THE “SWEET SPOT” OF A DRIVER BY MEASURES OF POST-IMPACT CLUBHEAD ROTATION

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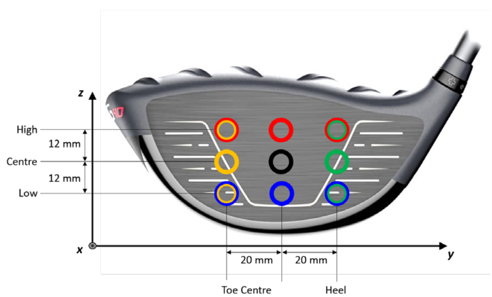
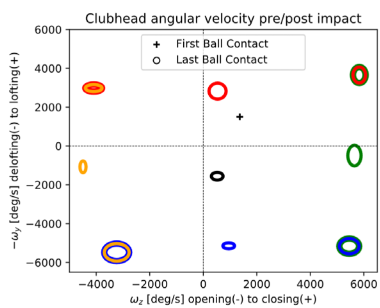
For golf clubs, there is no universal definition of the “sweet spot”. The energy transfer to the ball is subject to the complexity and variety of golf club dynamics, such as the shaft influence during impact [1]. A static indicator of the “sweet spot”, that ignores the influence of the shaft, is the projection of the clubhead centre of gravity (CG) onto the clubface. A dynamic indicator is the impact point $\boldsymbol{P}$ where the clubhead angular velocity pre-impact will be maintained post-impact, $\boldsymbol{\omega}^{(post)} = \boldsymbol{\omega}^{(pre)}$, causing a minimal torque reaction in the golf shaft. Another dynamic indicator is the impact point where the clubhead angular velocity pre-impact will be nullified post-impact, $\boldsymbol{\omega}^{(post)} = 0$, minimising the clubhead rotation during impact and therefore, the amount of spin imparted on the ball (in a square collision). Being able to measure these two points would be valuable in golf club design and fitting to fine-tune golf club properties for a given golf swing. In this work, a methodology is introduced to determine these points based on the tracking of clubhead rotation through impact. The method employs a high-speed stereo-camera system tracking a driver clubhead at 20000 fps throughout the ball-impact [2]. Golf swings were performed by a golf robot at 45 m/s clubhead speed, with 8 shots per impact location (see Fig. 1a) across which, mean and standard deviation of the clubhead angular velocity were calculated (see Fig. 1b).



(a)



(b)

Fig. 1: (a) Impact locations tested, (b) mean angular velocities ± 1 standard deviation pre-impact and post-impact plotted as error bar and error ellipses, respectively.

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Central impacts are offset to the zero-lines (dashed), i.e. a centre impact caused the clubhead to deloft and to close through impact. The interesection of the zero-lines represent $\boldsymbol{\omega}^{(post)} = 0$. Note that despite impact location, CG and the clubface curvature affect the clubhead rotation, causing the horizontal and vertical asymmetry. The analogy in the illustrations of impact locations (Fig. 1a) and angular velocity post-impact (Fig. 1b) indicates the correlation between the two. Linear regression yields

$$\omega_y^{(post)} = (2.2\ \mathrm{mm} - z) \cdot 371.8 \frac{°/\mathrm{s}}{\mathrm{mm}} \quad (r^2 = 0.997), \text{ and} \tag{1}$$

$$\omega_z^{(post)} = (y + 3.7\ \mathrm{mm}) \cdot 255.5 \frac{°/\mathrm{s}}{\mathrm{mm}} \quad (r^2 = 0.994). \tag{2}$$

The linear regressions (1) and (2) were solved to determine $\boldsymbol{P}(\boldsymbol{\omega}^{(post)} = \boldsymbol{\omega}^{(pre)})$ and $\boldsymbol{P}(\boldsymbol{\omega}^{(post)} = 0)$. Note, that using clubhead rotation post-impact is superior to using ball spin measures (with r^2 values of 0.60 and 0.27), as the signal-to-noise ratio is improved, and the clubhead rotation is less sensitive to varying clubhead presentations at impact. Results are listed in Table 1 alongside the projection of the clubhead CG onto the clubface. For the tested golf club and golf swing, the CG projection lies centrally between $\boldsymbol{P}(\boldsymbol{\omega}^{(post)} = \boldsymbol{\omega}^{(pre)})$ and $\boldsymbol{P}(\boldsymbol{\omega}^{(post)} = 0)$. Even though it ignores the shaft influence during impact, the CG can be a reasonable approximation of the "sweet spot", as the inertial effect of the shaft, in reality, is compromised by the "closing" rotation of the clubhead coming into the ball.

Table 1: Comparison of different "sweet spot" indicators. All values in millimetres.

Component	**Centre***	$\boldsymbol{P}(\boldsymbol{\omega}^{(post)}=\boldsymbol{\omega}^{(pre)})$	$\boldsymbol{P}(\boldsymbol{\omega}^{(post)}=0)$	**CG projection***
y	0	+1.6	-3.7	-2.1
z	0	+6.2	+2.2	+4.4

*Geometric centre and CG position from clubhead manufacturer

In future work, the effect of clubhead speed and mass distribution on the "sweet spot" indicators will be discussed. Understanding these factors will allow to control the location of the "sweet spot" for a given target golf swing. Advancements in inertial sensor technology may allow to measure clubhead rotation through impact more efficiently in future and enhance the usability of the proposed method in golf club engineering and fitting environments.

1. McNally W, McPhee J, Henrikson E (2018) The Golf Shaft's Influence on Clubhead-Ball Impact Dynamics. Proceedings, 2, 245:2-7.
2. Ellis KL, Roberts JR, Sanghera J (2010). Development of a method for monitoring clubhead path and orientation through impact. Proc. Eng. 2: 2955-2960.

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