A Study of Surface Roughness and Impacts between Golf Balls and the Face of a Golf Club Head

A Major Qualifying Project Report

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by

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Approved:

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Special Acknowledgement

This project was done in collaboration with Zhansong Xu. I would like to sincerely thank him for his diligence and cooperation. After working together on the topic of golf impacts, Zhansong completed a separate research report titled "A Study of Impact between Golf Ball and Face of Golf Club Head." Some of the information presented in the following report was taken verbatim from Zhansong's report; all of these sections were either written, proofread, or approved by myself.

1. Abstract

This project focused on evaluating golf club head surfaces by measuring the spin rate of a golf ball after impact. A repeatable test was created using finished stainless steel surfaces to replicate golf club head surfaces and to measure the effectiveness of various surface roughness on golf ball spin. An effective surface was determined to be one that created relatively more spin rate on the golf ball. The goal of this project was to study different surface roughness and evaluate their performances as a golf club head surface.

2. Introduction

Golf is an interesting and relaxing sport that requires skills to play well. Players need to shoot accurately to achieve better results. Imparting backspin to a golf ball will let it stop near the landing point, rather than continue going forward. Professional golfers have obtained the skills, experience, and knowledge necessary to inflict backspin on a golf ball.

Objective

2.1 The objective of this project is to advance the understanding of the interaction between a golf ball and the face of a golf club head during impact. By testing varying surface roughness, our goal is to better understand how the golf ball spin that can be achieved.

Rationale

2.2 According to a trainer at the Jim Mclean Golf Center, regarded as the top golf school in the United States, having the ability to apply backspin during a golf match has proven to improve a golfer's quality of play (McLean 2000). An in-depth study of golf backspin could help amateur golfers, as well as professionals, improve their golf game.

State-of-the-art

2.3 Many techniques in machining methods and material selection have successfully enhanced a golfer's ability to spin a golf ball but none of these are permitted by the USGA. For many years and still today, many golfers believe that the grooves inserted into all modern clubs enhance backspin. This was proven incorrect after many studies concluded that the sole purpose of the grooves was to shed water during the moment of impact between the golf club and the golf ball (Tannar 2015).

3. Background Research

Ping pong Ball Study

3.1 Impact behavior of ping-pong balls has been studied by the University of Sydney. The experiment was done by dropping a ping-pong ball by hand at speeds up to about 10m/s normally on a force plate. A 600 fps camera was used to measure the incident speed and rebound speed of the ping-pong ball. Force measured from the force plate versus time elapsed was plotted to analysis graphs in order to obtain properties of impact (Cross 2013).

Golf Ball Dynamic behavior due to impact

3.2 Researchers have been studying the impact behavior of golf balls by measuring contact force and time spin rate as a function of impact velocity. Experimenting by launching a golf ball horizontally to an oblique surface has previously been done. As inbound ball velocity increases, the mean angular velocity of the ball will increase after impact. Many impact experiments are hindered by air gaps below the testing surface. If a relatively smooth surface compare to rough surface is used as an impact surface, the angular velocity after impact will decrease (Arakawa et al. 2007).

Relevant Patents

3.3 For enhancing backspin, the golf club's face is an important asset. Inventors have found different ways to make golf club faces that enhance golf ball backspin over last century. In a patent invented by Igarashi, the club face has relatively sharp grooves compared to conventional clubs; these sharp grooved edges resulted in more spin (Igarashi 1995). This study directly contradicts that of Ken Tanner, who stated the lesser relevance of grooves on ball spin (Tanner 2015).

3.4 In another patent invented by Thompson, providing parallel steps from the lower edge to upper edge of club face can impart backspin to the golf ball, because "a plurality of edges adapted to bite into a golf ball upon impact to impart back spin to the ball" (Thompson 1975). Kitaichi invented a golf club head with elastic intermediate applied to the club face. When launching the ball, the elastic deformation of the elastic intermediate impart excessive backspin to a golf ball due to longer contact time (Kitachi 1995).

USGA Regulations

3.5 USGA regulation state the following: "the whole of the impact area must be of the same material." The regulations also indicate that "face treatments have may be applied (i.e. grooves, sandblasting, etc.)." Though extreme alterations to the material is not permitted, the USGA has many exceptions to allow various surface finishes.

Existing Device

3.6 The Spin Doctor Wedge is a modern golf club which is marketed for its enhanced backspin capabilities. It was created using an insert system called "Fresh Face Technology." By using a Spin Doctor Wedge, players are able to select different inserts and adjust during a golf match to accommodate the amount of spin necessary. The purpose of having these varying inserts is to generate a different backspin rate (Spin Doctor Golf Inc. 2015). On a side note, this golf club has been declared illegal by the United States Golf Association and is not permitted to be used by professional or amateur golfers.

Impact Force-time Curve

3.7 As shown in figure 1(Russell 2011), during an impact between a baseball and a bat without considering energy loss, force acting on the ball gradually increases to a point where it reaches maximum value from zero after the ball get in touch with bat, then gradually decreases to zero until the ball leaves the bat. The time spent by each of these two steps are equivalent.

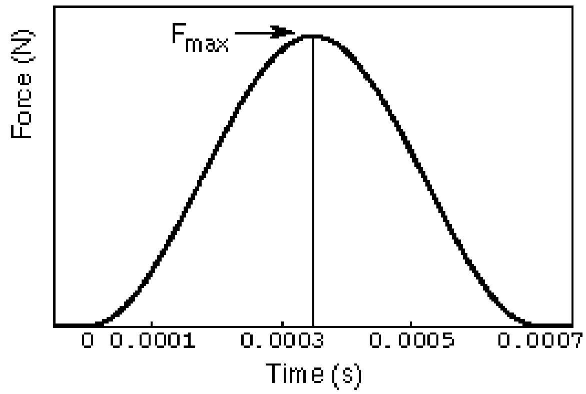

Figure 1: Force vs Time Graph (Russell 2011)

Impact Calculations

3.8 Impact is a high force applied over a short time period when two or more bodies collide. To show the relationship of initial and final kinetic energy when an object makes an elastic impact with another object which is stable, in an ideal situation where energy loss to heat is negligible, energy is constant and the equation of kinetic energy can be expressed as:

$$KEi=KEf \text{ [1].}$$

3.9 These express initial and final kinetic energy. Sum of kinetic energy can be expressed as the sum of linear kinetic energy and rotational kinetic energy, which is:

$$KE=KElinear+KErotational \text{ [2]}$$

3.10 Therefore, assuming that energy is conserved, Equation [1] can be expressed as:

$$12mvi2+12I\omega i2=12mvf2+12I\omega f2 \text{ [3]}$$

m is the mass of the object, *v* is the linear velocity of the object, *I* is the moment of inertia of the object and *ω* is the angular velocity of the object (Nave 2012).

3.11 To consider the force of impact, the force can be called “slow down force”, and distance of deformation when objects making elastic contact can be called “slow down distance”. When making elastic impact, object will be gradually slowed down to 0 speed and then bounce back off the surface from the stable object in a short time period. Therefore, the energy transfer can be considered as: kinetic energy→ potential energy→ kinetic energy. Maximum potential energy can be expressed as:

$$PE=\int(s)\cdot dssfs0 \text{ [4]}$$

3.12 F(s) is the force acting on the object by the stable object in a function of s, which is the displacement of the object during impact. Due to constant energy, energy equations can be shown as:

$$12mvi2+12I\omega i2=\int(s)\cdot dssfs0=12mvf2+12I\omega f2$$ [5].

Terminal Velocity of Golf Ball during Free Fall

3.13 When considering free fall with air resistance, equation for terminal velocity would be:

$$vt=\sqrt{}2mgC\rho A$$ [6]

C is the numerical drag coefficient, ρ is the air density and A is the cross-sectional area for falling object. In standard atmosphere, the air density is 1.29kg/m3. For a sphere like golf ball, drag coefficient is 0.47. For a standard golf ball of mass 46g and radius 42.7mm, terminal velocity of free fall is 16.1m/s (Nave 2012).

When considering free fall with air resistance, equation for terminal velocity would be: $vt=\sqrt{}2mgC\rho A$ [6] C is the numerical drag coefficient, ρ is the air density and A is the cross-sectional area for falling object. In standard atmosphere, the air density is 1.29kg/m3. For a sphere like golf ball, drag coefficient is 0.47. For a standard golf ball of mass 46g and radius 42.7mm, terminal velocity of free fall is 16.1m/s (Nave 2012).

4. Methods

This research focused on comparing and contrasting how different surface roughness affected the spin rate of a golf ball. During preliminary testing, it became apparent that 240 frames per second was an insufficient amount for analyzing golf impacts; the video quality provided many blurry images. Instead, the video was chosen for a macro shot which would be used solely to measure the velocity of the golf ball prior to impact. For a more detail video quality, a 4,500 frame per second camera was focused on the impact. This video footage would be used for measuring spin rate and velocity after impact. The stainless steel surfaces which were used for the impacts, were attached to a dynamometer. The dynamometer's purpose would be to measure the force of each impact and then correlate those findings with the results of the spin rate and velocities. To function properly, the dynamometer required a series of equipment, including an: amplifier, data acquisition system, and a LabVIEW program.

Ball Release

4.1. Due to the complexity of and numerous variables involved in a golf swing, it is very difficult for a golfer to swing consistently (Glazier 2013). For this experiment, a golf ball will need to be released consistently for the test results to be meaningful. Therefore, a ball release in a fixed position was determined to be more effective than an actual golfer swinging a club. Similar to an aforementioned ping pong study (Section 3.1), this project planned to use a vacuum technique and drop the ball from the same height using a foam tube. Though this would provide a consistent velocity and minimal spin prior to impact, the high speed camera was stationary inside of a laboratory and did not present a suitable environment. Instead, a slingshot was used to achieve consistency. Using a basic structure to fix the slingshot in a location allowed the golf ball to be released with both a constant velocity and minimal spin. The velocity of this golf ball prior to contacting the variable surface was also an important result to consider in this experiment.

Impact Creation

4.2. Following the consistent release of the golf ball, we needed to create an impact for testing. The golf ball was shot through the slingshot towards a stainless steel plate which was attached to a dynamometer. This stainless steel plate was interchangeable, as we tested five different stainless steel plates with varying surface roughness. To minimize the variables during impact, grease was placed in between the surfaces and the dynamometer in case there were any air gaps which may affect the consistency of results (Arakawa et al. 2007). The dynamometer needed to be connected to a series of an amplifier, data acquisition system, and a LabVIEW program on a computer. This dynamometer would be used to measure the forces during impact.

Data and Results

4.3. A study mentioned in section 3.1 of this report successfully used a 600 frames per second camera for measuring a ball's impact at 32 feet per second (similar velocity to our experiment). After designing a testing procedure, we used a high speed camera that recorded 4,500 frames per second for our data. The camera was focused in to visualize the impact, though it also recorded moments before and after the impact. This camera was used for measuring the spin rate of the golf ball in revolutions per minutes, both before and after impact. The purpose of measuring the spin rate before contact was to assure the consistency of our ball release. Next, the camera was also going to be used for measuring the time of impact between the surface and the golf ball, and the speed of the golf ball after impact.

Surfaces for testing

Material

4.4. Prior to selecting the material that would be used for the testing surfaces, careful research had to be completed. The purpose of this research was to assure that the testing surfaces would be identical to that of a golf club (refer to section 3.5). It was also important to remain within the restriction enforced by the United States Golf Association. To accommodate these requirements, stainless steel plates with variable surface finishes were selected.

Surface Finishes

4.5. A minimum of five different surface finishes was determined to be sufficient for this project. For the following test, professionally finished stainless steel plates were obtained from the New England Metals Finishing Company. The five surfaces consisted of a mirror finish, glass bead finish, 60 grit satin finish, 220 grit satin finish, and an aluminum oxide finish.

5. Results

The information in this section is an analysis and evaluation of all the test results. All of the outcomes from the experiment can be found in the appendix (Section A1).

To obtain our data, we tested five different stainless steel surfaces with variable roughness. Each surfaces tested consisted of eight trials. The results of the data included velocity prior to and after impact, and ball spin prior to and after impact. The ball spin and velocity prior to impact was to assure that the golf ball was being released consistently. “Invalid data” was inputted as data results for the two trials which did not have a definite high speed camera visual for calculating spin rate.

Data

Velocity

5.1 The data produced from this experiment provided an array of unexpected conclusions. The diagram below shows the velocity of the golf ball prior to and after impact with the surface. The table below represents the horizontal velocity of each trial of the experiment while the bar graph represents the mean velocity of the golf ball and its mean rebound speed. As hypothesized, the mirror finish resulted in the greatest rebound speed, while both 220 and 60 grit satin finish also rebounded at a speed at approximately 96% of the original speed. Meanwhile the glass bead and aluminum oxide finishes showed a more dramatic difference in rebound speed.

Test Results from High Speed Camera											
Horizontal Velocity of golf ball prior to impact (Ft/s)	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6	Trial 7	Trial 8	Mean	Standard Deviation	Variance
Mirror Surface	33.68	34.22	32.65	33.86	33.51	34.22	35.16	34.22	33.94	0.77	0.59
Glass Bead Surface	31.53	31.07	32.49	33.33	33.86	34.97	35.36	33.16	33.22	1.52	2.30
Aluminum Oxide	32.82	33.51	31.84	34.59	31.37	36.99	36.57	32.99	33.84	2.20	4.85
220 Grit	36.57	35.75	31.68	34.04	34.22	32.82	35.56	33.68	34.29	1.62	2.62
60 Grit	34.41	32.99	34.22	34.78	37.65	33.68	33.51	33.16	34.30	1.49	2.21
Horizontal Velocity of golf ball after impact (Ft/s)	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6	Trial 7	Trial 8	Mean	Standard Deviation	Variance
Mirror Surface	32.61	33.01	32.21	32.88	33.33	32.34	32.88	31.89	32.64	0.47	0.44
Glass Bead Surface	30.00	30.00	30.02	30.03	31.25	31.27	32.61	31.69	30.86	0.99	0.99
Aluminum Oxide	30.00	31.25	30.02	31.25	30.93	34.09	34.80	30.20	31.57	1.86	3.45
220 Grit	35.70	34.09	30.00	32.89	33.04	30.00	34.96	32.27	32.87	2.09	4.38
60 Grit	33.11	31.25	32.61	32.61	35.71	33.00	32.62	32.61	32.94	1.25	1.57

Table 1: Test Results: Velocity prior to Impact

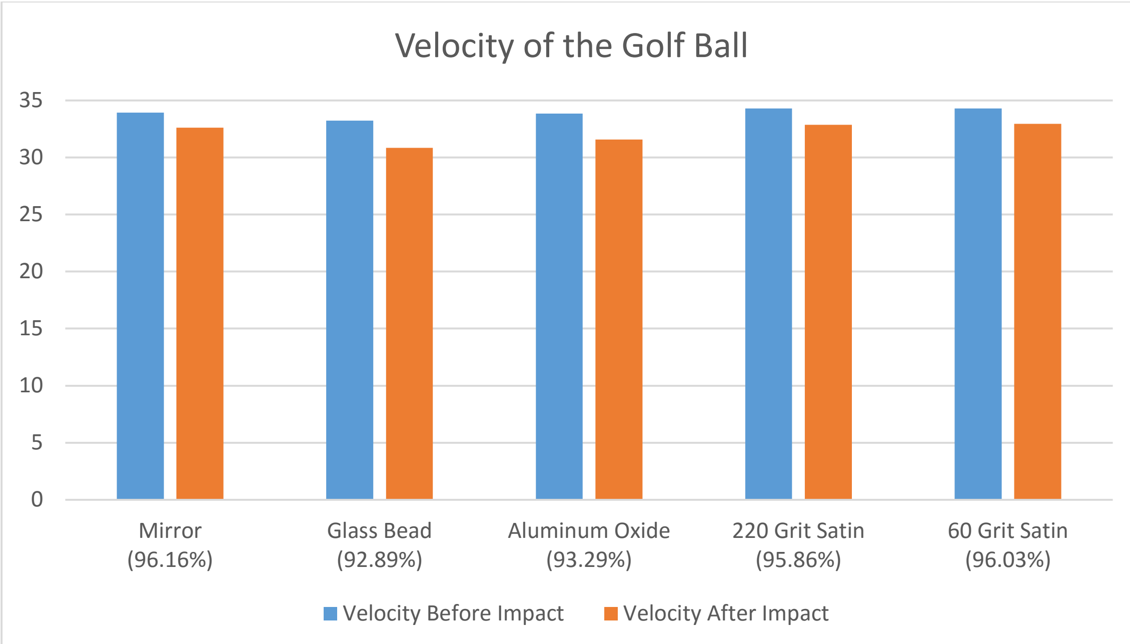

Figure 2: Velocity of the Golf Ball

Spin Rates

5.2 The velocity measurements were the first step towards obtaining consistent data. After declaring that the ball was released in a consistent manner, the results for the backspin of the golf ball could be validated. Below is a table which shows the mean spin rates of the five variable surfaces. Mirror finish, along with 220 grit satin (1,359.93 RPMs) and 60 grit satin (1,290.91 RPMs), proved to be the less effective finishes in this experiment. With an average horizontal velocity of 33.94 feet per second, the golf ball's spin rate, after impacting the stainless steel plate with the mirror finish applied, was 1,554.20 revolution per minute. Scaling this number linearly to match a 164 feet per second swing speed (average professional golfer's swing speed), would result in a 7,509.98 revolution per minute spin rate. 7,500 revolutions per minute is currently the high-end, mean spin rate (6,000-7,500 RPMs) that a professional golfer obtains.

Spin Rates	Mean-Standard Deviation	Mean	Mean+Standard Deviation
Mirror	944	1554	2164
Glass Bead	1545	1987	2431
Aluminum Oxide	1318	2030	2741
220 Grit Satin	1040	1291	1542
6 Grit Satin	618	1360	2102

Table 2: Mean and Standard Deviation of the Spin Rate Results

It is apparent from this chart below that glass bead and aluminum oxide, stainless steel finishes resulted in the greatest number of revolution per minute when measuring the spin of the golf ball. Furthermore, the aluminum oxide finish was clearly the most effective at a mean velocity of 33.84 feet per second and a mean spin rate of 2029.60 revolutions per minute. Scaling this number linearly to match a 164 feet per second swing speed, results in a spin rate of approximately 9,838.64 revolutions per minute. Though there are numerous factors that would alter this impressive spin rate, this approximation still presents optimistic results for achieving this projects goal; the goal to evaluate different surface roughness and increase the expected spin rate.

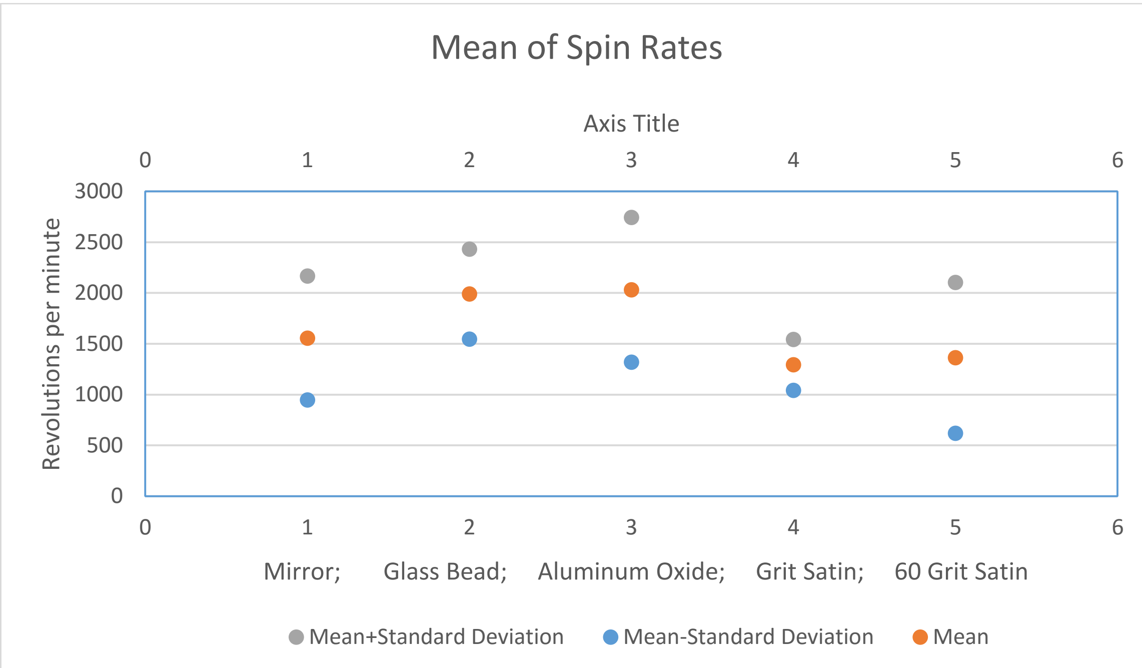

Figure 3: Mean and Standard Deviation of the Spin Rates

Standard Variation and Variance

5.3 Due to the complexity of dynamic impact testing, variation was expected in our results. The importance of the data was determined to reside in the range between the mean ± standard deviation. The results for the ball release showed relatively low variance and instilled confidence in the findings of the report. Meanwhile, the relatively high variance in the spin rates results, consequences creates a low confidence level. The data clearly shows that there is overlap between the variable surface tests. This implies that the impact test was likely done with more variable than those which were tested.

Experimental Errors

Errors during testing

5.4 Impact dynamic testing requires precaution and attention to detail in order to be considered successful. While this experiment produced noteworthy results, it is important to always considered factors that may have hindered the experiment's findings. The first testing error that may have resulted in inconsistent data was that an inconsistent amount of grease was applied to each surface. It is not known whether enough grease was applied between the stainless steel plates and the dynamometer to account for each air gap between the surfaces. Furthermore, the screws that attached the testing surface to the dynamometer were not torqued. This could have resulted inconsistent stability that the naked eye is not capable of seeing. Though the surfaces did not appear unstable within the visuals provided by the high speed camera, this is still an important variable to consider.

Another notable error that may have seriously altered the findings of this report is the positioning of the testing surfaces. The satin surfaces, which produced outcomes very similar to the polish finished surface, were positioned so that the ball would make contact parallel to the grains of the surface. The more effective positioning would have been perpendicular to the grains of the surface. This experimental error was not intended and may have drastically altered the contact surface.

Errors during analysis

5.5 Following the experiment, we used numerous videos and SolidWorks modeling to analyze our data. The first issue that became apparent during the analysis was that the 4,500 fps camera was not directly perpendicular to the force plate. This off-center view made the calculations more complex, hence potentially leading to more calculation errors. In addition, a software designed for converting two-dimensional recording into three-dimensional modeling, would have been a more precise tool for measuring spin and velocity.

6. Discussion

Comparing Impacts

6.1 The ball release was determined to be successful because it provided a consistent release with minimal spin. The variation of data for the ball release results also provided a high confidence level.

Spin Rate

6.2 This experiment did generate a relatively higher spin rate from the glass bead and aluminum oxide finished surfaces than the mirror finished surface. Though test results showed an apparent difference in the mean spin rate, but the variation between the data revealed a low confidence level for the findings of this experiment.

Repeatability

6.3 This test is considered to have a low chance of repeatability. Though the procedures and thought processes were well documented, there are evidently unknown variables which affected the results of the experiment.

7. Conclusions

1. Surface roughness has an effect on the speed at which a ball rebounds off of a surface.
2. The increased spin rate by aluminum oxide cannot be proven due to the variation in the data and the lack of confidence in the results.
3. Further work needs to be done to limit the variables and increase the confidence level in this experiment.

4. A dynamometer is needed for future experiments to better understand the forces which are present during impact.

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9. Acknowledgements

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Peter Hefti - WPI Engineering Experimentation Laboratory Staff

Russell Lang - WPI Civil Engineering Department

10. Appendices

A1: Test Results

Velocity of golf ball

10.1 The velocity of the golf ball before impact was measured using a 240 frame per second, Sony Action Camera. These results were obtained by placing two markers precisely 12 inches apart and recording the time taken for the ball to cross each marker. These values only represent the horizontal velocity of the traveling golf ball.

Test Results from High Speed Camera											
Horizontal Velocity of golf ball prior to impact (Ft/s)	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6	Trial 7	Trial 8	Mean	Standard Deviation	Variance
Mirror Surface	33.68	34.22	32.65	33.86	33.51	34.22	35.16	34.22	33.94	0.77	0.59
Glass Bead Surface	31.53	31.07	32.49	33.33	33.86	34.97	35.36	33.16	33.22	1.52	2.30
Aluminum Oxide	32.82	33.51	31.84	34.59	31.37	36.99	36.57	32.99	33.84	2.20	4.85
220 Grit	36.57	35.75	31.68	34.04	34.22	32.82	35.56	33.68	34.29	1.62	2.62
60 Grit	34.41	32.99	34.22	34.78	37.65	33.68	33.51	33.16	34.30	1.49	1.39
Horizontal Velocity of golf ball after impact (Ft/s)	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6	Trial 7	Trial 8	Mean	Standard Deviation	Variance
Mirror Surface	32.61	33.01	32.21	32.88	33.33	32.34	32.88	31.89	32.64	0.47	0.44
Glass Bead Surface	30.00	30.00	30.02	30.03	31.25	31.27	32.61	31.69	30.86	0.99	0.99
Aluminum Oxide	30.00	31.25	30.02	31.25	30.93	34.09	34.80	30.20	31.57	1.86	3.45
220 Grit	35.70	34.09	30.00	32.89	33.04	30.00	34.96	32.27	32.87	2.09	4.38
60 Grit	33.11	31.25	32.61	32.61	35.71	33.00	32.62	32.61	32.94	1.17	1.11

Table 3: Test Results: Velocity Results

Ball Spin before Impact

10.2 These calculation were derived from the 4,500 fps high speed camera. The purpose of these calculations were to validate that the ball was not spinning prior to contacting the test surfaces. To be determined a valid trial, the ball spin prior to impact needed to be less than one revolution per minute. This was achieved in all but two trial throughout the experiment.

Spin rate of golf ball prior to impact; **Must be less than one revolution per minute**	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6	Trial 7	Trial 8
Mirror Surface	☑	☑	☑	☑	☑	×	☑	☑
Glass Bead Surface	☑	☑	☑	☑	☑	☑	☑	☑
Aluminum Oxide	☑	☑	☑	×	☑	☑	☑	☑
220 Grit	☑	☑	☑	☑	☑	☑	☑	☑
60 Grit	☑	☑	☑	☑	☑	☑	☑	☑

Table 4: Test Results: Spin Rate prior to Impact

Ball Spin after Impact

Mirror Finish	Time 1	Time 2	Angle 1	Angle 2	Average Angle/3	Delta T	RPMs	
Trial 1	0.42	0.42	14.21	18.66	0.05	0.01	456.53	
Trial 2	1.15	1.16	43.69	42.82	0.12	0.00	1544.71	
Trial 3	0.63	0.63	64.96	60.37	0.17	0.00	2349.64	
Trial 4	0.52	0.53	80.39	96.96	0.25	0.01	2015.43	
Trial 5	0.11	0.12	69.60	52.36	0.17	0.01	1633.45	
Trial 6	nvalid data	nvalid data	nvalid data	nvalid data	0.00	0.00	0.00	
Trial 7	0.22	0.23	54.36	51.48	0.15	0.01	1167.44	
Trial 8	0.02	0.03	66.64	61.20	0.18	0.01	1712.20	
Averages						**Mean=**	**1554.20**	RPMs
						Standard Dev.=	**609.82**	
						Variance=	371878.48	

Glass Bead Finish	Time 1	Time 2	Angle 1	Angle 2	Average Angle/3	Delta T	RPMs	
Trial 1	1.08	1.09	96.13	96.34	0.27	0.01	2062.12	
Trial 2	0.76	0.77	47.71	40.15	0.12	0.00	2196.06	
Trial 3	0.83	0.84	117.41	93.44	0.29	0.01	2259.04	
Trial 4	0.53	0.54	46.38	49.38	0.13	0.00	1795.28	
Trial 5	0.40	0.41	60.53	72.78	0.19	0.00	2380.37	
Trial 6	0.42	0.42	11.04	35.67	0.06	0.00	973.12	
Trial 7	0.42	0.42	62.29	44.06	0.15	0.00	2099.12	
Trial 8	0.76	0.77	75.57	66.59	0.20	0.01	2132.23	
Averages						**Mean=**	**1987.17**	RPMs
						Standard Dev.=	443.44	
						Variance=	196636.71	

Aluminum Oxide	Time 1	Time 2	Angle 1	Angle 2	Mean Angle/360	Delta T	RPMs	
Trial 1	0.26	0.27	58.98	48.56	0.15	0.01	1680.42	
Trial 2	0.22	0.23	52.05	67.93	0.17	0.00	2142.81	
Trial 3	0.36	0.37	56.80	80.06	0.19	0.00	2444.28	
Trial 4	nvalid data	nvalid data	nvalid data	nvalid data	0.00	0.00	0.00	
Trial 5	0.43	0.43	67.41	32.00	0.14	0.00	2484.75	
Trial 6	0.58	0.59	69.95	68.81	0.19	0.00	2477.68	
Trial 7	0.17	0.17	16.71	14.47	0.04	0.00	556.75	
Trial 8	0.76	0.77	107.39	86.26	0.27	0.01	2420.50	
Averages						**Mean=**	**2029.60**	RPMs
						Standard Dev.=	711.42	
						Variance=	506124.46	

220 Grit Satin	Time 1	Time 2	Angle 1	Angle 2	Mean Angle/360	Delta T	RPMs	
Trial 1	0.97	0.98	31.15	47.97	0.11	0.00	1483.65	
Trial 2	0.70	0.70	35.20	22.81	0.08	0.00	1208.54	
Trial 3	0.50	0.51	51.79	76.50	0.18	0.01	874.72	
Trial 4	0.97	0.98	54.85	41.35	0.13	0.01	1503.22	
Trial 5	0.70	0.70	45.94	44.35	0.13	0.01	1354.24	
Trial 6	0.50	0.51	75.10	33.42	0.15	0.01	968.96	
Trial 7	0.97	0.98	44.35	45.94	0.13	0.00	1539.00	
Trial 8	0.70	0.70	42.84	39.00	0.11	0.00	1394.97	
Averages						**Mean=**	**1290.91**	RPMs
						Standard Dev.=	251.36	
						Variance=	63179.78	

60 Grit Satin	Time 1	Time 2	Angle 1	Angle 2	Mean Angle/360	Delta T	RPMs	
Trial 1	0.44	0.45	43.99	84.24	0.18	0.00	2185.69	
Trial 2	0.39	0.40	34.94	36.71	0.10	0.01	790.21	
Trial 3	0.78	0.78	77.02	47.25	0.17	0.00	2330.30	
Trial 4	0.36	0.36	22.05	19.74	0.06	0.00	870.62	
Trial 5	0.71	0.71	52.76	53.03	0.15	0.01	1133.58	
Trial 6	0.45	0.46	76.04	62.73	0.19	0.01	1486.78	
Trial 7	0.77	0.78	35.94	37.71	0.10	0.01	812.16	
Trial 8	0.36	0.36	21.28	25.96	0.07	0.00	1180.76	
Averages						**Mean=**	**1359.93**	RPMs
						Standard Dev.=	741.79	
						Variance=	550251.27	

Table 5: Test Results: Spin Rates after impact

A2: Improvements

10.3 For future experiments, it is highly recommended that a dynamometer is used for this experiment. This group originally planned to use a dynamometer for testing the forces associated with each impact. Due to a lack of communication and an inability to get the device functioning, the group was unable to have the dynamometer available during the experiment. The following visuals represent the LabVIEW front panel and block diagram that were created for the device. After many hours, the frequency shown below was achieved but unfortunately, this data (shown below) was irrelevant and independent to the forces being applied to the device.

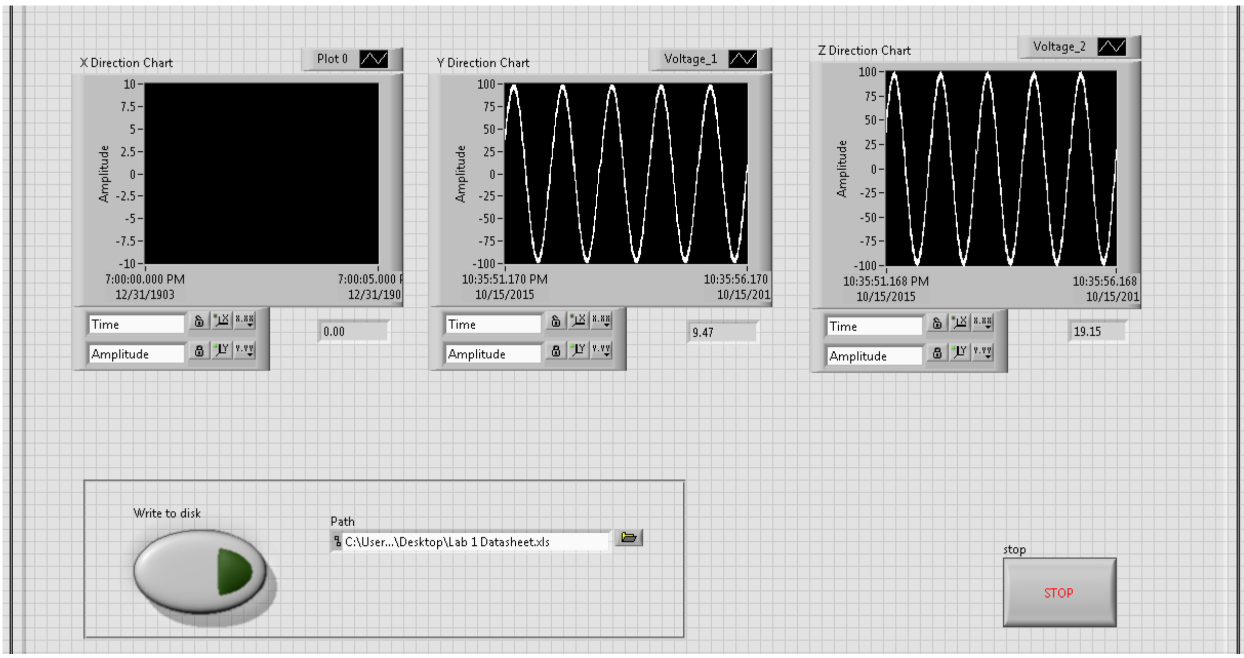

Figure 4: LabVIEW Front Panel for Dynamometer

Figure 5: LabVIEW Block Diagram for Dynamometer