R&A Rules Limited
and
United States Golf Association

PROCEDURE FOR MEASURING
THE MOMENT OF INERTIA OF
GOLF CLUBHEADS

Revision 1.0

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1. Scope

1.1 This method covers the procedure for measuring the moment of inertia of clubheads as administered by R&A Rules Limited (R&A) and the United States Golf Association (USGA).

1.2 The results of the conformance tests are used in determining conformity of the club to the Rules of Golf.

1.3 The values stated in imperial units are to be regarded as standard. The values stated in SI units are for information only.

2. Applicable Documents

2.1 R&A and USGA:
·Rules of Golf

3. Summary of Method

3.1 Using a moment of inertia measuring instrument, the moment of inertia of clubheads is measured.

NOTE: This procedure may change and the test tolerances may be reduced as the test methods are refined.

4. Significance

4.1 This method measures the moment of inertia of clubheads to determine the conformity to the Rules of Golf.

The moment of inertia of the clubhead shall not be greater than 5900 g cm^2 (2.019 lb in^2). A maximum test tolerance of 100 g cm^2 (0.034 lb in^2) is associated with this test.

Intermediate screening procedures may be used to determine clubhead conformance and increase testing efficiency.

5. Procedure for Measurement of Clubhead Moment of Inertia

The moment of inertia of the clubhead is determined using an Inertial Dynamics Inc. Model MOI-005-104 Moment of Inertia instrument (or equivalent).

Clubs will be tested for MOI as submitted by the club manufacturer. It is expected that submissions will weigh at or near the nominal head weight for the golf club. Submitted clubheads with unusually low head weights will require additional documentation from the submitter confirming that the submitted weight is at or near the nominal head weight of the golf club as it is intended to be used.

5.0 Start the “MOI Calcs” program.

5.1 Attach the MOI jig plate Figure 5.1 (see Appendix A for jig plate dimensions) to the moment of inertia machine, insuring that the plate is tight.

5.2 With the jig plate attached, assure that the inertia machine is level and tare the instrument.

Figure 5.1 – MOI Jig Plate

5.3 Measure the mass of the clubhead and record the value in the box labeled “Club mass” on the MOI Calcs User Interface, Figure 5.3

Figure 5.3–MOI Calcs Program User Interface

5.4 Insert the appropriate hosel fitting fully into the hosel of the clubhead making sure that the fitting is snug. (The hosel fitting is designed to keep the head at a prescribed lie angle of 60°. See Appendix A for hosel fitting dimensions.)

5.5 For right handed clubs, align the “R” face of the hosel fitting to be parallel with the middle of the club face (align the “L” face for left handed clubs)

5.6 Mount the clubhead on the jig at pin “0”. For right handed clubheads the pins on the left side of the jig must be used, Figure 5.6. The toe of the club should point to the center of the jig. (The pins on the right side of the jig must be used for left handed clubheads.)

Figure 5.6–MOI Jig Mounting Pin Locations

5.7 With the clubhead in place, measure the moment of inertia of the clubhead at position “0”. (The instrument will display the inertia measurement in g-cm^2.)

5.8 At the MOI Calcs User Interface enter the inertia value in the input box labeled “Pin 0”, Figure 5.8

5.9 Repeat steps 5.6 through 5.8 for pins 1 through 5 ensuring that the hosel fixture does not move while changing from pin to pin.

5.10 Once measurements at all six pin locations have been obtained; press the “Do Calcs” button on the MOI Calcs User Interface. The program will calculate the clubhead moment of inertia and display it on the User Interface. (Details of the moment of inertia calculation are given in Appendix B.)

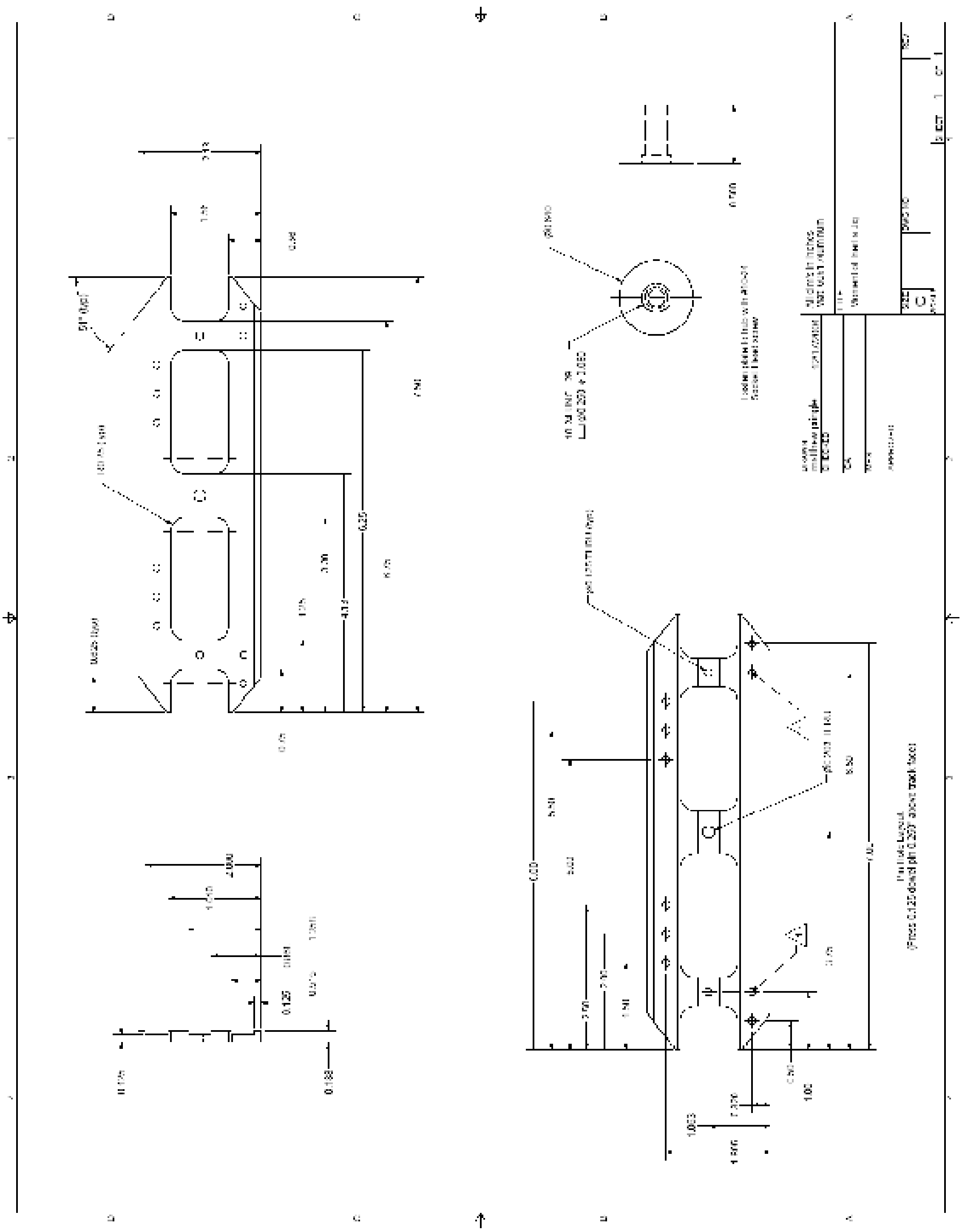
5.11 If the clubhead has moveable weights, repeat steps 5.5 through 5.10 for all possible weight configurations. The weight configuration that produces the largest moment of inertia is used for conformance determination.

6.0 Conformance Determination

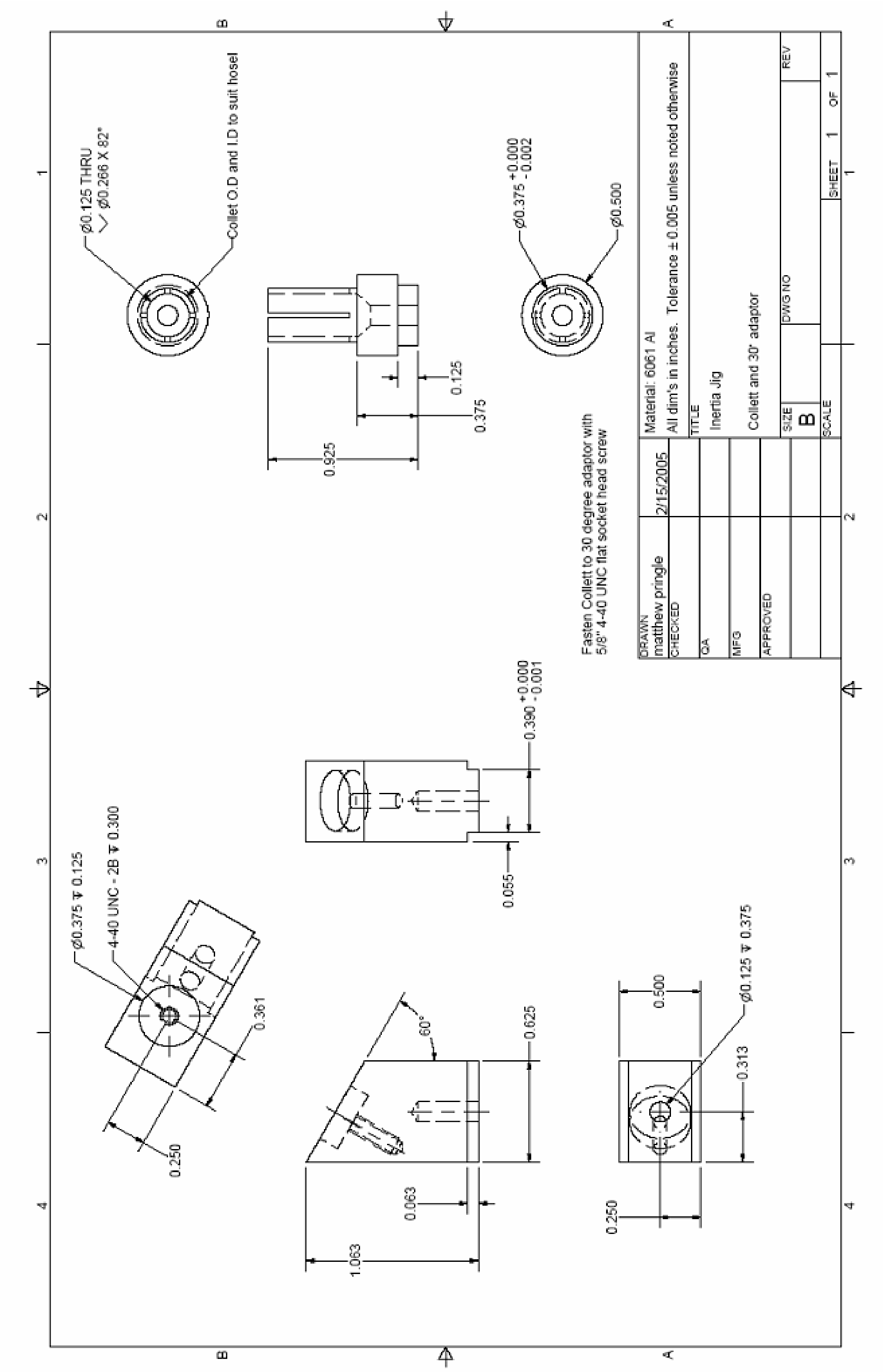
6.1 If the moment of inertia is less than or equal to **5900 g cm^2** plus the tolerance then the clubhead conforms to the Rules of Golf.

6.2 If the moment of inertia is greater than **5900 g cm^2** plus the tolerance then the test is over and the clubhead does not conform to the Rules of Golf.

Appendix A – MOI Jig Plate and Hosel Fitting Dimensions



MOI Jig Plate



MOI Hosel Fitting

Appendix B – Details of Moment of Inertia Calculations.

The mass moment of inertia of a body determines its angular acceleration when subjected to a moment. The mass moment of inertia (I) of a body about a particular axis is (Meriam, Kraige, 1986):

$$I = \int r^2 dm \tag{1}$$

where r is the distance from the axis of rotation to an increment of mass (dm) measured in the plane perpendicular to the rotation axis (referred to herein as the x-y plane).

We are interested in the mass moment of inertia of a club head rotating about its center of gravity. Unfortunately, the location of the center of gravity is not known a priori. Therefore, our measurement procedure will have to include determining this location. If we let the mass moment of inertia about the center of gravity be $\bar{I}$, the mass moment of inertia measured about another axis will be (Meriam, Kraige, 1986):

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

where m is the total mass of the body and d is the distance from the center of gravity to the axis of rotation (again measured in the x-y plane).

Now, in the x-y plane, we will define the location of the axis of rotation as the origin of a Cartesian co-ordinate system. Next, we will define the location of a known point on the club in this co-ordinate system to be (x, y). Finally, we will define the co-ordinates of the center of gravity of the club head, relative to the known point to be (x_{cg}, y_{cg}). Figure 1 shows the co-ordinate system. Referring to this co-ordinate system and equation (2):

$$\bar{I} = I - md^2 = I - m\left[\left(x_{cg} + x\right)^2 + \left(y_{cg} + y\right)^2\right] \tag{3}$$

Equation (3) cannot be solved on its own since there are three unknowns (x_{cg}, y_{cg} and $\bar{I}$). However, more than one set of measurements may be made by moving the known point (x, y) relative to the axis of rotation. Equation (3) may be generalized to, for each j[th] measurement:

$$\bar{I} = I_j - m\left[\left(x_{cg} + x_j\right)^2 + \left(y_{cg} + y_j\right)^2\right] \tag{4}$$

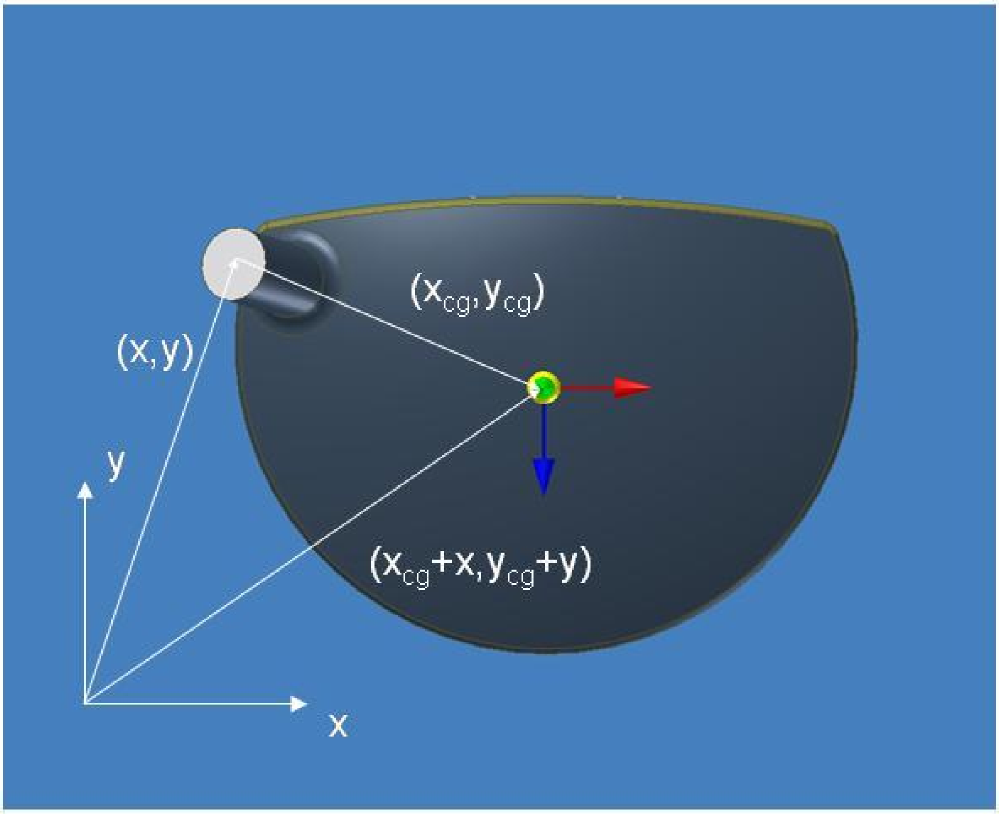


Figure 1: Inertia measurement co-ordinate system

Expanding and rearranging yields:

$$\frac{I_j}{m} - x_j^2 - y_j^2 = \frac{\bar{I}}{m} + x_{cg}\left(x_{cg} + 2x_j\right) + y_{cg}\left(y_{cg} + 2y_j\right) \tag{5}$$

In matrix form, (5) may be expressed as:

$$f = Kx \tag{6}$$

where:

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

(6) may be solved by:

$$x = K^{-1} f \qquad (7)$$

Note that if three measurements are taken, (7) may be computed directly. If additional measurements are included, the pseudo inverse of the *K* matrix is used, yielding a least squares solution of the three variables (Penrose 1955):

$$x = \left(K^T K\right)^{-1} K^T f \qquad (8)$$

Finally, it should be noted that the matrix *K* includes the unknowns x_{cg} and y_{cg}. Therefore, an iterative solution is required. Initial guesses of x_{cg} and y_{cg} are inserted into *K* and a solution is found. Since the equations are quadratic in the unknowns this iteration scheme converges in two iterations.

REFERENCES

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