Engineering

www.elsevier.com/locate/procedia

11th conference of the International Sports Engineering Association, ISEA 2016

Effect of clubhead inertial properties and driver face geometry on golf ball trajectories

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Abstract

There are many factors that influence the amount of side-spin imparted to a golf ball during impact with a driver. In general, the best golf drives are launched with minimal side-spin, producing a straight ball trajectory with maximum carry distance. During off-centre impacts, side-spin is generated due to a phenomenon known as the "gear effect." The extent of the gear effect depends on clubhead design parameters such as the moment of inertia and centre of gravity location. The bulge of a driver is a design feature implemented to counter-act the side-spin produced by the gear effect. In this investigation, an impulse-momentum impact model and an aerodynamic ball flight model are used to (i) examine the effect of the centre of gravity depth (distance from clubface) on ball trajectory during off-centre impacts, (ii) test the efficacy of movable weight technology, and (iii) optimize the bulge radius in relation to the clubhead's centre of gravity depth and moment of inertia. In the first study, it is qualitatively shown that side-spin increases linearly with increasing centre of gravity depth. In the second study, it is found that movable weights can have a significant effect on ball trajectory, especially at higher swing speeds. In the third study, a relationship between the bulge radius, centre of gravity depth, and moment of inertia is developed, and an equation for calculating the optimum bulge radius is fit to the simulation results.

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Peer-review under responsibility of the organizing committee of ISEA 2016

Keywords: Golf; Simulation; Clubhead Design; Optimization

1. Introduction

Designing a driver clubhead is a balancing act involving several physical design parameters. The goal is to produce a clubhead that provides the greatest carry distance while maintaining a suitable level of forgiveness for a particular golfer. A forgiving driver is one that maintains a high level of performance when contact is made outside the "sweet spot," or away from the centre of the clubface (CoF). When it comes to forgiveness, two of the most discussed design parameters are the clubhead's moment of inertia about a vertical axis (MOI_y), and its centre of gravity (CG) location. However, the bulge radius also plays a crucial role in controlling the trajectory of off-centre impacts, and often goes overlooked in the discussion surrounding driver forgiveness. Using computer models to simulate golf drives, the effect of these clubhead parameters on ball trajectory can be analyzed.

Nomenclature

CoF	centre of face	*b*	bulge radius
CG	centre of gravity	e	coefficient of restitution
CG_x	distance from the CoF to the CG along the 'x' axis	*X*	actual carry distance
MOI_y	moment of inertia about the vertical 'y' axis	*M*	weighted carry distance
ω	angular velocity	*W*	weighting parameter
R	horizontal distance from the CG to the contact point	*Z*	deviation
r	golf ball radius	Z_{max}	maximum acceptable deviation

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Peer-review under responsibility of the organizing committee of ISEA 2016
doi:10.1016/j.proeng.2016.06.329

1.1. Moment of inertia, centre of gravity, and the gear effect

A clubhead's MOI_y refers to its resistance to rotation about its vertical axis. A higher MOI_y provides more forgiveness during off-centre impacts with the golf ball. The mechanism behind this increase in forgiveness is due to a phenomenon known as the "gear effect," illustrated in Fig. 1 [1]. When the clubhead strikes the ball near the toe, the impact generates a moment about the clubhead's CG, causing it to rotate clockwise (right-handed golfer). During the impact, the clubhead and ball can be thought of as two gears that are meshed together. When two gears are meshed, the contact point on both gears must share the same tangential velocity, $v_{contact}$, equal to the radius of the gear multiplied by its angular velocity. Following this analogy, the side-spin imparted on the ball due to the gear effect can be approximated by Eq. (1), where R is the horizontal distance from the clubhead CG to the contact point (equivalent to CG_x), r is the radius of the golf ball, and ω is the angular speed, or spin.

$$R\omega_{\text{club}} = r\omega_{ball} \tag{1}$$

Given that r is a constant, the side-spin resulting from the gear effect is proportional to $R\omega_{club}$. Increasing the MOI_y of the clubhead reduces ω_{club} during off-centre impacts, thus reducing the amount of spin imparted to the ball, which leads to longer and straighter drives. Conversely, increasing R by moving the CG away from the clubface increases the spin imparted to the ball. In Fig. 1, the counter-clockwise ball spin generated from a toe impact causes the ball to curl to the left [2]. This ball flight is known as a "draw." A heel impact causes the ball to spin in the opposite direction, and creates a ball flight that moves to the right, known as a "fade." Due to the forgiving nature of high MOI_y, the sport's governing bodies have limited the clubhead's MOI_y to a value of 5,900 ± 100 g-cm^2 [3].

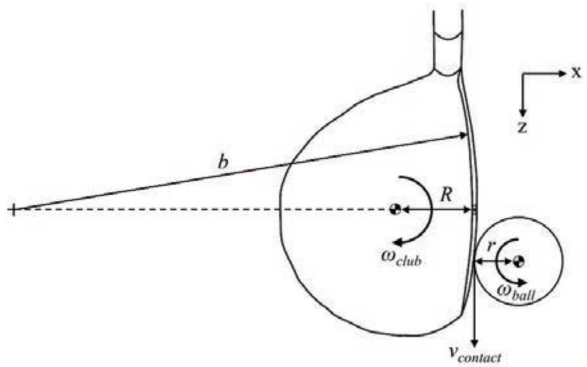

Fig. 1. Illustrating the gear effect for a toe impact.

1.2. Bulge

The bulge b of the clubhead is the radius of curvature of the clubface in the horizontal plane. The purpose of the bulge is to counter-act the side-spin generated by the gear effect during off-centre impacts. The bulge negates the gear effect both directly and indirectly. The bulge indirectly counter-acts the gear effect by altering the normal direction of the impact thus changing the direction of the ball's initial velocity. For example, the trajectory of a toed ball would start towards the right because of the bulge, and draw back towards the centre of the fairway due to the side-spin generated by the gear effect. The bulge directly counter-acts the gear effect spin by generating an opposing moment on the ball caused by the horizontal contact angle, assuming that the clubhead velocity is parallel to the X axis in Fig.1; this is analogous to the backspin produced by club loft. If the bulge radius is too small, the counter-spin generated can overpower the gear effect, causing the ball trajectory to remain straight or even curl the opposite way. If the bulge radius is too large, the spin generated from the gear effect will be overpowering, causing the ball to curl too much. Selecting the correct bulge radius can be the difference between a driver that is forgiving and one that is not.

1.3. Golf Drive Simulation

To simulate golf drives with varying clubhead parameters, an impulse-momentum impact model validated with finite-element analysis [4] is used in conjunction with an aerodynamic ball flight model [5]. The impact model requires the clubhead's physical properties and impact conditions as inputs, and outputs the ball launch conditions. The aerodynamic ball flight model uses the ball launch conditions to simulate the ball flight. An example of a perfectly square impact having an angle of attack of 0 degrees, an impact location of 2.5 cm towards the toe, and a clubhead speed of 50 m/s is shown in Fig. 2. Table 1 lists the nominal clubhead parameters used in the impact model. Due to the impact location being towards the toe, a drawing ball flight is observed.

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