Subject:	Adjusting RPM Rate vs. Ball MOI	
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Date: 12/23/15

Place: International Training & Research Center

Present: Danny Speranza

Purpose:

Rerun the RG and differential RG study but adjust the rotation rate based on using the same rotational energy for each ball. Test on a flat oil pattern.

Summary:

In the RPM vs. Ball Moment of Inertia Study we documented that bowlers rotate balls with different RPM rates based on the moment of inertia of the ball (MOI). The rotation rate was adjusted during this test based on these findings. The results changed from the previous RG and differential RG study where the RPM rate was held constant for all balls. The new results match better with many common beliefs about low vs high RG balls. Summary:

- Average Total Boards of hook
 - o Low RG, high differential RG ball hooked the most boards 18.3 boards
 - Medium RG, medium differential RG hooked the second-most 17.56 boards
 - High RG, high differential RG hooked third-most 17.35 boards
 - Low RG, low differential RG hooked the fourth-most 12.37 boards
 - High RG, low differential RG hooked the least 8.67 boards
- Average Entry Angle
 - High RG, high differential RG ball has the most entry angle 5.2 degrees
 - Med RG, med differential RG ball has the second-most entry angle 4.9 degrees
 - o Low RG, high differential RG ball has the third-most entry angle 4.5 degrees
 - o Low RG, low differential RG ball has the fourth-most entry angle 4.4 degrees
 - High RG, low differential RG ball has the least entry angle 3.4 degrees
- Average Total Angle
 - o High RG, high differential RG ball has the most entry angle 6.8 degrees
 - Med RG, med differential RG ball has the second-most entry angle 6.5 degrees
 - o Low RG, high differential RG ball has the third-most entry angle 6.0 degrees
 - o Low RG, low differential RG ball has the fourth-most entry angle 5.1 degrees
 - High RG, low differential RG ball has the least entry angle 3.9 degrees
 - Breakpoint location (feet down the lane where ball is closest to channel)
 - Ball paths were adjusted to hit the pocket, so only three balls had the same launch angle and lay down point
 - Low RG, high differential RG ball had the earliest breakpoint 42.4 feet
 - High RG, high differential RG ball had the second-earliest breakpoint 43.2 feet
 - Med RG, med differential RG ball had the latest breakpoint 43.4 feet





Data:

Test parameters

The basic test remains the same as outlined during the previous RG and differential RG Study tests. The only different is that the RPM rate was adjusted based on the moment of inertia of the ball, and the ball paths were adjusted so that all hit around the pocket to start the test.

This RG and differential RG study is a test to quantify the lane performance from these two ball properties. The RG and differential RG of a ball was varied by drilling six large 1-3/8" diameter holes in a ball on the x, y, z, -x, -y and -z axes and then inserting weights to adjust the ball properties. (See picture).

Based on bowlers' results, we discovered that the RPM rate imparted to the ball changes when the moment of inertia of the ball varies. ER8 documents these findings. Therefore, this test is to repeat the previous RG, differential RG test but vary the RPM rate per the bowler's findings. The RPM rate will be adjusted based on the moment of inertia of the ball about the PAP location. The table below calculates the RPM rate for each ball.



Ball	Wt.	RG min	RG max	RG @ PAP	MOI @ PAP	RPM	comment
2.51 / .000	15.9	2.51	2.506	2.51	100.17	282	
2.48 / .060	15.9	2.481	2.543	2.512	100.39	282	
2.57 / .030	15.8			2.585	105.58	275	base line for 275 RPM
2.593 / .031	16.1	2.594	2.625	2.609	109.25	270	
2.713 / .000	15.8	2.713	2.712	2.714	116.34	262	
2.72 / .060	15.8	2.68	2.74	2.710	116	262	

It should be noted that the RG value (and therefore MOI) about the Positive Axis Point (PAP) can be very different from the RG value that is associated with a ball when it has a high differential RG values. The 2.481 RG ball with .060 differential RG is actually 2.512 RG at the PAP. And, the 2.68 RG ball with .060 differential RG is actually 2.71 RG at the PAP location.





So, in this test we have:

- Low RG = 2.51 (PAP value for .000 and .060 differential RG)
- Medium RG = 2.609 (PAP value for .030 differential RG)
- High RG = 2.71 (PAP value for .000 and .060 differential RG)

The total change in the RPM rate was 20 RPM for this test. Typically, a bowler can expect to see a 20 RPM different it they were to throw a 2.51 RG vs. 2.71 RG balls.

New test balls were drilled for this test in an attempt to maintain the same total weight for each test ball, since the weight is one variable that effects the moment of inertia.

The same flat oil pattern was used. The lanes were oiled flat from gutter to gutter and tapered from the foul line to the oil line.



The test balls were thrown by E.A.R.L. The same test procedure was followed as used in the RG and differential RG Study. The one different is that the ball path was adjusted so that each ball began the test by hitting around the strike pocket. A single ball test consisted of 20 shots with E.A.R.L. being adjusted to move the ball path to the left after every five shots by 1.5 boards at the foul line and one board at the arrows.



The balls with .000 differential RG hooked a lot less and started with -0.3 to -0.5 degree of launch angle. Therefore, as soon as the direction changes by this angle, the ball had reached its breakpoint, and the ball path was no longer going toward the channel. This greatly affected the break point location results.







The 3 test balls with the medium differential RG (.030) and high differential RG (.060) all started with the same launch angle (-1.3 degrees) and lay down point (16 board). Therefore, their breakpoints can be compared to each other (see chart below).



BOLTS was used to collect the ball path data for every shot. The results are summarized below.

The following parameters were used for all tests:

- Velocity 18 MPH
- Axis rotation angle 60 degrees
- Axis tilt 13 degrees
- Rotation rate varied based on MOI of ball
- Pin was positioned 3.375" from PAP
- PAP located 5" over from center of grip





Test results

The following test parameters were monitored:

- Total hook
- Entry angle
- Breakpoint

Total hook:

BOLTS was used to measure the total hook. A straight line was extended using E.A.R.L.'s launch settings (lay down board and trajectory) to 60 feet. The number of "boards of hook" was calculated at 60 feet between this straight line and the ball path measured by BOLTS.







Below is a chart for the "boards of hook" for each shot with the various RG and differential RG settings. The color zones in the chart are for the five-shot grouping before E.A.R.L. was repositioned.



Also, in the text box on the above chart, is the average boards of hook for all 20 shots with each test ball.





Statistical analysis generated the following Pareto chart, interaction plot and main effects plot:



The Pareto chart above shows that the RG, differential RG and interaction of both properties all affect the boards of hook.







This interaction charts shows that the RG and differential RG properties have similar influence on the boards of hook (green line and blue line are almost parallel). The low RG (blue line) hooks more than the high RG balls (green line). The medium RG ball with medium differential RG (red point) also has significant amount of boards of hook.

Since the lines are almost parallel in the interaction plot, we should analyze the main effects plot below.



In the Main Effects Plot, the differential RG has a larger impact on the boards of hook than the RG. Although the RG does affect the boards of hook, low RG hooks more, and high differential RG hooks more. This matches well with common bowlers' perceptions.





Entry Angle:



Statistical analysis generated the following Pareto chart, interaction plot and main effects plot:







The Pareto chart shows that the differential RG and interaction between the RG and differential RG have a significant effect on the entry angle.



The Interaction chart lines intersect showing that the high RG ball had a large different in the entry angle results as the differential RG varied. The low RG ball had similar entry angles regardless of the differential RG. Since there is a large interaction, the main effects plot below can be ignored.



The entry angle slowly decreases from shot 1 to shot 20. This has to do with increasing the launch angle every five shots, which should reduce the final entry angle. Therefore, a better indicator of angle change is "Total Angle Change," which is adding together the Launch Angle and Entry Angle:





Here the results are more consistent from shot 1 to shot 20.

Statistical analysis generated the following Pareto chart, interaction plot and main effects plot and show the very similar conclusion as the entry angle analysis:

- Pareto shows significant influence from differential RG, RG and the interaction of both properties
- Interaction Plot cross
 - High RG ball has the most total angle, and the more change in the total angle, as the differential RG changes, then the low RG ball
 - Medium RG with medium differential RG has a large total angle change
 - Low RG ball has less total angle but does show some different, as the differential RG varies (but less than the high RG balls)
- Can ignore the main effects plot since the interaction chart shows a significant change













Breakpoint Location below (ball path location closest to the channel):







The breakpoint is the location of the ball path when it is closest to the channel. All ball paths were adjusted to start by hitting the pocket. The low differential RG balls did not hook very much. Therefore, their launch angle was very small (-.3 and -.5 degrees). Therefore, they were almost parallel to the boards at the start resulting in a very early breakpoint at the start of the test.



So, the Breakpoint Chart is divided into two charts below:

In the above chart, the high differential RG and med differential RG test balls were all thrown with the same launch angle (-1.3 degrees) and lay down point (16 board). Here, the low RG ball had the earliest breakpoint (42.4 feet), and the high RG and medium RG were at about the same distance (43.2 and 43.4 feet).







The above chart shows that the breakpoint location moved closer to the foul line for the .000 differential RG balls, but this was due to small launch angles. As the test went along, the launch angle was increased, making the ball go much farther down the lane before it reached its location closest to the channel.



