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Munson et al.

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(54) **GOLF CLUB HEADS WITH VARIABLE FACE THICKNESS**

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A63B 53/04 (2015.01)

(52) **U.S. Cl.**
CPC ***A63B 53/047*** (2013.01); *A63B 53/0408* (2020.08); *A63B 53/0416* (2020.08); *A63B 53/0445* (2020.08); *A63B 53/0458* (2020.08); *A63B 53/0462* (2020.08)

(58) **Field of Classification Search**
CPC A63B 53/0458; A63B 53/047; A63B 53/0416; A63B 53/0462; B21K 17/00; B21J 9/022
USPC 473/350
See application file for complete search history.

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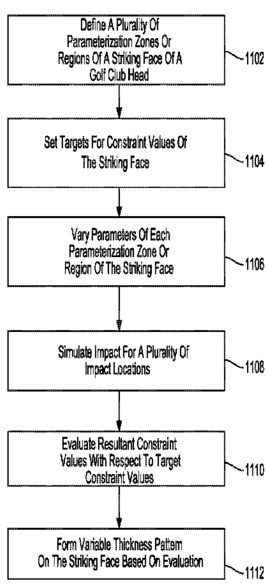
(57) **ABSTRACT**

A variable face thickness pattern is determined for a golf club head by setting a target value for a first constraint. Parametrization zones are defined and values set for a first parameter and a second parameter for each parametrization zone. Resultant first constraint values are evaluated from simulated impacts against the target first constraint value and the values are changed for the first and second parameters to result in a simulated face thickness pattern. In one aspect, the club head has a maximum coefficient of restitution at a first location of the striking face and a second coefficient of restitution that is no less than 98% of the maximum coefficient of restitution at a second location that is at least 7.5 mm from the first location. In another aspect, the club head has a moment of inertia, Izz, and a mass, mh, satisfying: Izz>mh*9.3 cm^2.

20 Claims, 7 Drawing Sheets



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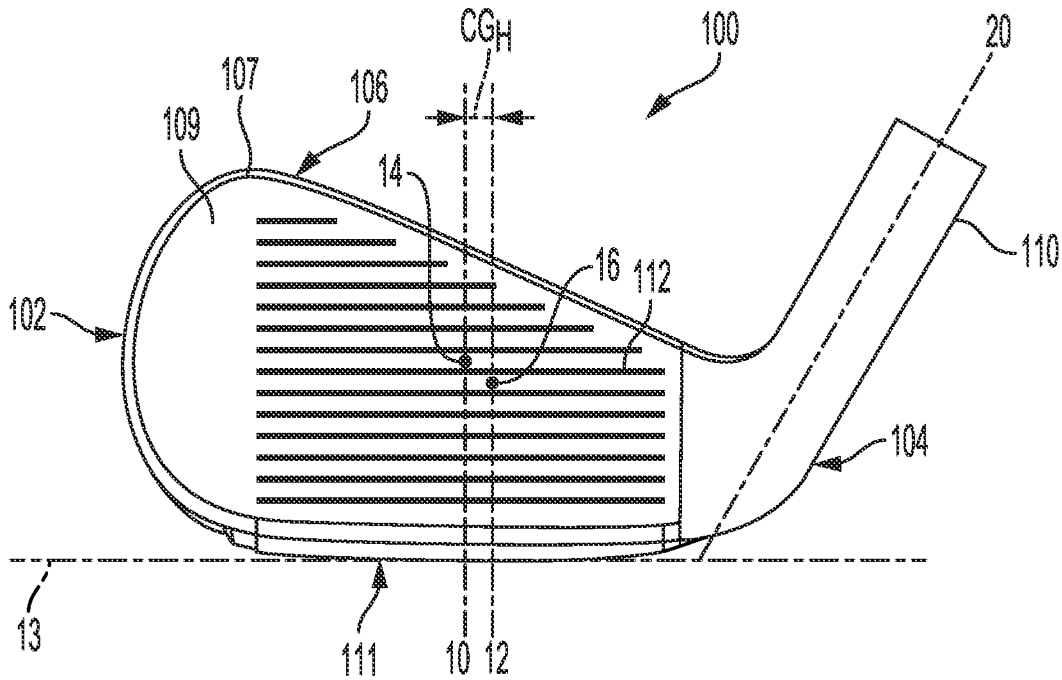
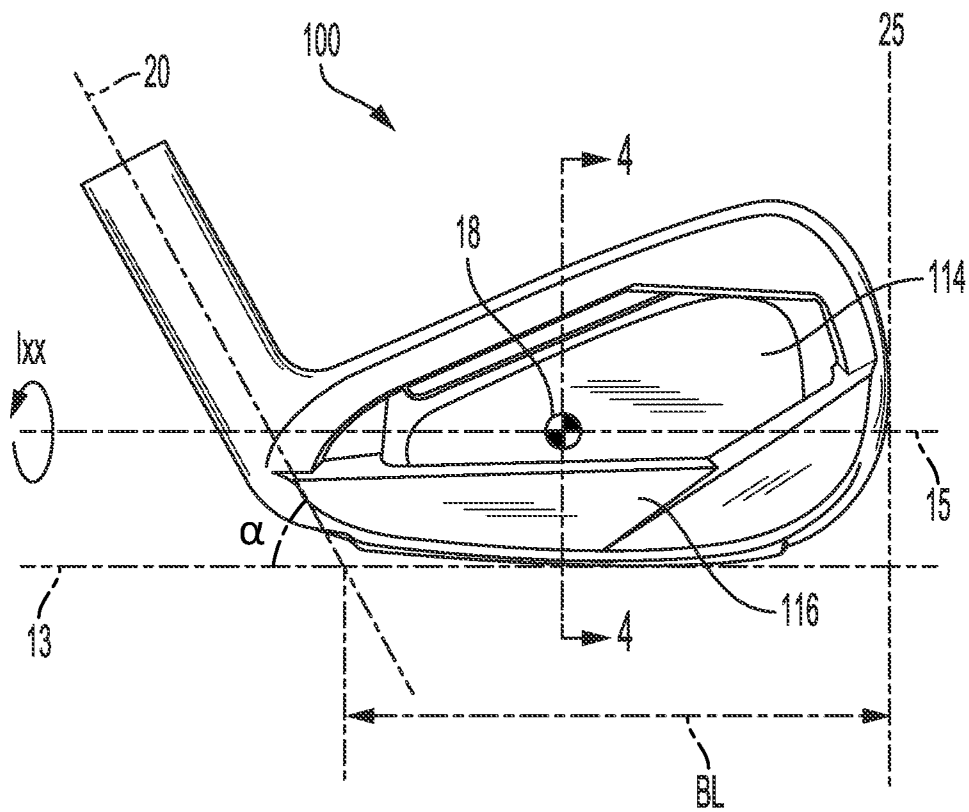


CG
H
100
20
107
106
109
14
110
16
112
102
104
13
111
10
12

FIG. 1



100
20
25
4
18
114
Ixx
15
α
13
4
116
BL

FIG. 2

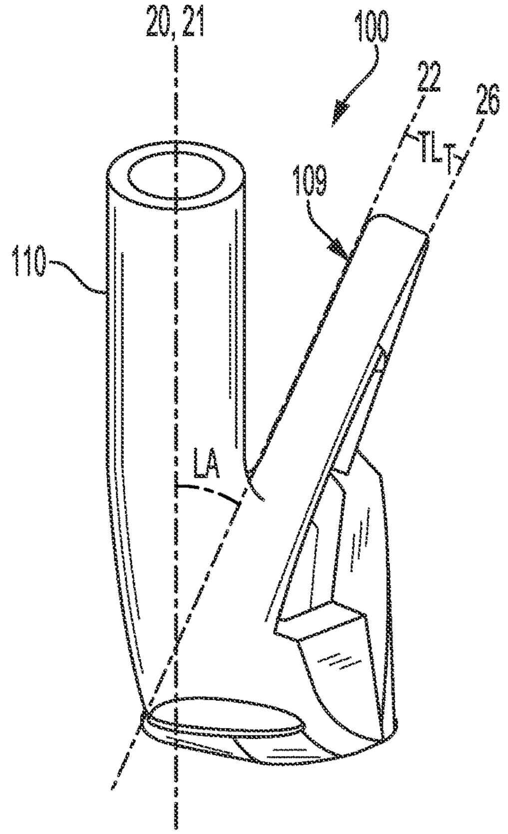

20, 21
100
22
26
TL
109
110
LA

FIG. 3

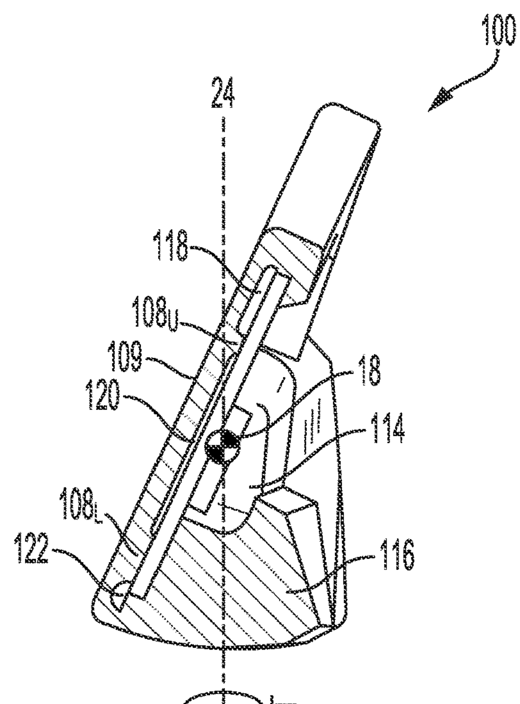

100
24
118
108U
109
18
120
114
108L
122
116
Izz

FIG. 4

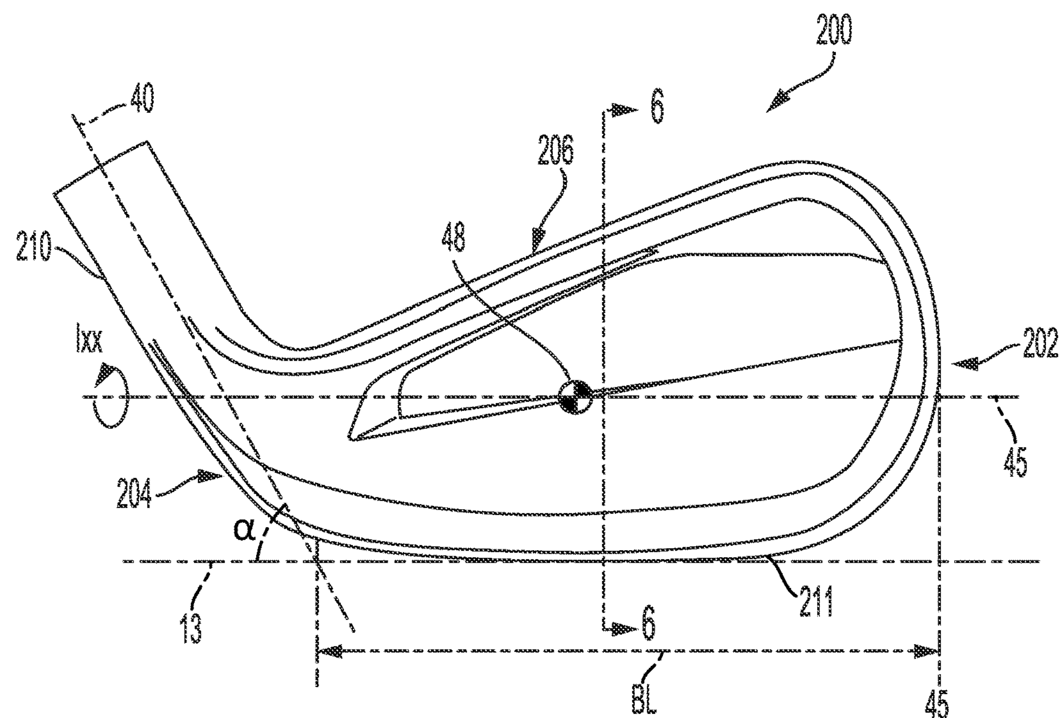

200
40
6
206
210
48
Ixx
202
45
204
α
13
6
211
BL
45

FIG. 5

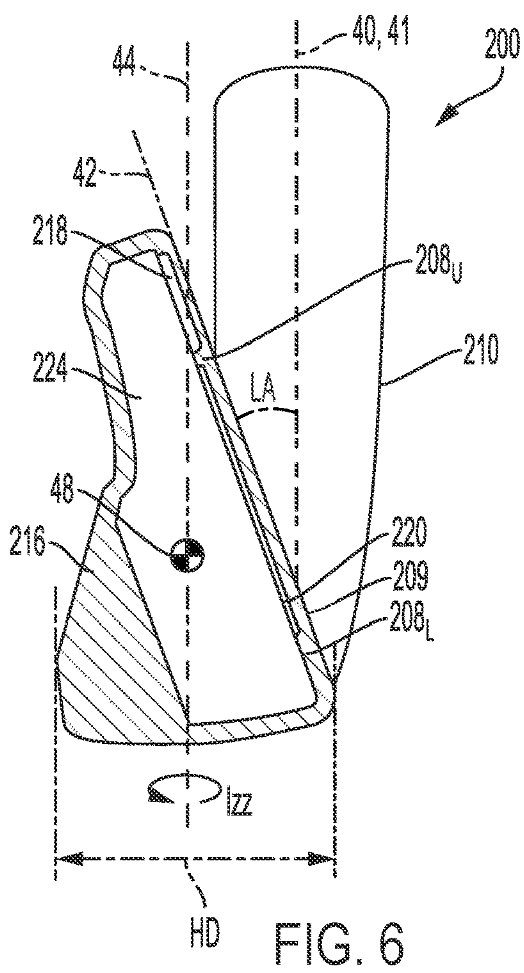

40, 41
200
44
42
218
208_U
224
LA
210
48
216
220
209
208_L
Izz
HD

FIG. 6

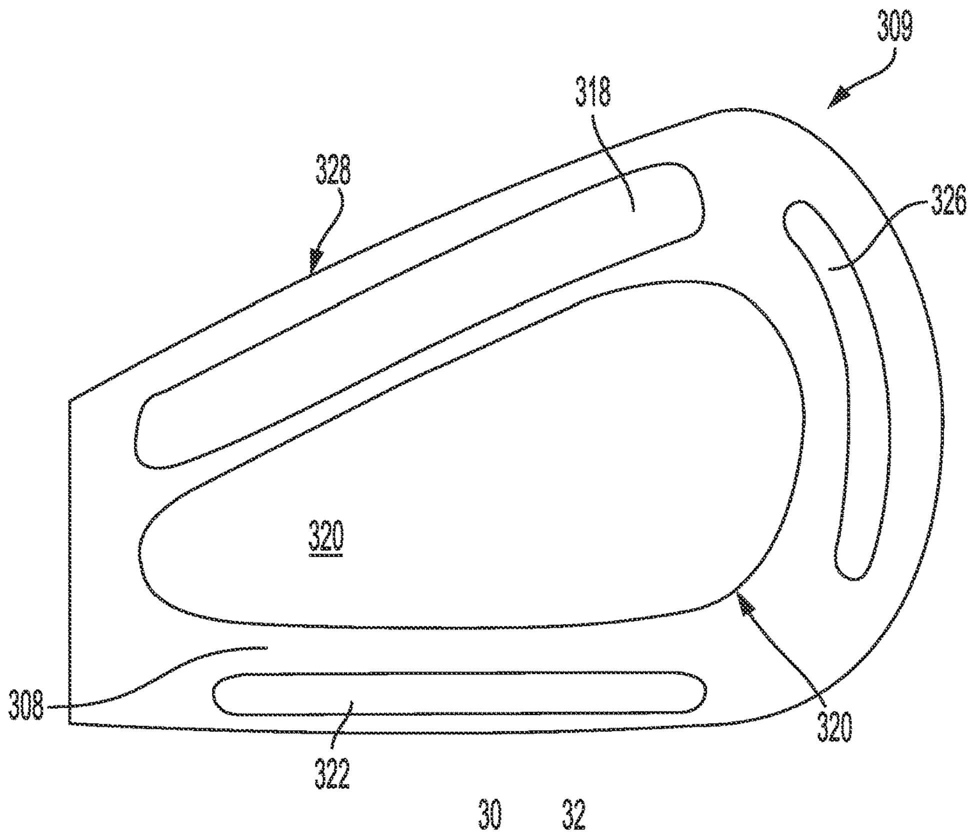

309
318
328
326
320
308
320
322
30
32

FIG. 7

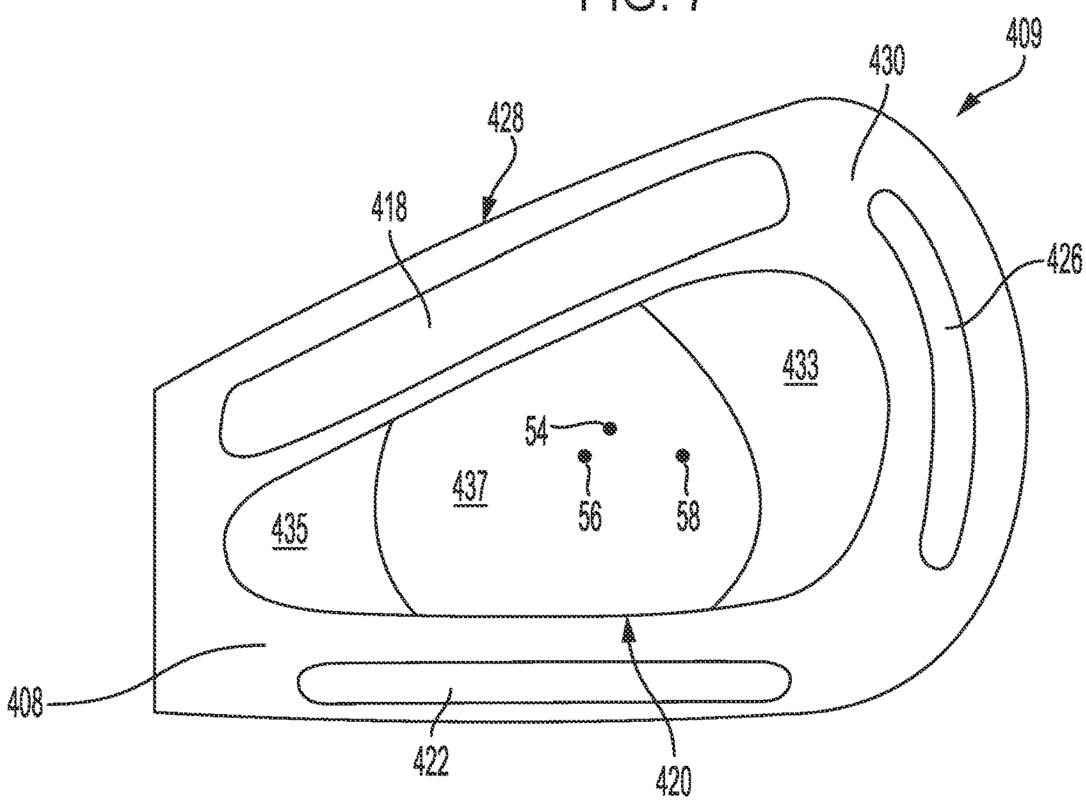

409
430
428
418
426
433
54
437
56
58
435
408
422
420

FIG. 8

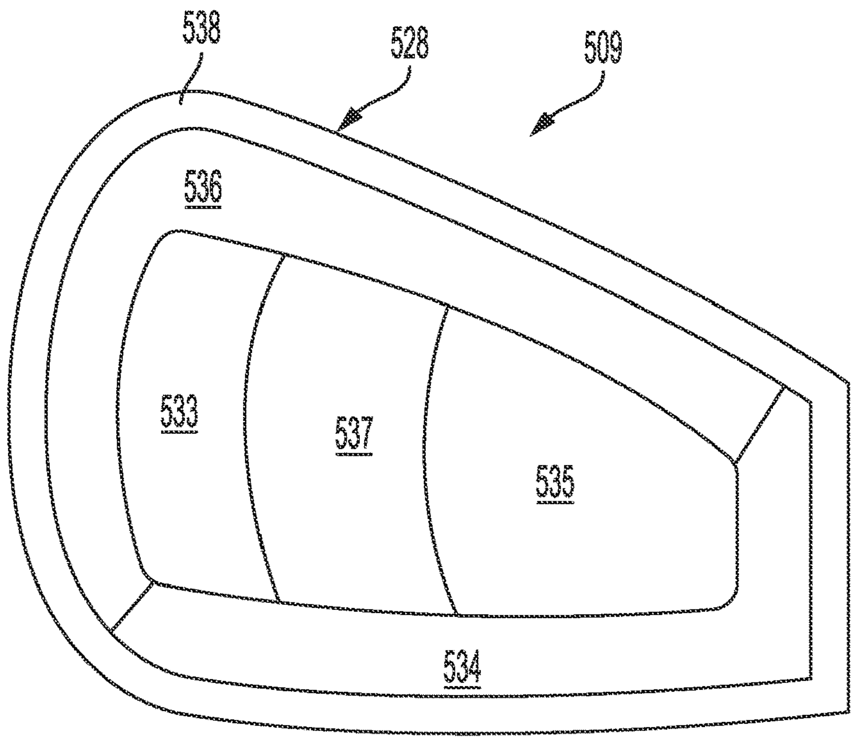


FIG. 9

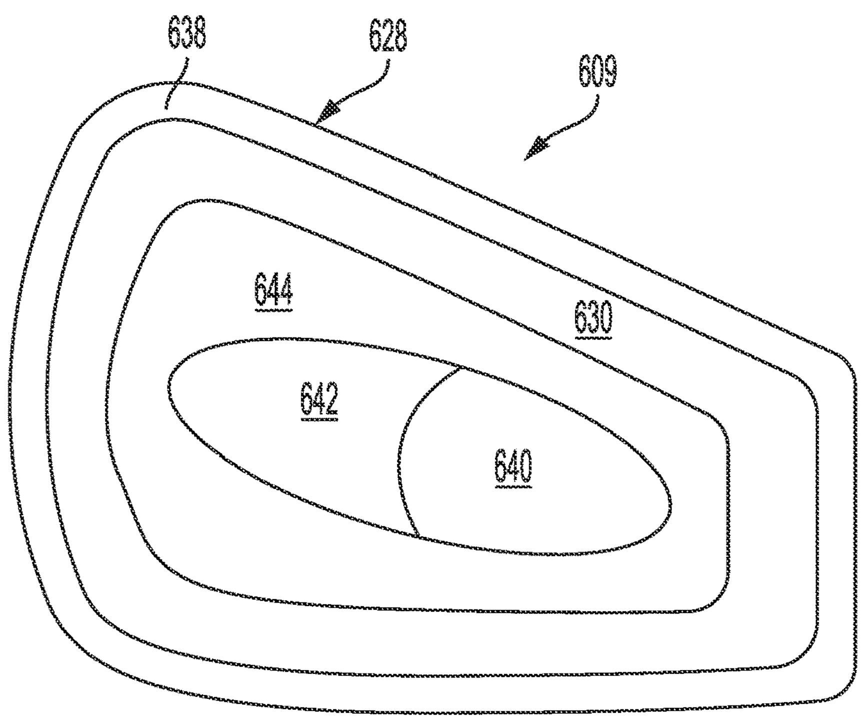


FIG. 10

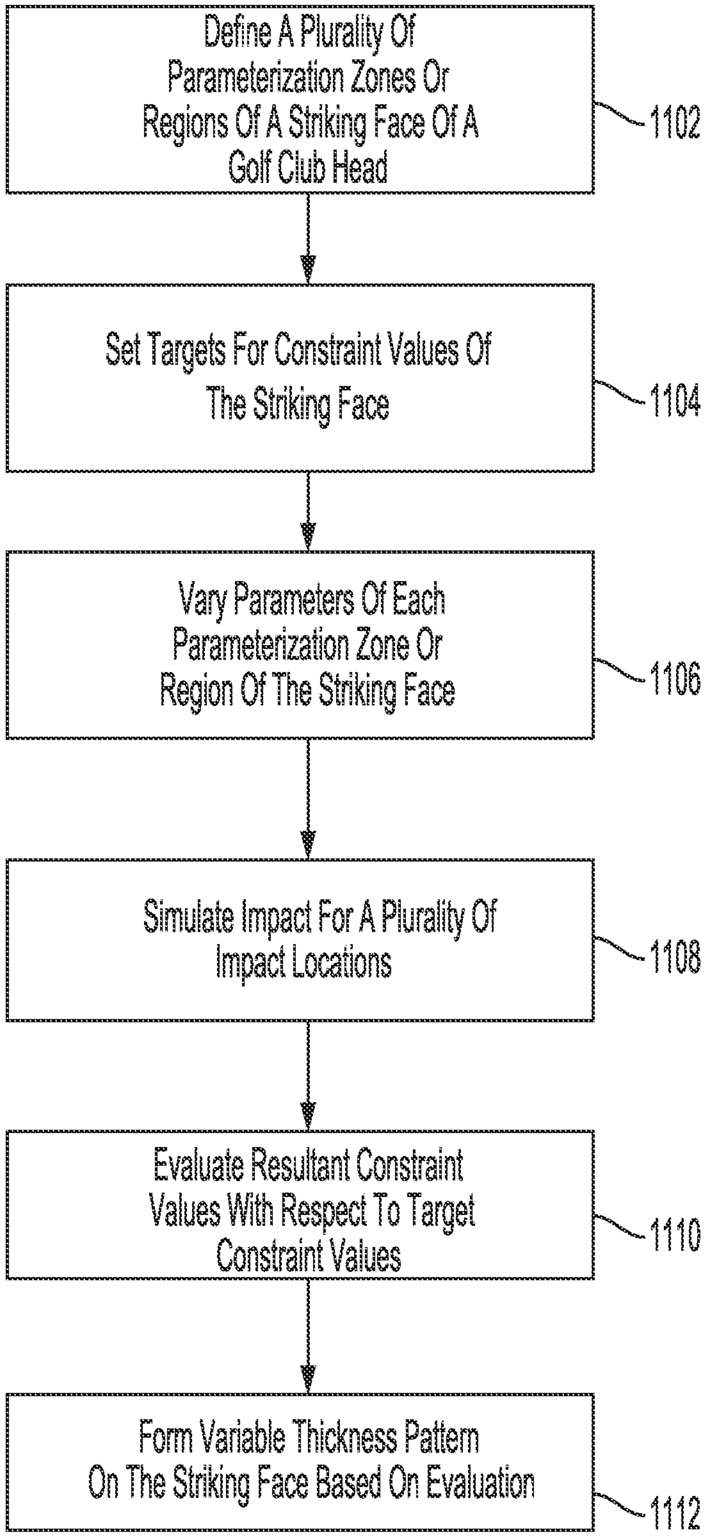

Define A Plurality Of Parameterization Zones Or Regions Of A Striking Face Of A Golf Club Head
1102
Set Targets For Constraint Values Of The Striking Face
1104
Vary Parameters Of Each Parameterization Zone Or Region Of The Striking Face
1106
Simulate Impact For A Plurality Of Impact Locations
1108
Evaluate Resultant Constraint Values With Respect To Target Constraint Values
1110
Form Variable Thickness Pattern On The Striking Face Based On Evaluation
1112

FIG. 11

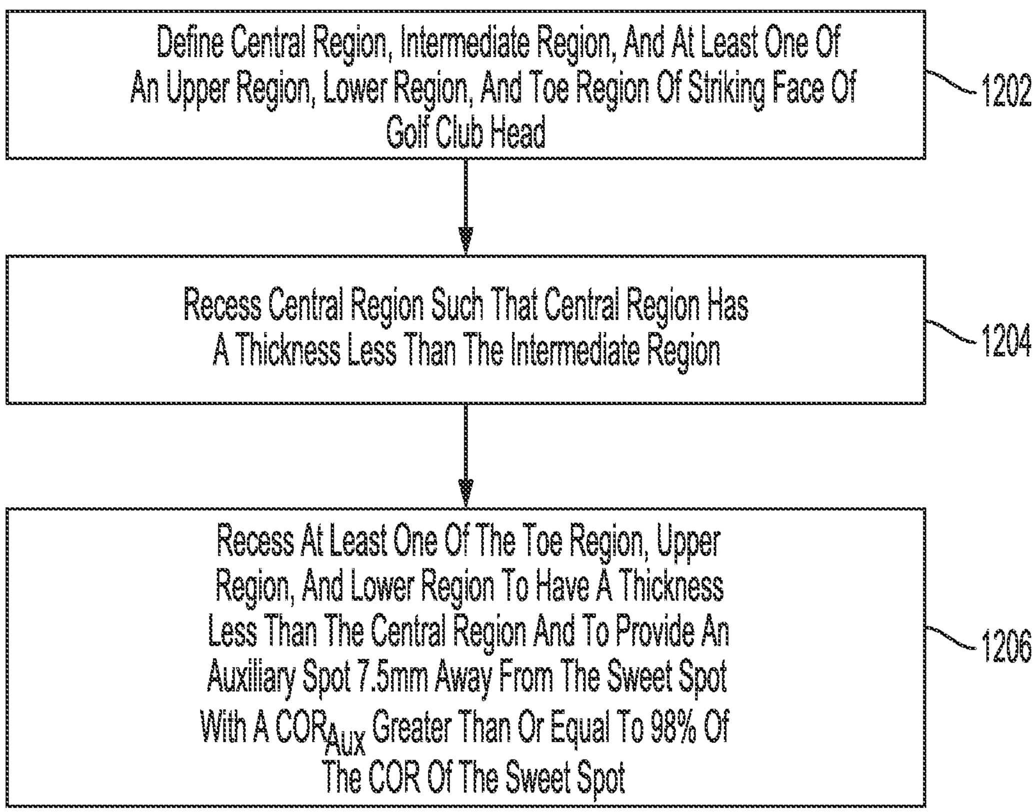

Define Central Region, Intermediate Region, And At Least One Of An Upper Region, Lower Region, And Toe Region Of Striking Face Of Golf Club Head
1202
Recess Central Region Such That Central Region Has A Thickness Less Than The Intermediate Region
1204
Recess At Least One Of The Toe Region, Upper Region, And Lower Region To Have A Thickness Less Than The Central Region And To Provide An Auxiliary Spot 7.5mm Away From The Sweet Spot With A COR_{Aux} Greater Than Or Equal To 98% Of The COR Of The Sweet Spot
1206

FIG. 12

GOLF CLUB HEADS WITH VARIABLE FACE THICKNESS

CROSS-REFERENCE TO RELATED APPLICATION

This application is a continuation of U.S. application Ser. No. 16/920,504, titled "GOLF CLUB HEADS WITH VARIABLE FACE THICKNESS", and filed on Jul. 3, 2020, the entire contents of which are hereby incorporated by reference.

BACKGROUND

Golf club heads have mass and performance properties that affect the quality and consistency of shots when hitting a golf ball. Such mass and performance properties are often related to the mass or the distribution of mass in the golf club head. Examples of such mass and performance properties can include the location of a Center of Gravity (CG) for the club head, Coefficients of Restitution (CORs) or Characteristic Times (CTs) at various locations on a striking face of the club head, and Moments of Inertia (MOIs) about different virtual axes passing through the CG.

As example of a mass property affecting performance, the location of the CG can affect, for example, how high a golf ball is hit, the amount of spin on the golf ball, or the forgiveness of a club head in terms of ball speed and straightness for shots where the impact occurs at off-center locations away from a "sweet spot" on the striking face. As conventionally defined, the sweet spot is the point on the striking face from which a normal projection passes through the club head's CG. For example, moving the CG lower toward the sole, and back from the striking face of an iron type club head can advantageously increase the height of shots for longer distance and result in more backspin on the golf ball for a more controlled shot. Locating the sweet spot closer to the center of the striking face may also better align the sweet spot to a player's expected sweet spot location. Due to the asymmetric shaping and mass distribution of traditional iron-type golf club heads, a laterally centered CG location typically requires, for example, including high density weights, which can be costly and negatively affect swing weight.

As another example of a mass property affecting performance, greater MOIs in a club head mean that the club head is more resistant to twisting when the golf ball is hit at off-center positions on the striking face that are farther from the sweet spot. Increasing the MOIs of the club head generally results in the club head being more stable or forgiving for off-center shots, allowing such off-center shots to be straighter and have a faster ball speed due to the greater MOIs.

As an example of a performance property, the COR is a measurement of energy loss or energy transfer between the striking face and the golf ball. Higher measured CORs on the striking face translate to less energy loss or better energy transfer when the striking face impacts the golf ball. More energy is transferred to the golf ball with a higher COR, which translates to a faster ball speed that typically results in a farther shot. The COR can be measured, for example, using conventional cannon testing in keeping with the United States Golf Association's (USGA's) prescribed method for determining the COR. In this regard, the USGA has migrated from using the COR to using a different performance property referred to as a Characteristic Time (CT) measurement to quantify the elasticity of the striking face. For all purposes herein, the CT refers to characteristic time as described in the USGA's "Procedure for Measuring the Flexibility of a Golf Clubhead" (Rev. 1.0.0, May 1, 2008).

The improvement of mass and performance properties of a club head are balanced against structural requirements for the intended use of the club head, such as stress properties. Mass and performance properties are also balanced against other limits, such as limits prescribed by regulatory bodies, such as the USGA, concerning the CT, dimensions, and club head mass. In addition, players generally have implicit expectations for club heads, such as an overall appearance with respect to size, or an overall expected weight of the club head for the type of golf club or the loft angle of the golf club.

SUMMARY

The present inventors recognized a need for a variable face thickness pattern for golf club heads, particularly iron-type club heads, that improves mass and performance properties of club heads, while maintaining similar stress limits, appearance, and overall club head weight. As discussed in more detail below, the improved mass and performance properties can include, for example, Coefficients of Restitution (CORs), Characteristic Times (CTs), Moments of Inertia (MOIs), and/or a Center of Gravity (CG) location for the club head. In some example embodiments, a cavity-back or a hollow bodied, iron-type club head has an improved variable face thickness pattern that allows for discretionary weight to be moved from the striking face of the club head to other areas of the club head to improve mass and/or performance properties of the club head. Advantageously, such club heads may have improved mass and performance properties, such as higher CORs on the striking face, higher MOIs, and more laterally centered, deeper, and lower CG locations than comparable club heads, while maintaining similar stress limits. Additionally, such club heads do not sacrifice traditional appearances, dimensions (e.g., blade length, topline thickness), and overall club head weight (e.g., swing weight) that may be preferred by some players.

Reducing weight in the face while maintaining an overall club head weight can be important for players who may associate specific lofts of a golf club head with a certain mass, and have a preferred golf club swing weight. Generally, when presented in a set, iron-type club heads increase in mass with loft. For example, the mass of iron-type club heads may adhere the following equation:

$$mh=2.1\ \text{g/degree}*\text{LA}+a, \qquad \text{Equation 1}$$

where mh is a club head mass in grams, LA is the loft angle of the club head when orientated in a reference position, and a is between 190 g and 210 g. In one or more embodiments, a golf club head maintains such a head mass mh, while having an improved face thickness pattern. Such a club head may have an improved face thickness pattern with a vertical MOI extending through the CG, Izz, that satisfies:

$$Izz>mh*9.0\ \text{cm}^2. \qquad \text{Equation 2}$$

In one or more aspects of the disclosure, a golf club head, when orientated in the reference position, includes a golf club head main body having a toe, a heel opposite the toe, a sole, and a top portion opposite the sole. The club head has a mass mh that satisfies Equation 1. In addition, the club head has a blade length less than 80 mm. The striking face of the club head defines a face plane and has a face center, and a virtual center plane extends vertically through the face center perpendicular to the face plane. As used herein, a face center of a striking face is determined according to the procedure described in the USGA's "Procedure for Measuring the Flexibility of a Golf Clubhead" (Rev. 2.0, Mar. 25, 2005). A CG of the club head is located not more than 2.0 mm from the virtual center plane, and an MOI about a vertical axis extending through the CG, Izz, satisfies Izz>mh*9.3 cm^2.

In some aspects, the striking face includes a central region including the face center, an intermediate region at least partially surrounding the central region, an upper region above the central region, an upper region above the central region, a lower region below the central region, and a toe region toe-ward of the central region. Each of the central region, the upper region, the lower region, and the toe region include a maximum width and an average thickness, and the intermediate region is disposed between the central region and each of the upper region, the lower region, and the toe region. The intermediate region has an average thickness greater than that of each of the central region, the upper region, the lower region, and the toe region. In one or more embodiments, the intermediate region fully surrounds the central region.

According to some aspects, at least one of the toe region, the upper region, and the lower region includes, on a rear surface thereof, an elongate groove or recess having a width no less than about 2.0 mm. Alternatively or additionally, the upper region, the lower region, and the toe region respectively include, on a rear surface thereof, an upper groove or recess extending generally in a heel to toe direction, a lower groove or recess extending generally in a heel to toe direction, and a toe groove or recess extending generally in a top to bottom direction.

In one or more aspects of the disclosure, a golf club head, when orientated in a reference position, includes a golf club head main body having a toe, a heel opposite the toe, a sole, and a top portion opposite the sole. A face insert of the club head has a mass mf fixedly attached to the golf club head main body and includes a striking face that defines a face plane. The club head has a mass mh that satisfies Equation 1. The club head has a blade length less than 80 mm, and an MOI, Izz, about a vertical axis extending through a CG of the club head that satisfies Izz>mh*9.3 cm^2. In addition, a ratio mf/mh is less than or equal to 0.22. In one or more embodiments, the ratio mf/mh of an iron-type golf club head is less than or equal to 0.20.

In some aspects, the striking face includes a sweet spot corresponding to a first COR, COR1, and an auxiliary location spaced at least 7.5 mm from the sweet spot corresponding to a second COR, COR2, where: COR2≥0.98*COR1. In some implementations, a variable thickness of the striking face may provide for a higher COR near the sweet spot, increase the COR in a region including the sweet spot, and/or provide a larger area of a higher COR near the sweet spot. In another aspect, the relocation of mass from the striking face can move the CG so that the sweet spot corresponds to an area with a higher COR and/or a more frequently hit area of the striking face by players. For example, the central region of the striking face may include a heel-side region that has a greater thickness than a toe-side region so as to improve the COR in areas of the striking face that are more commonly hit by players.

The recesses or grooves on the rear surface of striking faces of the present disclosure not only increase the COR of the striking face, but can also improve weight distribution of the club head by relocating mass from the striking face to other areas of the club head to increase MOIs and/or to better locate the CG of the club head for better performance. The recesses or grooves may also be determined with a stress limit on the striking face as a constraint so that the striking face is comparable to prior art club heads when tested for durability, despite the reduced mass of the striking face.

In one or more aspects of the disclosure, a method of manufacturing a golf club head includes forming a golf club head main body having a striking face, a heel portion, a toe portion opposite the heel portion, a sole, a top portion opposite the sole, and a blade length no greater than 80 mm. A thickness pattern of the striking face is formed by defining on the striking face a central region including the face center, an intermediate region at least partially surrounding the central region, and at least one of an upper region above the central region, a lower region below the central region, and a toe region toe-ward of the central region. The intermediate region can be disposed between the central region and each of, or at least one of, the upper region, the lower region, and the toe region. The central region is recessed such that the central region has a thickness less than the intermediate region. At least one of the toe region, the upper region, and the lower region is recessed such that the recessed region has a thickness less than that of the central region. The variable face thickness pattern is formed such that the striking face includes a sweet spot corresponding to a first COR, COR1, and an auxiliary location spaced at least 7.5 mm from the sweet spot corresponding to a second COR, COR2, where COR2≥0.98*COR1.

In one or more aspects of the disclosure, a method of manufacturing a golf club head includes forming a golf club head main body having a striking face, a heel, a toe opposite the heel, a sole, and a top portion opposite the sole. A variable thickness pattern is determined with a computing device by defining on the striking face a plurality of parameterization zones, including a central zone having the face center. Each of the parameterization zones includes at least one of a variable first parameter and a variable second parameter. A target value is set for at least one of a respective first constraint, second constraint, and third constraint. Each of the at least one variable first parameter and second parameter is varied for each of the parameterization zones. Impact of the striking face with a golf ball is simulated, and resultant values are evaluated against the target value for the at least one of first constraint, second constraint, and third constraint. The determined variable thickness pattern is formed on the striking face based on the evaluation. In some implementations, the first constraint is a striking face mass, the second constraint is mechanical stress on the striking face, and the third constraint is a weighted COR representing an overall effective or expected COR for the striking face based on the CORs for different portions of the striking face that have been weighted by their expected golf ball impact probabilities. In addition, the variable first parameter and the variable second parameter, in some implementations, may include a variable maximum width and a variable thickness for the parameterization zone or region.

In one or more aspects of the disclosure, a method of manufacturing a golf club head includes forming a golf club head main body having a striking face, a heel, a toe opposite the heel, a sole, and a top portion opposite the sole. A variable thickness pattern is determined with a computing device by defining on the striking face a central region including a face center of the striking face, an intermediate region at least partially surrounding the central region, an upper region above the central region, a lower region below the central region, and a toe region toe-ward of the central region. Each of the central region, the upper region, the lower region, and the toe region includes a variable width parameter and a variable thickness parameter. The intermediate region is disposed between the central region and each of the upper region, the lower region, and the toe region. A target value is set for at least one of a respective first constraint, second constraint, and third constraint. Each of the variable first parameter and the variable second parameter is varied for each region of the striking face. Impact of the striking face with a golf ball is simulated, and resultant values are evaluated against the target value for the at least one first constraint, second constraint, and third constraint. The determined variable thickness pattern is formed on the striking face based on the evaluation.

The various exemplary aspects described above may be implemented individually or in various combinations. The foregoing features and advantages, as well as other features and advantages, of the golf club heads of the present disclosure will become apparent to those of ordinary skill in the art after consideration of the following description, the accompanying drawings, and the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

The features and advantages of the embodiments of the present disclosure will become more apparent from the detailed description set forth below when taken in conjunction with the drawings. The drawings and the associated descriptions are provided to illustrate embodiments of the disclosure, and not to limit the scope of what is claimed.

FIG. **1** is a front view of an exemplary golf club head according to one or more embodiments.

FIG. **2** is a rear view of an exemplary cavity-back club head according to one or more embodiments.

FIG. **3** is a heel side view of the cavity-back club head of FIG. **2** according to one or more embodiments.

FIG. **4** is a cross-section view of the cavity-back club head of FIG. **2** according to one or more embodiments.

FIG. **5** is a rear view of an exemplary hollow club head according to one or more embodiments.

FIG. **6** is a cross-section view of the hollow club head of FIG. **5** according to one or more embodiments.

FIG. **7** depicts an exemplary rear surface of a striking face of a cavity-back club head according to one or more embodiments.

FIG. **8** depicts an exemplary rear surface of a striking face of a hollow club head according to one or more embodiments.

FIG. **9** depicts an exemplary rear surface of a striking face of a club head including a thickness pattern according to one or more embodiments.

FIG. **10** depicts an exemplary rear surface of a striking face of a club head including a different thickness pattern according to one or more embodiments.

FIG. **11** is a flowchart for an example thickness pattern forming process for a striking face according to one or more embodiments.

FIG. **12** is a flowchart for another example thickness pattern forming process for a striking face according to one or more embodiments.

DETAILED DESCRIPTION

Representative examples of one or more novel and nonobvious aspects and features of the golf club heads and methods of manufacturing such club heads as disclosed below are not intended to be limiting in any manner. Furthermore, the various aspects and features of the present disclosure may be used alone or in a variety of novel and nonobvious combinations and sub-combinations with one another.

FIG. **1** is a front view of exemplary golf club head **100** according to one or more embodiments. As shown in FIG. **1**, club head **100** includes toe portion **102**, heel portion **104**, topline portion **106**, and sole portion **111**. Club head **100** also includes hosel **110** that extends from heel portion **104**. Hosel **110** may include an open end for receiving a golf club shaft (not shown) of a golf club. Hosel axis **20** extends axially through the center of hosel **110**, and lies in a virtual vertical hosel plane (e.g., virtual vertical hosel plane **21** shown in FIG. **3**). Club head **100**, including striking face **109**, may be formed, for example, of a steel material.

In FIG. **1**, club head **100** is oriented in a reference position with sole portion **111** in contact with virtual ground plane **13**, and with central hosel axis **20** in the virtual vertical plane. As used herein, a club head is orientated in the "reference position" when the sole of the club head (e.g., sole portion **111**) is in contact with a virtual ground plane (e.g., virtual ground plane **13**), its central hosel axis (e.g., central hosel axis **20**) is positioned in a vertical plane, and its score-lines (e.g., score-lines **112**) are parallel to the ground plane. In the reference position, club head **100** is positioned at a predetermined Loft Angle (LA) (i.e., LA in FIG. **3**) and a predetermined lie angle (i.e., α in FIG. **2**). Unless otherwise indicated, all parameters of the various embodiments in this disclosure are specified with the club heads orientated in the reference position.

In one or more embodiments, LA ranges from about 18 degrees to about 40 degrees. In other embodiments, the golf club head is a wedge-type golf club head and LA ranges from about 40 degrees to about 64 degrees.

As shown in FIG. **1**, club head **100** includes striking face **109** configured to strike a conventional golf ball. In some implementations, striking face **109** may form part of a face insert that is fixedly attached to a main body of club head **100**. In other implementations, striking face **109** may be integrally formed as part of the main body of club head **100**. Striking face **109** is provided with one or more grooves or score-lines **112**, which impart additional spin to the golf ball when struck. In FIG. **1**, striking face **109** includes face center **14**, which is located on virtual center plane **10** that extends vertically through face center **14** perpendicularly to a face plane defined by striking face **109** (e.g., face plane **22** in FIG. **3**). As used herein, a "face center" of a striking face is determined according to the procedure described in the United States Golf Association's (USGA's) "Procedure for Measuring the Flexibility of a Golf Clubhead" (Revision 2.0, Mar. 25, 2005). In the example of FIG. **1**, face center **14** denotes a point on striking face **109** that is midway between the heel-to-toe extents of score-lines **112**, and midway between the sole-to-topline extents of striking face **109**. In other embodiments, score-lines may extend to a toe-side edge of the striking face. In such embodiments, the lateral dimension of the face center is determined as midway between the heel-most extent of the score-lines and a club face apex, such as club face apex **107** in FIG. **1**.

In the example of FIG. **1**, sweet spot **16** is located on striking face **109** a horizontal distance, CGH, toward heel portion **104** from virtual center plane **10**. Sweet spot **16** is located on virtual vertical CG plane **12** such that sweet spot **16** is located on striking face **109** where a virtual line projected normal to a face plane of striking face **109** (e.g., face plane **22** in FIG. **3**) passes through a CG of club head **100** (e.g., CG **18** in FIG. **2**). As used herein, a club head's "sweet spot" is defined as a location on the club head's striking face from which a virtual line projected normal to a face plane of the striking face passes through the club head's CG location.

As discussed in more detail below, striking face **109** has been formed with a variable thickness in different regions or parameterization zones of striking face **109** to provide improved mass and/or performance properties of club head **100**. Such properties can include, for example, greater Coefficients of Restitution (CORs) and/or greater Characteristic Times (CTs) on a larger area and/or more commonly hit area of striking face **109**, greater Moments of Inertia (MOIs) about a virtual vertical CG axis (e.g., virtual vertical CG axis **24** in FIG. **4**) and/or about a virtual horizontal CG axis (e.g., virtual horizontal CG axis **15** in FIG. **2**), and/or an improved CG location for club head **100**. The improvement of these mass and performance properties can be accomplished by the selective thinning or thickening of the different regions or parameterization zones and/or the relocation of discretionary mass from the striking face to other portions of the club head. As used herein, a striking face thickness is measured perpendicular to a face plane defined by the striking face (e.g., face plane **22** in FIG. **3** and face plane **42** in FIG. **6**).

A total mass of the club head may serve as a target total mass comprised of structural mass and discretionary mass. Structural mass as used herein generally refers to mass necessary to establish a minimum structural integrity for the club head to be operable for its intended use. Discretionary mass, on the other hand, can refer to the remaining mass that, given a target mass, is not needed to establish the minimum structural integrity of the club head, and may therefore be located primarily to adjust mass and/or performance properties of the club head.

For example, the thickness of different regions or parameterization zones of striking face **109** can result in mass being moved from such regions or parameterization zones to other locations in club head **100** to provide higher MOIs of club head **100** and an improved location for the CG of club head **100** (e.g., CG **18** in FIG. **2**), while increasing COR values in particular locations on the striking face. For example, mass removed from particular areas of the striking face can improve the COR of the striking face and the removed mass can be relocated in the club head so that the CG of club head **100** can be advantageously located closer to virtual center plane **10**, closer to virtual ground plane **13**, and farther behind striking face **109**. As a result, sweet spot **16** can be advantageously located closer to face center **14** to better correspond to a player's expected sweet spot location and/or a more frequently hit area the striking face, and to provide a more forgiving club head to result in better off-center shots in terms of shot height, straightness, and distance. In this regard, sweet spot **16** in some implementations can be located horizontally no greater than 2.0 mm from face center **14** as a result of the relocation of mass from striking face **109** in accordance with the present disclosure. In other words, the CG of club head **100** (e.g., CG **18** in FIG. **2**) in such implementations can be located not more than 2.0 mm from virtual center plane **10**. In one or more embodiments, golf club heads having this lateral CG location do not include any high-density materials (e.g., tungsten alloys).

As noted above, the variable thickness pattern of the striking face discussed in more detail below can increase the COR at locations on striking face **109** corresponding to more commonly hit locations or a larger area of striking face to provide better energy transfer for off-center shots or for a statistically greater number of shots. Additionally or alternatively, the disclosed variable thickness patterns for a striking face can increase the area of the striking face that has a relatively high COR. For example, in some implementations, striking face **109** in FIG. **1** may include a maximum COR no less than 0.80 at a first location, and a COR of no less than 98% of the maximum COR at an auxiliary location on the striking face that is no less than 7.5 mm from the first location. In such implementations, the first location corresponding to the maximum COR may be at or near sweet spot **16**, such as within 5 mm of sweet spot **16**. Some implementations of variable thickness patterns discussed below for improving CORs on the striking face include, for example, a central region of the striking face having a heel-side thickness greater than a toe-side region.

FIG. **2** is a rear view of an exemplary cavity-back club head according to one or more embodiments. In this regard, club head **100** in FIG. **2** includes rear cavity **114** behind at least a portion of striking face **109**, and rear muscle **116** near sole portion **111**. For the purposes of ease of illustration, FIG. **2** provides a rear view of club head **100** from FIG. **1**. However, those of ordinary skill in the art will appreciate with reference to the present disclosure that club head **100** may include a different construction in other implementations, such as the hollow body construction shown in FIG. **6**, for example.

As shown in FIG. **2**, CG **18** is located on virtual horizontal CG axis **15**. A horizontal MOI of golf club head **100**, Ixx, is shown about virtual horizontal CG axis **15**, which extends through CG **18** and is parallel to striking face **109**. As noted above, the reduction of mass achieved by varying the thickness of striking face **109** can allow for an increased Ixx, and thereby improve performance of golf club head **100** for off-center shots in a vertical direction along striking face **109** (e.g., toward topline portion **106** or toward sole portion **111**).

Club head **100** in FIG. **2** has a Blade Length (BL) measured between a toe-most extent of club head **100** at virtual vertical toe plane **25** and the intersection of hosel axis **20** and ground plane **13**, which also defines lie angle α. In some implementations, club head **100** can have a BL less than 80 mm. This blade length may, for example, correspond to an expected BL for an iron-type club head. In this regard, changes can be made to the thickness of striking face **109** without sacrificing the conventional outer dimensions of club head **100**, such as the BL or topline thickness of topline portion **106** (e.g., TL_T in FIG. **3**). In addition, the overall or target club head mass of club head **100** (e.g., swing weight) in some implementations may correspond to expected masses for iron-type club heads.

As noted above, the mass for iron-type club heads typically vary based on the Loft Angle (LA). When presented in a set, iron-type club heads can increase in mass with loft. For example, the mass of iron-type club heads may adhere the following equation:

$$mh = 2.1\ \text{g/degree} * LA + a, \qquad \text{Equation 1}$$

where mh is a club head mass, LA is the loft angle of the club head when orientated in a reference position, and a is between 190 g and 210 g. In some implementations, club head **100** maintains such a head mass, mh, while having an improved face thickness pattern.

FIG. **3** is a heel side view of club head **100** according to one or more embodiments. As shown in FIG. **3**, the LA of club head **100** is defined between face plane **22** and virtual vertical hosel plane **21**. As noted above, hosel axis **20** extends axially through the center of hosel **110**, and lies in virtual vertical hosel plane **21**. Face plane **22** is defined such that striking face **109** lies in face plane **22**. With reference to Equation 1 above, the club head mass of club head **100** may vary depending on the LA of club head **100** such that higher numbered clubs with larger angles for LA have a greater club head mass.

As shown in FIG. **3**, a distance between face plane **22** and rear side plane **26** defines Top Line Thickness (TL_T), which corresponds to a thickness of top line portion **106** shown in FIG. **1**. The TL_T of club head **100** is no greater than 6.5 mm. This TL_T may correspond to an expected TL_T for an iron-type club head. In this regard, changes can be made to the thickness pattern of striking face **109** without sacrificing the traditional outer dimensions of club head **100**, such as the TL_T of club head **100**, which may be preferred by some golfers.

FIG. **4** is a cross-section view of club head **100** taken along cross section line **4** in FIG. **1** according to one or more embodiments. As shown in FIG. **4**, a rear surface of striking face **109** facing rear cavity **114** and rear muscle **116** includes upper region groove **118**, central region recess **120**, and lower region groove **122**. In implementations where striking face **109** includes a face insert, a rear surface of the face insert can include upper region groove **118**, central region recess **120**, and lower region groove **122**.

The rear surface of striking face **109** also includes intermediate region **108** at least partially surrounding the central region including central region recess **120**. In this regard, intermediate region **108** includes upper intermediate region **108***u* and lower intermediate region **108**L above and below central region recess **120**, respectively. Each of the central region, the upper region, and the lower region including central region recess **120**, upper region groove **118**, and lower region groove **122**, respectively, has an average thickness that is less than the average thickness of intermediate region **108**, which may have an approximately uniform thickness. Upper region groove **118** and lower region groove **122** may extend in generally a heel to toe direction, as in the examples of upper region grooves **318** and **418** and lower region grooves **322** and **422** in FIGS. **7** and **8**, respectively.

In some implementations, at least one of upper region groove **118** and lower region groove **122** can be an elongate groove having a width no less than approximately 2.0 mm. In addition, thickness of central region recess **120** may taper in some embodiments such that a heel-side region of the central recess may be thicker than a toe-side region of the central recess, as in the example of central region recess **320** in FIG. **7**. As another example, the central recess can include a heel-side region that has a greater thickness than a toe-side region, as in the example of heel-side region **435** and toe-side region **433** in FIG. **8**. In some implementations, the thickness of the central region may decrease stepwise from a heel-side of the central region toward a toe-side of the central region.

In FIG. **4**, Izz, is centered about virtual vertical CG axis **24**. Discretionary mass removed or saved from striking face **109** to form upper region groove **118**, central region recess **120**, and lower region groove **122** can be relocated to heel portion **104** and toe portion **102** to increase Izz. In some implementations, Izz may satisfy:

$$Izz > mh*9.3\ \text{cm}^2 \quad \text{Equation 2}$$

where mh is the mass of club head **100**. As noted above, increasing the MOI about virtual vertical axis **24** extending through CG **18** improves the forgiveness of club head **100** so as to cause less bending of club head **100** about virtual vertical axis **24** during off-center shots in a horizontal direction along striking face **109** (e.g., shots that are more toe-ward or heel-ward of sweet spot **16**).

In addition, the variable thickness pattern of striking face **109** can increase the COR at locations on striking face **109** corresponding to more commonly hit locations or a larger area of striking face to provide better energy transfer for off-center shots or for a statistically greater number of shots. The variable thickness pattern of striking face **109** with upper region groove **118**, central region recess **120**, and lower region groove **122** can increase the area of the striking face that has a relatively high COR.

For example, mass removed from particular areas of striking face **109** can improve the COR of striking face **109**, and the removed mass can be relocated in club head **100** so that CG **18** can be advantageously located closer to a lateral center of striking face **109**, closer to virtual ground plane **13**, and farther behind striking face **109**. In such an example, mass removed or saved from striking face **109** to form upper region groove **118**, lower region groove **122**, and central region recess **120**, such as by machining (e.g., grinding, milling) or by a known casting or forging process, can be relocated to rear muscle **116** to lower the location of CG **18** and move CG **18** farther behind striking face **109**. As another example, mass removed from striking face **109** can be relocated from a heel-side of striking face **109** to a toe-side of striking face **109** to move CG **18** away from heel portion **104** toward toe portion **102**.

Those of ordinary skill in the art will appreciate with reference to the present disclosure that other implementations may vary from the arrangement shown in FIG. **4**. For example, other implementations of a cavity-back club head may include a different shape of rear cavity **114** or rear muscle **116**. As another example variation, the cross-section shapes of one or more of upper region groove **118**, central region recess **120**, and lower region groove **122** may differ from what is shown in FIG. **4** in other implementations. As yet another example variation, some implementations may not include central region recess **120**, and only include one or more grooves adjacent a periphery of the rear surface of striking face **109**, such as upper region groove **118** and/or lower region groove **122**.

FIG. **5** is a rear view of exemplary hollow body club head **200** head according to one or more embodiments. Club head **200**, including striking face **209**, may be formed, for example, of a steel material. As with club head **100** in FIGS. **1** to **4**, club head **200** includes a hosel **210**, a toe portion **202**, and a heel portion **204**. However, instead of having a rear cavity such as with rear cavity **114** in FIGS. **2** and **4** for club head **100**, club head **200** in FIGS. **5** and **6** includes interior cavity **224** behind at least a portion of striking face **209**, as shown in FIG. **6**. In some implementations, striking face **209** may form part of a face insert that is fixedly attached to a main body of club head **200**. In other implementations, striking face **209** may be integrally formed as part of the main body of club head **200**. For the purposes of ease of illustration, FIG. **5** provides a rear view of club head **200** that may have a similar exterior front appearance as club head **100** in FIG. **1**. However, those of ordinary skill in the art will appreciate with reference to the present disclosure that club head **200** may include a different construction in other implementations than shown in FIGS. **5** and **6**.

As shown in FIG. **5**, CG **48** is located on virtual horizontal CG axis **45**. A horizontal MOI of club head **200**, Ixx, is shown about virtual horizontal CG axis **45**, which extends through CG **48** and is parallel to striking face **209**, which is shown in FIG. **6**. The reduction of mass achieved by varying the thickness of striking face **209** can allow for an increased Ixx by relocating mass to other portions of club head **200**, and thereby improve performance of golf club head **200** for off-center shots in a vertical direction along striking face **209** (e.g., toward topline portion **206** or toward sole portion **211**).

Club head **200** in FIG. **5** has a Blade Length (BL) measured between a toe-most extent of club head **200** at virtual vertical toe plane **45** and the intersection of hosel axis **40** and ground plane **13**, which also defines lie angle α. In some implementations, club head **200** can have a BL less than 80 mm. This blade length may, for example, correspond to an expected BL for an iron-type club head. In this regard, changes can be made to the thickness of striking face **209** without sacrificing the conventional outer dimensions of club head **200**, such as the BL or topline thickness of topline portion **206**. In addition, in some implementations, the overall or target club head mass of club head **200** (e.g., swing weight) may correspond to expected masses for iron-type club heads.

As noted above, the mass for iron-type club heads typically vary based on the Loft Angle (LA). As shown in FIG. **6**, the LA of club head **200** is defined between face plane **42** and virtual vertical hosel plane **41**. Virtual vertical hosel plane **41** includes hosel axis **40** that extends axially through the center of hosel **210**. Face plane **42** is defined such that striking face **209** lies in face plane **42**. The mass of club head **200** can satisfy Equation 1 provided above with respect to the LA, while having an improved face thickness pattern. In addition, club head **200** can have a depth less than that of a typical hybrid-type golf club head. For example, club head **200** may have a depth less than 30 mm, as measured from a leading edge to a trailing edge of sole portion **211** of club head **200**. As noted above, the relocation of mass from striking face **209** can ordinarily allow for improved performance and mass properties, such as increased MOIs, better CG location, and increased CORs or CTs, without changing the expected dimensions, footprint, or exterior appearance of a conventional iron-type golf club head.

FIG. **6** is a cross-section view of club head **200** taken along cross-section line **6** in FIG. **5** according to one or more embodiments. As shown in FIG. **6**, a rear surface of striking face **209** facing interior cavity **224** and rear muscle **216** includes upper region groove **218**, and central region recess **220**. In implementations where striking face **209** includes a face insert, a rear surface of the face insert can include upper region groove **218** and central region recess **220**.

The rear surface of striking face **209** also includes intermediate region **208** at least partially surrounding the central region including central region recess **220**. In this regard, intermediate region **208** includes upper intermediate region $\mathbf{208}_U$ and lower intermediate region $\mathbf{208}_L$ above and below central region recess **220**, respectively. Each of the central region including central region recess **220**, and the upper region including upper region groove or recess **218** has an average thickness that is less than the average thickness of intermediate region **208**. In some implementations, intermediate region **208** may have an approximately uniform thickness. Upper region groove **218** may extend in generally a heel to toe direction, as in the examples of upper region grooves **318** and **418** in FIGS. **7** and **8**, respectively.

In some implementations, upper region groove **218** can have an elongate groove having a width no less than approximately 2.0 mm. In addition, a thickness of central region recess **220** may taper in some implementations such that a heel-side region of the central recess may be thicker than a toe-side region of the central recess, as in the example of central region recess **320** in FIG. **7**. As another example, the central recess can include a heel-side region that has a greater thickness than a toe-side region, as in the example of heel-side region **435** and toe-side region **433** in FIG. **8**.

Such a tapering or variation of the central region thickness or central recess can also ordinarily improve the COR in the central region and/or increase an area of striking face **209** having a greater COR, as discussed below in more detail with reference to FIGS. **7** to **10**. In addition, the thickness of different regions or parameterization zones of striking face **209** can result in mass being moved from such regions or parameterization zones to other locations in club head **200** to provide higher MOIs of club head **200** and an improved location for CG **48**, while increasing COR values in particular locations on the striking face.

For example, mass removed from particular areas of striking face **209** can improve the COR of striking face **209**, and the removed mass can be relocated in club head **200** so that CG **48** can be advantageously located closer to a lateral center of striking face **209**, closer to virtual ground plane **13**, and farther behind striking face **209**. In such an example, mass removed from striking face **209** to form upper region groove **218** and central region recess **220**, such as by machining or by a known casting or forging process, can be relocated to rear muscle **216** to lower the location of CG **48** and move CG **48** farther behind striking face **209**. In some implementations, striking face **209** can be formed separately and attached to a main body of club head **200** by welding or other known methods. As another example, mass removed from striking face **209** can be relocated from a heel-side of striking face **209** to a toe-side of striking face **209** to move CG **48** away from heel portion **204** toward toe portion **202**.

As a result, the sweet spot on striking face **209** (e.g., sweet spot **16** in FIG. **1**) can be advantageously located closer to a face center (e.g., face center **14** in FIG. **1**) to better correspond to a player's expected sweet spot location or to more frequently hit locations on striking face **209**. In this regard, the sweet spot of club head **200** in some implementations can be located horizontally no greater than 2.0 mm from a face center as a result of the relocation of mass from striking face **209**.

As noted above, the variable thickness pattern of the striking face can increase the COR at locations on striking face **209** corresponding to more commonly hit locations to provide better energy transfer for a statistically greater number of shots, resulting in an improved weighted COR for the striking face. Additionally or alternatively, the disclosed variable thickness patterns for a striking face can increase the area of the striking face that has a relatively high COR. For example, in some implementations, striking face **209** may include a maximum COR no less than 0.80 at a first location, and a COR of no less than 98% of the maximum COR at an auxiliary location on striking face **209** that is no less than 7.5 mm from the first location. In such implementations, the first location corresponding to the maximum COR may be at or near the sweet spot, such as within 5 mm of the sweet spot. Some implementations of variable thickness patterns discussed below for improving CORs on the striking face include, for example, a central region of the striking face having a heel-side thickness greater than a toe-side region.

In FIG. **6**, Izz, is centered about virtual vertical CG axis **44**. Discretionary mass removed or saved from striking face **209** to form upper region groove **218** and central region recess **220** can be relocated to heel portion **204** and toe portion **202** to increase Izz. In some implementations, Izz may satisfy Equation 2 provided above. Increasing the MOI about virtual vertical axis **44** extending through CG **48** improves the forgiveness of club head **200** so as to cause less bending of club head **200** about virtual vertical axis **44** during off-center shots in a horizontal direction along striking face **209** (e.g., shots that are more toe-ward or heel-ward of the sweet spot).

Those of ordinary skill in the art will appreciate with reference to the present disclosure that other implementations may vary from the arrangements shown in FIGS. **5** and **6**. For example, other implementations of a hollow body club head may include a different shape of interior cavity **214** or rear muscle **216**. As another example variation, the cross-section shapes of upper region groove **218** or central region recess **220** may differ from what is shown in FIG. **4** in other implementations. In this regard, other implementations may also include a lower region groove, as in the example of FIG. **4** discussed above. In yet other implementations, central region recess **220** may be omitted, such that the recess or recesses on the rear surface of striking face **209** may only include one or more grooves or channels adjacent a periphery of the rear surface, such as upper region groove **218**.

FIG. **7** depicts an exemplary rear surface **328** of striking face **309** of a cavity-back club head, such as cavity-back club head **100** in FIGS. **2** to **4**, according to one or more embodiments. As shown in FIG. **7**, rear surface **328** includes recesses in an upper region, a central region, a toe region, and a lower region. In more detail, rear surface **328** includes upper region groove or channel **318**, toe region groove or channel **326**, and lower region groove or channel **322** that are adjacent a periphery of rear surface **328**. Central region recess **320** is formed in a central region between upper region groove **318**, toe region groove **326**, and lower region groove **322**. Intermediate region **308** surrounds central region recess **320** and is disposed between central region recess **320** and each of upper region groove **318**, toe region groove **326**, and lower region groove **322**. In addition, intermediate region **308** has an average thickness that is greater than that of each of central region recess **320**, upper region groove **318**, toe region groove **326**, and lower region groove **322**.

Preferred dimensions of central region recess **320** have a face thickness of no more than 2.5 mm, that preferably tapers from 2.3 mm on a heel-side of central region recess **320** to 1.9 mm on a toe-side of central region recess **320**. Preferred dimensions of upper region groove **318** have a face thickness of no more than 1.5 mm, and a maximum width of no less than 5.0 mm. Preferred dimensions of toe region groove **326** have a face thickness less than upper region groove **318**, and a maximum width no less than 2.0 mm. Preferred dimensions of lower region groove **322** have a face thickness of no more than 1.5 mm, that is preferably greater than toe region recess **326**, and a width no less than 2.5 mm. As referred to herein, the width of a groove or channel is defined by a maximum perpendicular distance between the longer opposite sides of the groove or channel. A preferred thickness of intermediate region **308** surrounding the recesses of central region recess **320**, upper region groove **318**, toe region groove **326**, and lower region groove **322** has a thickness less than 3 mm and greater than 2.5 mm, and preferably about 2.7 mm.

Some preferred dimensions for the recesses of rear surface **328** in FIG. **7** can include the dimensions in Table 1 below. As used below, the thickness refers to a thickness of striking face **309**, the width refers to a distance measured perpendicular to opposing longest sides of the recess, and the radius refers to a radius of curvature between a bottom of the recess that has the face thickness indicated for the recess and an adjacent wall of the recess.

TABLE 1

Club Head	Central Region Recess 320	Upper Region Groove 318	Toe Region Groove 326	Lower Region Groove 322
Club Head 1A	Thickness: 2.3 mm (heel-side) tapered to 1.9 mm (toe-side) Radius: 0.4 mm	Thickness: 1.5 mm Width: 6.5 mm Radius: 0.4 mm	Thickness: 0.9 mm Width: 2.5 mm Radius: 0.4 mm	Thickness: 1.2 mm Width: 3.0 mm Radius: 1.5 mm
Club Head 2A	Thickness: 2.4 mm (heel-side) tapered to 2.0 mm (toe-side) Radius: 0.4 mm	Thickness: 1.5 mm Width: 6.5 mm Radius: 0.4 mm	Thickness: 0.9 mm Width: 2.5 mm Radius: 0.4 mm	Thickness: 1.2 mm Width: 3.0 mm Radius: 1.5 mm
Club Head 3A	Thickness: 2.4 mm (heel-side) tapered to 2.0 mm (toe-side) Radius: 3.0 mm	Thickness: 1.5 mm Width: 6.5 mm Radius: 3.0 mm	Thickness: 0.9 mm Width: 2.5 mm Radius: 1.25 mm	Thickness: 1.2 mm Width: 3.0 mm Radius: 1.5 mm

The foregoing preferred dimensions for central region recess **320**, upper region groove **318**, toe region groove **326**, and lower region groove **322** improve performance and mass related properties of cavity-back club heads. Such performance and mass related properties include, for example, the CG location for the club head, CORs or CTs at various locations on the striking face, and MOIs about different virtual axes passing through the CG. The recesses on rear surface **328** not only increase the COR of striking face **309** with a reduction of mass in striking face **309** at particular locations, but can also improve the weight distribution of the club head to increase MOIs and/or better locate the CG for performance, as discussed above. The recesses on rear surface **328** may also be determined with maximum face stress as a constraint so that striking face **309** is comparable to prior art club heads when tested for durability, despite the reduced mass of striking face **309**.

Those of ordinary skill in the art will appreciate with reference to the present disclosure that other implementations of a rear surface of a striking face for a cavity-back club head may differ from the arrangement shown in the example of FIG. **7**. For example, other arrangements may not include one or more of the recesses shown in FIG. **7**.

FIG. **8** depicts exemplary rear surface **428** of striking face **409** of a hollow body club head, such as hollow body club head **200** in FIGS. **5** and **6**, according to one or more embodiments. As shown in FIG. **8**, rear surface **428** includes recesses in an upper region, a central region, a toe region, and a lower region. However, unlike the example of rear surface **328** in FIG. **7**, rear surface **428** in FIG. **8** includes a different thickness pattern for central region recess **420**. In more detail, middle portion **437** of central region recess **420** is thicker than heel-side portion **435** and toe-side portion

433. Such an arrangement ordinarily further improves COR or CT for a larger area of striking face **409** in the central region.

In addition, rear surface **428** includes upper region groove or channel **418**, toe region groove or channel **426**, and lower region groove or channel **422** that are adjacent a periphery of rear surface **428**. Central region recess **420** is formed in a central region between upper region groove **418**, toe region groove **426**, and lower region groove **422**. Intermediate region **408** surrounds central region recess **420** and is disposed between central region recess **420** and each of upper region groove **418**, toe region groove **426**, and lower region groove **422**. In addition, intermediate region **408** has an average thickness that is greater than that of each of central region recess **420**, upper region groove **418**, toe region groove **426**, and lower region groove **422**.

Some preferred thicknesses in striking face **409** for the recesses of rear surface **428** in FIG. **8** include the following thicknesses for Club Heads 1B, 2B, 3B, and 4B in Table 2 below. The central region thicknesses provided for the Comparable Club Head B in Table 2 are measured thicknesses of its striking face at the locations where the central region recesses of FIG. **8** (i.e., heel-side central region recess **435**, middle central region recess **437**, and toe-side central region recess **433**) would otherwise be located. The Comparable Club Head B includes a continuous peripheral groove or channel of uniform width and depth along a majority of the periphery of the rear surface of its striking face. Table 2 also includes preferred widths for upper region groove **418**, toe region groove **426**, and lower region groove **422**, as measured perpendicularly between the two longest opposing sides of the groove.

mm toe-ward of sweet spot **56**, and a weighted COR representing an expected or overall COR for striking face **409** that is calculated by weighting the CORs at different locations on striking face **409** using a probability that a golf ball will be hit at the location.

In some implementations, striking face **409** can include a maximum COR no less than 0.80 at a first location, such as at or within 5 mm of sweet spot **46**, and a COR no less than 98% of the maximum COR at a second location **48** that is no less than 7.5 mm from the first location. The thicknesses of the recesses of striking face **409** may also be determined so as to increase a weighted COR. The weighted COR can be determined based on a bin-by-bin or location-by-location impact probability, as discussed in more detail in U.S. Pat. No. 10,456,643, titled "GOLF CLUB HEAD," and filed on Dec. 28, 2018, the entire contents of which are hereby incorporated by reference. The weighted COR, "expected COR" or "overall COR" may be considered to represent a probability-adjusted measure of club head performance that a typical golfer would actually expect given how impacts are empirically dispersed about striking face **409**. Using such information, a golfer may make a more informed decision in selecting a golf club based on its weighted COR. Alternatively or additionally, a golfer may determine which golf clubs may be better suited to the golfer's specific handicap or skill level.

The weighted COR can be determined by superimposing onto striking face **409** a rectangular virtual evaluation region comprising a first pair of horizontal sides having a length of 35 mm, a second pair of vertical sides having a length of 25 mm, and a geometric center that coincides with the face center. The rectangular virtual evaluation region is divided

TABLE 2

Recess Thickness or Width	Comparable Club Head B	Club Head 1B	Club Head 2B	Club Head 3B	Club Head 4B
Mid. Cent. Reg. Recess 437 Thickness	2.3 mm	1.8 mm	2.0 mm	2.0 mm	2.0 mm
Heel Cent. Reg. Recess 435 Thickness	2.3 mm	2.0 mm	2.2 mm	2.2 mm	2.2. mm
Toe Cent. Reg. Recess 433 Thickness	2.3 mm	1.6 mm	1.8 mm	1.8 mm	1.8 mm
Upper Reg. Groove 418 Thickness	1.1 mm	1.1 mm	1.1 mm	1.1 mm	1.1 mm
Toe Reg. Groove 326 Thickness	1.1 mm	0.9 mm	0.9 mm	0.9 mm	0.9 mm
Lower Reg. Groove 422 Thickness	1.1 mm	1.3 mm	1.3 mm	1.3 mm	1.4 mm
Upper Reg. Groove 418 Width	3.0 mm	6.5 mm	6.5 mm	6.5 mm	6.5 mm
Toe Reg. Groove 326 Width	3.0 mm	2.5 mm	2.5 mm	2.5 mm	2.5 mm
Lower Reg. Groove 422 Width	3.0 mm	4.0 mm	4.0 mm	4.0 mm	4.0 mm

The foregoing preferred dimensions for central region recess **420** (i.e., middle central region recess **437**, heel-side central region recess **435**, and toe-side central region recess **433**), upper region groove **418**, toe region groove **426**, and lower region groove **422** improve performance and mass related properties of hollow club heads. Such performance and mass related properties include, for example, the CG location for the club head, CORs or CTs at various locations on the striking face, and MOIs about different virtual axes passing through the CG. In this regard, Table 4 below provides measured or computer-simulated values for the removal of mass from striking face **409**, the COR at face center **54**, the COR at an off-center location **58** that is 7.5

into bins by dividing the rectangular virtual evaluation region into five rows (i.e., m=5) having equal height of 5 mm, and seven columns (i.e., n=9) having equal width of 5 mm, thereby forming a matrix of bins having coordinates i and j. An average COR is determined (e.g., measured or computer-simulated) for each bin represented by its coordinates i, j, and the weighted COR can be determined by Equation 3 below. In other implementations, a COR may be determined for a center position of each bin.

$$\text{Weighted COR}=\Sigma_{i=1}^{n}\Sigma_{j=1}^{m}p_{ij}*c_{ij} \quad \text{Equation 3}$$

where p_{ij} is an impact probability for the bin at coordinates i, j according to an impact probability matrix, such as Table 3 below.

TABLE 3

	i = 1	i = 2	i = 3	i = 4	i = 5	i = 6	i = 7
j = 1	0.42%	0.43%	0.30%	0.22%	0.11%	0.03%	0.03%
j = 2	3.58%	3.64%	2.96%	2.23%	1.20%	0.76%	0.31%
j = 3	5.46%	8.29%	8.54%	6.50%	4.42%	2.43%	1.06%
j = 4	3.36%	5.97%	6.55%	6.65%	5.01%	2.83%	1.19%
j = 5	1.52%	2.43%	3.31%	3.18%	2.49%	1.80%	0.81%

Other impact probability matrices may be used to determine the weighted COR in different implementations. For example, other impact probability matrices for determining a weighted COR or expected COR can include those disclosed in U.S. Pat. No. 10,456,643 incorporated by reference above. As another example variation, the measurement locations for the CORs can correspond to points or a differently shaped boundary than the rectangular bins described above for Table 3. In yet other variations, the COR measurement locations can correspond to areas that are spaced apart form each other that do not abut. As another example variation, the orientation of the bins or COR measurement locations may not form a rectangular matrix, but rather, an irregular arrangement of a different configuration, such as an annulus or sunburst configuration.

The recesses on rear surface **428** not only increase CORs of striking face **409** with a reduction of mass in striking face **409** at particular locations, but can also improve the weight distribution of the club head to increase MOIs and/or better locate the CG for performance, as discussed above. The recesses on rear surface **428** may also be determined with maximum face stress as a constraint so that striking face **409** is comparable to prior art club heads when tested for durability, despite the reduced mass of striking face **409**.

With reference to the dimensions in Table 2 above for the recesses of rear surface **428** in FIG. **8**, Table 4 below provides computer-simulated or measured mass and performance properties for the corresponding Comparable Club Head B, Club Head 1B, Club Head 2B, Club Head 3B, and Club Head 4B. As shown in Table 4 below, the amount of mass removed or saved from the striking faces decreases from Club Head 1B to Club Head 4B, as the face center COR, off-center COR, and weighted COR decreases from Club Head 1B to Club Head 4B. However, each of Club Head 1B to Club Head 4B provide greater values for the amount of mass removed, face center COR, off-center COR, and weighted COR than for Comparable Club Head B.

TABLE 4

Property	Comparable Club Head B	Club Head 1B	Club Head 2B	Club Head 3B	Club Head 4B
Mass Savings from Striking Face of Comparable Club Head	NA	7.57 g	5.67 g	5.14 g	4.97 g
Face Center COR	0.7976	0.8098	0.8053	0.8043	0.8039
Off-Center COR at 7.5 mm Toe-Ward of Sweet Spot	0.7843	0.7997	0.7936	0.7931	0.7926
Weighted COR	0.7837	0.7953	0.7910	0.7902	0.7897

Those of ordinary skill will appreciate with reference to the present disclosure that other arrangements of recesses are possible than those shown in FIG. **8**. In this regard, the removal of mass from striking face **309** with the recesses formed in rear surface **328** in FIG. **7** discussed above can also result in a reduction in mass from striking face **309**, an increased COR at the face center, an increased COR at an off-center location that is 7.5 mm toe-ward of the sweet spot, and an increased weighted COR. As another example variation, some implementations may not include one or more of upper region groove **418**, toe region groove **426**, lower region groove **422**, or central region recess **420** or portions thereof, such as heel-side central region recess **435**, middle central region recess **437**, or toe-side central region recess **433**.

In this regard, Table 5 below provides preferred striking face thicknesses and widths for recesses in variations of striking face **409** that do not include lower region groove **422**, but still include heel-side central region recess **435**, middle central region recess **437**, toe-side central region **433**, upper region groove **418**, and toe-side region groove **426**. All of the recesses in Table 5 below can have a radius of 0.4 mm between a bottom of the recess having the indicated thickness and an adjoining wall.

TABLE 5

Club Head	Central Region Recess 420	Upper Region Groove 418	Toe Region Groove 426	Lower Region Groove 422
Club Head 1C	Middle Central Region 437 Thickness: 2.15 mm Heel-Side Central	Thickness: 1.75 mm Width: 6.5 mm	Thickness: 1.75 mm Width: 6.25 mm	None

TABLE 5-continued

Club Head	Central Region Recess 420	Upper Region Groove 418	Toe Region Groove 426	Lower Region Groove 422
	Region 435 Thickness: 1.95 mm Toe-Side Central Region 433 Thickness: 1.95 mm			
Club Head 2C	Middle Central Region 437 Thickness: 2.00 mm Heel-Side Central Region 435 Thickness: 1.95 mm Toe-Side Central Region 433 Thickness: 1.95 mm	Thickness: 1.85 mm Width: 6.5 mm	Thickness: 1.85 mm Width: 2.5 mm	None

FIG. **9** depicts exemplary rear surface **528** of striking face **509** including an example thickness pattern according to one or more embodiments. The thickness pattern of FIG. **9** includes regions or parameterization zones that have varying thicknesses, as opposed to the grooves discussed above that are surrounded by an intermediate region of greater average thickness. Striking face **509** may be formed, for example, of a steel material.

As shown in FIG. **9**, rear surface **528** includes upper region **536**, perimeter region **538**, lower region **534**, and central region **520**, which includes toe-side central region portion **533**, middle central region portion **537**, and heel-side central region portion **535**. The determination of thicknesses for these regions may be determined, for example, using an iterative process, such as the thickness pattern forming process of FIG. **11** discussed below. The thicknesses may provide for improved CORs (e.g., greater maximum COR and/or weighted COR), while maintaining a maximum striking face stress limit or range as a constraint so that striking face **509** is comparable to prior art club heads when tested for durability, despite a reduced mass of striking face **509**.

In this regard, preferred thicknesses are provided in Table 6 below for the parameterization zones or regions shown in FIG. **9** for Club Head 1D, with resulting values for a stress limit for yielding (i.e., a von Mises stress for the striking face), weighted COR, maximum COR, and striking face mass shown in Table 7 below. Thicknesses for these regions are also provided below for a Comparable Club Head D in Table 6, with the resulting values for the stress limit, weighted COR, maximum COR, and striking face mass provided below in Table 7 for comparison. The thickness and width of perimeter region **538** for both Comparable Club Head D and Club Head 1D can be the same, such as with a thickness of 2.4 mm and a width of 2.5 mm, for example. The thicknesses provided below may vary between the regions, such as by tapering or with a stepwise transition. In some implementations, the thicknesses provided below may represent an average thickness for the region. In other implementations, the thicknesses provided below may represent a thickness at a center of the region.

TABLE 6

Region Thickness	Comparable Club Head D	Club Head 1D
Middle Central Region 537 Thickness	2.4 mm	2.8 mm
Heel Central Region 535 Thickness	2.5 mm	2.4 mm
Toe Central Region 533 Thickness	2.3 mm	1.8 mm
Upper Region 536 Thickness	2.2 mm	1.8 mm

TABLE 6-continued

Region Thickness	Comparable Club Head D	Club Head 1D
Lower Region 534 Thickness	2.3 mm	1.9 mm

As shown above, the thicknesses across the striking face of Comparable Club Head D are nearly uniform with a small variation in thickness among the different regions. In contrast, middle central region **537** of Club Head 1D is much thicker than the other regions, and especially thicker than toe central region **535**, upper region **536**, and lower region **534**. As shown in Table 7 below, such variations in the thickness of striking face **509** provide an increased weighted COR and an increased maximum COR, as compared to those of Comparable Club Head D. In addition, the variable thickness pattern of Club Head 1D also reduces the mass of striking face **509** by 6 g, while maintaining a similar or improved stress limit, and thereby providing a similar or greater durability than Comparable Club Head D. The removed or saved 6 g of mass from striking face **509** may be redistributed to other portions of the club head, such as to a rear muscle or toe portion to increase MOIs, and/or to better locate the CG and sweet spot for the club head, as discussed above.

TABLE 7

Property	Comparable Club Head D	Club Head 1D
von Mises Stress	1405	1472
Weighted COR	0.782	0.788
Maximum COR	0.822	0.825
Striking Face Mass	64 g	58 g

Those of ordinary skill in the art with reference to the present disclosure will appreciate that other implementations can include differently shaped or arranged regions or parameterization zones than those shown in the example of FIG. **9**. In this regard, FIG. **10** provides a different thickness pattern with a different arrangement of regions or parameterization zones.

FIG. **10** depicts exemplary rear surface **628** of striking face **609** of a club head including a different thickness pattern according to one or more embodiments. As with the example thickness pattern of FIG. **9**, the thickness pattern of FIG. **10** includes regions or parameterization zones that have varying thicknesses, as opposed to the grooves discussed above that are surrounded by an intermediate region of greater average thickness. Striking face **609** may be formed, for example, of a steel material.

As shown in FIG. **10**, rear surface **628** includes perimeter region **638**, outer region **630**, and central region **620**, which includes outer central region **644**, toe-side inner central region **642**, and heel-side inner central region **640**. The determination of thicknesses for these regions may be determined, for example, using an iterative process, such as the thickness pattern forming process of FIG. **11** discussed below. The thicknesses may provide for improved CORs (e.g., greater maximum COR and/or weighted COR), while maintaining a striking face stress limit or range as a constraint so that striking face **609** is comparable to prior art club heads when tested for durability, despite a reduced mass of striking face **609**.

In this regard, preferred thicknesses are provided in Table 8 below for the parameterization zones or regions shown in FIG. **10** for Club Head 1E and Club Head 2E, with resulting values for a stress limit for yielding (i.e., a von Mises stress for the striking face), weighted COR, maximum COR, and striking face mass shown in Table 9 below. The thickness and width of perimeter region **638** for both club heads can be the same, such as with a thickness of 2.4 mm and a width of 3.5 mm, for example. The thicknesses provided below may vary between the regions, such as by tapering or with a stepwise transition. In some implementations, the thicknesses provided below may represent an average thickness for the region. In other implementations, the thicknesses below may represent the thickness at a center location for the region.

TABLE 8

Region Thickness	Club Head 1E	Club Head 2E
Outer Region 630 Thickness	1.7 mm	1.7 mm
Outer Central Region 644 Thickness	2.2 mm	2.3 mm
Toe-Side Inner Central Region 642 Thickness	2.6 mm	2.5 mm
Heel-Side Inner Central Region 640 Thickness	2.6 mm	2.6 mm

As shown above, central region **620** is generally much thicker than outer region **630**, with toe-side inner central region **642** and heel-side central region **640** being even thicker than outer central region **644**. As shown in Table 7 below, such variations in the thickness of striking face **609** provide an increased weighted COR and an increased maximum COR, as compared to those of Comparable Club Head D discussed above with reference to Table 7. In addition, the variable thickness patterns of Club Heads 1E and 2E also reduce the mass of striking face **609** as compared to Comparable Club Head D by 6 g and 7 g, respectively, while maintaining a similar stress limit, and thereby providing a similar durability as Comparable Head D. The removed or saved 6 g or 7 g of mass from striking face **609** may be redistributed to other portions of the club head, such as to a rear muscle or toe portion to increase MOIs, and/or to better position the CG and sweet spot for the club head, as discussed above.

TABLE 9

Property	Club Head 1E	Club Head 2E
von Mises Stress	1448	1484
Weighted COR	0.782	0.788
Maximum COR	0.822	0.825
Striking Face Mass	64 g	58 g

FIG. **11** is a flowchart for an example thickness pattern forming process for a striking face according to one or more embodiments. The process of FIG. **11** may be used, for example, with the parameterization zones or regions shown in FIGS. **9** and **10** discussed above. A computing device or other electronic processing device may be used for determining the variable thickness pattern in some implementations.

In block **1102**, a plurality of parameterization zones or regions are defined for a striking face of a club head. The club head can be formed with a club head body having a striking face, a heel portion, a toe portion opposite the heel portion, a sole, and a top portion opposite the sole. The club head may be formed, for example, of a steel material, and may include a hollow body type club head or a cavity-back type club head. Each parameterization zone or region may have a variable first parameter and a variable second parameter. In some implementations, the first and second parameters can include a thickness and a width, or other dimension of the parameterization zone or region.

In block **1104**, a target value is set for each constraint value for the striking face. In some implementations, a first constraint value can be a striking face mass, a second constraint value can be a mechanical stress limit of the striking face, and a third constraint can be a weighted COR value for the striking face, as described above. The target value for each parameterization zone or region may be set, for example, based on desired improvements for the club head, such as an increased amount of discretionary mass to be redistributed from the striking face, an increased or minimum durability for the striking face, or an increased weighted COR that is balanced against rules for a maximum COR or CT set by a regulatory body.

In block **1106**, the parameters of each parameterization zone or region are varied. For example, a maximum width and a thickness may be varied as parameters for each of a central region, upper region, lower region, and toe region of the striking face. In some implementations, the parameters may be iteratively varied to generate sets of values for the one or more constraint values based on the changes to the parameters.

In block **1108**, impact with a golf ball is optionally simulated for a plurality of impact locations. In some implementations blocks **1106** and **1108** may be combined. For example, an impact probability matrix as in Table 3 above may be used with Equation 3 above to generate a weighted COR based on variations of first and second parameters for the parameterization zones or regions in block **1106**.

In block **1110**, constraint values resulting from the variation of parameters in block **1106** are evaluated with respect to the target value for one or more constraint values. For example, a resultant weighted COR value closest to 0.80 may at least in part determine the width and thicknesses of the parameterization zones or regions. As another example, a greatest mass removal or mass savings from the striking face may be another factor considered in determining a size and/or thickness of a parameterization zone or region.

In block **1112**, a variable thickness pattern is formed on the striking face based on the evaluation in block **1110**. In some cases, a rear surface of the striking face can have material removed using a cutting tool or other machining to form the variable thickness pattern. In other cases, the variable thickness pattern on the striking face may be formed by using a casting or forging process.

Those of ordinary skill in the art will appreciate with reference to the present disclosure that the thickness pattern forming process of FIG. **11** may differ in other implementations. For example, the setting of one or more targets for one or more corresponding constraint values in block **1104** may occur before the definition of parameterization zones or regions in block **1102**. As another example variation, varying of parameters for each parameterization zone in block **1106** may be combined with the evaluation of resultant constraint values in block **1110**. In some implementations, block **1108** may be omitted.

FIG. **12** is a flowchart for another example thickness pattern forming process for a striking face according to one or more embodiments. The process of FIG. **12** may be used, for example, with the parameterization zones or regions shown in FIGS. **7** and **8** discussed above. A computing device or other electronic processing device may be used for determining the variable thickness pattern in some implementations.

In block **1202**, regions of a striking face of a club head are defined including a central region, an intermediate region, and at least one of an upper region, lower region, and toe region. The club head can be formed with a club head body having a striking face, a heel portion, a toe portion opposite the heel portion, a sole, and a top portion opposite the sole. The club head may be formed, for example, of a steel material, and may include a hollow body type club head or a cavity-back type club head. The central region includes a face center of the striking face, and the intermediate region at least partially surrounds the central region. The upper region can be located above the central region, and a lower region can be located below the central region. A toe region can be located toe-ward of the central region. The intermediate region can be disposed between the central region and each of, or at least one of, the upper region, lower region, and toe region.

In block **1204**, the central region is recessed such that the central region has a thickness less than the intermediate region. In this regard, the intermediate region may have a uniform or approximately uniform thickness, such as a thickness of at least 2.5 mm and no more than 3.3 mm. The recess of the central region may be made by, for example, tapering the central region from a toe side of the central region to a heel side of the central region. In other implementations, the thickness of the central region may vary with stepwise changes in thickness to form the recess. The recess of the central region may be formed, for example, by machining to remove mass or by forging or casting at least a portion of the club head to save mass from the central region.

In block **1206**, at least one of the toe region, upper region, and lower region is recessed, such as with a groove or channel, such that the recessed region has a thickness less than that of the central region. Such a groove may include, for example, an elongate groove having a width no less than about 2.0 mm in at least one of the toe region, upper region, and lower region. The groove may be formed, for example, by machining to remove mass or by forging or casting at least a portion of the club head to save mass from the at least one region. In some implementations, the upper region may include an elongate groove or channel having a width of no less than 6.0 mm.

The recess of the central region formed in block **1204** and the recess of at least one of the toe region, upper region, and lower region in block **1206** result in a striking face that includes a sweet spot corresponding to a first COR, COR1, and an auxiliary location spaced at least 7.5 mm from the sweet spot and corresponding to a second COR, COR_{AUX}, where COR2≥0.98*COR1. In this regard, the foregoing addition of recesses and corresponding removal of mass or mass savings from the striking face increases an area of the striking face that has a relatively high COR. In some implementations, a maximum COR for the striking face may also be increased or better positioned to correspond to a sweet spot and/or a more frequently hit portion of the striking face, as may be quantified with a weighted COR, as discussed above.

In addition, the removal or saving of mass from the striking face can also allow for redistribution of the mass in the club head, such as to a rear muscle or toe portion of the club head, so as to increase MOIs and/or better position the club head CG and striking face sweet spot. For example, a sweet spot may be located not more than 2.0 mm from a vertical center plane perpendicular to the face plane and extending through the face center. As another example, a CG for the club head may be located not more than 1.0 mm from the vertical center plane so as to better position the sweet spot on the face with an expected location or more frequently hit location.

The foregoing description of the disclosed example embodiments is provided to enable any person of ordinary skill in the art to make or use the embodiments in the present disclosure. Various modifications to these examples will be readily apparent to those of ordinary skill in the art, and the principles disclosed herein may be applied to other examples without departing from the scope of the present disclosure. For example, some alternative embodiments may include different sizes or shapes of regions or parameterization zones of a striking face. Accordingly, the described embodiments are to be considered in all respects only as illustrative and not restrictive, and the scope of the disclosure is, therefore, indicated by the following claims rather than by the foregoing description. All changes which come within the meaning and range of equivalency of the claims are to be embraced within their scope. The described embodiments are to be considered in all respects only as illustrative and not restrictive. In addition, the use of language in the form of "at least one of A and B" in the following claims should be understood to mean "only A, only B, or both A and B."

The invention claimed is:

1. A method of manufacturing a golf club head, the method comprising:

(a) forming a golf club head main body by either a forging process or an investment casting process, a golf club head main body including a heel, a toe opposite the heel, a sole, and a top portion opposite the sole;

(b) determining, with a computing device, a variable face thickness pattern of a striking face for the golf club head by:

(i) setting a target value for a first constraint;

(ii) on a computer-simulated striking face having a simulated face center, defining a plurality of parametrization zones including a central zone having the simulated face center;

(iii) for each parametrization zone, setting values for a first parameter and a second parameter;

(iv) simulating impacts for a plurality of impact locations about the simulated striking face;

(v) evaluating resultant first constraint values from the simulated impacts against the target first constraint value; and

(vi) changing the values for the first parameter and the second parameter by increasing or decreasing the values, such changes in values resulting in a simulated variable face thickness pattern;

(c) forming the striking face such that the striking face includes a variable face thickness pattern corresponding to the simulated variable face thickness pattern; and

(d) attaching the striking face to the golf club head main body,

wherein the golf club head has blade length less than 80 mm and a moment of inertia, Izz, and a golf club head mass, mh, that satisfies: Izz>mh*9.3 cm^2.

2. The method of claim **1**, wherein step (c) further includes:

defining a central region, an intermediate region, and at least one of an upper region, a lower region, and a toe region;

recessing the central region to have a thickness less than a thickness of the intermediate region; and

recessing the at least one of the upper region, the lower region, and the toe region to have a thickness less than that of the central region thickness.

3. The method of claim **2**, wherein the central region, the intermediate region, the upper region, the lower region, and the toe region each correspond to one of the plurality of parametrization zones.

4. The method of claim **2**, wherein the golf club head has a weighted coefficient of restitution of no less than 0.79.

5. The method of claim **2**, wherein the intermediate region has a thickness of at least 2.5 mm and no more than 3.3 mm.

6. The method of claim **2**, wherein the recessing steps comprise removing material by machining.

7. The method of claim **1**, wherein the first parameter is a parametrization zone width and the second parameter is a parametrization zone thickness.

8. The method of claim **1**, wherein the first constraint is a mechanical stress limit of the striking face.

9. The method of claim **1**, wherein the golf club head is an iron-type cavity-back golf club head.

10. The method of claim **1**, wherein the golf club head has a topline thickness of no more than 6.5 mm.

11. A method of manufacturing a golf club head, the method comprising:

(a) forming a golf club head main body by either a forging process or an investment casting process, a golf club head main body including a heel, a toe opposite the heel, a sole, and a top portion opposite the sole;

(b) determining, with a computing device, a variable face thickness pattern of a striking face for the golf club head by:

(i) setting a target value for a first constraint;

(ii) on a computer-simulated striking face having a simulated face center, defining a plurality of parametrization zones including a central zone having the simulated face center;

(iii) for each parametrization zone, setting values for a first parameter and a second parameter;

(iv) simulating impacts for a plurality of impact locations about the simulated striking face;

(v) evaluating resultant first constraint values from the simulated impacts against the target first constraint value; and

(vi) changing the values for the first parameter and the second parameter by increasing or decreasing the values, such changes in values resulting in a simulated variable face thickness pattern;

(c) forming the striking face such that the striking face includes a variable face thickness pattern corresponding to the simulated variable face thickness pattern; and

(d) attaching the striking face to the golf club head main body,

wherein the golf club head has a blade length less than 80 mm, a maximum coefficient of restitution at a first location of the striking face, and a second coefficient of restitution that is no less than 98% of the maximum coefficient of restitution at a second location of the striking face that is at least 7.5 mm away from the first location.

12. The method of claim **11**, wherein the second coefficient of restitution is no less than 99% of the maximum coefficient of restitution.

13. The method of claim **11**, step (c) includes:

defining a central region, an intermediate region, and at least one of an upper region, a lower region, and a toe region;

recessing the central region to have a thickness less than a thickness of the intermediate region; and

recessing the at least one of the upper region, the lower region, and the toe region to have a thickness less than that of central region thickness.

14. The method of claim **13**, wherein the central region, the intermediate region, the upper region, the lower region, and the toe region each correspond to one of the plurality of parametrization zones.

15. The method of claim **13**, wherein the golf club head has a weighted coefficient of restitution of no less than 0.79.

16. The method of claim **13**, wherein the intermediate region has a thickness of at least 2.5 mm and no more than 3.3 mm.

17. The method of claim **13**, wherein the recessing steps comprise removing material by machining.

18. The method of claim **11**, wherein the first parameter is a parametrization zone width and the second parameter is a parametrization zone thickness.

19. The method of claim **11**, wherein the first constraint is a mechanical stress limit of the striking face.

20. The method of claim **11**, wherein the golf club head is an iron-type cavity-back golf club head.

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