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Putter features that influence the rolling motion of a golf ball

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Abstract

We present the results of a theoretical and experimental study into the influence of various putter head design features on the rotational dynamics of the ball following putter impact. It is found that ball launch conditions can be tailored by designing the putter head with the appropriate combinations of face loft, center of gravity and moment of inertia. Face treatments, such as inserts and grooves, effect the coefficient of restitution and friction coefficient at the contact point and thus provide additional design parameters to control the launch conditions of a putt. Experiments demonstrate that inserts and grooves can modulate the coefficient of restitution of the impact, but not in a manner that gets the ball rolling earlier for fixed length putts.

Keywords: Golf, Putting, Kinematics

1. Introduction

Putting, which accounts for nearly half of the strokes played, is obviously an important component of the golf game [1]. Since putting is performed with a single club, optimized putter design is therefore paramount. For a long time, putter design has mostly focused on tailoring the inertia properties of the clubhead in the horizontal plane, to maximize performance on off-center heel-toe impacts. Over the past 10 years, there has been interest in examining how the inertia properties of the putter in the vertical plane, as well as face treatments, would improve performance by reducing the skidding distance of a putt. The intent is to achieve pure rolling motion of the ball earlier in the putt trajectory, conceptually producing more stable putts via the spin stabilization effect [2].

Lindsay [3] presented a theoretical and experimental study showing that careful selection of the center-of-gravity (CG) and moment of inertia (MOI) of the putter head around the heel-toe axis could minimize and even eliminate the initial skidding phase of a putt. Brouillette and

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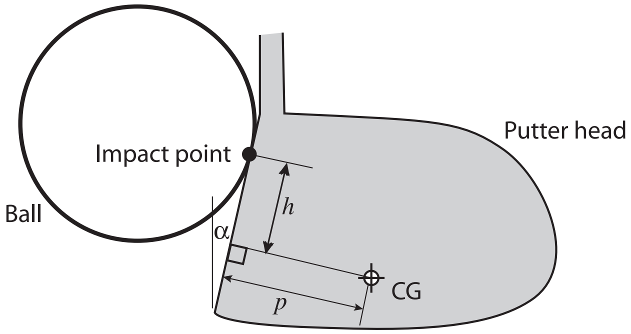

Figure 1: Schematic for collision of putter head with golf ball in the vertical plane passing through the center of gravity (CG) of the head.

Valade performed an experimental study on commercially available putters, all equipped with either polymer inserts or face grooves, that showed that these face treatments had a minimal effect on the skidding phase of a putt [4].

The present study examines how the combined effects of inertia and face properties of putter heads influence the rotational dynamics of the ball following putter impact. Specifically we first develop a theoretical model of the putter-ball collision accounting for the effects of face loft, CG location, MOI and normal/tangential collision coefficients. We then present experiments examining, for fixed putter inertia properties, how various face treatments can influence the initial motion of a putt.

2. Theory

A 2-D theoretical model for the collision of the putter head with the ball is used to examine the launch conditions of putts as a function of putter design parameters, in particular face treatments. The geometry of interest is shown in Figure 1, where, for the purposes of this study, we only consider collisions in the vertical plane passing through the clubhead CG. The CG is located at a depth p behind the face of loft angle α; the collision takes place on the clubface at a height h above the normal projection of the CG on the face and k is the radius of gyration of the putter head around the heel-toe axis passing through the CG. Since the response time of the shaft is much slower than the collision time with the ball, we can neglect the effects of the shaft. Assuming that both the clubhead and the ball behave as rigid bodies, for known head initial conditions it is possible to compute the launch conditions of the ball by applying conservation of linear and angular momentum. Closure of the system is achieved by defining a normal coefficient of restitution (COR) e, and specifying a tangential kinematic condition at the point of impact via a friction parameter f, where $f = 1$ applies a no-slip boundary condition and $f = 0$ a frictionless condition.

For a putter head in pure translation before colliding with the ball, the velocity and spin vectors of the ball just after the collision can be computed as a function of the putter initial velocity vector, all in the vertical plane. From the computed ball velocity and spin, it is then possible to define a so-called "ball roll ratio" R defined as the normalized quotient of the ball angular and translational velocity components, such that $R = \omega r/V$, where r is the ball radius, ω is the angular velocity and V the velocity of the ball just after the collision [3]. For $R = 1$ the ball is therefore in pure rolling motion and for $R < 0$ the ball has initial backspin; for any value of $R < 1$ there will be a potentially deleterious skidding phase before the ball acquires pure rolling motion.

If we assume that the putter face loft is small, we can obtain a simple relation for the roll ratio as a function of the various parameters of the collision:

$$R = \frac{HP}{[I\,(P^2 + M + 1)\,M]} - \frac{(M+1)\,f\alpha}{(1+e)\,[I\,(P^2 + M + 1)\,M]} \tag{1}$$

where $P = p/k$ is the normalized CG depth, $H = h/k$ the normalized impact height, $M = m_h/m_b$ the ratio between the mass of the head m_h and the mass of the ball m_b and I the normalized moment of inertia of the ball $I = I_b/(m_b r^2)$ with I_b the ball moment of inertia around its center.

This formula expresses the initial rolling motion of the ball as a function of putter design features, namely CG location, MOI, face loft, COR and friction parameter, which are, in concept, all under the control of the designer. The first term of Eq. 1 represents spin production via the so-called vertical gear effect and the second term describes backspin production through the oblique collision with a lofted face. A good putter design, at least from a ball rotation point of view, would balance these parameters to achieve a roll ratio as near to 1 as possible to avoid initial skidding of the ball. This is achieved by maximizing the first term while minimizing the second term in Eq. 1.

The position of the point of impact relative to the projection of the CG on the face determines the magnitude of the vertical gear effect; impacts below the CG projection (H negative) produce backspin while impacts above this point produce topspin. Since this effect is directly proportional to H, the roll ratio is improved by increasing the impact height, which can be achieved by lowering the CG. For low values of normalized CG depth, the vertical gear effect term is proportional to P, while for large value it goes inversely proportional to this parameter; this indicates that the vertical gear effect is maximized at an intermediate value of normalized CG depth. Vertical gear effect is also magnified with decreased putter mass. Indeed, as observed by Lindsay, a careful putter design, using a judicious combination of putter mass, CG height and depth, impact location and horizontal MOI, can produce initial topspin with a roll ratio near 1, thus nearly eliminating the skidding phase of a putt [3].

As can be seen from Eq. 1, the magnitude of the deleterious backspin term is directly proportional to putter loft α. To reduce initial backspin, this term can be minimized by decreasing face loft. Indeed, most recent putters with so-called roll-promoting performance have very little loft (2-3 degrees) as compared to conventional putters (4 to 12 degrees) [4]. However, putter loft cannot be reduced indefinitely without introducing negative effects such as low launch angle, which may drive the ball to plow through the grass rather than ride on top of it. Backspin can also be reduced with increased normalized CG depth; putter head mass however does not play an important role in backspin production.

Here we are interested in the effects of face treatments, such as inserts and grooves, on the roll performance of putters. From Eq. 1, these effects are parameterized through the COR e and friction parameter f, which appear only in the backspin term. It is seen that increasing the COR of the collision improves the roll ratio by reducing the magnitude of the backspin term. Improving the COR of the collision is achieved by matching the compliance of the face with that of the ball, and this can be implemented with numerous face treatments options, the simplest being face inserts. This effect is expected to be marginal, however, since the COR, already around

$e = 0.80$, cannot be increased beyond the value of 1. Furthermore, changing COR also directly influences ball speed, which ultimately determines the length of a putt. High COR putters would have to be swung more slowly and/or with a shorter amplitude of motion to avoid consistently long putts, potentially leading to more distance control problems.

The backspin term is also directly proportional to the friction parameter f, which can be modulated to tailor roll response. A high friction face would promote a non-slip boundary condition ($f = 1$) and thus produce more backspin than a frictionless face ($f = 0$) which could, in theory, eliminate backspin. Many design features can be used to modulate friction at impact. For example, grooves are used on wood and iron faces to increase the friction coefficient when grass is trapped between the clubface and the ball, such as for shots from the rough. For putting, however, the clubface has very little loft, there is no rough and backspin is to be avoided if the ball is to be set in pure rolling motion as early as possible. So it is not obvious that grooves, which conceivably increase the friction parameter, may be a useful design feature in putters and, in fact, they may produce more initial skidding. Some putter face inserts have also been promoted for their beneficial friction-reducing properties and there is a theoretical basis for this effect in the above formula.

Intriguingly, a negative value for the friction parameter would produce topspin on a lofted face. In concept, this could be achieved with a face treatment having a tangential compliance sufficiently small such that an oscillatory tangential motion of the ball would be promoted with a period of the same order of magnitude as the impact time. This effect could also be achieved with a high compliance face having specific design features that exploit the tangential compliance of the ball. In these cases, if all dynamic parameters are properly matched, the ball could in theory be released upwards with topspin, with a launch angle higher than face loft, or at least with less backspin and a higher launch angle than for a conventional face. It is doubtful that most recent face treatments used in commercial putters, such as polymer inserts and grooves, achieve a negative friction parameter in practice, and this was demonstrated in a recent experimental study [4].

3. Experiments

Our goal is to characterize the effect of different face treatments, such as inserts and grooves, on the incipient rotational motion of a putt. To achieve this, the same basic putter was used for all tests, for which various face treatments could be added while the inertia properties and the loft remained invariant.

Putts were performed with a mechanical golfer based on a pendulum design. Basically this comprised an arm attached to a frictionless pivot at the shoulder end. The grip end of the arm was equipped with a fixture to firmly hold the club. The entire arm-putter assembly was free to move as a rigid body around the pivot axis, which could be adjusted to ensure that the trajectory of the putter head lied in the vertical plane, producing a "pure inline stroke" [1]. To initiate a putt, the putter head was pulled back a pre-determined distance from the ball and released from rest from this starting position. Gravity was the only force exerted on the putter-arm assembly before and after collision with the ball. The motion of the ball during the putt was filmed using a digital high-speed video camera at a framing rate of 250 images per second. The field of view covered the motion of the ball for a spatial interval covering 0-90 cm from the initial ball location. Marks on the ball were used to measure the angular position from each frame, and angular velocities were obtained by simple backward finite difference from the angular position data. More details about the experimental setup can be found in [4].

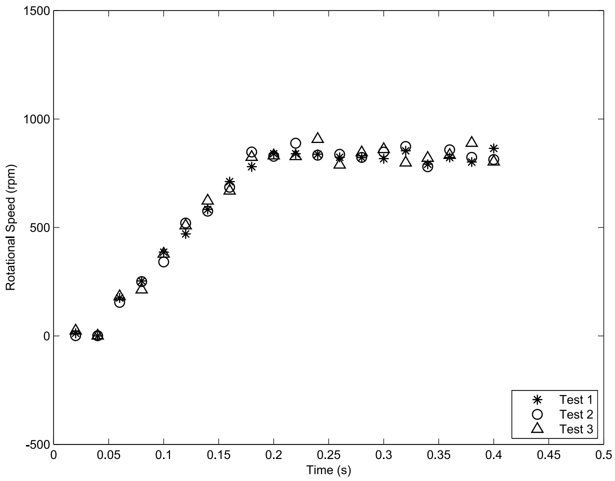

Figure 2: Rotational speed of the ball vs. time, plain putter. Time origin (t = 0) corresponds to putter impact with the ball.

Putts were performed for a variety of experimental conditions, but for brevity the present study only reports experiments performed with a two-piece ball rolling on a rubber surface with the collision taking place at a zero putter angle of attack for putts of about 20 feet (6 m). To ensure repeatability, at least three tests were performed for each experimental condition. Five different putter face configurations were created by attaching various 6 mm thick plates to the face with black electrical vinyl tape. Two plates were flat aluminum (Al) or polyacetal (Delrin) and two plates were from the same materials but had machined grooves (1 mm x 45 degrees); the fifth configuration (plain) had no plate attached.

Figure 2 shows typical results for the measured rotational velocity of the ball as a function of time after impact. The different symbols show the data for three identical tests, which exemplify the repeatability of the experiments. As expected, the rotational velocity is initially near zero and here is slightly negative, indicating backspin is produced. Following this initial backspin stage, the rotational velocity subsequently increases as the ball is skidding, until it reaches a maximum value at which point it begins its pure rolling motion; this maximum value of rotational velocity is also indicative of putt length. The time, ball position and ball velocity at which the ball has ended its skidding phase and begun its pure rolling phase can thus be inferred from the analysis of each curve. From these particular data it is found that the skidding distance for this putt is 43.9 +/- 0.4 cm.

Figure 3a shows the maximal rotational speed, in rpm, and skidding distance, in mm, for putts performed with the five aforementioned putter face configurations, with the putting pendulum set at a fixed backswing distance to produce identical initial conditions for all putts. As seen in Fig. 3a, the highest maximal rotational speeds, and therefore longer putts, are produced with the plain and Al face putters, indicative of similar high COR, while the Delrin face produces shorter putts, due to a lower COR. Both grooved faces lead to a reduction in putt length as compared to the non-grooved faces in the same materials, indicative of a reduction in COR due to the presence of

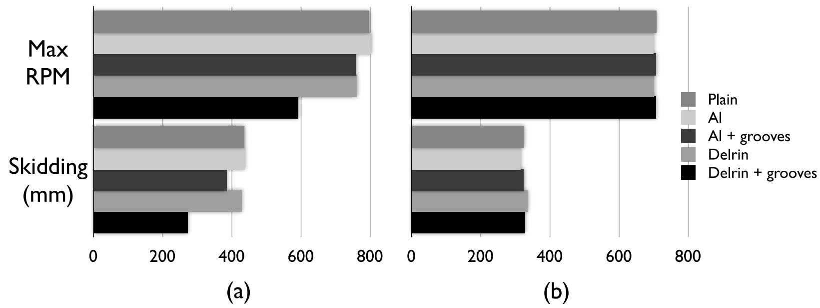

Figure 3: Maximum rotational velocity (in rpm) and skidding distance (in mm) for tests with the five putter configurations. (a) Putter backswing constant. (b) Putter backswing adjusted for uniform putt length.

grooves.

Figure 3a also shows the skidding distance for this experiment. The longest skidding distances are produced with the non-grooved faces and skidding distance is seen to decrease for both grooved faces, with the Delrin grooves providing the most dramatic reduction. This could be interpreted as an indication that grooves are improving rolling performance of putts, but one has to remember that putts with the grooved face are also shorter.

However, if the experiment is repeated by adjusting putter backswings to produce the same putt length for all face configurations, the conclusions are dramatically different, as shown in Fig. 3b. For the same putt length obviously the maximum ball rotational speed should be the same, and this result is confirmed in the figure. Interestingly the results also show that the skidding distances are also the same, indicating that the various face configurations investigated have no influence, within experimental error, on the rotational motion of the ball for putts of similar length.

The results seem to show that the use of various face materials and/or grooves can have a marked effect on the COR of the collision, directly influencing ball speed and therefore putt length. In the present case, the use of grooves appears as an effective method to modify the COR of the collision, as does the use of a soft face material such as Delrin. Within the studied face configurations, it appears that it was not possible to appreciably modulate the friction parameter and thus effecting the backspin produced. Indeed, the similar observed skidding distances appear to show that the friction parameter was similar for all tests, regardless of face material and grooves.

4. Conclusions

We have developed a simple theoretical model for the collision of a putter with a golf ball. The model shows that ball launch conditions can be tailored by designing the putter head with the appropriate combinations of face loft, CG location and MOI. For sufficiently low lofts typical of putters, it is theoretically possible to produce initial topspin on the ball for sufficiently low CG locations and small value of the MOI around a horizontal axis parallel to the face. Face treatments, such as inserts and grooves, may effect the coefficient of restitution of the collision and friction at the contact point between the clubface and the ball and thus can provide additional design parameters to control the launch conditions of a putt. In particular, modulating the effective tangential compliance at the impact point can in theory reduce backspin to shorten the skid phase of a putt.

An experimental study was performed with various face treatments applied to the same putter, so that the mass properties remained invariant. In particular, the putter was modified by attaching a 6-mm thick aluminum or Delrin plate to the face, and these plates were either flat or grooved. For a given stroke, it is found that face plates with grooves reduce the skidding distance of the ball, but also lead to lower ball speed and thus shorter putts. However, when adjusting the putter stroke to produce the same ball speed and putt length, there is no difference in skidding distance for all face plates and even the unmodified putter, within experimental error. This suggests that face treatments such as inserts and grooves, can indeed modulate the normal interaction between the putter and the ball, but, for a given putt length, they have no effect on the skidding distance of the ball in the present study.

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