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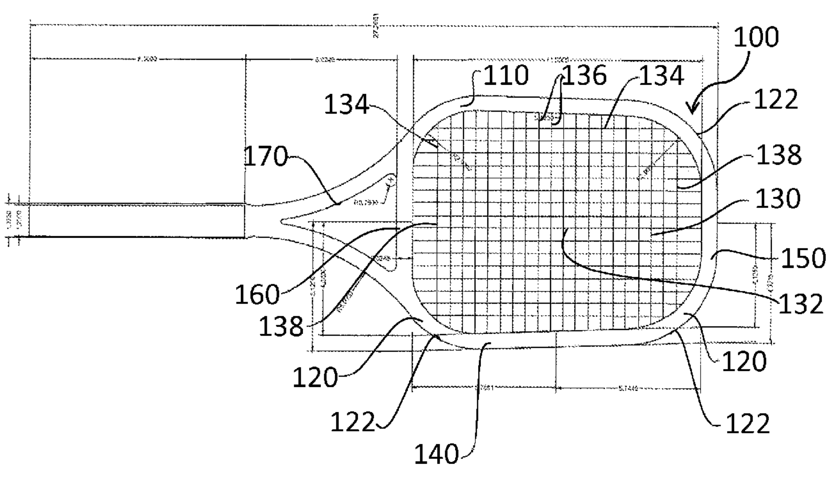

Fig. 3

(57) Abstract: A sports racket is provided that has a racket body with a racket head. The racket head has a frame that has substantially rectangular face shape with appropriately rounded corners. The frame has a string mounting positions in a predetermined arrangement on the four sides of the rectangular face shape. There are lockable grommets integrally disposed in the frame with each grommet at a different string mounting position. A string mounted to the racket head at the string mounting position forms individual strings of the main string portion and the cross string portion of the racket head. The lockable grommets can adjust tension of each individual string to control tension and thus vibration in the entire racket head.

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SPORTS RACKET AND METHOD OF MANUFACTURING SAME

BACKGROUND OF THE DISCLOSURE

1. Field of Disclosure

The present disclosure relates to a sports racket. More particularly, the present disclosure relates to a sports racket and a method of manufacturing and stringing same.

2. Description of the Related Art

U.S. Patent Nos. 6,344,006 and 7,081,056 provide advantages of tennis rackets with main strings of equal length, and cross strings of equal length or, more generally, of equal string vibration frequencies. In U.S. patent application Serial No. 61/436,259, carbon fiber based construction methods for manufacturing and testing such rackets were presented.

Contrary to the prior art, the present racket provides a racket with more strength, acceptable weight and larger sweet spot and improved playability, and teaches away from the requirement that all main and all cross strings have equal length.

SUMMARY OF THE DISCLOSURE

The present disclosure provides a racket face that resist stresses without becoming unacceptably heavy.

The present disclosure also provides a racket face that has more rounded corners and a shorter outer side that results in greater strength with lighter weight, an even larger sweet spot, and improved playability and appearance.

The present disclosure further provides a racket face with appropriately curved corners so that the racket face has the desired strength and playability, yet the affected strings can be made to vibrate at the same frequencies as the unaffected strings.

The present disclosure still further provides a racket face that has lockable grommets or LG's as integral to the racket face to maintain the equal string vibration frequencies on the shorter strings within the rounded corners. These grommets enable the setting of the tension of each string to optimize the sweet spot of the racket face.

In certain preferred embodiments, the racket may be made of a metallic construction material. The metal framework or construction will not be tubular but will be such to enable seamless incorporation of the lockable grommets, to maintain narrow but strong corners, control vibrations, and create a pleasant looking and aerodynamic one-piece product.

The present disclosure also provides for integral lockable grommets strong enough to secure strings with tensions up to 70 lbs, yet light enough to not adversely affect the racket weight or balance.

The present disclosure further provides for the use of lockable grommets that enable implementation of an improved stringing protocol. The protocol alternates main and cross string tensioning, to sequentially eliminate any significant bowing of the frame or frame face during stringing. This allows the sides of the frame to be very light but still strong enough for stability, because the strings themselves will contribute to the stability. Thus, the strings provide additional structural support that enables the use of metal instead of carbon fiber, notwithstanding metal’s lower strength to weight ratio, to obtain a strong yet light racket.

The present disclosure still further provides an equivalent stringing mechanism in which all strings are tensioned simultaneously.

The present disclosure yet further provides for the use of lockable grommets that enable the racket stringer to precisely set the desired tensions on each string. Thus, it is possible to further enlarge the sweet spot by providing lower tensions (higher power) on strings near the frame sides. Also, the lockable grommets will allow for simple string tension adjustment and individual string replacement.

The rackets of the present disclosure, including rackets that have metallic frames with somewhat rounded corners, integrated lockable grommets, and coordinated stringing protocols, provide for sweet spots that cover nearly the entire face of the racket. The rackets can be designed to provide almost any desired weight and balance, maximal power without any loss of control, and an appearance that is unique and pleasing.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is prior art that includes Figs. 1A to 1D.

Figure 1A is a plan view of a known perfectly rectangular racket face.

Figure 1B is an enlarged view of an elliptical corner tangent to two adjacent sides of a known racket face.

Figure 1C is a racket face with minimal curvature.

Figure 1D is a racket face with small curvature, and consequent thick corners.

Figure 2 is a racket face of the present disclosure.

Figure 3 is a preferred racket face of the present disclosure.

Figure 4A is a carbon fiber (CF) racket with square corners.

Figure 4B is a carbon fiber racket with rounder elliptical corners.

Figure 4C is a carbon fiber outwardly bowed racket with thick round corners.

Figure 4D is the racket of Fig. 4C with straight sides after stringing.

Figure 4E is a CAD of the racket of Fig. 4C.

Figures 5A to 5C is a first lockable grommet or LG1 of the present disclosure.

Figures 6A to 6D is a second lockable grommet or LG2 of the present disclosure.

Figures 7A to 7D is a third lockable grommet or LG3 of the present disclosure.

Figures 8A to 8C is a fourth lockable grommet or LG4 of the present disclosure.

Figures 9A to 9E is a threaded crimping cylinder of the present disclosure.

Figure 10 is a string-tensioning cylinder and external threaded crimping cylinder.

Figures 11A to 11C is a fifth lockable grommet or LG5 of the present disclosure.

Figures 12A to 12C is a sixth lockable grommet or LG6 of the present disclosure.

Figures 13A to 13E is a seventh lockable grommet or LG7 of the present disclosure.

Figure 14A is an eighth lockable grommet or LG8 of the present disclosure.

Figures 14B shows two alternatives for LG8 of Figure 14A.

Figure 15 shows that forces exerted on the frame by the tensioned strings are mainly perpendicular to the CF weave

Figure 16 shows that the same as Fig. 15 is true for the CF table-sandwich frame sides.

Figures 17 shows that for quasi-rectangular frames, the corner curvature is relatively sharp and the string tensions therefore give rise to large forces within the corners parallel to the weave.

Figure 18 shows a rupture of an insufficiently thick strongly curved CF racket.

Figure 19 shows grommets, holes and the strings.

Figure 20 is a shock absorbing racket handle configuration.

Figures 21A-D show a preferred solid metal frame concept of the present disclosure.

Figure 22A is symbolic racket face before stringing.

Figure 22B is face with two main strings attached, showing exaggerated bowing of the four sides.

Figure 22C is face with two main strings and two cross strings attached, showing the return to the original face (a).

Figure 23 is preferred string designations.

Figure 24 shows (a) single tensions and (b) multiple tensions.

Figure 25 is a simple demonstration of release shock.

Figure 26 is a preferred stringing platform.

Figure 27 is the automated gearing mechanism under the stringing platform that tensions all of the racket strings simultaneously.

Figure 28 is a hand held stringing device.

Figure 29 is a racket parameter notation.

Figure 30 is the sweet spot of a quasi-rectangular racket with equal main and equal cross string tensions.

Figure 31 is the sweet spot of a quasi-rectangular racket with equal main and equal cross string frequencies.

Figure 32 with the large forehand (equal tension) sweet spot indicated.

Figure 33 is the resultant sweet spot of Fig. 32 that practically encompasses the entire racket face.

Figures 34A and B show a new titanium/carbon fiber racket of the present disclosure with Fig. 34B being a sectional view taken along line A-A of Fig. 34A.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to the drawings and, in particular, the prior art of Fig. 1, Fig. 1A shows a generally rectangular racket or racket face or racket head generally represented by reference number 10. For a nearly rectangular or rectangular racket 10, the performance is far superior with respect to power. However, racket 10 has a frame 11 and four corners 12. Corner 12 is shown more clearly in Figs. 1B and 1C. Corner 12 has a relatively small radius of curvature. Such corners 12 must blend into straight sides 14 that have essentially no curvature as shown in Fig. 1D. This structure gives rise to strong internal stresses within the frame of the strung racket 10.

The present disclosure provides new techniques that can be used to produce rackets that resist these stresses without becoming unacceptably heavy. When a beam has a curved section, the internal stress produced by an applied force will be magnified throughout this section. As an example, consider first a uniform straight beam of length l and rectangular cross section h x b, fixed at each end. If a uniform force F is applied along the length l in the h-direction, the stress is largest at the ends, and this maximum stress is

$$S = Flh/24I = Fl/2bh^2,$$

where I $bh^3/12$ is the area MOI of the beam cress section. If the beam is not straight but instead ends in a curved section, then at a point in this section with radius of curvature r, the stress is

increased relative to the above straight-beam value by a (stress concentration) factor Q which is a function of r/h: $Q = Q(r/h)$. For large r/h (large curvature), Q reduces to 1, and for small r/h (small curvature), Q

becomes very large. The values of Q for intermediate values of r/h depend on the frame material and structure. Typical values are: Q(1) = 1.4, Q(3) = 1.1, Q(5) = 1.05.

Because of this stress enhancement, the corners of our prototypes cannot be right angles, as in Fig. 1A. That would create enormous stress and consequent rupture. Some curvature at the corners is therefore required, but, because of the stress concentration, the smaller the curvature, the larger will be the required thickness h relative to the required straight beam thickness. For example, if a straight racket side requires a thickness of h = 0.5" to withstand the stresses created by the applied string tensions, then curved corners of radius r will require a thickness of at least h = 0.55" for r = 1", h = 0.52" for r=2", and h = 0.51" for r = 4". (These non-linear results are derived using software.)

Referring to Fig. 1B, racket face rounded corners 12 must join the straight face sides tangentially in order to avoid a further stress enhancement. To join each connected side tangentially, the simplest corner curves are elliptical quadrants as illustrated in Fig. 1B.

A minimally curved racket face is illustrated in Fig. 1C. This requires very thick corners 12 and therefore a heavy and unpleasant looking, racket 10. A racket face 15 with more curvature is illustrated in Fig. 1D. The sides 18 are bowed outward in order that they become straight after the strings 19 are attached, as explained in Patent Application 61/436,259. The corner curvature 17 is as large as possible if equal string lengths are required, but this curvature remains too small to avoid the need for thick corners and consequent additional weight.

Fig. 2 generally shows an oval-shaped racket or racket face 20 of the present disclosure. Racket face 20 has a frame 21 that is large and has a relatively uniform curvature about the edges 22. The frame is about one and one-quarter (1 and ¼) feet by about ten and three quarter (10 and

¾) inches. The string area inside the frame 21 is about one (1) foot by nine by about one-half (9 and ½) inches. The curvature of frame 21, especially corners 22, allows for a strong, stable, and light weight product, but the performance of such a racket 20 is far from optimal. This relatively uniform curvature is appropriately rounded curves in that it provides sufficient strength. As shown in Fig. 2, the rounded corner 22 is about three (3) inches in the axial direction otherwise called the main direction, and two and one-half (2 ½) inches in the direction perpendicular to the axial direction, otherwise called the cross direction. It is noted that in the main direction there is a one (1) inch arc from the sides of the racket frame side 24, and one and one half (1 ½) inches from ends 25.

Racket face corners 22 incorporate curvature that is large enough to provide the desired strength and playability, yet small enough so that the affected strings 26 can be made to vibrate at the same frequencies as the unaffected strings 28. Equal frequency requires that shorter strings carry less tension, but these shorter strings must be long enough so that the appropriate tensions are reasonable.

In order to implement greater corner curvature, the present disclosure teaches deviation from a requirement that all main and all cross strings have equal length. Instead, the present disclosure requires the performance equivalent that all main and all cross strings have equal vibration frequencies. (The response of a racket string bed to an impact from a tennis ball is complicated, and it involves the superposition of many frequencies, but it is shown in U.S. Patent 6,344,006 that optimal performance obtains when the fundamental (lowest) frequencies are equal.) The frequency of a vibrating string with fixed ends, of length l, linear mass density m, under tension t, is

$$f = \frac{1}{2l}\sqrt{\frac{t}{m}}$$

If the longest main strings (length 12) have t2 = 60 lb. tension, and the shortest main strings (length 11) have at least t1 = 40 lb. tension (the lowest commonly acceptable value), and the density m is fixed, then the smallest acceptable length ratio 11/12 is (t1/t2)^.5 = 0.82. In other words, 11 must be not less than 82% of 12. (If t2 = 70 lb., (the largest commonly acceptable value), 11 must be not less than 76% of 12.)

Therefore, there is a limit on how much curvature can be accommodated. Too much curvature will require strings of less than acceptable lengths. Choosing shorter strings to have higher density as well as lower tension will allow for even shorter string lengths.

Fig. 3 shows a general racket face 100 of the present disclosure. Racket face 100 has a frame 110 with sufficient corner curvature 120 to provide stability without the need for overly thick corners. Racket face 100 does not have so much curvature as to require unacceptably low tensions on the shorter strings. In a preferred embodiment, with the racket strings 130 strung in the conventional way (wrapped around the outer edges of the frame 110) the longest main strings 132 have length 12 = 13.25" and the shortest (main strings 134 have length 11= 12.5". The longest cross strings 136 have length k2 = 10.75", and the shortest (topmost and bottommost) cross strings138 have length k1 = 10.0". The inner radii of the curved corners 120 are 2.5" and 3". With these values, the length ratios are acceptable (11/12 = 0.94, k1/k2 = 0.93). Thus, if the long string tension is 60 lbs., the shortest main string tension is 53 lb., and the shortest cross string tension is 52 lbs. Also, the corner ratios are at least r/h = 2.5/.625 = 4.0, so that the corner thickness need be only 0.650" if the side thickness is 0.625", an increase of only 0.025".

The above preferred embodiment can be fabricated to weigh much less than the previous racket faces. This lower weight is due to the absence of thick corners, and the reduction in perimeter length, both consequences of the greater strength and reduced circumference provided by the increased curvature.

Rounded corners 120 have another advantage in that when a tennis player attempts to hit a low ball with a racket that is not held horizontally, the rounded corners 120 facilitate striking of the ball.

Concerning the present disclosure that provides the racket with the shorter strings that have less tension than the longer strings, a review of stringing procedures is of assistance. In the conventional stringing procedure, a single string is snaked through the grommets and sequentially tensioned, to produce approximately equal tensions on all main strings and on all cross strings, after equalization. To produce lower tensions in the shorter strings, these strings must be strung separately, using a suitable tie off procedure. A better way to accomplish this is to use lockable grommets or "LGs” as discussed below.

Having strings of different lengths in a racket presents further benefits. The strength can be increased, and therefore the weight further decreased, of the racket face by providing the face with long sides that are not exactly parallel. A preferred embodiment of this racket face 100 is shown in Figure 3. The long face sides 140 are directed slightly inward toward the distal end 150, reducing the length of the outer short side relative to the length of the inner short side. This construction provides many advantages. First, the shorter outer side or distal end 150 is intrinsically stronger (because internal stress is proportional to beam length) and it can therefore be thinner and lighter. The inner short side 160 gains extra strength from the adjacent throat 170, and so it need not be as short as the outer side nor excessively thick. Second, the shorter outer side 150 is additionally lighter because beam weight is also proportional to beam length. Third, the shorter outer side 150 provides more support to the long sides 140 because they are more resistant to bending. Fourth, the face sides 110, 140, 150 and 160, as shown, support each other because of the geometry of an arch. Fifth, the main and cross strings 130 that terminate within the outer face area are shorter and will therefore carry lower tensions. These strings 130 will therefore provide more power and extend the sweet spot out towards them. Sixth, the shorter and more curved outer or distal corners side 122 improves playability for returning low tennis balls.

Seventh, the shorter outer side 150 provides a better appearance.

The above advantages, taken together, provide a racket 100 that has enough intrinsic strength to allow for a variety of possible fabrication materials and for a very light overall weight. This, and even more weight reduction, is achieved by the preferred stringing protocol discussed below.

Because of the shape of the racket face 100 in Fig. 3, virtually all cross strings (for example, 134 and 136) have different lengths. Therefore, it is not possible to string racket 100 in the conventional way and achieve equal frequencies for these strings. Lockable grommets or LG's are required to accomplish this.

Lockable grommets will enable the string tensions to be set separately, with shorter strings receiving the appropriate lower tensions. Use of lockable grommets simplifies this task for another reason. The placement of each lockable grommet within each string hole can be chosen such that the point within the hole where the string is held is optimal. Thus, the shorter strings 134 and 138 can be clamped closer to the outer edges of the frame, thus rendering them to be effectively longer, and the longer strings 132 and 136 can similarly be made effectively shorter. In this way, the string lengths can be made more nearly equal before the corresponding tensions are set. This arrangement requires that the lockable grommets be integrated into the frame to create an entirely new type of racket, and a new approach to racket design and stringing. This approach will be explained in below.

The above discussion is concerned with the racket shapes in the plane of the face. The cross sections of the frames or racket faces are equally important. The advantages of rectangular sections over conventional tubular sections were disclosed in U.S. patent application Serial No. 61/436,259. Other, more effective, cross sections will be described below.

We have constructed prototypes of all rackets discussed. Some prototypes are shown in Figs. 4A-4E.

Referring to Fig. 4A, a carbon fiber or "CF" racket 200 with square corners 210 is shown. Racket 200 must be very heavy in order not to rupture. Fig. 4B shows a carbon fiber racket 220 with rounded elliptical corners 230. This still heavy racket 220 has parallel sides 235 before stringing, but note, as shown in Fig. 4B, how the sides became inward bowing after stringing. The carbon fiber prototype racket 240 shown in Fig. 4C has only slightly rounded corners 250 and so the corner thickness is relatively large. The C-sections 255 around the perimeter have a Kevlar outer cover that holds the grommets in place and prevents damage to the racket 240. This unstrung racket 240 has outwardly bowed sides 245 designed to become straight when the racket is strung. The strung racket 240 is shown in Fig. 4D. Fig. 4E shows a CAD drawing of a prototype of the preferred embodiment described above.

Referring to Figs. 5 A-C, 6A-D, 7A-D, 8A-C, 11A-C, 12A-C, 13A-E and 14A-B, preferred lockable grommets or LGs of the present disclosure are shown. The lockable grommets will be strong enough to secure strings with tensions up to 70 lbs, yet light enough to not adversely affect the racket weight or balance. It will be easy to secure the grommets within the racket frame, and it will be easy to secure the strings within the grommets. The lockable grommets will lock the strings into place securely enough so there is no slippage, but will not penetrate into the strings so as to weaken them.

In order to provide the desired tension on each racket string, the lockable grommet technology will be incorporated into the racket as an integral part thereof. The lockable grommets are necessary to maintain the equal string vibration frequencies on the shorter strings within the racket face. The lockable grommets must be strong enough to secure strings under tensions up to 70 lbs, yet light enough not to adversely affect the racket weight or balance. It must be easy to secure the grommets within the racket frame, and it must be easy to secure the strings within the grommets. The lockable grommets must lock the strings into place securely enough so there is no slippage, but must not penetrate into the strings and cause them to weaken. The present disclosure provides preferred lockable grommets.

Referring to Figs. 5A to 5C, grommet 500 is a conical shaped slit metal section with a central hole 510 (through which the string passes) and a rounded head 520. The accommodating hole section 511 has three sections. The three sections are an inner (string bed facing) section 512, an outer (threaded) section or hole 514 that is cylindrical, and a central connecting section 516 that is conical. The string is inserted through the grommet and through a threaded cylinder 519, with a concave inward facing head, that screws into outer hole 514. As this cylinder is screwed in after the string is tensioned (using, for example, a suitable forked screwdriver), to force the grommet 500 forward into the central conical hole section 516. This conical structure compresses the grommet onto the inserted string, and locks the grommet in place. As an alternative to using a threaded hole section, an external threaded support can be used as shown in Fig. 8.

Referring to Figs. 6A to 6D, grommet hole 510 accommodates a cylindrical cam mechanism or cam 522 with an off-center shaft 525. After the string is inserted and tensioned, cam 522 is rotated so that it pushes against the string and holds it in place. This mechanism is self-correcting. If the string is pulled inward (for example, from a ball impact), it starts to rotate cam 522, causing the cam to further compress the string and tighten its hold on it.

Referring to Figs. 7A to 7D, a two-piece ferrule-type grommet 540 having an inner part 541 that is a disk 542 with an outward-facing convex face 543, and an outer part 544 that is a conical section, with a concave inward-facing face 545. The outer section of the central grommet is a cylinder 546 with an inward facing concave conical indentation 547. After the string is inserted through the central hole in the grommet 540 and retaining cylinder 548, and then tensioned, the two grommet parts 541 and 544 are pushed together and pushed into the retaining cylinder 548. Each of the two grommet parts 541 and 544 is thus clamped onto the string. The outer part 544 is clamped because its narrow end is forced into the conical indentation of the retaining cylinder 548, and the inner part 541 is clamped because its convex narrow end is forced into the concave indentation on the inner side of the outer part 544. This string locking mechanism is particularly effective because it clamps the string in two separate places. This clamping of the string in two places increases the overall holding power, and presents less of an intrusion into the string because it spreads out the applied force.

Referring to Figs. 8A-C, this grommet 550, like LG3 shown in Fig. 7C, provides two separate clamps onto the string. Grommet 550 has an inner end 551 and an outer end 553. Each of inner end 551 and outer end 553 are conical convex sections. The retaining hole 554 has a concave conical section 555 between an inward facing small cylindrical section 556 and an outward facing larger cylindrical section 557. The outward section is threaded to accommodate a threaded crimping cylinder 558 with an inward facing concave conical indentation. Threaded crimping cylinder 558 is shown in Fig. 9C. After the string is inserted through the central holes in the grommet and threaded crimping cylinder 558, and then tensioned, the cylinder 558 is screwed into the retaining hole. As this cylinder 558 turns onto the outward facing end of the grommet 550, it clamps this end onto the string. At the same time, the inward motion of the turning cylinder 558 forces the inward facing end of the grommet 550 into the concave conical part of the retaining hole. This causes this grommet end to clamp onto the string. The end result is a double clamped string with increased holding power and a spread-out balanced force on the string.

As an alternative, and preferred, means of compressing the grommet onto string 620, an external drive device 600 shown in Fig. 10 is part of the present stringing device. String 620 is inserted through the central hole in the two-coned grommet, through an external threaded crimping cylinder 600, and into and around a perpendicular tensioning cylinder 595. The threaded crimping cylinder 600 is screwed into a threaded hole in an external fixed holding element. The racket holding clamps (not shown), tensioning cylinder 595, and holding element (not shown) are all rigidly attached to a fixed platform 900 such as the one shown in Fig. 26. The external threaded crimping cylinder 600 has the same inward facing concave conical indentation as the internal cylinder 558 shown in Fig. 9C. The first step in the string installation is to rotate the tensioning cylinder 595 until the desired tension is given to the string. A preferred way to accomplish this is insert a torque wrench into an accommodating hole 596 in the top of the tensioning cylinder 595. If this wrench is set to slip at a torque that corresponds to the desired string tension, this desired tension will be applied to string 620.

The second step is to rotate the threaded cylinder into the threaded holding element so that its inward facing concave conical indentation moves forward onto the outward facing end of the grommet. As this forward motion proceeds, both ends of the grommet will clamp onto the string as described above. One advantage of this clamping mechanism over the above one is that it eliminates the need to thread the grommet retaining hole. This reduces the required strength and weight of the racket face. Another advantage is that it makes it possible to tension all of the strings at once.

Referring to Figs. 11A-C, grommet 700 also provides two separate clamps onto the string, and it also consists of two parts. The first part 710, that is inward facing, is a conical section with a diameter that slowly increases towards its outer end, with a central hole and relatively small outer diameter. The second part 720 is a conical section with a diameter that increases towards its outer end. The accommodating or retaining hole 750 has three sections. The inner section 760 is a cylinder with a relatively small diameter. The middle section 770 is conical with a diameter that increases towards its outer end. The outer section 780 is a cylinder with a relatively large diameter. Grommet 700 is forced into the inner hole section by either of the mechanisms described for lockable grommet 550 or LG4 of Fig. 8C, namely a threaded cylinder screwed into the threaded outer retaining hole section, or screwed into the threaded hole in an external fixed holding element. When grommet 700 is forced into the conical middle section of the accommodating hole, both its first and second parts 710 and 720, respectively, are independently clamped onto the string, provided all of the relevant angles are suitably chosen.

Referring to Figs. 12A-C, grommet 800 is similar to lockable grommet 550 (LG4) of Fig. 8. The angles are different, and the conical part 860 of the retaining hole 850 is longer. This conical section 860 here serves to compress the inward facing convex end 810 of grommet 800, and it also helps compress the outward facing convex end 820 of grommet 800 onto the string. Grommet 800 is forced into this section by either of the above mechanisms described for lockable grommet 550 or LG4 of Fig. 8C, namely a threaded cylinder screwed into the threaded outer retaining hole section, or screwed into the threaded hole in an external fixed holding element. The cylinder pushes grommet 800 into the conical part 860 of retaining hole 850, causing both ends of grommet 800 to clamp onto the string. The inward facing concave conical indentation in the cylinder further compresses the outward facing end of grommet 800 onto the string. This double clamping mechanism creates a strong and balanced hold on the inserted string.

Referring to Figs. 13A-E, accommodating hole 950 is similar to accommodating hole 750 in lockable grommet 700 - LG5 of Fig. 11B. Accommodating hole 950 has three sections. The inner section 960 is a cylinder with a relatively small diameter. The middle section 970 is conical with a diameter that increases towards its outer end. The outer section 980 is a cylinder with a relatively large diameter. The lockable grommet 900 consists of three suitably sized spring 920 with loaded balls 910 distributed symmetrically around the inserted spring 920 within the central conical hole section. This construction is self-locking. Pulling the string inward, towards the string bed, tightens the grip of balls 910 on the string.

Referring to Fig. 14A, grommet 1000 is a ferrule type stop sleeve that is clamped onto the string at an appropriate location before the string is inserted into the frame hole. The tensioning sequence is illustrated in Fig. 14A. The string 1010 is inserted through the left frame hole 1020, then through a slotted set screw 1030 (a threaded cylinder), then through grommet 1000, and finally though the threaded right frame hole 1040. Grommet 1000 is crimped onto string 1010 at a location that is such that the appropriate string tension is provided after the string is pulled from the right into frame hole 1040. With string 1010 held at the desired tension, set screw 1030 is screwed into the right threaded hole 1050 `until it reaches the clamped grommet 1000, where it holds grommet 1000 in place. This design has the important advantage that the string's tension can be adjusted afterwards simply by rotating set screw 1030 in or out.

A close up of the grommet 1000 and set-screw 1030 arrangement after stringing is illustrated in lower half of Fig. 14B. An alternative design is illustrated in the upper half in Figure 14B. In this latter arrangement, the clamped grommet1000 resides within the hollow set screw 1030 so that the string tension can be adjusted by rotating the screw from outside the frame by inserting and rotating an appropriate tool (indicated on the right) into an accommodating hole, as shown.

There is an additional important advantage to the use of lockable grommets. With a conventionally strung racket, when a string breaks, all of the connected strings lose their tensions, and the racket becomes essentially unplayable. The player with a broken string on his racket will lose the point in contention nearly every time. With the present lockable grommet equipped rackets, the breakage of a single string will only slightly decrease the playability of the racket because the remaining strings will not be affected.

Disclosure of the above embodiments should not be read to limit the scope of available subject matter, or the range of equivalents, that may be claimed. Possible variations of the above embodiments, which use the concepts that we have taught herein, are considered to be within the scope of disclosure.

The present disclosure also provides for some preferred frame materials. Such materials include a metallic frame, such as 7050 aluminum or titanium, for the following reasons for all except one embodiment, namely a unique titanium/carbon fiber racket head, discussed below. First, a metallic frame can easily accommodate the sculptured cavities required to secure the lockable grommets. Second, a metallic frame can provide strong yet light corners. Carbon fiber (CF) is stronger per oz., but its strength is in directions perpendicular to the weave. For a racket frame, much of the force arising from the string tensions is parallel to the weave, so that relatively heavy carbon fiber sections are required for stability, especially in the face corners. Metals are equally strong in all directions, so the advantages of carbon fiber are largely negated. Furthermore, it would be much more difficult, and require additional weight, to secure lockable grommets to carbon fiber frames.

Third, a metallic frame can be cut out of a single metallic plate, with large holes inserted in the direction perpendicular to the string bed. These holes are necessary to lighten the frame, but they also reduce the air resistance encountered by the swinging racket, thus enabling the racket to be swung faster and with more control. Fourth, a metallic frame can easily incorporate a vibration control mechanism that effectively eliminates all of the painful low-frequency shock waves arising from impacts with a ball.

Almost all contemporary tennis rackets are fabricated using a carbon fiber based composite material. The reason is that rackets must be strong, to withstand the more than 2000 pounds of force exerted by the strings on the frame, and must be light, so that they can be easily held and swung. Since carbon fiber has a much larger strength to weight ratio than other available materials, it has been the material of choice in rackets for the past thirty years.

However, there are two reasons why this conventional material is not the optimal choice for all, but the one unique titanium/carbon fiber racket head, of the rackets of the present disclosure. First, there is the present need for strongly curved corners to maintain the primarily straight, nearly parallel sides. Second, is the need for lockable grommets to create separate tensions on separate strings in order to maintain equal vibration frequencies. When these needs are taken into account, carbon fiber is not the preferred material. Instead, it is frames fabricated from metals, such as aluminum or titanium that are preferred.

Carbon fiber reinforced polymer is very strong per ounce, but only in the direction perpendicular to the carbon fiber weave. Conventional tubular carbon fiber tennis racket frames have gentle local curvature (large radii of curvature), so the forces exerted on the frame by the tensioned strings are mainly perpendicular to the carbon fiber weave as shown in Fig. 15 that represents a frame cross-section with a string force direction shown by arrow. These frames can therefore be made very light. The same is true for the carbon fiber table-sandwich frame sides described in U.S. Patent Application Serial No. 61/436,259, and shown in Fig. 16. For our quasi-rectangular frames, however, the corner curvature is relatively sharp (small radii of curvature) and the string tensions therefore give rise to large forces within the corners parallel to the weave as shown schematically in Fig. 17. The forces (in arrows 1) exerted by the strings on the two shown adjacent sides cause these sides to bend inward, and this creates strong tangential forces (in arrows 2) along the carbon fiber weave. These tangential forces are compressional on the inside of the corner and elongational on the outside. Since the carbon fiber is not strong in these tangential directions, thick and heavy corners are required to support these forces and prevent a rupture, as shown in Fig. 1D. (A rupture at the beginning of an insufficiently thick strongly curved carbon fiber racket corner is shown in Fig. 18.) Again, these disadvantages are addressed by the unique titanium/carbon fiber combination racket head discussed herein.

Unlike carbon fiber, metals are homogeneous and isotropic. Thus, metals are equally strong in all directions. The corners on rackets constructed out of metals therefore do not have to be especially thick and heavy, as long as the curvature is not too great. (As explained above for radius/thickness ratios r/h greater than 4, the stress concentration factor is essentially 1). For CF-based rackets, the corner stresses can cause rupture even for more gentle curvature because of the weakness of carbon fiber parallel to the weave. Quasi-rectangular metallic frames are therefore competitive in weight to carbon fiber frames.

The second advantage of using metal-based, instead of CF-based, racket frames is that metal frames can accommodate lockable grommets much more easily and uniformly. It is possible to incorporate lockable grommets in frames made of carbon fiber, or other composites, but it is not a natural fit. With a metal frame, lockable grommets can become an integral part of the racket. In the preferred embodiments, the frame-grommet system is treated as a whole. The frame is designed as an integrated face-throat-handle- grommets entity. In other words, the grommets are not considered as tubes inserted into racket frames. Instead, the grommets are considered an essential part of the racket itself.

As mentioned previously, there is one embodiment of the present disclosure that differs from the discussion above concerning carbon fiber rackets. It is the present disclosure’s unique racket head shown on Figs. 34A and 34B. In this embodiment, the racket head 2000 is made of a number of titanium cylinders or cores A. Cylinder A has a carbon fiber weave or fabric B thereon. Carbon fiber weave B is preferably made of carbon fibers with a layer of Kevlar thereon. However, it is believed that carbon fiber weave B can be made entirely of carbon fibers or entirely of Kevlar carbon fibers. A strip (or beam) of titanium C holds the cylinders A within the weave B. As shown in Fig. 34B, there is a string D that goes through core A, and a portion of weave B and layer C, as well as grommet E. It should be understood that two cores A are used per string. It is believed that this racket overcomes the disadvantages of carbon fiber racket heads mentioned, above yet has most, if not all of, the advantages set forth above for carbon fiber racket heads.

Whatever type of lockable grommet is utilized, incorporation within a metal frame is advantageous. The isotropic strength of metals provides a strong holding mechanism for lockable grommets, and allows for a wide range of holding cavities. Metal frames can be easily threaded and/or shaped to accommodate any desired lockable grommets mechanism.

If lockable grommets are incorporated into carbon fiber frames, metal cavities would be required to contain them, and these would significantly increase the racket weight and complexity. With metal rackets, the grommet cavities can be made part of the frame, and therefore require no additional weight. Taken together, the weight reductions from thinner corners and from lockable grommets integration render metal quasi-rectangular lockable grommet frames as light as, or even lighter than, equally strong carbon fiber frames of the same. Also, even further weight reduction can be achieved by using the stringing protocol discussed in detail below.

There are further advantages of metal frames beyond the above ones. One of these is the possibility of incorporating an improved aerodynamic profile. Our preferred racket frame is fabricated out of a solid sheet of aluminum. This frame must remain solid in the areas where the grommets are inserted, but between these areas we cut large transverse holes into the frame to lighten it. This construction is illustrated in the forces exerted on the frame by the tensioned strings are mainly perpendicular to the carbon fiber weave as shown in Fig. 15 that represents a frame cross-section with a string force direction shown by arrow. These frames can therefore be made very light. The same is true for the carbon fiber table-sandwich frame sides described in U.S. Patent Application Serial No. 61/436,259, and shown in Fig. 16. For our quasi-rectangular frames, the corner curvature is relatively sharp (small radii of curvature) and the string tensions therefore give rise to large forces in the corners parallel to the weave as shown schematically in Fig. 17. The forces, shown by arrows 1, exerted by the strings on the two shown adjacent sides cause these sides to bend inward, and this creates strong tangential forces, shown by arrows 2, along the carbon fiber weave. These tangential forces are compressional on the inside of the corner and elongational on the outside. Since the carbon fiber is not strong in these tangential directions, thick and heavy corners are required to support these forces and prevent a rupture, as shown in Figure 1D. A rupture 1110 at the beginning of an insufficiently thick strongly curved carbon fiber racket corner 1100 is shown in Fig. 18. Fig 19 shows grommets represented by the black rectangles 1120, the holes are the ovals 1130, and the strings are arrows 1140.

The presence of these holes 1130 considerably reduces the drag on the racket when it is swung through the air. Air resistance is proportional to the frontal area of the racket face, and this area is significantly reduced because of the incorporated holes 1130. In addition, the drag coefficient of the racket with face holes 1130 is further reduced relative to that of a racket without face holes because the holes 1130 decrease the size of the turbulent wake behind the racket face. The result is that our racket with face holes 1130 can be swung faster than a conventional racket with the same weight. The exact swing speed increase depends on the details of the executed stroke direction and speed, and on the physiology of the player, but a typical value of the speed increase is 2 - 4 miles per hour. Equally important as this increase in swing speed is the fact that the reduced air drag allows for more control of the racket trajectory.

These holes 1130 can also be used to easily adjust the weight and balance of the present rackets. Weights can be inserted into one or more of these holes 1130, and held in place with a set screw, to affect a desired weight or balance change.

An advantage of metal frames is that such frames allow for a variety of optimal new face cross sections. Their side profiles can be sculpted out of the solid metal to create the most effective and attractive geometry.

Another advantage of metal frames is that such frames allow for unparalleled control over racket vibrations. Low frequency handle vibrations, which are transmitted from the strings to the frame after a ball impact, can be uncomfortable and damaging. The associated shock can cause immediate distraction and pain. Over time, this can lead to significant soreness in the wrist, elbow, and shoulder of a player that are believed to be causes of "tennis elbow".

These vibrations have historically been more severe in aluminum rackets. This is often cited as a main reason that metal rackets have given way to carbon fiber rackets. Surprisingly, the metal frames provide more effective vibration control than carbon fiber frames may therefore appear to provide. It is, in fact, the case that the vibrations in conventional aluminum rackets are at a lower frequency and larger amplitude than those of a carbon fiber racket of the same weight, size, and string tensions. However, in the preferred embodiments of the present disclosure, the many large holes inserted around the face, which were incorporated to reduce weight and air drag, also serve to increase the vibration frequency and decrease the vibration magnitude. This is because, after a vibration wave spreads around a hole, it recombines as the superposition of two waves of close but different frequencies. The interference of these waves gives rise to a beat pattern that has a lower average amplitude. In addition, the vibrations that arise in a solid metal racket can be easily channeled into a suitable elastomer where they can be dissipated before they reach the player's hand. This shock absorbing mechanism is described in detail in US Patent

6,863,628, "Vibration Damping Striking Implement".

To implement this mechanism into our tennis rackets, the racket throat will not simply curve into a solid handle base as in Fig. 3. The throat instead will terminate into a relatively short rod 1200. This rod 1200 will be surrounded by an appropriate elastomer 1220, and an outer handle shell 1240 will surround this elastomer 1220 to complete the handle. This construction is illustrated in Fig. 20. The dimensions of this terminating bar or rod 1200 are chosen to increase the vibration frequency and decrease the vibration amplitude, and to render this frequency within the absorption band of the elastomer. In this way, essentially all potential shock will be reduced and absorbed before it reaches the hand of the player. The combination of the racket face holes and terminating bar already make the vibrations less severe than those arising in a similar carbon fiber racket. When combined with the absorption within the elastomer, any generated sting will almost be totally eliminated from the present rackets.

Another possible vibration damping mechanism uses damping elastomers attached in some (or all) stringing holes or attached to some (or all) grommets. This device can absorb the string vibrations before they create the frame vibrations that are transmitted to the racket handle.

It is possible, but much harder, to incorporate these shock absorption mechanisms into a carbon fiber racket. To attach a suitable terminating rod to a carbon fiber throat would require significant additional complication and weight. With the preferred construction herein, the rod can be cut out of the same single metal block from which the face and throat are made. This one-piece construction provides a racket with an enormous sweet spot, extreme power, and control, light weight, fast swing speed, negligible sting, and revolutionary appearance.

The preferred embodiment of our solid metal frame concept is shown in Figs. 21A-D. It incorporates the design elements taught above. First, the frame width narrows towards the outer face side 1310 as shown in Fig. 21A, for added strength and playability. Most importantly, the shorter cross strings 1320 and main strings 1330 terminating within this narrower face area will carry lower tensions, and will therefore provide greater power so that the racket's sweet spot will be extended into the face areas through which these strings pass. Second, each string is attached at one end to a lockable grommet that is integrated into the frame face. This enables the separate tensioning of each string, in an optimal tensioning sequence and at its optimal value. Third, the frame 1300 incorporates a plurality of transverse holes 1340 that lighten the racket, reduce the air drag that it encounters, decrease the vibrations, and produce a striking and revolutionary appearance. Fourth, frame1300 is constructed out of a single aluminum plate (apart from the handle coverings), and therefore provides the necessary strength, rigidity, and vibration control. Fifth, the face cross-section, illustrated in Fig. 21B, is optimally shaped to accommodate the lockable grommets (within the indicated generic hole), and to provide the desired strength to weight ratio.

The inner section of the racket handle has the cross-section illustrated in Fig. 21D. This section is machined out of the same aluminum plate used for the racket face and throat. It is designed to accommodate a variety of light-material inserts which are such that the outer handle perimeter has the desired size and conventional octagonal shape illustrated in Fig 21C. However, if the shock absorbing mechanism described above is utilized, the racket throat will instead terminate in a suitable metal rod, as shown in Fig. 20. The light outer part of the handle would then be attached around this bar and surrounding elastomer.

In the conventional stringing process, a single long main and a single long cross string are each snaked and tensioned throughout the frame. Instead of utilizing the conventional stringing process, the stringer is provided with a plurality of strings, to be inserted through opposing grommet holes, then stretched to a desired tension, and thereafter locked into place. The stringing order will alternate between the main and cross strings to keep the frame from bowing and keep it balanced. The racket will be supported, the tensions will be produced, and the grommets will be locked using an innovative stringing platform. There are further advantages of this procedure such as shorter stringing times and the absence of release shock. Also, the stringing platform can be upgraded so that all main and cross strings are tensioned simultaneously to their desired values. This provides the advantages of the stringing compensation protocol and significantly reduces the time required for stringing.

In a conventionally strung tennis racket, there is no precise control over the string tensions, no matter the stringing pattern used. The most common pattern first uses a single long string to create all of the main strings, with two tie-offs, and then a second long string to create all cross strings, by winding around the main strings, with another two tie-offs. A stringing machine is used to pull each string to the desired tension. It is assumed that, because of slippage through the grommets and around the outer frame sides, all strings end up with the same tension.

Among the many problems that arise from this stringing protocol and its variations are the following. First, each applied tension changes the shape of the frame (more or less, depending on the racket and the clamping devices on the stringing machine), and therefore changes the tensions on each previously-tensioned main and cross string. Second, the slippage mechanism is not perfect because of the tension forces themselves and the consequent friction forces. Third, as the cross strings are stretched to their desired tension value, the strings encounter substantial friction and elastic resistance from the main strings that they pass over and under. This causes the final achieved cross and main string tensions to differ from their intended values since as the cross strings are tensioned, the main strings are stretched and their tensions are therefore increased, and, as the main strings relax, the cross strings are shortened and their tensions are therefore reduced. Fourth, when the racket clamps are released after the racket is strung, the frame shape is further changed and a large release shock is encountered (see below), causing still further tension changes. Fifth, because of these tension variations, even on strings of equal length, the string vibration frequencies will not be even approximately equal. This substantially reduces the racket's power and sweet spot size. Sixth, the induced face shape changes create large internal stresses in the frame, and this greatly limits racket design possibilities. Seventh, when the strung racket strikes a ball, the impact force causes further string slippage and consequent tension changes

There are many possible variations of the above stringing pattern, but the variations suffer from these same problems. Stringers claim that they can take some of these effects into account as a racket is strung, but even the best stringers only achieve a rough approximation to the necessary compensations. The actual tensions in a racket given to a player by a stringer are almost always very different from the requested tension. However, very few players are even aware of this.

The above problems are solved by use of the present lockable grommets and the associated stringing pattern taught herein. The stringing pattern maintains the racket shape throughout the stringing procedure, compensates for cross string friction and elastic forces, and eliminates release shock. The lockable grommets completely eliminate slippage and maintain equal string vibration frequencies. The final string tensions will therefore be almost exactly equal to the desired tensions.

The present new stringing idea is to alternate the main and cross string tensioning so that any local frame change induced by an applied main string tension is immediately compensated for by a suitable applied cross string tension. This stringing idea is illustrated, in a highly exaggerated way for clarity, in Figs. 22A-C. Fig. 22A represents the racket face before stringing, illustrated for simplicity as a pure rectangle. Fig. 22B represents the racket face after two main strings 1400 are symmetrically attached, but showing exaggerated bowing of the four sides. The tensions in these strings 1400 cause the outer and inner faces 1420 to bow inward, and the left and right face sides 1430 to bow outward. (The bowing distances are magnified and symmetrized for clarity. The actual distances are typically less than 0.1" on each side, and the actual shapes are more complicated. The outer and inner bowing distances are shown as identical, whereas in reality the inner distance will be less than the outer distance because of the support from the throat attached to the inner side.)

Fig. 22C shows a face with two main strings and two cross strings attached, showing the return to the original face Fig. 22A. Fig. 22C represents the racket face after two cross strings 1410 are subsequently symmetrically attached. The tensions in these cross strings 1410 are chosen to cause the outer and inner face sides to bow outward and approximately return to their original positions, and to cause the left and right face sides to bow inward and also approximately return to their original positions.

The present stringing protocol proceeds sequentially in this way. A pair of cross strings is inserted after each pair of main strings, with tensions chosen such that the face sides approximately maintain their original shapes. In this way, the racket has its string tensions almost exactly the desired ones on each string, but also one that is extremely strong for a given weight, because the substantially unbent sides carry substantially reduced internal stresses. The ability to accomplish this and achieve equal string frequencies is achieved by the use of lockable grommets. The actual tension values that achieve both side stability and equal frequency depend on the material and geometry of a given racket as discussed herein.

The stringing procedure or protocol of the present disclosure is equally effective as those in the prior art but quicker to implement. The present stringing protocol idea achieves tension to all strings, main and cross, simultaneously. This string protocol insures that there is minimal change to the racket face shape during the stringing because the main and cross forces exerted by the springs will be continuously balanced.

With conventional stringing, in which, for example, all of the main strings are attached first, very strong stresses are created within the clamped frame. The racket must be constructed to withstand these stresses, the additional stresses from the cross strings (even though there may eventually be some partial compensation), and more additional stresses from the release shock (that can momentarily double the applied stresses). This severely limits how rackets can be designed and manufactured. Thus, conventional rackets have had an oval face shape, which gives rise to very strong and light rackets, but places severe limitations on the racket's power and control. The present rackets and stringing protocol essentially overcome these limitations. With the present stringing protocol, made possible by our use of the integral lockable grommets, the internal racket stresses are greatly reduced throughout the stringing process. This enables the rackets to have new shapes and structures, and much better performance, such as the present preferred quasi-rectangular faces. The sharply curved corners incorporate in the present rackets would require the rackets to have significantly more corner thickness and weight if not for the increased stability achieved by the present stringing protocol.

There are a number of possible stringing sequences in the present protocol that can accomplish the frame stability goal in the present rackets. The following is an example that is effective on the preferred racket embodiment shown in Fig. 21A.

Figure 23 shows string designations. The main strings are labeled y1,y2,...,y16, and the cross strings are labeled x1,x2,...,x18. The 16 main strings are labeled y1,y2,...,y16, and the 18 cross strings are labeled x1,x2,...,x18. The preferred stringing sequence is the following.

STRINGING SEQUENCE		
Step	String 1	String 2
1	x2	x17
2	y3	y14
3	y2	y15
4	x3	x16
5	y1	y16
6	x1	x18
7	x4	x15
8	y4	y13
9	x5	x14
10	y5	y12
11	y6	y11
12	x13	x6
13	y7	y10
14	x12	x7
15	y9	y8
16	x11	x8
17	x10	x9

The two cross strings x2 and x17 are attached first, and the two main strings y3 and y14 are attached next, as described above, and so on. With the tensions chosen, the fully strung racket will have the same shape and dimensions as the unstrung racket to within a deviation of less than 1%.

The present stringing protocol, together with the present lockable grommets, provides complete and unprecedented control over the string tensions. With conventional stringing on a conventional racket, there is almost no control over the tension on any previously tensioned string. The tension will change as each new string in added, but not in a controlled or measured way. Each added string changes the frame shape and, therefore, the lengths and tensions of the previous strings. Each added cross string also increases the tensions in the main strings because the cross string pulls the main strings up or down as cross string is stretched into place. With the present lockable grommets, the tensions on any previously strung string can be re-adjusted to compensate for any changes created by the addition of other strings. The result will be a racket in which every string tension is precisely the desired value.

Fig. 24A shows single tensions s and t acting on a rigid corner at distances g and g' from the pivot, and Fig. 24B shows multiple tensions ti acting at distances xi, separated by distance z. The tension values that accomplish our frame stability goal depend on the details of the racket construction, but a simple model illustrates the technique. Consider two rigid bars connected at right angles, as illustrated in Fig. 24A. Strings are attached at distances g and g' from the corner, and tensions t and s are applied to these strings. The values of these tensions that prevent a rotation of the system must satisfy gt = g's. This is the condition that would determine the cross string compensation tension if our racket were equivalent to this simple system.

A more realistic, but still highly simplified rigid rod model, assumes that n/2 strings, equally spaced along half of a racket side, with tensions t1,t2,...,tn/2, are balanced by n'/2 such strings along half of the adjacent side, with tensions s1,s2,...,sn'/2. (For notational simplicity, n and n' are assumed to be even.) Let g be the gap distance between the corner and the first string, and let z be the distance between two adjacent strings. Then, the distance of string i from the corner is

$$xi = g + (i - 1)z$$

(See Fig. 24B), and the torque exerted by the n/2 strings on the corner is

$$\tau = \sum_{i=1}^{n/2} xi \ \times ti.$$

In the special case in which the tensions are constant, ti= t, this becomes

$$\tau = \frac{nt}{2}\left(g + \frac{z}{2}\left(\frac{n}{2} - 1\right)\right).$$

Equating this torque to the similar one exerted by the adjacent side determines the cross string compensation tensions if our racket were equivalent to this simple system.

Because of the complexity of realistic tennis rackets, appropriate string tensions can only be determined by computer using a finite element analysis. However, it is simpler to determine the tensions by monitoring the stringing procedure. By placing a digital caliper or an equivalent across opposite sides of the racket face, the distance between these sides can be measured throughout the stringing process. When a pair of strings is added in one direction, this distance will slightly change. Then, a string pair in the cross direction can be tensioned so that the distance changes back to, or close to, it's original value. Proceeding in this manner, the strung racket shape will end up as a very good approximation to its original shape.

Since racket shape changes cannot be specified by a single pair of numbers, the above procedure cannot be used to insure that the final face shape is identical to the initial shape. It is fortunately not necessary for the face shape to return to exactly the original shape. As long as the face shape change is less than a few percent, the stresses within the frame will be minimal and will enable the frame thickness and weight to be acceptable. In any case, minimizing the frame changes during stringing is not the only condition placed on the string tensions, also included is the equal frequency requirements.

The present stringing protocol is very different from the conventional stringing protocol. Once mastered, the present stringing protocol should require less time to be used than the conventional one. The present strings will come pre-cut and knotted at one end so they will need to be only inserted into the appropriate hole on one side of the racket, and then tensioned at the opposite hole within the lockable grommet. Subsequent tension adjustment may be necessary, but since there is no need to unwind, measure, cut, clamp, or tie-off the strings, the present string procedure is at least as fast as the conventional stringing protocols. Also, individual strings can quickly be replaced on the present rackets if the string breaks or needs to be re-tensioned.

There is another fast, and equally effective, stringing protocol that uses the present lockable grommets. This protocol provides tension to all racket strings simultaneously. Accordingly, all of the desired main and cross string tensions and cross string compensations without any substantial frame deformation at any time during and after the string process is provided. This protocol can be easily incorporated into the preferred stringing protocol.

There is shock exerted on a racket frame when the strung racket is released from the clamps that hold it in place during the stringing procedure. This shock effectively doubles the force exerted by the stings on the frame for a brief period of time. This shock requires that the frame be stronger and heavier than it otherwise would have to be, in order to support the string tensions after the release. The shock also causes many string tensions to change. With the present stringing protocol, the racket is free to respond during the stringing so there is never a sudden frame release and consequent shock. This enables the construction of rackets with non-conventional and superior shapes.

The source of the release shock is an intrinsic property of elastic systems. When the force within a stretched elastic body (such as, a racket string) is instantaneously applied to another body (such as, a racket frame), the force exerted on the second body initially raises to a value that is approximately double the equilibrium value. The time required to reach this maximum force value, the time required for equilibrium to set in, and the exact value of the maximum force depend on the elastic and damping properties of the bodies involved.

Fig. 25 is a simple demonstration of release shock. Consider a weight Mg held in place and attached to an unstretched massless damped spring, with elastic constant K, with the top of the spring attached to a rigid or fixed support, as illustrated in Fig. 25A. First, the weight is released at time t = 0 when the string is un-stretched. Second, the weight falls a maximum distance 2D = 2Mg/K, after time t = icko π/ω (o2 ω2 = K/M, assuming no damping). Third, after a sufficiently long time, because of damping, the weight comes to rest at a distance D below the initial release height. Here, the upward spring force KD balances the downward weight Mg. The maximum force exerted on the support, at time it/w, is 2DK = 2Mg, twice the exerted force after the weight comes to rest.

Stated another way, when the weight is released at time t = 0, it oscillates up and down and eventually comes to rest with the spring stretched a distance D = Mg/K, where K is the spring constant. (At equilibrium, the upward spring force KD balances the downward gravitational force Mg. See Fig. 25C. Ignoring the damping, the equation of motion of the weight is My" = Mg - Ky, with initial conditions y(0) = y'(0) = 0. (y is the position of the weight COM, which is equal to the spring stretch distance.) The solution is y(t) = D(1-coscot), with cot = K/M. The maximum of y occurs at t = n/co, where y = 2D. At this point, the force exerted by the stretched spring on the support is 2DK = 2Mg, twice the exerted force after the weight comes to rest. See Fig. 25B.

For the general case of interacting elastic bodies, the shock force is again approximately double the static force between the bodies. It is exactly double when the following simplifying (but very reasonable) assumptions are made:

1. The elastic stiffness is the same for static and dynamic loading.
2. The support weight is much less than the applied load.
3. There is no resistive energy (heat) loss during the deformation

of the side.

Applied to tennis, the result is that the force on a racket side when the stringing machine restraining clamps are instantaneously released is approximately double the static force on the side exerted by the string tensions. To avoid this force amplification when conventional stringing is performed, it is necessary to release the restraining clamps gradually. This can be done by inserting one or more adjustable restraining rods between opposite sides before stringing, and by slowly shortening and then removing these rods after stringing. Such a cumbersome and time-consuming procedure is not necessary with our stringing protocol.

Figure 26 is a preferred stringing platform. There is a tensioning cylinder for each string, and a fixed structure that contains a threaded hole for each string. As threaded cylinders are screwed into these holes, their outer ends move into the grommet holes to crimp the enclosed grommet. See Figures 8-10. The tensioning cylinders can be turned individually, or all at once using the gears shown at the top of the illustration. These gears are located under the platform. See Fig. 27. The clamps that hold the racket in place during the stringing are not shown.

A present preferred way to string the preferred embodiment of our tennis racket is to use a complete set of pre-cut strings, one for each pair of main and cross string holes. (For the embodiment shown in Fig. 26, there are 36 such strings. For the illustrated frame, there is room for two additional cross strings, and one or both of these can be incorporated as options.) Each string will be labeled to indicate it's appropriate location within the string bed, and there is a length and linear mass density appropriate to that location. Each string will be knotted at one end, and the other end will be inserted into the appropriate hole on one side of the frame, and then through the chosen lockable grommet on the opposite side of the frame. The string will then be pulled to the appropriate tension and then locked into place using one of the present lockable grommets set forth in Figs. 5-8 and11-14. The optimal tensioning sequence has been described above.

A present preferred stringing platform 900 is illustrated in Fig. 26. Platform 900 incorporates 36 tensioning cylinders 910, one for each string, and a fixed structure 911 that contains a threaded hole for each string. Each threaded hole has a threaded cylinder 912, whose inner-facing end is a crimping tool such as the one illustrated in Fig. 9A-E. As these cylinders are screwed into the holes, their outer ends move into the grommet holes and crimp the enclosed grommet. See Figs. 8 - 10. The tensioning cylinders can be turned individually, or all at once using the gears shown at the top of the illustration. These gears are located under the platform. See Fig. 27. The clamps that hold the racket in place during the stringing are not shown. The placement of the lockable grommets on the left and right racket face sides have been alternated in order to insure symmetry and a balanced face. All main string grommets are, however, placed in the outer side of the face so that there is no interference from the racket throat. (An option is to locate one or more lockable grommets on the inner (throat-facing) side in areas where the throat does not interfere. One such possibility is to insert a single string through one of the two central main string holes in the inner face side, loop it around the corresponding two holes in the outer side, and then insert it into a lockable grommet within the other central hole in the inner face side.)

If the string tensioning cylinders are turned individually, preferably in the sequence given in "Stringing Protocols" above, they must be rotated until the desired tension is given to the string. (A preferred way to do this is to insert a torque wrench into an accommodating hole in the top of the tensioning cylinder. If the wrench is set to slip at a torque that corresponds to the desired string tension, this desired tension will be applied to the string.) Then, the threaded crimping cylinder is screwed into the threaded holding element so that its inward facing concave conical indentation moves forward onto the outward facing end of the grommet. As the forward motion proceeds, the grommet will clamp onto the string as previously described.

The racket stringing will proceed faster and more accurately if we arrange for all strings to be tensioned simultaneously. The preferred embodiment of an automated gearing mechanism under the stringing platform that tensions all of the racket strings simultaneously is shown in Fig. 27. The illustrated automated gearing mechanism is placed under the stringing platform that is shown in Fig. 26. The upper rod is threaded to match external threads placed on the upper tensioning cylinders (a worm mechanism), so that these cylinders rotate and tension the attached strings as the rod turns. The two side rods are similarly threaded and are matched to external threads placed on the side tensioning cylinders. The side rods are connected to the upper rod via rack and pinion beveled gears as illustrated in Fig. 27. Therefore, these side bars turn as the upper bar turns, so that the side tensioning cylinders rotate simultaneously with the upper ones. Thus, all racket strings are tensioned simultaneously. The diameters of the tensioning cylinders are selected to provide each string with the appropriate tension. The system is activated by an electric motor shown in the upper right corner, or by an attached hand crank in place of the motor. The rods are supported by ball bearing supports shown as 913.

The present disclosure provides a hand-held stringing device that can be used in the absence of a stringing platform, or to simply replace a broken or loose string. A preferred embodiment is shown in Fig. 28. The hand held stringing device includes handle 1, shaft 2, trigger 3, crimping cylinder 4, string tensioning cylinder 5, interior frame support rods 6, exterior frame support rods 7, resistance spring 8, and holding latch 9.

To use this device, a racket frame is held by handle 1 and first locked in placed between the interior (6) and exterior (7) support rods, so that the relevant string hole in the frame aligns with the crimping cylinder (4). A knotted string is then inserted through the corresponding hole in the opposite side of the frame, through the grommet placed within the frame hole, and through the central hole in the cylinder (4). The trigger (3) -

spring (8) - latch (9) mechanism is then used to move the handle section along the shaft (2), and thus move the crimping cylinder into the frame hole and onto the grommet. Before the crimping cylinder crimps the grommet onto the string, the outer end of the string is wrapped around the tensioning cylinder (5), and the tensioning cylinder is then rotated (e.g., using a torque wrench) until the tension in the string reaches the desired value. Lastly, the crimping cylinder (4) is rotated onto the grommet to crimp the grommet onto the tensioned string, thus locking the grommet into place. The latch (9) is then released so that the crimping cylinder can be moved out of the frame hole, and the racket can be removed from within the support rods.

There are many possible variations of the above embodiment. For example, the string tensioning cylinder can be fixed onto the outer end of the shaft instead of within the handle section, the trigger mechanism can itself be used to set the string tension, and geared mechanisms can be used instead of the spring sliding mechanism. Other variations will be apparent to those skilled in the art.

Figs. 29 to 33 show the preferred string tension values, tension adjustment devices, and string replacement devices of the present disclosure.

Fig. 29 provides a racket parameter notation in which the n main strings have lengths li and tensions ti. The n' cross strings have lengths kj and tensions sj. g is the gap between the frame and the adjacent main strings. g' is the gap between the frame and the adjacent cross strings.

Tension values will be chosen to accomplish three distinct goals: (1) obtaining equal vibration frequency on main and cross strings; (2) eliminating frame bowing; and (3) providing greater power on strings near the frame. Each goal requires the use of lower tensions on shorter string. The present preferred embodiments achieves all three goals simultaneously. The present disclosure also provides equal frequencies on the main and cross strings (using strings of different densities).

The primary advantages of the lockable grommets of the present disclosure is they enable the setting of any desired string tension on any given string. There are four criteria for determining optimal tension: (1) Equal Frequencies, (2) Extra Power Regions, (3) Maximal Power, and (4) Crossing Compensations. Each criteria requires that the shorter strings on a racket carry lower tensions. This makes it possible to satisfy all conditions at the same time.

The term "power" as used herein means (it is conventionally used in reference to racket performance) the coefficient of restitution (COR) between the racket and the ball as the measure of performance. The COR is defined as the ratio $(v' - V')/(v + V)$ of the relative speeds after and before an impact. (v is the incident speed of the ball, V is the swing speed of the racket at the point of impact, v' is the rebound speed of the ball, and V' is the speed of the racket after the impact.) For a given ball, this COR is the direct and precise measure of the racket performance. (Performance increases as the COR increases.) For given ball and racket, and given incident ball speed and racket swing speed, the hit ball speed increases linearly as the COR increases. The use of the term "power" herein means the precise quantity COR.

The term "control" as used herein (conventionally used in reference to a player's ability to make a struck ball go where he intends it to go) is defined as follows. A racket is said to provide more control if a hit ball trajectory deviates less from the intended trajectory as the result of an imperfect impact. To be technically precise, we should use the angular error (AE) arising from imperfect impacts as the measure of control. With a perfectly executed racket swing, if the ball is hit at the geometric center of the racket face, the ball will rebound with zero AE and will travel in the intended direction, with the intended velocity and spin. Such an impact is, of course, a rare event. Furthermore, the face center is usually not the optimal impact point, because it is too far from the racket center of mass. Therefore, almost all hits are off-center, either because of a player error or because the face center is not the intended impact location.

An off-center impact induces an AE for three reasons. First, an off-center impact on a single string produces non-equal tangential forces on each side of the struck ball, and therefore produces a deflection of the hit ball away from the perpendicular. This is the AE that decreases with increasing tension. Second, an impact on a pair of adjacent strings away from the center of the racket face gives rise to different forces from each of the strings if these strings have different lengths. The resultant AE is greatly reduced on our rackets because our string lengths are all equal, or approximately equal. Third, an impact away from the racket central axis (the axis through and parallel to the handle) causes the racket to rotate away from the impact point, around this axis, during the impact. This induces an AE because the ball will then leave the racket face after it has rotated. This AE is greatly reduced on the present rackets because the present rackets have much larger MOI about the central axis that greatly decreases the magnitude of the backward face rotation.

(1) Equal Frequencies**.** On a generic racket face, the n main string lengths as li (i = 1,2,...,n) and tensions as ti, and the n' cross-string lengths as kj (j = 1,2,...,n') and tensions as sj. See Fig. 29. Given the expression $f = (t/m)/21$ for the fundamental frequency of a string of length l, tension t, and mass/length m, fixed at each end, the equal main-string frequency and equal cross-string frequency conditions are (assuming m is the same for all strings) conditions are

$$(\sqrt{ti})/li = \text{const},\ (\sqrt{sj})/kj = \text{const},\ i = 1,2,\ldots,n,\ \ j = 1,2,\ldots,n',$$

It is shown in U.S. Patent No. 6,344,006 that optimal performance obtains when these conditions are satisfied.

(2) Extra Power. The above equal frequency conditions produce increased power because all main strings and all cross strings respond in unison to accelerate a struck tennis ball, so that all strings are pushing the ball at the same time. However, there is a different, more conventional, power criterion. It is often stated that strings with lower tension produce more power, but less control. The usual explanation is that there is more "trampoline effect" with lower tension, but this explanation is misleading. The correct reason is that with lower tension the strings bend inward more, so the ball compresses less, and this increases the efficiency of the impact because the energy stored in bent strings is largely returned to the ball, whereas much of the energy stored in a compressed ball is dissipated as heat.

The lockable grommets of the present disclosure provide a way to exploit this effect. Consider a quasi-rectangular racket 20 such as the one illustrated in Fig. 2. This racket 20 is shown again in Fig. 30 with the large forehand (equal tension) sweet spot indicated as the area 1500 inside the ellipse. "Sweet spot" is defined as the area on the fixed racket face where the rebound ball speed is at least 80% of the incident ball speed. In Fig. 30, the sweet spot of a quasi-rectangular racket with equal main and equal cross string tensions. Note that, because the strings terminate within the face corners, the strings that lie entirely outside of this sweet spot 1500 have shorter length than the other strings in the same direction. This means that by providing these shorter strings with lower tensions, in order to provide them with the same frequency as the longer strings, they are also provided with the ability to produce additional power. This effect spreads the sweet spot further out towards the frame perimeter, making it even larger. The result will be a very large sweet spot 1600, as shown in Fig. 31. This effect will be even greater with our preferred embodiment. In Fig. 31, the sweet spot of a quasi-rectangular racket with equal main and equal cross string frequencies.

The shorter strings have lower tensions.

Our preferred embodiment is illustrated in Fig. 3, and again in Fig. 32 with the large forehand (equal tension) sweet spot indicated as 1700. In this racket 100, some strings are shorter because they terminate within the face corners as above, and some are shorter because the racket face narrows as the distance from the throat increases, and some are shorter for both reasons. Providing these shorter strings with lower tensions extends the sweet spot well into the upper face area. The result is a sweet spot 1800 that practically encompasses nearly the entire racket face 100 as shown in Fig. 33.

One aspect of the above analysis needs clarification. While true that lower string tension provides greater power, it is also true that longer string length provides greater power, and does so in the same proportion. That is, an x% decrease in tension provides approximately the same power increase as an x% increase in length. It might be considered that the aforementioned sweet spot extension towards the outer racket side will not materialize because the power increase due to the decreased tension is compensated for by the power decrease due to the decreased lengths. Fortunately, since the tension is decreased in proportion to 1^2, not 1, it does occur. In other words, the ratio t/l of tension to length that determines power (power increases when t/1 decreases) behaves like $t/t^2 = 1/t$ when the equal frequency condition t^2/l = const is invoked, and so t/l decreases as t decreases in this case. Thus, the decrease in power arising from the shorter strings is more than made up by the increase in power arising from the lower tensions on these strings.

Can the racket be provided with even more power on the shorter strings, and a consequent even larger sweet spot, by providing the shorter strings with even less tension than that required for equal frequencies? Some power that results from equal frequencies would be surrendered, but some power from the lower tensions will be gained. To answer this question, a detailed computer evaluation is required because of the complicated interactions amongst all racket strings. The performed calculation provided the answer "no". Optimal performance is obtained when the equal frequency conditions are satisfied. Decreasing short string tensions below their equal frequency values results in a decrease from optimal performance.

The lockable grommets of the present disclosure can also be used on conventionally shaped rackets to reduce the tensions and, therefore, increase the power provided by the shorter strings. Most of these shorter strings are much too short to vibrate at the same frequencies as the long strings, so the power increase would not offset the accompanying decrease in control.

The general increase in control and decrease in power that arises from increase in string tensions provides another important advantage of the present preferred rackets over conventional ones. The present rackets provide much more power than conventional ones strung at the same tensions because of the present equal frequency implementation. This means that the present rackets can use larger tensions to gain more control, while regaining the consequent power loss as a consequence of the present equal frequency conditions. Thus, the tennis player is provided with optimal control and optimal power at the same time.

(3) Variable Densities and Maximal Power. Above assumed that the linear densities (mass/length) of each string are equal (m = const). With the freedom provided by lockable grommets, it is not necessary to impose this restriction. For a conventionally strung racket, with a single long string used for all the individual main string segments, it would be extremely difficult to provide different densities on different main strings, and similarly for the cross strings. For the preferred embodiments using

lockable grommets, with each string pre-cut for a given location on the racket face, it is very easy to accommodate any desired available density on each string. This opens up new stringing possibilities and provides for equal frequencies on all strings without using unrealistic tensions. With non-constant densities, the equal frequency conditions become

$$(\sqrt{ti/mi})/li = \text{const},\ (\sqrt{sj/m'j})/kj = \text{const}, i = 1,2,\ldots,n,\ \ j = 1,2,\ldots,n',$$

where mi is the density of main string i and mj ' is the density of cross string j.

Different strings can have different linear densities for two reasons: the strings can have different diameters, or the strings can be made from different materials. String diameter ranges are conventionally specified by "gauge" values, approximately as follows.

GAUGE	DIAMETER (mm)
15	1.41 - 1.49
15L	1.33 - 1.41
16	1.26 - 1.34
16L	1.22 - 1.30
17	1.16 - 1.24
18	1.06 - 1.16

Thinner strings apparently provide more feel and control, while thicker strings are more durable. The (mass/volume) densities of some common strings are as follows.

MATERIAL	DENSITY (g/cm^3)
Nylon	1.15
Polyester	1.20
Kevlar	1.31

The linear density of a string is $m = \pi d^2 \rho/4$, where d is the string diameter and p is the string volume density. Based on the above tables, the range of available linear densities m is between ml = 0.02 g/cm (for 15 gauge Kevlar) and m2 = 0.01 g/cm (for18 gauge Nylon).

Using variable string linear densities greatly increases the range of acceptable string lengths on a racket design that maintains equal string frequencies. With constant density, and a range of acceptable tensions between T1 = 40 lbs and T2 = 70 lbs, the minimum length ratio L1/L2 between the shortest and longest strings $\sqrt{}(T1/T2) = .76$, but with variable density, this minimum ratio is $\sqrt{}(T1*m2/T2*m1) = .53$. With constant density, if the longest string length is L2= 12", the shortest string length must be at least 9.1", while with variable density, the shortest string length can be as small as 6.4". This assumes that all string diameters and materials are acceptable to the racket owner, in terms of feel and durability. Specific diameter or material requirements can increase the length of the shortest acceptable string, but exploiting variable string linear densities will always be beneficial.

Using variable string density, the cross string frequencies can be arranged to be the same as the main string frequencies. Since cross string lengths are almost always greater than 53% of main string lengths, the cross strings with large enough diameter and/or volume density so that they vibrate at the same frequency as the main strings is easy. The equal frequency conditions become

$$(\sqrt{}ti/mi)/li = (\sqrt{}sj/m'j)/kj = const, i = 1,2,\ldots,n, \quad j = 1,2,\ldots,n',$$

The resultant racket, with all strings having the same lowest frequency mode, will be the most powerful possible. Also, this optimal performance is only made possible by the present lockable grommets.

(4) Crossing Symmetry. Above discussed how to string the

present rackets in a sequence so that the main and cross strings balance each other to reduce the stress within the frame. There are a number of values of the main string tensions ti and cross string tensions si that accomplish this. The optimal values of these tensions depend on the details of the racket material and geometry, and on the desired maximum tensions. The following a simple model illustrates the present concept.

For illustrative purposes, assume that all main strings have equal tensions ti = t, and that all cross strings have equal tensions sj = s. For simplicity, model the frame face as a rectangle with sides that terminate at fixed corners. The frame parameters are denoted as follows:

frame thickness = h,
cross section area MOI main string lengths = 1,
cross string lengths = k,
number of main strings =n,
number of cross strings= n' .

The stress at a corner from the string tensions across the long side is mslh/241, and the stress at the corner from the short side is ntkh/241. Assume that the balancing condition (crossing symmetry) is the equality between these two corner stresses. This is equivalent to the equality n's1 = ntk, or

$$s/t = nk/n'1.$$

This tension ratio is less than 1 (s < t) because k <1, and because n < n' (there are more strings attached to the long side than the short side). The typical values n = 16, n' = 20, k = 9.5", 1 = 11.5", give s/t = 0.66, so s = 40 lbs if t = 60 lbs.

This model is too simplistic to be numerically accurate in general, but it is noted that the above crossing condition can be added to the cross-main equal frequency condition to give

$$s/tnk/n'l\ (m/m')(k/1)^2,\ \text{or}\ n/n'\ mk/m'l.$$

In the context of the simple crossing model, a racket whose strings satisfy this condition would have minimal stress within the frame (and therefore minimal weight), and equal frequency on all strings (and therefore maximal performance).

It is not difficult to choose racket and string parameters that satisfy this equation, even with main and cross strings of the same material ($m = m'$). Let z be the distance between adjacent strings, g is the gap distance between the long (main) racket sides and the adjacent main strings, and g' is the gap distance between the short (cross) racket sides and the adjacent cross strings as shown in Fig. 29. Then, the equations to be solved are

$$k = nl/n',\ 2g = k - (n - 1)z,\ \text{and}\ 2g' = l - (n' - 1)z.$$

Choosing, for example, inputs of 1 = 11.5", n = 16, n' = 19, and z = 0.5", the outputs are the very reasonable values k = 9.7", g = 1.10", and g' = 1.25". The tension ratio is t/s = 1.41. So if, for example, the cross string tensions are s = 45 lbs., the main string tensions are t = 63.5 lbs.

To summarize, the present rackets satisfy equal frequency conditions and are therefore maximally powerful for impacts everywhere on the racket face. Also, the present rackets satisfy crossing symmetry conditions and are therefore maximally strong for their weight. The preferred embodiment is a racket that satisfies both of these conditions, and it is therefore an essentially perfect product.

Other embodiments of the present disclosure include the use of alternative racket shapes and materials and lockable grommets designs.

Other possibilities are rackets with some, but not all, lockable grommets, and rackets incorporating carbon fiber - metal combinations. An embodiment of this combination is a carbon-fiber tubular frame with its outer face perimeter contains an embedded metallic strip that contains metallic cylinders into which the grommets are placed.

The preferred embodiment described above and shown in Figure 21, incorporates the following attributes: The racket material is solid aluminum. The racket face has straight, nearly parallel, sides, apart from the corners of radii 2.5" and 3". The outer side of the face is shorter than the inner face (adjacent to the throat). The racket contains a plurality of large transverse holes. The face cross section, illustrated in Fig. 21B, is wider and concave on the outward facing end. The face contains lockable grommets and associated accommodating cavities, of the type (LG1 - LG8) discussed above and shown in Figs. 5 to 8 and 11 to 14. The face contains a lockable grommet for each string. The racket contains a vibration absorbing mechanism. The racket is fabricated out of a single metal plate. The racket is strung according to one of the protocols and with one of the stringing devices discussed in the present disclosure. The string tensions are chosen so that all of the main strings have the same fundamental vibration frequency, and all of the cross strings have the same fundamental vibration frequency, and the frame shape is approximately the same after stringing as it was before stringing. The string linear densities are chosen so that all main strings and all cross strings have the same fundamental vibration frequency.

Each attribute can be changed somewhat without changing the essence of the present disclosure, as follows:

(1) The material need not be solid and need not be aluminum. Other metals, such as titanium, and other aluminum alloys, and non-metals, such as carbon fiber, Kevlar, or Nylon, can be used, so long as they are

sufficiently strong and light. Also, tubular or sandwich-type frames (as described in U.S. patent application Serial No. 61/436,259) can be used. Some of these alternatives might require thicker corners or more-complicated lockable grommet insertions, but the resultant racket will still be better performing than conventional rackets.

(2) A variety of face configurations can be used, so long as our equal-frequency conditions are implemented without the need for unacceptable string tensions or densities.

(3) The outer side of the face can have the same length, or greater length, so the inner face, as long as the frame is strong enough to support the string tensions without being unacceptably heavy. If the outer side of the face is not shorter than the inner face, the upper strings will not be shorter than the other strings, and so they will not be assigned the lower tensions that extend the sweet spot outward. Such rackets will, nevertheless, be better performing than conventional rackets.

(4) The holes are necessary to lighten the frame if a solid metal construction is used, and they also reduce the air drag and the vibrations. The holes can have any shape or size so long as the holes achieve the required lightening. The holes are not necessary if light tubular metal or any light non-metal material is used.

(5) The face cross section can have any shape or size, so long as the resultant racket sides are strong enough to support the string tensions and lockable grommet cavities, and light enough so that the racket weight is acceptable.

(6) The preferred lockable grommet and containment cavity constructions are discussed above. However, there are other possibilities, except the possibilities must be strong enough to support the string tensions, gentle enough to prevent damage to the locked string,

small enough to fit into an acceptable sized frame, easy enough to install, and easy enough to use. Such alternatives can be readily designed and constructed using the basic concepts that we have introduced.

(7) Lockable grommets are in the preferred embodiments for the above stated reasons. Some advantages of the present quasi-rectangular face shapes obtain without using lockable grommets on each and every string. If lockable grommets are used only on strings that are substantially shorter than most of the other strings, to lower the tensions on these shorter strings, the resultant rackets will still perform better than conventional rackets. Even if lockable grommets are not used on any strings, so long as most main and most cross strings have approximately the same lengths and tensions, the resultant rackets will still perform better than conventional rackets, although many of the advantages provided by lockable grommets will be lost.

(8) Metal rackets will, in general, have larger vibration amplitudes and lower vibration frequencies than non-metal rackets. However, the transverse holes that are incorporated lessen this effect. With the present vibration absorbing mechanisms, these vibrations can be effectively dissipated before they reach a player's hand. There are other ways to dissipate these vibrations using the present concepts. However, the effect of racket vibrations is subjective and, therefore, for many players no vibration absorbing mechanism is required.

(9) The single plate construction has the above advantages. However, many of these advantages are obtained even if the racket is constructed by piecing together different sections. It is important that such a piecewise fabrication does not significantly increase the racket weight or reduce its integrity.

(10) The stringing protocols of the present disclosure insure that all string tensions are set at their desired values, and that the shape of the frame face is essentially the same before and after stringing. Other

stringing patterns are possible, but they may require a stronger frame and may produce deviations from the desired tension values. If the present other teachings are adhered to, the strung rackets will, nevertheless, be better performing than conventional rackets.

(11) The string tension relations of the present disclosure satisfy the equal frequency and crossing symmetry requirements of embodiments of the present disclosure, and therefore provide the best possible combinations of power, control, sweet spot size, and racket weight. With other tension choices, some of this optimal performance will be reduced, but if the basic principles of the present disclosure are approximately adhered to, the racket performance will still exceed that of conventional rackets.

(12) Because the main string lengths of the preferred embodiment are approximately equal, and the cross string lengths are also approximately equal, equal string vibration frequency conditions can be satisfied using tension variations alone, while maintaining equal linear mass density on all strings. Since even better performance will be obtained if the main and cross string frequency values are also equal, and since the cross strings are usually too short to accomplish this using reasonable tension choices, a most preferred embodiment uses separate density values on (some) separate strings to obtain equal frequencies on all strings, as discussed herein. For players who are not comfortable using more than one string density, it does not need to be used because even an approximation to the present equal frequency conditions will provide a performance level that greatly exceeds that of conventional rackets.

(13) Our preferred stringing device (Fig. 26) has been devised to string, tension, and lock in place (with the present lockable grommets) all strings on the present preferred rackets. This device can be used to set the strings in place one at a time, or all at once, using the gearing assembly that we have invented. The preferred hand-held string device (Fig. 27)

that sets the strings in place one at a time, and can be used to re-tension or replace any given string. There are, of course, different ways to string the present rackets, using the basic ideas of the present disclosure.

The present disclosure provides unique embodiments for each component and the combinations of same. Thus, the components are frame, lockable grommets, tensions that produce equal frequencies, stringing protocol, and stringing devices. The components, especially in combination, produce the best possible tennis racket in terms of power, control, sweet spot size, comfort, and convenience.

The present disclosure and the above embodiments thereof should not be read to limit the scope of available subject matter, or the range of equivalents, hereof. Variations of the above embodiments, which use the concepts taught herein, are considered to be within the scope of present disclosure.

WHAT IS CLAIMED IS:

1. A sports racket comprising:

a racket body having a racket head, the racket head having a frame that has substantially rectangular face shape with appropriately rounded corners, the frame having a plurality of string mounting positions in a predetermined arrangement on the four sides of the rectangular face shape;

a racket handle affixed to the racket head;

a plurality of lockable grommets integrally disposed in the frame of the racket head, each of the plurality of grommets at a different one of the plurality of string mounting positions; and

at least one string mounted to the racket head at the plurality of string mounting positions to form individual strings of the main string portion and individual strings of the cross string portion of the racket head, wherein the plurality of lockable grommets can implement tension of each individual string of the main string portion and the cross string portion.

2. The sports racket of claim 1, wherein the racket head that has more rounded corners and a shorter outer sides than known substantially rectangular sports rackets to provide greater strength, lighter weight and a larger sweet spot size than known sports rackets.

3. The sports racket of claim 1, wherein the curved corners creates affected strings and unaffected strings, and wherein the affected strings can be made to vibrate at the same frequencies as the unaffected strings.

4. The sports racket of claim 1, wherein all individual strings of the main string portion have equal frequencies.

5. The sports racket of claim 1, wherein all individual strings of the cross string portion have equal vibration frequencies.

6. The sports racket of claim 1, wherein each individual string also has a density and diameter, and wherein the tension, density and diameter of each individual string is chosen so that the individual strings of the main string portion and the individual strings of the cross string portion have equal vibration frequencies.

7. The sports racket of claim 1, wherein the plurality of grommets lockable grommets enable the string tensions to be set to maintain the equal string vibration frequencies on the shorter strings within the rounded corners.

8. The sports racket of claim 1, wherein each of the plurality of lockable grommets have a sleeve portion with an axial string passage, and wherein each of the plurality of lockable grommets provides a double securing of the individual string.

9. The sports racket of claim 1, wherein the racket is made of a metallic material that is not tubular.

10. The sports racket of claim 9, wherein the racket maintains narrow but strong corners, and controls vibrations.

11. The sports racket of claim 1, wherein each of the plurality of lockable grommets is strong enough to secure each individual string with a tension up to 70 lbs.

12. The sports racket of claim 1, wherein each of the plurality of lockable grommets enable implementation of a stringing protocol that alternates main and cross string tensioning, to sequentially eliminate any significant bowing of the frame during stringing.

13. The sports racket of claim 1, wherein the frame has a two pairs of opposed sides that are very light but stable since the individual strings contribute to the stability of the frame.

14. The sports racket of claim 1, wherein each of the plurality of lockable grommets enable the sweet spot to be enlarged by providing lower tensions on the selected individual strings near the sides of the frame.

15. The sports racket of claim 1, further comprising an equivalent stringing mechanism in which all of the individual strings are tensioned simultaneously.

16. The sports racket of claim 1, wherein the plurality of lockable grommets enable the precise setting of the desired tension on each individual string.

17. The sports racket of claim 1, wherein each of the plurality of lockable grommets allow for individual string tension adjustment and individual string replacement.

18. The sports racket of claim 1, wherein each of the plurality of lockable grommets provides at least a double clamp on the individual string.

19. The sports racket of claim 1, wherein the double clamp provides

a spread-out balanced force on the string.

20. The sports racket of claim 1, wherein the frame is primarily made of carbon fiber, and wherein the frame has a face perimeter that contains an embedded metallic strip.

21. The sports racket of claim 1, wherein the embedded metallic strip has metallic cylinders into which the plurality of grommets are placed.

22. A sports racket comprising:

a racket body having a racket head, the racket head having a frame that has substantially rectangular face shape with appropriately rounded corners and the area in the frame defining the racket face, the frame having a plurality of string mounting positions in a predetermined arrangement on the four sides of the rectangular face shape, the frame being made of a metal;

a plurality of lockable grommets integrally disposed in the frame of the racket head, each of the plurality of grommets at a different one of the plurality of string mounting positions; and

at least one string mounted to the racket head at the plurality of string mounting positions to form individual strings of the main string portion and the cross string portion of the racket head, wherein the plurality of lockable grommets adjust tension of the individual strings.

23. The sports racket of claim 22, further comprising a stringing protocol that provides a sweet spot formed by some of the individual strings, wherein the sweet spot is nearly the entire racket face.

24. A stringing protocol for a sports racket that provides means of compressing the grommet onto a string, the string protocol comprising:

inserting the string sequentially through a central hole in a grommet, an external threaded crimping cylinder, and into and around a perpendicular tensioning cylinder, the grommet having a pair of opposed ends with one of the pair being an outward facing end, the threaded cylinder having inward facing concave conical indentation;

rotating the tensioning cylinder until the desired tension is given to the string.

rotating the threaded cylinder so that the conical indentation moves onto the outward facing end of the grommet so that both ends of the grommet clamp onto the string.

25. The stringing protocol of claim 24, wherein the string is a plurality of strings, and wherein the stringing protocol can tension all of the strings simultaneously.

26. The stringing protocol of claim 24, wherein the sports racket comprises:

a racket body having a racket head, the racket head having a frame that has substantially rectangular face shape with appropriately rounded corners, the frame having a plurality of string mounting positions in a predetermined arrangement on the four sides of the rectangular face shape;

a racket handle affixed to the racket head;

a grommet integrally disposed in each one of the plurality of string mounting positions in the frame of the racket head; and at least one string mounted to the racket head at the plurality of string mounting positions to form individual strings of the main string portion and individual strings of the cross string portion of the racket head, wherein each grommet in each of the plurality of string mounting positions can implement tension of each individual string of the main string portion and the cross string portion.

27. The stringing protocol of claim 26, wherein the racket is strung using a stringing platform that has a tensioning cylinder for each individual string and a fixed structure that contains a threaded hole for each individual string.

28. The stringing protocol of claim 27, wherein each threaded hole accommodates a threaded cylinder with an inner facing end that is a crimping tool and an outer end, and wherein, as the threaded cylinder is screwed into the threaded hole, the outer end of the threaded cylinder moves into the grommet hole and crimps that grommet.

29. The stringing protocol of claim 26, wherein the racket is strung using a hand-held device that includes a tensioning cylinder and a perpendicular crimping cylinder, and wherein the perpendicular crimping cylinder can rotate onto one grommet to crimp the one grommet onto the individual string tensioned by the tensioning cylinder.

30. The stringing protocol of claim 24, further comprising a plurality of grommets and a plurality of strings, wherein each string is tensioned by a separate tensioning cylinder, and wherein the tensioning cylinders are all turned simultaneously.

31. The stringing protocol of claim 30, wherein the tensioning cylinders are all turned simultaneously using gears.

32. The stringing protocol of claim 31, wherein the gears are located under a platform.

33. The stringing protocol of claim 30, wherein each tensioning cylinder has a diameter that provides the individual string with the desired tension as the individual strings are tensioned.

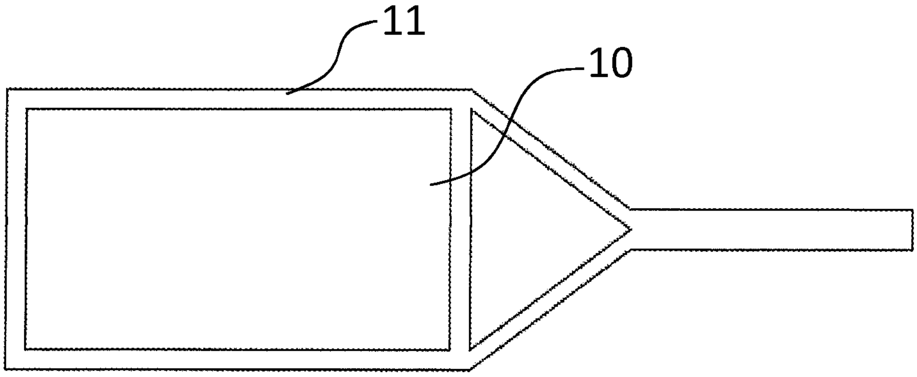


Fig. 1A

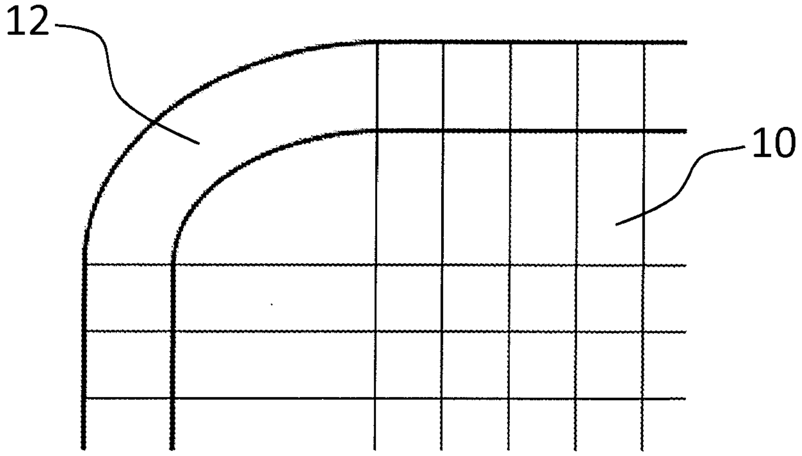


Fig. 1B

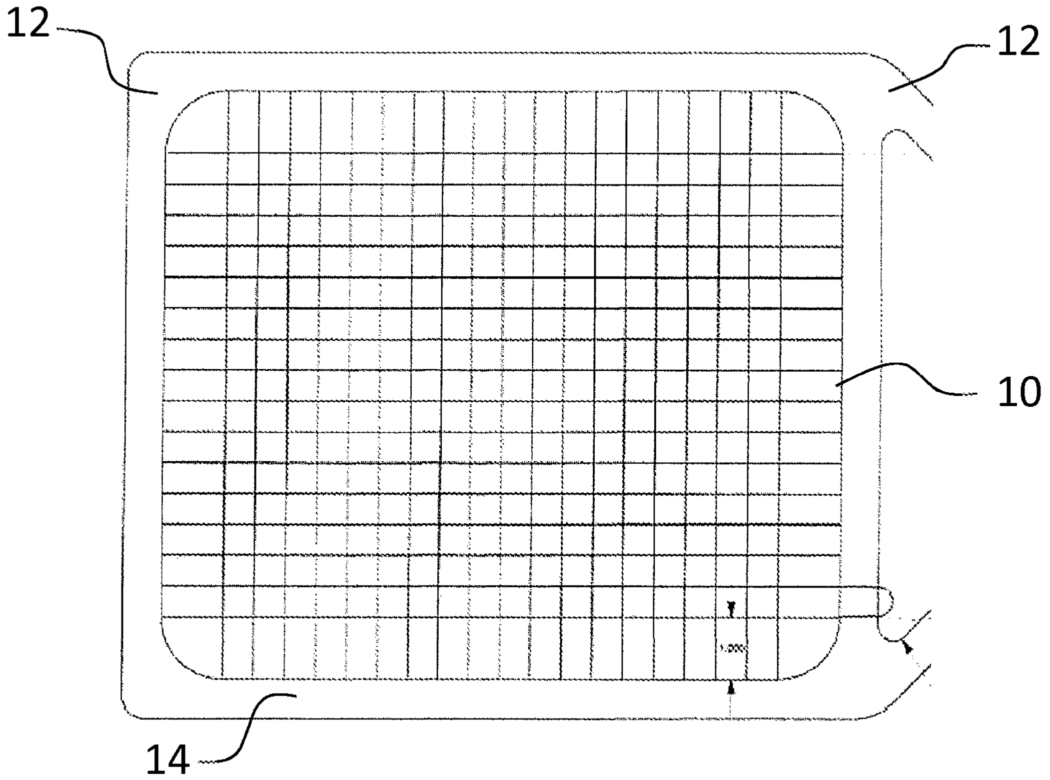

12
12
10
1.000
14

Fig. 1C

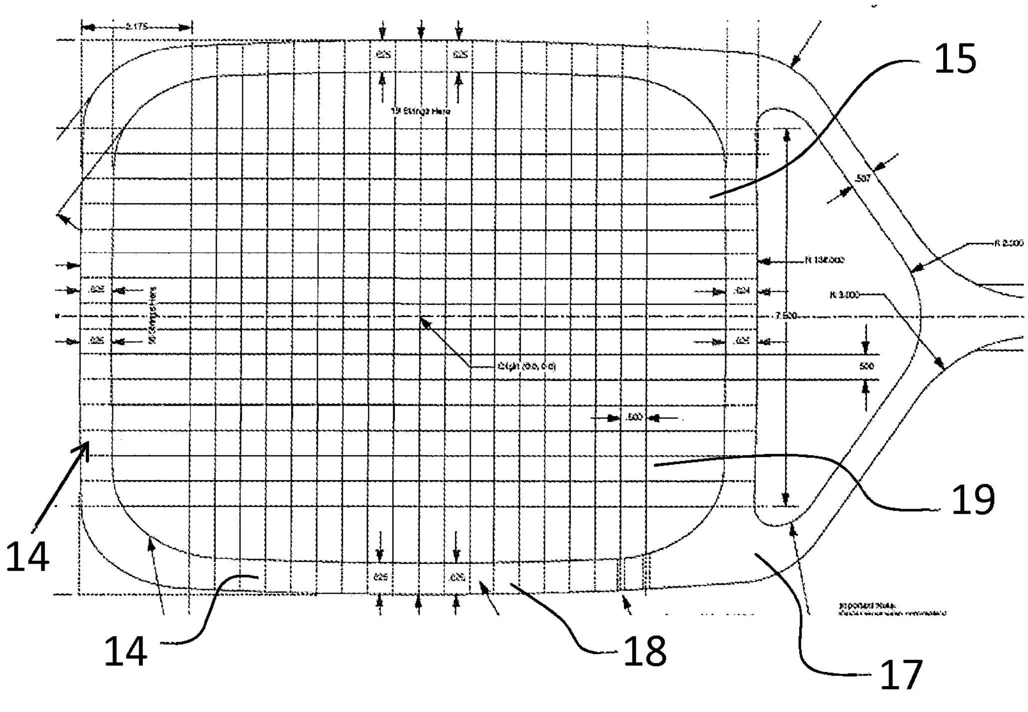

2.175
.025
.025
19 Strings Here
15
.507
R 2.000
R 136.000
.025
.024
R 3.000
7.520
.025
.025
Origin (0.0, 0.0)
.500
.500
19
14
.025
.025
14
18
17

Fig. 1D

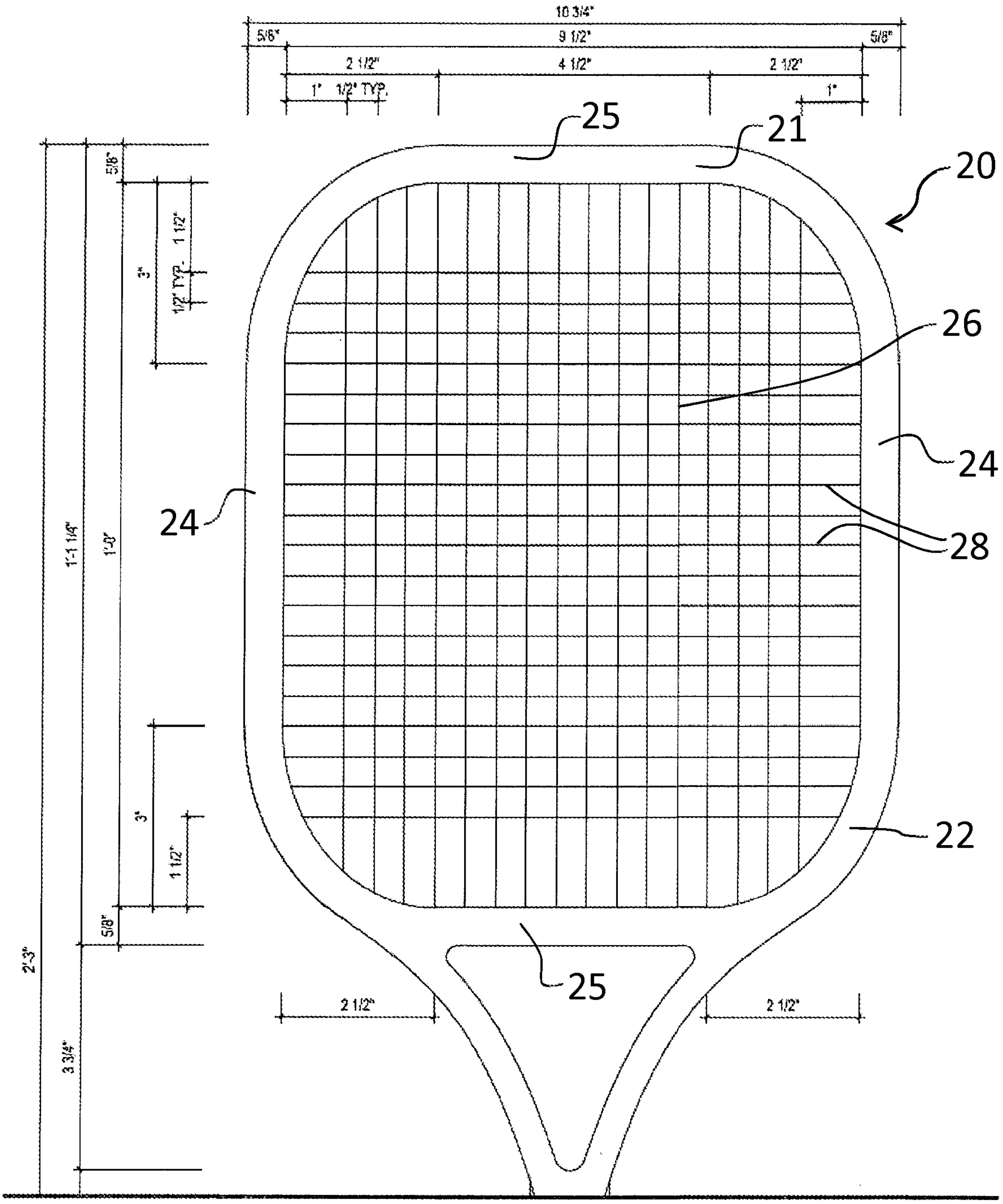
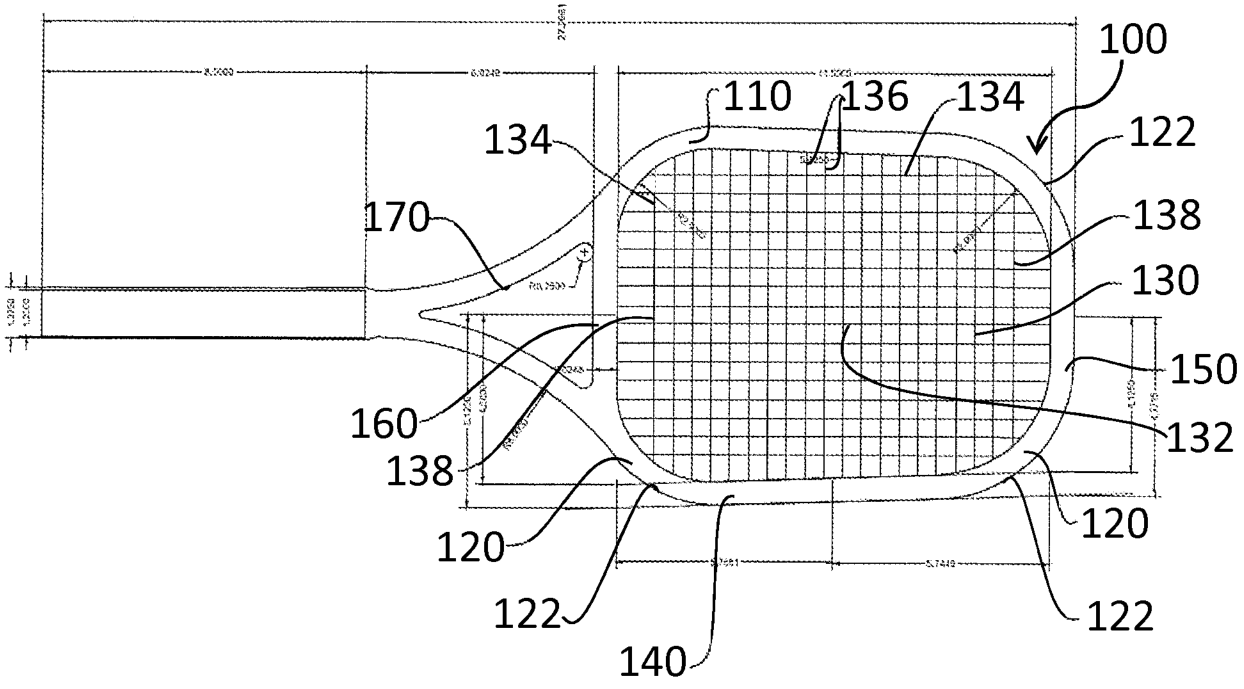

10 3/4"
5/8"
9 1/2"
5/8"
2 1/2"
4 1/2"
2 1/2"
1"
1/2" TYP.
1"
25
21
20
5/8"
1 1/2"
3"
1/2" TYP.
26
24
24
1'-1 1/4"
1'-0"
28
3"
1 1/2"
22
5/8"
2'-3"
25
2 1/2"
2 1/2"
3 3/4"

Fig. 2


27.2681
8.5000
6.0248
100
110
134
136
134
122
170
138
130
150
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132
138
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120
122
122
140

Fig. 3

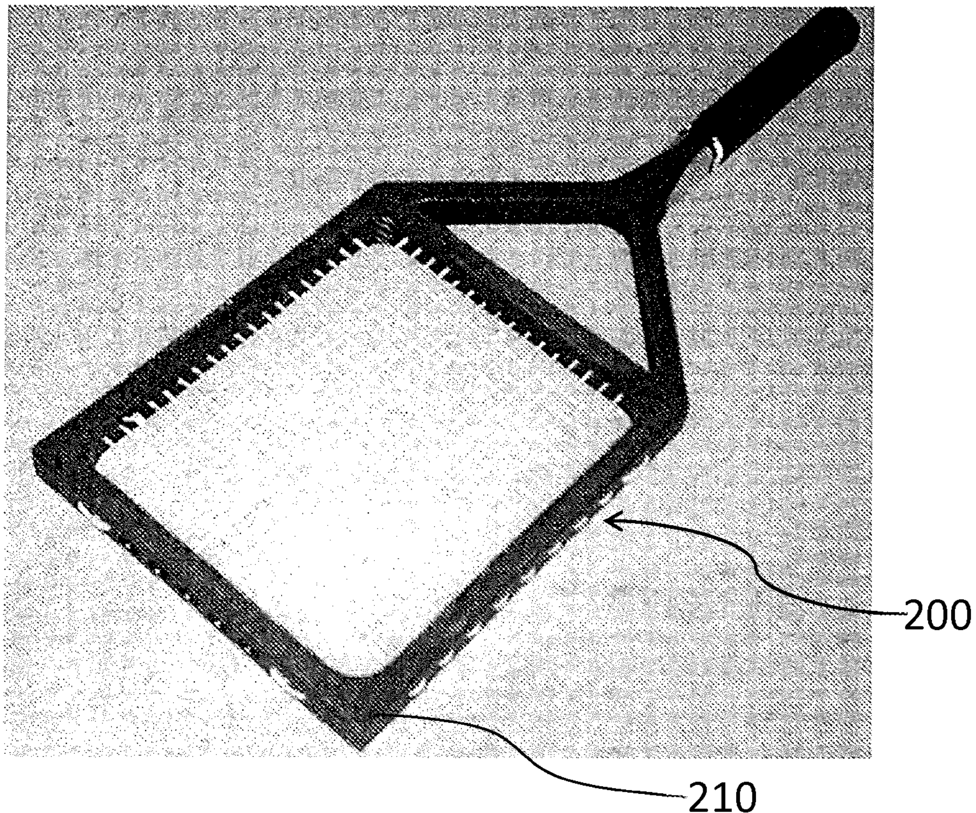


Fig. 4A

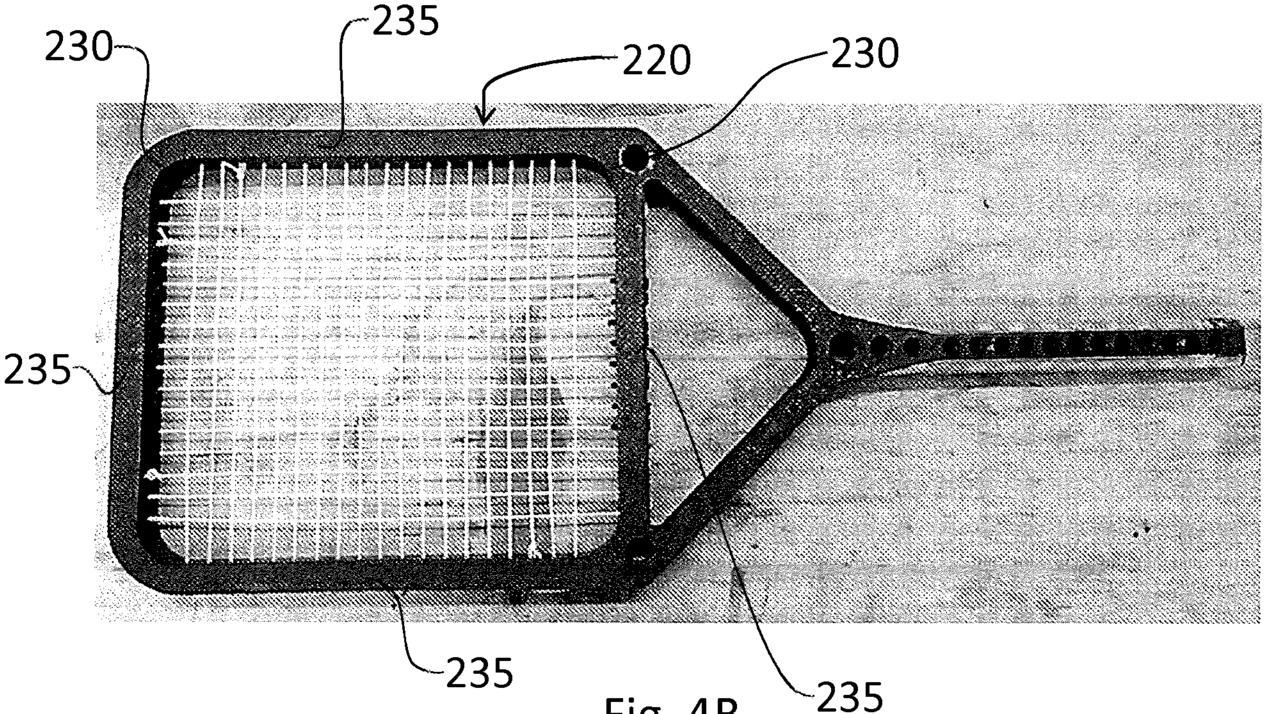


Fig. 4B

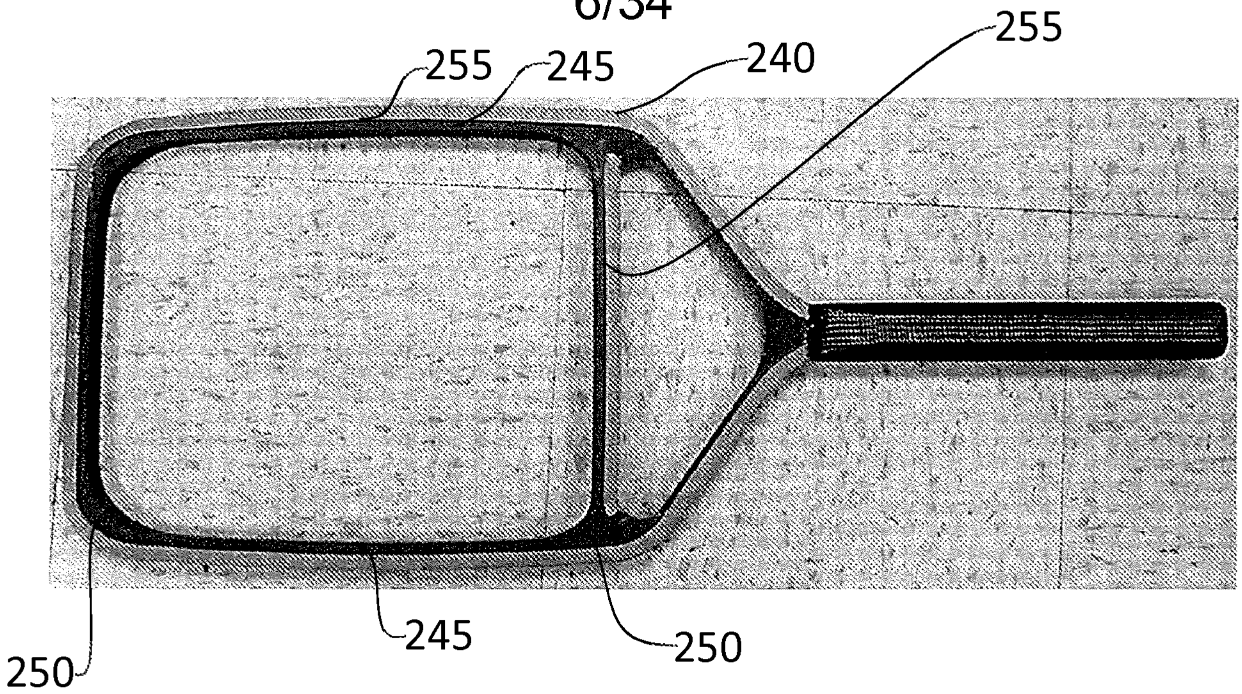


Fig. 4C

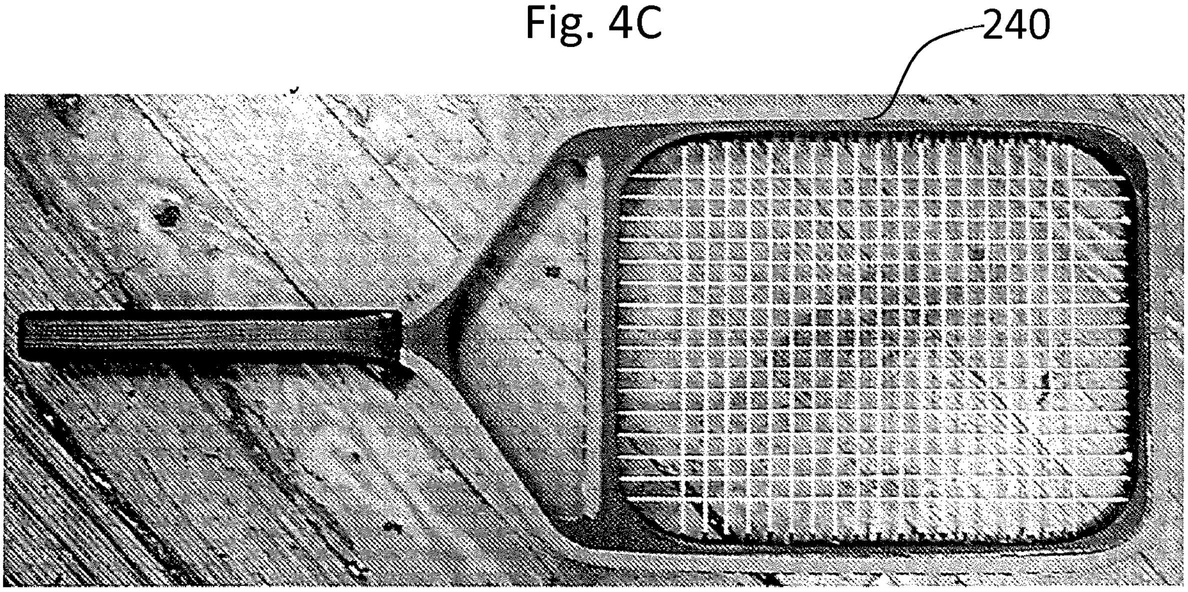


Fig. 4D

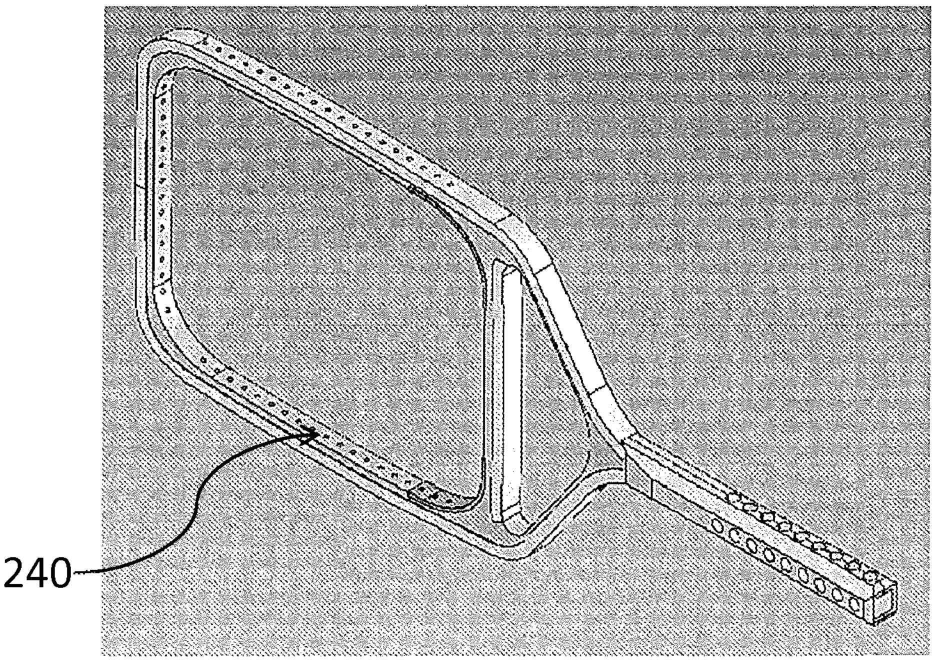


Fig. 4E

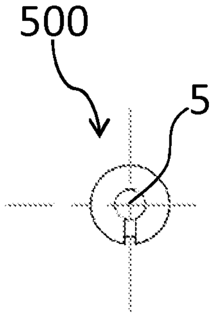


Fig. 5A

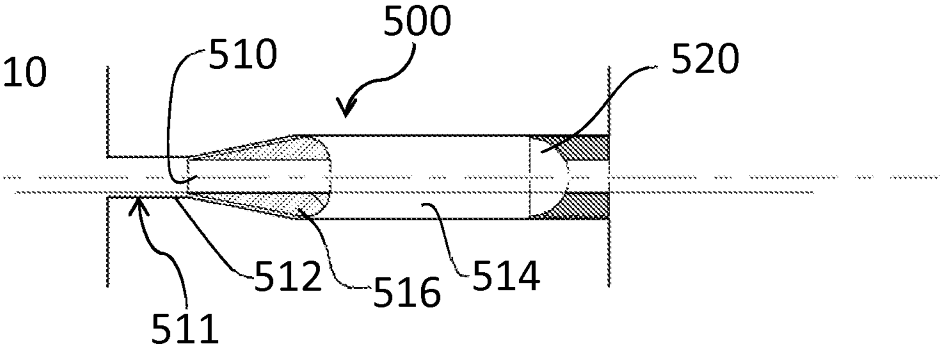


Fig. 5B

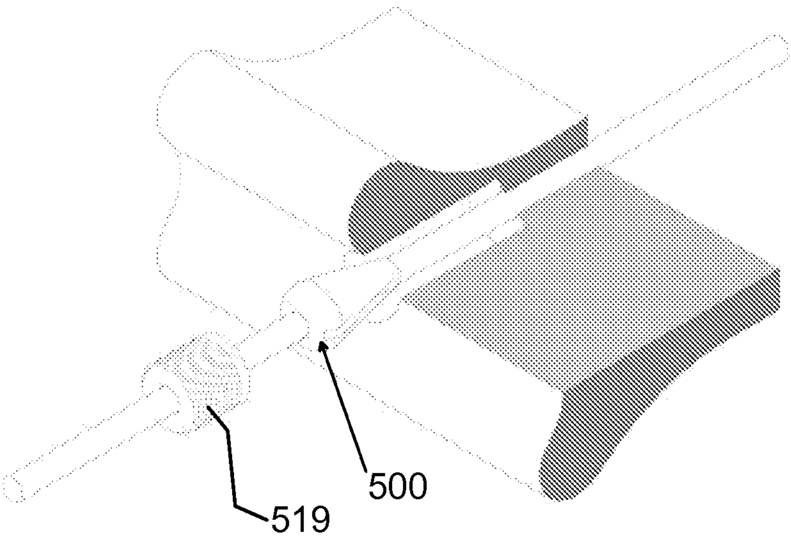


Fig. 5C

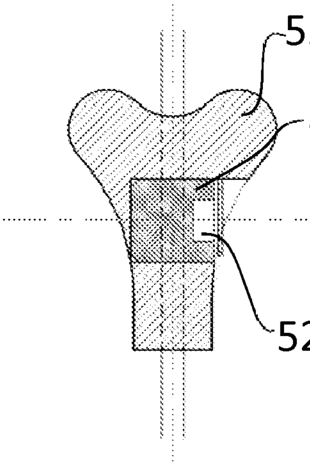


Fig. 6A

Fig. 6B

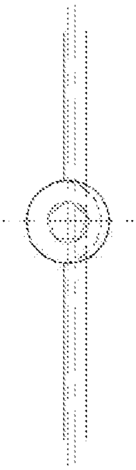


Fig. 6C

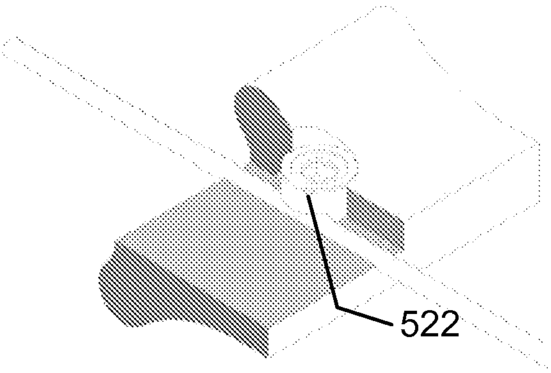


Fig. 6D

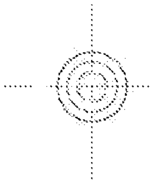


Fig. 7A

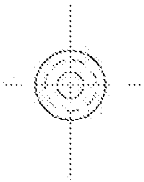


Fig. 7B

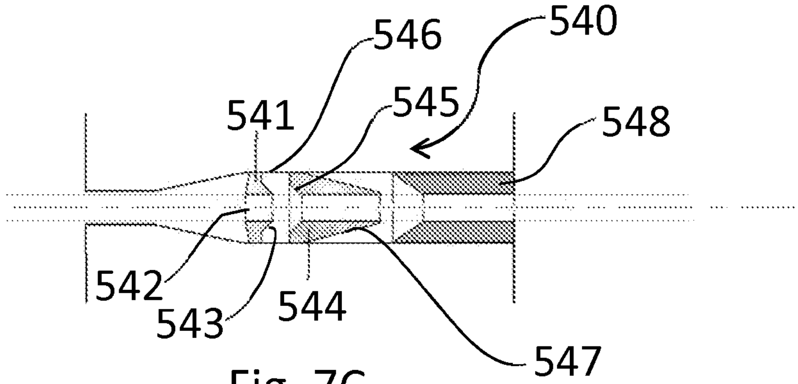


Fig. 7C

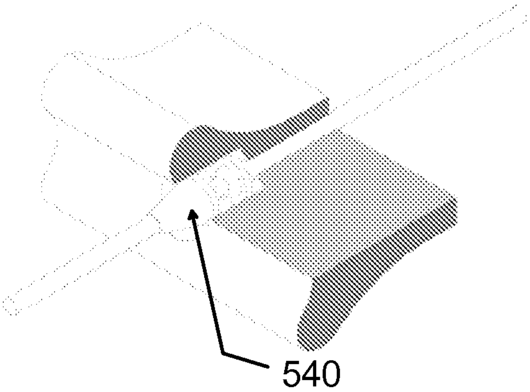


Fig. 7D

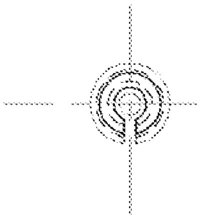
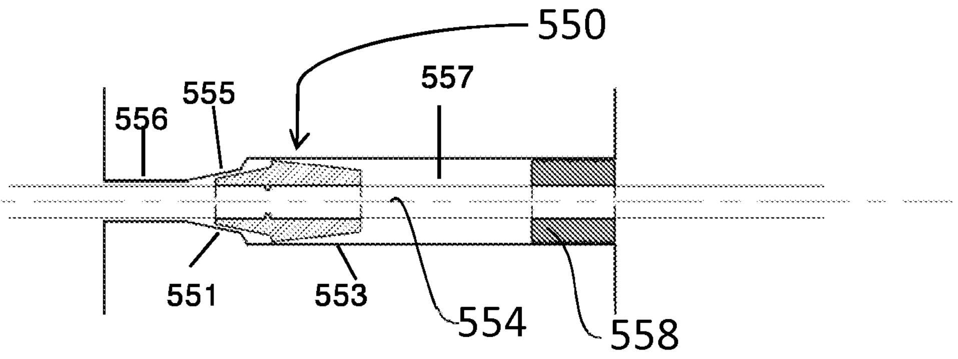


Fig. 8A



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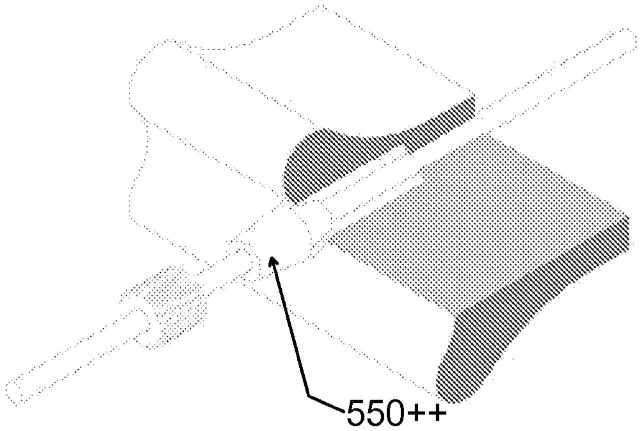


Fig. 8C

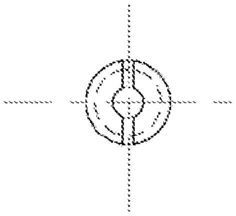


Fig. 9A

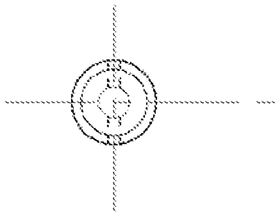


Fig. 9B

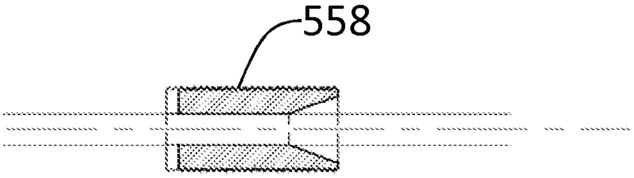
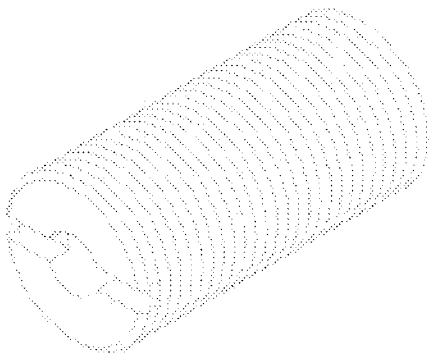


Fig. 9C



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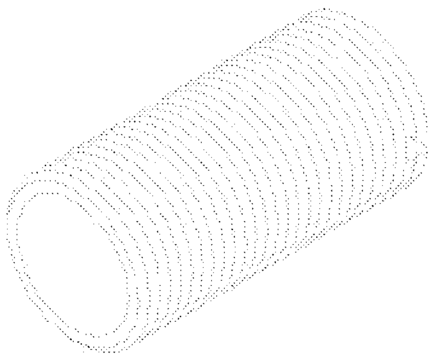


Fig. 9E

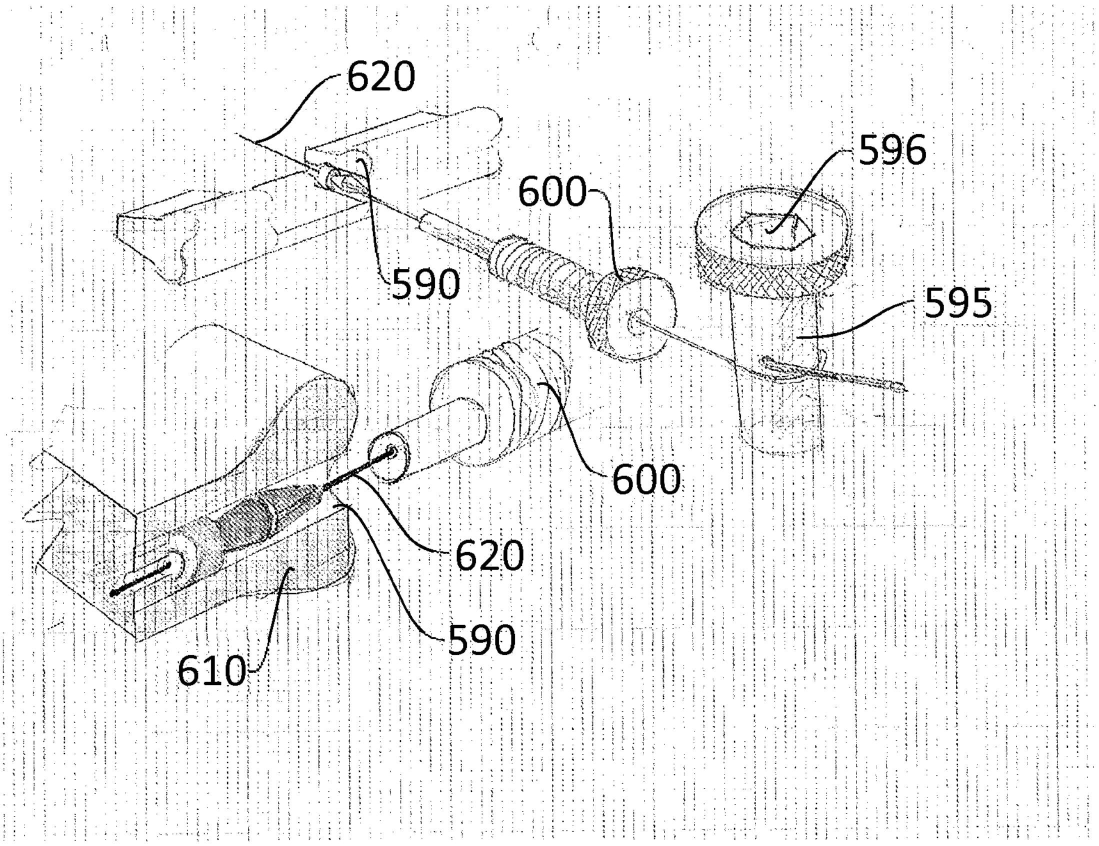


Fig. 10

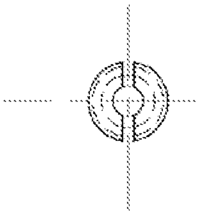


Fig. 11A

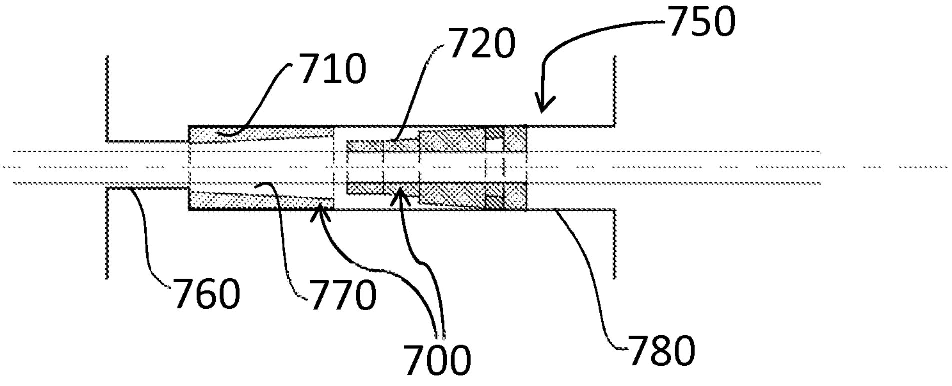


Fig. 11B

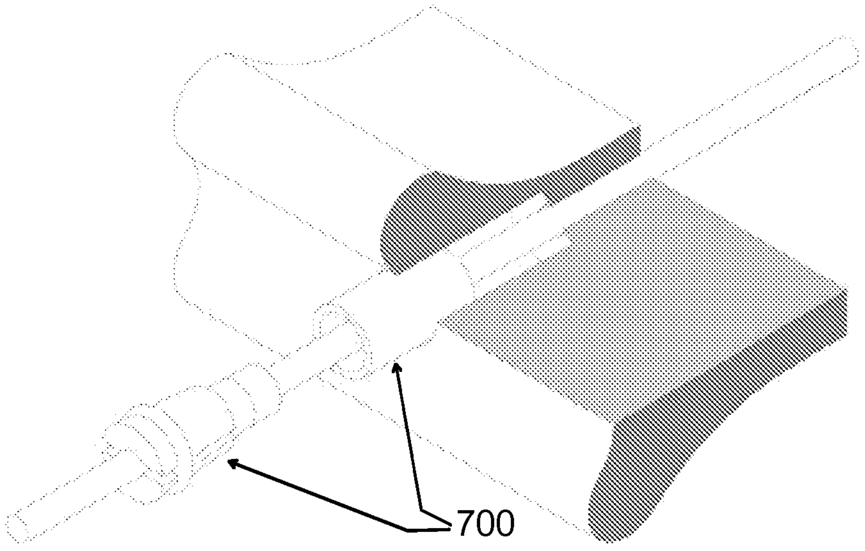


Fig. 11C

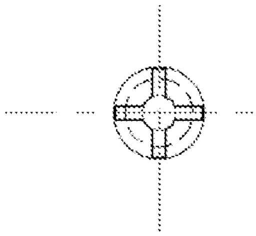


Fig. 12A

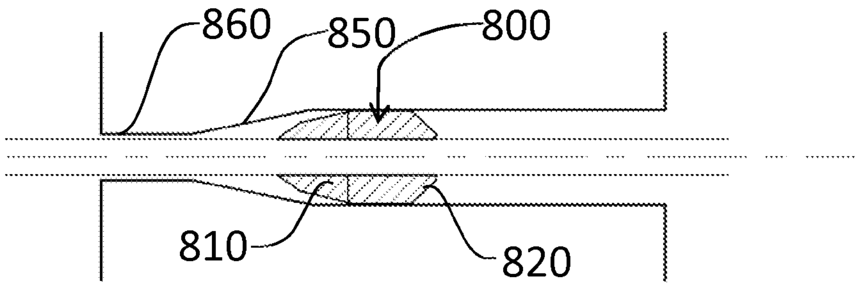


Fig. 12B

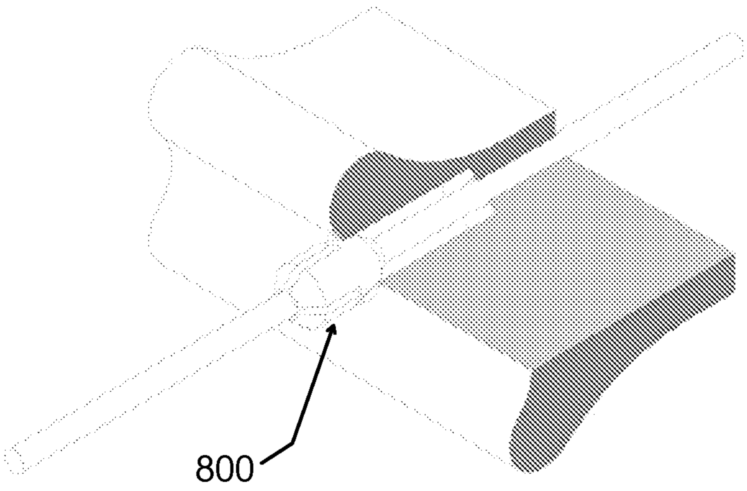


Fig. 12C

Fig. 13A

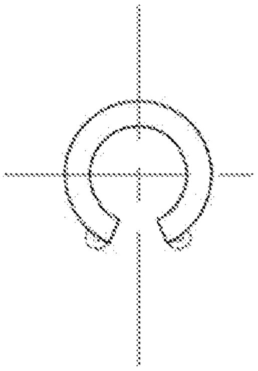


Fig. 13B

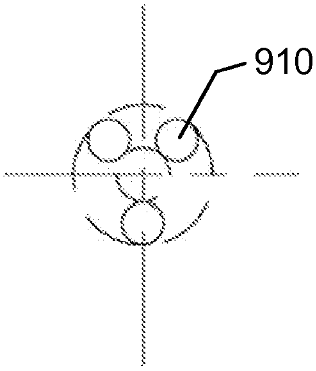


Fig. 13C

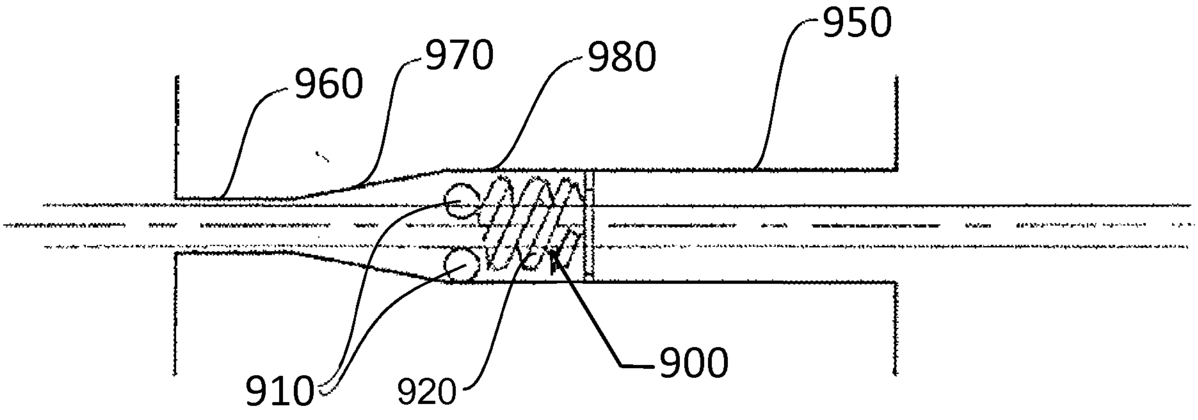


Fig. 13D

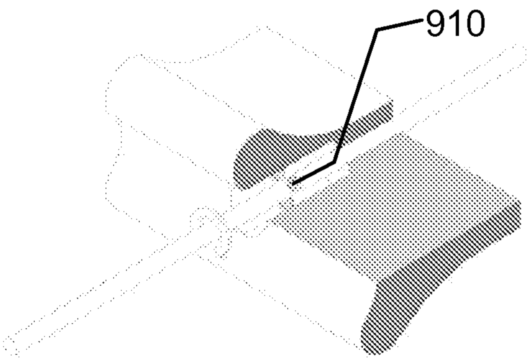
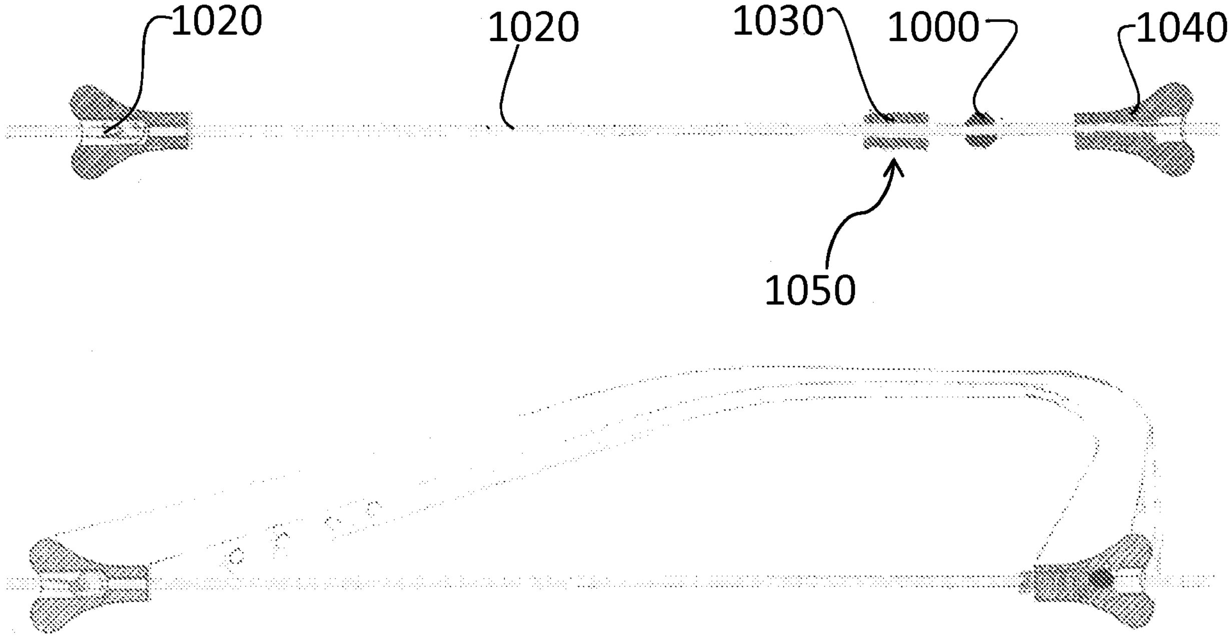


Fig. 13E



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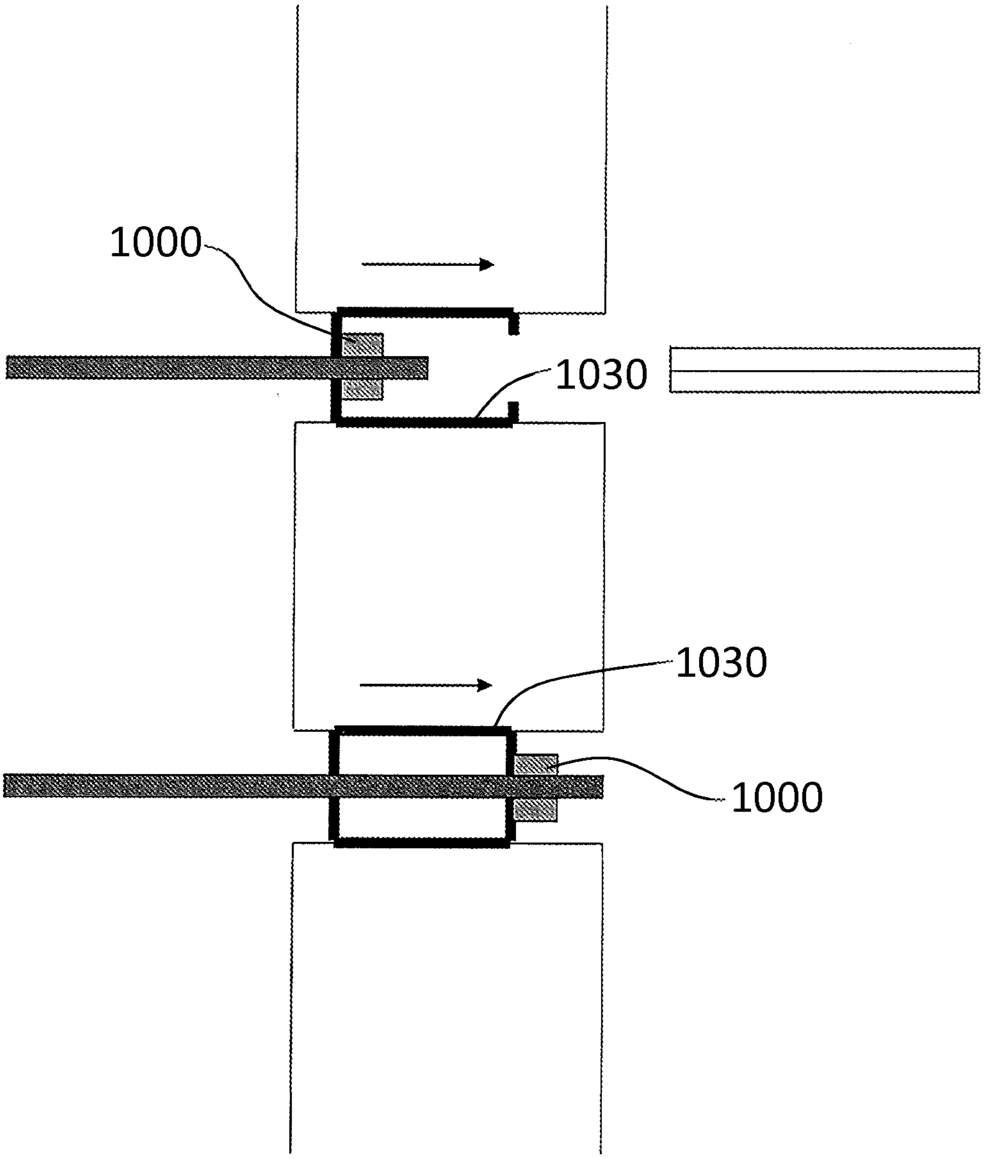


Fig. 14B

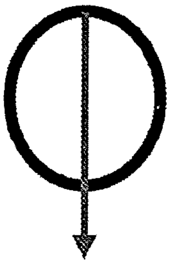


Fig. 15

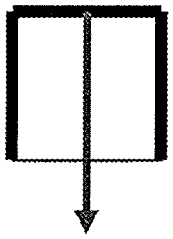


Fig. 16

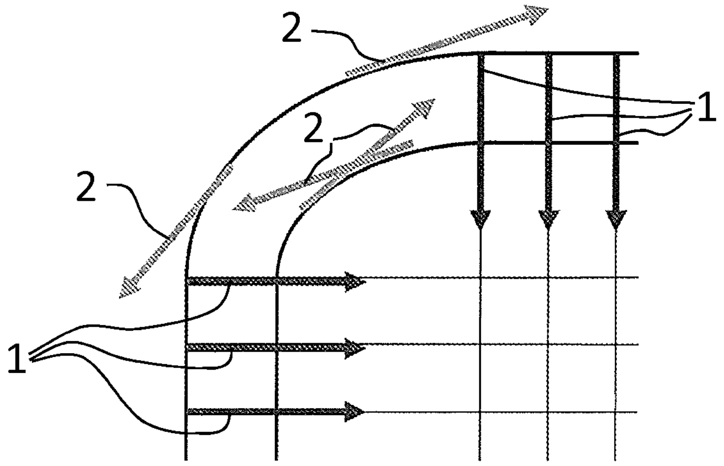


Fig. 17

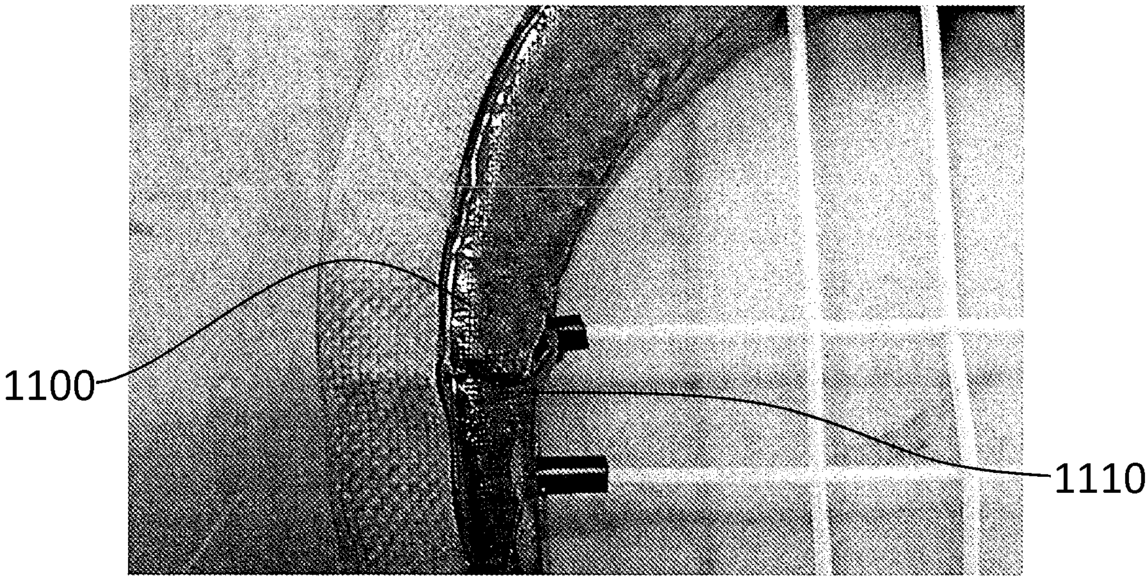
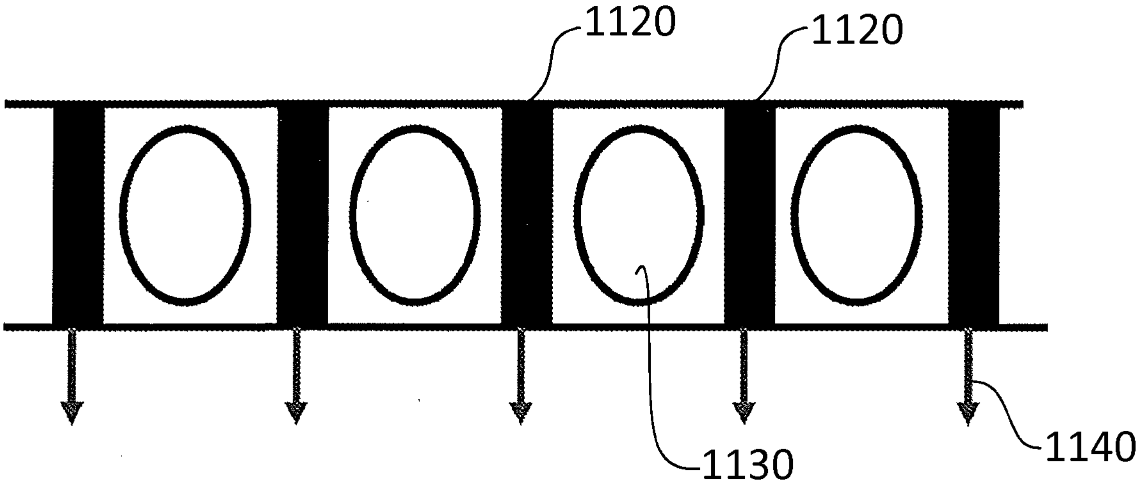


Fig. 18



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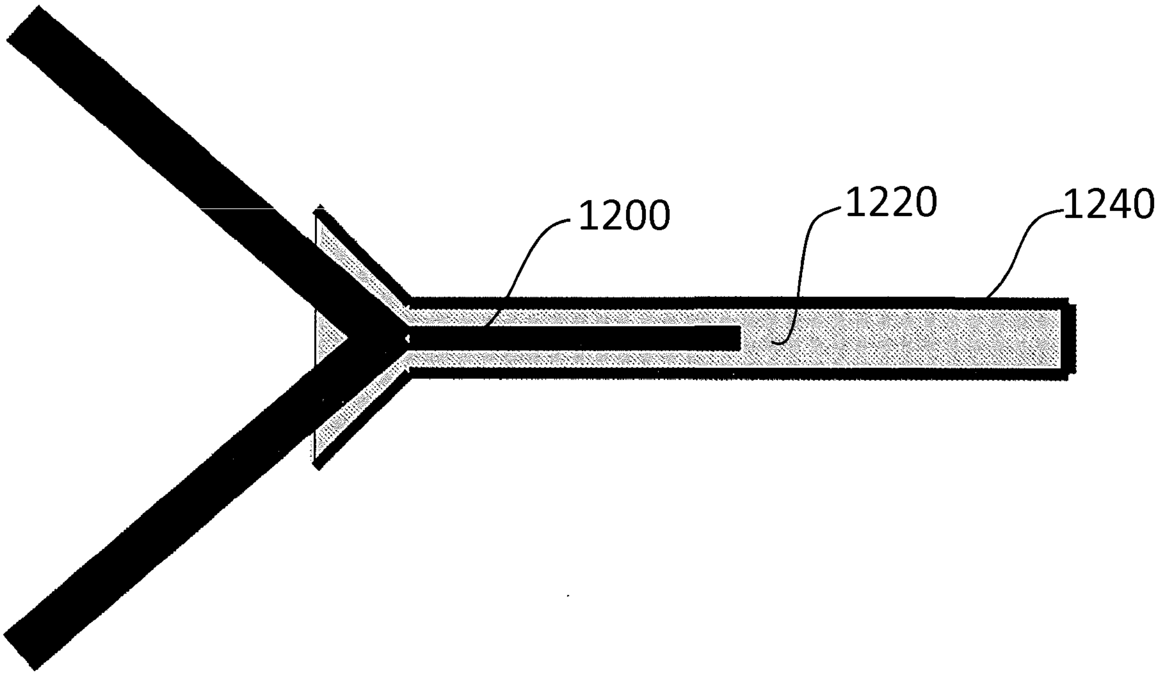

Fig. 20

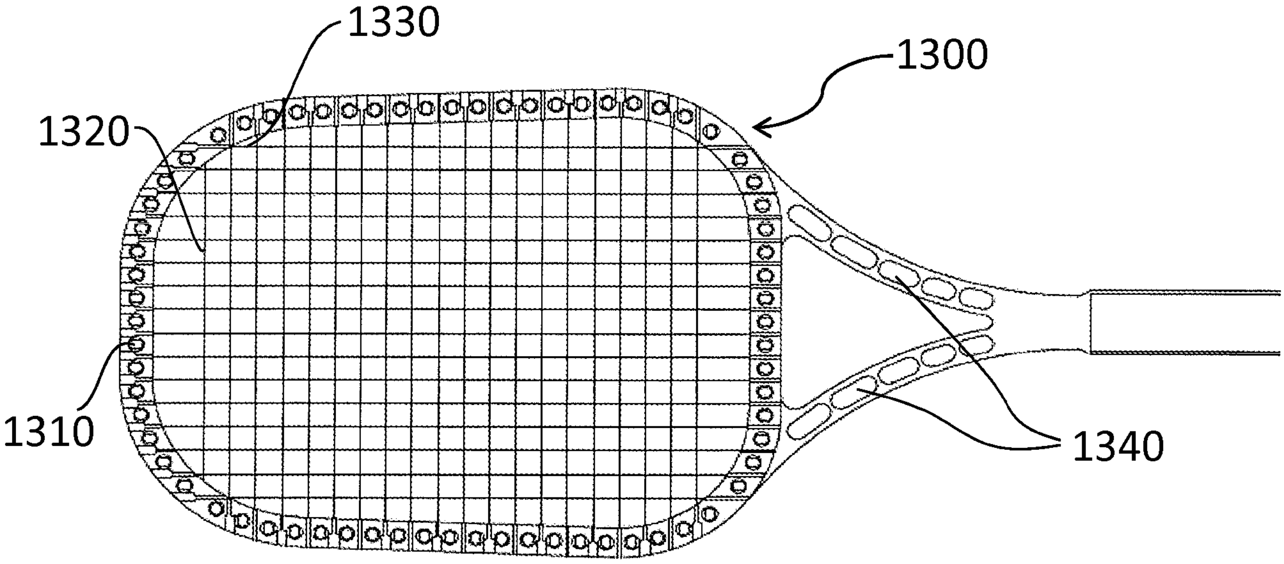

Fig. 21A

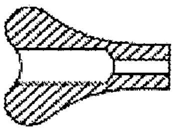

Fig. 21B

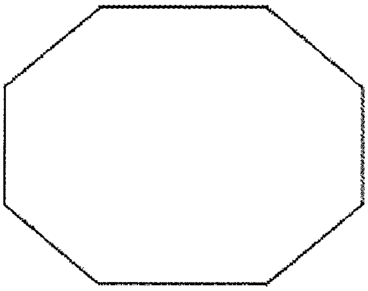

Fig. 21C

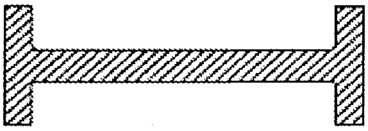

Fig. 21D

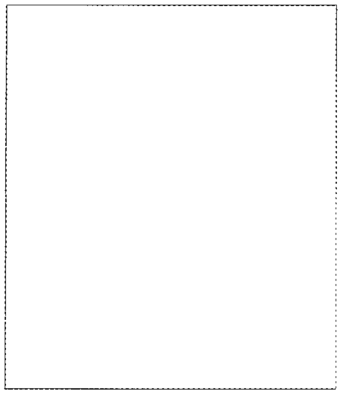

Fig. 22A

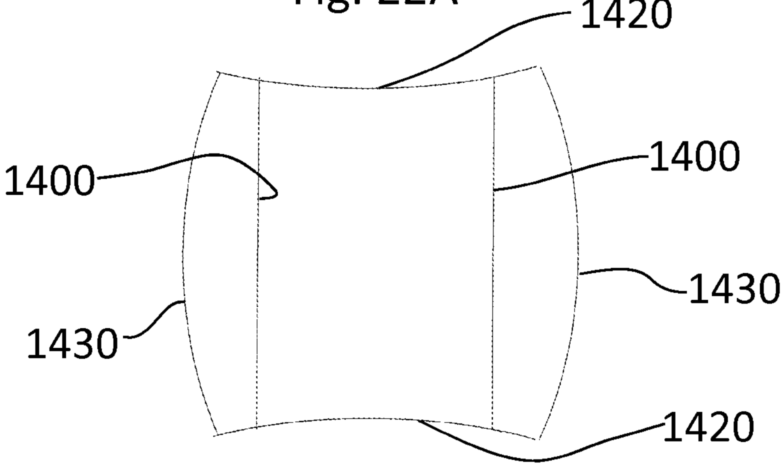

Fig. 22B

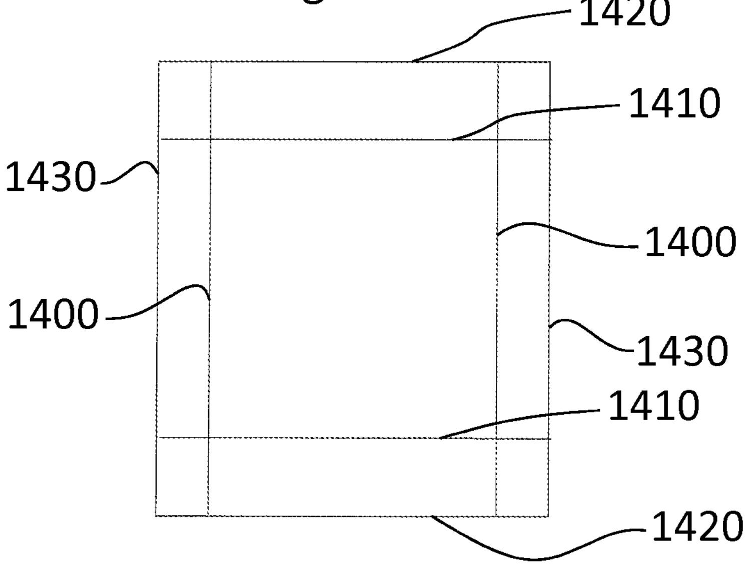

Fig. 22C

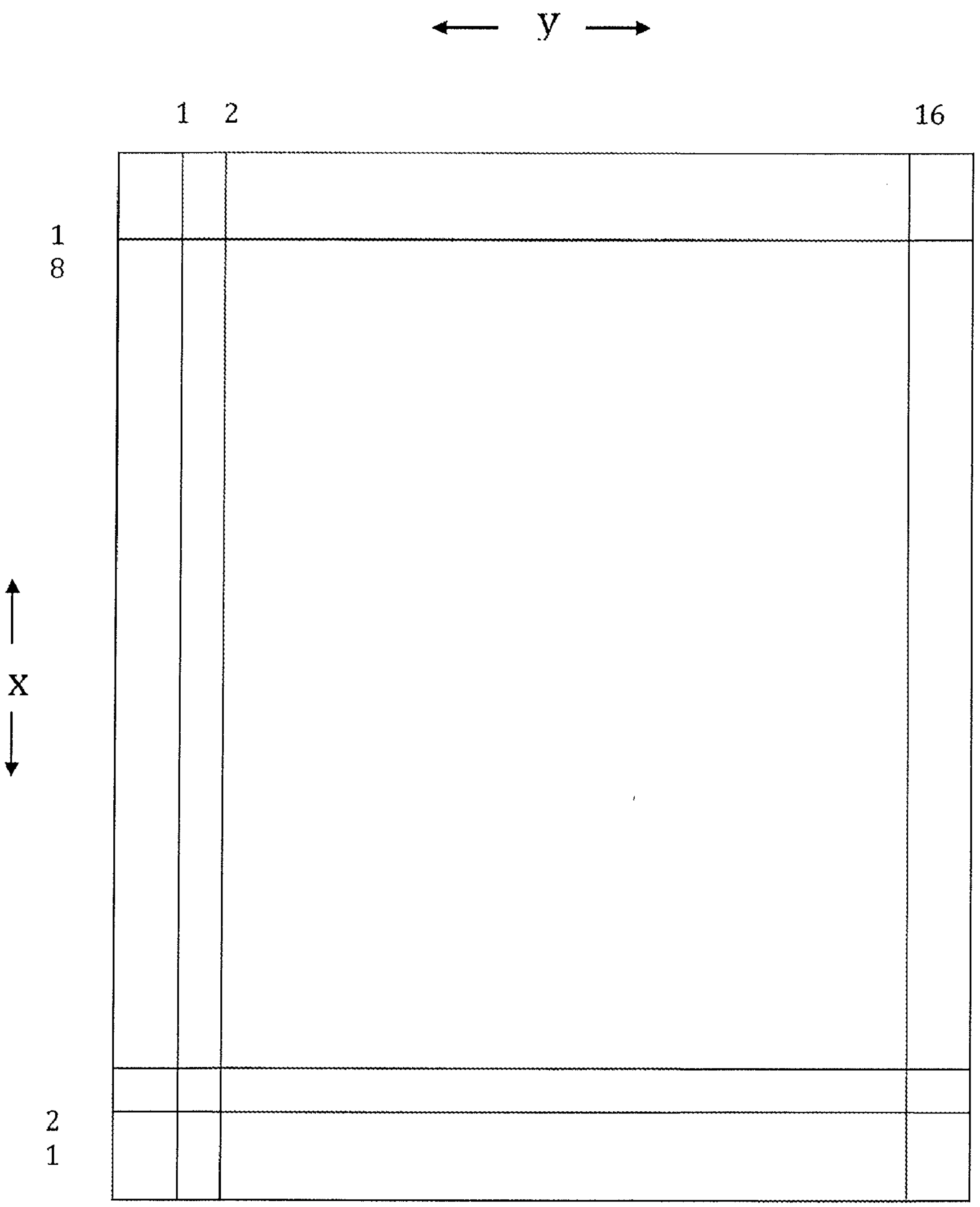

Fig. 23

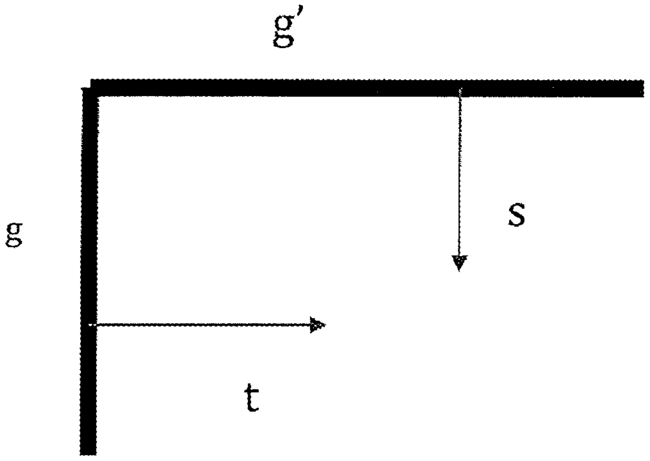

Fig. 24A

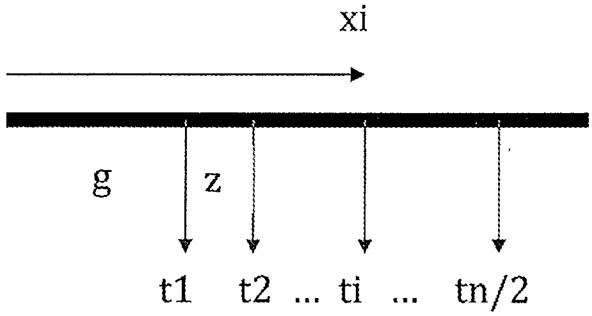

Fig. 24B

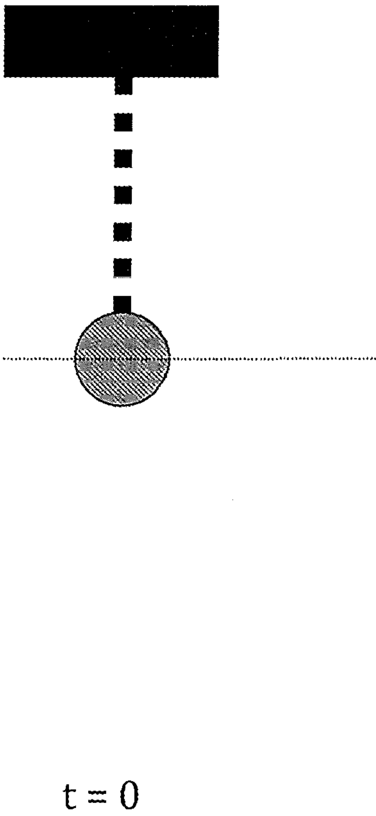

Fig. 25A

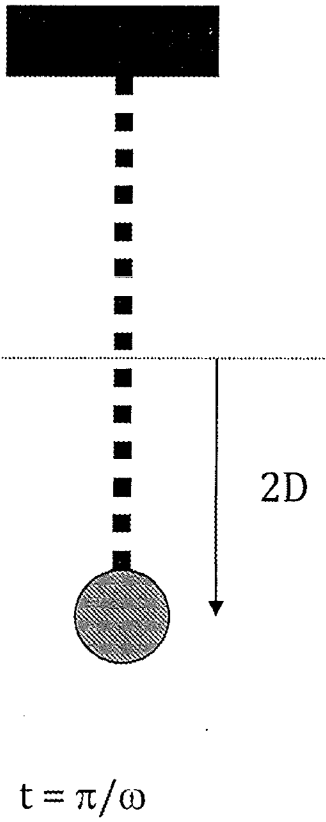

Fig. 25B

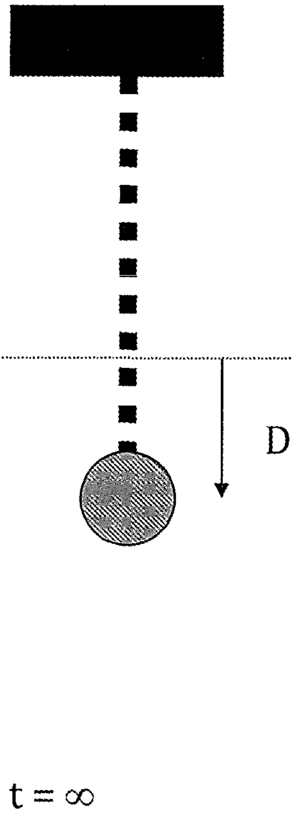

Fig. 25C

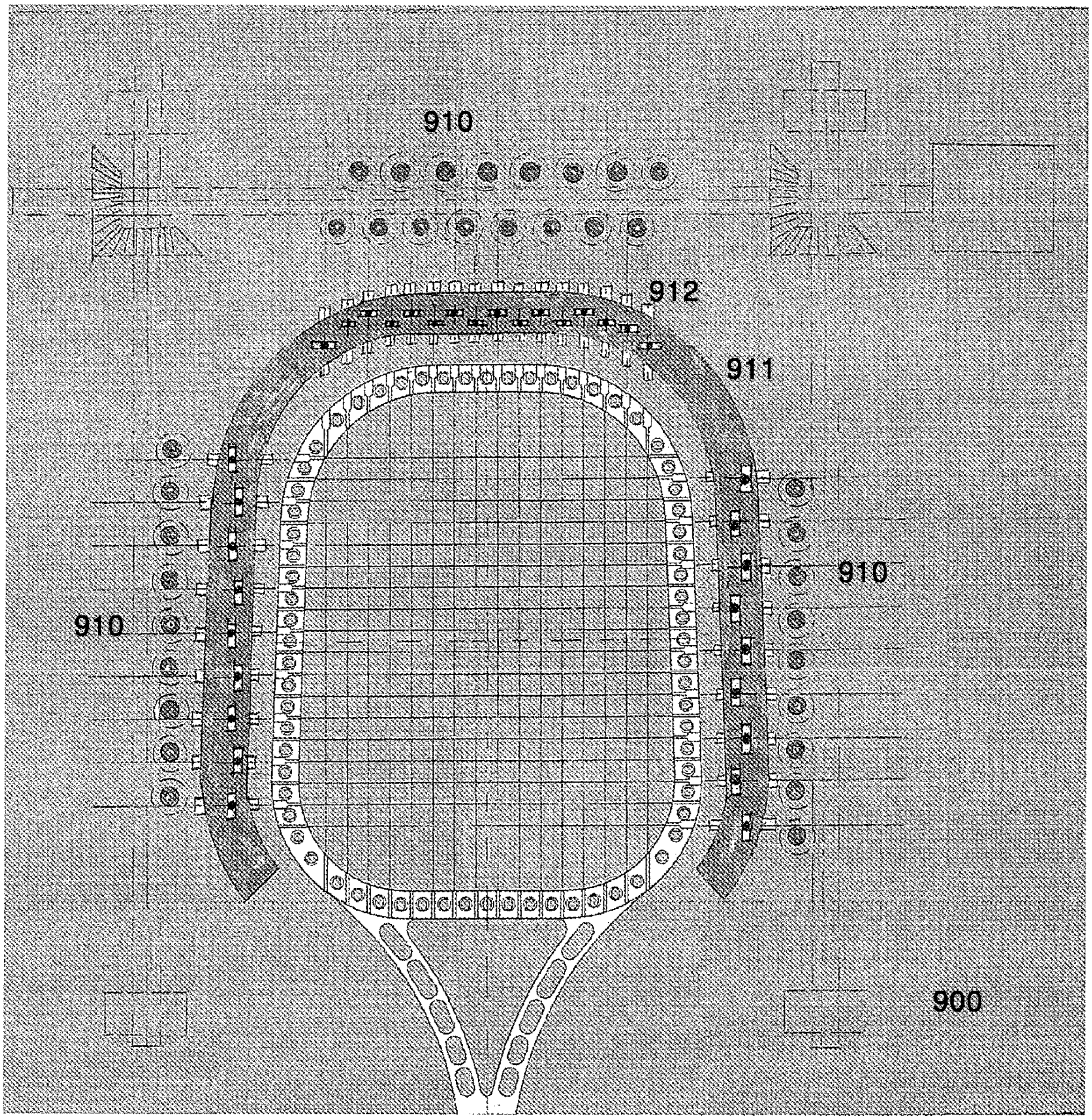

Fig. 26

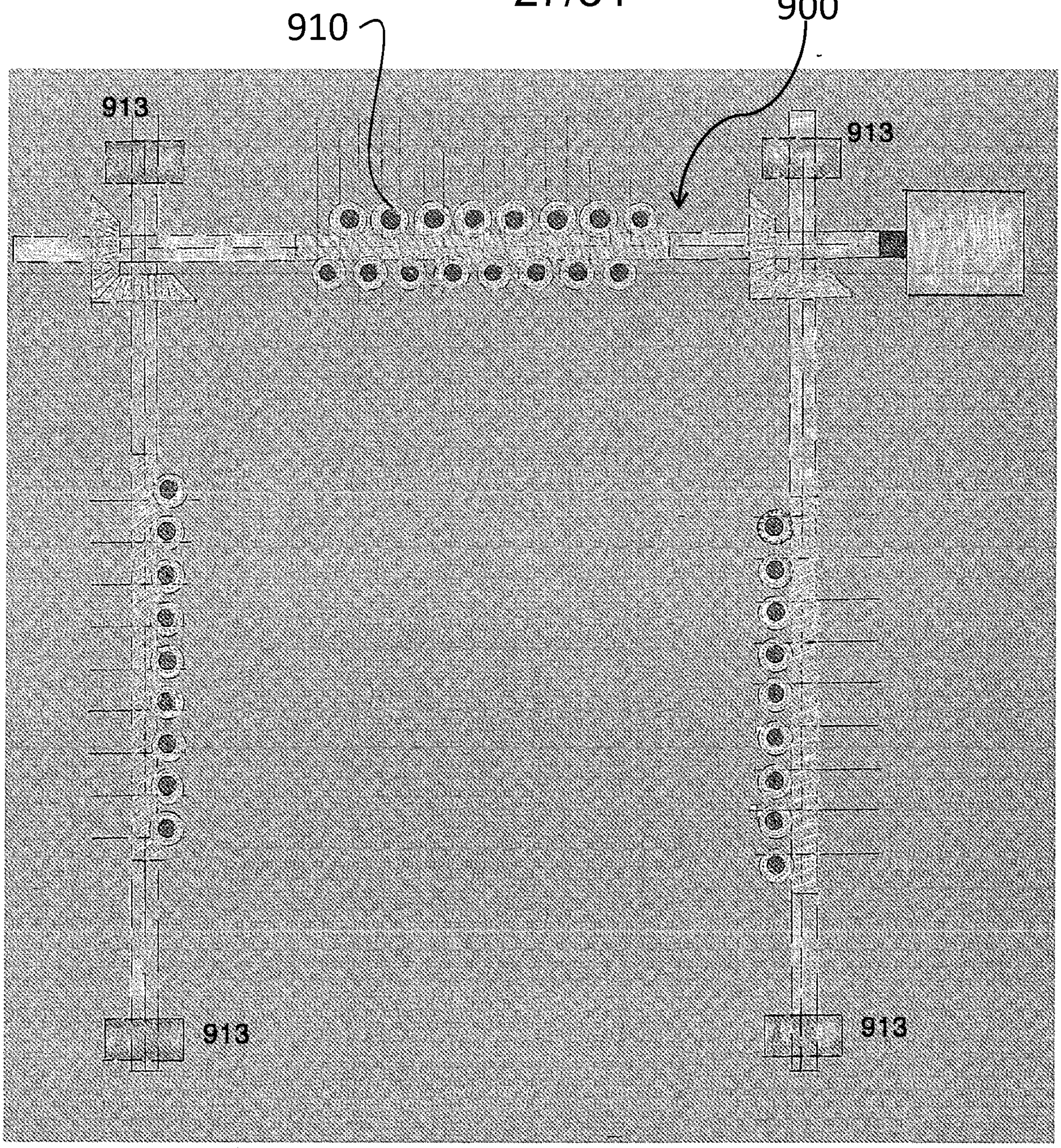

Fig. 27

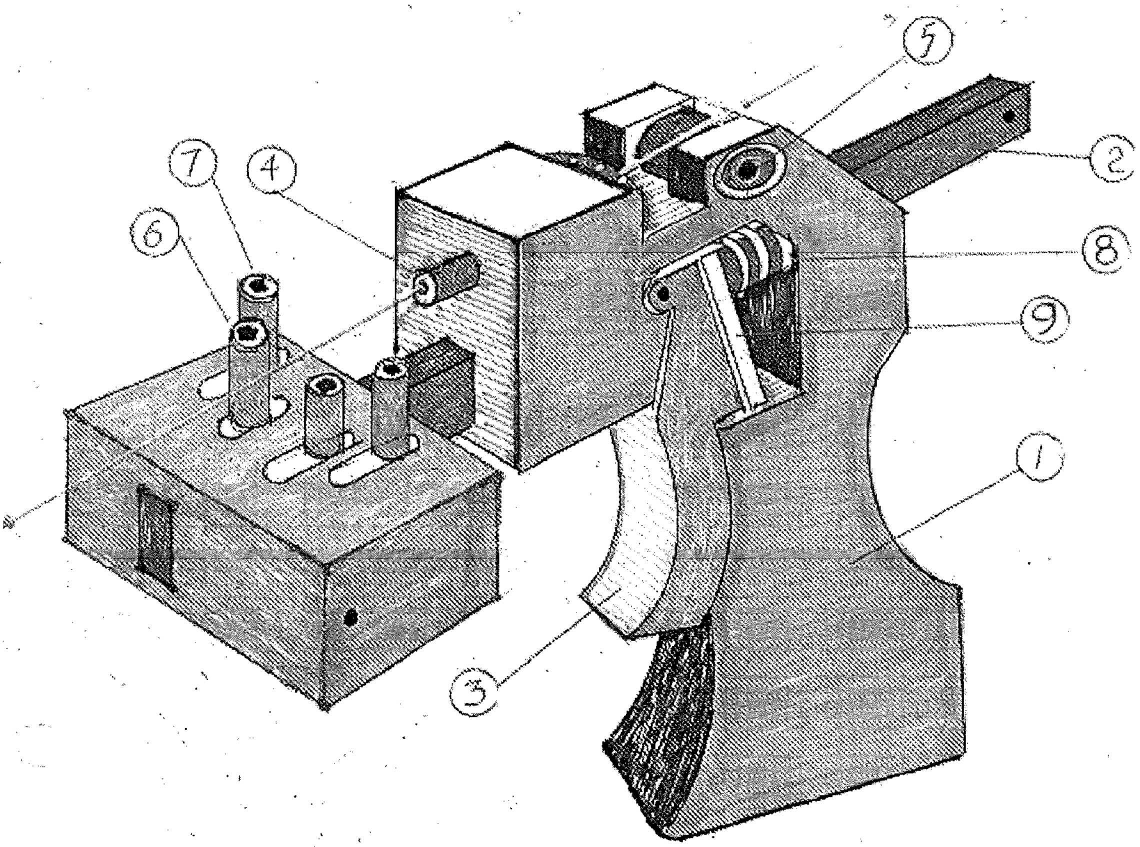

Fig. 28

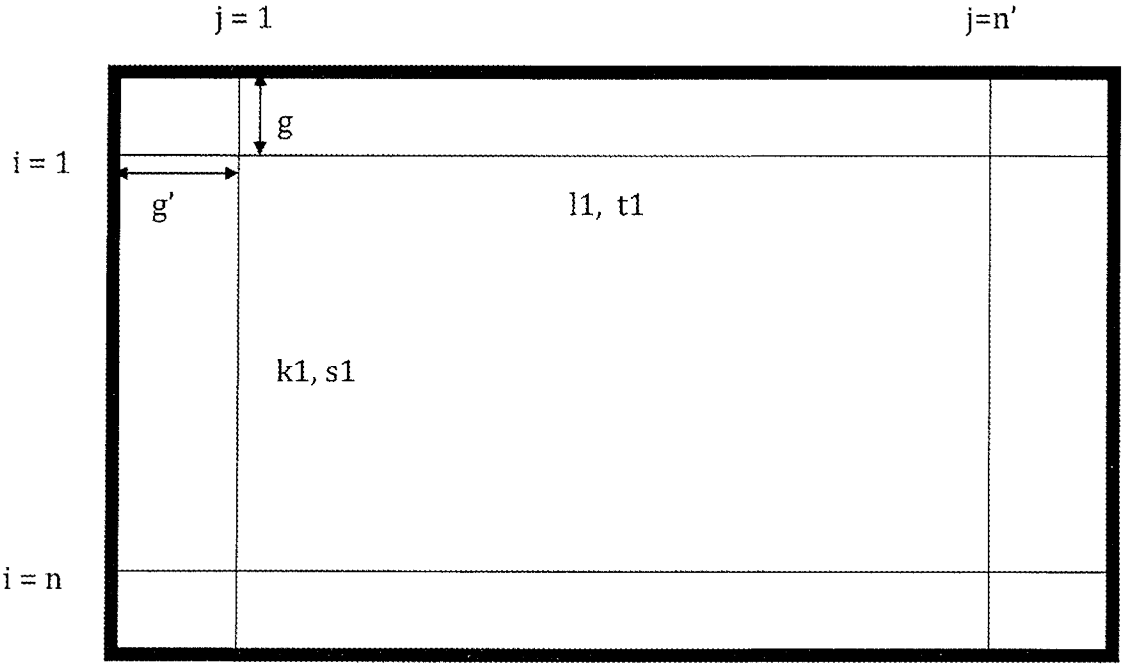

Fig. 29

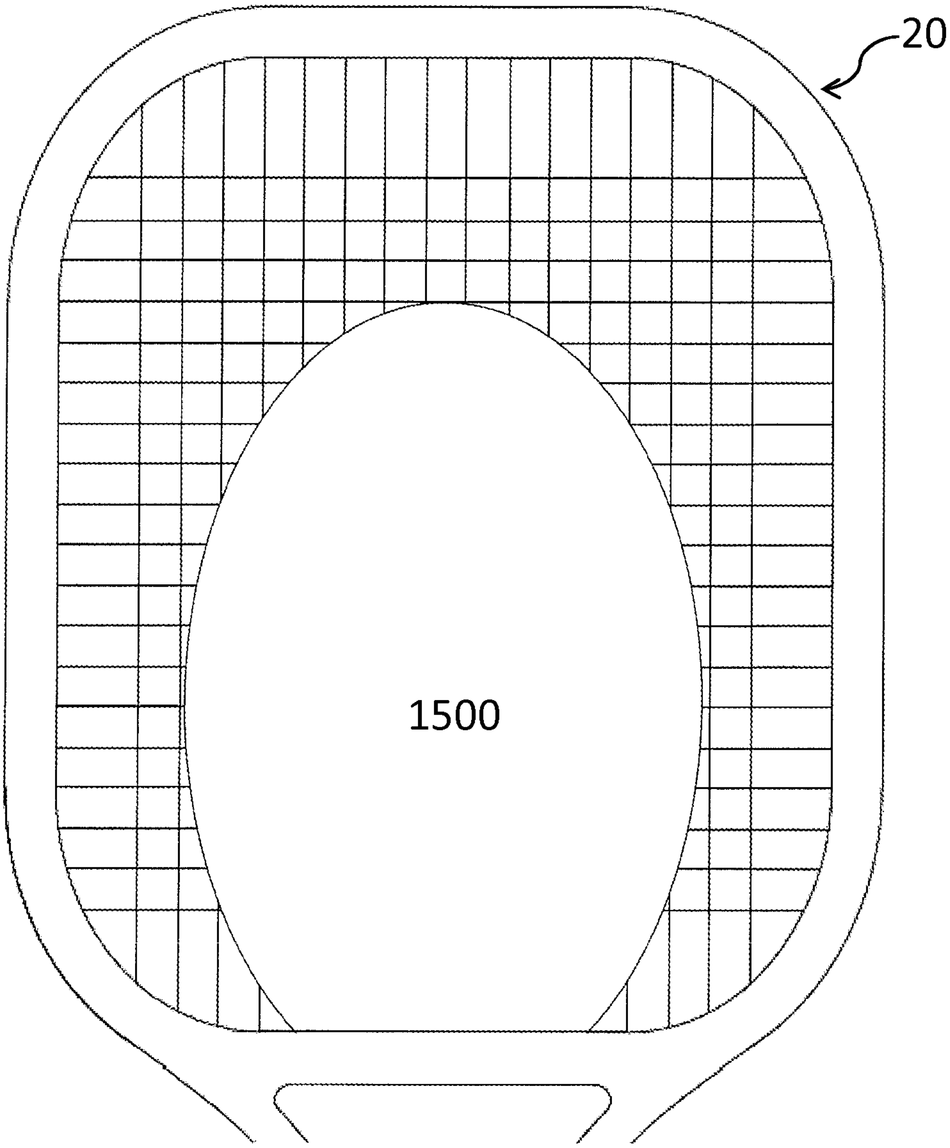

Fig. 30

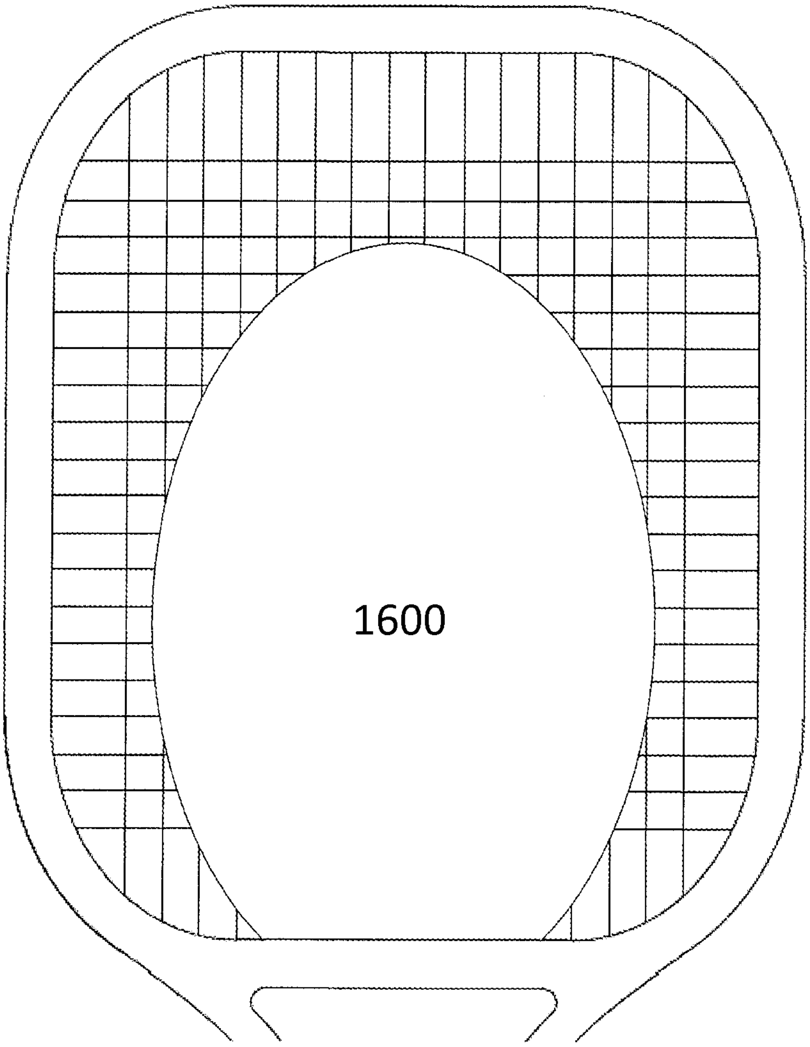

Fig. 31

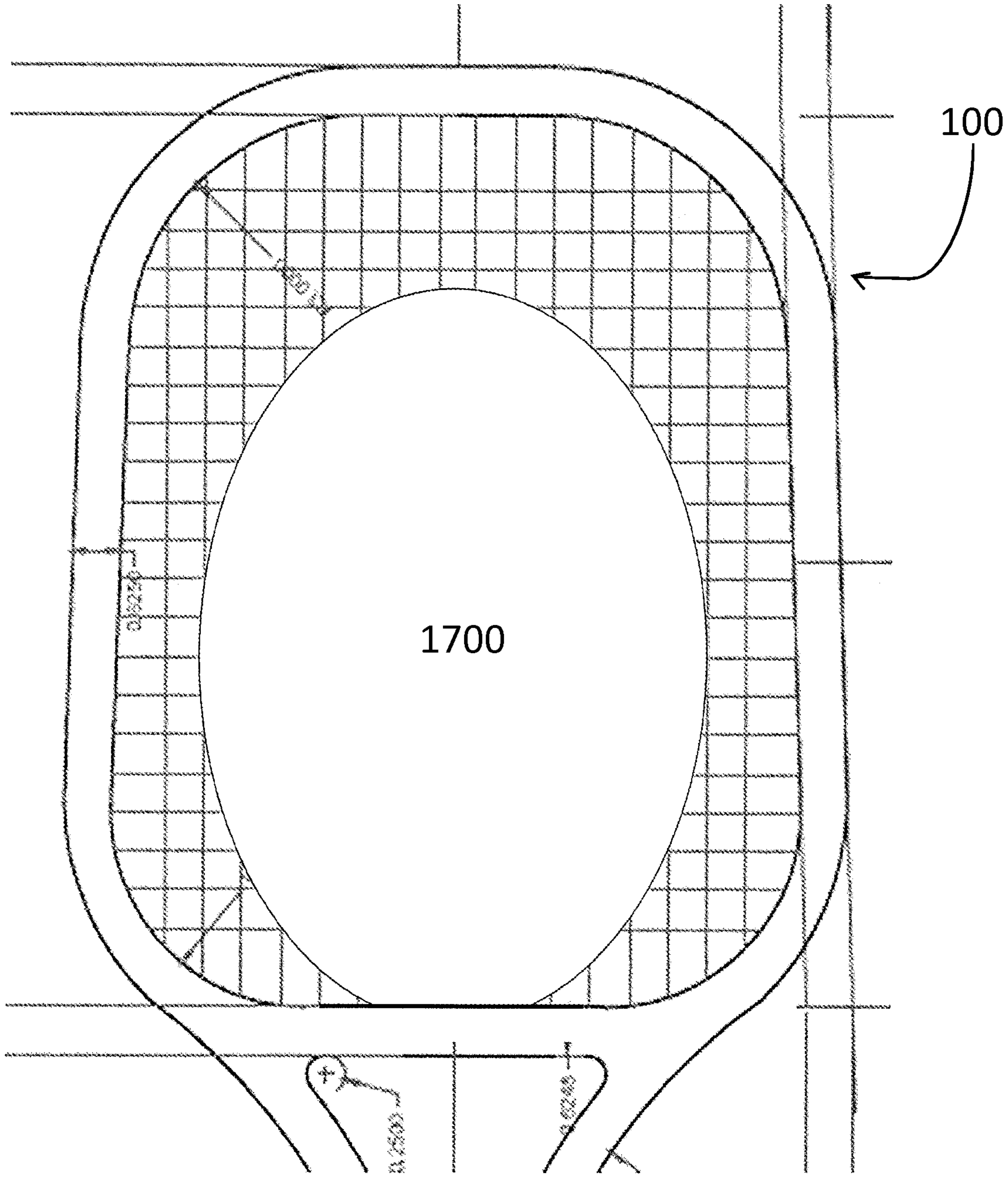

Fig. 32

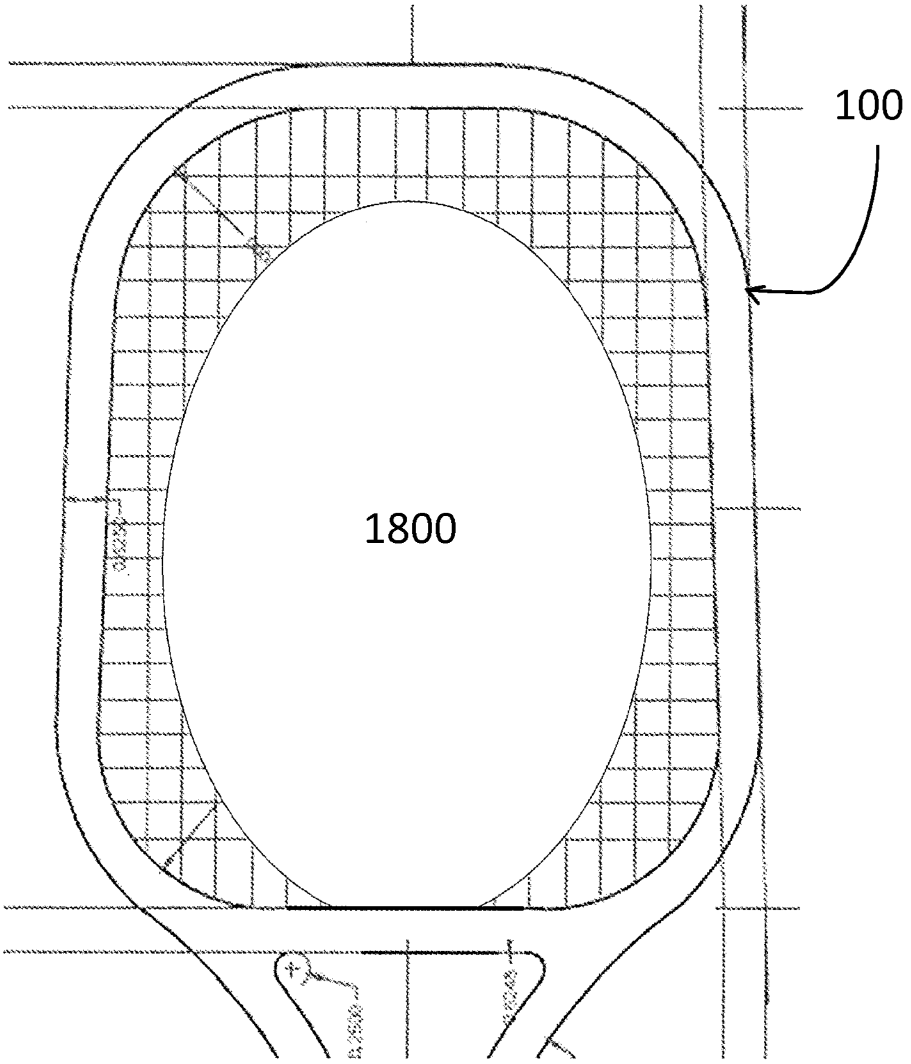

Fig. 33

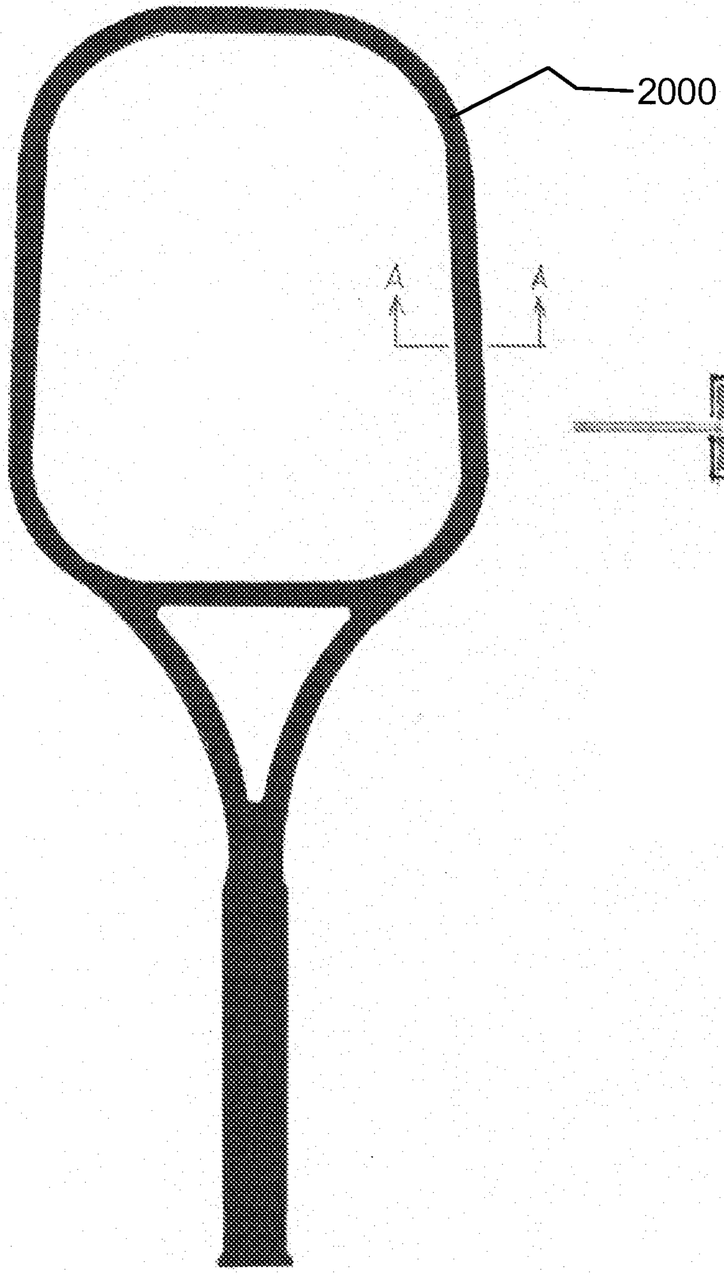

Fig. 34A

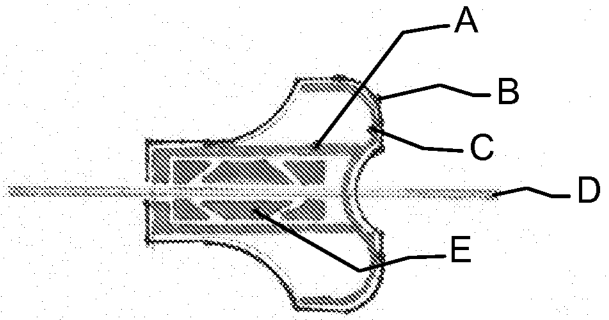

Fig. 34B

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 13/22141

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - A63B 51/12 (2013.01)
USPC - 473/534
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC(8) - A63B 51/12 (2013.01)
USPC - 473/534

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
IPC(8): A63B 51/12, 49/00 (2013.01)
USPC: 473/533, 534, 524, 539, 540, 543, 544, 545

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
PatBase, Google Patents, Google and Google Scholar: racket, racquet, rectangle, square, tension, frequency, vibrate, oscillate, adjust, tune, modify, change, alter, string grommet, lock, connect, fasten, couple, carbon fiber, metal, strip, metallic

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y	US 4,566,695 A (Melby) 28 January 1986 (28.01.1986), entire document, especially col 2, ln 21-28; col 2, ln 56-67; col 3, ln 19-25; col 4, ln 23-27; Fig. 1-2	1-3, 9-10, 12-13 and 22-23 --- 15, 20-21
X --- Y	US 6,506,134 B2 (Bertolotti) 14 January 2003 (14.01.2003), entire document, especially col 3, ln 54-67; col 7, ln 60 to col 8, ln 16; col 9, ln 7-22; Fig. 1-2, 10 and 12	24 --- 1, 4-8, 11, 14-19, and 25-33
Y	US 7,081,056 B2 (Brandt) 25 July 2006 (25.07.2006), entire document, especially col 4, ln 1-32; col 4, ln 63 to col 5, ln 4; Fig. 1-3	1, 4-8, 11, 14-19 and 26-29
Y	US 2008/0274843 A1 (Gazzara et al) 06 November 2008 (06.11.2008), entire document, especially para [0036] and [0044]	20-21
Y	US 4,995,608 A (von Hackewitz) 26 February 1991 (26.02.1991), entire document, especially col 2, ln 46-61; Fig. 2	15, 25 and 30-33
A	US 5,993,337 A (Janes et al) 30 November 1999 (30.11.1999), entire document, especially col 4, ln 28 to col 6, ln 17	1-33
A	US 5,386,991 A (Rochette) 07 February 1995 (07.02.1995), entire document, especially col 2, ln 28 to col 3, ln 6	1-33

☒ Further documents are listed in the continuation of Box C. ☐

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search 06 March 2013 (06.03.2013)	Date of mailing of the international search report 29 MAR 2013
Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	Authorized officer: Lee W. Young PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 6,280,354 B1 (Bertolotti) 28 August 2001 (28.08.2001), entire document, especially col 6, ln 58 to col 7, ln 35	1-33
A	US 7,335,120 B1 (Pittner) 26 February 2008 (26.02.2008), entire document, especially col 2, ln 48 to col 3, ln 45	1-33