ENGINEERING REPORT

Subject: The Effects of Balance Holes

Date: 10/19/2017

Place: International Training & Research Center

Present: Tom Frenzel, Jason Milligan

Purpose:

To summarize data gathered and presented to the Equipment Specifications Committee in the October meeting of 2017.

Summary:

Our research indicates that 1 ¼ inch diameter balance holes can change the RG and RG differential of bowling balls by upwards of 0.020 inches. Alternatively, balance holes of ¾ inch or smaller impact the designed RG and RG differential values much less, often by approximately 0.005 inches.

Discussion:

To measure the impact on a ball's core properties due to modern drilling techniques, the team enlisted the help of the blueprint ball layout technology. Two balls were selected to run a simulation to determine how accurate blueprints results are. The two balls were measured undrilled, drilled with no balance hole, drilled with a ¾ inch balance hole that was 3 inches deep, drilled with a 1 ¼ inch balance hole 3 inches deep. Ball A was drilled with a "strategically placed hole" (a balance hole that is opposite the thumb hole to maximized RG differential). Ball 2 was drilled with a balance hole 5 ½ right of the center of grip. The following tables illustrate the change from the undrilled ball for the properties of RG, differential RG, and intermediate differential RG:

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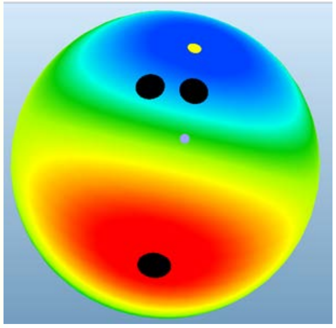
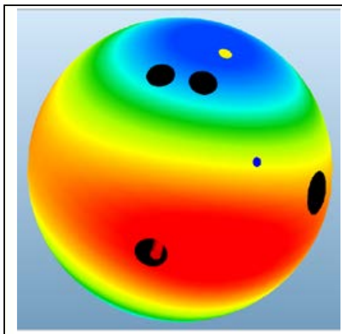
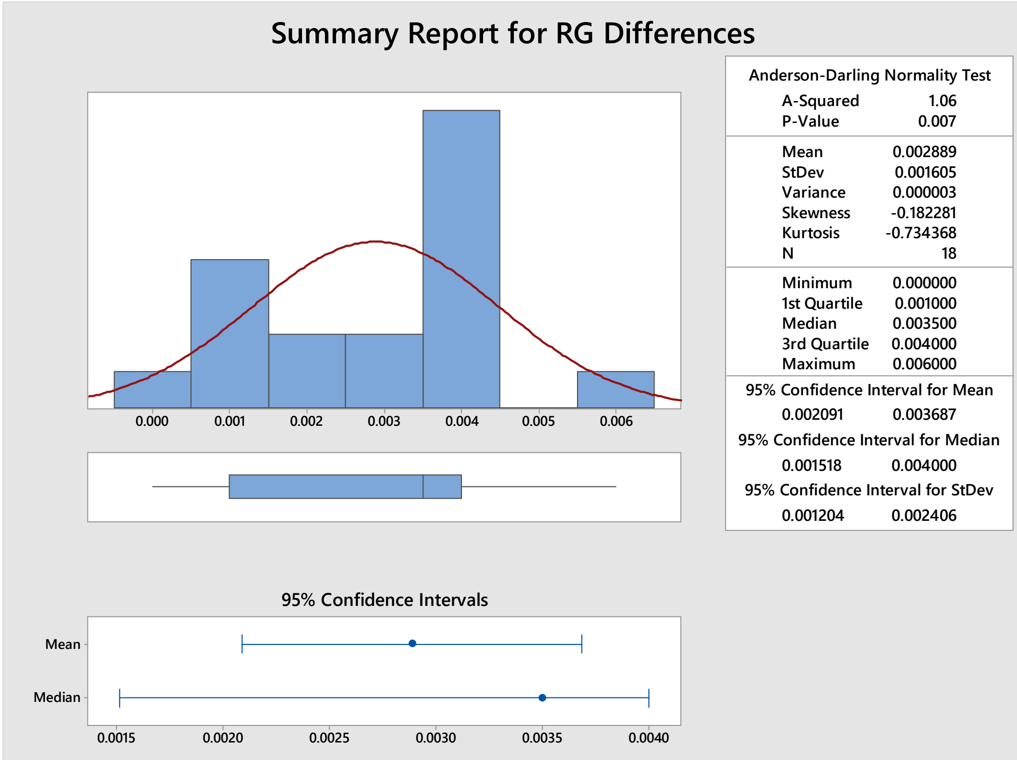
	Ball 1 (Modeled with Blueprint)	RG-X	Differential	Int. differential
	Undrilled	2.480	0.048	0.001
	Drilled 70 X 5" X 30 - No Balance Hole	+0.002	+0.002	+0.009
	Drilled - Balance Hole 3/4" X 3" (opposite thumb hole)	+0.001	+0.008	+0.015
	Drilled - Balance Hole 1 1/4" X 3" (opposite thumb hole)	+0.000	+0.019	+0.026

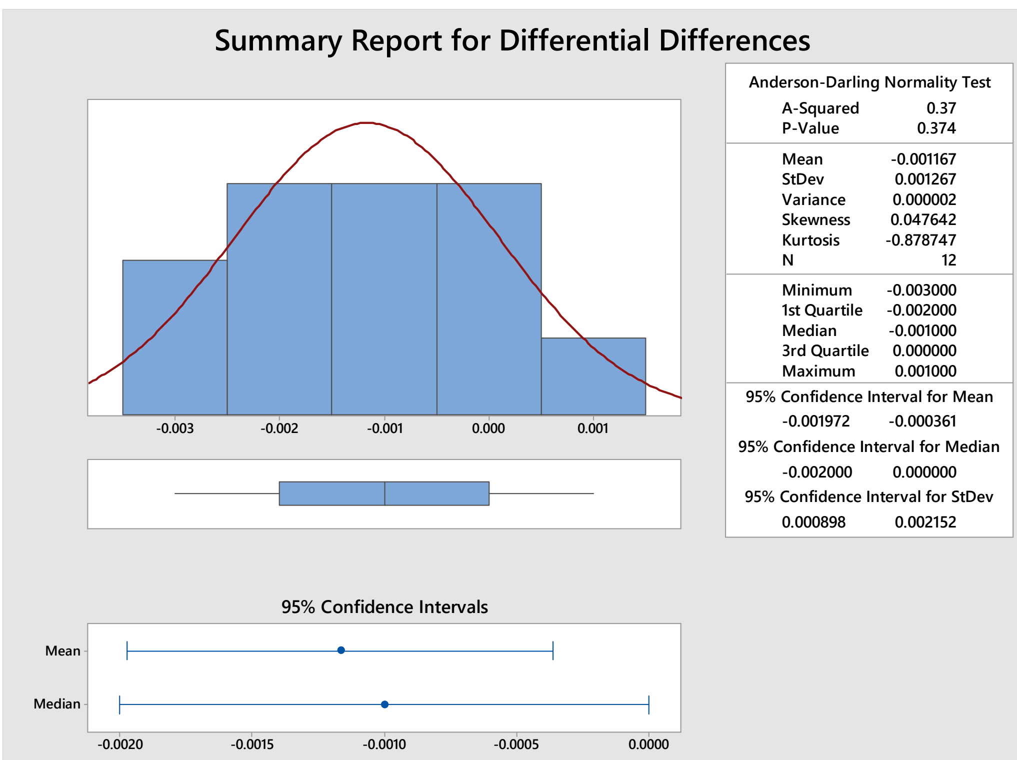
	Ball 1 (Drilled and Measured)	RG-X	Differential	Int. differential
	Undrilled	2.474	0.057	0.002
	Drilled 70 X 5" X 30 - No Balance Hole	+0.006	+0.001	+0.007
	Drilled - Balance Hole 3/4" X 3" (opposite thumb hole)	+0.005	+0.005	+0.014
	Drilled - Balance Hole 1 1/4" X 3" (opposite thumb hole)	+0.004	+0.017	+0.024

	Ball 2 (Modeled with Blueprint)	RG-X	differential	Int. differential
	Undrilled	2.476	0.058	0.017
	Drilled 70 X 5" X 30 - No Balance Hole	+0.003	+0.000	+0.011
	Drilled - Balance Hole 3/4" X 3" (5 1/2" over)	+0.003	+0.000	+0.006
	Drilled - Balance Hole 1 1/4" X 3" (5 1/2" over)	+0.003	+0.002	+0.001

	Ball 2 (Drilled and Measured)	RG-X	differential	Int. differential
	Undrilled	2.474	0.052	0.015
	Drilled 70 X 5" X 30 - No Balance Hole	+0.006	+0.000	+0.011
	Drilled - Balance Hole 3/4" X 3" (5 1/2" over)	+0.006	+0.000	+0.005
	Drilled - Balance Hole 1 1/4" X 3" (5 1/2" over)	+0.007	+0.003	+0.002

Differences in the predicted and measured changes were tabulated for RG-X, RG-Y, RG-Z, total differential RG, and intermediate differential RG. The results were grouped into RG differences and differential differences and can be seen in these histograms:

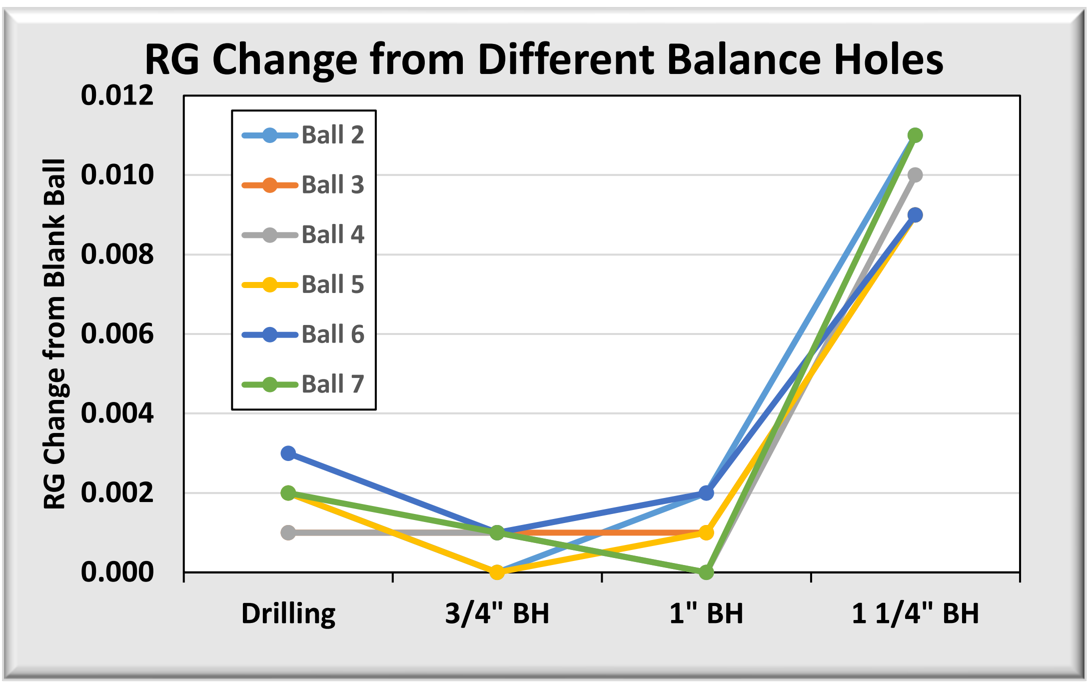




The results for the RG differences failed a normality check due to a “saw tooth” distribution since blueprint truncates their decimals at 3 digits. However, based on a distribution analysis the normal distribution is a better fit to the data than the rest. The differential differences passed the normality check.

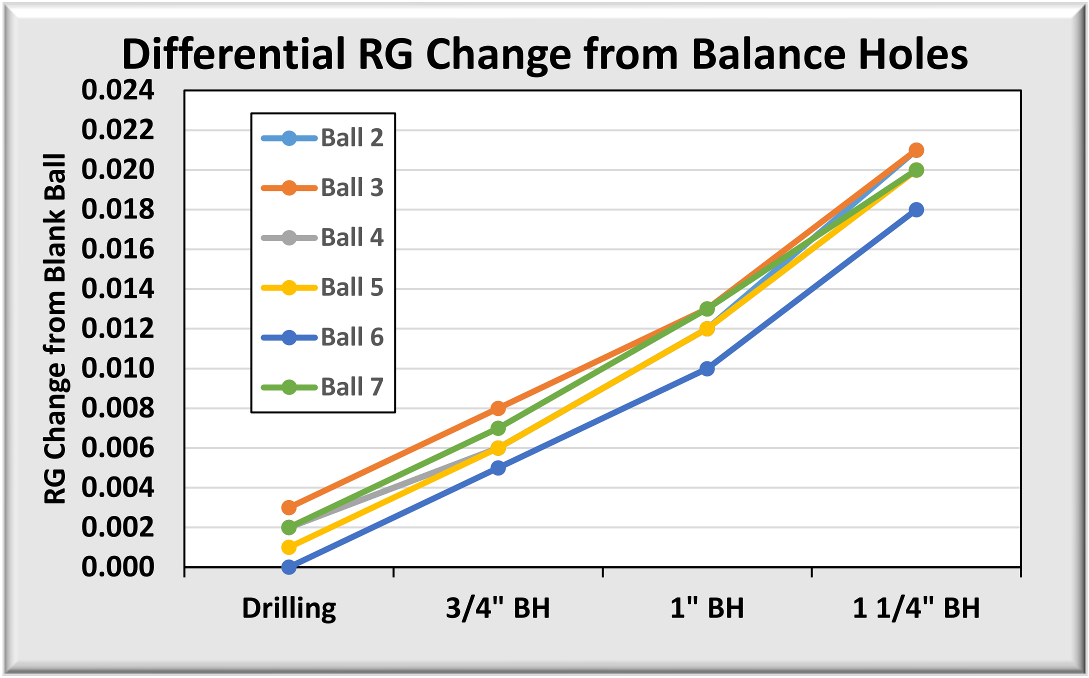
By performing a Paired T statistical analysis on the RG differences and the differential differences we find that measured RG differences tend to be about 0.003" greater than the blueprint predictions. We also find that measured differential differences tend to be about 0.001" less than the blueprint predictions. However, the net result is that the blueprint modeling is near enough to real world drilling and measurements to make predictions with.

Once the model was shown to be accurate enough for our purposes, we modeled 6 additional of bowling balls with balance holes of varying sizes and positions. The greatest differences in differential RG were found when the balance hole was drilled opposite the thumb hole. Looking at that layout with blueprint while varying the balance hole diameter shows us that large balance holes can have a large impact on both the RG and total differential as seen in the following figures.

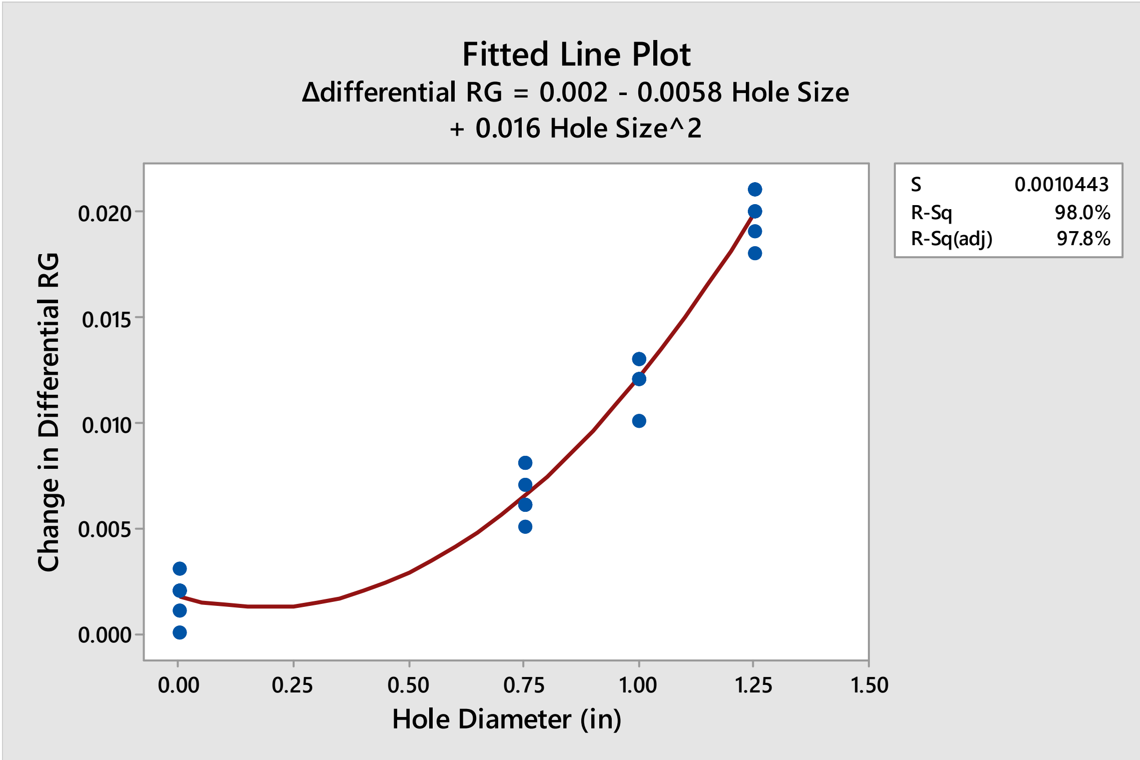


This chart describes how the low RG axis of the bowling ball changes with respect to the diameter of a 3-inch deep balance hole drilled in the strongest position. Since RG is the square root of the ratio of moment of inertia divided by mass, $RG = \sqrt{\frac{I}{m}}$, as the holes are drilled both of these quantities appear to decrease approximately the same until the hole gets larger than 1 inch, leaving the low RG value relatively unadjusted. When the 1 ¼ inch hole is drilled, the mass decreases by more than the additional decrease in moment of inertia resulting in the RG value increasing by approximate 0.010" across our selected ball models.

Differential RG is a different story:



Drilling the finger and thumb holes has little effect on differential RG compared to the undrilled ball. However, after the balance hole is drilled we immediately see an increase of approximately 0.006" for a ¾ inch diameter hole. This difference doubles to approximately 0.012" with a 1-inch balance hole in the same position. Finally, at 1 ¼ inch diameter balance holes, we saw differences in differential RG of approximately 0.020". This difference is noticeable from the initial drilling of the balance hole and for a depth of 3-inches, we see a quadratic relationship between changes in differential RG and the diameter of the balance hole.



Conclusion:

This study has shown that balance holes placed in the optimum place to maximize differential can increase the differential RG significantly beyond what the ball was designed to be. We verified the accuracy of our modeling to be within ~0.001" of the true measurements on drilled balls which is well within our gauge tolerance. A large diameter balance hole has the greatest effect in changing the built-in differential RG of an undrilled ball. Reducing the allowable diameter of a balance can help to maintain the original built-in differential RG, but even a ¾" diameter balance hole can alter the differential RG by approximately .006 inches.