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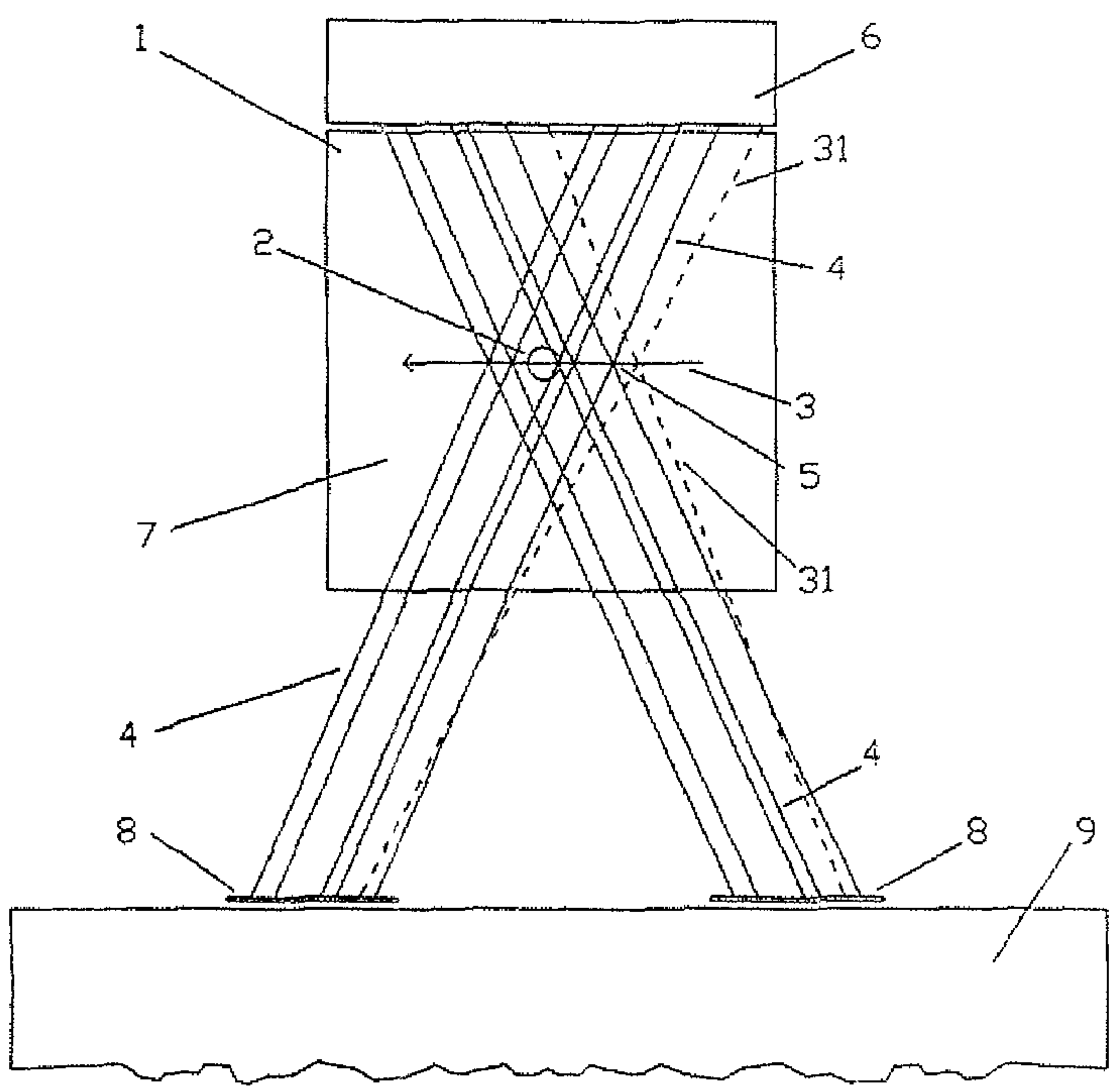

Figure 3

(57) Abrégé/Abstract:
A system or apparatus (1) determines movement characteristics of a golf club (19) and ball (13), including spin characteristics of the ball, without addition or detection of marks or markers on the ball. A beam interrupt system measures club movement up to and including impact and ball movement at and following impact. Spin characteristics are determined, including spin components and causes of spin.

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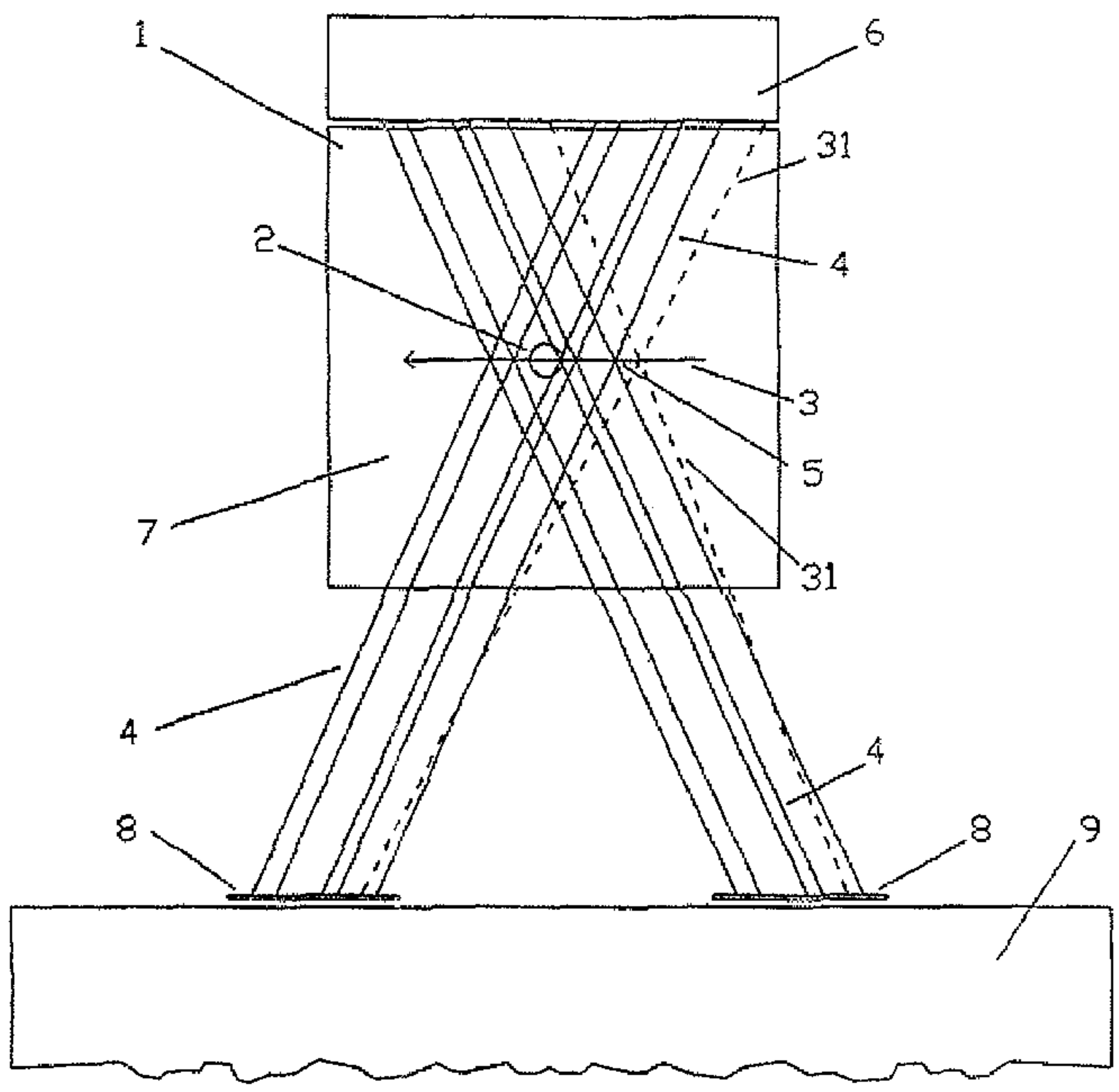

Figure 3

(57) **Abstract**: A system or apparatus (1) determines movement characteristics of a golf club (19) and ball (13), including spin characteristics of the ball, without addition or detection of marks or markers on the ball. A beam interrupt system measures club movement up to and including impact and ball movement at and following impact. Spin characteristics are determined, including spin components and causes of spin.

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DETERMINING AND ANALYSING MOVEMENT AND SPIN CHARACTERISTICS IN A GOLF SHOT

The present invention relates to a system and apparatus for determining movement characteristics related to a golf swing where impact occurs between a club and a ball, which includes ball spin characteristics. The invention relates more specifically, but not exclusively, to a method and apparatus of this type which includes analysis of the causes of these ball spin characteristics and which fully or largely operates in an automatic manner without the aid of a human technician or expert.

The following prior art documents disclose devices which claim to determine movement characteristics, including spin characteristics, in a golf shot.

US 4,136,387; US 5,471,383; US 6,592,465 and US 20040030527, all disclose devices which are stated to be capable of determining spin characteristics by using a processor to analyse changes in the geometric positions or sizes of permanent marks or markings on the surface of a ball between two or more successive images of the moving ball. The images are captured by one or more high-speed cameras. However, these systems are known to be inherently limited in several respects, particularly in that they provide very low levels of accuracy or reliability in determining sidespin parameters, due to typical movement of marks or markings resulting from sidespin being very small compared to that resulting from backspin. They also have the limitation of requiring specially marked balls and of ensuring that the marks or markings are positioned such that they are detected in each image. They are also not capable of distinguishing between angle spin and off-centre spin. Angle spin and off-centre spin are defined and explained later in the specification.

Some systems, similar to the above, have attempted to obviate the need to use specially marked balls. US 7,292,711 B2, discloses a system similar to those described above, but where detection of special marks or markings is substituted by detection of natural surface marks, such as blemishes, cuts or dimples on the surface of the ball. US 2006/0046861, discloses a system where detection of special marks is substituted by detection of temporary thermal marks. However, it is believed that neither of these systems is capable of working in a practical situation. Furthermore, even if they could work in a practical situation, they would not overcome the other limitations associated with very low levels of accuracy or reliability in determining sidespin parameters and would again not be capable of distinguishing between angle spin and off-centre spin.

US 2002/0107078 and US 6,224,971 B1, disclose devices which are stated to be capable of determining spin characteristics by using radar systems to capture reflected signals from contrasting reflective marks applied to the ball. The reflected signals are analysed by a processor to determine spin characteristics. However, these systems are unable to measure spin axis and side spin. They are also not capable of distinguishing between angle spin and off-centre spin. An additional limitation is a requirement that the ball describe a significant amount of angular rotation during measurement, which necessitates a relatively long tracking distance for low spinning, high speed shots, such as a driver shot, thus preventing use with close-range nets. Further limitations include the requirement to provide the special reflective marks on the balls and to have them orientated in a specific direction before the ball is struck.

US 20090075744, discloses a radar device, which is stated to be capable of determining spin parameters without the limitation of having to use a ball with special reflective marks, by means which are stated to include determining the spin velocity from a frequency analysis of a radar signal comprising spectrum traces positioned equidistantly in frequency. The device also appears to overcome the limitation of not detecting sidespin by determining the spin axis solely from a determination of the trajectory of the ball flight. However, this system introduces several further limitations. One of these is that it can only be used where the distant trajectory of the flight can be tracked, thus preventing use in indoor conditions or where the ball is hit into a net. Another is that unaccounted wind conditions may affect the trajectory in a manner similar to spin, leading to inaccuracies in the determination of related spin parameters. An additional limitation is that it is not capable of distinguishing between angle spin and off-centre spin.

An additional limitation of all of these prior art disclosures is that although they may determine spin characteristics of the ball, they provide no information as to how or why these characteristics occurred. The present invention seeks to overcome these limitations of the prior art.

BACKGROUND OF THE INVENTION

Ball spin is generally accepted as being of great importance in the game of golf, because it significantly influences the flight and subsequent bounce and roll of the ball. Although spin occurs about a single axis of rotation, in traditional golf coaching, it is usually studied in relation to its vertical and horizontal components of backspin and sidespin. Backspin is always present in typical aerial golf shots and will usually have an optimal value at launch, depending on the type and requirements of the shot. Sidespin is sometimes present in typical aerial shots and is associated with a gradual lateral deviation of the trajectory. Throughout this specification, terminology will be used which refers to a player who plays from right to left, which includes almost all right handed players and a large proportion of left handed players. Throughout the specification, discussion of spin shall refer only to iron and wood shots, with the term ‘wood’ encompassing all metal woods, including driver and hybrid clubs. The specification excludes putter shots, which occur substantially in two dimensions at relatively low speeds.

When a golf club strikes a ball, there are two general circumstances which cause spin. One of these circumstances, which gives rise to what shall be referred to as ‘angle spin’, occurs where the 3D normal to the contact point on the clubface is not parallel to the 3D direction of club travel when impact occurs. This arises to some extent in all typical accomplished golf shots due to the loft angle of the club, where the clubface is angled about a horizontal axis. It also arises if the clubface is angled about a vertical axis, i.e. if the clubface is ‘open’ or ‘closed’. It additionally arises where the normal to the contact point is aligned correctly to the target direction, but the clubhead incorrectly approaches the ball at impact in a direction which is not aligned to the target direction. It also arises in an otherwise correctly orientated and directed shot where the ball is struck away from the centre of the clubface and where the clubface is curved, such as is typically the case with drivers and other woods, because the curvature of the clubface will cause the normal to misalign with the target direction.

The other general circumstance which causes spin, arises where the ball is struck off-centre, either horizontally or vertically, by the club and where the centre of gravity of the clubhead lies significantly behind the clubface, such as occurs particularly with drivers and to a lesser degree with other woods, but to a much lesser degree or not at all with iron clubs. This type of spin is associated with rotation of the clubhead, causing the ball to pick up a contra spin by frictional engagement between the surface of the ball and the surface of the rotating clubhead surface. It is frequently referred to in golfing parlance by the somewhat unscientific term ‘gear effect spin’ but shall be termed ‘off-centre spin’ throughout this specification. In those cases where some off-centre spin occurs with irons, its effects compared to those experienced with woods are further reduced by the proportionately higher angle spin typically occurring with irons, and by the typically shorter distances of irons shots where side spin has less effect on trajectory. Off-centre spin will promote a tendency to a hooked trajectory for horizontal off-centre toe hits, a sliced trajectory for horizontal off-centre heel hits, a dipped trajectory for vertically off-centre high hits and a raised trajectory for vertically off-centre low hits. ‘Toe’ and ‘heel’ refer to the lateral sides of the clubface away from and adjacent the shaft, respectively. To partly counter these spin effects and provide some degree of ‘forgiveness’ in the club, manufacturers of drivers and other woods provide ‘bulge’ and ‘roll’ curvatures in the horizontal and vertical directions across the clubface, respectively. This curvature promotes a degree of angle spin and directional hit in the opposite direction to that caused by off-centre spin, although typically off-centre spin is left in the ascendancy. Under the Rules of Golf, this curvature is permitted for woods, but is not permitted for irons which must have a flat face.

Where both angle spin and off-centre spin occur, they are combined in a single resultant spin, which may be viewed in terms of back spin and side spin components, although actually existing as one overall resultant spin with the spin axis tilted depending on the proportions of back and side spin components. Where side spin is absent, the spin axis is horizontal and orthogonal to the direction of travel of the ball. The direction of spin rotation is such that the leading edge of the ball is rising and the trailing edge is falling. Although spin typically accounts for less than 1% of the kinetic energy of the impacted ball, it can have a disproportionately large effect on its trajectory because it lifts and bends the trajectory without directly expending its energy, acting somewhat in the manner of a rudder. Lift is generated at right angles both to the spin axis and the direction of the ball. This causes the ball to veer to the left or right where side spin tilts the spin axis away from horizontal. It also causes a backward component decelerating the ball, alongside drag forces, where the ball is ascending. Similarly, it causes a forward component accelerating the ball, against drag forces, where the ball is descending. The ball will typically retain most of its initial spin energy by the time it reaches the ground.

The centre of the clubface is substantially defined by a normal to the clubface projected back to the centre of gravity of the clubhead. It is not necessarily at the geometric centre of the clubface because manufacturers sometimes deliberately arrange it slightly off-centre to effect some special feature, for example it is sometimes moved a few millimetres towards the heel to compensate where players are believed to have a tendency to slice a shot. Also, the normal to the clubface from the centre of gravity will typically be a little above the geometric centre of the face. For typical high speed shots, the shaft will usually have no significant effect on the movement behaviour of the club about a vertical axis at impact. It will also have very little significant effect on the movement behaviour about a horizontal axis at impact, unless the shaft is provided with a very stiff tip at the clubhead end.

DESCRIPTION OF THE INVENTION

The invention is more particularly defined in the appended system claims and apparatus claims which are hereby incorporated into this description.

An aspect of the invention relates to an insight that, in general use, indirect measurement or determination provides the optimum means, and frequently the only means, for determining certain spin parameters with accuracy and convenience. The term ‘general use’ refers typically to use by golfers and golf coaches in normal practice and coaching, and not to use by specialists with access to specialised laboratories or equipment. The term ‘indirect measurement’ refers to determination by measurement of secondary or derivative causes or effects of the characteristic rather than direct or immediate detection of the characteristic, where, for example, detection of movement of marks or markings on the ball surface constitutes a direct or immediate measurement in the present instance.

A further aspect of the invention relates to an insight that these spin parameters can be determined by effective reconstruction and appropriate analysis of relevant aspects of the impact event by identifying and using measurable characteristics related to ball and club movement. Such effective reconstruction involves determining the circumstances surrounding the event and then determining the characteristics of the event from the determined circumstances.

An additional aspect of the invention relates to an insight that measurable movement characteristics with limited and sometimes inadequate levels of measurement accuracy can be used to determine certain spin characteristics with much higher levels of accuracy both because there is considerably more measurable information available than is strictly required and because it is possible to devise means to utilise this potential surplus of information to upgrade levels of accuracy in the determinations. With respect to this insight, it is noted that complete knowledge of club movement characteristics and club and ball physical properties is theoretically sufficient to fully determine relevant ball movement characteristics, including spin characteristics, and that advance knowledge of ball movement characteristics is not theoretically required. Ball movement characteristics, other than spin characteristics, are amenable to direct measurement by general users and can be used to provide the said surplus information in advance of the determination. Means by which potentially duplicate or superfluous information, with limited levels of accuracy, can be used to determine results with higher levels of accuracy include artificial intelligence systems, such as neural networks, which are capable of receiving unrestricted numbers of inputs and which are trained to identify results taking all inputs and their interrelationships into account.

Another aspect of the invention relates to an insight which overcomes many difficulties which would otherwise be present in accurately determining spin characteristics, and at the same time results in more meaningful and more consistent determinations for the user. This relates to a realisation that frequently the most useful feedback information to the user, related to spin characteristics, appertains to the empirically established average properties of particular classes or types of balls under known conditions, rather than the specific properties of the actual ball and ambient conditions used in the measured shot, and that this allows solution of many unknowns in the determination of the characteristics along with eliminating the unnecessary determination of irrelevant variables. In particular, spin characteristics of a ball are influenced by several characteristics related to coefficients of restitution of the ball material and cover hardness condition, which can vary in ways which are not of practical interest to the user. For example, spin characteristics can vary significantly with circumstances such as ball temperature, age and structural condition, which may be collectively referred to as ‘ball conditions’, all of which are usually unknown to the user. The user will typically be more interested in spin characteristics which result from his or her shot with a particular class or type of ball at a known pre-selected temperature and condition. This also provides results of greater consistency allowing more meaningful comparison between different shots played with different individual balls under different ambient conditions.

Some properties of a ball affect spin performance in a real shot but are unlikely to affect indirect measurements and are always advantageously replace by standard properties which are relevant to the user's normal play. An example of this is given by typical types of surface wear or damage. Some properties may affect indirect measurements, but usually these will not be very significant and it still will usually be advantageous to the user to use standard properties, because deviations in the indirect measurements will be due to properties which will not be of relevance to the normal user. To minimise these effects, the user should use test balls which have properties similar to balls with standard properties.

Figure 1 is a block diagram showing principal elements of information flow in an example of the invention using a combination of the inventive aspects outlined above. Abbreviations used in the figure are shown in parentheses in the following brief description. Blocks within the dashed boundary correspond to internal processes within the method or apparatus. Measurement of ball information (MB) and club information (MC) is made when a golf swing (S) is executed on the apparatus. An artificial intelligence (AI), such as a neural network, receives inputs from the measured ball (MB) and club information (MC) and also from a user selection of ball type and conditions (SB). Determination of further club information (DC) is made based on information received from the artificial intelligence (AI) and measured club information (MC). Determination of spin characteristics (DS) is then made based on combined information from measured ball information (MB), the artificial intelligence (AI), determined club information (DC), measured club information (MC) and the user selection of ball type and conditions (SB). An analysis (A) of the swing is made using measured ball information (MB), determined spin characteristics (S), measured club information (MC), determined club information (DC) and the user selection of ball type and conditions (SB). The analysis is communicated externally (C), as required.

An additional aspect of the invention relates to an insight that the difficulty of accurately measuring the important component of angle side spin, because of its typically relatively small magnitude compared to angle backspin, can be overcome by separately determining certain characteristics, which are amenable to accurate determination. One of these characteristics relates to the angle of the spin axis, which would occur if off-centre spin either was not present or not accounted. The other relates to the overall resultant angle spin rate.

Figure 2 is a block diagram similar to Figure 1, but confined to a portion of the overall process and showing principal elements of information flow related to the inventive aspect outlined in the previous paragraph. Measured and determined ball and club information (MDBC/AI), where artificial intelligence may possibly have been employed, is used to determine the angle spin rate data (DASR) and also to determine the angle spin axis data with no off-centre spin (DASANO), that is to say, which would have occurred if off-centre spin had not been present. Determination of angle spin component data (DASC), that is angle sidespin and angle backspin, is then made based on combined information from the determined angle spin rate data (DASR) and the angle spin axis data, where no account is taken of off-centre spin (DASANO). Measured and determined ball and club information (MDBC/AI) is also used to determine off-centre spin data (DOS). Determination of spin characteristics (DS), or at least of those not yet determined, is made based on combined inputs from determined angle spin rate data (DASR), determined angle spin component data (DASC) and determined off-centre spin data (DOS). User selection of ball type and conditions (SB) is also an input to the measurement and determination of ball and club information (MDBC/AI), determination of angle spin rate data (DASR) and determination of spin characteristics (DS).

Determining angle spin axis and angle spin rate.

From considerations of symmetry, it can be shown that the angle spin axis is orientated perpendicular both to the resultant club travel direction just prior to impact, and to the initial resultant ball travel direction, as the ball departs the clubface. Throughout this specification, unless otherwise stated, ‘direction’ refers to direction in 3D (three dimensional) space. The resultant club travel direction, being synonymous with clubhead travel direction, shall be referred to as the ‘club direction’, and the resultant ball travel direction shall be referred to as the ‘ball direction’. Since the club direction and ball direction are never parallel in any typical accomplished shot, their orientations accordingly define the orientation of the angle spin axis. The angle spin axis is the axis about which the ball would spin if off-centre spin was either not present or not accounted.

The ratio between sidespin and backspin components of angle spin is given by the relationship: $\tan(\lambda) = \omega_{as}/\omega_{ab}$, where λ is the angle between the horizontal and the spin axis, if off-centre spin was either not present or not accounted; ω_{as} is the rate of angle sidespin; and ω_{ab} is the rate of angle backspin.

The rate of angle spin does not practically lend itself to precise universal mathematical treatment due to the variability and uncertainty with which the ball deforms on the clubface as angle spin is generated. However, the following results have been found from empirical testing. All other things being equal, angle spin is substantially linearly proportional to club speed and the sine of face-direction-angle; and inversely linearly proportional to the moment of inertia of the ball. The term 'face-direction-angle' refers to the angle between vertical and the 3D normal to the clubface at the point of contact with the ball at impact. Angle spin is similarly substantially linearly proportional to the ratio $m_c/(m_b+m_c)$, where m_b and m_c are the masses of the ball and club head, respectively. It is similarly substantially linearly proportional to the ratio of differences in ball speeds resulting from differences in the elastic properties of the clubface. This ratio may also be represented by the equivalent ratio of coefficients of restitution of the ball and clubface combination. Angle spin is also strongly dependent on the structural, elastic and deformation properties of the ball, including variables such as ball temperature, age and condition. These latter dependencies are complex, variable and difficult to represent mathematically. They are conveniently removed from the exercise by focusing the determination of angle spin on an appropriate range of ball examples at pre-determined ambient conditions, as previously discussed

Momentarily leaving aside the club related variables of clubhead mass and clubface elasticity, for a given ball and club under given ambient conditions, the resultant rate of spin is given by: $\omega_a = K.V_c.\sin\alpha$, where ω_a is the resultant rate of angle spin; K is a constant value for given ball and club conditions; V_c is the resultant speed of the club head just prior to impact; and α is the face-direction-angle. A value for K is determined by trial testing for each type of ball under whatever conditions are required or selected. The need to determine club related variables can also be eliminated if a club of similar properties is used in the trial testing to establish a value for K. Alternatively, a single value for K can be used for clubs with different clubhead mass or clubface elasticity properties by multiplying the determined value of angle spin by the appropriate adjustment ratio as described above.

In those instances where adjustment is made for clubhead mass but the mass is not known in advance, it may be determined by direct measurement of ball and club speeds using a relationship of the following type, based on conservation of momentum before and after impact, for example in the direction of club travel prior to impact: $m_c.V_c = m_c.W_c.\cos(\xi) + m_b.V_b.\cos(\psi)$, where m_c is the mass of the clubhead; m_b is the mass of the ball; V_c is the clubhead velocity before impact; W_c is the clubhead velocity after impact; V_b is the ball velocity after impact; ξ is the angle between clubhead directions before and after impact; and ψ is the angle between clubhead directions before impact and ball velocity after impact. All of the terms in the relationship, other than m_c and m_b can be obtained by direct measurement. The value for m_b is readily estimated as it is very similar for all typical balls, since the upper value of ball weight is limited by the regulatory authorities.

The variable of clubhead elasticity primarily refers to the additional elasticity typically obtained with thin faced metal woods, in particular large-headed titanium drivers. These additional elastic properties are subject to maximum limits by the regulatory authorities and it appears increasingly likely that all or most metal woods of a given face size will ultimately have similar elasticity properties. Thus elasticity will increasingly be accounted in the value of K determined by testing.

Determining face-direction and face-direction-angle.

From considerations of symmetry, it can be shown that the orientation of the 3D normal to the clubface, where contact is first made with the ball, lies in the same plane as the club direction and ball direction. This normal to the clubface shall be referred to as the ‘face-direction’.

The angle which the normal to the clubface makes within the 3D frame of reference, shall be referred to as the ‘face-direction-angle’, and may be conveniently defined within a frame of reference with axes including vertical direction and intended direction. Where the clubface is square in the horizontal plane, the face-direction-angle is the same as the ‘dynamic loft angle’ of common golf terminology. Face-direction-angle can be determined by direct or indirect measurement, or estimated using an empirically established method, such as that disclosed below, which will be referred to as the ‘empirical’ method for determining this angle.

Face-direction-angle values range from about 130% to about 110% of resultant ball direction angle depending on the loft angle of the club, with the values in all cases decreasing with decreasing face-direction and club loft, and with values across the range also varying with the type of ball. Tests indicate that for any given ball type, a single mathematical expression, such as the following second order polynomial relationship, can provide a reasonably accurate estimate of face-direction-angle across the range of typically encountered ball direction angles: $\gamma = a.\theta^2 + b.\theta$, where γ is the face-direction-angle; θ is the ball direction angle; and a and b are the empirically derived coefficients of the expression. The following relationship has been found suitable for one common type of ball at commonly encountered conditions: $\gamma = (0.027).\theta^2 + (0.75).\theta$. Tests further indicate that the results are only moderately sensitive to ball type, such that data for a relatively small representative sample of ball types can adequate cover all types, with similar levels of accuracy. Data for the coefficients in the mathematical expressions are readily obtained by trial testing.

Determining off-centre spin.

Where off-centre spin occurs, the off-centre impact causes the clubhead to rotate about its centre of mass, which in turn causes the clubface to move along the surface of the ball, thereby imparting spin. A simple analysis of the relevant forces, movement and geometry involved in this impact and combined rotation provides the following relationships, where consistent units are used: $\beta.I = V_b.d.m_b$, and $\omega_o = A.\beta/\pi D_b$ It therefore follows that: $\omega_o = [V_b.d].[A/I].[m_b/\pi D_b]$, where ω_o is the resulting rate of off-centre spin of the ball; β is the angular velocity of the clubhead about its centre of mass as the ball leaves the clubface; d is the off-centre distance from the point of impact to the normal from the clubface to its centre of mass; m_b is the mass of the ball; V_b is the velocity of the ball after impact; I is the moment of inertia of the clubhead about an axis through its centre of mass and about which the clubhead rotates; D_b is the diameter of the ball; and A is the distance of the centre of mass behind the clubface.

In this instance it is better to separately calculate the horizontal and vertical components of off-centre spin because the values for moment of inertia of the clubhead are quite different for rotation about vertical and horizontal axes and are normally only available, or readily calculated, across these axes. The relationships may be written as follows, where subscripts h and v refer to horizontal and vertical terms, respectively: $\omega_{oh} = [V_b.d_h].[A/I_h].[m_b/\pi D_b]$ and $\omega_{ov} = [V_b.d_v].[A/I_v].[m_b/\pi D_b]$, where ω_{oh} is the resulting horizontal component of off-centre spin of the ball; d_h is the horizontal component of the off-centre distance from the point of impact to the normal from clubface to the centre of mass, i.e. the horizontal offset of the force; I_h is the moment of inertia of the clubhead about a horizontal axis through its centre of mass; ω_{ov} is the resulting horizontal component of off-centre spin of the ball; d_v is the horizontal component of the off-centre distance from the point of impact to the normal from clubface to the centre of mass, i.e. the horizontal offset of the force; and I_v is the moment of inertia of the clubhead about a horizontal axis through its centre of mass.

The values of all of the terms in $[m_b/\pi D_b]$ relate to the ball and are readily available. Most balls conform to the limits currently set by the relevant regulatory authorities, with diameters at the minimum allowed 4.267 cm and mass at the maximum allowed 45.93 g. The values for $[A/I_h]$ and $[A/I_v]$ are particular to the club, and are published and available for many clubs, particularly for horizontal values. Alternatively, the values can be calculated in advance by standard well known and established methods. It is also noted that the ratio A/I tends to be fairly constant across most clubs which fall into general categories of design, including the majority of modern driver clubs which are manufactured at the volume limit of 460 cc currently set by the relevant regulatory authorities. This allows use of standard default values for A/I, unless it is known that the club falls outside these typical values, whereupon more relevant values can be substituted. It is also noted that the relevant regulatory authorities currently set a maximum value for the horizontal moment of inertia of the clubhead at 5900 g cm2 but that few, if any, clubs actually attain this value.

Relationship between spin characteristics.

The components of angle spin and off-centre spin are combined in the same frame of reference to determine the overall components of spin rate and axis of spin. This combination is conveniently accomplished by various well established mathematical techniques. The term ‘overall’ in this context shall refer to the combination of angle spin and off-centre spin or to a combination of their components. The terms ‘overall spin’, ‘overall sidespin’ and ‘overall backspin’ are also synonymous with the terms ‘spin’, 'sidespin' and 'backspin', respectively, where these terms are not specifically associated with angle spin or off-set spin.

The spin rate components are mathematically related as follows: $\omega_a^2 = \omega_{as}^2 + \omega_{ab}^2$ and $\omega_o^2 = \omega_{os}^2 + \omega_{ob}^2$, where ω_a is the rate of angle spin; ω_{as} is the rate of angle sidespin; ω_{ab} is the rate of angle backspin; ω_o is the rate of off-centre spin; ω_{os} is the rate of off-centre sidespin; and ω_{ob} is the rate of off-centre backspin.

Where angle spin and off-centre spin are defined in the same frame of reference, or are resolved into the same frame of reference, then: $\omega_s = \omega_{as} + \omega_{os}$ and $\omega_b = \omega_{ab} + \omega_{ob}$, where ω_s is the overall rate of sidespin; and ω_b is the overall rate of backspin. Note that 'backspin' may assume positive or negative values. The rate of angle backspin and the overall rate of backspin are always positive in typical accomplished golf shots. However, the rate of off-centre backspin component is frequently negative, where it subtracts from the positive angle backspin component which is typically greater in magnitude.

Also, the axis of overall spin, defined or resolved in the same frame of reference, is given by: $\tan(\varphi) = \omega_s/\omega_b$,where φ is the angle between the horizontal and the spin axis, with all spin accounted. This axis of overall spin, together with the ball direction and club direction, determines the orientation of the aerodynamic lift force, which lies in the same plane as the club direction, and is oriented orthogonally to the spin axis and ball direction.

DETAILED DESCRIPTION OF AN EMBODIMENT OF THE INVENTION

In the procedures disclosed in the preceding paragraphs, it can be seen that the set of overall spin characteristics, and its component sets of angle spin characteristics and off-centre spin characteristics, can be determined from certain movement characteristics and pre-determined items of information. The movement characteristics are those measured or determined for the specific shot, comprising the club velocity vector immediately prior to impact; the ball velocity vector after impact; the club velocity vector after impact if club mass is not already accounted in the 'K' value; and the impact position on the clubface. They also include the face-direction immediately prior to impact, which can be either measured or determined for the specific shot, or can be determined by applying the 'empirical method' for determining face-direction-angle relationship, previously disclosed, to the values measured for ball direction angle. The pre-determined items of information relate to the class or category of shot, comprising the established angle spin related ‘K’ value for the given ball and club conditions; the A/I_h and A/I_v values for the clubhead; and the clubface elasticity, if not already accounted in the ‘K’ value. The terms ‘club velocity vector’ and ‘ball velocity vector’ are defined as vectors which describe the position, direction of movement and magnitude of velocity of the club and ball, respectively, and thus include the ‘club direction’ and ‘ball direction’.

The required movement characteristics can be measured by various means, including, but not limited to, high-speed camera systems, radar detection systems, and beam interruption systems.

The movement characteristics may be determined with sufficient speed to allow the method to operate interactively, providing feedback to the user during practice sessions.

The invention will now be described more particularly with reference to Figures 3 to 12(b), to show, by way of example only, an embodiment of the invention which uses a beam interruption system to determine movement characteristics, including ball spin characteristics, of a golf shot. Beam interruption systems, which determine movement characteristics of golf shots, are known, and reference is made to prior art document WO 2006/061809, although the document does not include determination of ball spin characteristics. Beam interruption systems of this type can be made operable to capture very high speed motion in a 3D stereoscopic manner. In an alternative embodiment, a high speed camera system is used which captures images stereoscopically, either by using two or more cameras viewing at different angles, or using a single camera viewing at different angles through an optical device such as a prism.

Referring now to Figure 3, this shows a diagrammatic external plan view of the apparatus arrangement, including the paths of the beams, although the beams are not visible in reality.

Figure 4 shows a closer view of the central beam region of Figure 3 and includes identifying labels on the beams.

Figures 5 and 6 show views similar to Figures 3 and 4, respectively, showing optional variations in the apparatus arrangement.

Figure 7 shows a diagrammatic side view of one of the beams, including the emitter, receiver, collimating lens and other optical components. The beam outline is shown as a solid line and the beam is shown as a set of parallel lines in the playing region where it comprises a flat band of collimated rays. The view is shortened along the collimated path of the beam which in reality is much longer than that shown, as can be appreciated from Figures 3 or 5. The view also shows a ball interrupting the outward path of a central portion of the beam.

Figure 8 depicts a diagrammatic sectional plan view through the collimating lens on a magnified scale, with a beam passing through one of its facets.

Figures 9(a) and 9(b) show a front and side view of a typical driver clubhead and portion of its adjoining shaft. The clubhead is shown in its neutral orientation, i.e. with zero roll angle and with dynamic loft angle equal to static loft angle.

Figures 10(a) and 10(b) show a front and side view of a typical iron clubhead and portion of its adjoining shaft. The clubhead is shown in its neutral orientation.

Figure 11(a) shows a view of the driver clubhead in neutral orientation, shown in Figures 9(a) and 9(b), as viewed in the scan direction of any of beams B1, B2, B3 or B0, as depicted in Figures 4 or 6. The figure also indicates various measurements which may be taken where the clubhead is scanned in these beams.

Figure 11(b) shows a view of the driver clubhead in neutral orientation, shown in Figures 9(a) and 9(b), as viewed in the scan direction of any of beams F1, F2, F3 or F0, as depicted in Figures 4 or 6. The figure also shows various measurements which may be taken where the clubhead is scanned in these beams.

Figure 12(a) shows a view of the iron clubhead in neutral orientation, shown in Figures 10(a) and 10(b), as viewed in the scan direction of any of beams B1, B2, B3 or B0, as depicted in Figures 4 or 6. The figure also shows various measurements which may be taken where the clubhead is scanned in these beams.

Figure 12(b) shows a view of the iron clubhead in neutral orientation, shown in Figures 10(a) and 10(b), as viewed in the scan direction of any of beams F1, F2, F3 or F0, as depicted in Figure 4 or 6. The figure also shows various measurements which may be taken where the clubhead is scanned in these beams. Figures 11(a) and 12(a) show 'heel beam' views of the clubs where the leading edge of the image is on the heel side. Figures 11(b) and 12(b) show 'toe beam' views where the leading edge of the image is on the toe side.

The following is an index of the reference numerals used in Figures 3 to 12(b):

1. Apparatus
2. Ball at starting rest position
3. Line showing intended direction of flight
4. Beam
5. Beam intersection
6. Enclosure housing emitters and detectors
7. Playing surface
8. Retroreflector
9. Standing surface or mat
10. Emitter / laser
11. Emitter lens / laser lens
12. Collimating lens
13. Ball
14. Beam splitter
15. Photoelectric detector array
16. Collimating lens facet
17. Collimating lens beam screen
18. Collimating lens locating flange
19. Clubhead
20. Club face
21. Shaft
22. Hosel
23. Blade
24. Toe
25. Heel
26. Guide marks

27. Shaft axis
28. Heel leading edge
29. Toe leading edge
30. Reference point intersection of axis and outline
31. Pilot beam

Referring now to Figure 3, the apparatus includes an enclosure which houses the emitters and receivers, a playing surface, retroreflector units and a standing surface or mat for the user. The figure also shows a golf ball placed in position, prior to being struck by the club, and shows an imaginary straight line and arrow head representing the intended direction of motion of the ball from right to left. The view shows the layout for a typical driver shot where the standing surface and retroreflector units are positioned far from the ball. They are positioned progressively closer to the ball for shorter clubs, with the closest position used for putting. The ‘intended’ direction normally refers to the target direction in which the ball is to be struck and the user may, for example, align his or her shot with the parallel edges of the enclosure, playing surface or standing surface.

Referring to Figure 4, the labelled beams have the following functions and arrangement. Forward facing parallel beams, F1 and F2, and backward facing parallel beams, B1 and B2, are used to detect club movement. Beams F3 and B3, are used to detect ball rest position, time of impact and club movement. Forward facing parallel beams F4 and F5 and backward facing parallel beams B4 and B5 are used to detect ball movement. All of the beams are set at 65° to the intended direction. For the sake of brevity and clarity, pairs of related beams, such as beams F1 and B1, shall sometimes be denoted in the format ‘F1-B1’. The intersections of beams F1-B1, F2-B2, F3-B3, F4-B4, and F5-B5 all lie on the line of intended direction passing through the centre of the ball. The distances between the intersections of F1-B1 and F2-B2, and the intersections of F2-B2 and F3-B3 are 50 mm and 20 mm, respectively. The distance between the intersection of F2-B2 and the centre of the ball is 38 mm. The distance between the centre of the ball and the intersection between F4-B4 is at least 41 mm. The distance between the intersections between F4-B4 and F5-B5 is 30 mm.

Figures 5 and 6 are similar to Figures 3 and 4, respectively, but comprise two optional variations in beam arrangements. One of these optional variations comprises an additional beam pair F0-B0, with club movement being detected solely by beam pairs F0-

B0, F1-B1 and F2-B2, and ball rest position and time of impact being detected by beam pair F3-B3. The other optional variation comprises an additional ball detecting beam pair F6-B6.

The arrangement shown in Figures 3 and 4 has fewer components and relative advantages of lower cost, reduced complexity and reduced size and may be used where its performance meets the operating requirements. In the arrangement shown in Figures 5 and 6, low trajectory shots, such as occur with wood and long iron shots, are measured across beam pairs F4-B4 and F6-B6, and high trajectory shots are measured across beam pairs F4-B4 and F5-B5. Beam pair F6-B6 is added to provide a greater distance over which ball flight is measured in order to increase measurement accuracy. Beam pair F5-B5 cannot be moved to this distant position because high trajectory shots would rise above the top level of the 110 mm high beam at this distance. In the arrangement shown in Figures 5 and 6, a single set of beams no longer detects the ball starting conditions and club movement. There are several circumstances where this separation of functions may be judged desirable, including the following. The loss of portions of the beam, occluded by the ball, may be judged to adversely affect the reliability and accuracy of detecting the club. A detector suitable for accurate static position detection of the ball may be judged unsuitable for accurate high speed detection of the club.

Other beam arrangements and dimensional variations can be used. It is not essential to use sets of parallel beams which are symmetric about the target line through the ball, but this arrangement simplifies calculation and understanding of the system and optimises many variables, partly because like conditions apply on both sides of the target line. Using consistent beam angles has the advantage of standardising components and facilitating more closely packed component layouts. Beam angles are principally chosen as an optimum compromise between lateral detection sensitivity and minimising apparatus size. Distances between beams and heights of beams are principally chosen as optimum compromises between detection sensitivity, range of shots captured and minimising apparatus size.

Although the exemplary system comprises six club measuring beams set at two different angles, the minimum requirement for club measuring beams is at least three or four beams and at least two different angles. However, four beams are preferable to achieve balance between groups at different angles and attain high levels of accuracy. Greater numbers of beams provide additional information on changes in characteristics or variables as the club moves towards and into the impact region. They may also share functions, such as measurement of the stationary ball and time of impact. Similarly, although the exemplary system comprises four or six ball measuring beams, again set at two different angles, the minimum requirement for ball measuring beams is two beams, and once again they must be set at different angles. The minimum number is less that that required for club movement due to the symmetry of the ball and the reduced number of measurement characteristics or variables. However, greater levels of accuracy are achieved with greater numbers of ball measuring beams, as discussed in the description of the exemplary arrangement.

The apparatus comprises a playing surface and a ball positioned directly on the surface, or on a support or tee on the surface, prior to the shot being taken. The playing surface comprises a durable artificial turf or polymer mat. The ball is positioned at the required height on a flexible or collapsible support, similar to types used on driving range surfaces. The standing surface or mat is used to equalise the height of the user's standing position with that of the playing surface. Although not shown in the figures, the apparatus also includes a user interface and a programmed electronic processor which is operable to convert signals from the beams to movement characteristics of the club and ball, generally in line with the methods described elsewhere in this specification.

Referring now to Figure 7, each of the beams depicted in Figures 3 to 6 comprises an arrangement of the type shown in Figure 3. An emitter, comprising a laser diode, emits a beam which strongly diverges in a vertical direction and less strongly diverges in a lateral direction. The beam passes through a lens, which will be referred to as a laser lens, which modifies the beam into a flatter shape with also modifies its intensity distribution from one which is weakest at the edges to one which is weakest at the centre. The intensity distribution is modified to give the most even final distribution at the photodiode array, since optical transmission losses are higher towards the edges of the beam.

The flattened beam is intercepted by a beam splitter, where a proportion is transmitted, which continues to an elongate vertical collimating lens, which modifies it to parallel collimated format. The collimated beam crosses the playing surface in this format, unless blocked or partly blocked by a club or ball, and is reflected back along the outward path by a retroreflector. The reflected beam returns to the collimating lens where it is converted from its parallel collimated format to a converging format, substantially opposite to its conversion on its outward path. The returning beam meets the beam splitter, where a proportion is reflected back, to form an image on a vertically orientated photoelectric detector array, which may optionally be inverted as shown in the figure. The beam splitter is rotated, about a vertical axis, slightly away from orthogonal to the outgoing and returning beam path, such that the detector array is positioned slightly offset from the collimating lens and outgoing beam path. Thus any object passing through the main collimated beam will form a proportional silhouetted image on the detector array. The components are arranged such that the main collimated beam is substantially 1mm in thickness and 110 mm in height.

The collimating lens, comprising a vertical array of Fresnel facets, carries out the two tasks of directing the diverging rays from the laser and laser lens into a parallel collimated format in the outgoing operating beam which crosses the playing surface and focusing the returning beam into converging rays which ultimately create the image on the photoelectric detector array. The collimating lens is produced as a polymer injection moulding and its cross section is shown diagrammatically in Figure 8. The facets are approximately 1 mm in vertical height and about 2 mm wide. They are substantially flat when viewed across a horizontal section, but are curved when viewed across a vertical section. Each facet is set at the appropriate angle which refracts the element of the beam passing through it to the required collimated direction. The moulding is produced with the array of facets at the angle of the beams, allowing the moulding to be readily and accurately mounted in the enclosure with its body and locating flanges orientated along the main axis of the enclosure. The moulding is also provided with integral moulded screens on the surface opposite to the facets. These screens comprise angled surfaces which extend over the full height of the optical portion of the moulding and serve to deflect away from the operating beam any increase in its width greater that the distance between the screens, set at the selected beam thickness, which is 1 mm in the described example. The collimated beam is thus trimmed to a beam of 1 mm width on its outward path and is again trimmed to 1 mm on its return. This helps to remove divergence due to diffraction at various edges along the beam path and also any other optical spreading effects occurring laterally at the retroreflector.

The retroreflectors also comprise polymer injection mouldings, but in this instance a single moulding is used to reflect all forward facing beams and a second moulding is used to reflect all backward facing beams. Typically, the retroreflector surface comprises closely packed arrays of optical corner cubes which reflect light back towards the source. The corner cubes have three reflective faces at 90 degrees to each other. The general orientation of the retroreflector is very uncritical from a signal viewpoint, although it can affect intensity level, and will return the impinging beams along the same path with a high degree of accurately.

The photoelectric detector may comprise various types of device, including photodiode, CCD (charge-coupled device) and CMOS (complementary metal oxide semiconductor) linear arrays, each comprising a single arrangement of vertically aligned pixels. The selection of detector array type will usually include a compromise between cost and image resolution in the vertical and horizontal directions.

Retroreflection causes a large proportional reduction in beam intensity, which can be minimised by use of rear coatings or minimising the angle between the beam and the normal to the face of the retroreflector. Uncoated retroreflectors have higher potential reflection efficiency that some common inexpensive coatings, such as aluminium coatings, but are more sensitive to direction angle and contamination with dirt or condensation on the rear surfaces. Silver coatings are more efficient but are more expensive.

Reduction in beam intensity from retroreflection, necessitates higher output laser power, which in turn may require special measures to ensure that laser intensity levels are kept within eye safety limits. One or a combination of the following of such special measures is used in the exemplary embodiment. Intermittently powered laser beams can be used, which have much higher eye safe intensity levels when switched on than they would if continuously powered. Across the range of common low-cost mass-produced laser diodes, there is a choice of wavelengths, and those of higher wavelengths have advantageously higher eye safety levels. For example, those at near infra red wavelengths of around 980 nm can be safely used at significantly higher intensity levels that those at visible wavelengths of around 785 nm or less. Laser intensity in the exposed external beams can also be increased by using an uneven beam splitter which, in the exemplary system, reflects a greater proportion of returned light to the photodiode or sensor than the proportion of outgoing light which is transmitted back towards the laser. Where intensity at the photodiode is the controlling factor, this allows lower intensities in the exposed external beam than would occur with an even beam splitter, but requires a higher powered output laser. Where intensity at the photodiode is not the controlling factor, it is usually better to use an even beam splitter, which transmits and reflects approximately equal amounts of light.

Momentary switching of beams can be achieved by providing pilot beams just upstream of the first set of club beams. When the pilot beams are disrupted by the club, the laser beams are switched on for a brief period sufficient to capture club and ball movement. The pilot beams may comprise, for example, two LED or laser point beams of sufficiently low power to safely allow continuous operation. In the exemplary arrangement, the pilot beams are disposed parallel or near parallel to the first two club beams, and are returned by the retroreflector. The point beams are approximately at a level equivalent to the mid position of the banded beams of the club. The returned signal is detected by a single light sensor. The pilot beams do not pass through a Fresnel lens or beam splitter. Near parallel pilot beams may be used to direct the pilot beam towards the retroreflector to avoid having to use a retroreflector of greater size than required for the club and ball measurement beams. The near parallel pilot beams are arranged to be upstream of the club beams in the region of club measurement. Pilot beams of this type are shown as dashed lines in Figure 3 and Figure 5. Where a laser point beam is of the type supplied with a built-in photodiode feedback control, this photodiode may also be used to supply the returning signal. The LED or laser point beams may be mounted on the front part of the enclosure, approximately in line with the array of Fresnel lenses. They will not increase the required length of the casing because the angle of the first two club beams causes their Fresnel lens to be positioned well away from the edge of the enclosure. The use of pilot beams provides two further benefits. It minimises unwanted heating from continuous operating club and ball measuring beams, which might otherwise lead to unwanted thermal expansion of components and optically distorting air convection within the enclosure. It also minimises power use, which is of importance where the device is battery powered.

As mentioned above, the laser diode emitter is selected on criteria including, divergence characteristics; cost; and the maximum power which provides a completely safe beam external to the sealed apparatus enclosure and conforms to safety considerations and regulations. Laser intensity can be increased by matching the characteristics of the laser lens to produce a beam with vertical and horizontal divergences matched to the aperture at the collimating lens.

Each individual apparatus is subjected to electronic calibration following manufacturing assembly to optimise beam detection accuracy. This may, for example, be carried out by means such as passing appropriately shaped precision targets, under carefully controlled conditions, through the beams of the assembled apparatus and recording differences between theoretically correct values and normalised actual detector pixel readings. Software within the apparatus processor is then provided with data related to these differences which corrects the detected readings for each pixel in accordance with the calibration test results. This calibration process eases the manufacturing accuracy requirements up to final assembly of the beam system and increases the overall accuracy of the beam system in its completed form.

Optionally, the apparatus may also be provided with means to allow calibration of the apparatus by the user, such as could be used if, for example, the apparatus lost accuracy after trauma or prolonged use. Such calibration may, for example, be carried out by providing the apparatus with a software facility which, when activated by the user, allows calibration of pixel values by hitting a high-speed, low-trajectory golf ball, such as occurs in a conventional driver shot, through the beams, approximately along the target direction in either direction. Tee positions may be used which facilitate hitting through all beams. The known symmetric shape of the golf ball, combined with the substantially straight and constant speed of the driver shot, provides a known precision target where theoretically correct pixel values can be predicted and compared to normalised actual detector pixel readings, allowing automatic calibration by the apparatus processor. It is not necessary for the calibration test shot to be hit with at a precise azimuth or elevation angle as calibration is solely based on the shot being straight and at high speed.

Measuring the ball velocity vector.

The general method for measuring the ball velocity vector is to first determine the trajectory of the ball through the beams by tracking a reference location on the ball, as it passes through each beam. The ball velocity vector is then calculated from analysis of that information. The three dimensional symmetry of the ball, when in free flight, allows the centre of the ball to be used as a reference location. A first stage in the method involves determining the height of the reference point as it passes through the centre of each beam, together with the time stamp of that event. At this stage, the lateral positions of the reference point in the beams are not known. In a second stage, these determined heights of the reference point; time stamps; the known geometry of the beams; and the knowledge that the ball travels in a substantially straight line at constant speed; are used to determine the straight line direction of travel and speed of the ball in three dimensions, since only one trajectory and speed will match these conditions. The calculations are determined by the apparatus processor. In a third stage, the starting point of the ball velocity vector is determined by estimating the time stamp corresponding to the commencement of free flight of the ball.

Various image processing techniques can be used to determine the height of the centre of the ball and corresponding time stamp as the centre passes through each beam and one such technique shall now be described. At each beam, a succession of scans at high speed is taken by the detector array as the ball passes though it, with each scan producing a measured value at each pixel of the detector array. The scan data is normalised in advance of the shot for each pixel using calibration values established between the laser diode being switched off and being switched on where the beam is not obscured. The normalised data is smoothed using conventional methods. Image definition is improved by increasing the scan frequency and by increasing the number of pixels in the photodiode array, and vice versa. Important criteria in choosing these variables include component costs. In the exemplary system, a sixteen pixel photodiode array scanned at around 120 kHz has been found satisfactory and can be produced at relatively low unit cost, including the cost of processing means.

Each scan produces an image corresponding to the manner in which the ball obscured the beam at the relevant scan time. Various image processing methods may be used to determine the ball centre from the scan data, For example, the processor may fit a symmetric curve, of type such as a best-fit Gaussian curve, either to the pixel values for each scan or to the scan value for each pixel, depending on factors such as whether resolution is greater along the vertical axis or the horizontal axis for the particular apparatus arrangement. The centres of each of these curves is then found by differentiation and a final symmetric curve, again of type such as a best-fit Gaussian curve, is fitted to these centres. The centre of this final curve is again found by differentiation, and corresponds to the ball centre reference point passing through the midpoint of the thickness of the beam. The time stamp and vertical height, corresponding to this ball centre reference point, is recorded for each beam. This technique allows all values collected on all scans detecting the ball to contribute to the final pinpointing of the ball centre. Appropriate adjustment is made where a minority portion of the top of the ball is too high to be captured by the beams. Where properly applied, the symmetry of this measurement technique provides equally accurate results for balls passing orthogonally or obliquely through the beams.

The starting point of the ball velocity vector is reckoned by estimating the time stamp for the point where the ball separates from the clubface and free flight commences. This time stamp is estimated by adding an estimate of the duration of contact between the ball and clubface to the measured initial time of impact. The initial time of impact is determined by the time stamp corresponding to the first significant change in signals on the pixels of beams F3-B3 which are obscured by the ball in the tee-ed up or rest position. The duration of contact between the ball and clubface is close to 0.45 ms for all normal golf shots, varying slightly with ball type and condition and clubhead loft and speed.

Measuring initial ball position and time of impact.

In the exemplary embodiment of the invention the ball is mounted on a flexible mount or tee which approximately positions the ball in the ideal symmetric position with respect to the beams. The initial rest ball position is then measured by the F3-B3 beams, which are partly occluded by the ball in its ground or tee-ed up position. The processor is calibrated to identify the unique pattern of pixel occlusion which occurs for each possible rest position of the ball. This method may be preferred over use of a fixed precision mount relative to the beams for several reasons. One reason is because the tee or mount is arranged to be flexible or collapsible to withstand the impact from the club, and can be expected to partly deform or wear with use, as typically occurs with the types of durable rubber tees used on practice ranges. Another reason is that a rigid mount could send problematic shock waves to the apparatus, or cause a portable playing surface or apparatus to move when struck.

The F3-B3 beams are also used to measure the precise time of impact, which will coincide with the initial change in the output signals of these beams, following detection of the incoming club by the upstream club beams. Conventional signal processing methods, using grey scale measurement of pixel values, are used to interpolate the precise time of initial movement to provide a resolution accuracy which is much finer than the scanning frequency of the detector arrays.

The F3-B3 beams are also used to advise the user whether or not the ball is correctly mounted or tee-ed up. For example, the user may be warned by suitable visible or audible means if a ball is located outside the feasible detection region of the beams, for reasons such as misalignment from a damaged tee or misplacement of the playing surface.

Determining club speed, club direction, club type and face-direction-angle.

When the passage of a clubhead is scanned by one of the club beams, the optimal direct result is a two-dimensional silhouette-type image of the clubhead as seen at the oblique angle of the beam. Such images of clubheads present various detection and measurement difficulties, particularly due to the irregularly curved shapes of clubheads and the range of orientations in which they can be presented. Although wood clubs have flattish faces and iron clubs have completely flat faces, all of which are clearly distinguished from the body of the club head, the face-direction or face-direction-angle cannot be readily detected in an oblique two-dimensional view of the outline silhouette due to the varying curved outlines of the clubface and body. This can be appreciated with the typical driver club shown in Figures 9(a) and 9(b), even with the clubhead in its neutral orientation and with clear views of the leading heel edge and leading toe edge, respectively. The term ‘neutral orientation’ refers to the club being orientated with its dynamic loft angle equal to its static loft angle, and its roll angle at zero degrees, i.e. with the clubface and clubface guidelines orientated horizontally. The face-direction-angle becomes even more difficult to ascertain if the view can vary away from the neutral orientation. In the case of the leading toe edge of the iron club shown in Figure 10(a), the face-direction-angle can be distinguished to some degree, because the clubhead outline is less curved than in the case of a driver or wood club. However the revealed angle will vary as the vertical dynamic loft angle and roll angle of the clubhead vary in a real shot, and the face-direction-angle remains difficult to ascertain. Furthermore, for certain orientations of iron clubheads, particularly the longer irons with lower lofts, much of the leading edge can be obscured by the hosel. In the case of the leading heel edge of the iron club shown in Figure 10(b), the face-direction-angle cannot be distinguished at all, as the rear of the clubhead and lower region of the hosel completely obscure the visible edge. Difficulties similarly arise in attempting to ascribe any fixed references points to the images or measurements which can be directly compared to known clubhead characteristics.

It is necessary to overcome these difficulties if the required movement characteristics are to be accurately measured or determined. The present invention overcomes these difficulties and a detailed example of how this is achieved is set out below. The method is summarised in steps to aid description. The steps do not necessarily have to occur in the chronological sequence or groups shown.

STEP 1: The clubhead is scanned at each of the six club beams.
STEP 2: The scanned data are processed into predefined relevant data, which for convenience will be referred to as ‘key parameters’.
STEP 3: Some of these key parameters are used to determine reference points relative to the clubhead. The reference points are tracked as the clubhead progresses through the beams and provide values for the direction and speed profile of the clubhead.
STEP 4: The direction and speed values are used to normalise key parameters.
STEP 5: Previously determined ball movement characteristics, together with club key parameters, normalised and not-normalised, are used to determine club type and face-direction-angle.
STEP 6: Data obtained from previous steps, together with knowledge of time stamps and beam geometry, are used to refine and finalise values for club direction, club speed and face-direction-angle as the clubhead passes through the beams and progresses to the instant of impact.
STEP 7: The position of the centre of the clubface is identified relative to certain key parameters, using memorised, or otherwise available, information specific to determined club type and accounting for face-direction.
STEP 8: Previously determined ball information, together with club information determined from previous steps, are used to determine spin characteristics using methods disclosed earlier in the specification.

The steps shall now be described in greater detail for the arrangement shown in Figures 3 and 4.

STEP 1: The clubhead is scanned at each of the six club beams, F1, B1, F2, B2, F3 and B3. Signals are initially routinely processed in a manner similar to that described earlier for measurement of ball direction, including normalisation and smoothing.

STEP 2: The scanned data are further processed into predefined key parameters.

In a first variant of this step, the key parameters include the position and angle of the shaft axis and a selection from various other relatively simply defined measurements such as the length and height of the image, shown as ‘A’ and ‘B’, respectively, in Figures 11(a) to 12(b) and the height of the leading point on the leading edge, shown as ‘C’. With woods and toe-beam irons, they also include the intersection of the hosel with the outline of the clubhead, shown as ‘D’ and ‘E’ in Figures 11(a), 11(b) and 12(a). With heel-beam irons, they additionally include the vertical and horizontal relative positions of the lowest point of the crook between blade and hosel, shown as ‘F’ and ‘G’ in Figure 12(b).

In a second variant, the key parameters again include the position and angle of the shaft axis. They also include all or portions of the silhouette-type outline of the clubhead and hosel, obtained by image processing the scans. Various secondary measurements are determined from the outline, including measurements similar to those mentioned in the first variant, and the angles of lines best-fitted to the leading edges of toe-beam woods and irons, to the leading edges of heel-beam woods and to the top blade edges of heel-beam irons.

As will be appreciated from Figure 12(a), there are no maxima, minima or reference points visible on the heel side outline of heel-beam iron images. The intersection of the extension of the shaft axis and lower outline of the club is instead taken as the end point or reference point. This intersection lies advantageously close to the heel side edge of the flat face of the clubhead.

Shaft axis angle is a particularly important measured value for two reasons. The first is that it has the potential to be measured with a relatively high degree of accuracy. This arises because the shaft axis comprises a straight line which is bounded by the shaft edges and hosel edges which are laterally equidistant from it. The shaft axis is also typically close to vertical, and crosses a relatively large number of detector pixels as it progresses through successive scans. These factors facilitate high accuracy measurement. The second reason for the importance of this parameter is that shaft axis angle is closely or directly related to the face-direction-angle, vertical dynamic loft angle, roll angle and lie angle of the club. The apparatus is arranged to ensure that a sufficient portion of the shaft and hosel pass through the relevant beams. For elevated tee-ed up shots, the apparatus may be elevated such that the lower regions of the beam matrix are raised to coincide with the lower regions of the club, which will be sufficient to capture the necessary portions of shaft and hosel in the upper regions of the beam matrix.

STEP 3: Certain key parameters are used to determine a reference point, relative to the clubhead, which is tracked as the clubhead progresses through the beams. These key parameters are the angle of the shaft axis and any convenient marker along the shaft axis, such as the intersection of the shaft axis with a horizontal line corresponding to the highest or lowest detected point of the clubhead, or with a horizontal line corresponding to the midpoint of the highest and lowest detected points on the clubhead. The resulting intersection point will define specific time stamps as it crosses each beam, measured at the centre of the thickness of the beam. When the shaft axis angles and locations, measured for each pair of beams, are combined, they define a shaft angle in three-dimensional space for each of the beam pairs F1-B1, F2-B2 and F3-B3. Appropriate statistical measures, such as the averages of the intersection points and time stamps for each shaft axis pair are used as the reference point and time stamp for the three-dimensional shaft axis.

The positions and time stamps for the tracked reference points at beam pairs F1-B1, F2-B2 and F3-B3 are used to determine the average directions and speeds of the reference point travelling between F1-B1 and F2-B2 and between F2-B2 and F3-B3. The directions and speeds may remain constant over these two distances or may show a change in direction or speed. Where changes occur, these may be presumed to occur gradually over the two distances, and the processor computes a smooth three-dimensional path and speed profile through the three points. This allows clubhead speed and direction of travel to be individually estimated at each of the six beams.

Although not expected in typical accomplished shots, if impact occurs before the reference point has passed through all six beams, a speed adjustment is required across any distance within which impact occurs. This speed adjustment can be avoided if the reference point is redefined to one which is in a position closer to the toe or heel side of the club, depending on which beam had been interrupted after impact. Alternatively, the original reference point can be retained and the necessary speed adjustment made. In this case, the clubhead and points on it may be assumed to linearly decelerate from a substantially constant pre-impact speed to a substantially constant post-impact speed over an impact duration of about 0.45 ms. Pre-impact and post-impact speeds can be estimated by timing any distinguishable feature on the club over a passage through a beam which is fully pre-impact or fully post-impact.

STEP 4: The clubhead direction and speed, determined in the previous step, are used to normalise key parameters. When the clubhead is scanned as it passes through a beam, the apparent lengths of its features in a horizontal direction will decrease with increasing clubhead speed and vice versa. They will also decrease as clubhead direction of travel is angled further away from the angle of the beam, in either direction of rotation, and vice versa. The normalisation process uses the detected direction and speed to correct these changes and convert the lengths of the features in a horizontal direction to what they would be at a consistent standard direction and speed. Typically, the standard direction is chosen as the intended or target direction.

STEP 5: Key parameters, normalised and not-normalised, together with certain other available data, are used to determine face-direction-angle and club type. The determination may be carried out using the potentially duplicate or superfluous information on ball and club movement characteristics, discussed earlier in this specification, with their mixed levels of accuracy, using a neural network type artificial intelligence system, which is capable of receiving unrestricted numbers of inputs and which is trained to identify results taking all inputs and their interrelationships into account. This predicts results with a much higher level of accuracy that can be achieved by applying relationships to direct measurements without potentially surplus information.

The input information to the neural network or artificial intelligence system includes known ball information, primarily including ball direction angle, and also ball speed and selected type and conditions. It also includes known club information, including a selection from relevant normalised and not-normalised key parameters at each beam, club direction and speed at each beam determined in previous steps. The output predictions are club type and the face-direction-angle at each beam or each set of beams. The network may be trained using an automated software programme operating on three-dimensional scanned images of typical ranges of clubheads, thus saving much of the cost which would be involved in field training with actual clubhead inputs. The automated software training inputs may be provided with statistical variations about their theoretical values, replicating what would be expected to occur in actual measurement. This allows the final working network to cope with normal errors occurring in actual measurement.

In the final working network, club type is included in the predicted outputs. The system is also pre-programmed with a full set of required properties for all club types which it is operable to predict. Automatic club type identification provides various advantages over other methods, such as manual inputting of club type or properties by the user. It is convenient for the user, particularly where different clubs are used in succession; it avoids user errors in inputting information; it will likely inspire increased user confidence in the accurate operation of the system; and it overcomes the potential problem of relevant information or operating instructions not being known or available to the user.

Alternatively, and as mentioned previously, face-direction-angle may be estimated using the empirical method previously described.

Other methods may also be optionally used to determine club type and club type related properties. Examples include the following: the user may directly enter details of relevant club properties; the user may enter the club make and model and the system applies relevant properties drawn from a pre-programmed memory, or otherwise available, set of such properties; the system may obtain information on the type of club being played where the processor is under the control of an interactive coaching system and where the user is instructed to play with a specific type of club, this information also being made available to the system; the system may assume that a shot of a particular type is played with a user's specific club already known to the system, where a log for that user is held in the system's memory; or the system may assume that a shot is played with the same club as the preceding shot, where a shot is determined to be of a similar type and is taken within a short predefined period of the preceding shot. Club type may also be predicted using simpler types of algorithm or artificial intelligence system, such as rule based fuzzy logic systems using key parameter inputs.

STEP 6: Information obtained from the previous step involving club type and face-direction at each of the six club beams, together with data obtained from previous steps and knowledge of time stamps and beam geometry, are used to refine and finalise values for club direction and club speed profile as the clubhead passes through the six club beams and progresses to the instant of impact. In previous steps, statistical measures such as averages for club direction and club speed were taken across pairs of beams. The present step includes a refined interpolation of club direction, club speed and face-direction to the instant of impact.

STEP 7: The system identifies the position of the centre of the clubface, relative to the clubhead. To achieve this, the system is provided with specific memorised information which maps the centre of the clubface to certain key parameters, accounting for face-direction for every club type which the system is operable to identify. This information is used to determine the centre of the clubface at impact using the already determined club type, key parameters and face-direction established in previous steps. Various key parameters can be used in this technique. In one example, the memorised information specific to the club type is used to identify the centre relative to the determined clubhead reference point, appropriately accounting for determined face-direction. In another example, the memorised information specific to the club type is used to identify the horizontal and vertical coordinates relative to the determined key parameters of length and height, again appropriately accounting for determined face-direction.

STEP 8: The determined club movement characteristics at the point of impact; the determined ball movement characteristics following impact; and the identified point of contact between the ball and clubface, relative to the centre of the clubface; are used to determine the various spin characteristics, including the components of angle spin and off-centre spin, as generally disclosed earlier in the specification. The position of the clubface and clubface centre, at the initial instant of impact, is known from previous steps. The position of the ball at the initial instant of impact is known from data received from beams F3-B3, as discussed earlier. Initial contact between the ball and clubface occurs tangentially to the spherically curved surface of the ball which is of known radius.

Analysis and interactive application.

The invention, as described, determines the ball direction; ball speed; and the resultant, vertical and horizontal components of overall spin rate; all of which are sufficient to fully described the trajectory of the ball for given ball type and conditions.

In determining these movement characteristics, the method inherently investigates and identifies events and causes immediately leading to the manner in which the ball is launched on its trajectory, and in this respect differs from prior art methods which do not include this investigative aspect. The present method, as described, also measures or determines the resultant, vertical and horizontal components of angle spin; the resultant, vertical and horizontal components of off-centre spin; the type and properties of the club; the horizontal and vertical components of the point of contact on the clubface; the history of clubhead speed leading up to impact; the history of clubhead path leading up to impact; and the history of club face angle leading up to impact, including its component histories of vertical dynamic loft angle, horizontal face angle, roll angle, and dynamic lie angle in the lower region of the shaft.

This characteristic of the invention advantageously provides a ready basis for analysis of the shot, either by direct human interpretation of the measured and determined information, or by automatic interpretation within the software of the apparatus processor. This characteristic of the invention also advantageously provides a ready basis for driving interactive coaching software during practice sessions with the apparatus.

It is to be understood that the invention is not limited to the specific details described herein which are given by way of example only and that various modifications and alterations are possible without departing from the scope of the invention as defined in the appended claims.

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CLAIMS:

1. A method for determining, or determining and analysing, movement characteristics related to a specific golf swing where impact occurs between a club and a ball, where direct measurement is made which defines 3D direction of motion of the ball at impact and/or after impact, when said specific golf swing is executed, characterised in that;

a) movement characteristics include ball spin characteristics which comprise a selection from: angle spin characteristics; and angle spin characteristics and off-centre spin characteristics;

b) angle spin characteristics comprise rate of angle spin and 3D orientation of the axis of angle spin;

c) ball spin characteristics are determined without the need for addition or detection of surface or internal marks or markers on the ball;

d) 3D orientation of the axis of angle spin is determined using direct measurement which defines 3D direction of motion of the ball before impact and/or at impact when said specific golf swing is executed, and direct measurement which accurately defines 3D direction of motion of the club at impact and/or after impact, when said specific golf swing is executed; and

e) rate of angle spin is determined using pre-determined information on a ball instead of actual information on the ball used in the specific golf swing; together with direct measurements which define a selection from the following movement characteristics when said specific golf swing is executed: 3D direction of motion of the ball; magnitude of ball speed; 3D direction of motion of the club; magnitude of club speed; and 3D face-direction-angle of the club.

2. A method according to Claim 1, which analyses movement characteristics and indicates causes of ball spin characteristics.

3. A method, according to any of the previous claims, which automatically measures, determines and analyses or interprets spin characteristics, club movement characteristics and ball movement characteristics, without the aid of a human technician or expert.

4. A system according to any of the previous claims, where ball spin characteristics are determined by effective reconstruction of the impact event from measured club movement characteristics before impact and/or at impact and measured ball movement characteristics at impact and/or after impact.

5. A method according to any previous claim, where spin characteristics are determined by combining potentially duplicate information from measurements of club movement characteristics before impact and/or at impact in the specific swing and ball movement at impact and/or after impact in the specific swing, to create new information of greater accuracy or reliability related to ball spin characteristics.

6. A method according to Claim 5, where movement characteristics are combined by an artificial intelligence means.

7. A method according to Claim 6, where the artificial intelligence means comprises a neural network system which is trained with training inputs, comprising measurements of club movement characteristics before impact and/or at impact and ball movement characteristics at impact and/or after impact, and training outputs, comprising ball spin characteristics.

8. A method according to any previous claim, where values of ball properties required in the determination of ball spin characteristics are based on pre-determined standard properties.

9. A method according to Claim 8, where properties used as standard properties do not significantly influence measurements of ball movement characteristics used in determining ball spin characteristics.

10. A method according to any of Claims 6 or 7, where ball spin characteristics are determined from; measured club movement characteristics before impact and/or at impact; and ball movement characteristics at impact and/or after impact; and combined data from the artificial intelligence system.

11. A method according to Claim 10, where ball spin characteristics are also determined from pre-determined ball data and/or the artificial intelligence means also uses pre-determined ball data.

12. A method according to Claims 10 or 11, where ball spin characteristics are also determined from; measured club movement characteristics; and/or further club information

which is determined from measured club information and combined data from the artificial intelligence means.

13. A method according to Claims 10, 11 or 12, where the swing is analysed.

14. A method according to Claim 13, where; measured ball movement characteristics and/or measured club movement characteristics and/or further club information which is determined from measured club information and combined data from the artificial intelligence means; are also used in the analysis.

15. A method according to Claim 14, where pre-determined ball data are also used in analysing the swing.

16. A method according to any previous claim where a component of angle spin, such as side spin, is determined by determining spin characteristics which would apply if off-centre spin was not present or not accounted.

17. A method according to Claim 16, where measured club movement characteristics and measured ball movement characteristics, are used to determine; angle spin rate data; and/or angle spin axis data which would have occurred if off-centre spin had not been present; and/or off-centre spin data.

18. A method according to Claims 6 and 17, where data combined from ball and club data using artificial intelligence is also used.

19. A method according to Claims 17 or 18, where angle spin component data are determined from; angle spin rate data; and angle spin axis data which would have occurred if off-centre spin had not been present.

20. A method according to Claim 19, where spin data are determined from; angle spin rate data; and angle spin component data; and off-centre spin data.

21. A method according to Claim 8 and any of Claims 17, 18, 19 or 20, where pre-determined ball data is also used.

22. A method according to any of Claims 1 to 12 and 16, where angle spin characteristics are determined from measurements which include; club velocity and club face direction at or just after impact; and a constant value which is pre-determined by trial for given club and ball conditions.

23. A method according to any of Claims 1 to 12, where clubhead mass is determined from, club movement characteristics measured before impact, and ball movement characteristics and club movement characteristics measured after impact.

24. A method according to any of Claims 1 to 12, where club face direction angle is determined from a mathematical relationship, such as a second order polynomial, established by trial where the variable is ball direction angle.

25. A method according to any of Claims 1 to 12, where spin data are determined from measurements which include the club velocity vector at impact or just after impact and ball velocity vector at impact or just before impact.

26. A method according to Claim 25, where angle spin data are determined from measurements which include; the club velocity vector at impact or just after impact, ball velocity vector at impact or just before impact; and club face direction before impact.

27. A method according to Claim 25, where off-centre spin data are determined from measurements which include; the club velocity vector at impact or just after impact, ball velocity vector at impact or just before impact, and impact position on the clubface.

28. A method according to any previous claim, where club movement characteristics and/or ball movement characteristics are measured using a high-speed camera system, a radar detection system, or a beam interruption system.

29. A method according to any previous claim, where images of the club and/or ball are captured stereoscopically at different angles at high speed.

30. A method according to Claim 28 or Claim 29 where the angle of the club shaft is measured or determined and is used as an important measure in determining movement characteristics of the club.

31. A method according to any of Claims 28 to 30, where club movement characteristics are measured or determined by a beam interruption system, which includes a selection from the following features;
a) a plurality of beams are disposed in the path of the club;
b) there are at least three club measurement beams;
c) where accuracy is important, there are at least four club measurement beams; and
d) club measurement beams are set at different angles.

32. A method according to any of Claims 28 or 29, where ball movement characteristics are measured or determined by a beam interruption system, which includes a selection from the following features;
a) a plurality of beams are disposed in the path of the ball;
b) there are at least two ball measurement beams;
c) where accuracy is important, there are at least four ball measurement beams;
d) where accuracy is important, and where shots vary significantly in loft angle, there are at least six ball measurement beams; and
e) ball measurement beams are set at different angles.

33. A method according to any of Claims 28 to 32, where club movement characteristics and/or ball movement characteristics are measured or determined by a beam interruption system, which includes a selection from the following features;
a) changes are detected when a beam is obscured or partly obscured;
b) beams are flat, with thickness much less than their width;
c) beams are horizontally collimated;
d) beams have intensity increased near the edges and reduced near the centre;
e) beams are returned along the same path by retroreflection;
f) beams are divided with a beam splitter; and
g) beams are laser beams and are transmitted through a laser lens which modifies the beam such that its vertical and horizontal divergences are matched to an aperture at a collimating lens.

34. A method according to any of Claims 28 to 33, where club movement characteristics are measured or determined by a beam interruption system; where beams are laser beams and are retroreflected; and/or transmitted and reflected by a beam

splitter; and are sensed by a sensor means; which includes a selection from the following features;

a) beams are generated and disposed at or around near infra red wavelength;

b) beams are divided by an uneven beam splitter which reflects or transmits a greater proportion of returned light to the sensor means than the proportion of returned light transmitted or reflected back towards the laser; and

c) beams are generated non continuously by being momentarily switched on when the club and ball are in the region of the beams and switched off when not in the region of the beams.

35. A method according to Claim 34, where beams are momentarily switched when the club interrupts or triggers a pilot beam; which includes a selection from the following features;

a) a pilot beam is disposed in the path of the club in the region where the club first enters the beams;

b) a pilot beam is disposed in a path where it is disrupted by the club before the club disrupts a club measuring beam;

c) a pilot beam is generated as a point beam:

d) changes in a pilot beam are detected using a single sensor;

e) a pilot beam is generated with an intensity within eye safety levels for continuous operation; and

f) two pilot beams are disposed, one parallel or near parallel to one of the first club measuring beams and the other pilot beam parallel or near parallel to the other of the first club measuring beams.

36. A method according to any of Claims 28 to 35, where the position of the ball is measured and/or monitored by detection of changes in beams partly occluding the ball prior to impact.

37. A method according to Claim 36, where the time of impact is detected by changes in beams occluding the ball, and interpolating signal grey scale to increase resolution accuracy.

38. A method according to any of Claims 28 to 37, where measurements, related to club movement characteristics and ball movement characteristics, are calibrated within

the system software by measuring known precision positions or movements or objects, and correcting for differences between measured values and known values.

39. A method according to any of Claims 28 to 37, where measurements, related to club movement characteristics and ball movement characteristics, are calibrated within the system software by measuring a ball hit through the beams, and substantially travelling in a straight line and at constant speed.

40. A method according to any of Claims 28 to 39, which includes the following steps;

a) club measurements are taken at club measuring beams and processed into relevant club data;

b) club data are used to determine positional references for the club at club measuring beams, which are used to determine club speed and direction;

c) club speed and direction data are used to normalise club data;

d) club speed, club direction, club data and normalised club data, are used to determine club type and club face-direction-angle. These, together with memorised or otherwise available information on club type, are also used to determine impact position on the club face;

e) ball measurements are taken at ball measuring beams and used to determine positional references for the ball at ball measuring beams, which are used to determine ball speed and direction; and

f) club data and ball data determined from preceding steps, are used to determine ball spin characteristics.

41. A method according to any of Claims 28 to 40, where an artificial intelligence means, such as a neural network system, determines club type where the artificial intelligence means inputs include data related to measured club movement characteristics; the artificial intelligence means is trained with, a large set of club movement characteristics training inputs, and corresponding club type training outputs.

42. An apparatus for determining, or determining and analysing, movement characteristics related to a specific golf swing where impact occurs between a club and a ball; the apparatus including a ball measurement means and a processor means; the ball measurement means is operable to directly measure, at impact and/or after impact,

movement characteristics of the ball, from which 3D direction of motion of the ball can be determined, when said specific golf swing is executed; characterised in that;
a) the apparatus is operable to determine movement characteristics related to the specific swing which include ball spin characteristics which comprise a selection from: angle spin characteristics; and angle spin characteristics and off-centre spin characteristics;
b) the apparatus is operable to determine angle spin characteristics which comprise rate of angle spin and 3D orientation of the axis of angle spin;
c) the apparatus is operable to determine ball spin characteristics without the need for addition or detection of surface or internal marks or markers on the ball;
d) the apparatus also includes a club measurement means which is operable to directly measure, before impact and/or at impact, movement characteristics of the club, from which 3D direction of motion of the club can be accurately determined, when said specific golf swing is executed;e) the processor means is operable to determine 3D orientation of the axis of angle spin using said direct measurement which defines the 3D direction of motion of the club before impact and/or at impact, and said direct measurement which defines 3D direction of motion of the ball at impact and/or after impact; and
f) the processor means is operable to determine rate of angle spin using pre-determined ball information available to the processor means instead of actual information on the ball used in the specific golf swing; together with a selection from the following characteristics involving direct measurement when said specific golf swing is executed: 3D direction of motion of the ball; 3D direction of motion of the club; 3D direction of motion of the ball; magnitude of club speed where the club measurement means is operable to measure club speed; magnitude of ball speed where the ball measurement means is operable to measure ball speed; and 3D face-direction-angle of the club where the processor means is operable to determine 3D face-direction-angle using movement characteristics measured by the club measurement means and ball measurement means.

43. An apparatus according to Claim 42, wherein the processor means is operable to analyse movement characteristics and to indicate causes of ball spin characteristics.

44. An apparatus, according to Claim 42 or 43 where the club measurement means, ball measurement means and processing means are operable to measure, determine and analyse or interpret spin characteristics, club movement characteristics and ball movement characteristics, without the aid of a human technician or expert.

45. An apparatus according to any one of Claims 42 to 44, wherein the processor means is operable to determine ball spin characteristics by effective reconstruction of the impact event from measured club movement characteristics before impact and/or at impact and measured ball movement characteristics at impact and/or after impact.

46. An apparatus according to any of Claims 42 to 45, wherein the processor means is operable to determine spin characteristics by combining potentially duplicate information from measurements of club movement characteristics before impact and/or at impact in the specific swing and ball movement at impact and/or after impact in the specific swing, to create new information of greater accuracy or reliability related to ball spin characteristics.

47. An apparatus according to Claim 46, which includes an artificial intelligence means which is operable to combine movement characteristics.

48. An apparatus according to Claim 47, wherein the artificial intelligence means comprises a neural network system which is trained with training inputs, comprising measurements of club movement characteristics before impact and/or at impact and ball movement characteristics at impact and/or after impact, and training outputs comprising ball spin characteristics.

49. An apparatus according to Claims 42 to 48, wherein the processor means is operable to use values of ball properties, required in the determination of ball spin characteristics, based on pre-determined standard properties.

50. An apparatus according to Claim 49, wherein properties used as standard properties do not significantly influence measurements of ball movement characteristics used in determining ball spin characteristics.

51. An apparatus according to any of Claims 47 or 48, wherein the processor means is operable to determine ball spin characteristics from; measured club movement characteristics before impact and/or at impact; and ball movement characteristics at impact and/or after impact; and combined data from the artificial intelligence means.

52. An apparatus according to Claims 43 and 51, wherein the processor means is operable to determine ball spin characteristics from pre-determined ball data and/or the artificial intelligence means also uses pre-determined ball data.

53. An apparatus according to Claims 51 or 52, wherein the processor means is operable to determine ball spin characteristics from; measured club movement characteristics; and/or further club information which is determined from measured club information and combined data from the artificial intelligence means.

54. An apparatus according to Claims 450, 51 or 52, wherein the processor means is operable to analyse the swing.

55. An apparatus according to Claim 54, wherein the processor means is operable to also use; measured ball movement characteristics and/or measured club movement characteristics and/or further club information which is determined from measured club information and combined data from the artificial intelligence means; when analysing the swing.

56. An apparatus according to Claim 43 and 51, wherein the processor means is also operable to use pre-determined ball data when analysing the swing.

57. An apparatus according to any of Claims 42 to 56, wherein the processor means is operable to determine a component of angle spin, such as side spin, by determining spin characteristics which would apply if off-centre spin was not present or not accounted.

58. An apparatus according to Claim 57, wherein the processor means is operable to determine; angle spin rate data; and/or angle spin axis data which would have occurred if off-centre spin had not been present; and/or off-centre spin data; from measured club movement characteristics and measured ball movement characteristics.

59. An apparatus according to Claims 47 and 58, wherein the processor means is operable to also use data combined from ball and club data using artificial intelligence in the determination.

60. An apparatus according to Claims 58 or 59, wherein the processor means is operable to determine angle spin component data from; angle spin rate data; and angle spin axis data which would have occurred if off-centre spin had not been present.

61. An apparatus according to Claim 60, wherein the processor means is operable to determine spin data; from angle spin rate data; and angle spin component data; and off-centre spin data.

62. An apparatus according to Claim 49 and any of Claims 57, 58, 59 or 60, wherein the processor means is also operable to use pre-determined ball data in the determination.

63. An apparatus according to any of Claims 42 to 53 and 57, wherein the processor means is operable to determine angle spin characteristics from measurements which include; club velocity and club face direction at or just after impact; and a constant value which is pre-determined by trial for given club and ball conditions.

64. An apparatus according to any of Claims 42 to 53, wherein the processor means is operable to determine clubhead mass from, club movement characteristics measured before impact, and ball movement characteristics and club movement characteristics measured after impact.

65. An apparatus according to any of Claims 42 to 53, wherein the processor means is operable to determine club face direction angle from a mathematical relationship, such as a second order polynomial, established by trial where the variable is ball direction angle.

66. An apparatus according to any of Claims 42 to 53, wherein the processor means is operable to determine spin data from measurements which include the club velocity vector at impact or just after impact and ball velocity vector at impact or just before impact.

67. An apparatus according to Claim 66, wherein the processor means is operable to determine angle spin data from measurements which include; the club velocity vector at impact or just after impact, ball velocity vector at impact or just before impact; and club face direction before impact.

68. An apparatus according to Claim 66, wherein the processor means is operable to determine off-centre spin data from measurements which include; the club velocity vector at impact or just after impact, ball velocity vector at impact or just before impact, and impact position on the clubface.

69. An apparatus, according to any of Claims 42 to 68, wherein the ball measurement means and/or the club measurement means comprise a high-speed camera system, a radar detection system, or a beam interruption system.

70. An apparatus according to any of Claims 42 to 69, which is operable to stereoscopically capture images of the club and/or ball at different angles at high speed.

71. An apparatus according to any of Claim 69 or 70, where the club measurement means and/or processing means are operable to measure or determine the angle of the club shaft and use it as an important measure in determining movement characteristics of the club.

72. An apparatus according to any of Claims 69 to 71, wherein the club measurement means comprises a beam interruption system, which includes a beam generation means and a detection means which are operable to execute a selection of the following tasks;
a) dispose a plurality of beams in the path of the club;
b) dispose at least three club measurement beams in the path of the club;
c) where accuracy is important, dispose at least four club measurement beams in the path of the club; and
d) dispose club measurement beams at different angles;

73. An apparatus, according to either Claims 69 or 70, wherein the ball measurement means comprises a beam interruption system, which includes a beam generation means and a detection means which are operable to execute a selection of the following tasks;
a) dispose a plurality of beams in the path of the ball;
b) dispose at least two ball measurement beams in the path of the ball;
c) where accuracy is important, dispose at least four ball measurement beams in the path of the ball;
d) where accuracy is important, and where shots vary significantly in loft angle, dispose at least six ball measurement beams in the path of the ball; and

e) dispose ball measurement beams at different angles.

74. An apparatus, according to any of Claims 69 to 73, wherein the ball measurement means and/or the club measurement means comprise a beam interruption system, which includes a beam generation means and a detection means which are operable to execute a selection of the following tasks;
a) detect changes when a beam is obscured or partly obscured;
b) generate beams which are flat, with a thickness much less than their width;
c) generate beams which are horizontally collimated using a collimating lens;
d) generate beams which have intensity increased near the edges and reduced near the centre;
e) return beams along the same path using retroreflector means;
f) divide beams using beam splitter means; and
g) comprises a laser lens which modifies a laser beam such that its vertical and horizontal divergences are matched to an aperture at a collimating lens.

75. An apparatus according to any of Claims 69 to 74, wherein the club measurement means comprises a beam interruption system; which includes a laser beam generation means; a detection means which includes a sensor means, a retroreflection means and/or a beam splitter means; which are operable to execute a selection of the following tasks or activities;
a) generate and dispose beams at or around near infra red wavelength;
b) divide beams with an uneven beam splitter which reflects or transmits a greater proportion of returned light to the sensor means than the proportion of returned light which is transmitted or reflected towards the laser; and
c) generate beams non continuously by momentarily switching on beams when the club and ball are in the region of the beams and switching off beams when not in the region of the beams.

76. An apparatus according to Claim 75, where beams are momentarily switched, wherein the apparatus is operable to execute a selection of the following tasks or activities;
a) dispose one or more pilot beams in the path of the club in the region where the club first enters the beams;

b) dispose a pilot beam in a path where it is disrupted by the club before the club disrupts a club measuring beam;

c) generate a pilot beam which comprises a point beam:

d) detect changes in a pilot beam using a single sensor;

e) generate a pilot beam with an intensity within eye safety levels for continuous operation; and

f) dispose two pilot beams, one parallel or near parallel to one of the first club measuring beams and the other pilot beam parallel or near parallel to the other of the first club measuring beams.

77. An apparatus according to any of Claims 69 to 76, wherein beams are disposed which partly occlude the ball prior to impact, whereby the processor means is operable to measure and/or monitor the ball prior to impact by detecting changes in these beams.

78. An apparatus according to Claim 77, where the processing means is operable to determine the time of impact by detecting changes in beams occluding the ball, and is operable to interpolate signal grey scale to increase resolution accuracy

79. An apparatus according to any of Claims 69 to 78, wherein the processor means is operable to calibrate the club measurement means and/or ball measurement means within the system software, by measuring known precision positions or movements or objects, and correcting for differences between measured values and known values.

80. An apparatus according to any of Claims 69 to 78, wherein the processor means is operable to calibrate the club measurement means and/or ball measurement means within the system software, by measuring a ball hit through the beams, and substantially travelling in a straight line and at constant speed.

81. An apparatus according to any of Claims 59 to 80, which is operable to execute the following steps;

a) obtain club measurements at club measuring beams and process them into relevant club data;

b) use club data to determine positional references for the club at club measuring beams, and use them to determine club speed and direction;

c) use club speed and direction data to normalise club data;

d) use club speed, club direction, club data and normalised club data, to determine club type and club face-direction-angle. Use these, together with memorised or otherwise available information on the club type, to determine impact position on the club face;

e) obtain ball measurements at ball measuring beams and determine positional references for the ball at ball measuring beams, and use these to determine ball speed and direction; and

f) use club data and ball data determined from preceding steps, to determine ball spin characteristics.

82. An apparatus according to any of Claims 59 to 81, wherein the processor means comprises an artificial intelligence means, such as a neural network system, and is operable to determine club type where the artificial intelligence means inputs include data related to measured club movement characteristics; where the artificial intelligence means is trained with a large set of club movement characteristics training inputs and corresponding club type training outputs.

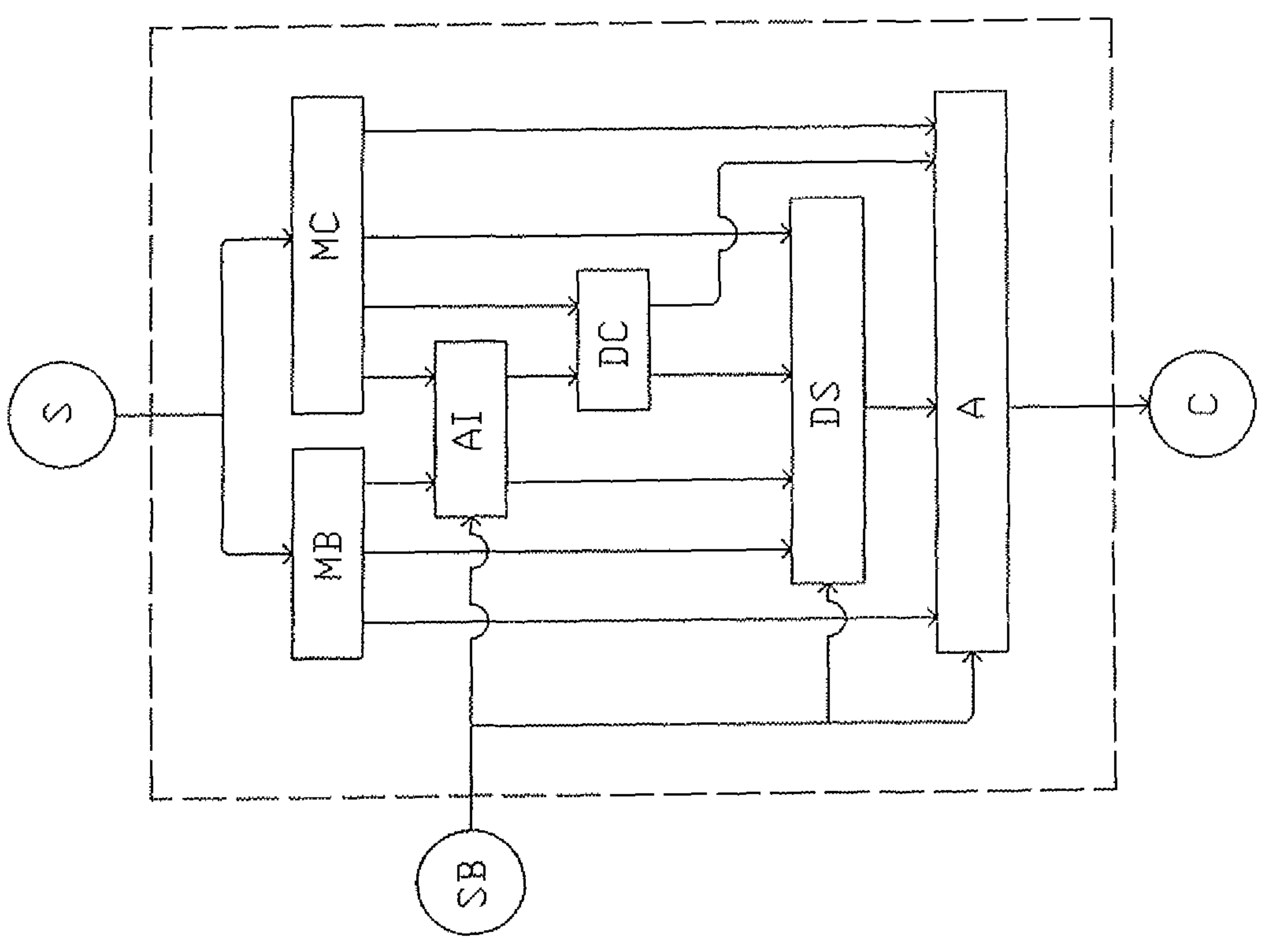


Figure 1

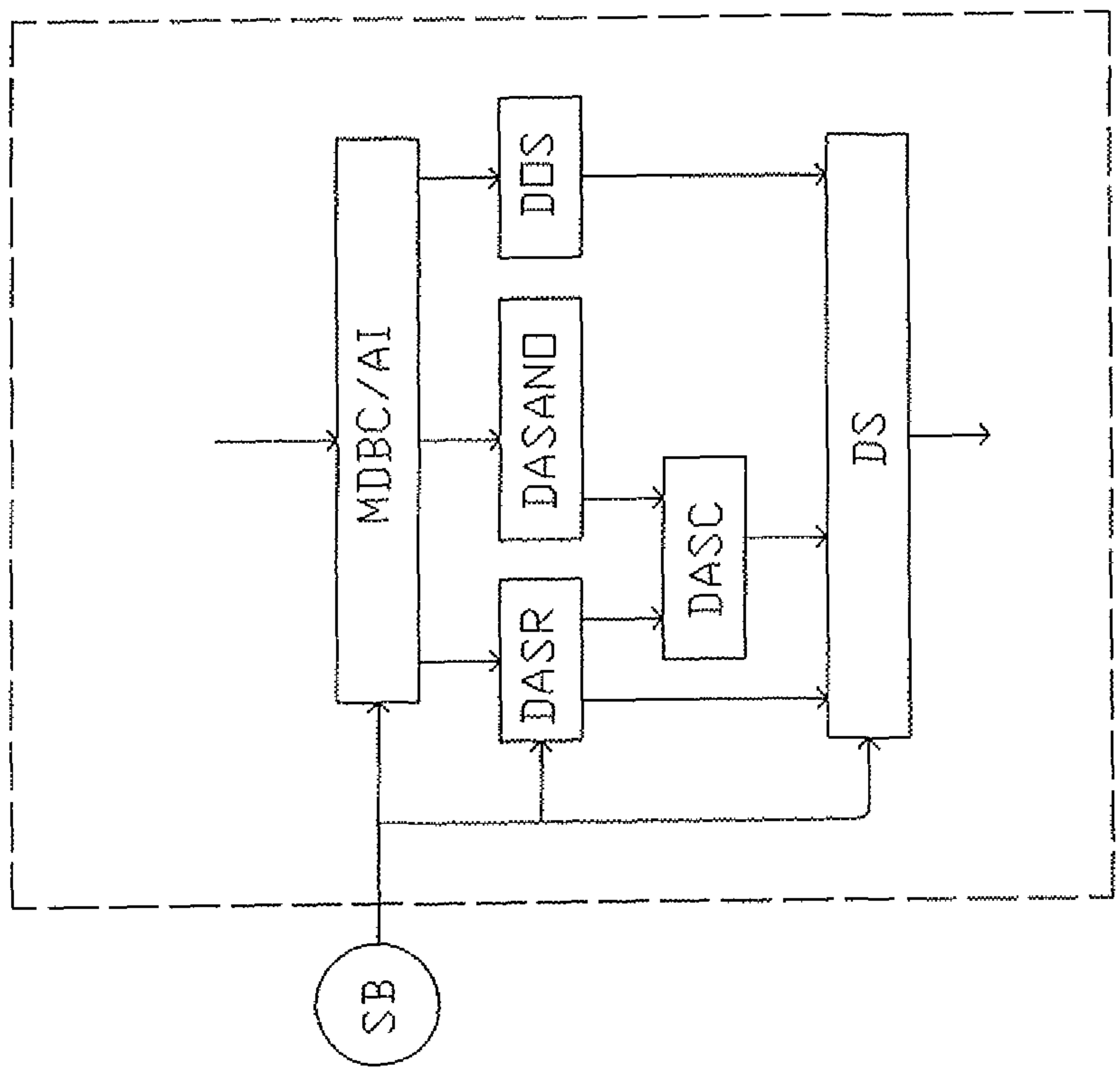


Figure 2

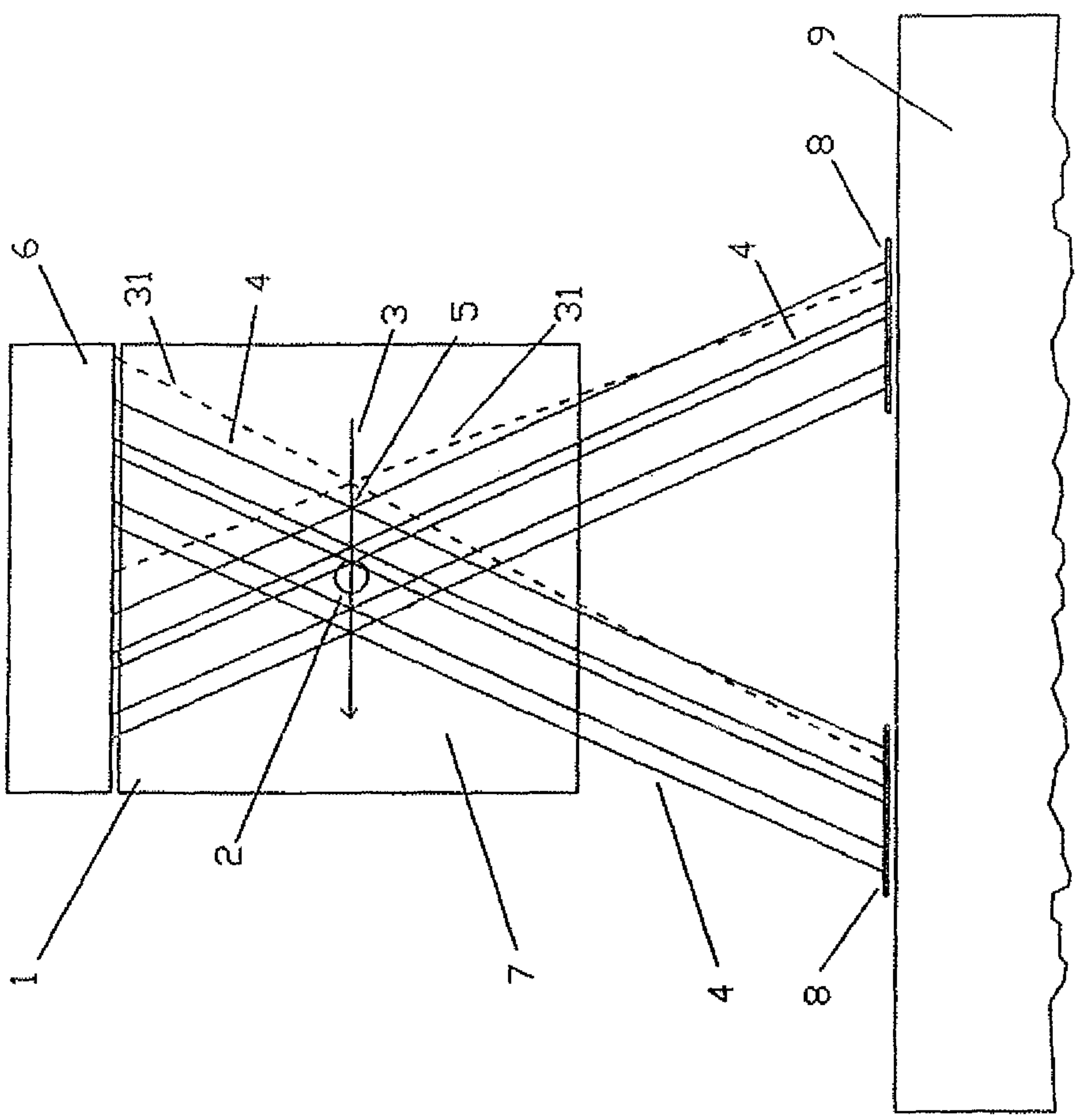
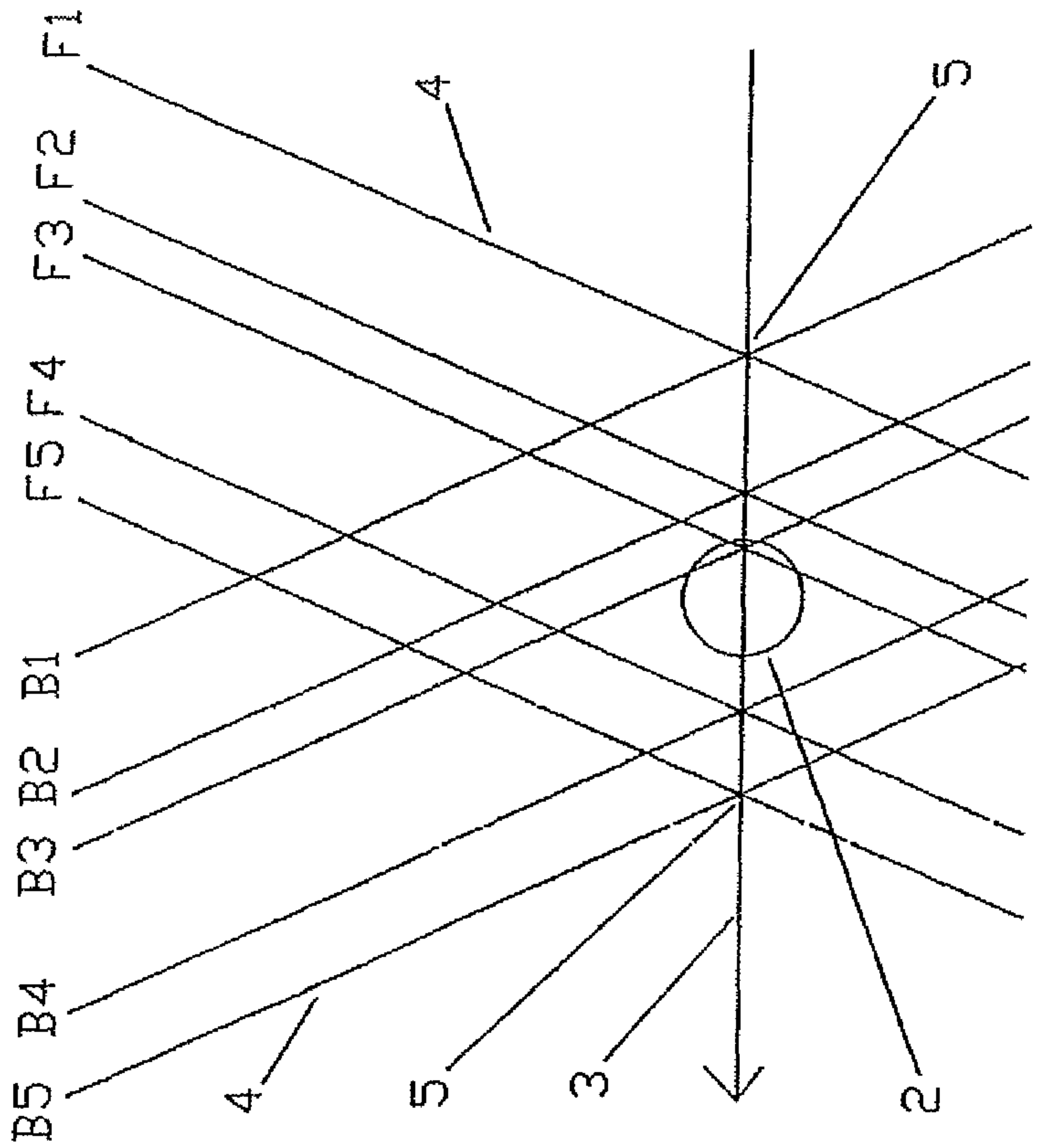


Figure 3



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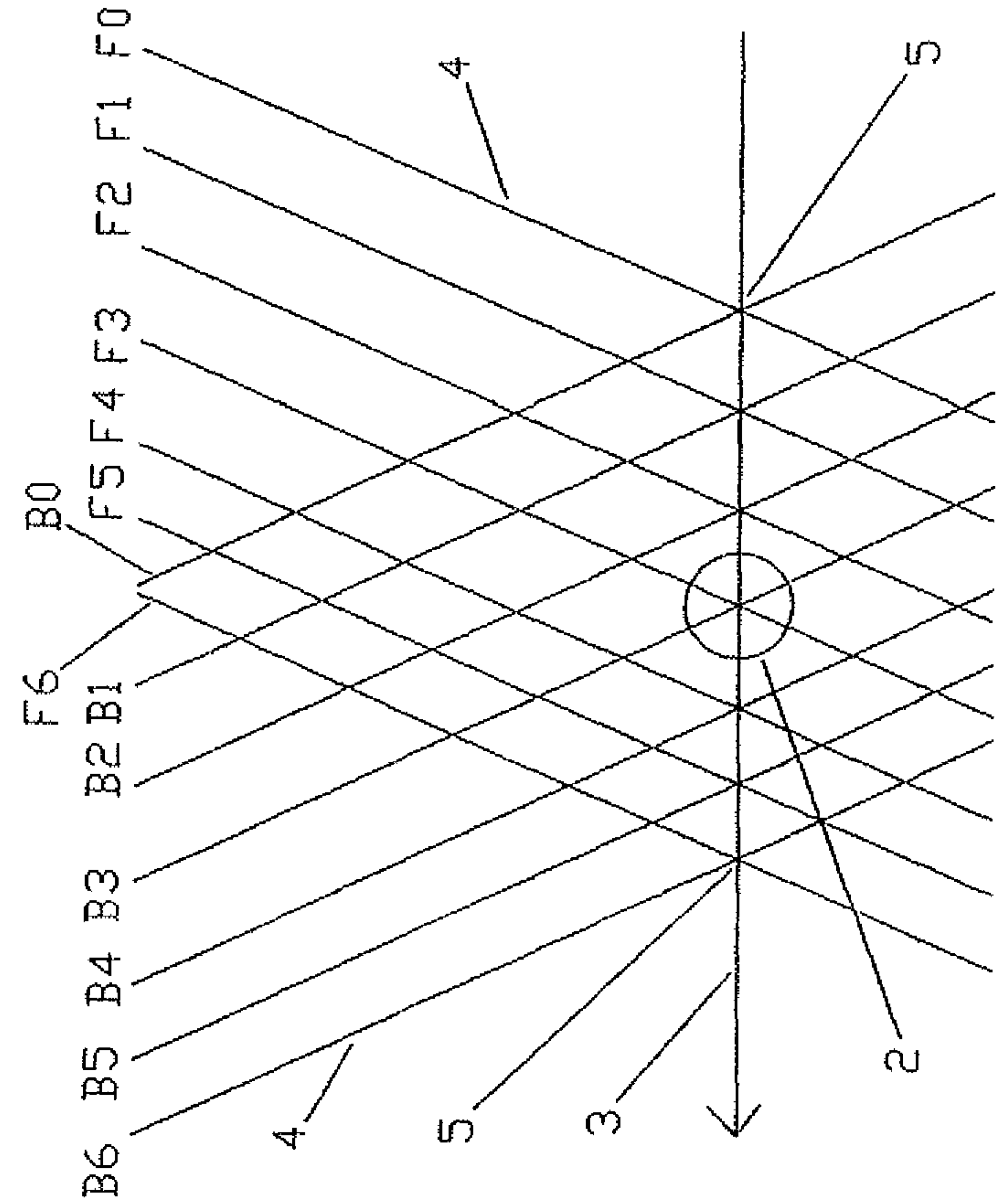


Figure 6

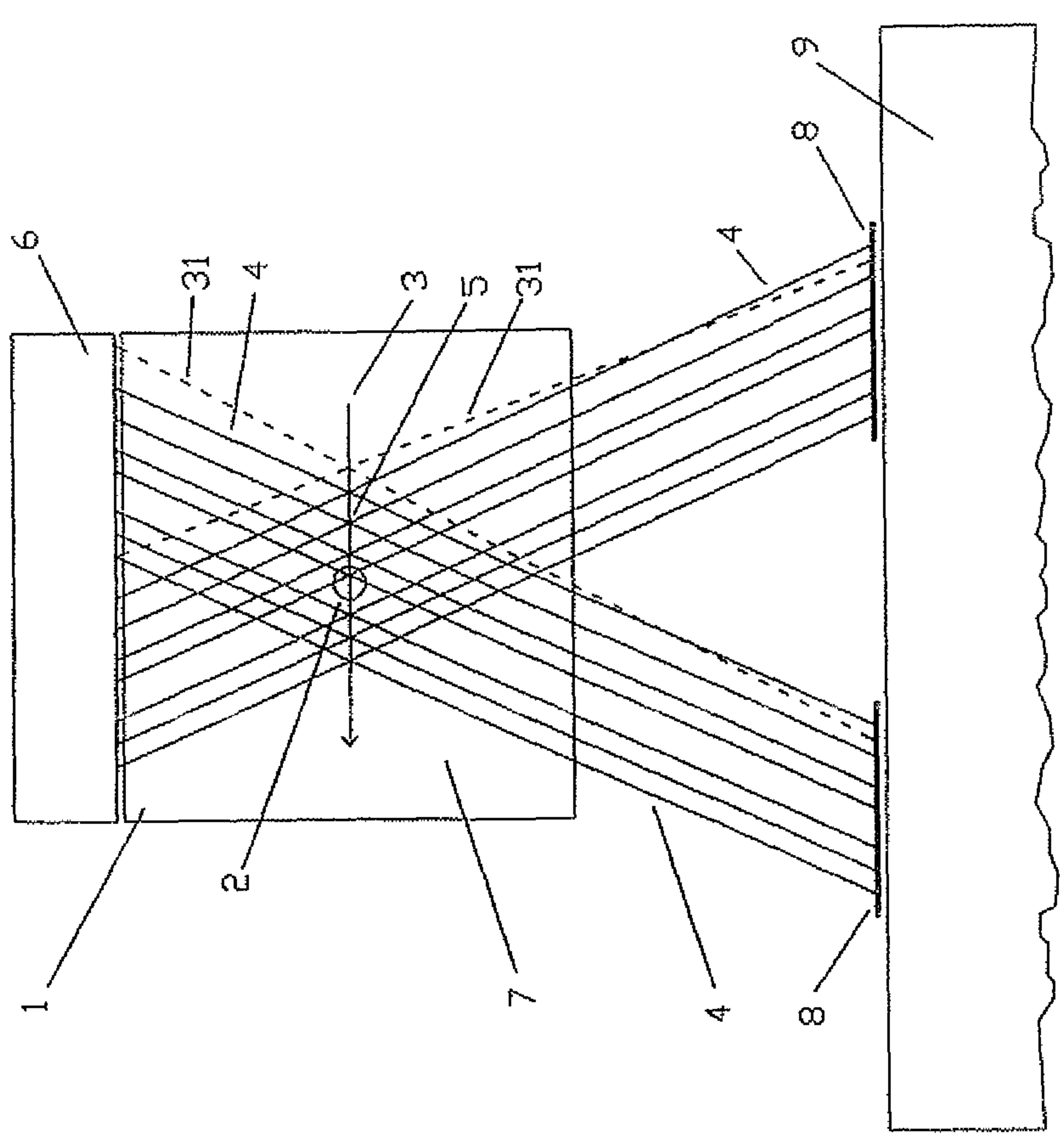
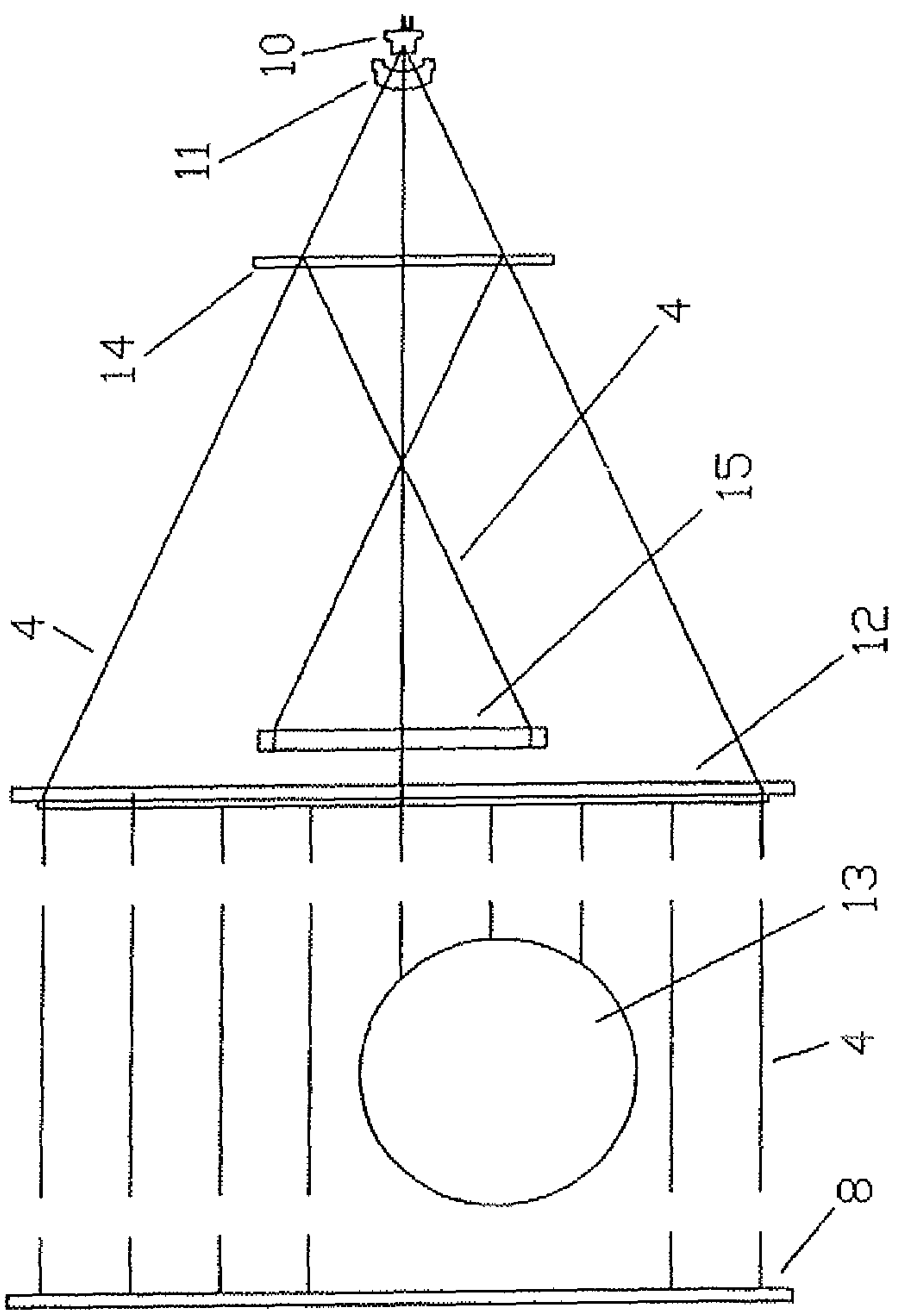


Figure 5



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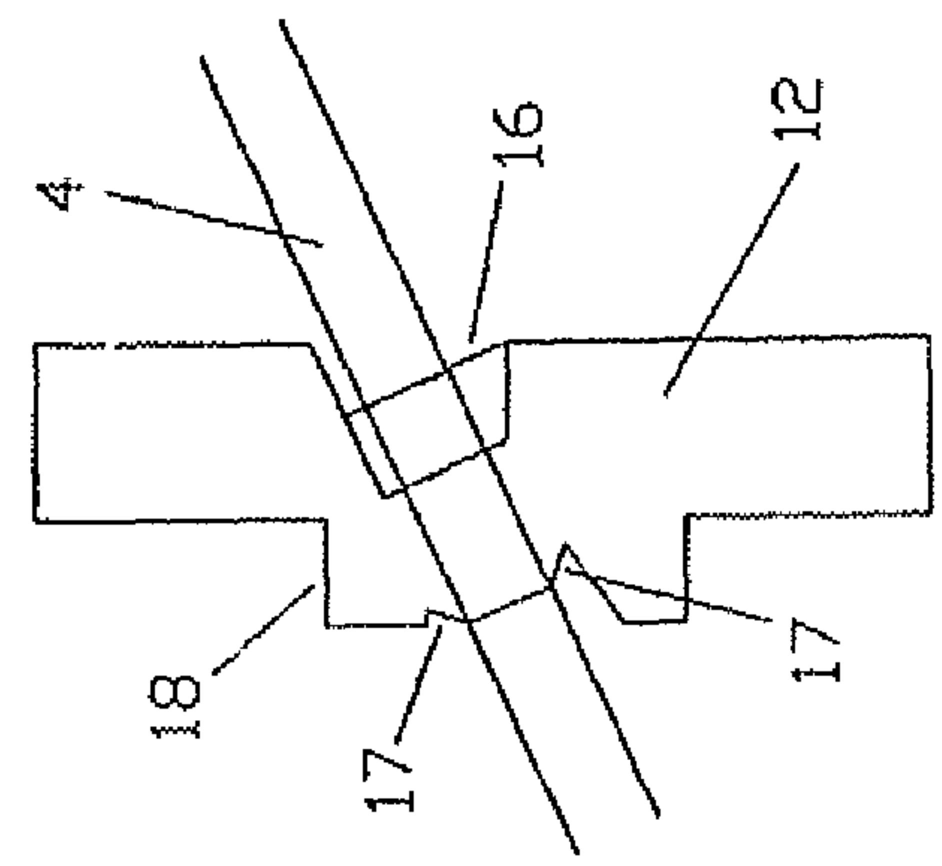

Figure 8

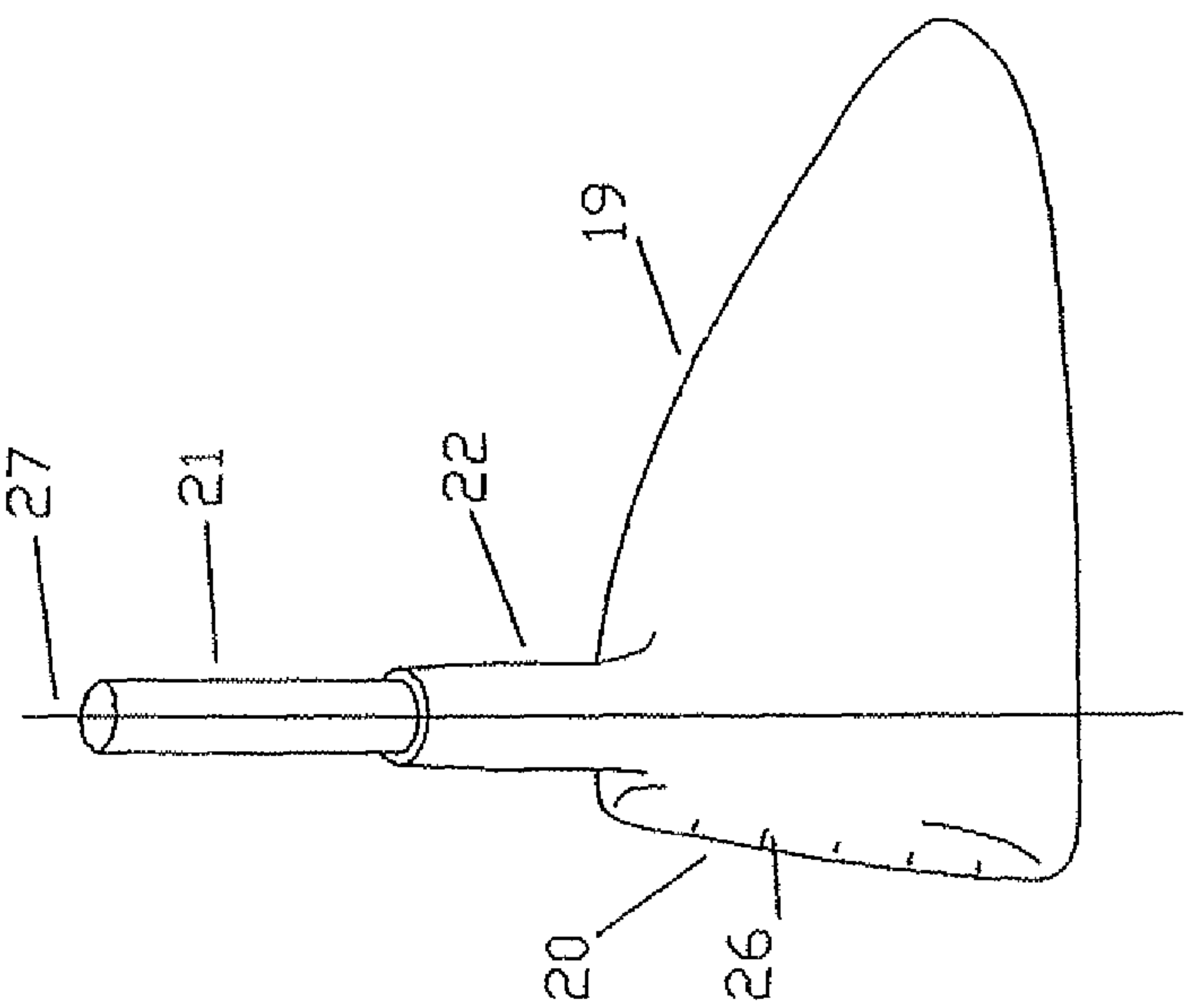

Figure 9(b)

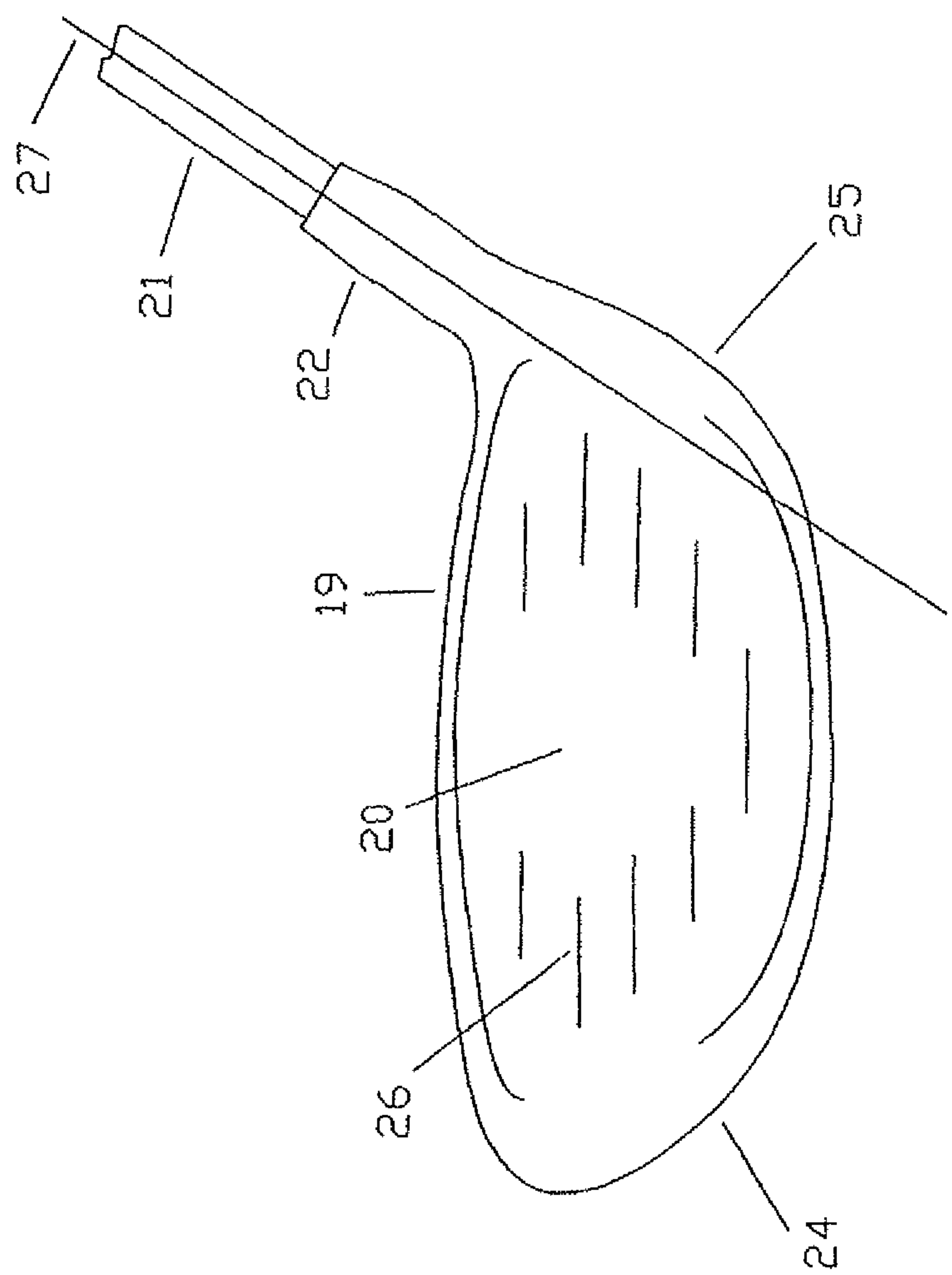

Figure 9(a)

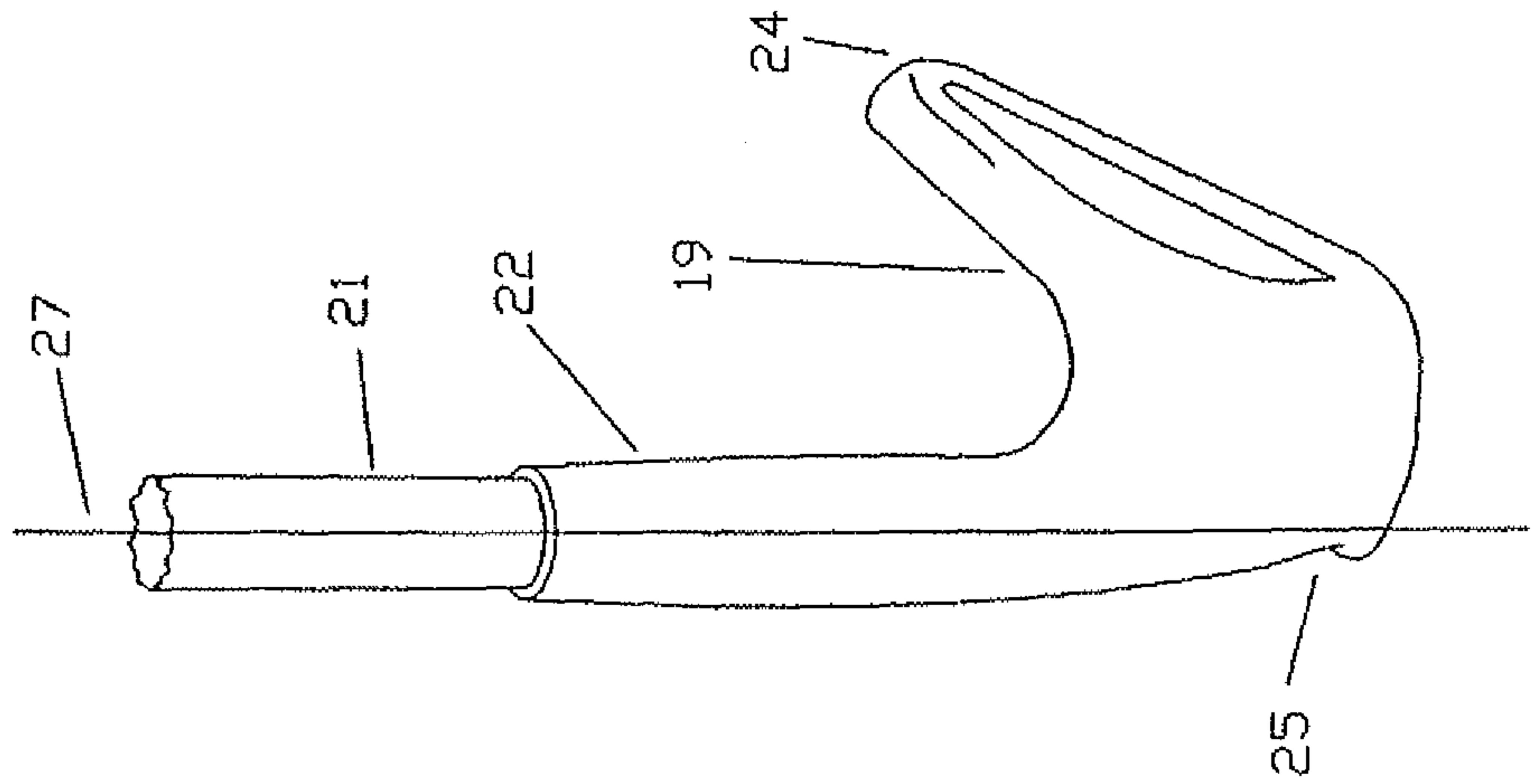

Figure 10 (b)

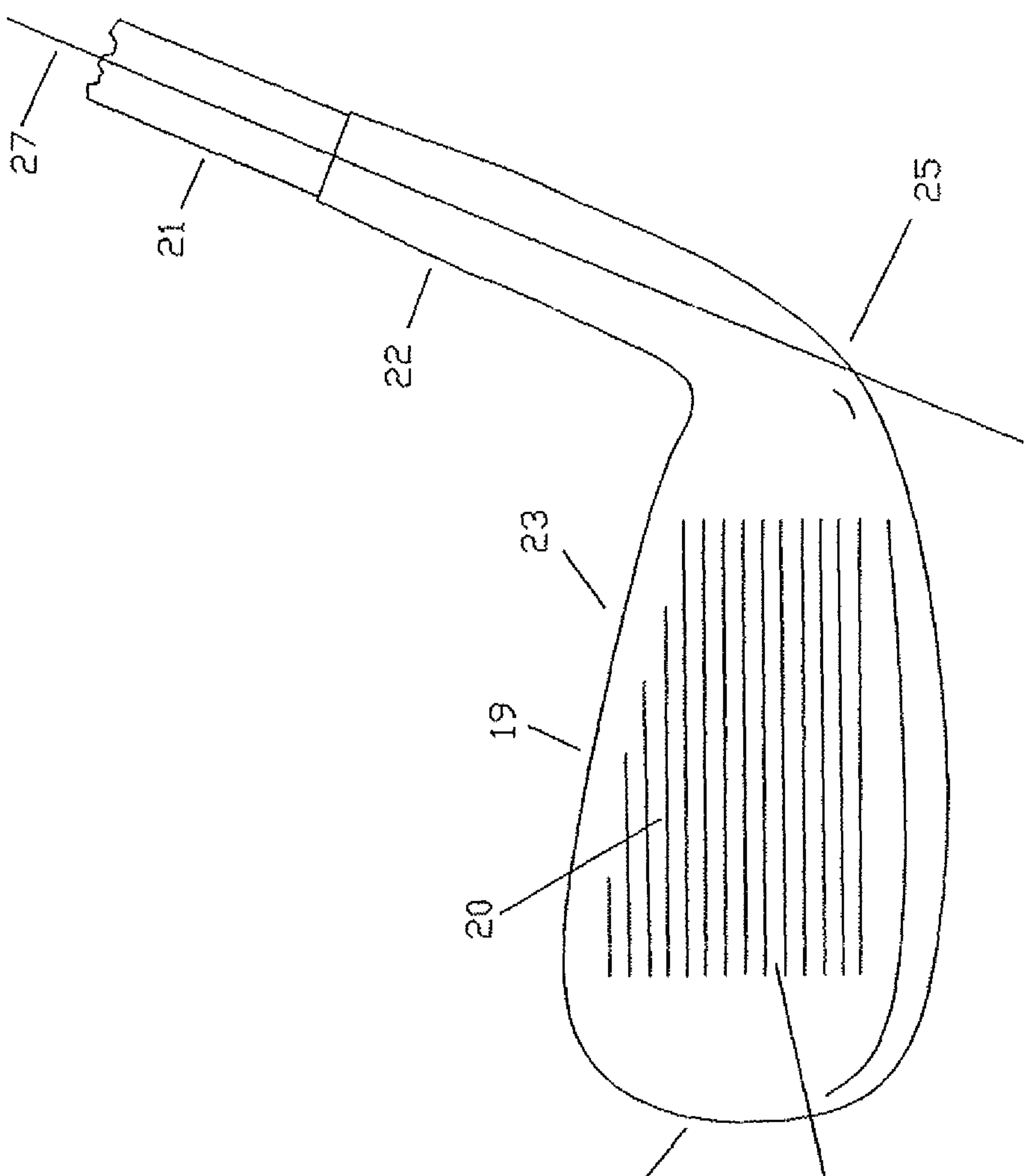

Figure 10 (a)

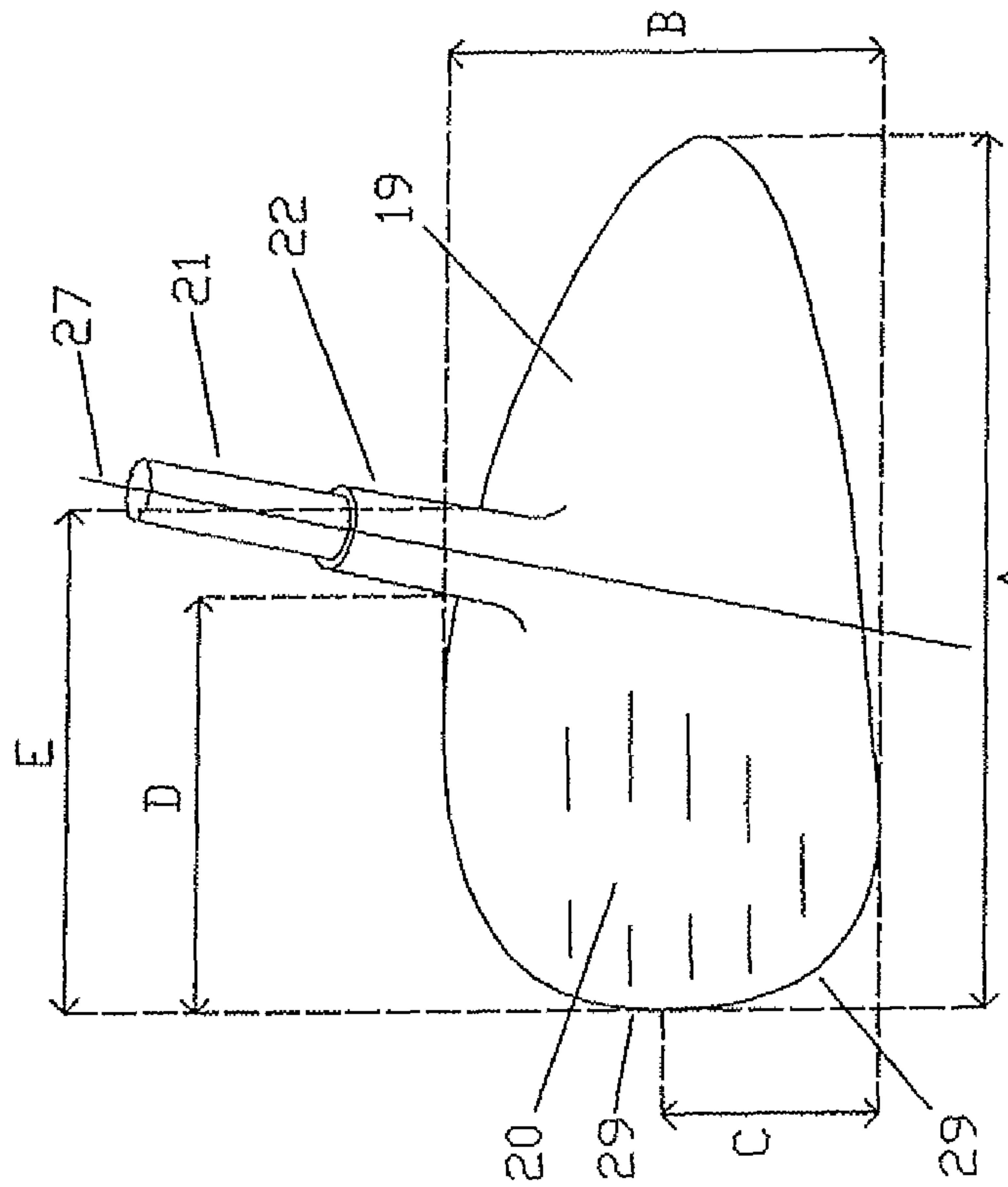

Figure 11(b)

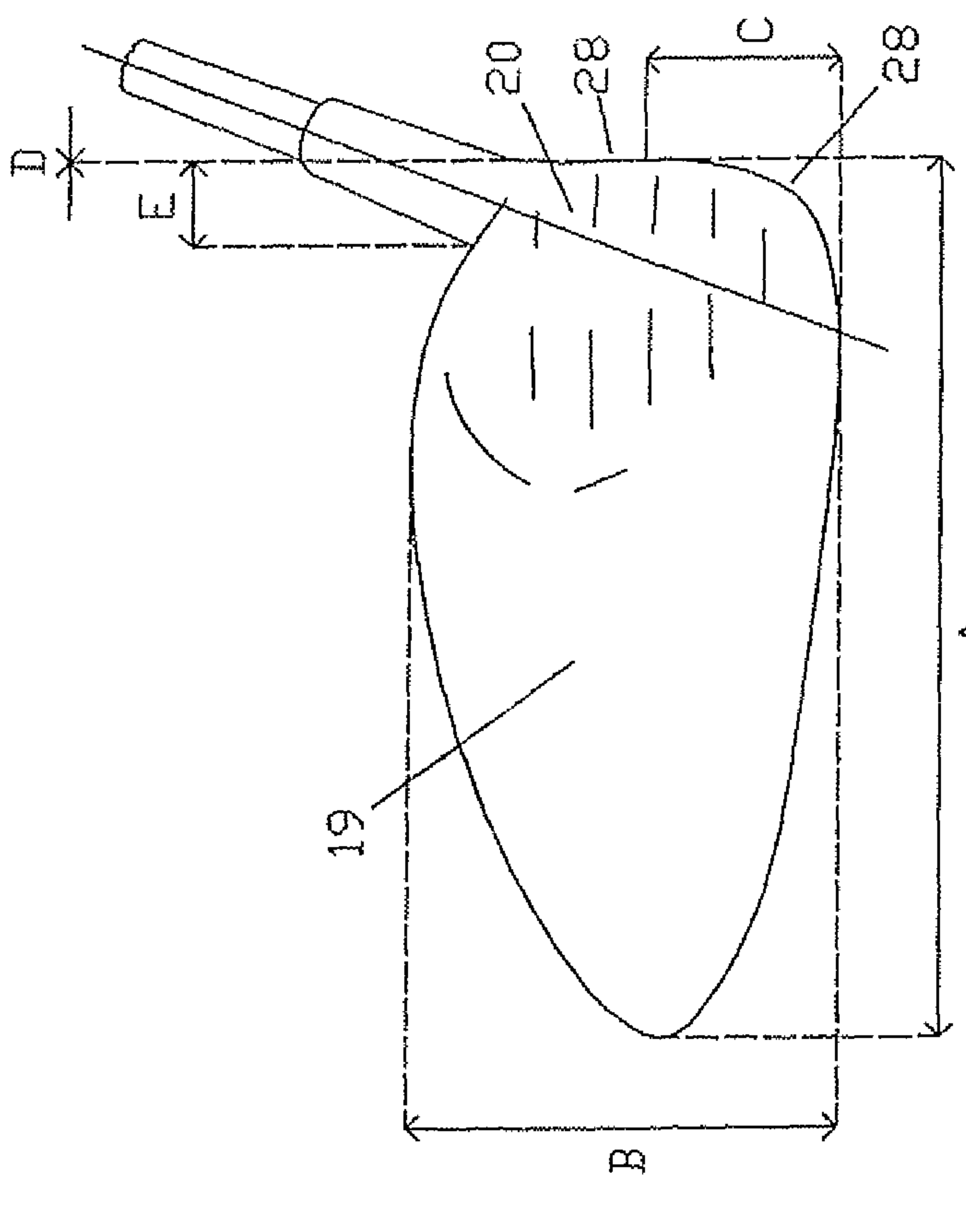

Figure 11(a)

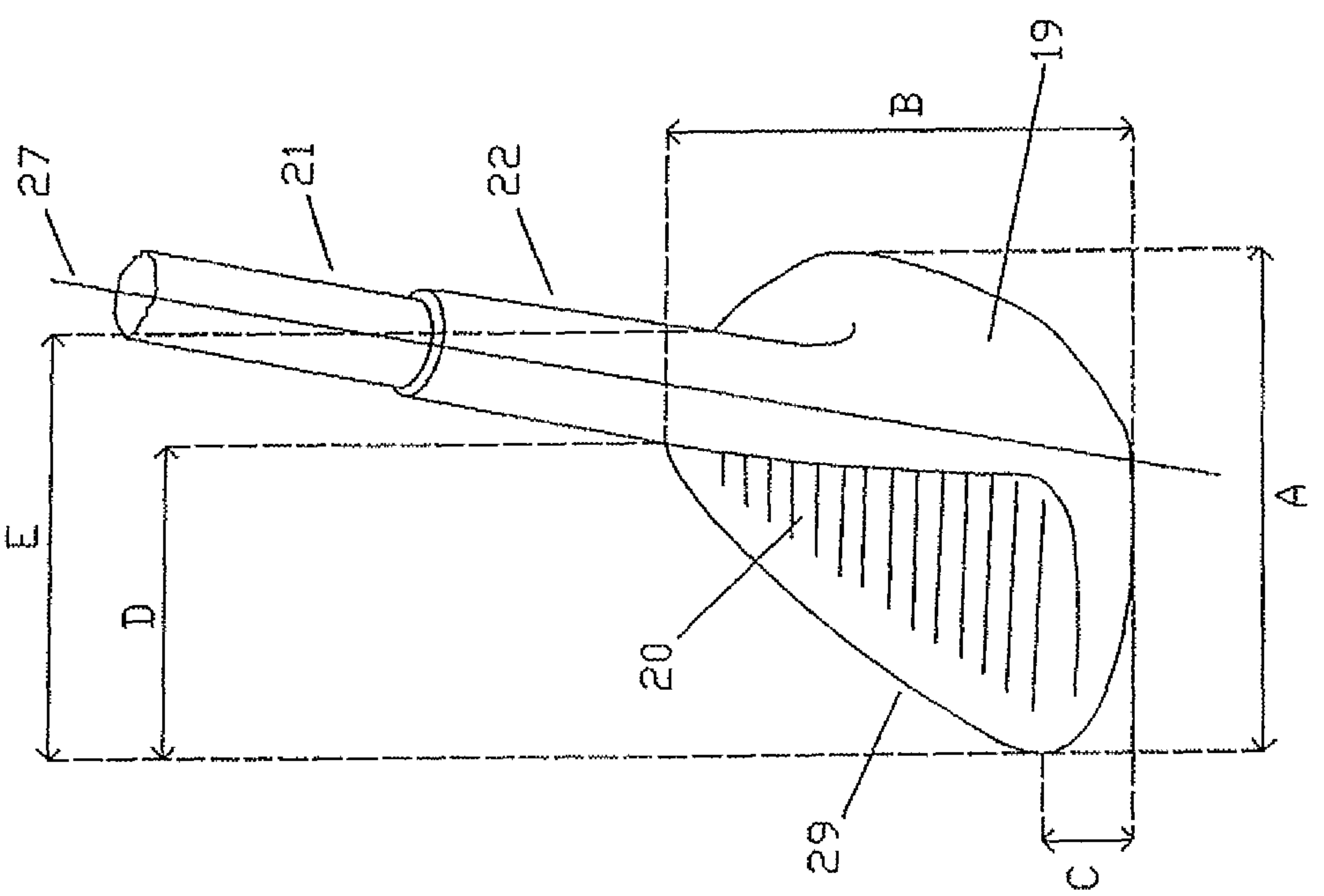

Figure 12(b)

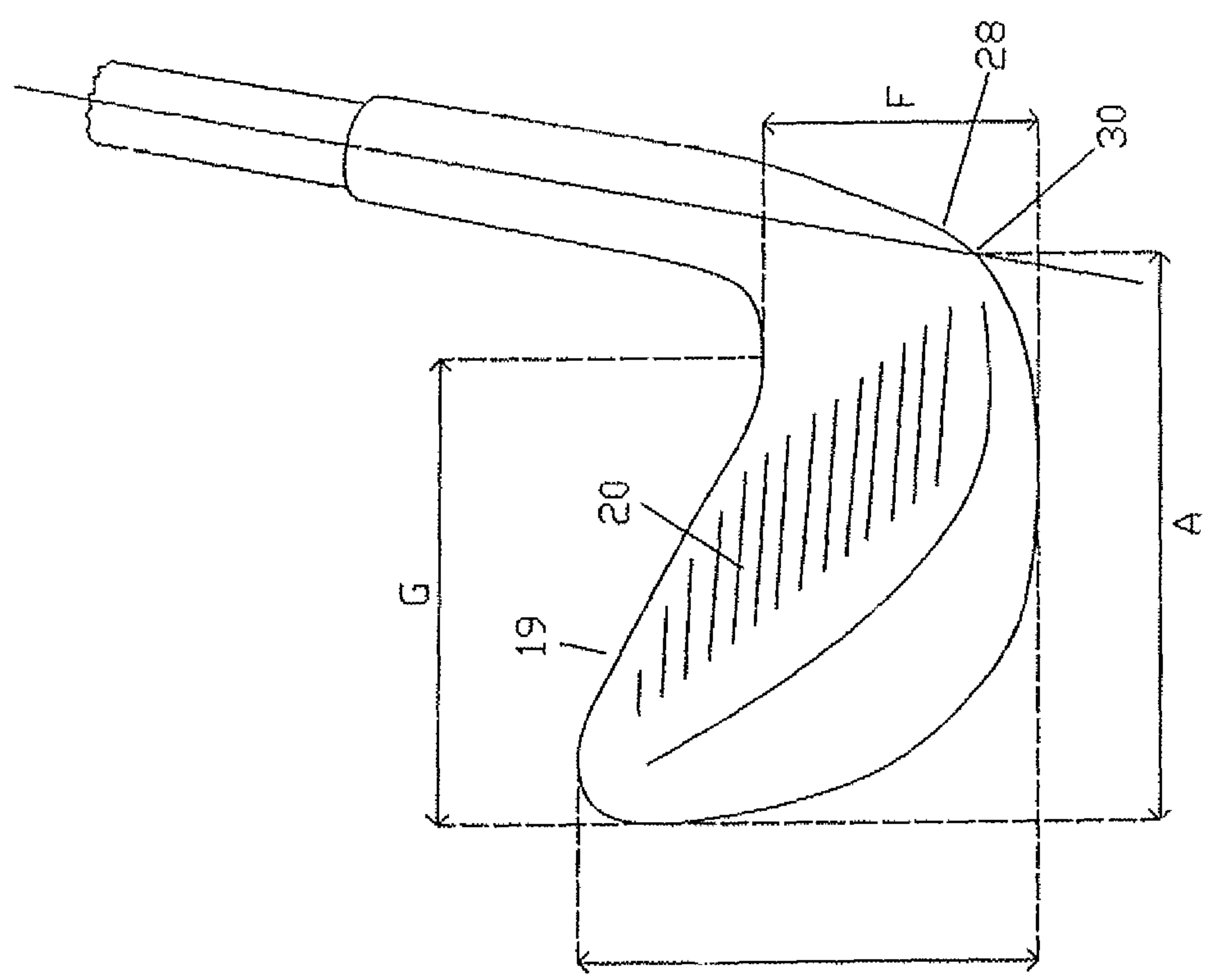

Figure 12(a)

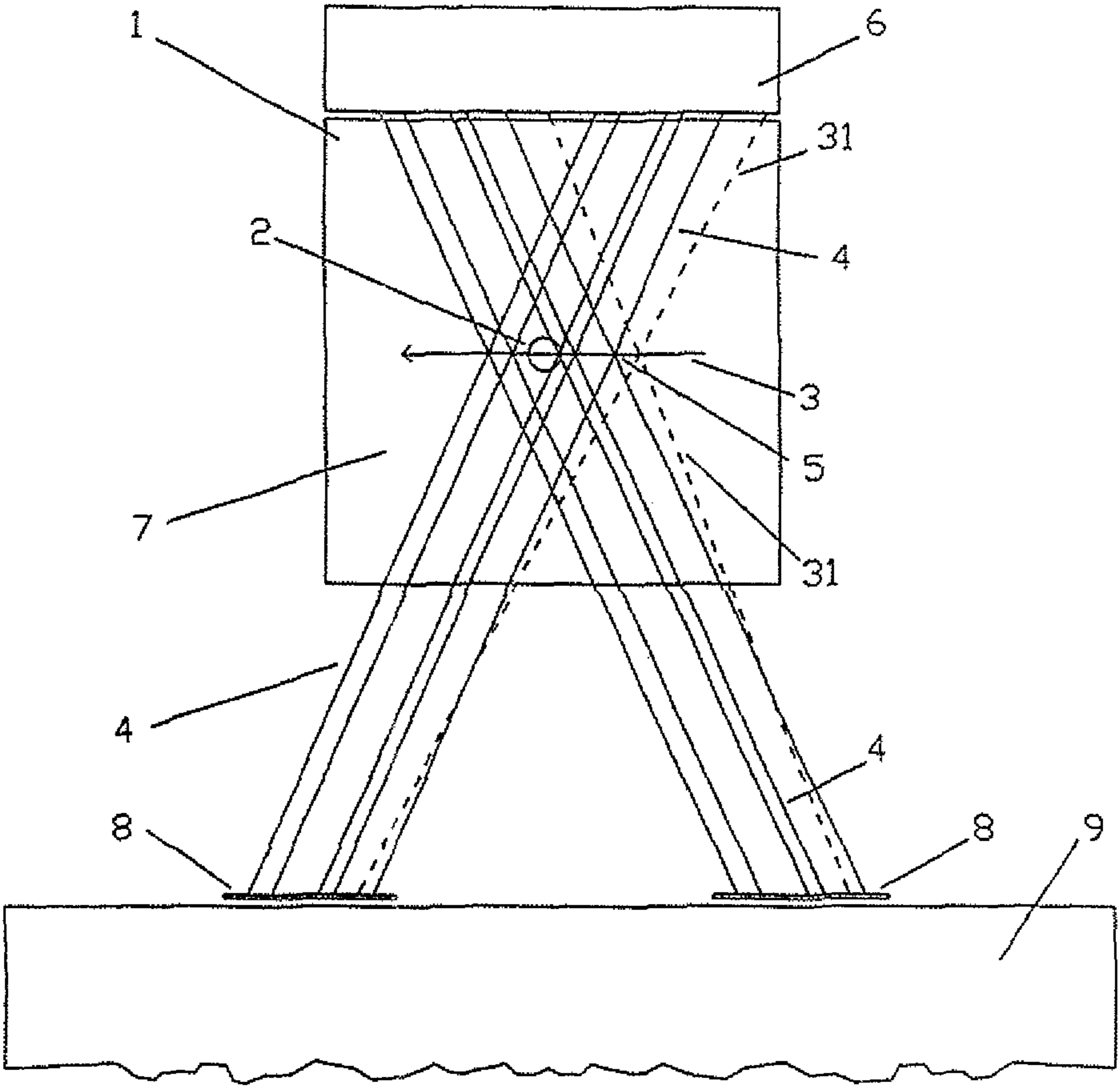

Figure 3