PERFORMANCE ANALYSIS AND IMPROVEMENT DESIGN OF GOLF CLUBS

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ABSTRACT
Recently, golf has become a very popular sport, and most golfers focus on improving their skills and learning process. However, many researchers have studied and found that the hardness and vibration frequency of golf club, and the weight and angle of club head can result in unstable swing distance and accuracy. The golfers modify their swings attitude to adapt to the equipments, or even change the club set, and sometimes these situations cause sports injuries to golfers. Therefore, this study discusses how to design an optimal club set for individual golfers by customization and decreases the cases of sports injuries. The Taguchi method is applied to analyze and design the optimum club for shaft hardness, club head weight, spine and grip weight. The improved club is tested, and the result shows that the driving distance is increased by more than 10%, so that the maximum efficiency of hitting is increased. This study provides important reference for design of golf clubs.

Keywords: club head; spine; Taguchi method.

ANALYSE DE LA PERFORMANCE ET UNE CONCEPTION AMÉLIORÉE DES BÂTONS DE GOLF

RÉSUMÉ
Le golf est devenu ces derniers temps un sport très populaire, et la plupart des golfeurs se concentrent surtout sur l'amélioration de leurs habilités et le processus d'apprentissage. Toutefois, un bon nombre de chercheurs ont constaté dans leurs recherches que la dureté et la fréquence de vibration du bâton ainsi que le poids et l'angle de la tête peuvent amener une instabilité dans la distance du drive et la précision. Les golfeurs modifient leur attitude lors de l'élan pour l'adapter à l'équipement, ou même vont changer leur ensemble de bâtons. Parfois ces situations occasionnent des blessures. Par conséquent, notre recherche s'intéresse à la possibilité de concevoir un ensemble de bâtons personnalisés pour chaque joueur, et diminuer ainsi le risque de blessures. La méthode Taguchi est appliquée pour analyser et concevoir le bâton optimal dans la dureté de son manche, du poids de la tête du manche, la courbure et la prise. Le bâton amélioré a été soumis à des tests, et les résultats ont démontrés que la distance du drive est augmentée par plus de 10%, pour donner le maximum d'efficacité au coup. Cette étude présente des références importantes pour la conception des bâtons de golf.

Mots-clés : tête du bâton; courbure; méthode Taguchi.

1. INTRODUCTION

Increasingly, consumers or golfers have higher demands of golf clubs, and also the lightweight and an accurate hit of clubs become major demands. As a result, the golf club manufacturing industry continues to research and develop golf technology. The advancements in precision technology for golf have introduced new materials, and different materials are applied for the design of club shaft. The shaft has developed and evolved wooden, iron, alloy and carbon fiber clubs [1, 2]. Manufacturing requirements lower for carbon fiber clubs than for alloy clubs. Also, the carbon fiber club has a better flexibility, and the hitting distance of club is better. Therefore, the clubs available in the market are mostly carbon fiber clubs. Nowadays, the alloy has light weight and high hardness, performs better in direction control, and is thus preferred by golfers [1].

A golf club is constituted of shaft, club head and grip, and according the recent studies, appropriate shaft hardness and club head weight can result in optimum club with better coordination, farther distance and straighter trajectory. Also, the golfers can reduce sports injuries and strive for better athletic performance by using optimum clubs. It is the goal and contribution of this paper. The Taguchi method is adopted for the quality analysis [3, 4] and applied to evaluate the spine position of the club and extend to a set combination of golf club. The analysis results can be served as criteria of club combination, and be the design basis of subsequent development of customized and high value added clubs [5, 6].

2. EXPERIMENTAL PROCESS AND METHOD

2.1. Application of the Taguchi Method for Experiments

The Taguchi method and a three-level L9(34) orthogonal array are applied for improvement analysis of the influence of shaft, club head, spine and grip on No. 7 iron club. The experiment analyzes two groups of key factors. One group is the hitting distance and since it is a 'the-Larger-the-Better' case, this means the quality characteristic is the larger, the better. The other group is the distance from the ball and tee to the central line of green; this is a 'the-Smaller-the-Better' case which indicates the quality characteristic is the smaller, the better. The process of experiment is described as follows:

Step 1: Four factors including hardness of club with different levels, club spine at different positions, club head with different weights and club grip with different weights are combined with three levels of No. 7 club for each factor.

Step 2: The swing tester has to make regular preparations before hitting, such as several trial swings, aiming, deep breathing and so on. Each club rests for ten minutes after it hits five balls.

Step 3: The flight distance of five balls and the deviation from the central line are measured, and recorded in Taguchi's orthogonal array.

Step 4: Repeat the last two steps till three sets of club finish hitting.

Step 5: The adhesive between club head and shaft is softened by hot-air fan, the club head and collar are pushed away by collar fixture; the grip is separated from the shaft by air compressor. The shaft finishing machine grinds the adhesive away from the shaft, combined with the clubs of three groups of factors again. The collar is mounted by collar fixture, the shaft part close to the club head is coated with adhesive to fix the club head, the spine is aligned with the relative position of club head, the grip is mounted five minutes later. When the new club is composed, Steps 2 to 5 are repeated till the nine clubs of different factor combinations finish hitting.

Step 6: The maximum quality characteristic factor obtained from the experiment matches one club, Steps 2 and 3 are repeated, compared with the driving distance and deviation from the central line of No. 7 iron club used by the swing tester.

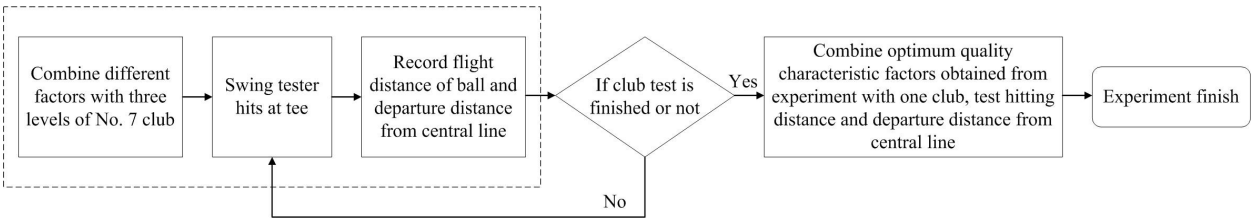

Fig. 1. Experimental process.

Table 1. Experimental materials [7].

No.	Item	Material or model	Specs
1	Shaft	70 g cloth rolled 100% carbon fiber shaft	285 cpm, 300 cpm, 310 cpm
2	No. 7 club head	Loft 35°, elevation 61°	271 g, 281 g, 291 g
3	Grip	Semi-mixed rubber and cotton yarn	42 g, 47.5 g, 52 g
4	Adhesive	Chemically reactive binding agent	1 bottle
5	Golf ball	Titleist PRO V1	30 balls

2.2. Experimental Materials

The materials for the Taguchi experiment are listed in Table 1, according to the experimental features, and the required items are also described.

2.3. Experimental Apparatuses and Equipments

Table 2 shows the experimental apparatuses and equipments used in the Taguchi experiment. Also the required items are described.

Table 2. Experimental apparatuses and equipments.

No.	Equipment designation	Model or brand
1	Angle meter, Torque meter, Vibration measurer, Spine measurer ,Shaft abrader, Hot-air fan, Swing speed detector	GOLF MECHANIX
2	Shaft cutter, Collar fixture, Infrared aligner	HONO GOLF
3	GPS satellite positioning device	GARMIN

2.4. Experimental Control Parameters

This experiment uses the Taguchi method to find out better club combination according to specific swing tester. As the swing tester's swing speed is relatively high, the shaft and club head are different from general ones. The cpm (cycle per minute, club vibration frequency) value of shaft is higher, i.e. the higher the shaft hardness, the heavier the club head . Table 3 shows the control factors and levels of this experiment.

3. EXPERIMENTAL RESULTS

The shaft hardness CPM and club head weight are determined according to the swing speed when the golfer chooses the golf club. For high swing speed, hard shaft and heavy club head are recommended; on the contrary, for low swing speed, soft shaft and light club head are recommended, such a club combination still needs to be validated to check if it is a better club. Therefore, this paper uses the Taguchi method for analysis and comparison to determine the better club of maximum hitting distance and minimum deviation from the central line.

Table 3. Experimental control factors and levels.

Factor	Description	Level 1	Level 2	Level 3
A	Shaft hardness	285cpm	285cpm	285cpm
B	Spine angle (degree)	0 or 180	90 or 270	Others
C	Club head weight	271 g	281 g	291 g
D	Club grip weight	42 g	47.5 g	52 g

Table 4. Hitting distance improvement experiment record and data (unit: yd).

EXP.	y1	y2	y3	y4	y5	Ave	S	S/N
1	160.4	159.1	164.2	176.7	173.1	166.7	7.82	44.4
2	177.4	180.6	175.8	181.3	182.1	179.4	2.71	45.1
3	141.3	143.8	136.1	148.7	145.9	143.2	4.79	43.1
4	179.5	184.9	195.6	190.4	183.5	186.8	6.29	45.4
5	167.1	172.3	176.2	170.9	171.1	171.5	3.26	44.7
6	160.3	165.2	166.2	157.6	156.9	161.2	4.28	44.1
7	175.3	177.2	179.5	189.3	170.3	178.3	7.01	45.0
8	170.2	171.3	174.1	189.8	182.4	177.6	8.35	45.0
9	172.1	162.1	164.4	176.5	174.8	170.0	6.39	44.6

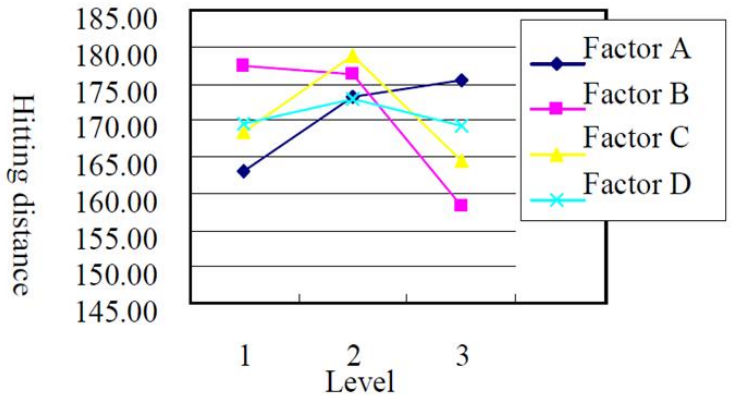

Fig. 2. Factorial effect of hitting distance.

3.1. Analysis of Hitting Distance

From the results, it is shown that the S/N ratio characteristic is determined according to different requirements. This experiment uses Larger-the-Better type, larger value represents farther hitting distance, as well as better quality characteristic. Therefore, the S/N ratio data of various groups can be obtained from mean value and standard deviation. Figure 2 shows the data response of hitting distance S/N ratio.

For factorial effect of hitting distance, the values of A1, B1, C1 and D1 are used as mean values, the values of level 1 are summed up and averaged, which are 163.10, 177.27, 168.50 and 169.40, respectively. The values of A2, B2, C2 and D2 are mean values, the values of level 2 are summed up and averaged, which are 173.18, 176.17, 178.73 and 173.00, respectively. The values of A3, B3, C3 and D3 are mean values, the values of level 3 are summed up and averaged, which are 175.29, 158.13, 164.33 and 169.17, respectively. The factorial effect is maximum level value minus minimum level value, so the effect of Factor A is 12.19, the effect of Factor B is 19.14, the effect of Factor C is 14.40, and the effect of Factor D is 3.83. A group of optimum parameters can be obtained from the factorial effect of hitting distance in Fig. 2, the better design

Table 5. Analysis of variance in hitting distance.

Factor	A Club hardness	B Spine angle	C Club head weight	D Grip weight	Error	Total
Contribution	12.85%	35.00%	37.83%	1.39%	12.91%	100.00%

Table 6. Hitting accuracy improvement experiment record and data (unit: 100 yd).

EXP.	y1	y2	y3	y4	y5	Ave	S	S/N
1	0.06	0.02	0.03	0.05	0.04	0.040	0.016	27.45
2	0.02	0.03	0.02	0.01	0.03	0.022	0.008	32.68
3	0.12	0.13	0.11	0.1	0.09	0.110	0.016	19.10
4	0.02	0.05	0.03	0.01	0.04	0.030	0.016	29.59
5	0.01	0.02	0.03	0.03	0.04	0.026	0.011	31.08
6	0.09	0.06	0.07	0.08	0.1	0.080	0.016	21.80
7	0.03	0.02	0.03	0.04	0.02	0.028	0.008	30.76
8	0.04	0.01	0.02	0.03	0.02	0.024	0.011	31.67
9	0.06	0.05	0.08	0.07	0.06	0.064	0.011	23.77

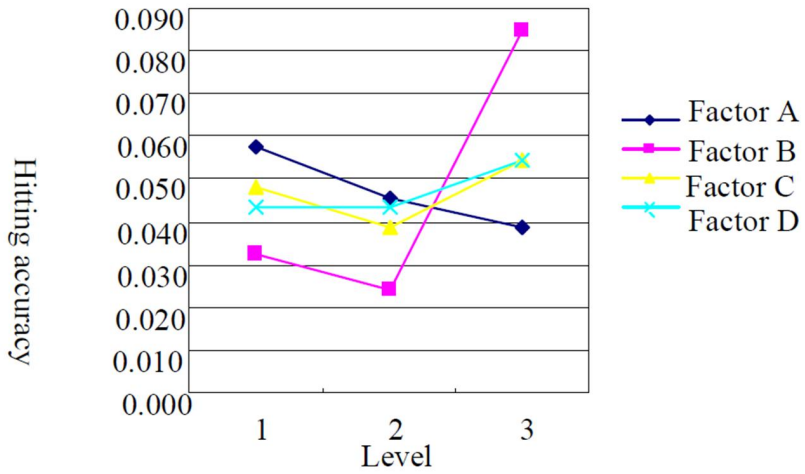

Fig. 3. Factorial effect of hitting accuracy.

factor is A3B1C2D2 parameter combination. The fundamental purpose of analysis of variance is to evaluate the experimental error: only if the factorial effect is great large compared with the experimental error, this factorial effect is proved meaningful or important. From Table 5, the contribution of factor C is 37.83%, and the experimental error contribution is 12.91%. So, factor C has the most significant influence on the experiment.

3.2. Analysis of Hitting Accuracy

Table 6 and Fig. 3 show that the values of A1, B1, C1 and D1 are taken as mean values. The values of level 1 are summed up and averaged, which are 0.057, 0.033, 0.048 and 0.043, respectively. The values of A2, B2, C2 and D2 are used as mean values, and the values of other levels are summed up and averaged. The factorial effect is maximum level value minus minimum level value, e.g., so the effect of Factor A is 0.019, the effect of Factor B is 0.061, the effect of Factor C is 0.016, and the effect of Factor D is 0.011. According to the factorial effect, Factor B has the most significant influence on the hitting accuracy, followed by Factor

Table 7. Records of improved combined club (unit: yd).

EXP.	y1	y2	y3	y4	y5	Mean
Improved combined club	191.2	188.1	182.7	198.7	194.8	191.10
Swing tester's No. 7 club	176.2	173.8	173.5	177.8	168.8	174.02
Hitting efficiency						9.81%

Table 8. Comparison of club hardness for hitting distance and accuracy.

Description	Level 1	Level 2	Level 3
A factor	285CPM	300CPM	310CPM
Club specification	S	SG	X
Hitting power	Slight	Moderate	High
Hitting distance	163.10 yd	173.18 yd	175.29 yd
Hitting accuracy	5.7 yd	4.5 yd	3.9 yd

A and Factor C. Factor D has the minimum influence. A group of optimum parameters can be obtained from the factorial effect of hitting accuracy in Fig. 3. The better design factor is the A3B2C2D2 parameter combination.

3.3. Analysis of Improved Club

The combined improved club and the swing tester's No. 7 club hit five balls respectively. The records are shown in Table 7. The hitting distance of the improved club is 191.2, 188.1, 182.7, 198.7 and 194.8, respectively. The average hitting distance is 191.1. The hitting distance of the swing tester's No. 7 club is 176.2, 173.8, 173.5, 177.8 and 168.8, respectively. The average hitting distance is 174.02.

The hitting efficiency trial is 9.81% (hitting efficiency computing mode (191.10–174.02)/174.02x100% = 9.81%). The actual average hitting distance of the improved club is 191.1 yd. The prediction value of the improved club is 192.72 yd. The difference is about 0.84%, the experimental value approaches the prediction value, proving the rationality of experiment.

4. RESULTS AND CONCLUSION

According to the experimental results, the club head weight has the most significant effect on the hitting distance among the four factors, and the angle of spine is the first influencing factor in the hitting accuracy.

4.1. Analysis of Hitting Distance Results of Golf Club Shaft Verification

Table 8 shows that the hitting distance varies with the club hardness (cpm). The three levels of Factor A are 285, 300 and 310 cpm, respectively, the hitting distance in the experiment is 163.10, 173.18 and 175.29 yd, respectively. In terms of club hardness 310 cpm, the maximum hitting distance is 175.29 yd. In this paper, the cpm of the swing tester's club is set as 310 to 300. As the swing tester's hitting power is very strong, the club specification is X, so the maximum hitting distance results rationally.

The data of hitting accuracy at level 1, level 2 and level 3 are 5.7, 4.5 and 3.9 yd, respectively. For professionals, the iron club placement within 5 yd is in normal range, the hitting accuracy of level 1 is not ideal. This is because the club is too soft compared with the swing tester's hitting power: the club is bended during hitting, so the striking angle slightly deviates.

4.2. Results of Golf Club Spine Verification

According to the experimental data, in Factor B (spine angle), the hitting distance of level 1 is 177.27 yd, the hitting accuracy is 3.3 yd, as shown in Table 9. The hitting distance of level 2 is 176.17 yd, and the

Table 9. Comparison of spine for hitting distance and accuracy.

Description	Level 1	Level 2	Level 3
B factor	0 to 6 o'clock direction	3 to 9 o'clock direction	45° direction
Hitting distance	177.27 yd	176.17 yd	158.13 yd
Hitting accuracy	3.3 yd	2.4 yd	8.5 yd

Table 10. Comparison of club head for hitting distance and accuracy.

Description	Level 1	Level 2	Level 3
C factor	271 g	281 g	291 g
Club specification	S	SG	X
Hitting power	Slightly strong	Moderately strong	Highly strong
Hitting distance	168.50 yd	178.73 yd	164.33 yd
Hitting accuracy	4.8 yd	3.9 yd	5.5 yd

hitting accuracy is 2.4 yd. The hitting distance of level 3 is 158.13 yd, and the hitting accuracy is 8.5 yd. The measured hitting distance or hitting accuracy of level 1 are very close to that of level 2. The hitting distance is 177.27 and 176.17 yd, respectively. The difference is 1.1 yd. The hitting accuracy is 3.3 and 2.4 yd, respectively, the difference is 0.9 yd. Therefore, levels 1 and 2 are correct spine angles, and these are the spine angles adopted by various golf club manufacturers worldwide.

As level 3 is the club without adjusted spine, the direction of stroke deviates from the preposition, and the hitting distance is shortened by almost 20 yd, the efficiency of hitting distance is reduced by 12.1%. It is obvious that the accuracy of spine angle is of great importance, it not only influences the hitting accuracy, but also influences the hitting distance. If the hitting distance is short, there may be problems in the spine angle, the spine angle shall be adjusted properly.

4.3. Results of Golf Club Head and Grip Verification

In the experiment on club head and grip, the relationship of the club head to the hitting distance and accuracy can be obtained from Table 10. The hitting distance of level 1 is 168.5 yd, and the hitting accuracy is 4.8 yd. The hitting distance of level 2 is 178.73 yd, the hitting accuracy is 3.9 yd. The hitting distance of level 3 is 164.33 yd, the hitting accuracy is 5.5 yd. The maximum hitting distance is 178.73 yd of level 2, followed by the 168.5 yd hitting distance of level 1. The minimum hitting distance is 164.33 yd of level 3. The level 2 has the best experimental hitting accuracy of 3.9 yd, followed by the hitting accuracy 4.8 yd of level 1. Level 3 has the worst hitting accuracy of 5.5 yd. As the swing tester's hitting power is very strong, according to the club specification sheet of Hono Golf, the club head weight shall be 291 g (level 3). However, level 3 has the shortest experimental hitting distance and the lowest experimental hitting accuracy, whereas level 2 has the longest hitting distance and the best hitting accuracy. It is obvious that the club specification sheet derived from empirical values and golfers' feedback must be corrected partially. The better club hitting distance in the club specification sheet of Hono Golf is compared with the estimated value of hitting distance of improved club.

Table 11 compares the grip weight for hitting distance and accuracy. Level 2 has the best hitting distance and hitting accuracy, then level 1, and level 3 is worst. Although the grip weight influences the hitting distance and accuracy slightly due to the hitter's feeling and subjective factor in grip, this factor is taken into the improved club.

Table 11. Comparison of grip weight and hitting distance and accuracy.

Description	Level 1	Level 2	Level 3
D factor	42 g	47.5 g	52 g
Club specification	S	SG	X
Hitting power	Slightly strong	Moderately strong	Highly strong
Hitting distance	169.40 yd	173.00 yd	169.17 yd
Hitting accuracy	4.3 yd	4.3 yd	5.5 yd

Table 12. Comparison between experimental values and predicted values of improved club.

Description	Hitting distance (yd)
Improved combined club	191.10
Predicted design value of improved combined club	192.72
Swing tester's No. 7 club	174.02
Predicted design value of club of HONO GOLF	174.50

4.4. Comparison of Improved Club

The improved process parameter combination is concluded from many assumptions. Mass production before the assumptions are proven to be correct, may cause heavy losses. The improved club and swing tester's club test analysis is shown in Table 12 and compared with the predicted design values of Hono Golf. The predicted design value of improved combined club is 192.72 yd. The measured hitting distance of the improved combined club is 191.10 yd. The experimental hitting distance of the swing tester's club is 174.02 yd. The improved parameter factor combination of the club of HONO GOLF is A3B1C3D3, and the predicted design value y is obtained by

$$y = \bar{y} + (A_{LA} - \bar{y}) + (B_{LB} - \bar{y}) + (C_{LC} - \bar{y}) + \cdots \tag{1}$$

The predicted value of the improved club of HONO GOLF is 174.50 yd. It is observed in Table 14 that there is a difference in the measured hitting distance or the hitting distance calculated from the equation. The measured hitting distance of the improved combined club is 191.10 yd, that of the swing tester's No. 7 club is 174.02 yd, the difference is 17.08 yd. In terms of equation calculated hitting distance, the predicted design value of the improved combined club is 192.72 yd, the predicted design value of the club of HONO GOLF is 174.50 yd, the difference is 18.22 yd. It is obvious that the data derived from empirical and the golfers' feedback data are different from the measured results to some extent. The experimental values are quite consistent with the predicted values (i.e. the 191.10 and 192.72 yd measured values are quite close to each other in Table 12, and the 174.02 and 174.50 yd measured values are close to each other), so calculations in this paper are precise and reliable.

5. CONCLUSION

The experimental values and predicted values of improved club mentioned in this paper can be important reference for golf companies to customize the clubs in the future, the hitting distance can be increased by about 10% to increase the maximum hitting efficiency of club. According to the experimental results of the improved club, the spine angle is the major factor influencing the hitting distance and hitting accuracy. Therefore, the spine angle must be adjusted in order to make a good club. The swing speed, i.e. the hitting power, is the main basis of choosing club specification, but in terms of club head weight, higher hitting power does not mean to choose heavier club head, the optimum club parameter combination must be found by using the Taguchi method, so as to determine the club head weight. With advancement of

technology, new materials are developed continuously and applied to golf industry, and the hitting distance increases continuously, manufacturers shall aim at using reliable and precise experimental data to design high efficiency clubs.

If there are swing testers with different typical hitting powers for experiment, all experimental data are rearranged effectively, and the Taguchi method is used to design new club specification look-up tables, the hitting distance and hitting accuracy can be increased greatly, and there will be a standard process for golf manufacturers to improve clubs, as well as important reference for the future club customization. It is found in the experimental process that the stress point is set in the center section of club when the golf manufacturer measures the spine, but the stress point of a real hitting shall be at the end of club. Therefore, changing the club measuring position approaches real hitting. Different measurement modes result in different spine positions in some clubs, which can serve as a reference for future researches.

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