R&A Rules Limited

and

United States Golf Association

PROTOCOL FOR MEASURING THE MOMENT OF INERTIA OF GOLF CLUBHEADS

Rev. 2.0

1 December 2020

Revision	Date	Details of Revision
1.0	Jun-2005	Original published version.
2.0	1-Dec-2020	Updated references to The Equipment Rules. Reformatted step numbering and section titles to be consistent with other protocols. Eliminated requirement for use of Microsoft Excel spreadsheet and equipment specificity.

1 Scope

This protocol describes the methods used to determine the clubhead moment of inertia of woods to the Equipment Rules, Part 2, Section 4b (i), as administered by R&A Rules Ltd. (The R&A) and the United States Golf Association (USGA).

2 Test Protocol

2.1 Measurement

a. Using a calibrated mass balance or equivalent, measure and record the mass of the clubhead.
b. Measure the moment of inertia of the clubhead about the vertical axis of the clubhead orientated at a 60° lie angle, See Figure 1.

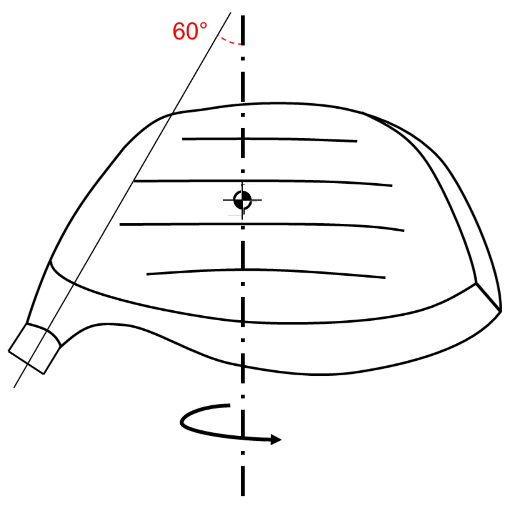

Figure 1: Clubhead mounted such that the axis of rotation is parallel to the vertical axis of the clubhead.

i. Measure the moment of inertia about the centre of mass of the clubhead in this orientation.
ii. If the position of the centre of mass is unknown, or if measurement of the moment of inertia is impracticable, see Appendix, 4)

3 Determination of Conformance Status

If the moment of inertia of the clubhead about its centre of mass exceeds 5,900 g-cm² plus a test tolerance, the clubhead does not conform to the Equipment Rules, Part 2, Section 4b (i).

Appropriate screening methods may be applied.

4 Appendix: Moment of Inertia Calculations, Unknown Centre of Mass

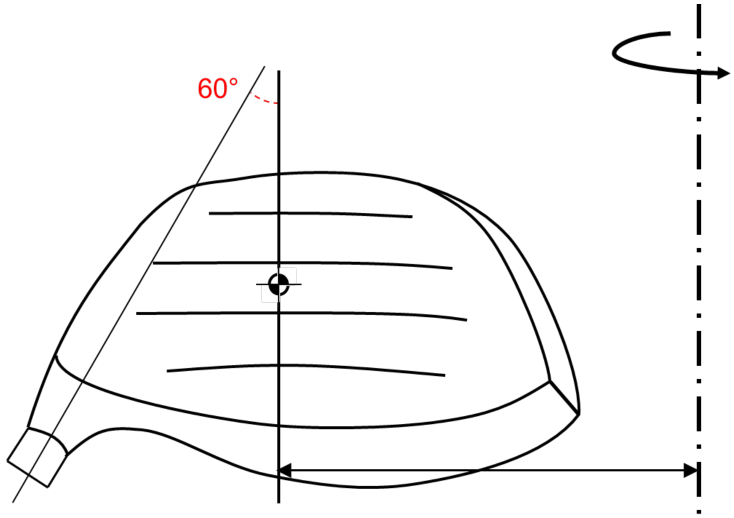

Figure 2: Measurement of the moment of inertia of a club head, unknown centre of mass.

In the case that the position of the centre of mass is unknown, or if measurement of the moment of inertia is impracticable:

a. Measure the moment of inertia of the clubhead about the vertical axis of the clubhead orientated at a 60° lie angle, with the club at a known position.
b. Measure the distance between the axis of rotation and a known point on the clubhead. This distance should be expressed in Cartesian coordinates on a plane normal to the axis of rotation. The origin of this plane should be the axis of rotation.
c. Repeat the moment of inertia measurement (step a.) eight further times varying the distance between the axis of rotation and the known point on the clubhead.
    i. Note that the orientation of the clubhead relative to the axis of rotation should be kept constant.
d. Using the parallel axis theorem, calculate the moment of inertia of the clubhead about its centre of mass.

The parallel axis theorem may be expressed as:

$$I = \bar{I} + md^2 \tag{1}$$

where *m* is the total mass of the body and *d* is the distance from the center of mass to the axis of rotation. In a Cartesian coordinate system, this may be rearranged to show:

$$\bar{I} = I - md^2 = I - m\left[\left(x_{cg} + x\right)^2 + \left(y_{cg} + y\right)^2\right] \tag{2}$$

This may be generalized for a collection of measurements *j*:

$$\bar{I} = I_j - m\left[\left(x_{cg} + x_j\right)^2 + \left(y_{cg} + y_j\right)^2\right] \tag{3}$$

It can be shown that this may be expressed as:

$$\mathbf{f} = \mathbf{Kx} \tag{4}$$

where:

$$\mathbf{f} = \begin{Bmatrix} \dfrac{I_1}{m} - x_1^2 - y_1^2 \\ \dfrac{I_2}{m} - x_2^2 - y_2^2 \\ \cdot \\ \cdot \\ \cdot \\ \dfrac{I_n}{m} - x_n^2 - y_n^2 \end{Bmatrix}, \quad \mathbf{K} = \begin{bmatrix} \dfrac{1}{m} & x_{cg} + 2x_1 & y_{cg} + 2y_1 \\ \dfrac{1}{m} & x_{cg} + 2x_2 & y_{cg} + 2y_2 \\ & \cdot & \\ & \cdot & \\ & \cdot & \\ \dfrac{1}{m} & x_{cg} + 2x_n & y_{cg} + 2y_n \end{bmatrix}, \quad \mathbf{x} = \begin{Bmatrix} \bar{I} \\ x_{cg} \\ y_{cg} \end{Bmatrix}$$

For multiple points (n>3), this system may be solved to arrive at a least-squares solution by use of the pseudo inverse of the K matrix:

$$\mathbf{x} = \left(\mathbf{K^T K}\right)^{-1} \mathbf{K^T f} \tag{5}$$

An iterative solution is required such that initial guesses of $x_{cg}$and $y_{cg}$are inserted into **K** and a solution is found with the iteration scheme converging in two iterations.