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UNIVERSITY OF ALBERTA

A COMPARATIVE EVALUATION OF GOLF PUTTERS ON THE BASIS OF SELECTED IMPACT MEASUREMENTS

BY

KENNETH GILLES RONDEAU ©

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF MASTER OF SCIENCE

DEPARTMENT OF PHYSICAL EDUCATION AND SPORT STUDIES

EDMONTON, ALBERTA

SPRING, 1990

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ISBN 0-315-60193-0

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DEGREE: MASTER OF SCIENCE

YEAR THIS DEGREE GRANTED: SPRING, 1990

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled A COMPARATIVE EVALUATION OF GOLF PUTTERS ON THE BASIS OF SELECTED IMPACT MEASUREMENTS submitted by KENNETH GILLES RONDEAU in partial fulfilment of the requirements for the degree of MASTER OF SCIENCE.

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ABSTRACT

The purpose of the study was to provide a comparative evaluation on the variation of selected putters when struck off the centre of percussion. Testing involved three phases; 1) location of the center of percussion, 2) non human application and 3) subject application.

Location of the center of percussion was determined by striking the putter face and recording impulses on an accelerometer attached to each putter shaft.

Non human application involved a putter stabilizing device which allowed free or restricted rotation about the shaft centerline of the putter head on contact. Each putter was drawn back a specified distance and placed into a release mechanism to allow for consistent velocity for each strike. When released, the putter struck a golf ball which was suspended on a pendulum. The ball travelled over a graphic background and the result was recorded photographically. Two parameters were measured, the distance travelled for each strike and the direction with respect to the intended path.

It was found that the center of percussion on most putters was not located in accordance with the markings placed on the putter by the manufacturer.

Restricted rotation identified a variance in angular

displacement of the putter head when struck off the center of percussion. In all tests the ball travelled along a path perpendicular to the putter face at the position at contact. This was verified with high speed filming.

An unexplained phenomenon that occurred with subjects was an anti-clockwise rotation of the ball for strikes that occurred towards the toe of each putter.

For all tests with off center contact, the ball had left the putter face before rotation of the putter head commenced. In general, there seems to be no real evidence that peripheral weighted putters increase accuracy on ball striking off the center of percussion when there is some form of restricted rotation.

ACKNOWLEDGEMENTS

The author wishes to express his sincere appreciation to his committee members, Dr. R. Macnab, Dr. S. Mendryk and Dr. D. Budney for the patience, guidance and constructive criticism throughout the writing of this thesis.

Special thanks to Dr. P. Smy, Department of Electrical Engineering and his technician Richard Daley for their technical advice and assistance in the high speed filming.

Many thanks to Indoor Golf World who generously donated putters for the testing.

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CHAPTER I

STATEMENT OF THE PROBLEM

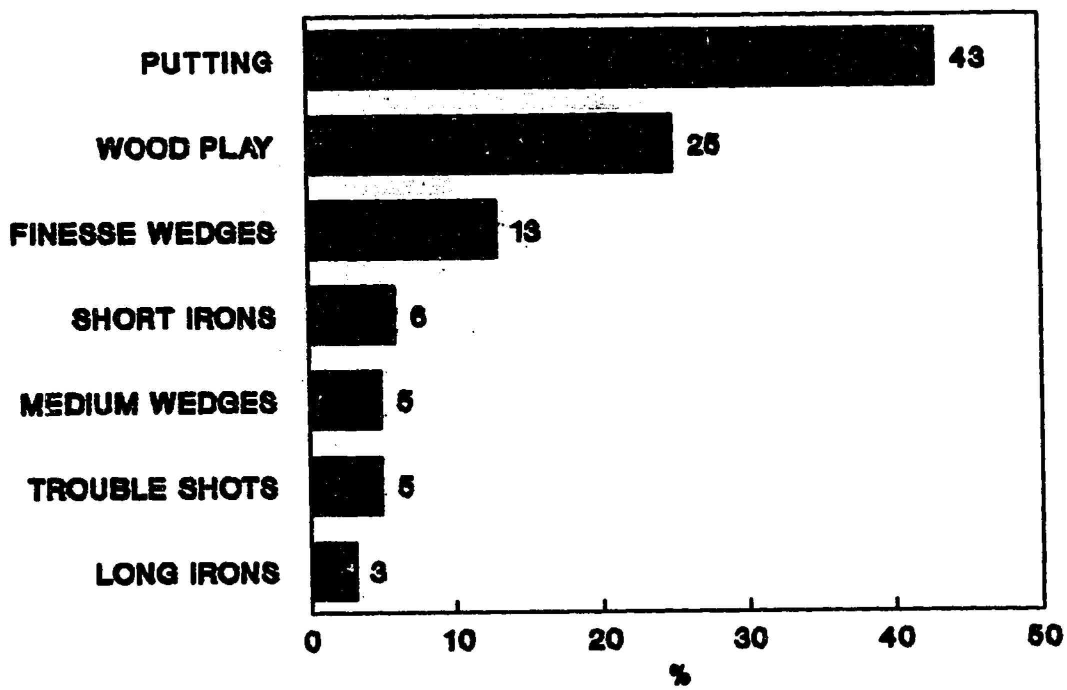
Introduction

Golf is a game which may be broken down into several unique, but related components. One component which is relatively effortless to accomplish, yet considered to be of major importance, is putting. In putting the author suggests three factors are necessary for increasing the rate of success. Various styles may be adopted, but all of these styles require the three essential factors. Various styles can be observed by professionals and amateurs alike.

The three factors 1) keeping the putter face perpendicular to the path of movement, 2) striking the golf ball with the necessary force, and 3) the ability to define and maintain the correct path of movement. Understanding these factors, the putter now becomes the tool required to perform these imperatives.

What is putting? Putting is any stroke made with a putter in which the player uses a normal pendulum stroke (Pelz, 1989). Based on this definition, according to Seitz (1983), putting is 43% of all golf shots that the professional golfers play (Fig. 1).

FIGURE 1: Percentage of various components of the game (adapted from Pelz, 1989).

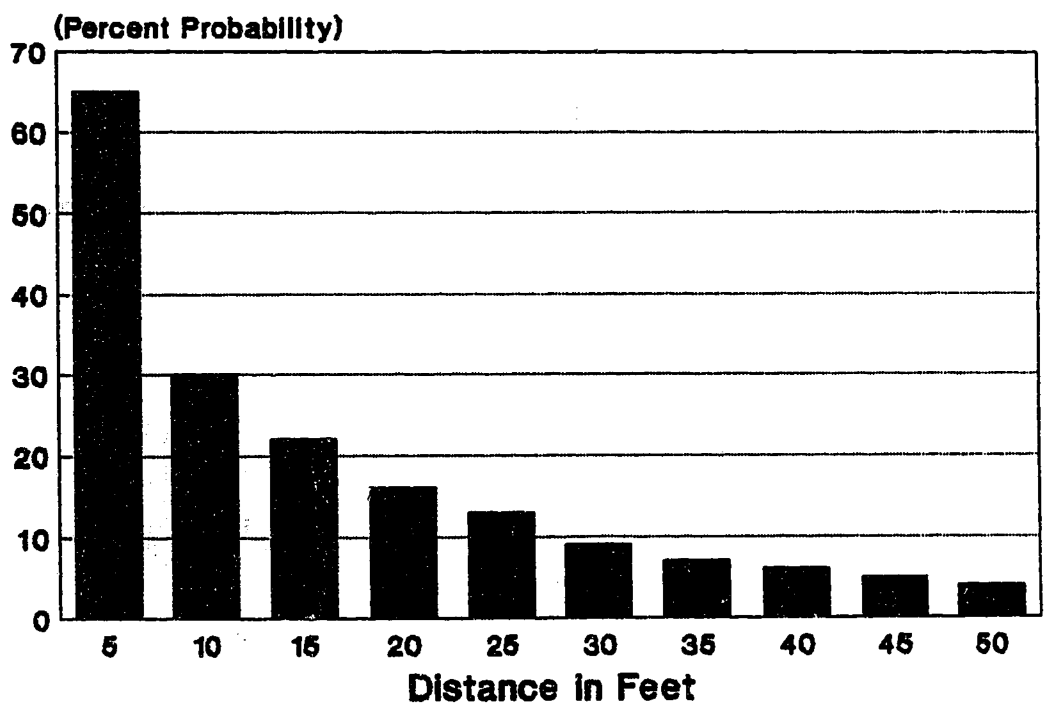


Putting is of vital importance in determining the ultimate score achieved in a round of golf. Professionals who shoot an average score of 70 use approximately 30 strokes with a putter; most 8 handicap players use approximately 35 putting strokes; and the 25 handicappers putt about 38 times per round of golf. Golf courses are structured to allow two putts on each green. Based on an average eighteen-hole golf course, 36 putts or 50% of the total strikes are allowed to maintain par. In fact, if a player happens to be unsuccessful with the initial drive, fairway or chip shot, it is still possible to save par with a good putt, but if a putt is missed the player gains a stoke which can not be eliminated.

A good putt has to have sufficient velocity to have a chance to be successful (Pelz, 1987), but velocity does not always increase success. Variables such as break, grain, spike marks, footprints, wind and rain have an effect on velocity. The influence of outside variables was evident in tests conducted by Pelz on tour professionals. Under perfect conditions, where the ground was flat and the surface smooth, the professionals were successful 99 percent on 3 footers, 85 percent on 6 footers and 70 percent on 10 footers. When tests were conducted on real surfaces with irregularities the percentage of putts decreased. Figure 2 identifies the percentage of successful putts at varied distances.

Considering the imperatives mentioned earlier, it would seem that a putter which allows these factors to take place repeatedly would benefit the average individual. It is these factors that have directed manufacturers to build the most biomechanically effective putter possible.

Figure 2: Percentage of successful putts under actual game conditions by Professional Golfers (adapted from Pelz, 1987).



For this reason, the purpose of this study was to analyze a variety of putters, taking into consideration a number of variables to rate all the putters tested at the present time and to possibly make suggestions for structuring new putters.

There are over 80 manufacturers designing putters with an assortment of models. When the manufacturers advertise the superiority of their models over those of their competitors, it only leads to confusion for the consumer. When the author tried to retrieve information on data to substantiate the claims of each manufacturer, (review of literature) most literature was unavailable to the public or there was no research done. The continued request for data that had been partially published in golf documents led to much resistance on the part of the manufacturers.

The Problem

The problem is of significant importance for the following reasons:

1. There is an abundance of equipment available on the market.
2. Each manufacturer markets its putter as the best product.
3. Information on putters is limited and available to

limited individuals.

4. The most efficient putter will increase the moment of inertia resulting in less twist of the putter head when struck off the centre of percussion.
5. There is uncertainty regarding the point identified as the center of percussion on available putters.
6. Instruction is limited to the full golf swing and less adopted in the areas of putting.

Definition of Terms:

Acceleration: The change in velocity per unit of time.

Centre of Percussion (Sweet Spot): A point at which the weight of a rigid body may be considered to be concentrated.

Coefficient of Restitution: Ratio of relative velocity of separation to relative velocity of approach for two objects which make contact.

Deceleration: The decrease in velocity per unit of time.

Distal: The point farthest from the grip.

Free Rotation: The movement of the putter shaft in the vertical axis.

Friction: The force that resists the sliding of one surface upon another.

Handicap: The number of artificial strokes a player receives (or gives, in the case of a plus handicap) to adjust his scoring ability to the common level of scratch or zero handicap golf.

Inward Rotation: The anti-clockwise rotation of the golf ball when struck off the toe of a right hand putter.

Moment of Inertia: The measure of the putters resistance to turning when hit off the center of percussion.

Peripheral Weighting: A method of restructuring the mass around the perimeter of the putter head to increase the moment of inertia and reduce angular displacement when the ball is struck off the centre of percussion.

Projected Velocity: The speed and direction of an object at the instant of projection.

Proximal: The end closest to the grip.

Power: The product of an applied force and the speed with which it is applied.

Putter Head Balance: When the putter shaft is balanced on a knife edge so that the grip end and head are in balance (the shaft is horizontal) then the putter face points upward (or downward).

Restricted Rotation: Prevention of movement of the putter shaft about the vertical axis.

Velocity: The speed and direction of an object.

Work: The force applied to a body multiplied by the distance through which the force is applied.

Limitations:

This study is limited to the authors selection of equipment and methods of measurement. There were nine putters selected of various styles (center shafted, heel shafted) and shapes (pheripheral weighted and mallet). The method used to evaluate each putter was limited to results centered around the center of percussion.

CHAPTER II

REVIEW OF THE LITERATURE

Introduction:

A study to determine the best available putter on the market can be a difficult task. If one were to consider the variables inherent in technique, research would be endless. By considering only a few variables which closely relate to the technical aspect, confusion would be limited, thereby decreasing consumer reaction.

Putting is relatively a simple task, providing all factors are correct at impact. But as golfers are all aware, putting is so precise an art, the task is not that simple. By eliminating certain variables and focusing directly on the putter, researchers can provide information which may lead to improved performance.

According to Hay (1973) golfers have three distinct tasks to perform in putting:

1. They must determine how much clubhead speed is required to strike the golf ball in order to have it fall into the hole.
2. They must determine the direction in which to strike the golf ball in order to have it fall into the hole.

3. They must be able to execute their putting stroke in a manner consistent with both of the above variables. Essentially, they must keep the face of the putter perpendicular to the desired trajectory of the golf ball.

Available literature reveals the structural components of the putter and the limited research in testing that was available to the author. A total of 82 manufacturers were contacted, with minimal response.

Structural Components

Every putter has a centre of percussion (sweet spot). The sweet spot can vary dramatically from putter to putter (Seitz,1983). By consistently contacting the ball on the sweet spot, the line of flight and velocity will remain constant. Since not all golfers consistently strike the ball's sweet spot, increased moment of inertia can allow for greater consistency through peripheral weighting. In 1962 Cochran and Stobbs (1968) did a comparison of three forms of putters: blade, centre-shafted and mallet. Table 1 describes the differences between these three forms of putters. Among the three types, the centered shafted putter was identified as a slightly better putter. Putters of the past were considered very vulnerable to twisting when struck off the centre of percussion, as opposed to centre-shafted putters.

A modern putter with peripheral weighting increases the moment of inertia thereby decreasing angular rotation on off centre hits. There is no doubt that the appearance of a putter is as important as the playability. Certain factors such as cleaner lines and less complicated structures are less distracting to the golfer (Barkow and Low, 1976).

Barker and Low (1976) suggest the following elements should be taken into consideration when selecting a quality putter:

1. A little offset -easier to line up putts, sets hands ahead of the putter.

2. Weight - An overall weight of 17-18 ounces with a pronounced head (feel better with weight at distal end instead of equal distribution).

3. Grip - Thin (no matter the size of the individual's hands) as it produces a better feel.

4. Grip material - Leather is best (choice is of personal preference).

Prior to 1960, putters had an eight degree loft. Modern putters have approximately three degrees of loft, with some models none at all. Recently one company has designed a putter with inverted loft. The manufacturer claims that it diminished the sliding action that occurs in putting and it initiated the roll more rapidly.

Table I: Comparison of three types of putters at a professional tournament (from Cochran and Stobbs, 1968).

	Percentage Holed		
Length of putt	Blade	Center Shafted	Mallet
0 - 3 feet	97%	97%	97%
3 - 6 feet	65%	66%	64%
6 - 9 feet	37%	40%	37%
Average distance long putts over 30 feet finished from hole	3.0 ft	3.3 ft	3.1 ft
Average number of putts per green	1.82	1.81	1.88

Material makeup is dependent upon personal preference. There are suggestions that the softer the material, the better the feel (Styx, 1989). Presently the author would suggest that this does not necessarily increase consistency in putting.

If an individual can putt with an old hickory shafted putter or another ancient style design, material makeup does not necessarily prove to accomplish better results.

Runyan (1987) and Runyan and Aultman (1979) suggest that the following criteria is essential in the selection of a good putter:

1. Putter Head Balance - A putter which naturally balances squarely to its arc of swing would seem least likely to require extra effort to make square contact with the ball.

2. Identification of the Sweet Spot - Some putters have lines marked on them to identify this area, but the accuracy of these markings is questionable.

3. Weight and Shaft Flex - Clubhead speed is more of a factor than clubhead mass. Therefore a putter with medium to heavy mass is better. The amount the shaft flexes is dependent upon its overall length and overall weight distribution. A shaft of stiff nature will tend to decrease clubhead feel. If it is too flexible, the putter head will

increase velocity into the ball and a shaft that is too flexible will increase angular displacement on off centre hits.

4. Loft and Face Depth - These are considered the foundations of a good putter fitting program. Success is greater if the putts roll along smoothly rather than skid towards the hole. The deeper the face, the greater the loft required to prevent skidding and hopping.

Related Studies

One of the most widely quoted reference sources is that of Cochran and Stobbs (1968). Cochran and Stobbs found that when the ball was struck off the centre of percussion, the putter head would rotate, affecting both distance and direction. Results of the study are shown in Table 2. Runyan and Aultman (1973) support this finding and states that "Missing the sweet spot by one-half an inch results in the putt being ten to fifteen percent shorter and five to ten percent off line."

Table 2: Effect of hitting the ball one inch on either side of the center of the putter face on two different lengths of putts. (Each figure is the average of 24 putts using one particular putter in the putting machine)
(from Cochran and Stobbs, 1968)

	Distance		Deviation (L or (R)	
Point of contact	Putt		Putt	
of ball on face	Force 1	Force 2	Force 1	Force 2
1" towards toe	14-1 ft	9-0 ft	5" R	8" R
centre	20-4 ft	11-2 ft	0	0
1" towards heel	17-4 ft	9-2 ft	8" L	7" L

Along with the decrease in velocity, there was a correlation to the length of the balls flight and where the ball was struck off center. For Cochran and Stobbs tests, a simple machine was constructed to hold the putter stationary and allow movement only in the perpendicular plane (similar to a surveyor's tripod). Unfortunately, the tests were conducted with only one style of putter. From the results, suggestions were made for manufacturers to re-design putters to allow for an increased effective hitting area, around the center of percussion to reduce angular rotation on off center hits.

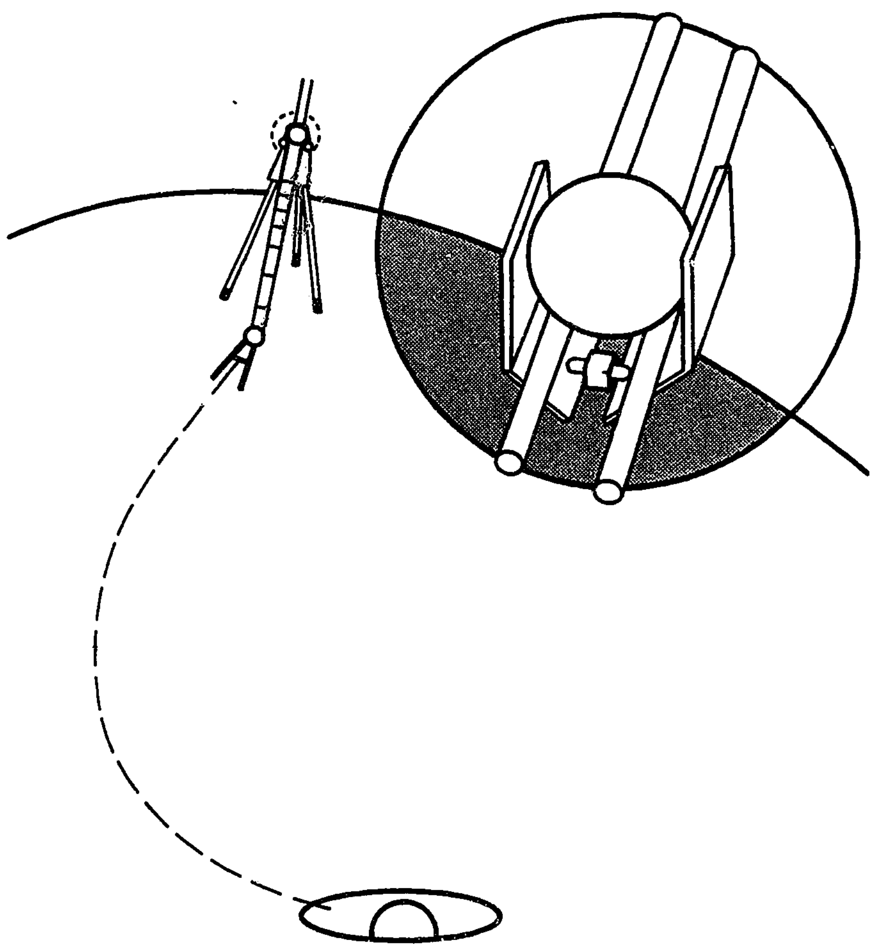
Distance lost and lateral deviations from the desired direction could be reduced if some of the weight of the putter heads was shifted to the heel and some towards the toe. An eccentric force exerted by the ball at impact causes the putter head to be angularly accelerated and consequently the effect produced on the golf balls subsequent motion is inversely proportional to the inertia of the putter head (Hay, 1973). Thus, since the suggested redistribution of weight of the putter head increases its moment of inertia, the effect of off centre hit will be less marked than one with which the weight is not so distributed. Twenty years after Cochran and Stobbs' initial research a redevelopment in the structural design to allow for peripheral weighting can be seen.

Recent studies by Pelz (1989) has again seen the concept of "Man vs Machine" to help develop a more biomechanical efficient putter. Pelz's experiment was to compare the differences between a mechanical device designed to putt as opposed to a human subject. The mechanical device enlisted a motorized mechanism that pulled the clubhead back a specific distance, then released it. Results showed several missed putts enabling the human subjects to beat the machine. From the testing, Pelz discovered that there needed to be a better method of ball propulsion. This initiated the construction of what is now called the "True Roller".

Cochran and Stobbs (1968) have identified that when a golf ball is struck with a putter the initial reaction is for the ball to skid, prior to rolling. Pelz (1989) concurs with Cochran and Stobbs and claims that the ball will maintain its intended path more accurately if the ball begins rolling more quickly. To eliminate the skidding effect the "True Roller" was designed.

The True Roller (Fig 3) consists of an eight-foot long ramp made of two circular, precision-machined rods spaced exactly one inch apart. These rods are placed on a tripod that can adjust the height to control the speed of the ball at release. At the top of the two rods is a release mechanism with an adjustment knob, which allows for the movement up or down the ramp so the ball can be released with different projection velocities. The mechanism is aimed at the intended target line. The ball is released by pushing the release mechanism. After release the ball starts rolling by the aid of gravity only, therefore initiating a true roll immediately. Results were increased, but still inconsistent. Further tests were conducted on the golf balls themselves.

Figure 3: The True Roller.

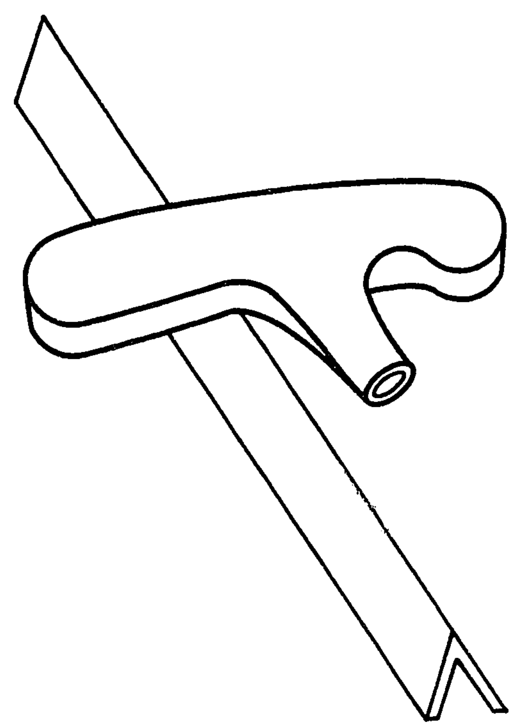


In physics the sweet spot is an infinitesimal point. There is no such thing as an "enlarged sweet spot" as many manufacturers claim with their putters. Manufacturers who promote this concept are unaware of this fact or are engaging in "salesmanship". If a ball contacts any putter in a spot other than the true sweet spot, there is a small vibration, rotation and loss of energy (Pelz, 1989).

There has been mention as to the accuracy of the placement to the line manufacturers place on the putterhead to indicate the centre of percussion. Several individuals (Wiren, 1987; Maltby, 1982) advise confirming the centre of percussion prior to use of the putter selected. Their method to determine the location involves holding the putter by gripping loosely between the thumb and forefinger in a hanging position, then gently tapping the putterface with a pointed instrument. When the putterhead resists twisting, that identifies the centre of percussion.

Maltby claims that a more precise method involves removing the putterhead from the shaft and balancing it on a sharp edge (Fig. 4).

Figure 4: Checking Putter head for Center of Percussion



This method may readily identify the balance point, but it does not take into consideration the weight of the golf shaft when attached to the putterhead. It also negates the position of the center of percussion on the vertical axis. Therefore, the author would suggest that this method is less accurate than the method presented in this study, to identify the centre of percussion when selecting a putter.

One misconception that several manufacturers claim relates to the moment of inertia. MacGregor and Slotline are two such companies who claim that their putters have a greater moment of inertia. Doubling the moment of inertia does not mean that the twisting movement about the vertical axis is decreased by the same value. There is no direct relationship in increasing the moment of inertia (Pelz, 1989). Performance testing on several putters showed that a putter with a moment of inertia three times higher than another putter performed about ten percent better in terms of the number of putts made.

An area that some companies advertise their putters effectiveness over others is the concept of force balancing. This concept allows for the club's design to let the putterhead move down the target line with the face remaining square to the direction of the force. A force balanced putter is self-aligning, allowing the individual to keep the blade square to line without any holding force.

As mentioned earlier, the author has attempted to obtain further literature from the manufacturers. Only ten percent responded to the author's request. Of those that responded, six replied that they do not test their putters. One of these companies included in this response was Lynx, yet it advertise "response feel" in national publications. This presumably refers to the fact that vibration of the graphite shaft for eccentric impact is transmitted to the hands better than that of steel shafts. Two companies responded that their data was confidential and was unavailable to the public.

Other claims by manufacturers which lead to confusion by the consumer, are listed below. In addition to mass distribution features, some of these points are also considered in these tests.

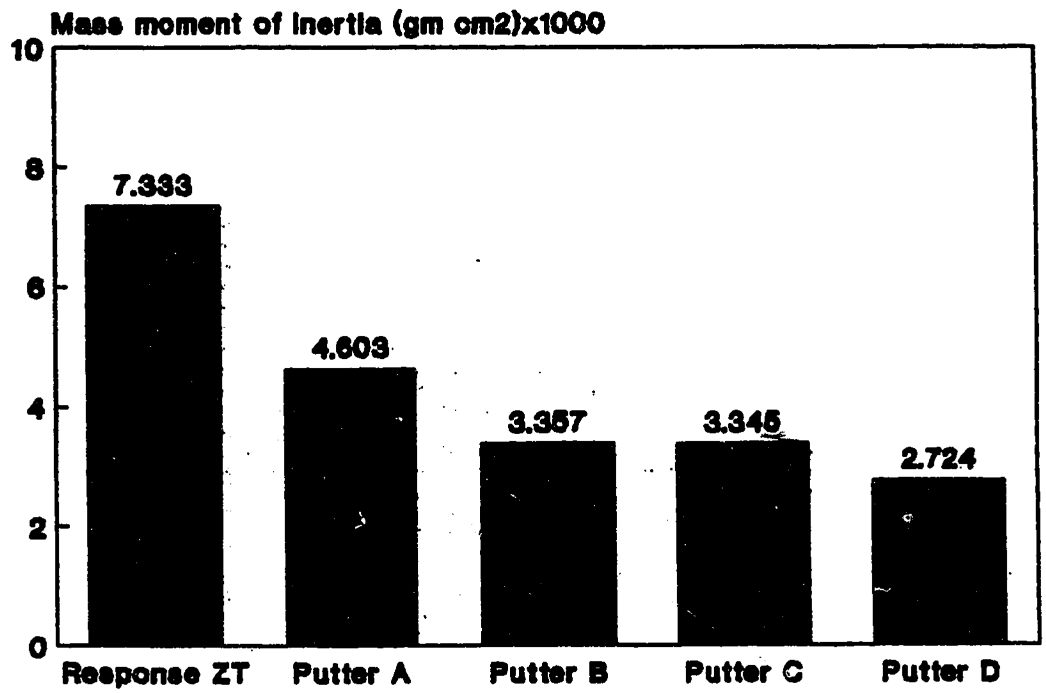
STX Inc. came to the conclusion that there were two problems in putting that had to be contended with. First, a golfer must establish the correct alignment with the putting cup. Second, the golfer has to "feel" the ball in order to put the correct speed on the putt. STX tackled the problem of alignment by concentrating the weight directly behind the sweet spot with a low centre of gravity. In an effort to impart more feel "Adiprene" urethane elastometer was molded on to the putterface. This material increases the coefficient of friction greater than with traditional metal putter faces. The manufacturer claims the extra feel produces more accurate putts.

Daiwa claims their sightsetter putter incorporates a special top flange which encourages a better roll by imparting overspin. Also their inclusive alignment system claims to be precisely the diameter of the golf ball, making it easier to set the target line. In addition, the hosel is offset to promote an accelerating stroke.

MacGregor has stated their data is confidential, but have supplied the author with test results against four other putter types. Their research claims the MacGregor putter showed a twenty-five percent performance in successful putts of varied distances over the next best putter. Other results are represented in Fig 5.

Inverted Loft has designed a series of putters with one unique feature. All of the models have a negative loft, as compared to most other manufacturers designs. Most manufacturers have approximately three degrees of loft. By designing a putter with three degrees of negative loft, the company claims that a more true roll is created when the ball is struck, thereby negating any sliding movement. This suggests that the ball will stay on line more accurately.

Figure 5: Moment of Inertia of five different putters
(adapted from MacGregor, 1988).

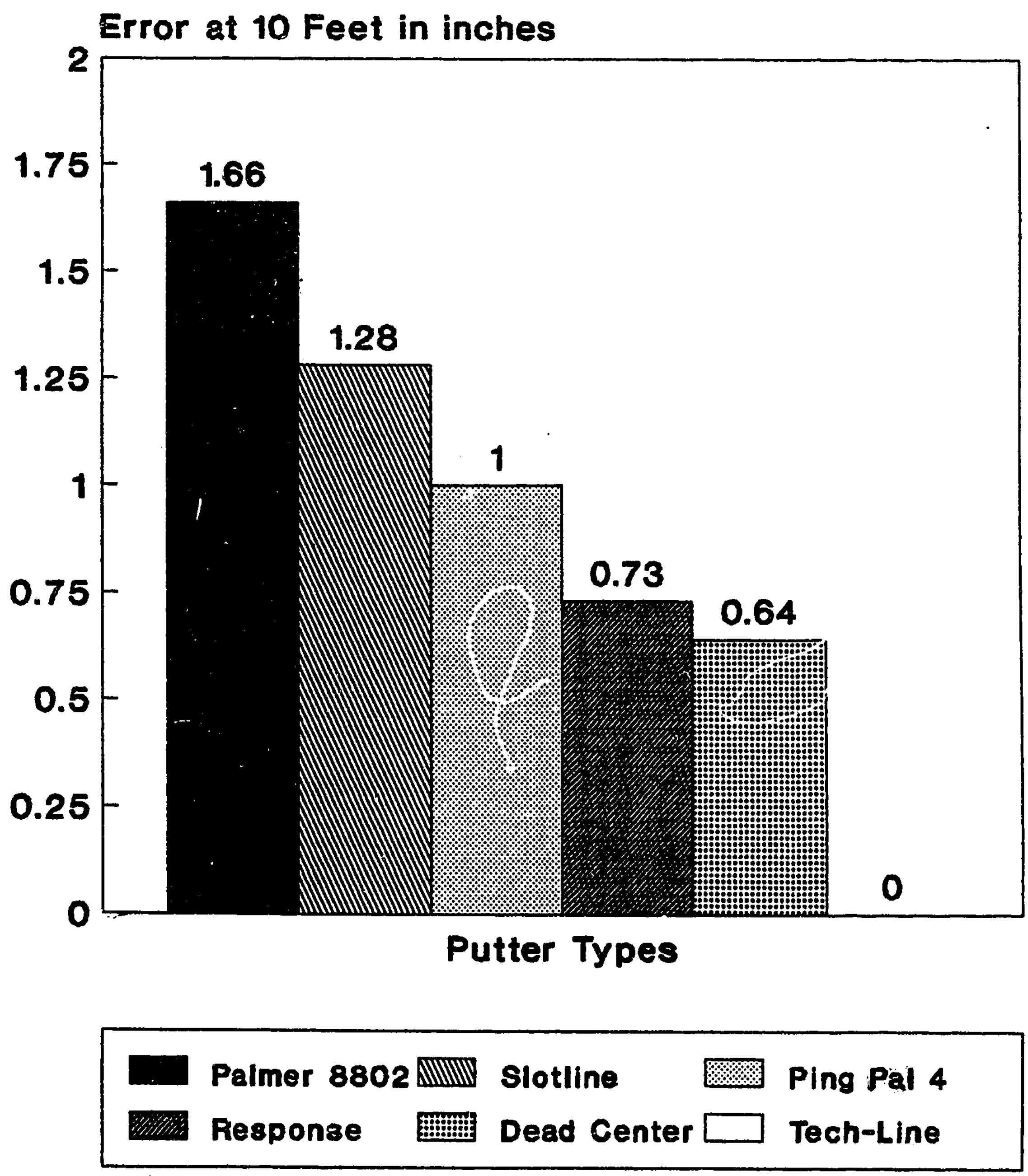


Tech-Line has developed a putter to eliminate aiming errors caused by variations in lie angle. Tech-Line claims are based upon the "aimer". It is the only aimer square to the putter face in both the toe-heel and up-down direction. Therefore, the aimer always squares the putter face to the direction it points because it is truly perpendicular to the putter face. The Tech-Line putters center of percussion was designed to match the golfers hit zone. Using results from testing putters on the Tech-Line Putting Machine and from research conducted by Tech-Line, computer simulated putts on a flat green were completed. The results are seen in Figure 6.

Slotline has incorporated the design of Duclos (1979). Through this design claims are made that the Slotline putter will stay on line and resist twisting better than any other putter ever made. With the combination of three metals (aluminum, lead and brass) this technically gives the Slotline putter the highest moment of inertia ever achieved. This suggests that this means they resist twisting off-line better than any putter made.

Titleist (1987) claims their Dead Center model is the only putter that shows the player every alignment mistake before the putt is made. When all lines on the putter face converge, the player is then assured of proper preparation for a perfect putt every time.

Figure 6: Results of putting at ten feet in inches on selected putters. (adapted from Techline, 1989)



Tommy Armour Golf Company (1987) claims its putter is the best alignment putter in the game of golf. The two main components that they recognize in the putting stroke as being detrimental to success are; positioning the eyes over the ball and keeping the clubface square to the intended line. With the T-Line alignment system, placing the white line between the two yellow lines assures the correct eye position. The white T-square helps the player square the putter face and accurately center the ball on the face of the putter.

Accurad Golf (1989) has introduced a new putter which claims to eliminate any skidding which happens on contact. The putter has a convex face which the manufacturer claims allows the ball to roll smoothly time after time, regardless of the players stroke.

Balanced Blade (1986) introduced a putter that was not based on cosmetics. After 3,500 computer analyzed putts, their engineers determined the four most common reasons for missed putts. The errors outlined involves;

1. The ball is hit off the center of percussion.
2. The putt is aimed wrong.
3. The low point of the putter contacted the ground before the ball.
4. The heel or toe of the putter contacted the gro before striking the ball.

To eliminate these variables four critical features are incorporated into their putter. These are;

1. A seven degree dihedral angle prevents the heel or toe from striking the ground before the ball.
2. An elongated aiming flange identifies the correct alignment.
3. A runner placed on a skid plate reduces the frictional forces to the point of extinction.
4. Equal weight distribution towards the end of the putter to minimize deflection and distance errors if struck off the center of percussion.

Balanced Blade claims that these designs solves all the preceding problems that most golfers have.

Gartner (1988) claims their new putter had combined all the necessary technology to achieve better putter performance. The three dimensional weighting incorporated the necessary features for increased accuracy. A four degree negative loft automatically puts overspin on the ball. By centering the golf shaft, pushing or pulling putts is almost eliminated. A rounded racing hull on the bottom of the putter decreases resistance when the ground is struck prior to the ball. Longer sight lines aid in aiming the putter more accurately.

CHAPTER III

METHODS AND PROCEDURES

Introduction

The experimental apparatus consisted of three phases of testing. The three phases were: locating the center of percussion, non-human apparatus testing and subject application.

Initially, the concept was to complete the first two phases. From the results achieved from these two phases it was necessary to expand the testing to subject applications. This additional testing was carried out in an attempt to further explain the results found during non human testing. It was necessary to determine if there was a relationship between mechanical and human testing procedures. Therefore, each phase is discussed independent of the other.

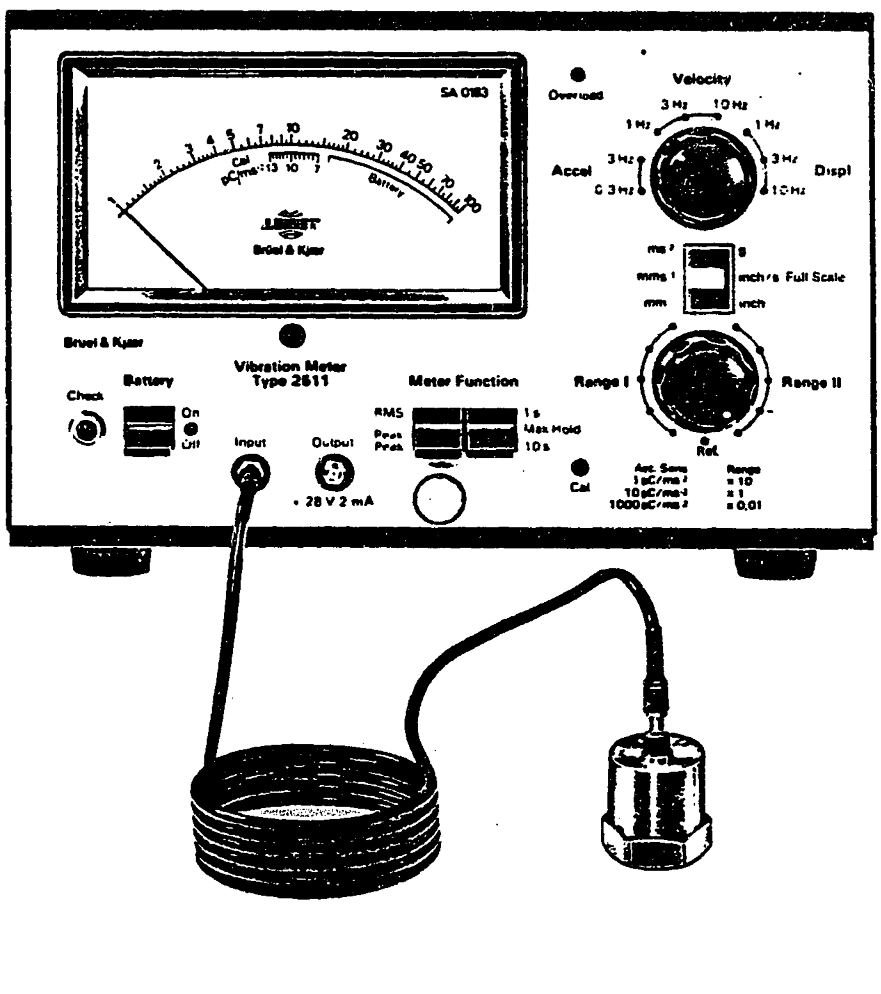
Phase I: Center of Percussion

Due to the uncertainty regarding the position of the center of percussion, it was necessary to establish a method to correctly identify the center of percussion. Because of the unreliability of the manual methods to locate the center of percussion a mechanical test was conducted. This allowed for consistency in all trials among the selected putters in testing. Equipment involved to test the center of percussion consisted of a pendulum device, an accelerometer, and an oscilloscope.

A small tripod was constructed to allow a two ounce lead ball to be suspended. The ball was drawn back and placed into a clip release. When released the lead ball would strike the putter face with consistent velocity.

The putter was fastened to a stabilizing device, which was also used for the experimental testing in phase two. Attached twenty centimeters from the distal end of the putter was an accelerometer. The accelerometer was connected to a vibration meter (type 2511) (Fig 7). Each putter had an impregnated paper attached to the putter face. This would readily identify where each strike made contact with the putter face. When the strike occurred, an impulse was recorded through the accelerometer and recorded through an oscilloscope. The oscilloscope was set at a single sweep and the range was set to allow the triggered beam to travel across the screen only once. Each beam was stored and the peak elevation was measured in millivolts. The lowest peak achieved indicated a minimum vibration and indicated contact on the putter face at the center of percussion. This position was then marked on the putter face for identifying the center of percussion during other phases of testing.

Figure 7: Vibration Meter (type 2511)



Phase II: Non-Human Testing

Non-human testing involved the construction of a device to evaluate nine different putters when struck on and off the center of percussion.

The experimental device consisted of a putter stabilizing device, putters, a pendulum release mechanism, a chart matrix layout and a photographic device.

The pendulum stabilizing device (Fig 8 and 9) was accomplished by constructing a frame using dexion. Leg levelling units were attached to the bottom to ensure consistency in lie angle of each putter. An aluminum rod with a roller bearing on each end was fastened to the front of the frame (Fig 10) to create a pendulum motion. Welded to the aluminum rod was a plate to allow the attachment of each putter. Once the putter was placed on to the aluminum plate, the putter head was drawn back 92 centimeters from the contact point on the golf ball at a height of 45 centimeters and placed on to a release mechanism (Fig 11).

An electric switch was connected to the solenoid release mechanism to allow consistent release of the mechanism every time.

Figure 8: Pendulum Stabilizing Structure (front view)

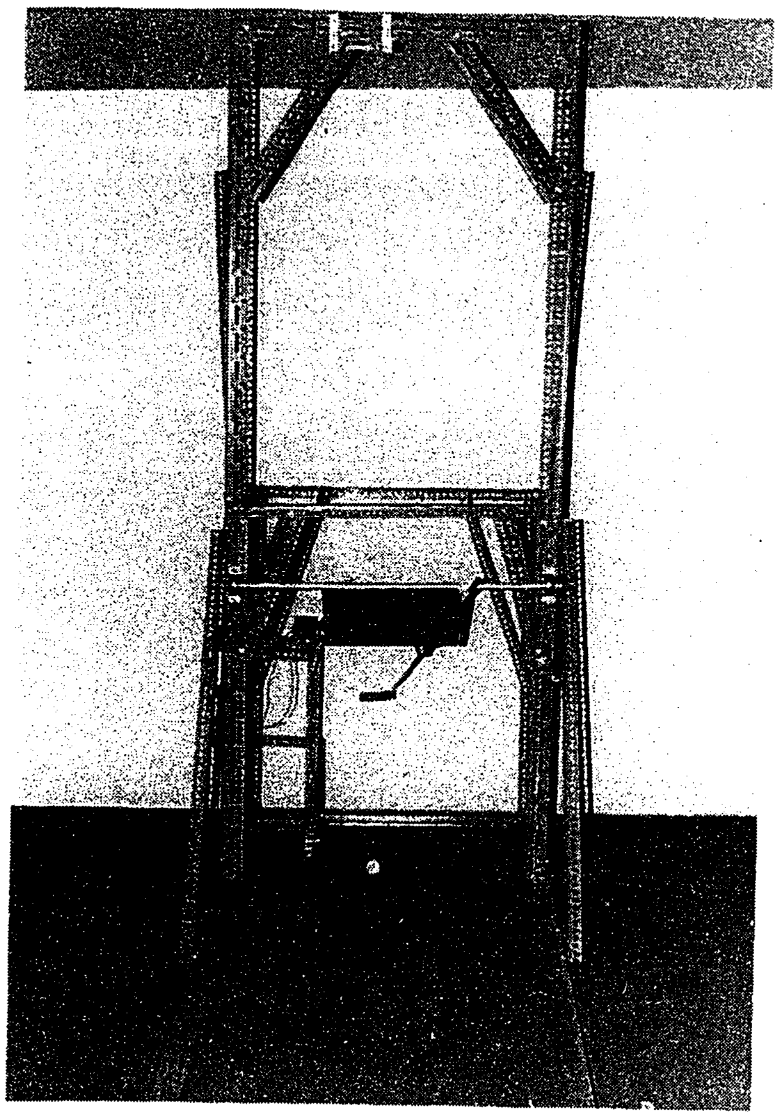


Figure 9: Pendulum Stabilizing Structure (side view)

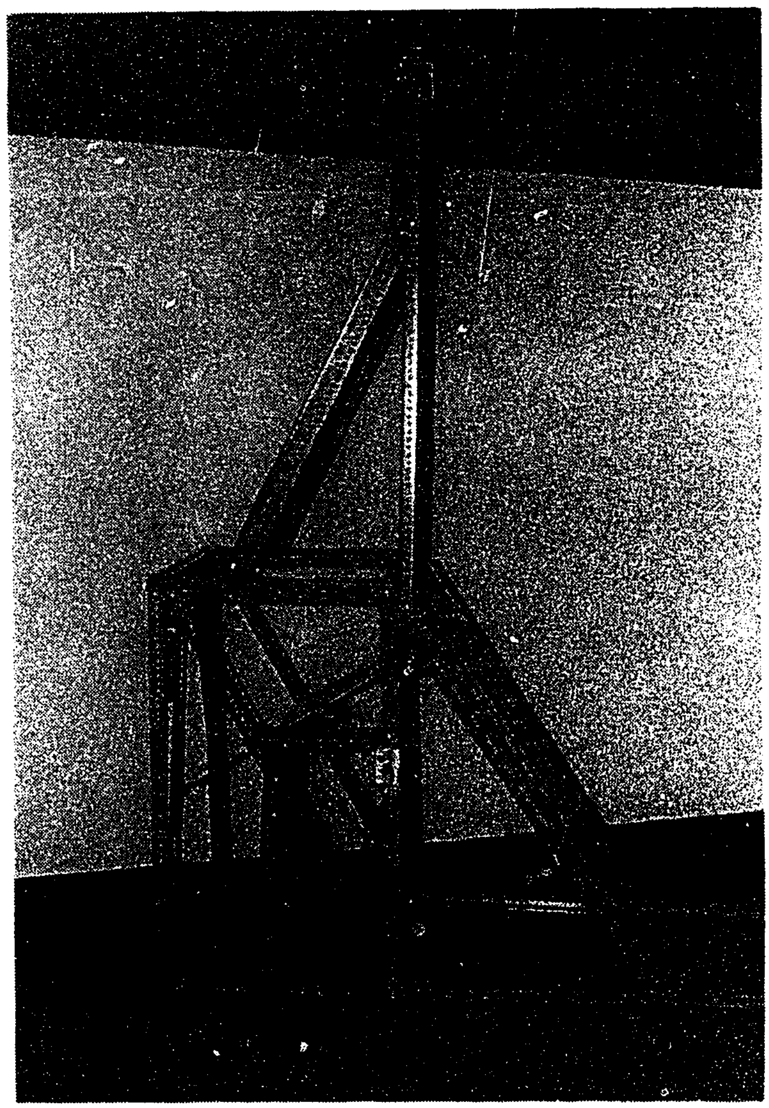


Figure 10: Aluminum plate in which putter is attached to the front of the structure.

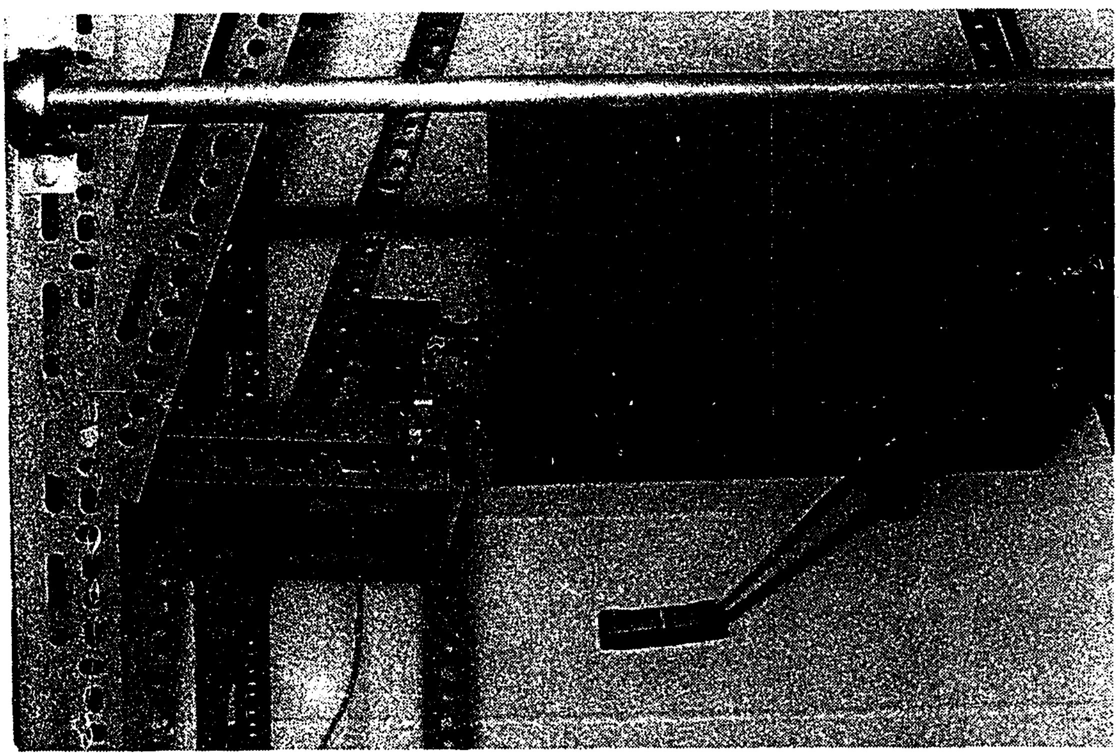
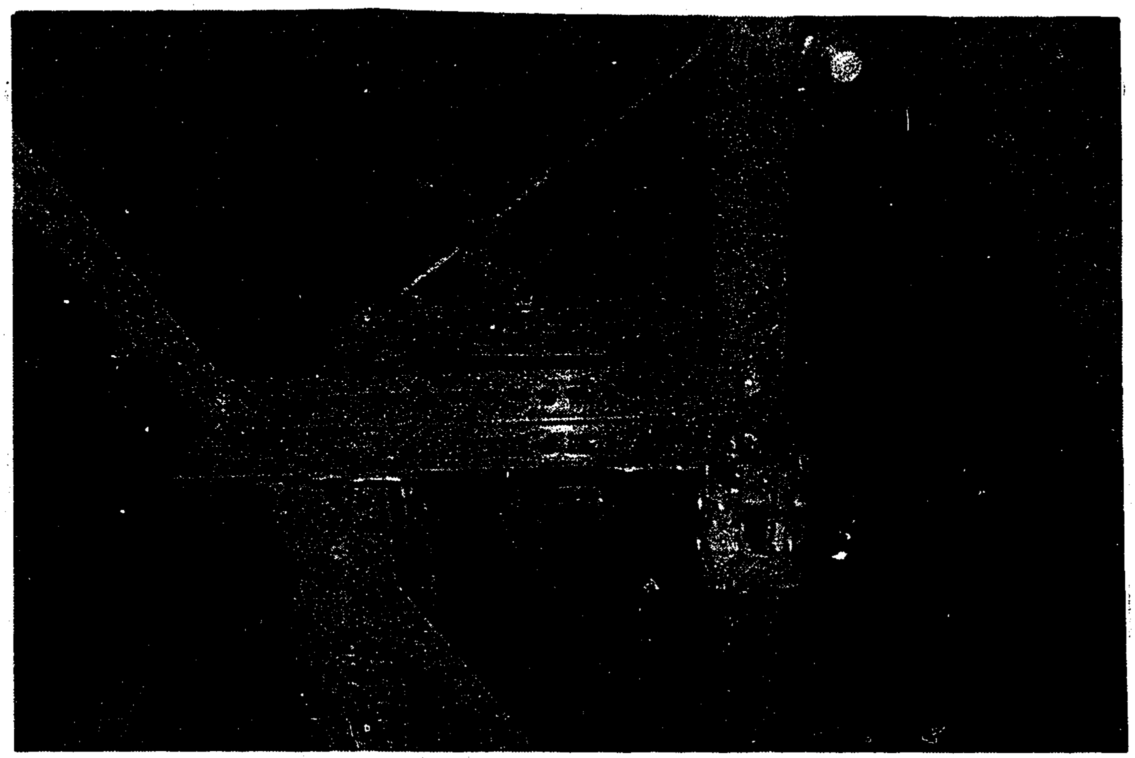


Figure 11: Putter release mechanism.



During each trial the same golf ball was attached through the center with an inextensible cord and suspended from the top of the frame in front of the aluminum plate. At the top of the frame a sliding mechanism was created to allow adjustment of the ball position at contact with the putter face.

When the electrical switch was triggered, the putter was released and achieved a velocity of approximately 3.0 meters per second, striking the golf ball on a specific location on the putter face. The golf ball would travel across a matrix graph (consisting of two centimeter squares) (Fig 12). As this occurred a camcorder recorded the position of the golf ball over the matrix. Hard copies of each result were obtained via a graphics screen printer (Fig 13).

Recorded results were established from a fixed zero point placed on the matrix chart prior to testing. All values are a representation about this fixed point on the matrix. Each putter was submitted to two forms of testing, with six trials at three locations on the putter face. The first form of testing allowed pendulum movement which restricted rotation about the shaft. The second form allowed pendulum movement with free rotation. The three locations of each trial consisted of the center of percussion, two centimeters towards the toe and two centimeters towards the heel of the putter.

Figure 12: Schematic of center of percussion test.

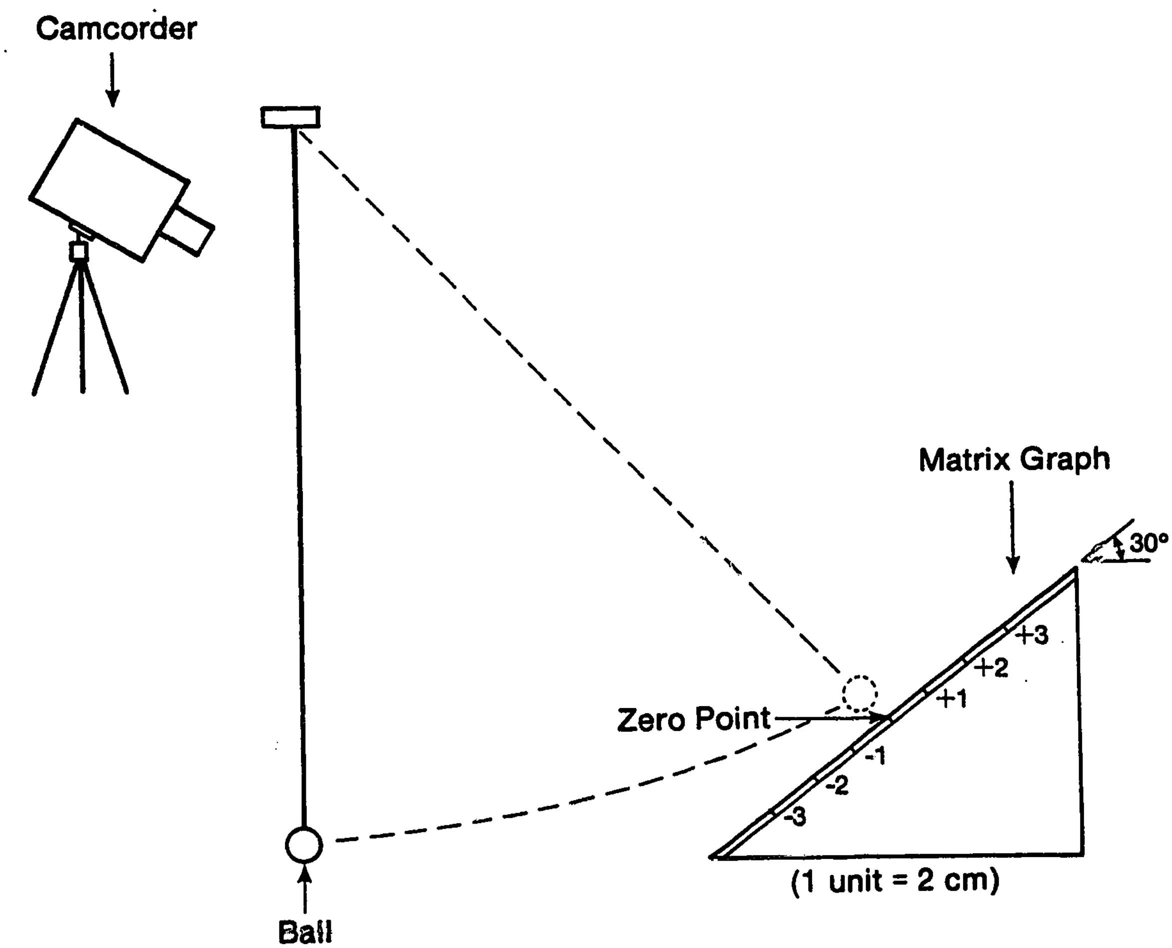
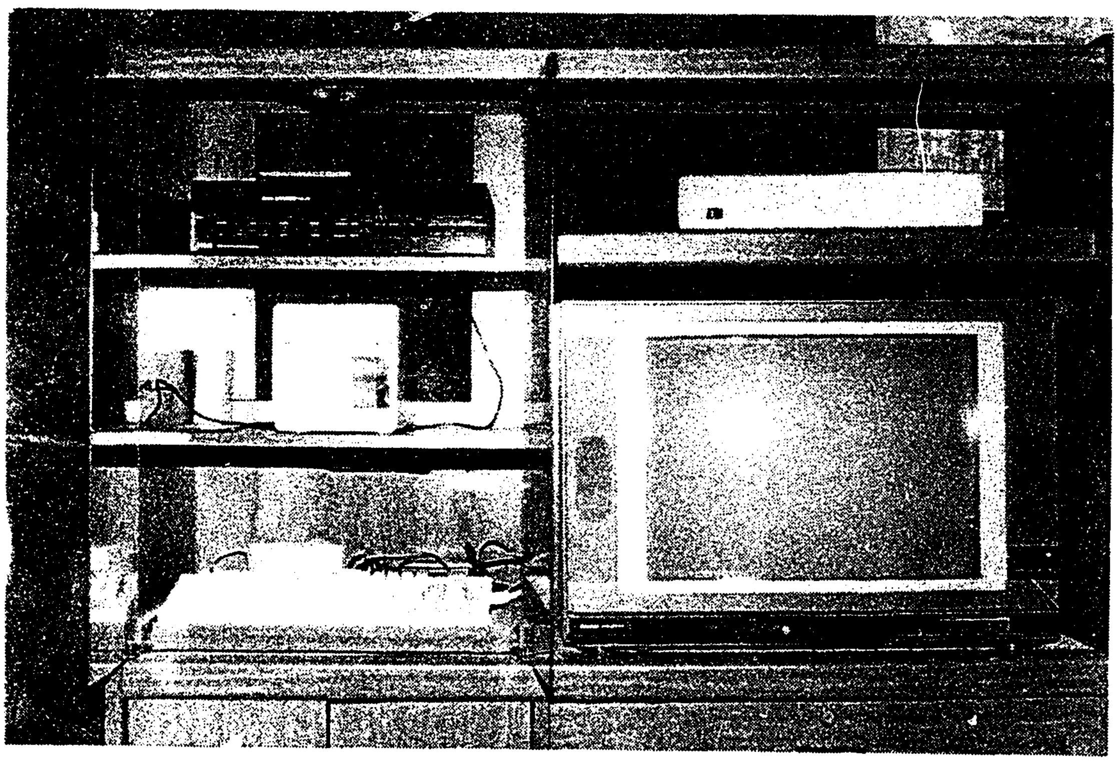


Figure 13: Graphics printing device.



Phase IIB:

A second element of testing was completed to identify and evaluate the results achieved from the initial phase of testing. A putter was retested on all three putter face locations. This phase of testing photographically measured the path of movement of the putter head at contact when striking the ball. Results were recorded using the SP2000 Motion Analysis System (Fig 14). This is the same system that the Karsten Manufacturing Corporation enlist in their research (Mattes, 1987).

Phase III: Subject Application

To identify whether a relationship existed between a mechanical putting device and human subjects the third phase of testing was enlisted. High speed filming of the path of movement of the putter head and golf ball was photographically measured.

Five subjects, using various putter types were instructed to strike a golf ball on or near the center of percussion, towards the toe and towards the heel of the putter. The putting ramp used was marked at ten millimeter intervals. An SP2000 Motion Analysis System recorded the results. This system permits video taping of the motion at speeds of 2000 frames per second. It is a development of the Eastman Kodak Company.

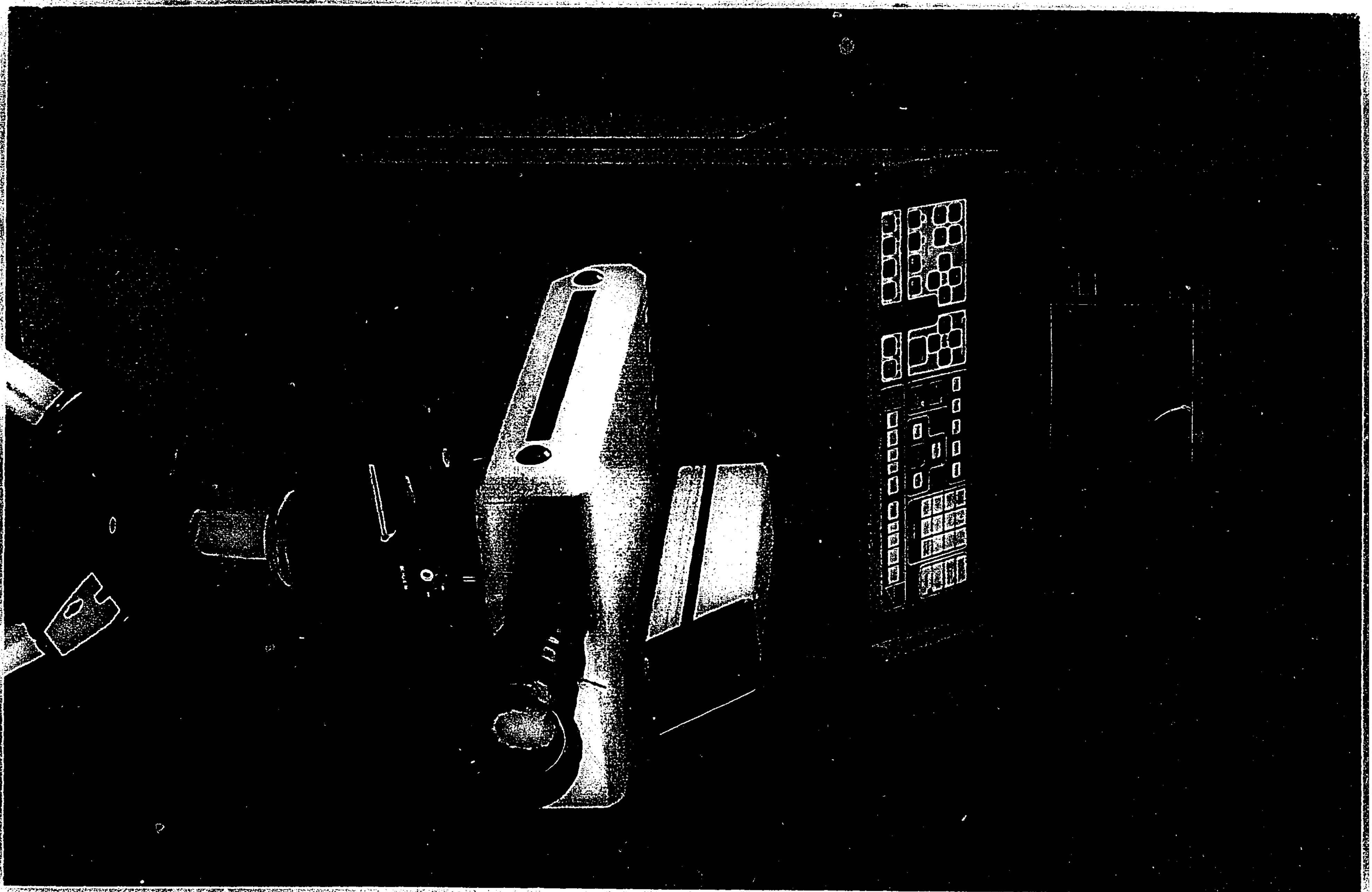


Figure 14: SP200C Motion Analysis System

CHAPTER IV

ANALYSIS AND RESULTS

Center of Percussion:

Nine putters were selected to test in the authors research (Table 3). Each putter was selected on the basis of different designs, shaft location and material makeup. The purpose was two fold. First, to increase putter testing consistency, each putter had to be struck on the center of percussion, then at specified locations in relation to the center of percussion. Secondly, a comparison of the center of percussion identified by the author and that of the manufacturers marking of the center of percussion. Of the nine putters tested, only three putters were consistent with the manufacturers markings. The remaining putters identified the center of percussion more towards the toe of the putter on all heel shafted putters. This leads the author to believe that placement of the shaft has an effect in the center of percussion.

The restructuring of the mass around the center of percussion identifies that there is an increased moment of inertia with different styles of putters. Figure 15 identifies an extended area of decreased impulses when struck off the center of percussion with peripheral weighted designs. Figure 16 represents a less extended area of decreased impulses with a mallet head design. Table 4 identifies the range of impulses in millivolts of each putter when struck off the center of percussion with the authors method of measurement.

Table 3: Putters selected for testing.

Code	Manufacturer	Model	Shaft Position	Face Material
P1	Ping	B62	H	SS
P2	Inverted Loft	Inverted	C	SS
P3	Ping	Original	C	BR
P4	Slotline	Offset	C	AL
P5	Styx	Styx	H	AD
P6	Titleist	Dead Center	H	SS
P7	MacGregor	Response	H	AL
P8	Ram	Zebra	H	CA
P9	Wilson	Sail	H	AL

Code: C = Center shafted   H = Heel shafted

SS = Stainless Steel   BR = Brass

Al = Aluminum   AD = Adiprene

CA = Cast

Figure 15: Voltage dissipated when struck off the center of percussion with a peripheral weighted design (putter #7).

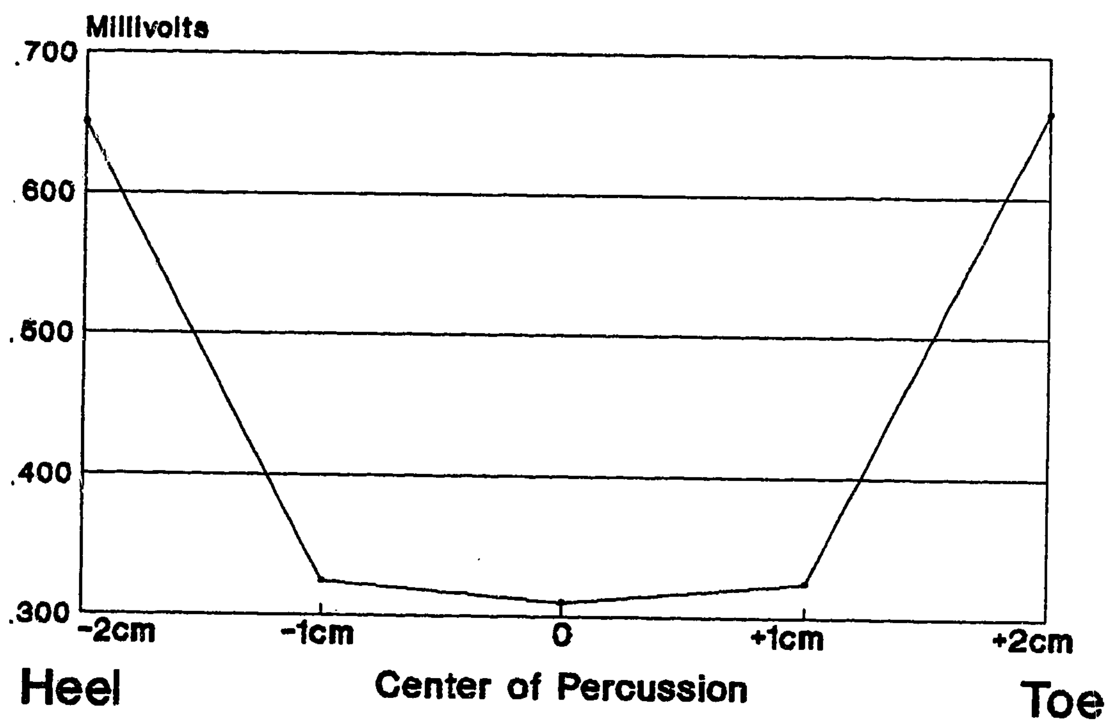


Figure 16: Voltage dissipated when struck off the center of percussion with a mallet design (putter #8).

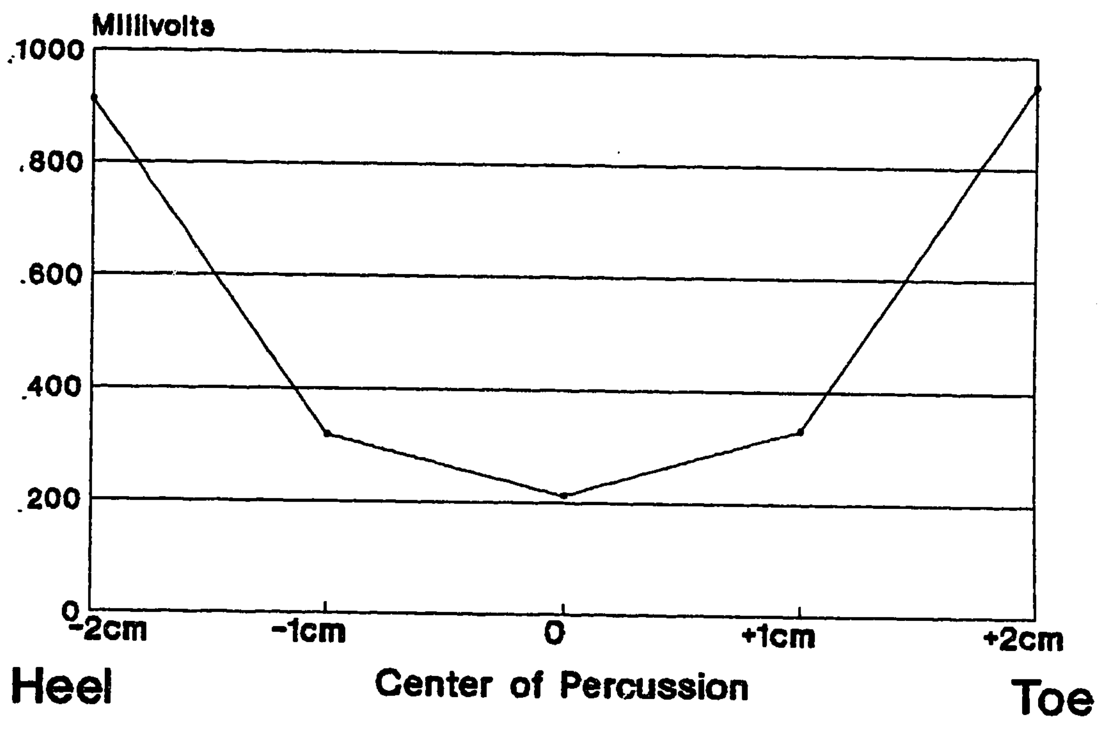


Table 4: Voltage dissipated when struck off the center of percussion on nine selected putters.

Putter Number	Voltage Dissipated (millivolts)				
	Heel		C of P	Toe	
	2cm	1cm	0	1cm	2cm
P1	.780	.330	.308	.340	.820
P2	.896	.318	.298	.328	.912
P3	.798	.264	.210	.312	.818
P4	.764	.312	.296	.318	.789
P5	.437	.074	.064	.082	.488
P6	.740	.246	.234	.263	.745
P7	.650	.325	.310	.325	.660
P8	.912	.317	.212	.329	.947
P9	.800	.300	.212	.320	.980

Restricted Rotation:

Striking the golf ball with a pendulum swing and the clubface perpendicular to the path and with restricted rotation of the shaft about the vertical axis resulted in a path of the golf ball perpendicular to the face of the putter. When the ball was struck on the center of percussion there was no measurable deviation of the ball from its desired path for all putters. The only variance which occurred was the distance that the ball travelled with each putter. Figure 17 represents the units travelled with each putter. The reference point is zero. If the ball travelled past this reference point results would indicate a positive result. When the ball did not have enough velocity to reach the reference point, the resultant would be identified as a negative results. For each putter tested, standard deviations are not shown since scatter was negligible (raw data shown in appendix B).

Analysis of tests on striking the golf ball two centimeters towards the heel indicated similar results in respect to perpendicular displacement. The moment of inertia (as discussed earlier) of each putter affects how much the putter head turns and dissipates energy on off center strikes. Results in figure 18 indicates a loss of energy in toe and heel contact due to vibration of the shaft.

Figure 17: Distance ball travelled when struck at the center of percussion with restricted and free rotation (distance travelled related to putter mass and material makeup).

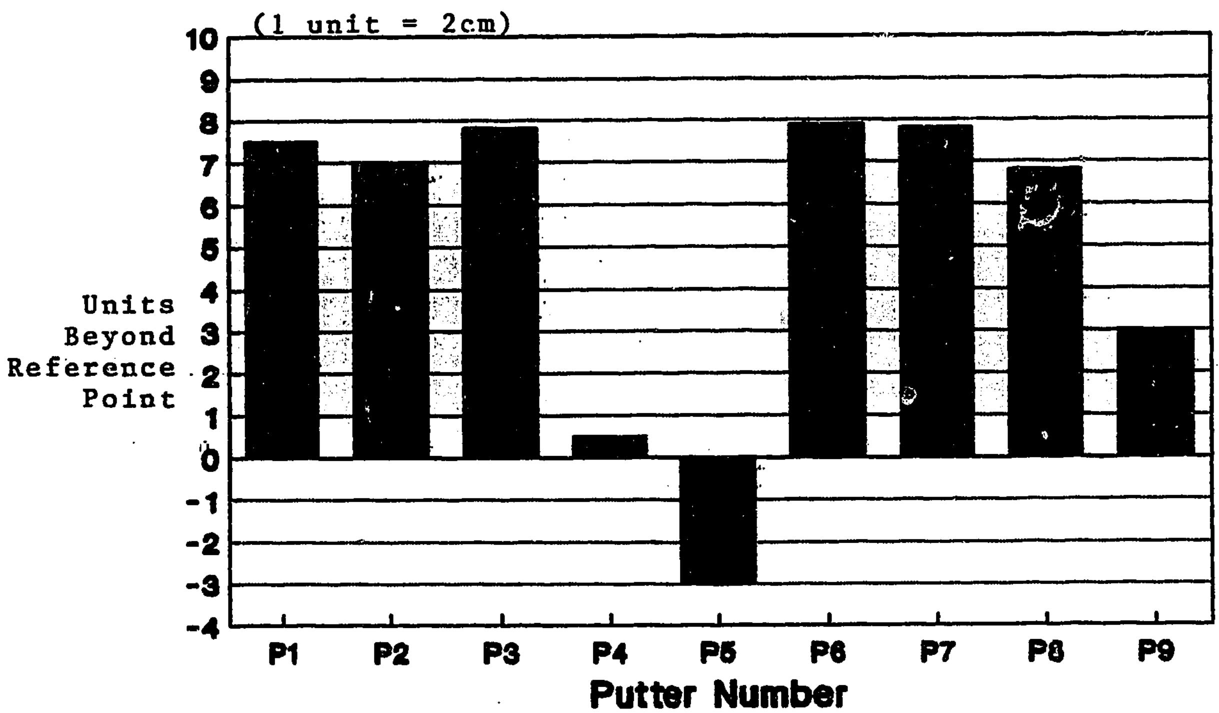
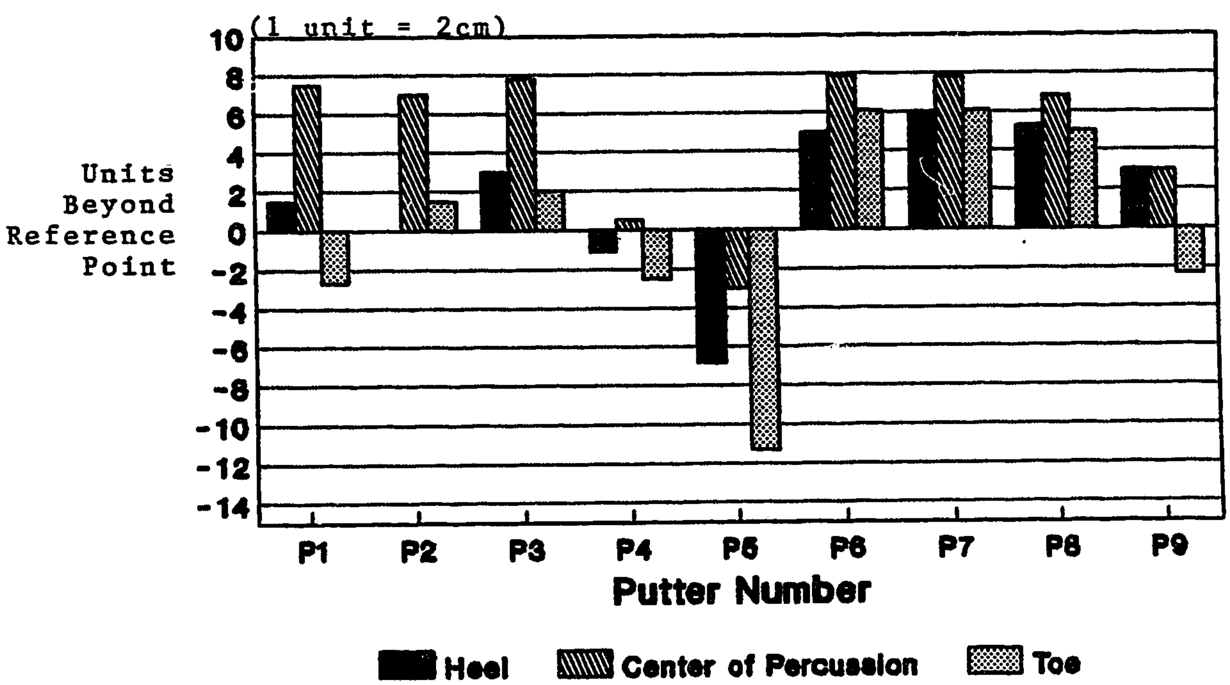


Figure 18: Distance achieved when struck off the center of percussion on selected putters. (There are no results on heel strikes for P2 due to the shaft placement, eliminating testing to occur on all trials)



In most instances with all putters where the shaft is inserted near the heel of the putter, all tests indicated that there was less energy lost on heel strikes as opposed to toe strikes. Where the shaft is located nearer the center of percussion, the difference in energy loss was decreased. This would indicate that the placement of the putter shaft on the putter head has a direct relationship on the effect that the golf ball travels on off center strikes.

One other area that had an effect on the distance was the material makeup of the putter face. The softer the putter face material (refer to Styx) resulted in decreased velocity that was transmitted from the putter head to the golf ball. This would indicate that an individual requiring a need to strike the golf ball with additional force to get longer putts to the hole, use a putter with a material of a harder nature. Those requiring less force and more feel should benefit from a softer material as in the Styx putter.

To confirm the results with restricted rotation and to help understand why the golf ball travelled perpendicular to the putter face on off center strikes, photographic analysis of the putter head was repeated with the SP2000 system. The speed was set at 1000 frames per second. Upon investigation of the photographic findings, there was indication of some movement of the putter head on off center strikes, although this occurred after the ball had left the putter face. At contact, the putter face remained perpendicular to the target line. In most cases rotation of the putter head was not until the golf ball had left the putter face between 1/1000 - 2/1000 of a second. Due to the time element that the golf ball leaves the putter face, this leads the author to believe that there is a direct correlation to the angle that the golf ball leaves the putter face. It is felt that whatever the angle is, the ball will always come off at a perpendicular line of that of the putter face. This would seem to support Cochran and Stobbs theory that the golf ball cannot be sliced or hooked, in the putting stroke. Slicing or hooking the ball is only possible with appreciable topspin or backspin, so as to make the ball spin about a horizontal axis along the line of play. It is almost impossible to do this with a putter (Cochran and Stobbs, 1968).

Free Rotation

In all tests impact off the center of percussion always caused the putter head to rotate. At impact, the golf ball resists the putter head's attempt to propel the ball down the line of flight. When the force is applied through a point other than the center of percussion, the putter head rotates around the center of percussion. Test results identify these occurrences when struck two centimeters towards the toe and heel on each putter tested. The results are consistent with the findings of other researchers (Cochran and Stobbs, 1968; Pelz, 1989; Maltby, 1972). Figure 19 indicates the loss of distance due to rotation of the putter head around the center of percussion.

Figure 19 does not identify results of heel strikes on putter number one , two and three. Putter numbers one and three resulted in a distance equal to the zero point selected by the author on the matrix. Putter number two is void of a result because of the placement of the shaft by the manufacturer. There is an inability to strike the golf ball two centimeters towards the heel from the center of percussion. Therefore, all tests on heel strikes in phase I and phase II were eliminated for P2.

Figure 20 represents angular deviation from the desired path (measured in degrees) for heel and toe strikes of each putter. In all cases where the shaft placement was towards the heel of the putter, there was increased rotation of the putter head on toe strikes. Putter number seven indicated identical results for both toe and heel strikes.

In all instances more energy was dissipated on toe strikes compared to heel strikes. Putters with good heel and toe weight distribution will hit putts only slightly farther on off center strikes than putters which are center weighted. This is identified by a slightly smaller loss on two of the center weighted putters as opposed to the more peripheral weighted designs.

One occurrence that should be reported is that of face balancing (described in review of literature). On all tests conducted where no friction was applied to prevent rotation, upon release of each putter, it would tend to rotate about the axis prior to making contact with the ball. This occurred even with the putters that stated that they are face balanced. To adjust the mechanism so the putter would strike the ball with the putter face perpendicular, tape was applied to the putter to maintain alignment. The tape would break at contact when the putter face struck the ball,to allow for rotation.

Figure 19: Loss in distance when struck off the center of percussion with free rotation (units from zero)
Values for putter #1, #3 and #9 are at the zero level. There is no result for putter #2.

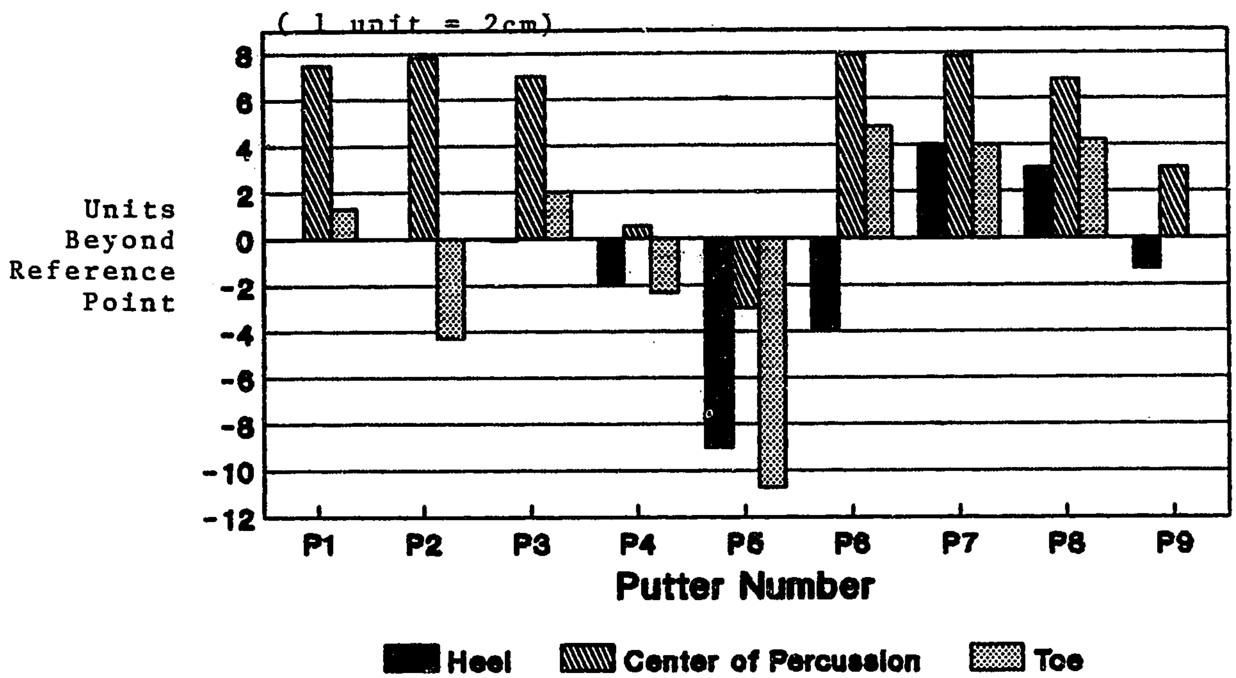
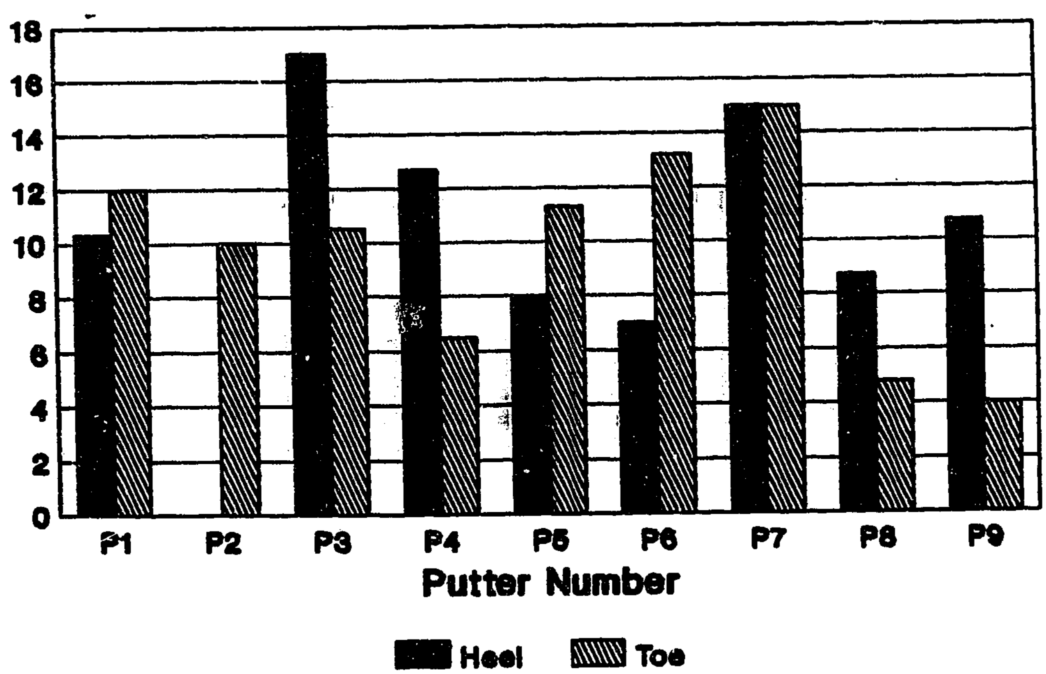


Figure 20: Angular displacement (degrees) for heel and toe strikes with free rotation.

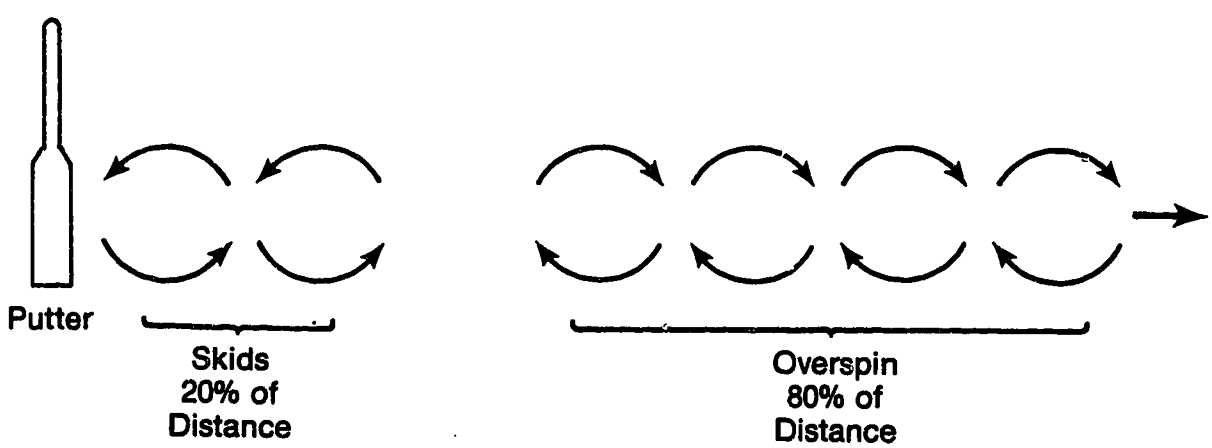


Subject Application

To develop a further understanding of the reality in putting, five subjects were tested using the criteria outlined in the experimental design. Each subject made contact with the golf ball on or near the center of percussion, towards the toe and towards the heel. Using the SP2000 system for photographic analysis, results of each subject were recorded.

As mentioned in the review of the literature, Maltby (1982) stated that on every flat surface regardless of distance, the golf ball will skid for approximately twenty percent of the total distance (Fig 21).

Figure 21: Ball reaction after impact with a putter (from Maltby, 1982).



The ball rolls with overspin the remaining eighty percent of the total distance. As the golf ball slides, friction between its cover and the surface of the ground begins to slow it down. The frictional force increases the spin ratio to reduce forward momentum. When the two speeds reach equilibrium the ball stops skidding and rolls the remaining distance until it stops.

In all hits taken by the subjects with the various putters, the skidding effect was noted (Fig. 22, 23, and 24). Duration of impact was in the range of 1/1000 - 2/1000 of a second. This occurred on all shots whether on the center of percussion or off the center of percussion. On off center strikes, the putter did have a tendency to open or close, but this occurred only after the golf ball left the putter face. All putters concurred with the Maltby's theory on skidding, with the exception of putter number two. There was a significant decrease in the skidding that occurred when compared to all of the other models (Fig 25, 26, and 27). The possibility for this explanation is the variance in the loft on the putter face. Putter number three has a negative loft of approximately three degrees, while the remaining putters have a positive loft of three to four degrees. The negative results in the top of the putter face striking the top of the golf ball, thereby applying the force above the center of percussion. This may indicate that the negative loft is not responsible for the decrease in skidding, but the relative position of contact made with the putter face on the position of the golf ball.

One phenomenon which occurred on all hits towards the toe and some on the center of percussion was an anti-clockwise rotation of the ball while it was skidding (Fig. 28, 29, and 30). In all cases where the phenomenon was observed the putter face was either perpendicular or slightly open on contact with the golf ball. Variations in putter head design or shaft placement did not seem to alter this phenomenon.

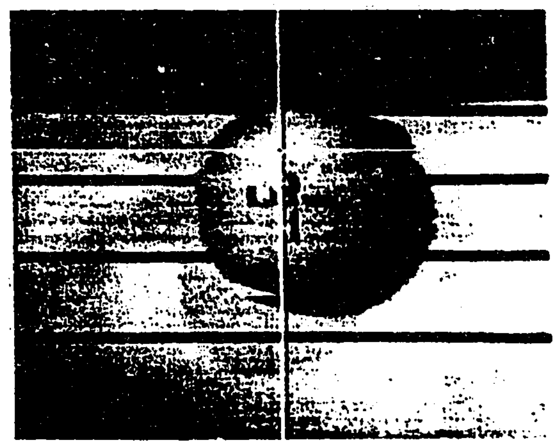


Figure 22: Effects of ball at impact on C of P with restricted rotation.

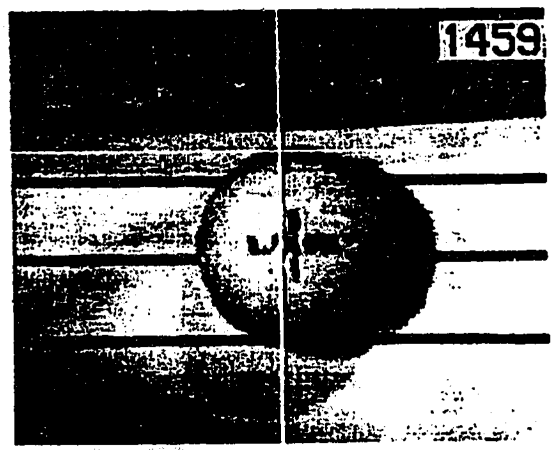


Figure 23: Effects of ball 1.0 cm after impact on C of P with restricted rotation.

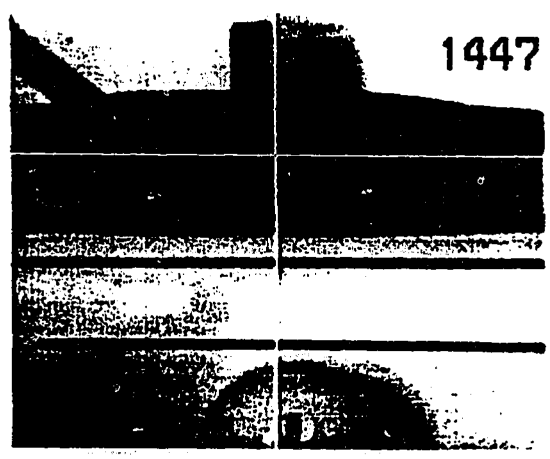


Figure 24: Effects of ball 6.25 cm after impact on C of P with restricted rotation.

Figure 25: Effects of ball at impact with negative loft and restricted rotation.

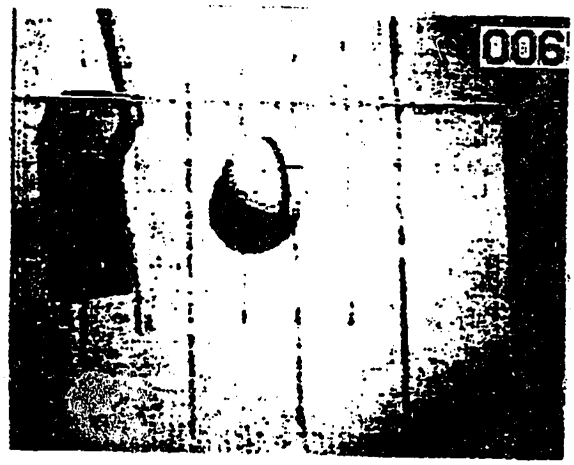


Figure 26: Ball 5.0 cm after impact with negative loft and restricted rotation.

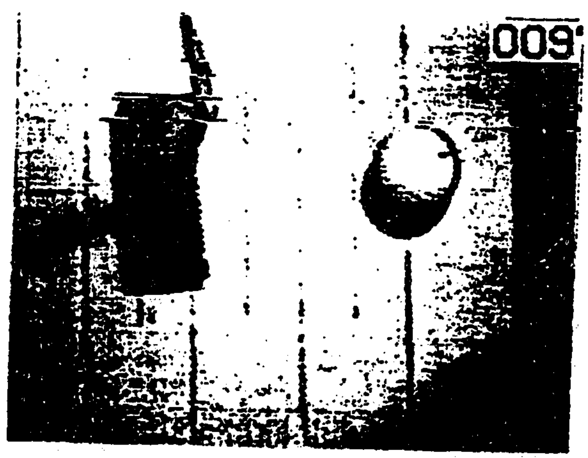


Figure 27: Ball 11.0 cm after impact with negative loft and restricted rotation.

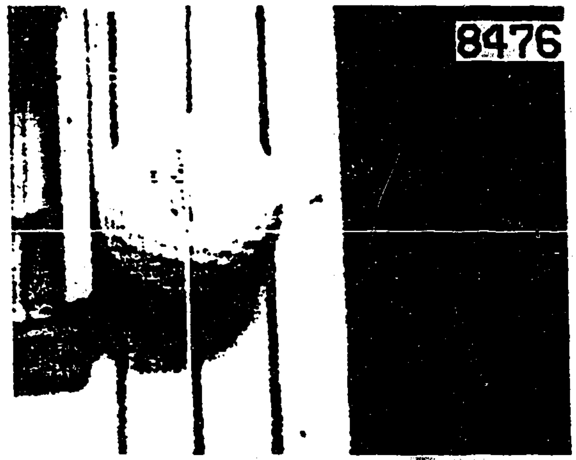


Figure 28: Ball at impact when struck on toe of putter with restricted rotation.

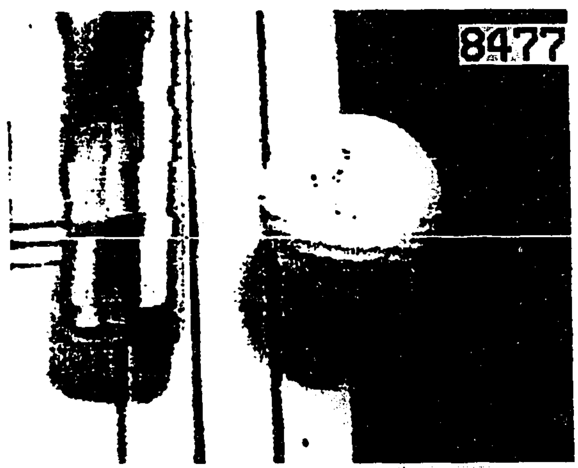


Figure 29: Ball 4.0 cm after impact on toe strike with restricted rotation.

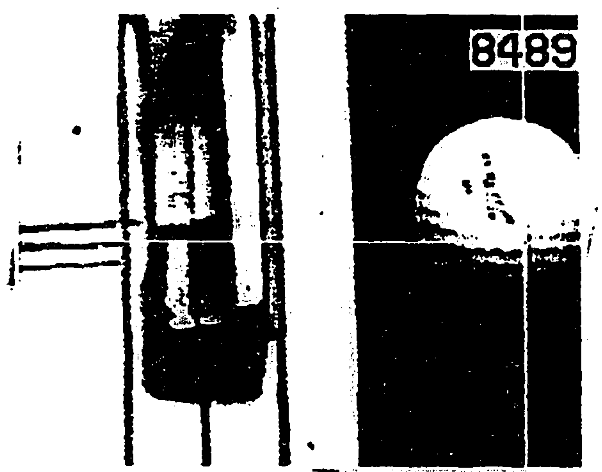


Figure 30: Ball 8.0 cm after impact on toe strike with restricted rotation.

Cochran and Stobbs (1968) use the explanation of gear effect to explain "full shots". What occurs is that the ball must be struck near the toe of the club, which causes an apposing effect to come into play. First, the ball hit off a little to the right of the intended line, and tending also to impart slicing spin to it; second, the "gear effect" imparts hooking spin. With a perfectly flat faced club the gear effect predominates and a "toed" shot sets off to the right, but hooks back across the intended line to the other side.

This phenomenon does occur when the mass and velocity is increased. When a driver strikes the golf ball at 160 kilometers per hour and the mass of the driver head is increased the gear effect is implemented.

This does not apply with putters. Photographic analysis shows rotation of the clubhead does not occur until the ball has left the putter face, thereby negating this theory. This was determined by Cochran and Stobbs as well.

CHAPTER V

SUMMARY AND CONCLUSIONS

Purpose

Since putting represents 43 percent of the golf game, it is of interest to the player to be able to use the best available putter. The rationale for putter selection has been described and illustrates many of the inadequacies associated with putting research. In particular, many of the reported qualities by the manufacturer have not been available to independent researchers. In light of the observations by various manufacturers, it was the purpose of this study to evaluate golf putters on the basis of selected impact measurements.

Methods and Procedures

Locating the center of percussion was employed to maintain consistency in ball striking among the selected putters. Nine putters of various designs were used. Once the center of percussion was located the putters were tested with free rotation and restricted rotation on strikes on and off the center of percussion. High speed filming was implemented to help understand results achieved in free and restricted rotation. The two variables measured on all strikes were the distance the ball travelled from a fixed point and the angle from the intended path. One final element of testing consisted of human subjects striking the golf ball to identify if there was a correlation between mechanical and human testing.

Results

There was no evidence to suggest that one putter was better than another. This concurs with that of Robot Golf Laboratories (1989). Findings from locating the center of percussion indicate that the markings placed on the putter by the manufacturer may not necessarily be correct.

Free rotation indicates a loss in velocity on heel and toe strikes, with a greater degree in displacement on toe strikes when the putter shaft is located towards the heel of the putter.

Evidence with restricted rotation does not show differences in the path of the golf ball. The only noticeable change occurred with a variance in distance the ball travelled off the center of percussion. This was due to the material makeup of the putter. The softer the material, the less velocity that was transmitted to the golf ball.

In all incidents, the ball left perpendicular to the putter face prior to any rotation of the putter head. This was confirmed by high speed filming of the putter head with both mechanical and subject testing.

Conclusions

On the basis of the present study, the following conclusions were made;

1. Corrective measures need to be employed to locate the center of percussion.

2. Peripheral weighted putters do not enhance accuracy on off center strikes, within the limitations of the testing. The golf ball leaves perpendicular to the putter face before rotation of the putter head occurs.

3. Material makeup of the putter face affects the amount of velocity that is transmitted to the ball.

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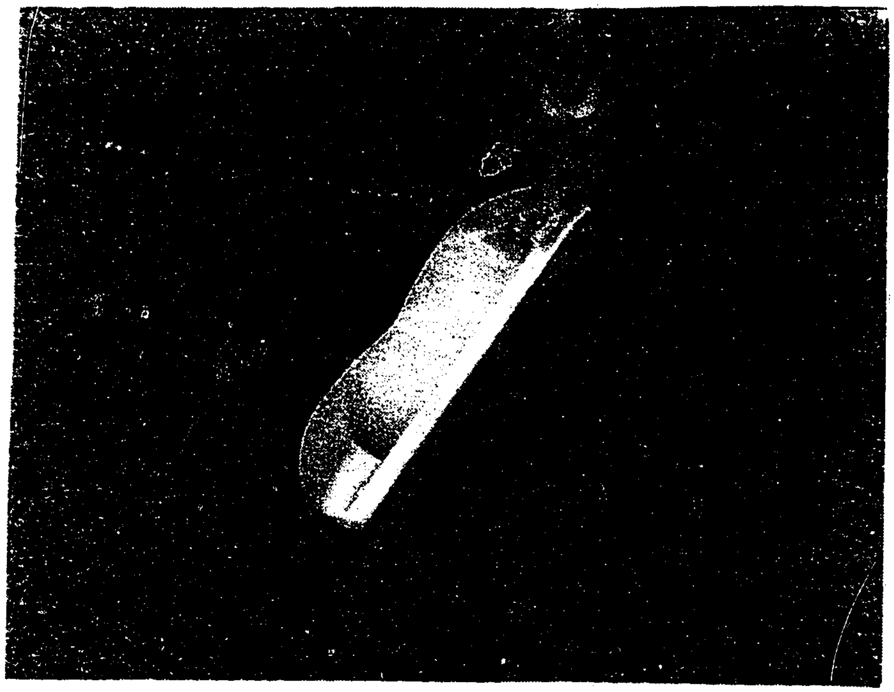
APPENDIX A

PUTTERS USED

PHOTOGRAPHIC DESCRIPTION OF PUTTERS

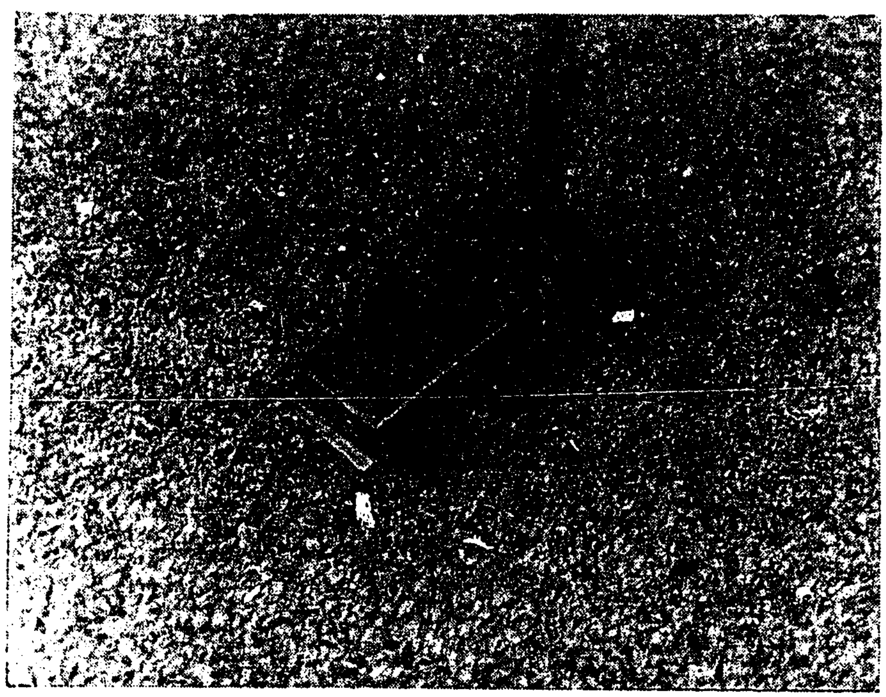
P1

PING B62



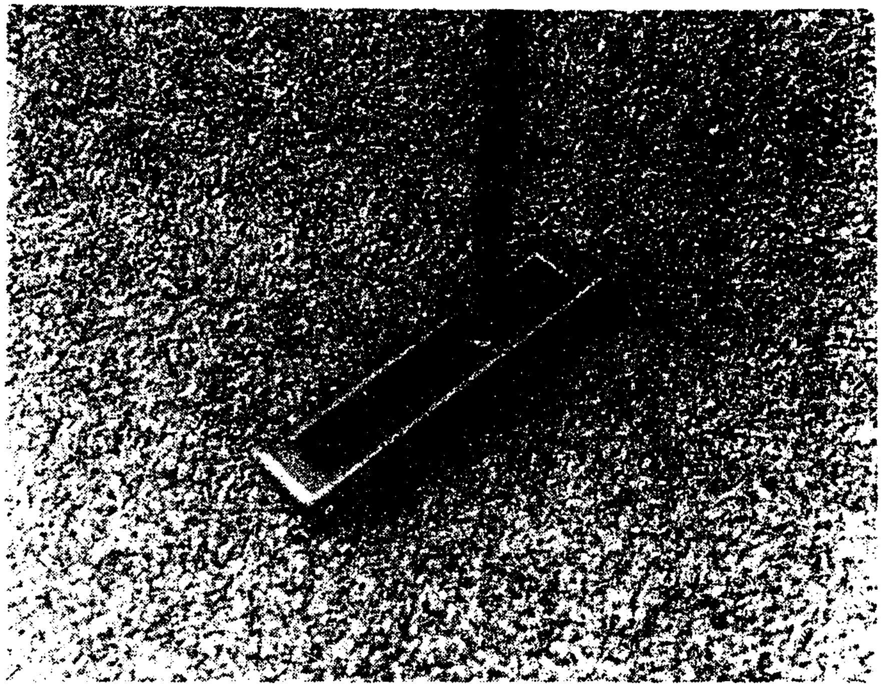
P2

INVERTED LOFT



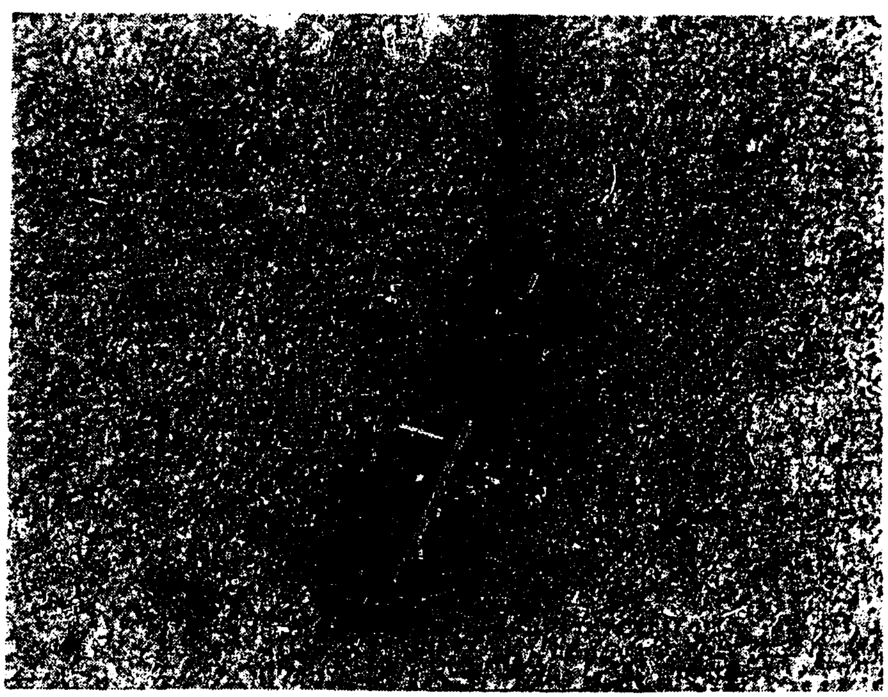
P3

PING BRONZE



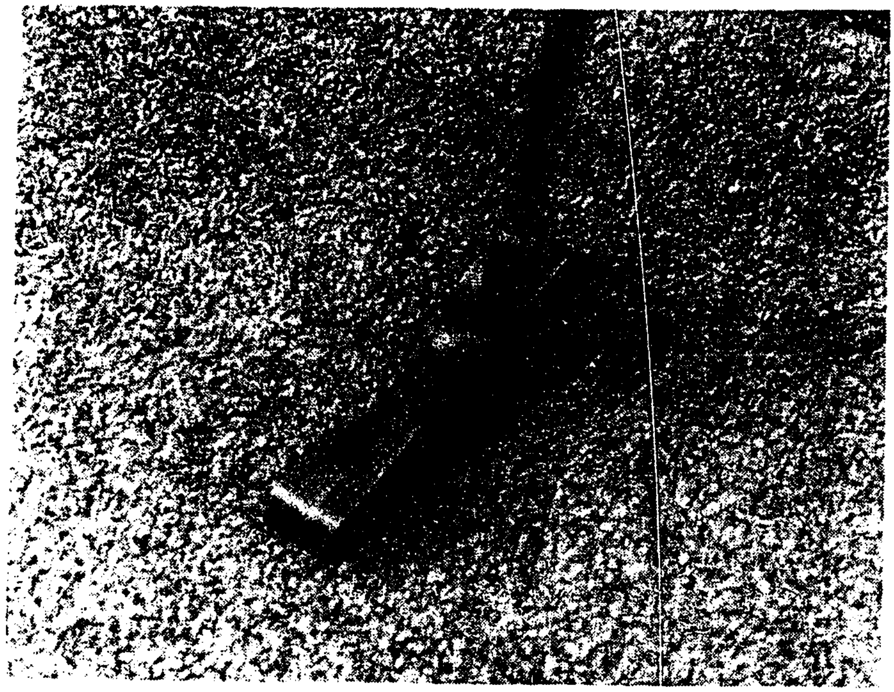
P4

SLOTLINE



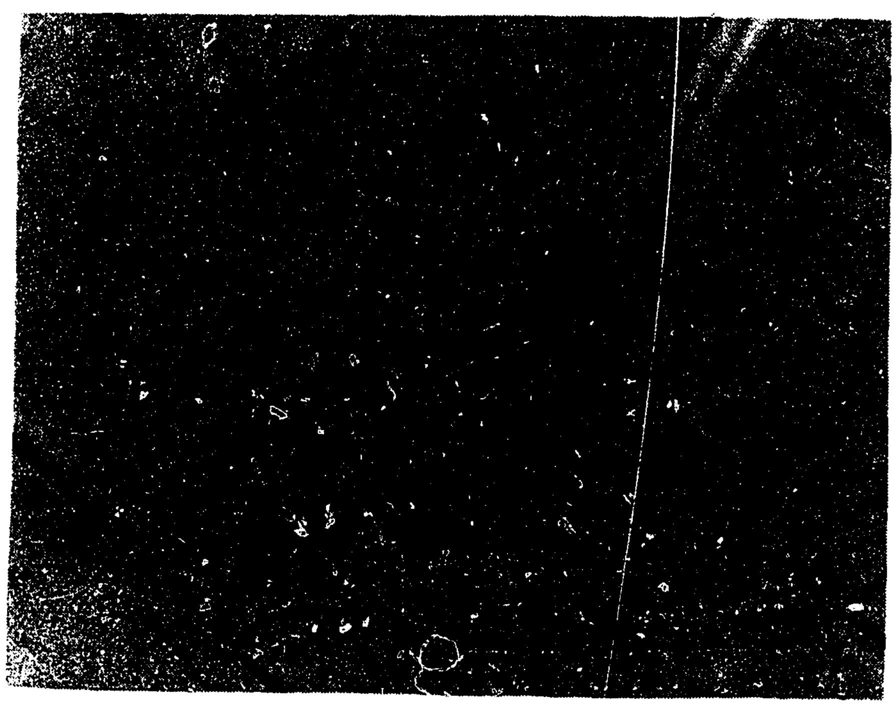
P5

STYX



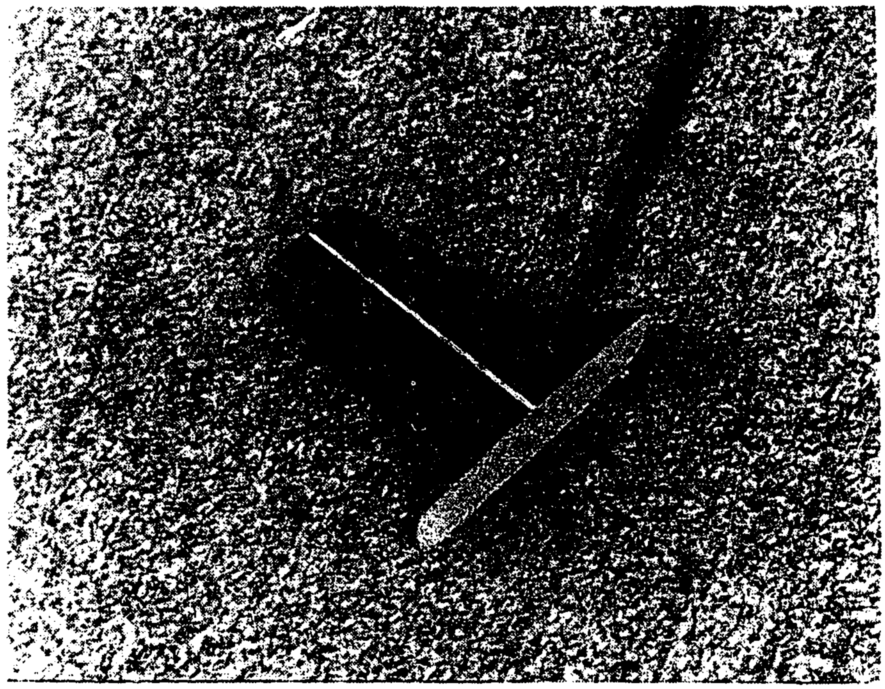
P6

TITLEIST



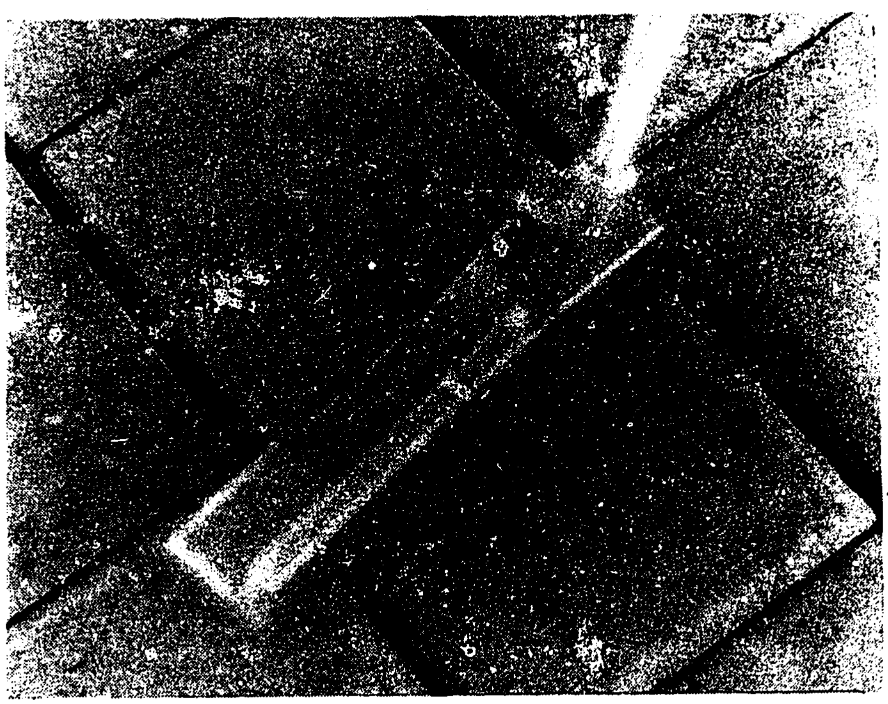
P9

WILSON

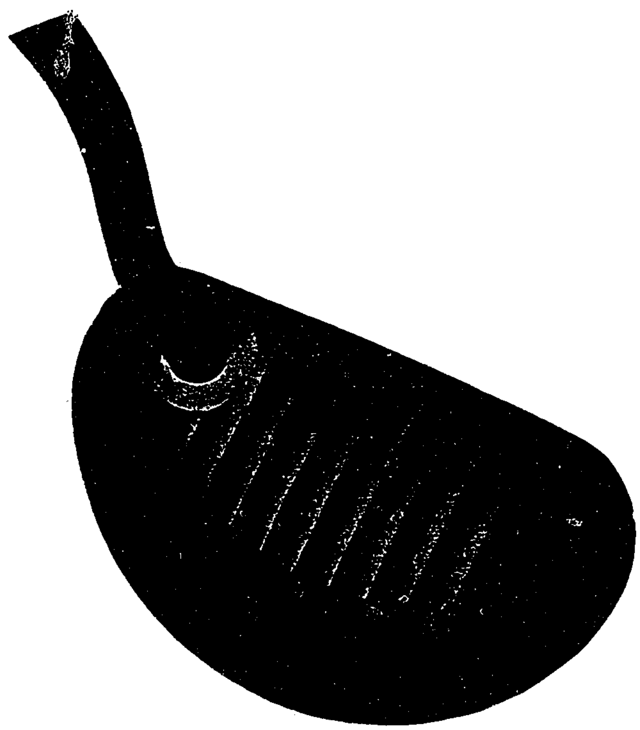


P7

MACGREGOR



P8
RAM



APPENDIX B

RAW DATA

ON

EACH PUTTER TRIAL

RESTRICTED ROTATION

(Tabular information on displacement units from zero)

Putter	Test #		Heel	C of P	Toe
Ping B62	1		+1	+8	-2
	2		+1	+8	-2
	3		+1	+7	-4
	4		+3	+7	-2
	5		+1	+8	-2
	6		+2	+7	-4
		M	+1.5	+7.5	-2.66
Inverted Loft	1			+7	+2
	2			+7	+3
	3			+7	+1
	4			+7	+2
	5			+7	+1
	6			+7	+1
		M		+7	+1.5
Ping Original	1		+3	+8	+2
	2		+3	+7.5	+2
	3		+3	+8	+2
	4		+3	+7.5	+2
	5		+3	+8	+2
	6		+3	+8	+2
		M	+3	+7.83	+2
Slotline	1		0	+1	-2
	2		-1	+0.5	-2
	3		-3	+1	-4
	4		-0.5	0	-2
	5		-1	0	-3
	6		-1	+0.5	-2
		M	-1.08	+0.5	-2.5

Putter	Test #	Heel	C of P	Toe
Styx	1	-7	-3	-10
	2	-7	-3	-10
	3	-7	-3	-12
	4	-7	-3	-12
	5	-7	-3	-12
	6	-6	-3	-12
	M	-6.83	-3	-11.3
Titleist	1	+4	+8	+6
	2	+5	+8	+6
	3	+5	+8	+6
	4	+5.5	+8	+6.5
	5	+55	+7.5	+6
	6	+5	+8	+6
	M	+4.92	+7.92	+6.08
Wilson	1	+6	+8	+6
	2	+6	+8	+6
	3	+6	+7.5	+6
	4	+6	+8	+6.5
	5	+6	+8.5	+6
	6	+6	+8	+6
	M	+6	+7.83	+6.08
MacGregor	1	+5.5	+6	+5
	2	+5	+7	+5
	3	+5.5	+7	+5
	4	+5	+7	+5
	5	+5.5	+7	+5
	6	+5	+7	+5
	M	+5.25	+6.83	+5
Ram	1	+3	+3	-2
	2	+3	+3	-2.5
	3	+3	+3	-4
	4	+3	+3	-1.5
	5	+3	+3	-2

6		+3	+3	-2
	M	+3	+3	-2.33

FREE ROTATION

(Tabular information on displacements units from zero)

Putter	Test	Heel		C of P	Toe	
		Units	Degrees		Units	Degrees
Ping B62	1	0	12	+8	+2	12
	2	0	12	+8	+1	13
	3	+1	8	+7	+1	12
	4	0	10	+7	+2	10
	5	-1	10	+8	+2	12
	6	0	10	+7	0	13
	M	0	10.3	+7.5	+1.3	12
Ping Orig.	1	0	14	+7	+2	10
	2	0	14	+7	+2	10
	3	-1	18	+7	+2	11
	4	-2	20	+7	+2	10
	5	-1	18	+7	+2	11
	6	-1	18	+7	+2	11
	M	-.08	17	+7	+2	10.5
Inverted	1			+8	-4	10
	2			+7.5	-5	10
	3			+8	-4	10
	4			+7.5	-5	10
	5			+8	-4	10
	6			+8	-4	10
	M			+7.83	-4.83	10
Slotline	1	-2	12	+1	-2	6
	2	-2	12	+0.5	-2	6
	3	-2	14	+1	-3	6
	4	-2	14	0	-2	9
	5	-2	12	0	-2	6
	6	-2	12	+0.5	-3	6
	M	-2	12.7	+0.5	-2.3	6.5

Putter	Test	Heel Units	Heel Degrees	C of P	Toe Units	Toe Degrees
Styx	1	-9	8	-3	-10	9
	2	-9	8	-3	-10	9
	3	-9	8	-3	-12	16
	4	-9	8	-3	-12	16
	5	-9	8	-3	-10	9
	6	-9	8	-3	110	9
	M	-9	8	-3	-10.7	11.3
Titleist	1	-4	7	+8	+5	13
	2	-3.5	9	+8	+5	13
	3	-4	7	+8	+5	13
	4	-4	8	+8	+5	13
	5	-4	7	+7.5	+4	14
	6	-4	7	+8	+5	13
	M	-3.9	7.5	7.92	+4.8	15
Wilson	1	+4	14	+8	+4	13
	2	+4	14	+8	+4	13
	3	+4	17	+7.5	+4	17
	4	+4	17	+8	+4	13
	5	+4	14	+8.5	+4	17
	6	+4	14	+8	+4	17
	M	+4	15	+7.83	+4	15
MacGregor	1	+3	10	+6	+3.5	6
	2	+3	8	+7	+4	5
	3	+3	10	+7	+4	5
	4	+3	8	+7	+4.5	5
	5	+3	8	+7	+5	3
	6	+3	8	+7	+4	5
	M	+3	8.7	+6.83	+4.2	4.8

Putter	Test	Heel		C of P	Toe	
		Units	Degrees		Units	Degrees
Ram	1	-1	10	+3	0	4
	2	-1	10	+3	0	4
	3	-1	10	+3	0	4
	4	-1	10	+3	0	4
	5	-2	12	+3	0	4
	6	-2	12	+3	0	4
	M	-1.3	10.7	+3	0	4

APPENDIX C

FORMULAS