Golf Putters and Technology Part 1*

by Frank D. Werner and Richard C. Greig

This is the first part of a four-part serialized report co-authored by the Chairman of the Board, Frank Werner, and President, Dick Greig, of the Techline Putter Corporation.

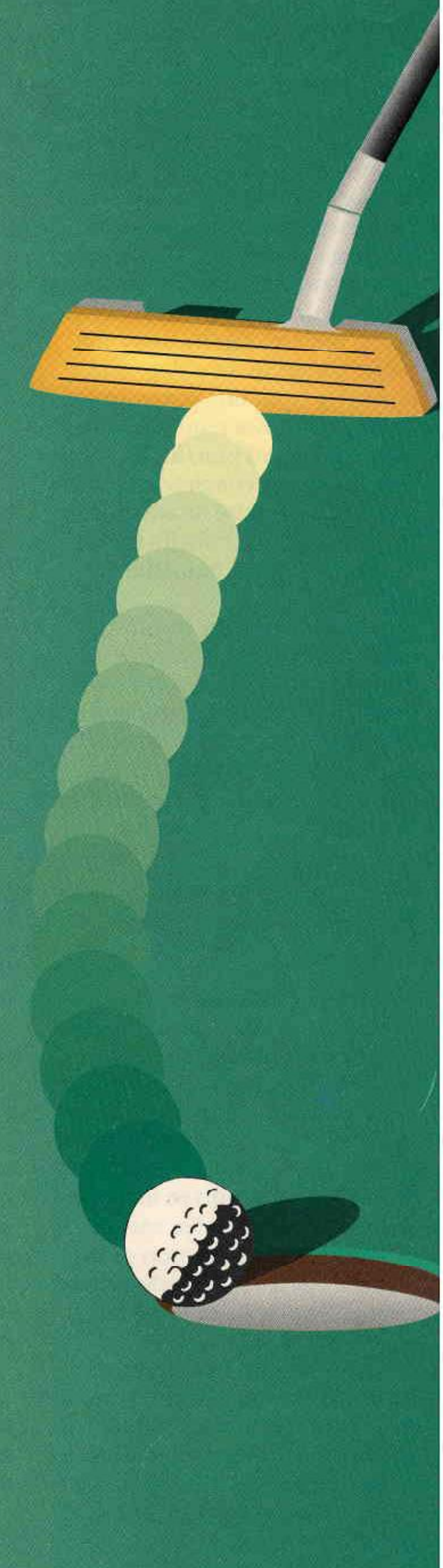
We have discovered several things about golf putters and putting which will be of general interest to a serious student of the game. First is a thorough discussion of the scatter pattern of where the ball contacts the putter face. It typically varies in a predictable way with handicap. We studied and defined the "Hit Pattern", "Hole Zone", and "Stop Zone" which showed which putts would be successful. These three things lead to a definite conclusion as to how far to aim past the hole (where the ball should stop) for best results, the "Aim Point", and shows how this varies with putt distance, handicap, and green speed. The hit pattern also leads to the logical definition and evaluation of an "Accuracy Rating" for putters. Other important factors are discussed, based on a strong technical foundation: the effect of lie angle variations and how the shape of the bottom of the putter and of a special aim line can reduce this effect; and the effect of changes in the press angle. Appendixes briefly describe some of our research and demonstration equipment which was used to confirm that these ideas do indeed work correctly in the design of putters. This work was a result of research we did in the process of optimizing the design of the Tech-Line putters.

This is not a putter design manual, nor does it deal with putting technique. We did apply this information to the design of our putter, but that is another long story, of little interest to the average golfer, and much of it is proprietary information.

This report contains hard data on how far past the hole to aim, the size and location of the pattern of hits on a putter face, the effect of lie angle variations, the effect of press angle variations, the importance of milled putter faces and of face balance, and the importance of never deliberately trying to hit elsewhere than the center of the sweet spot. Learning to control putt distance is probably the most important single factor in learning to putt well. Other interesting things are the size and location of typical patterns on the putter face and frequency of scuffing. Dependence is given for many of these things upon Stimp, handicap, and putt distance. Much of this information is given here for the first time.

Introduction

Proper technical design of a putter can make it easier to aim a putt and can minimize certain errors. It can do nothing to assure that the golfer reads the green correctly and makes exactly the swing he wants. While golfers' errors generally predominate, there is no reason to tolerate any



putter errors which can be reduced or eliminated.

Stated otherwise, a professional golfer can putt well with any putter, but still gains a little by using a more accurate putter. Even a very small gain can count for much for a tour pro. Conversely, a duffer can gain much more with a more accurate putter, and needs much more to significantly improve his game. In either case, changing from one putter to another sometimes requires considerable time and practice to adjust to a change in characteristics of a new putter, before its advantages may be realized. Usually the advantages become immediately apparent.

Golfers always try to hit the ball exactly in the center of the sweet spot but can never do this perfectly. A thorough understanding of this problem is the basic starting point for putter design. This reveals much about putting in general.

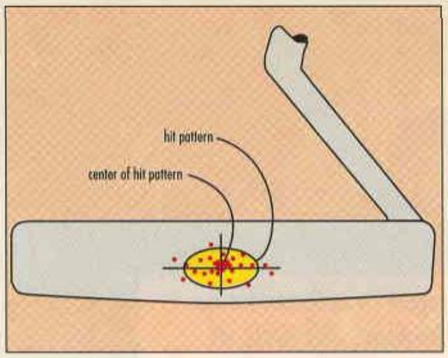


Figure 1. The scatter points on a putter where contact is made with the ball, the "Hit Pattern".

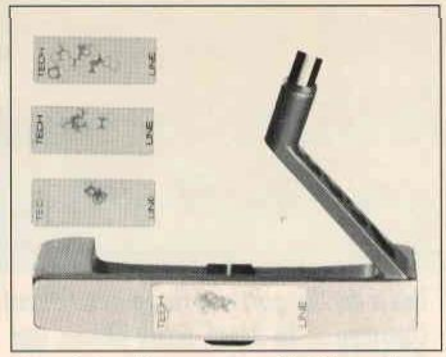


Figure 2. Actual hit patterns, using Tech-Line marking tape.

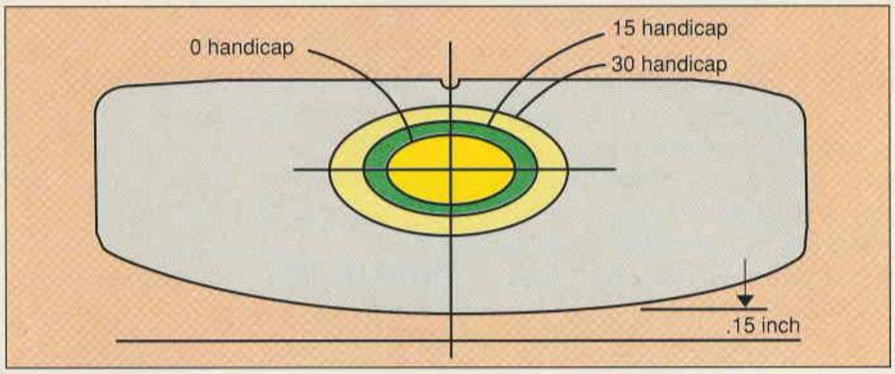


Figure 3. Actual size of the hit pattern for various handicaps. These ellipses contain 99.5% of all hits. For most purposes, it is reasonable to think of them containing nearly all hits. Patterns two thirds these sizes contain 91.1% of hits and one third these sizes contain 46.6% of hits. These are deviations for each pattern about its own center position (see Figure 4).

Golfers' Hitting Errors

The Hit Pattern

Figure 1 shows a front view of a putter and illustrates what happens. Most contact points are close to the center, but some scatter rather widely. In order to study this in detail, we put a special kind of marking tape on the face of a putter and asked a number of golfers of various handicaps to make typically 50 putts each. For each putt, we measured the location of the contact point and recorded it, then cleared the imprint for the next hit.

Figure 2 shows how the actual hit patterns look, when 10 or more hits are made on a single tape. As expected, the best golfers have the smallest patterns. This is an easy and interesting test to make, and Tech Line Hit Tape is available for this use. This test can also be used to adjust Tech Line putters for a "super customizing" process called PAR Fitting, to adjust the putter for each individual golfer.

We used statistical methods to get the most out of this data. This is explained further in Note 1 at the end of this report. Most readers may wish to skip detail in the notes. Figure 3 shows the results. Remember that this figure shows deviations for each pattern about its own center position. Better golfers have distinctly smaller patterns. The figure caption explains how much smaller is the size of the hit patterns if more of the widely scattered hits are disregarded. The hits tend to cluster near the center in a bell-shaped probability curve, but some hits scatter greatly.

While Figure 3 shows average deviations of hits about the center of each pattern, Figure 4 shows how the locations of the centers vary among golfers. This pattern is not a simple elliptical shape as discussed in Note 1. It doesn't vary particularly with handicap. That is, golfers of all handicaps are about equally likely to center their patterns high, low, or toward the toe or heel. As the percentages indicate, very few golfers center their pattern as far out as the outer curve or even the intermediate curve. Not surprisingly, no centers are so high (meaning the putter is low) that they scuff on center hits. A very few, however, are close, but these are the curves for which only .5% of centers lie outside and of these, few fall below the curves, most of the .5% falling in other directions. (The up-down scatter follows a curve which actually gives no points below the scuff line...see Note 1).

Figure 5 shows results when both hit pattern and variations of the center location are considered. This is what a putter designer must consider. The figure caption explains more about how this curve was combined from Figures 3 and 4.

Scuffs were fairly common. We regard this data as preliminary. Even though the figure shows a very few scuffs for good golfers (poor golfers have many more), most are so slight they are not noticed. In taking this data, we measured each point immediately after it was made. These measurements revealed scuffs immediately. After each set of tests was completed, we asked the subject if any scuffs were felt. In all but a very few cases, they were not felt. This confirms our observation that light scuffs aren't noticed, even though at least a small distance penalty must result. We intend to study scuffs and their effect on distance much more completely, time permitting.

The center of the curves show that clearance above the ground averaged .15 inch and didn't depend much on handicap. This is interesting, because most golfers have only a vague idea how much clearance they have, since they can't see nor feel it. This is different from other clubs where swinging too high or too low gives obvious signals to the golfer.

There are 4 numbers needed to describe an individual's hit pattern: its width, its height, the toe-heel location of its center, and the up-down location of its center.

The Hole Zone

We needed to know the importance of errors in distance and the importance of lateral errors. To find out, we rolled many balls down a ramp which controlled its speed, onto several flat, level greens. We took care to use several directions to allow us to nullify the effect of grain or slight slope. We developed an equation (Note 2) which fairly accurately related the distance each ball rolled to the speed at the bottom of the ramp and to the Stimp reading of the green. With the ramp just a few inches from the edge of the hole, we aimed at the center of the hole and raised the speed until the ball would just fail to drop into the hole and recorded this speed. We aimed slightly to the side and repeated this. We continued the process until we reached the edge of the cup. The distance equation then allowed us to convert these measurements of speed into the distance each ball would have rolled, had the hole been smoothly covered.

When we studied the data, we were surprised to find that the effective diameter of the hole is much larger when the Stimp reading is low. An equation which represents this effect is given in Note 3. Table 1 shows the effective diameter of the cup at various Stimp readings and the amount of increase over the basic cup diameter, based on this equation.

The reason for this effect is easy to imagine. When the grass is deep and slow, and the ball is rolling very slowly near the edge of the cup, there are fewer blades supporting the ball on the side nearest the hole, so it tends to move toward the hole. When the green is fast , the ball sinks into the grass very little and this effect is much reduced. This data is for bent grass. Bermuda grass may be somewhat different. It is a factor making putting a bit easier for slow greens than would otherwise be the case.

Figure 6 shows the results of the distance measurements and the small effect of the varying effective diameter of the hole. We call this the "Hole Zone". The Stimp reading has a large effect, and we found that the length of the hole zone was proportional to Stimp. We also have an equation for this curve, which is a parabola with a small error function to sharpen the tip end. This figure shows on the right that very short putts broaden the hole zone, helping to make shorter putts easier.

Figure 7 shows how uphill, downhill, and sidehill putts affect the hole zone. This is only indicat-

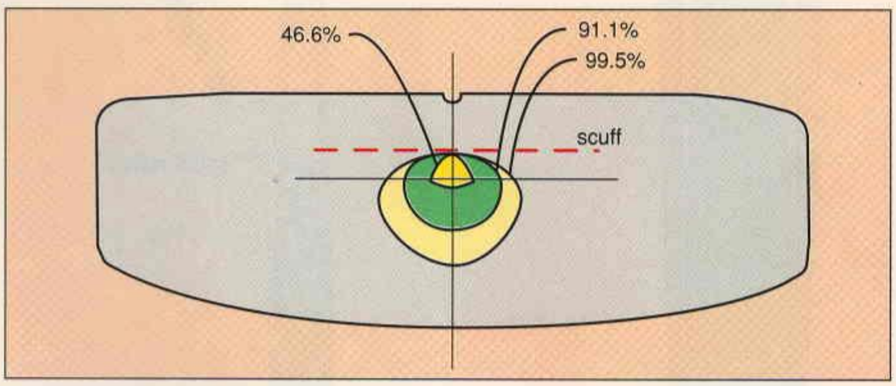


Figure 4. Each individual golfer centers his hit pattern (Figure 3) at some location, depending on his habits. These curves show how this varies among individuals. The percentages indicated show the portion of centers which are inside of each curve. They illustrate that very few golfers center their patterns as far off as shown by the outer curve. Handicap has little effect on these curves.

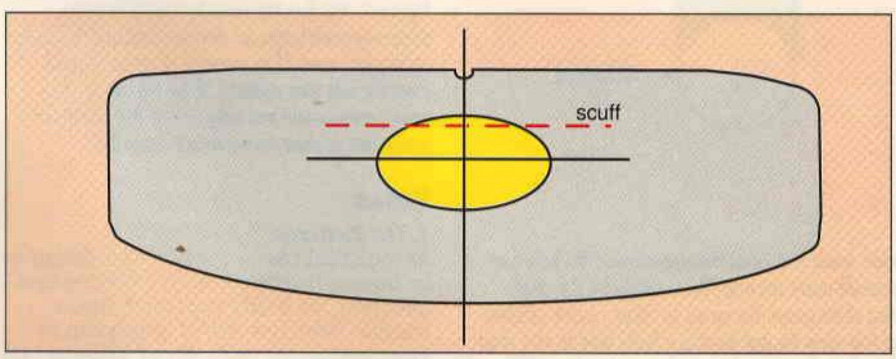


Figure 5. This curve shows the result when variations of both size and location of the patterns are included. It is for 91.1% of hits for 15 handicap and thus combines the middle curve of Figure 4 with two-thirds size of the middle curve of Figure 3. It shows that slight scuffs, probably rarely felt, are not unusual.

Table 1.
Effective Hole Diameter is larger on slow greens

Stimp	Diameter	Increase
∞	4.25	.0
15	4.51	.26
12	4.57	.32
9	4.68	.43
6	4.89	.64
3	5.53	1.28

ed to show trends. The effects of slope of the green were not evaluated experimentally.

The hole zones are interesting in themselves, but their real value is that they provide an essential part of the information we need in order to calculate something of direct interest and utility. This is the optimum distance past the hole at which a golfer should plan for his ball to stop if the hole were absent, which we call the "Aim Point".

Part II of this report will appear in the next issue of The Golfsmith Clubmaker

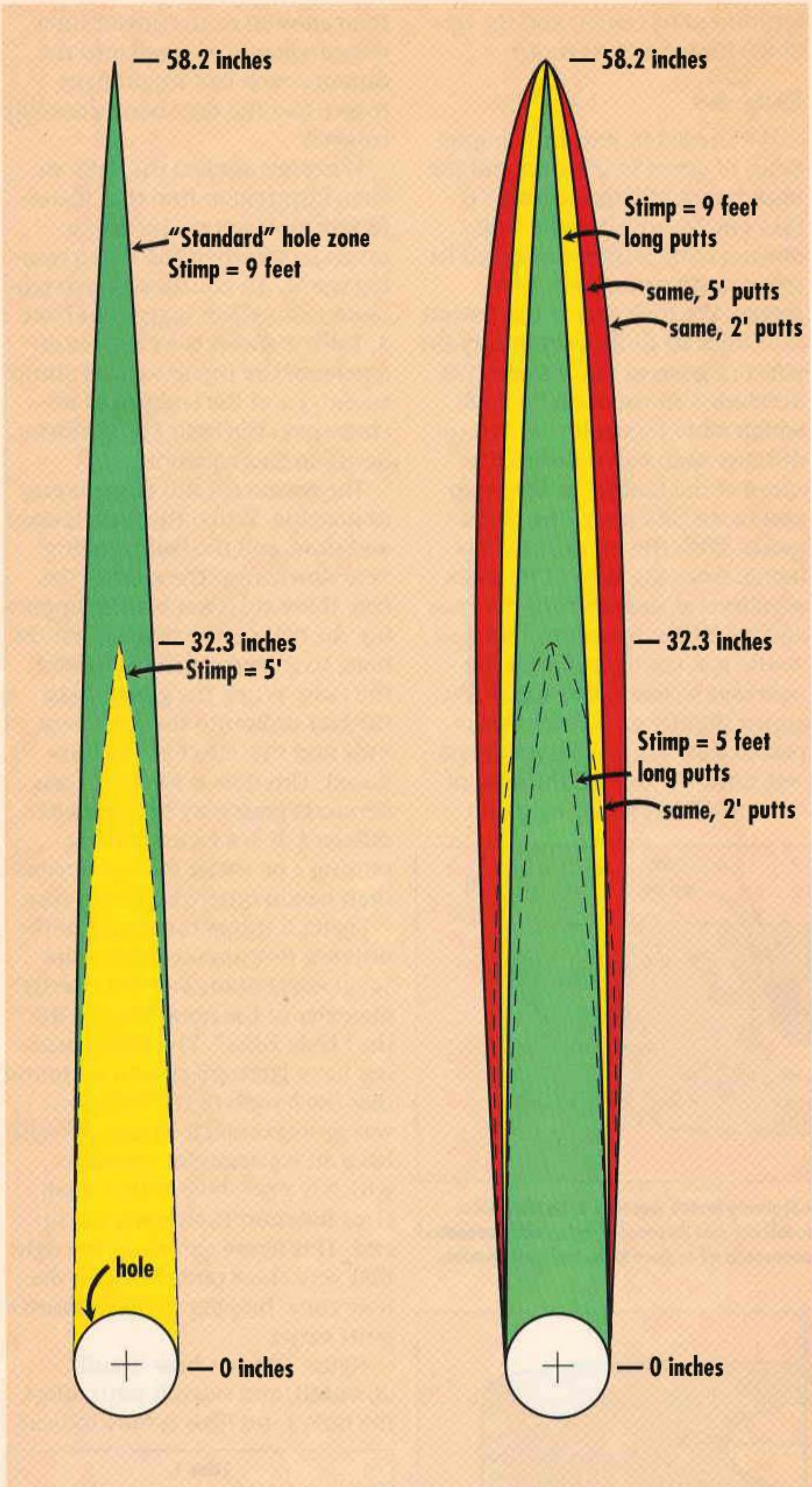


Figure 6. The "Hole Zone". Refer to the left drawing. Putts which would stop inside these envelopes if the hole were covered, would drop when the hole is present. Those stopping outside would not drop. This is strictly for flat, level greens. The hole zone length is proportional to the Stimp reading of the green. The curves for Stimp reading of 9 feet and for 5 feet clearly show this effect. The right drawing shows that when the putt distance is fairly short or very short, the hole zone becomes wider as the outer contours indicate. This effect disappears for putts longer than 10 or 12 feet. As the curves show, putts can go a remarkable 58.2 inches past the hole for Stimp+9, if they are on dead center, but much less if even slightly to the side.

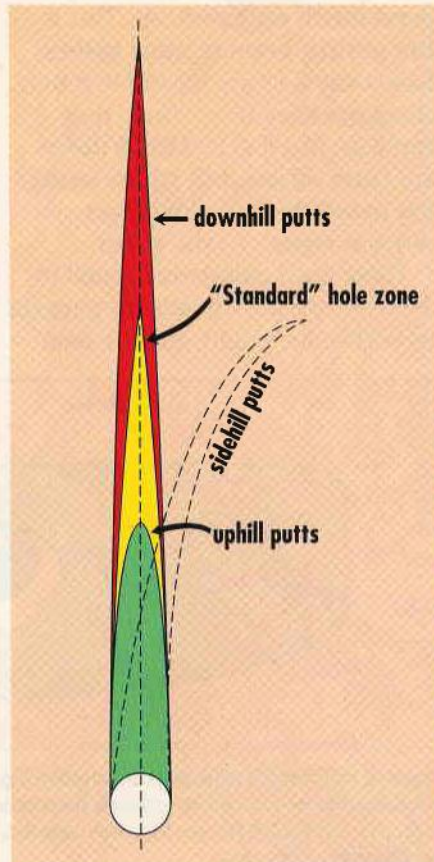


Figure 7. This drawing shows how the hole zone is effectively much longer for downhill putts and shorter for uphill putts, as would be expected. Also, sidehill putts curve the hole zone sideways. These are not based on actual measurement and analysis as in the case of flat greens, but do show the trends to be expected.

Notes

1. Hit Patterns.

In statistical terms, the hits were found to be normal distributions. For the toe-heel direction, we found that the 3-sigma fraction (which is .9973) of hits can be expressed mathematically as .606+.0174H inches, where H is the handicap. A similar equation for up-down hits is .312+.0101H. Accordingly for handi-

caps of 0,15, and 30, respective widths of the ellipse are .607, .868, and 1.129 inches. Respective heights are .312, .463, and .614. These 3-sigma ellipses include .9973A2, or 99.46% of the hits.
In the toe-heel direction the centers of the hit patterns averaged .054 inches toward the toe, a nearly negligible amount. A width of .65 inch included the 3-sigma fraction of centers of hit patterns. In the up-down direction, 99.73% of the centers were within a band .51 inch high. Toe-heel scatter was a normal distribution; clearance was a gamma distribution. Neither correlated significantly with handicap.

It was interesting that the mean clearance of the bottom of the putter from the ground was .15 inch, which depended little upon handicap. By "ground" is meant the level slightly below the tips of the grass at which the bottom of the ball rests.

2. Distance Equation.
The distance equation is: (distance in feet) = .04771~(Stimp reading in feet)~(velocity in feet per second) Al.595. This is true for all kinds of grass on the putting green provided the Stimp reading is known. We believe it depends very little on the kind of golf ball, though this would be interesting to study further.

3. Hole Diameter.
The equation for effective hole diameter is: (diameter in inches) = 4.25+3.85 /(Stimp reading in feet). It appears to fit the data well for Stimp readings above 3 to 5. It would not fit well for much lower Stimp readings, but that is not important in golf.

4. Stop Zone.
Distance and lateral variations were normal distributions. The 3-sigma stop zone dimensions were, respectively: (3.86 + .123H)L and (2.16 + .0049H)L inches, where L is the putt distance in feet. Thus for 10 foot putts, lengths were 38.6, 57.1, and 75.5 and widths were 21.6, 22.3, and 23.1 inches. As mentioned in the text, these curves were very nearly true elliptical shapes when the length is less than a few percent of the putt distance, such as for smaller sigma values or lower handicaps. We treated them as ellipses. A refinement which would alter results very little would be to express them in the equations of an ellipse, but in polar coordinates. That is, replace x"2 with (radius*theta)^2 and y^2 with (radius)^2. We expect this might reduce the aim point distances by only an inch or two, even for long putts.

5. Video.
A 6-minute video is available, showing the putting machine and the two demonstration machines in action.

About the Authors

Frank Werner has a degree in physics, and graduate degrees in aeronautical engineering, including the PhD. He began technical work at The Johns Hopkins University's Applied Physics Laboratory during World War II on the anti-aircraft proximity fuse, then spent a number of years in aeronautical instrumentation research at the University of Minnesota's Aeronautical Research Laboratories. After completing his graduate work, he founded Rosemount Inc., an instrumentation company specializing in measuring instruments, which is now one of the largest in the world in instrumentation and control. After he left that firm, he formed Origin Inc, a product development firm which, among other things, has done much of the research behind Tech-Line putters. He has been a prolific inventor with some 70 patents.

Dick Greig has bachelor's and master's degrees in aeronautical engineering, and has completed the course work for his PhD, with a strong minor in math. He has spent the past 20 years with Origin Inc. involved in a wide variety of product research and development. He also has a number of patents.

Both have been involved in analysis and design of golf putters during much of their time for the past 5 or 6 years. They are respectively, Chairman and president of Tech-Line Corp., developers and manufacturers of the Tech-Line putter line.

May/June '92

Part II

Golf Putters and Technology

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This is the second part of a four-part serialized report co-authored the Chairman of the Board, Frank Werner, and President, Dick Grieg of the Techline Putter Corporation.

The aim point is very difficult to evaluate by putting on an actual green, because of unavoidable variations of greens and balls, even when a precision putting machine is used to start the ball off in a controlled roll. Reasonably accurate mathematical analysis such as we have done allows such comparisons to be done quickly, and reveals the importance of even very slight variations in putter designs, which would be extremely difficult to detect on an actual green.

Stop Zone

We needed to know actual golfers' lateral and distance errors, which we call the "Stop Zone", so we had a number of golfers aim at a target with no hole present. We found such errors depended on handicap and putt length, but not on Stimp reading. We used math to remove putter effects so that the results were as if every putt was made exactly on the center of the sweet spot. Lateral and distance errors still remained.

Figure 8 shows the result. Its caption explains more detail. The curves show that the main difference between good and poor golfers is control of the distance of the putt. The curves are egg shaped or pear shaped, but far less so when errors are less (for example, better golfers, or curves including a much lower percentage of the points). They become very close to perfect elliptical shapes.

Figure 9 shows how the stop zone and the hole zone combine to allow study of the success in putting. Three different putt distances are illustrated. For each handicap level, the stop zones were adjusted to center farther or closer to the hole so as to minimize the number of putts to hole out. These small adjustments can be seen by comparing the curves in Figure 9.

Aim Point

Calculating the Aim Point

The hole zone combined with the stop zone as shown in Figure 9 allowed us to find the optimum aim point for minimum strokes to hole out under any flat-green conditions we chose. Results from short putts were used for longer putts which missed to determine their total putts. Interestingly, for high handicaps and very long putts, we could get 3 and even 4 putts to hole out.

We programmed a computer to putt out for flat greens, based on this understanding of golfers' putting. We had computers do this for days on end, automatically finding how far past the hole to hit for the least strokes for sinking putts, with full consideration to the makeability of the next putt(s) if the first failed. This distance past

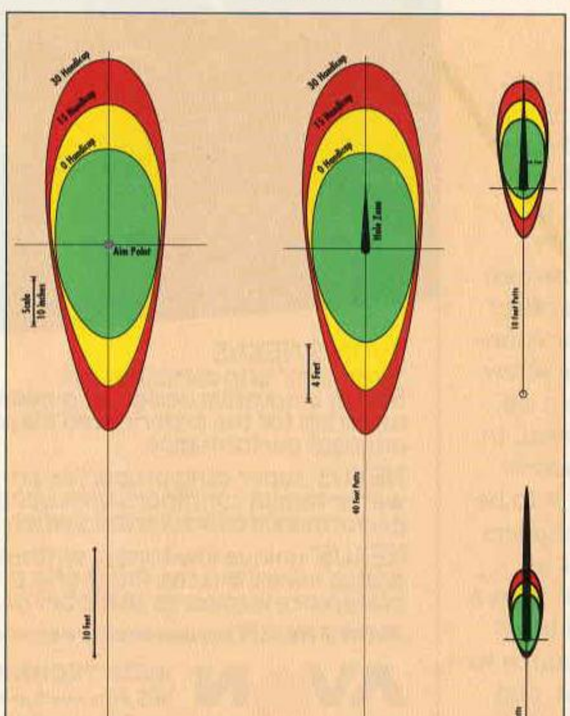


Figure 8. The "Stop Zone". Putts intended to stop at a point 10 feet away on a flat green will scatter as shown. These curves contain 99.5% of points we measured. Curves two thirds the length and width contain 91.1% of points and one third as large contain 46.6%. All dimensions grow in proportion to putt length. Stimp has little effect. When the size as a percentage of putt distance is reduced, these curves become much less egg-shaped and very near true elliptical shapes. Control of distance is the main thing which separates low and high handicap golfers.

Figure 9. Stop zones for various putt distances and handicaps, with distance beyond the hole adjusted for each handicap so as to minimize the number of putts to hole out. The black shape is the hole zone for Stimp 9 as explained in Figure 6. Putts which stop within, drop; those outside require 1 or more additional putts. These curves are smaller scale versions of Figure 8, except for the fundamental difference that for each handicap, the center of each curve has been moved toward or away from the golfer so as to achieve minimum putts. Careful comparison for the 3 putt distances will reveal these differences.

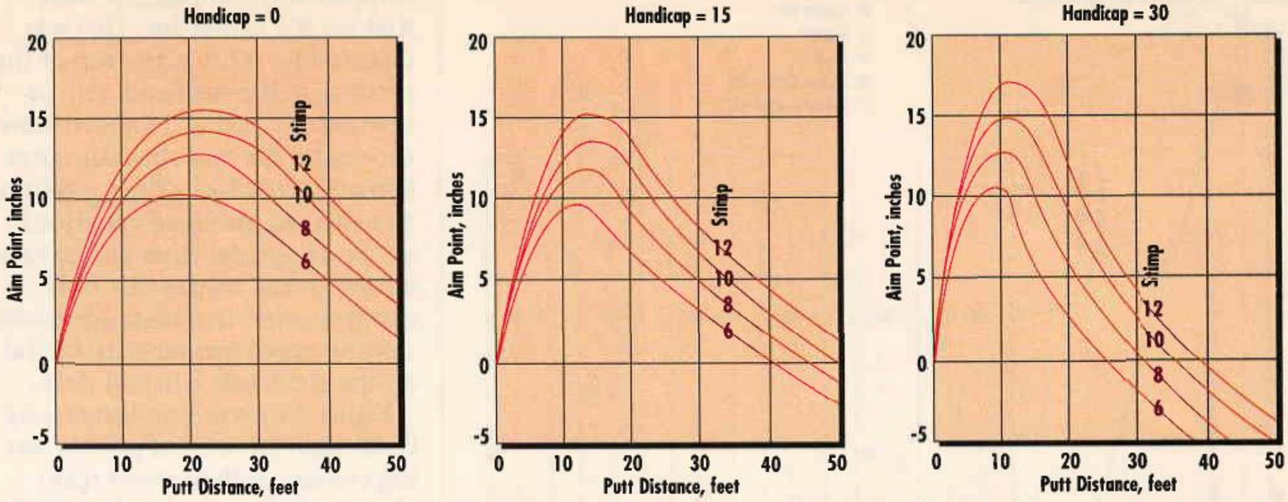


Figure 10. The "Aim Point". This is the best distance to aim (the point where the ball should stop). It represents inches beyond the center of the cup, though in a few cases it may short of the center (negative). It varies with the Stimp reading and handicap as shown. This data is for a flat, level green.

the center of the hole where you want the ball to stop is what we named the "Aim Point".

Figure 10 shows the result. It is not much different from what may be expected. It does have some useful, previously unknown information as to how the aim point changes with distance, Stimp reading, and handicap.

It appears surprising that negative aim points can happen for high handicap golfers. We finally realized that it is because some of their putts spread out laterally so much that if going very far beyond the hole, the distance for the next putt is considerably more than if equally short of the hole. This is related to the fact that very few of their first long putts are successful. It is important to know that even though this effect looks large on the graph for a 30 handicapper, at 40 feet, 3 inches short is only 0.6% of the distance, pretty close to negligible.

These aim point results are in reasonable agreement with the very extensive and careful studies reported in Reference 2, though our aim points are a little shorter, and much more detailed. A basic difference is that Reference 2 maximized the probability of success on a given putt, whereas we minimized the number of putts to hole out. That is, we gave consideration to the success of the remaining putts (if any) needed to hole out, as well as accuracy on the first putt. This is correct because, after all, it is the total number of strokes which matters.

Useful Rules

0-handicap golfers might remember to aim 7 inches past the hole for 5 foot putts, 13 inches past for 20 foot putts, then diminishing to 7 inches past for 40 foot putts.

15-handicap golfers might remember to aim 9 inches past the hole for 5 foot putts, 13 inches past for 15 foot putts, then diminishing to 3 inches past for 40 foot putts.

30-handicap golfers might remember to aim 12 inches past for 5 foot putts, 14 inches past for 10 foot putts, then diminishing to 3 inches *short* of the hole for 40 foot putts.

For all handicaps estimate intermediate aim point distances. Add about 10% for very fast greens and deduct about 10% for very slow greens. Reduce the amounts for uphill putts and increase them for downhill putts.

From Putter Head to Target

We carefully worked out the general mathematical relations for impact of a putter and golf ball. This is much too complex to give here. It gives us the speed, direction, and rate of spin of the golf ball, and shows how it depends on the weight (more accurately, "mass") of the ball and putter, the head speed; the distribution of weight in the putter head, the loft angle of the head, the angular orientation of the head and the direction of its motion, and where contact is made on the putter face. Our putting machine, described in Appendix A confirmed the accuracy of these calculations.

Following impact, we calculated how far the ball would fly, then how far it would slide before it became pure rolling motion, and from the distance equation mentioned earlier, we could find out how far it went after pure rolling commenced.

A very useful result is given in Table 2. It shows that a small change in the location of the hit far from the center of the sweet spot has a far greater effect on distance than a small change at or near the center of the sweet spot. Thus a golfer should know the sweet spot location accurately and never try to hit on some other part of the face.

Accuracy Ratings

We used many of the same mathematical relations which we applied to the aim point to arrive at our "Accuracy Rating". We assumed that center hits were aligned with the aim mark or line on a putter, or lacking one, we assumed midway

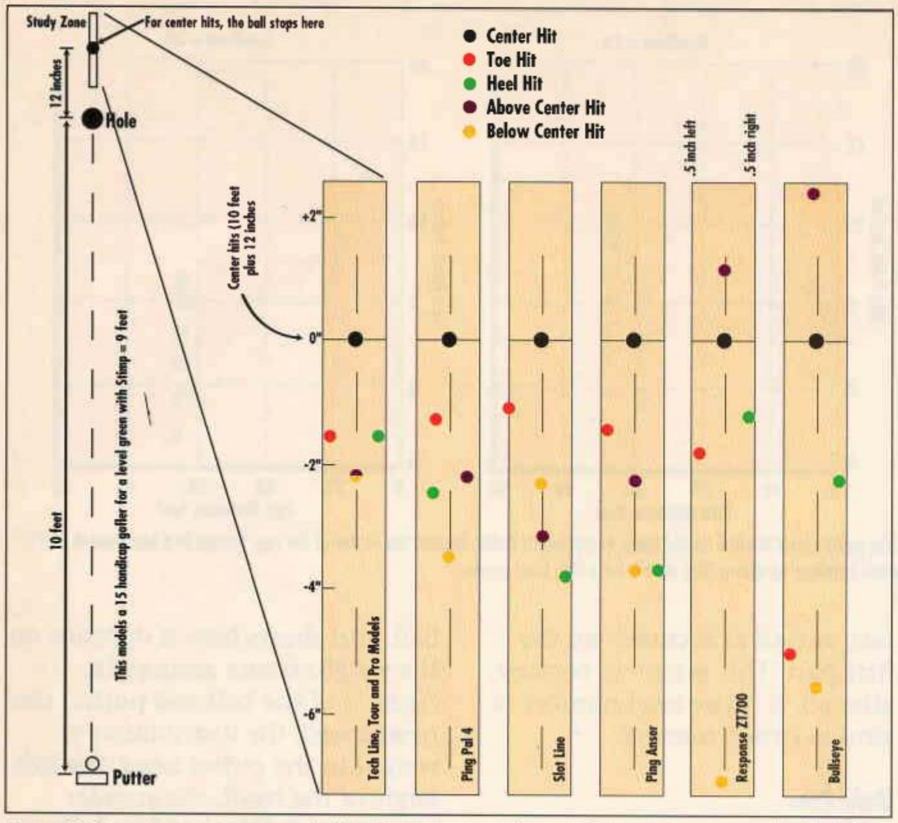


Figure 11. Dispersion or scatter patterns for hits at various points on the putter face on various putters, when hit by the putting machine. This represents scatter due only to his hit pattern for a typical 15 handicap golfer on a flat, level green with Stimp = 9. It is as if he had no errors in his swing or alignment. The accuracy rating is derived from this data. The circles show where the ball would stop rolling if the hole were absent. What is particularly important is the dispersion of the hits at toe, heel, up, and down from all the black central hit.

between toe and heel. We assumed The putter ground clearance was .15 inch as revealed by our study of hit patterns. We adjusted head speed precisely, so that center hits caused the ball to stop at exactly the desired aim point. For simplicity, we assumed 15 handicap and Stimp = 9 feet. Other handicaps or Stimp readings affect our numerical results but have little effect on the relative ranking of putters.

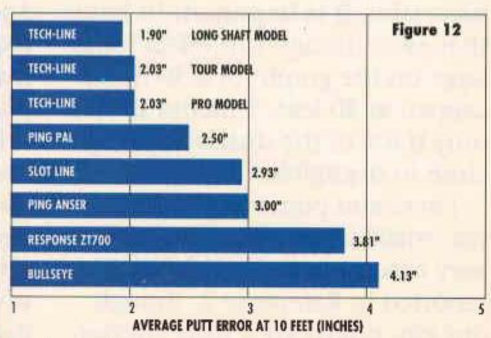
Next, we assumed hits at the toe end of the hit pattern for a 15 handicap golfer as shown on Figure 3 that appeared in Part I. We calculated the ball's distance and lateral position when it stopped and compared it with that for the center hit. This was repeated for a hit at the top of the pattern, at the heel end, and at the bottom. Figure 11 shows how the center hit plus the four outer hits affect the ball's final position. As expected, distance variations are much greater than lateral variations, but of course, the hole zones showed that distance errors may be much greater than lateral errors and a putt will still drop.

Figure 11 reveals an interesting basic characteristic of putters having centers of their sweet spots above or below the location of the center hits. Notice that a hit at the top of the hit pattern (purple circle) coincides with a hit at the bottom of the hit pattern (gold circle) for the Tech-Line putters. This shows that the center of the sweet spot is at the location of the center hit, half-way between top and bottom of the pattern, as we designed it. The Ping Pal 4 putter has the center of its sweet spot somewhat below the central hit, which is revealed by the bottom hit having a smaller distance penalty than the top hit. The Response ZT700 is the opposite: the center of its sweet spot is rather far above the central hit so a bottom hit is much below and shows a large distance penalty. This is also true of the Bullseye, and both show an additional fact. That is that when the top hit is

Table 2

Variations in putt distance for hits at extremes of hit pattern for 15 handicap, 10 foot putts, Stimp = 9, and Tech Line Model 320 putter. The up-down errors cause much greater variations than toe-heel variations, especially for other putters. Toe hits cause huge variations.

distance from pattern center to sweet spot center (inches)		putt distance penalty at center of pattern (inches)	putt distance variations between a hit at one extreme of the hit pattern and a hit at opposite extreme (inches)	
on center	.0	.00	up-down extremes	.00
up or down	.1	.40	up-down extremes	3.58
up or down	.2	1.57	up-down extremes	7.06
on center	.0	.00	toe-heel extremes	.00
toe or heel	.2	.33	toe-heel extremes	2.82
toe or heel	.4	1.32	toe-heel extremes	5.57
toe or heel	1.0	7.91	toe-heel extremes	12.85
toe or heel	2.0	27.61	toe-heel extremes	19.62



This bar graph condenses each dispersion pattern into a single number, the "Accuracy Rating". It is done by multiplying all lateral deviations from the central hit by 3 because they are about 3 times more important and then squaring all of the lateral and all of the distance deviations (measured in inches), finding their average or mean value and taking its square root. this is a statistical method which considers all deviations but weighs the larger ones more heavily than the smaller ones.

APPENDIX A. The Putting Machine

The putting machine consists of a golf ball hung on a thin polyester string from a high support. A plate was made to which the putter grip could be clamped, and this plate was hinged so as to be able to swing quite freely, allowing the putter to swing about a horizontal axis a little above the top of its grip. The hinge axis was adjustable in the toe-heel and in the up-down directions by micrometer adjustments.

We made provision to pull the putter head back with a string to a fixed location, and provided a latch to release it carefully and repeatably. It was very important to attach this pull back string at the correct place on the putter and to have it carefully aligned with the swing path so that no perceptible vibrations of the putter head nor shaft took place upon release. It is especially important to avoid lateral vibrations of the head. The ball was brought to rest with a special constraint so that when hit, the putter hit it always at precisely the same point. We avoided hitting on a dimple and chose a point between dimples, on a ball having certain areas with rather large spaces between dimples. These precautions eliminate problems with non-circular balls and unbalanced balls, because such factors could not change during our tests.

When testing putters having non-milled faces, lateral errors were sometimes so large due to face waviness, that they much exceeded the lateral errors being measured. It was necessary to machine such putter faces flat before testing in the putting machine.

For a test, with the ball in its constraint, the latch is tripped, allowing the putter to strike the ball. The ball swings out, stops, and returns, as a near-perfect pendulum. We measured how far it swung, and how much to either side of center, with the help of a video camera viewing the extremity of the ball travel against a background measurement grid. The distance on the grid allowed the ball velocity to be calculated with precision. The side-to-side position of the extremity of the swing reveals lateral deviations of the ball path.

All uncertainties of variations in a putting green, in the golf ball construction, weather, and human variations are completely avoided. Tests could be repeated with great precision.

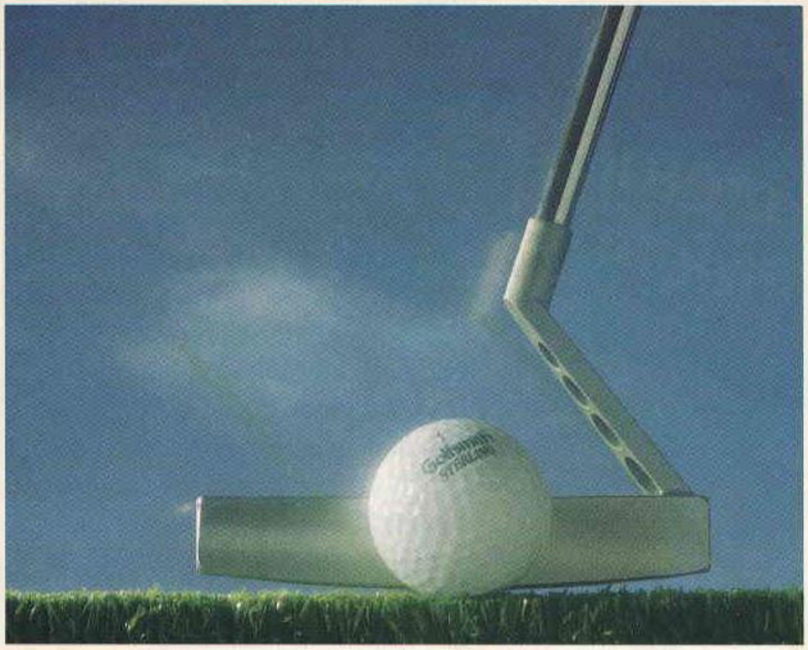
closer to the center of the sweet spot than the all-black center hit, they go farther than a central hit.

After we had the data on dispersion of these 4 extreme hits from the central hit, we tabulated the differences in distance and in lateral position for each of the perimeter hits from the central hits. From hole zone proportions, we were able to show for flat putts, that lateral errors are 6.56 times more important than distance errors. Distance errors become much more important for putts which break to either side. We arbitrarily multiplied all lateral errors by 3 rather than 6.56 to allow for this effect. While a change of this multiplier would change our numerical results somewhat, they have little effect on the relative ratings of putters. This puts lateral and distance errors on the same footing. Next, we used a statistical procedure for which we squared all of the adjusted differences, found their mean or average value, and took the square root. This number is the accuracy rating. Fig. 12 shows this result graphically.

As a practical matter, we gained both convenience and accuracy by using our putting machine which is described in Appendix A in place of many of the calculations, when we were comparing with other putters to get the results shown in Fig. 12.

We believe there is a reasonable correlation between acceptance by golfers of various putter designs and their accuracy ratings. That is, those with better ratings tend to be more widely accepted.

Part III of this report will appear in the next issue of The Golfsmith Clubmaker.



Part III

Golf Putters and Technology

by Frank D. Werner and Richard C. Grieg

This is the third part of a four-part serialized report co-authored the Chairman of the Board, Frank Werner, and President, Dick Grieg of the Techline Putter Corporation.

Sweet Spot

The concept of a "sweet spot" has been around for a long time. It is a thoroughly useful concept, suggesting that hitting too far away from its center makes progressively larger errors.

Sometimes the center of the sweet spot is thought of as being directly forward of the center of gravity (cg) of the club head, but that is not generally quite right, even though the cg location has a very strong influence on the location of the center of the sweet spot. Certainly, the cg of the entire club is much higher than the cg of the head and is not close to the sweet spot.

Another statement is that the center of the sweet spot is the "center of percussion" for the putter. Actually, center of percussion applies to perfectly rigid bodies and is not even defined for elastic bodies. During impact, the shaft is most definitely elastic (it bends remarkably freely during the very short time of impact, suggestive of a wet noodle).

The center of percussion concept has often led to the conviction that the center of the sweet spot is the point where the face of the putter can be tapped with minimal vibration sensation at the grip. However, there is no point where a putter, being an elastic body, can be tapped without disturbance being transmitted to the grip. Because the shaft is sufficiently flexible that a putter is not a rigid body, tapping the putter face is not a good guide for finding the toe-heel center, and it definitely does not reveal the up-down location.

Our experience shows that the central markings on most putters do not give a good indication of the center of the sweet spot, since the problem of how to locate it has not been fully understood.

We have never seen a reasonable definition for the sweet spot nor for its center. *We define the center of the sweet spot to be that point which gives maximum distance for a given putter head speed.* This can be located with a putting machine plus limited analysis or with much analysis, but neither is convenient and easy.

At this point, we suggest further examination of Figure 11 and of similar information in Table 2 (Part II). They show that if the center of the sweet spot were not where we have defined it, hits at any of the extremes of the hit pattern (or generally, hits off center) will result in greater deviations from a perfect center hit.

We did find much greater

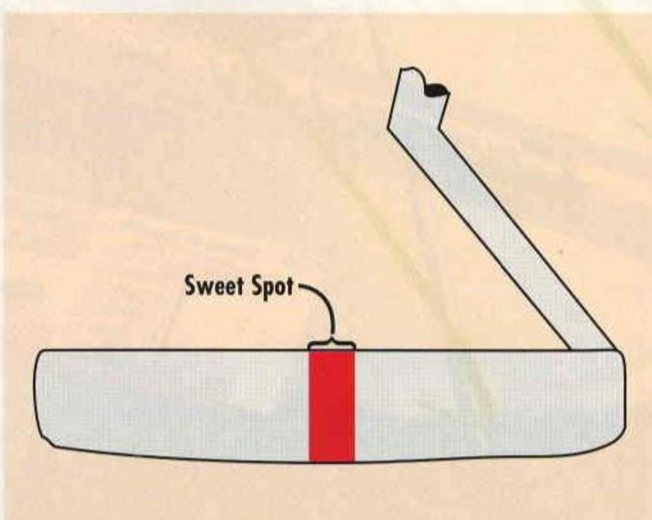


Figure 13. The traditional sweet spot concept. In the up-down direction, it is not defined.

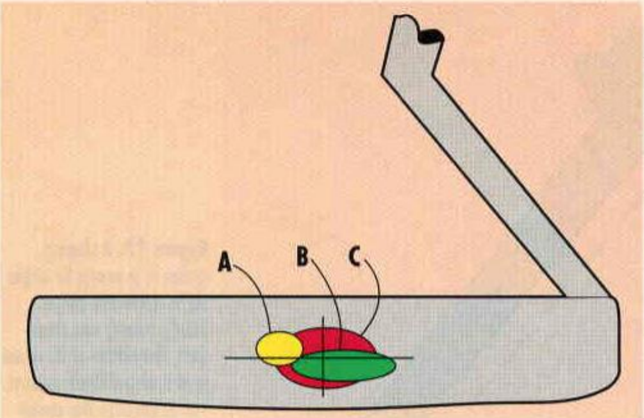


Figure 14. The real nature of the sweet spot. A is typical of a compact putter, B is for a typical toe-heel weighted putter, and C is the Tech-Line putter. In face, even in shape, these are schematic sketches but could be made actual by making an arbitrary definition relating them to the accuracy ratings for each putter. The accuracy rating is the more meaningful description of the merit of a particular putter.

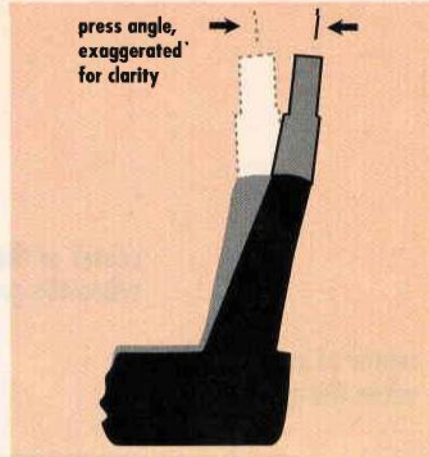


Figure 16. The "Press Angle". Some golfers play the ball to the rear in their stance or have their hands somewhat forward at impact. This tilts the shaft forward, giving a positive press angle, illustrated. A non-zero press angle alters the effective loft angle and the up-down location of the sweet spot. In turn this alters the feel at impact (the "impact feel").

sensitivity to up-down hitting errors than for toe-heel errors, which is thoroughly confirmed by the theory and research we have outlined above. So far as we know, this was the first time serious attention was given to the relatively elusive up-down size and location of the sweet spot. Appropriate treatment of this aspect has been an important innovation in our putter design work.

Figure 13 shows the general idea of the sweet spot for putters. Figure 14 shows more detail. It shows schematically how some sweet spots are wider than others, some are higher, and the center may be variously located toward the toe or heel and upward or downward, 4 variables in all. Even so, only locations of the centers are strictly meaningful in Figure 14. The shape and size of the sweet spot are merely schematic. The accuracy rating is precisely defined and is a more meaningful concept than size of a sweet spot. The size concept has been around so long that it easily conveys a general idea to most golfers. The idea of "size" for a sweet spot will probably stay around.

Other Features

Loft Angle and Press Angle

Figure 15 shows that the point of contact is very dependent on the loft angle. Obviously, for a wedge, contact is very low on the ball and on the face, but a change of 10 degrees changes the point of contact much less than for a low-lofted club like a putter.

Figure 16 shows what we call the "Press Angle". Close consideration shows that rocking the putter forward raises its center of gravity, unless it is a very narrow blade, that is, quite thin from

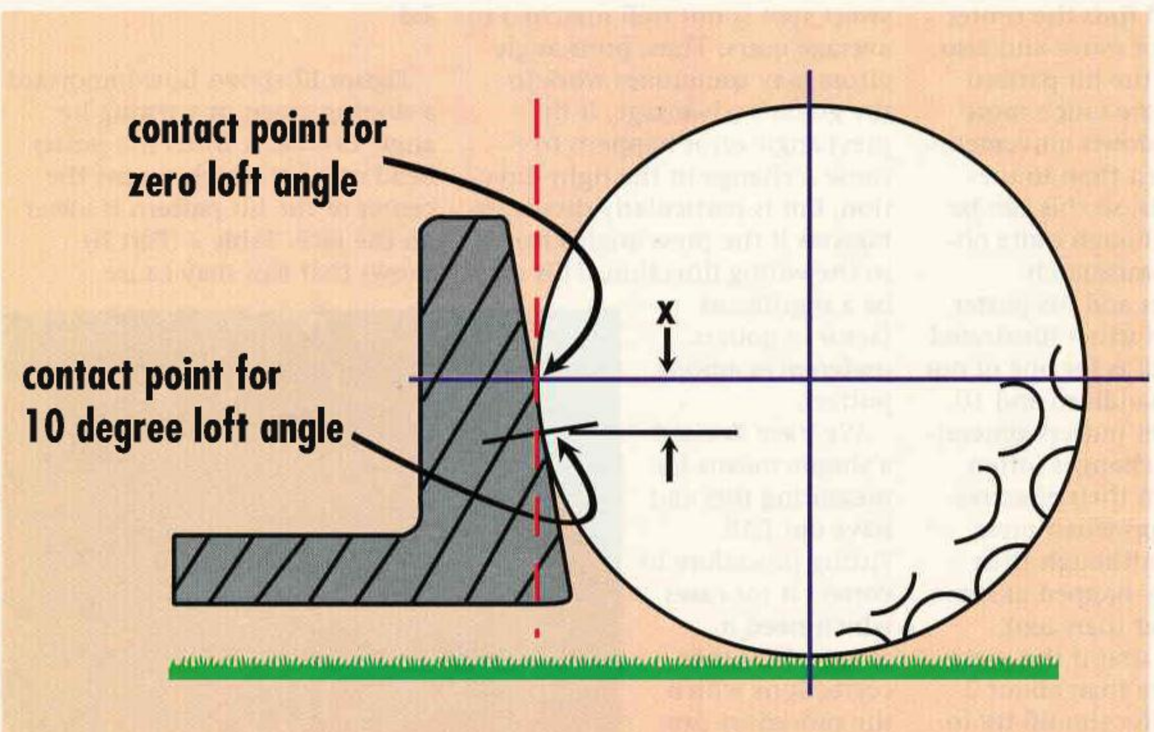


Figure 15. Effect on the loft angle on up-down location of the contact point. A golfer can alter the loft angle of a club, to a new effective loft angle, depending on his press angle (Figure 16).

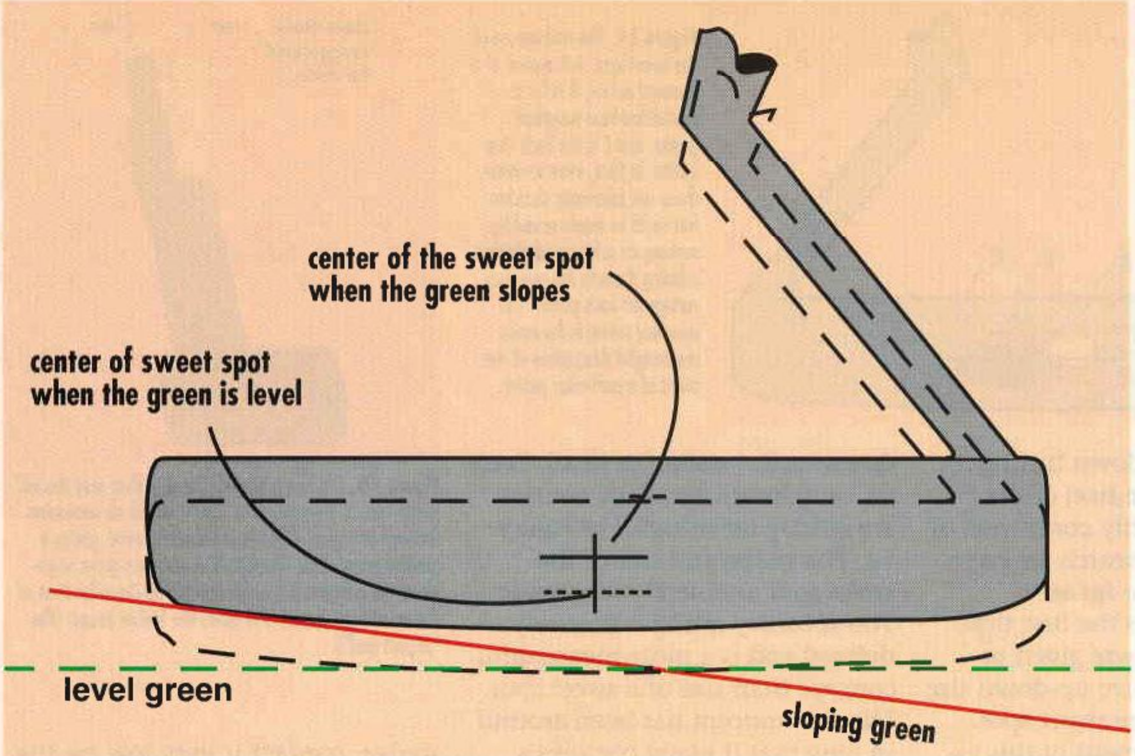


Figure 17. A sloping green or a wrong lie angle shifts the entire putter head upward, and therefore, the center of its sweet spot is also shifted upward. This is because the center of the toe contacts the green in the case shown. The heel does the same thing.

front to back. Also, reference to Figure 15 shows that the contact point moves upward considerably with a small forward rocking (which is a positive press angle).

This makes it clear that changes in the press angle from zero can make important changes in the up-down location of the center of the sweet spot. That is, both the cg and thus the center of the sweet spot move and also the location of the hit pattern moves. Putters are much more sensitive to up-down movements of the hit pattern than to toe-heel movements, so this can be an important, though quite obscure source of mismatch between a golfer and his putter.

This effect is further illustrated in Table 3 which is for one of our putters for 15 handicap and 10-foot putts. Other putters generally have greater changes (often much greater) in their effective Accuracy- Ratings when press angles change, although their best ratings may happen at some press angle other than zero.

We conclude that if the press angle is off more than about 2 degrees, the golfer should try to reduce his press angle, unless by chance, it happens to improve his particular putter. This means for a 36 inch putter, the top of the grip should be no more than about 1.25 inches forward or rearward of the face of the putter at the instant of contact.

Press angle is an important item of mismatch. In most putters, the up-down location of the sweet spot is not well matched to average users. Thus, press angle errors may sometimes work to the golfer's advantage, if the press angle error happens to cause a change in the right direction, but is particularly disadvantageous if the press angle error is in the wrong direction. This may be a significant factor in golfers' preferences among putters.

We have devised a simple means for measuring this and have our PAR Fitting procedure to correct it for cases which need it, along with other corrections which the procedure provides.

So far as we can see, press angles are related to the forward "offset" built into some putters and other clubs. The press angle adjustment seems a much more straightforward way to match a putter to a golfer than trying to choose a putter which has a particular degree of offset built in.

Rail

Figure 17 shows how important a sloping green or a wrong lie angle can be. It shifts the putter head upward which means the center of the hit pattern is lower on the face. Table 2 (Part II) shows that this may cause

Table 3.
Press Angle Affects Putter Accuracy Rating.

Press Angle	Effective Loft	Accuracy Rating
+3	0	2.35
+1	2	2.05
0	3	2.03
-1	4	2.17
-3	6	3.15

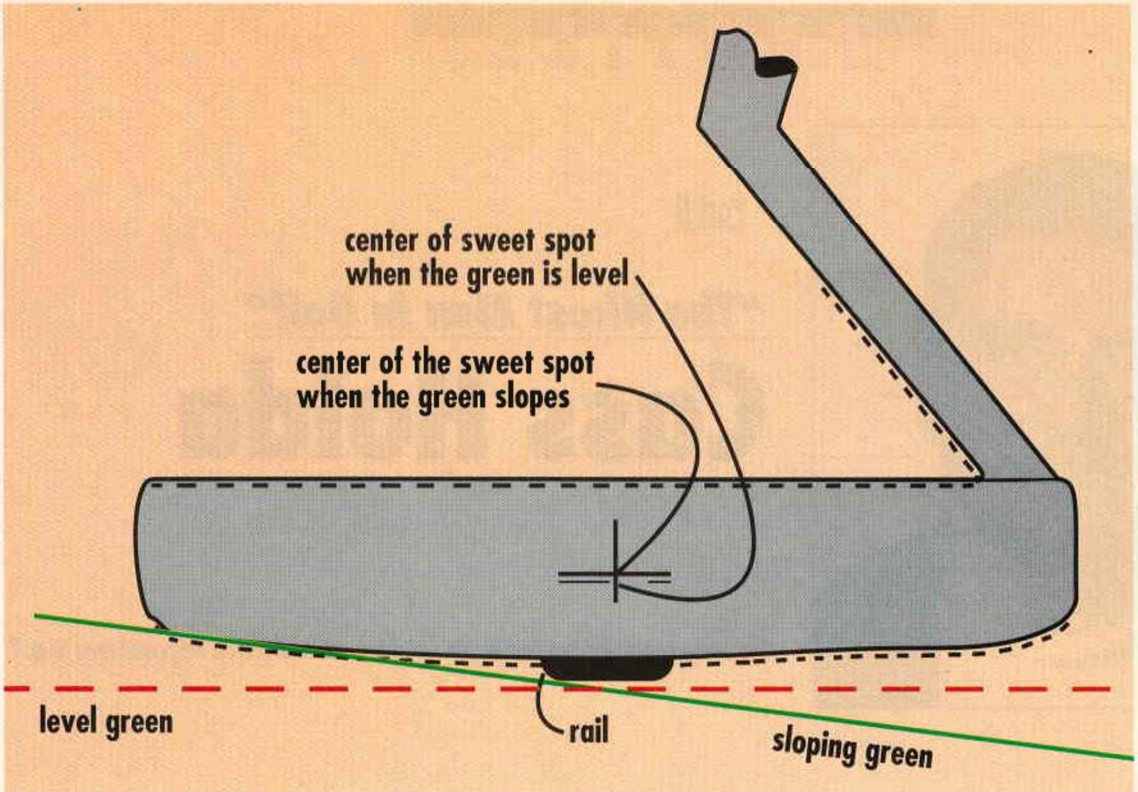


Figure 18. The rail nearly eliminates the upward shift of the sweet spot, because the toe (or the heel) does not contact the green until the slope or lie angle error is extreme. Figures 17 and 18 show that a curved sole is helpful but much inferior to a V-shaped sole or a rail. A flat sole is quite bad.

marked changes both in distance for hits at the center of the pattern, and in variations for hits at extremes of the pattern.

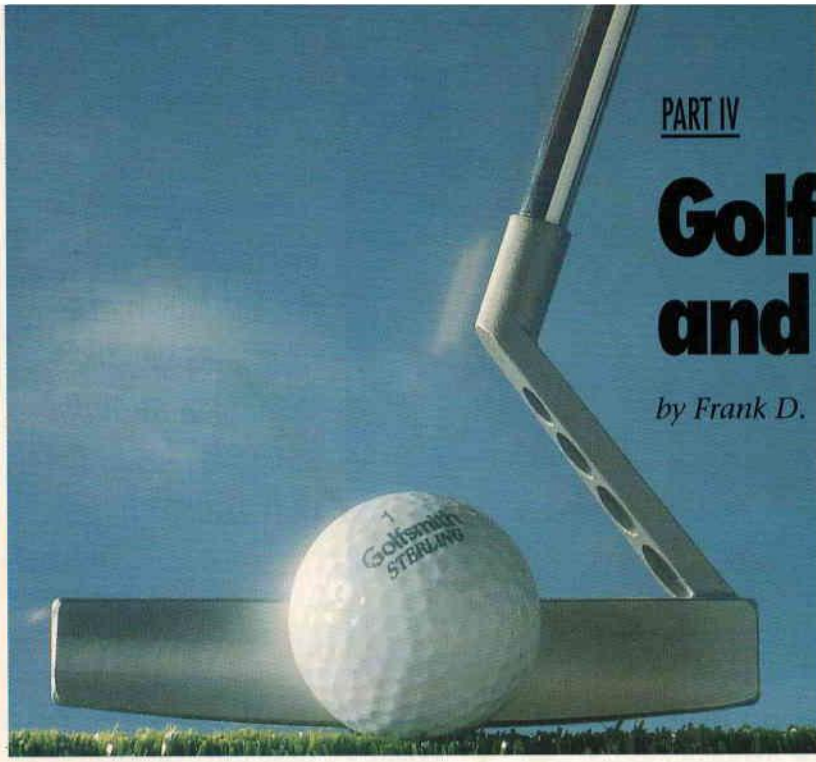
Figure 18 shows how the rail nearly eliminates this effect. A Vee-shaped bottom on the putter could also serve this purpose, but the slippery rail does this with less penalty for a scuff.

These figures also show that the rail nearly eliminates any accidental scuff on the toe or heel. Such scuffs are particularly bad, since they not only slow the head speed but also rotate the club head.

The rail is not just for duffers. While a scratch golfer probably never worries about scuffs, he will have the same up-down movement of the center of the sweet spot as a duffer when putting from a sloping spot on the green (not up or down the slope, but across it). This will have a marked effect on the distance of his putts.

The final installment of this article will appear in the September/October *Golfsmith Clubmaker*.

Sept/Oct '92



PART IV

Golf Putters and Technology

by Frank D. Werner and Richard C. Grieg

This is the final part of a four-part report co-authored by the Chairman of the Board, Frank Werner, and President, Dick Grieg of the Techline Putter Corporation.

Aimer

The Sloping Aim Line

The aim line on our putters is unique among putters. When viewed from above, the aim line is perpendicular (square) to the face as would be expected. When viewed from the toe or heel (if you could see through the putter's end), the aim line is also perpendicular to the face. In math terms, these statements mean simply that it is perpendicular to the plane of the face. Thus, close examination shows that it slopes upward at the loft angle which happens to be 3 degrees.

This aimer arrangement eliminates a visual aiming error which would otherwise exist. Figure 19 will help to explain this. It is a rear view of a 5 iron which shows the effect in exaggerated form because of its higher loft. The aimer peg in the figure serves the identical purpose as the sloping aim line on our putter. It is perpendicular to the face. It is well known and not hard to perceive that if the lie angle is off (toe high as shown), and the lower edge of the club face is used to aim at the target, the ball will travel to the left of the target. The ball leaves the face in a direction nearly perpendicular to the face. Since the aimer peg is also perpendicular to the face, it points very nearly in the ball direction.

Now imagine a top view as for a putting stroke, with eyes directly over the ball. The ball path will be to the left, and the aimer peg will point to the left, as before. Pointing the aimer at the target instead of aiming with the edge of the club face has the desired effect of aiming at the target, correcting the aiming error. A lie angle error in the opposite direction (heel high) has the opposite effect. Again, aiming the aim line at the target is all that is required to correct the error if the eyes are over the ball.

There is no reason to have this error when the sloping aimer can prevent it. This error is greater on

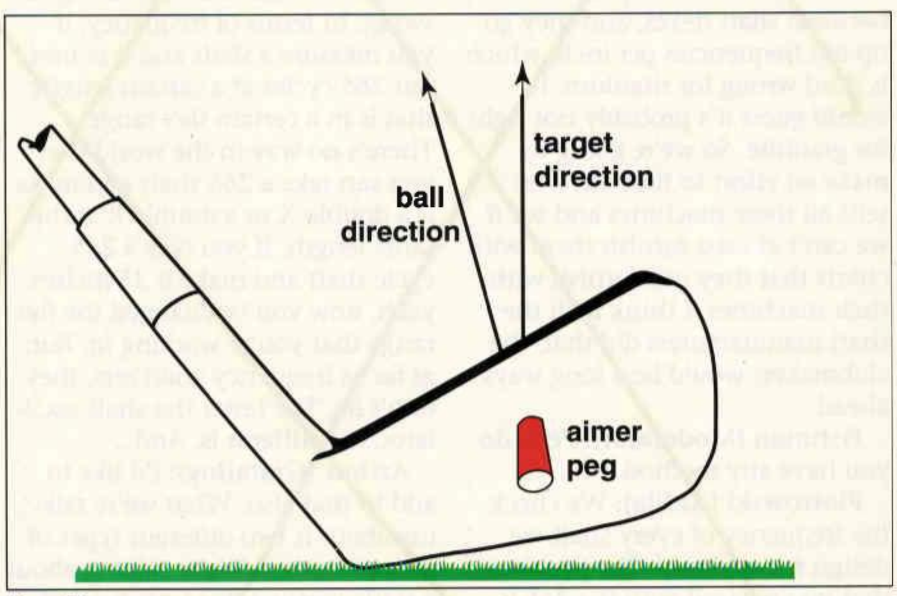


Figure 19
Rear view of a 5 iron with an erroneous lie angle (the toe is up). The ball direction is very nearly perpendicular to the face so the ball goes to left of target when the bottom edge of the putter is used for aiming. The aimer peg is also perpendicular to the face and always points in the ball direction. Viewed from above, with eyes over the ball (if this were a putter), the aimer always points in the ball direction regardless of lie angle, so if such an aimer were present, the golfer should aim it at his target, rather than squaring the sole to the target line. this is how the sloping Tech-Line aimer works (it is perpendicular to the plane of the face).

putters having higher loft angles. For 5 commercially available putters examined, with a 2 degree lie angle error, lateral errors for a 10 foot putt were .26, .29, .40, .51, and .66 inch. Reference to Figure 11 shows that this lateral error can be comparable to or even larger than errors caused by hitting toward the toe or heel.

Length of the Aim Line

The aim line length was chosen with much care. We made a series of lab tests. We mounted an 8-inch diameter white disc on the top of a putter and mounted the bottom of it on a free-turning vertical shaft submerged in the floor. One after another, we put narrow black lines of various lengths on top of the white disc to simulate the front of a putter blade. Then we asked a number of golfers to aim at a fixed target, using each of the different lengths. We had an arrangement to precisely measure the angle they selected.

We repeated this with various lengths of line down to ½ inch. Next we did the same tests with a line perpendicular to the face, (as an aimer or aim line) and asked the golfers to aim his line at the target.

We reduced the data statistically. We disregarded the average angle and paid particular attention to the scatter. A golfer is able to correct for his average pointing error, but his scatter remains as an error. Thus, what we studied was the scatter about the average angle.

From rather limited testing, we concluded that the aim line was a little better than the line along the face. The very short lines clearly didn't serve as well as the longer ones, but beyond about 2 inches, even up to 8 inches, length didn't matter much. For our putter design, 1.5 inch was practical and the data showed that this is nearly as good as a longer aimer.

Other Uses of the Aimer

Many golfers are concerned with keeping the path of the putter on a straight line back and forward through the putt. A little concentration allows a golfer to take advantage of image retention, which is a well known characteristic of human eyesight. The white aim line can be perceived as a white streak after the stroke is completed, showing the path of the putter head. The golfer should strive to keep this as a straight line. With care, it can even reveal any tendency to open or close the club face during the swing because the aim line is prominent enough to show such rotations of the club head.

Face Balance

We were convinced that a putter should be face balanced and a few other manufacturers feel the same. This means that if you lay a putter shaft across the corner of a table, its face should come to rest in approximately a horizontal position. This is because the shaft axis passes through the putter head directly forward of the cg. We decided to investigate the importance of this.

Figure 20 shows how a face balanced putter behaves in comparison with a non-face balanced putter. In a putt, the golfer accelerates the putter head right through contact. In Case B of Figure 20, the putter face will tend to swing to an open position because it is not face balanced. For Case A, the cg is behind the shaft axis and there is

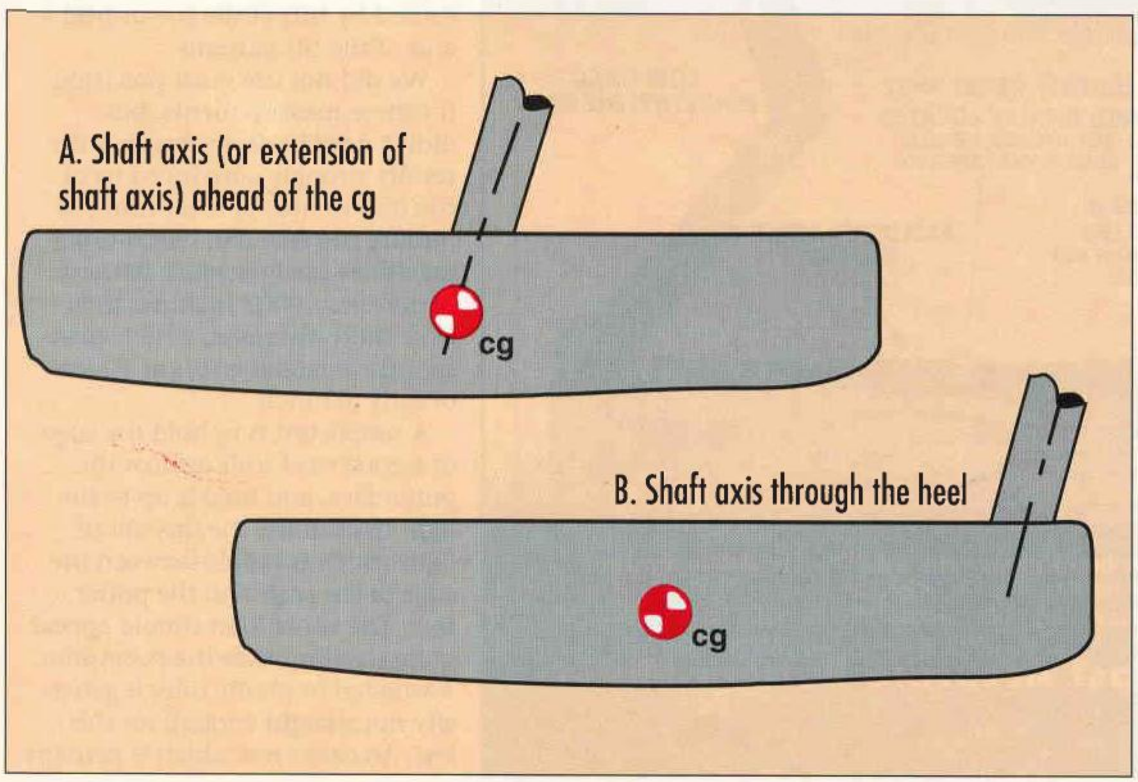


Figure 20
In A, when the golfer accelerates the head to ball contact, there is no tendency for the head to rotate. In B, the heel will tend to lag behind with consequent head rotation. A is called "Face Balanced". B is not face balanced.

no tendency for the putter head to rotate during the putt.

To learn more, we had various golfers grip a putter just as if they were ready to hit. We arranged to give the putter head an almost instantaneous, controlled rotation and measured the angular displacement before the golfer had time to attempt to resist. In this way, we were able to measure the torsional stiffness of the golfer's grip. With the help of movies, we found that those golfers who accelerate gently into contact had low torsional stiffness in their grips. Those who accelerate strongly had high stiffness.

The low stiffness with low acceleration gives about the same angular error as the high stiffness with high acceleration, as might be expected. Face balance is about equally important in each case.

On a long putt, there must be more acceleration of the putter head as compared to a very short putt We didn't study this in detail, but expect that the importance of face balance may vary with length of putts.

We didn't take time to make enough tests for a statistical analysis so that we could give actual numbers for such lateral errors. Since heel-axis putters are widely used with good success, we believe that a highly precise axis location for Case A is not necessary.

We did become convinced that there is no reason a golfer should bother to control this effect. It is an additional, unnecessary variable.

The grip design is also a consideration. In the above, it is assumed that the axis of the grip coincides with the shaft axis, as is usual. Certain grips such as "pistol grips" have an axis which deviates from the shaft axis. In such cases, what is important is where the axis of the grip passes through the putter head. On most of these grips, the grip axis changes if the hands are moved up or down a bit. On the whole, we believe such grips are a complication best avoided.

Face Flatness

We were concerned with learning the importance of flatness of the face of a putter. Many or most investment cast putters are sanded reasonably smooth or even used in an as-cast condition, and their faces are slightly wavy or irregular.

We studied 15 commercially available putters which did not have faces milled flat. We measured the variations of slope in the toe-heel direction on the faces, in the vicinity where most putts are struck. By a simple calculation, we converted the worst of the slope variations for each putter to the lateral errors which would be caused. The following 15 numbers are the various maximum lateral errors in inches for 10 foot putts which we found for these putters: .51, 0,1.02,1.53, .51, .51, 1.53, 2.04, 2.04,1.02, .51, .51, .51,1.02, and 2.55. Comparison with Figure 11 shows that these variations may be much greater than the typical .50 inch lateral deviations caused by hits at the toe or heel end of the hit patterns.

We did not use great precision for these measurements, but didn't need to do so, because the results strongly convinced us of the importance of machining or milling the face flat. Our milling machines easily achieve flatness better than .0002 inch per inch over short distances, which corresponds to lateral errors at 10 feet of only .02 inch.

A simple test is to hold the edge of a good steel scale against the putter face, and hold it up to the light to examine the tiny slit of light which is visible between the edge of the scale and the putter face. The slit of light should appear quite constant near the sweet spot. A wooden or plastic ruler is generally not straight enough for this test. An easier test which is perhaps

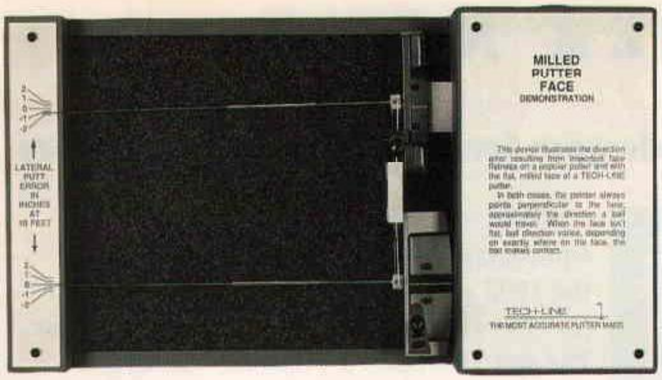


Figure 22. The milled face demonstrator. The two putters are driven to move slowly back and forth. The tiny "roller skates" follow any waviness and the pointer shows the lateral errors for a 10 foot putt. On the unmilled putter face, errors of about 1.5 inch to the side at 10 feel are indicated; on the milled face, lateral errors are negligible.

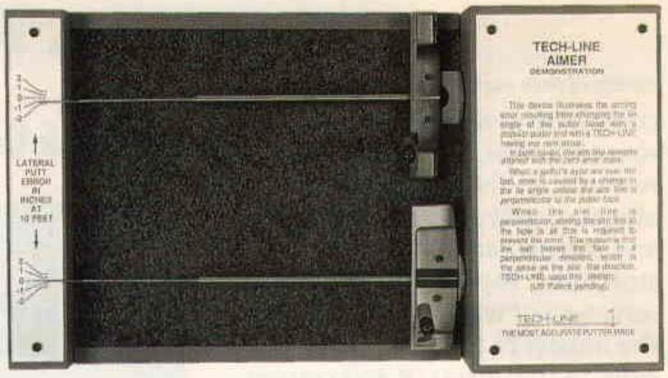


Figure 23. The aimer demonstrator. The two putters rock slowly back and forth so that their lie angles vary from toe-down to heel-down. The pointer is perpendicular to the face in each case, and therefore shows the ball direction. On one putter, the aim line is horizontal and errors of about 1 inch to each side for a 10 foot putt are shown at the tip of the pointer. On the other, the aim line slopes upward slightly, so that it is perpendicular to the face, and when viewed from above, it always points at the target, even when the lie angle varies.

not quite as good, is to hold the putter face up to the light and look at it with nearly grazing incidence in the toe-heel direction. That is, look from heel toward the toe and slowly rotate the toe downward until it nearly disappears. Just before your view of the face disappears altogether, the face of even a fairly rough putter surface will finally reflect light like a mirror. This mirror should not appear wavy. If it doesn't look like a good, flat mirror, the face is not flat. This is mainly important near the center where you make your hits.

Combined Errors

It is important to realize that the Accuracy Rating discussed in Figure 12 is strictly concerned with rating a putter for the best distribution of weight in its head. We have discussed other errors which can be minimized by proper design. Included were errors due to: press angle errors, which can be designed to match each golfers choice in the same way as is done with shaft length or lie angle; sweet spot movement upward due to sloping ground or wrong lie angle; target alignment errors if an aim line perpendicular to the face is not used (assuming eyes over the ball); length of the aim line; face balance (or lack of it); and face flatness.

All of these combine to make a

continued on page 25

Milled Face and Aimer Demonstration Machines

Having a flat face on a putter is remarkably important, as described in the text. Lateral errors for a ten foot putt can be as large as two inches or more if the face is not flat, some four times greater than lateral errors due to hitting rather far from the center of the sweet spot in a toe or heel direction. Precisely milling the face can prevent this almost completely.

Figure 22 is a photo of a machine designed to demonstrate this effect. The two puller heads are motor-driven to travel slowly back and forth. Each has a tiny "roller skate" spring-loaded against its face. Each skate carries a long pointer rod which oscillates back and forth on the scale as the skate passes over uneven areas on the putter face.

One face is a typical, flat-milled putter face. The other is a popular commercially available putter of investment cast bronze, but is sold non-milled, with small casting imperfections still evident upon close inspection.

While the visual impact is largely lost in still photos, the pointer movements of about 1.5 inch error at 10 feet for the non-milled face and 0 for the milled face are realistic indications of the error.

The importance of our sloping aim line which is perpendicular to the putter face was discussed in some detail in the text. We designed a machine similar to the one for milled faces. Figure 23 is a photo of it.

In this case, the two putters are driven to rock slowly back and forth through lie angle variations. The pointers are perpendicular to the faces of the putters. The Tech-Line putter is mounted so that its aim line, when viewed from above is always pointed at the target. Since the aim line is perpendicular to the face and the pointer is also, the pointer doesn't change direction during the rocking motion. The other putter is mounted so that the base of its face is always square to the target. Its aim line is horizontal, so it always points to the target, also. The pointer oscillated back and forth, since the loft angle is not zero. This displays large lateral errors of about 1 inch for a 10 foot putt, unlike the first putter which shows no error.

Again, the visual impact is largely lost in still photos, but the illustrated pointer movements are a realistic indication of the errors avoided by the special aim line.

The Great Shaft Debate

continued from page 15

the help of Lew Fishman, Editor of *Golf Shop Operations* and Chief Technical Editor for *Golf Digest* and *Golf World* magazines, as the moderator. Fishman, who is acknowledged as one of the most respected equipment experts in the industry, had prepared a number of questions for the panel, and they were supplemented by questions from the audience of clubmakers. Time prevented all the clubmakers' questions from reaching the panel (we would have needed another four days), but the questions that were posed were generally appreciated as thought provoking and information producing.

Some of the subjects addressed include:

- The lack of industry standards for measuring flex, torque and length.
- Swingweight as it relates to shafts
- Frequency matching
- Matching of clubs
- Static vs. Dynamic shaft comparisons
- Shaft material differences
- Shaft weights
- Shock absorption qualities of shafts
- Filament winding of continuous fibers
- Seams in graphite shafts and steel shafts
- Shafts and the rules of golf
- Proprietary shafts and replacements
- Heavy graphite shafts
- Rebound rates of shafts
- Range of torque properties in shafts
- Swing speed and tempo as it relates to shafts
- The future of golf shafts
- Grips and their effect on shaft performance
- Parallel vs. taper tip shafts
- Torque and flex relationships
- Head and shaft compatibility

In this issue, a series of articles begins (page 16) that are nearly verbatim (the uuhs and aahs have been deleted) excerpts from the shaft panel discussion. Due to the length of the discussions, the excerpts will be continued in the next several issues of the *Golfsmith Clubmaker*.

Golf Putters and Technology

continued from page 23

good accuracy rating much less important if most or all of these features are not properly treated in the design, or conversely, make a putter having a good accuracy rating actually perform much better than another lacking these other design considerations but having the same accuracy rating. We have been giving thought as to how some or all of these other characteristics could be statistically combined with accuracy rating to give a broader overall rating. This may or may not eventually prove to be practical.

Finally, we should point out that even the very best design which is consistent with USGA rules cannot be expected to make a great improvement in score. If that happened, it would tend to change the nature of the game of golf and USGA has a valid concern with preventing that. Still, a serious golfer is always concerned with even a small improvement and shouldn't tolerate any increase in his score caused by his putter.