

# **Spindle Runout Effects on Positional Accuracy**

As presented at  
the University of Wisconsin  
'Symposium on Small Hole Technology'

February 22, 1990  
Palm Springs, California

Authors:

Don L. Martin  
Robin O. Wilcox  
Lion Precision  
Minneapolis, Minnesota

# Spindle Runout Effects on Positional Accuracy

Improving drilled hole quality is a continuous process within the printed circuit board industry. The emphasis on small hole and microhole drilling has led management to further study the parameters which can affect quality. One area of growing interest is spindle/collet runout and its affect on hole registration. It has been suspected that spindle and collet runout contribute to hole quality but there has never been any confirmation of this belief. In the past, the tools available to the drilling department did not allow personnel to analyze runout and take corrective action if needed. Rather, the typical runout test involved a dial indicator positioned against a gage pin, with the spindle manually rotated. Interpretation of the results was difficult and open to operator variability. Because of these limitations, and because a concrete connection between runout and hole quality concerns such as misregistration has never been made, drill room management typically has not closely monitored spindle/collet runout. Although some facilities check runout daily with the dial indicator, decisions are still primarily made as a result of trial and error rather than quantitative analysis. The use of the Lion Precision Dynamic Runout System has changed the situation, allowing the drilling department to accurately monitor spindle/collet runout at operating speeds on the drilling machine. As a result, new questions are being asked. These questions were not asked before, not because of a lack of interest, but because there was no easy way to get the answers. One topic of interest is the suspected impact of excessive runout on hole registration. The purpose of this paper is to present a study completed at several printed circuit companies which evaluated the impact of runout on registration.

## Study Design

The study was completed in December and January, 1989 and 1990, at two printed circuit board facilities in Minneapolis, Minnesota. Four different hole sizes were studied by first drilling the holes and then inspecting for hole registration. The ideal hole center and standard deviation of the actual holes was then calculated.

### Drill Bit Sizes

.045 inch  
.0225 inch.  
.018 inch  
.0135 inch

+ Drill bits supplied by "Tycom

### Drill Machines

Excellon Automation Mark V  
• Ball Bearing Spindle  
Excellon Automation Mark V Stretch  
• Westwind Air Bearing

### Inspection Equipment

Excellon Opic III Inspection Station  
View Engineering Précis 3000

### Measurement Equipment

lion Precision Dynamic Runout System  
WBBI Transducer Holder for spindle mounting

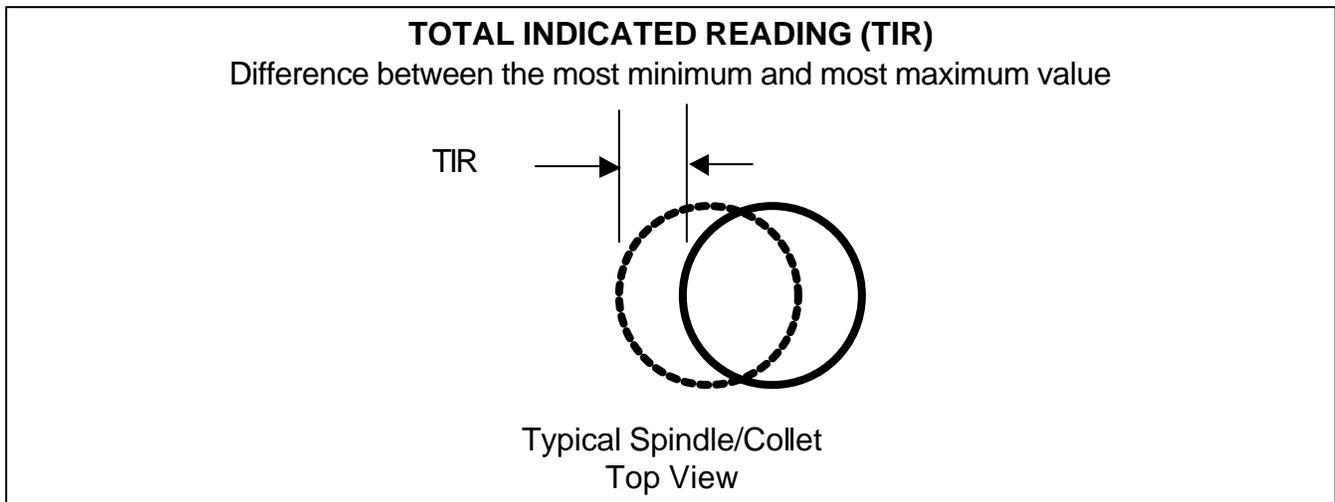
### Panel Construction

Part 1: 112 ounce Copper, FR4, 6 layer, 3 high  
Part 2: 112 ounce Copper, FR4 2116,8 layer, 3 high

The first part of the study used actual production panels with .045 and .0225 inch drill bits, using ball bearing spindles. Inspection was completed on the pit 1~ inspection station. Repeatability studies done by the authors of the study suggest operator error when the Opic III was used. As will be seen below, the results of this part of the study were somewhat inconclusive, in part because of registration measurement problems. Further study was completed on 018 and .0135 inch holes, this time using a test pattern drilled with air bearing spindles. These holes were then inspected using automatic inspection station. The results found in this second part of the study are more reliable than the first part, because of the use of the automatic inspection station(accuracy better than +/- .0002 inches).

## Total Indicated Reading

TIR is a measurement of the variation from the ideal path a spindle/collet system will follow when turning. It is defined as the difference between the closest and farthest away point the target surface travels, admeasured from a reference point (please see Figure 1).



**Figure 1**

The Lion Precision Dynamic Runout System uses capacitance technology to measure TIR. The device monitors the position of target surface (in this case the gage pin surface) as the gage pin revolves. The difference between the minimum and maximum positions, or runout, is then displayed. The analog signal of the position is also available for output to an oscilloscope or other analytical device. The advanced circuitry design provides for high frequency response, allowing accurate measurement at speeds of over 120,000 rpm, down to 0 rpm.

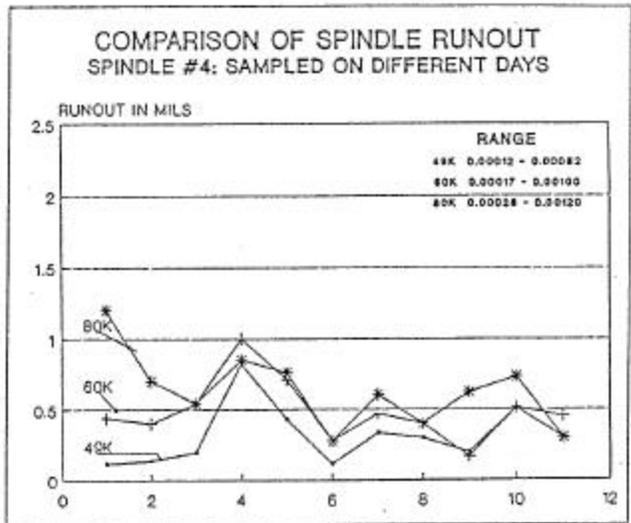
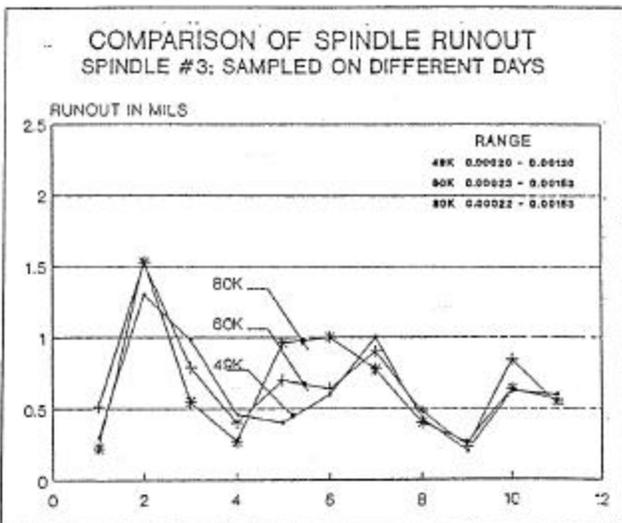
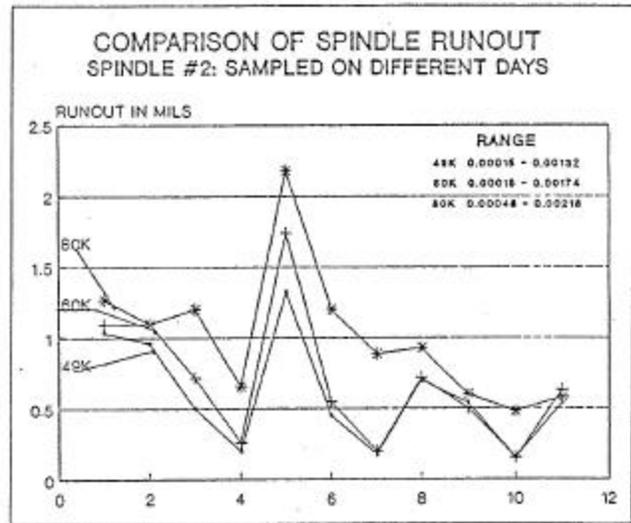
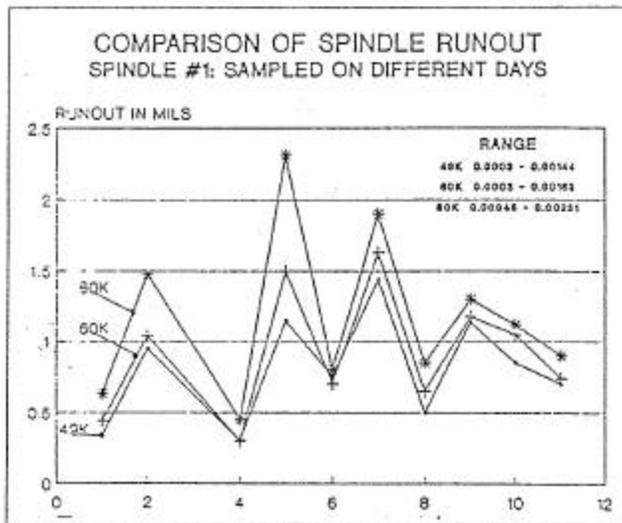
## Larger Hole Study

Larger Hole Study portion of the study was completed on .057 inches thick pane/s, 6 layers, FR4 clad with 1/2 ounce copper. The panels were drilled three high. The feed rate for the 045 inch hole was 16 inches per minutest 49,000 rpm, for the .0225 inch hole 80 inches per minute at 80,000 rpm. No strong correlation between high runout and misregistration was seen on these panels. The standard deviation between low runout and high runout was essentially the same, from .0003 to .0006 inch (one sigma), depending upon the hole size and speed of drilling. These results suggest two possible conclusions, that 1) either runout is not a significant contributor to hole misregistration at larger holes sizes or 2)the operator error

using the Opic III caused the data to be unusable. Repeatability studies done by the authors of the study found low repeatability. The authors were not skilled in the use of the equipment and, because of a time constraint, training was minimal. While it is believed the registration data has some problems with it, data gathered in the second part of the study suggests runout does not have a large effect on registration at larger hole sizes. Runout and registration information was collected for eleven days. For most of those days, runout was checked at the beginning of the first shift, after collet cleaning. An interesting 'lack of consistency' can be seen in Figure 2 for each of the four ball bearing spindles monitored: a) Runout was monitored at three different speeds. Regardless of the speed, the runout variation from day to day was rather dramatic, with the changes apparently random. 6) Although the higher speeds generally had higher runout than the lower speeds for any one spindle, this was not always the case. Occasionally runout at higher speeds was actually lower than at lower speeds. For example, in Figure 2, Spindle 3, the runout at 80,000 rpm was lower than the runout at 49,000 rpm on several days. The same operator completed the runout monitoring each day after collet cleaning. The variation seen between the daily readings suggests other forces are at work besides operator variability. These results on ball bearing spindles are consistent with results seen in the field, both by Lion Precision and by customers.

## Runout Over Time

Figure 2



## Small Hole Runout

The second part of the study was completed during one four hour period. The panels were approximately .060 inch thick, 8 layers, with FR4 2116 glass, 1 ounce copper inner layers and 1/2 ounce copper outer layers. The panels were drilled three high, using a test grid, at 80,000 rpm. Drill bit sizes were .018 and .0135 inches. Two different collets were used, with “small runout” and “large runout,” for comparison purposes.

Runout measurements are seen in Figure 3:

Runout Measurements		
Speed	“Small” Runout	“Large” Runout
0 rpm	.0002* inch	.0015* inch
20,000 rpm	.000109 inch	.001476 inch
40,000 rpm	.000103 inch	.001520 inch
60,000 rpm	.000123 inch	.001607 inch
80,000 rpm	.000167 inch	.001712 inch
100,000 rpm	.000221 inch	.001790 inch

\*Measured using dial indicator

Figure 3

## Study Results – Range

The X and Y coordinate Range information can be found in Appendix B. Figures 4 and 5 summarize the data.

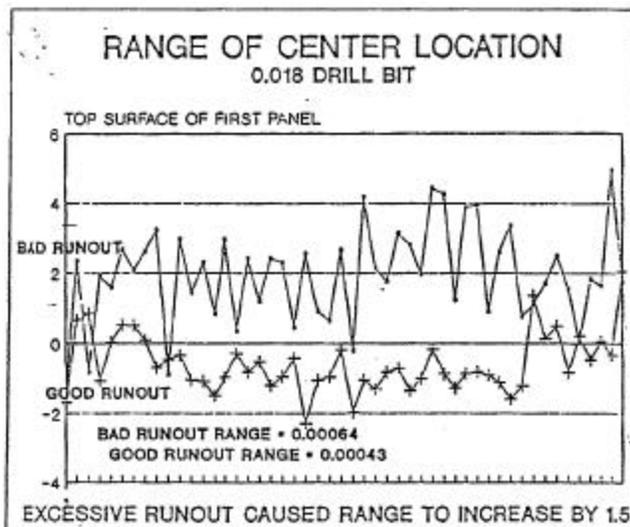


Figure 4

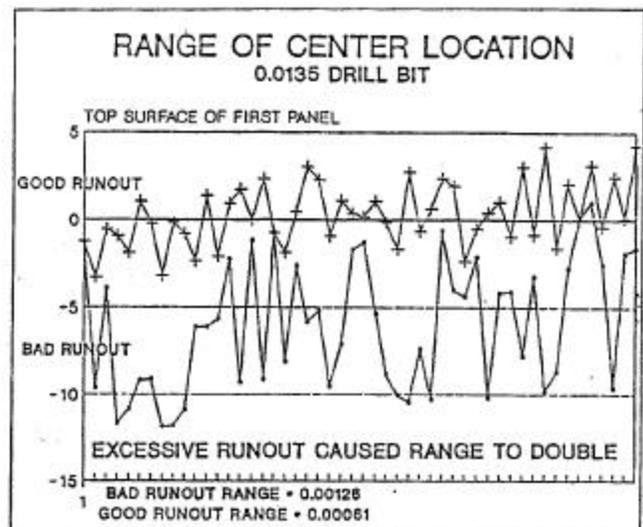


Figure 5

The following conclusions can be made:

- The X Range gets larger as the drill bit proceeds through the three panels, with the largest range occurring on the bottom surface of the third panel.
- The same is true of the Y Range; that is, the range grows as the drill bit proceeds through the panels. The Y Range is generally higher than the X Range, which is expected since in this study the Y coordinate reflects the impact of table movement as well as the impact of runout.
- The X coordinate Range of the .0135 inch holes drilled under the “large” runout condition was about twice as large as the Range of the same size drilled hole with “small” runout.
- The X coordinate Range of the .018 inch holes drilled under the “large” runout condition was 10 to 50 % larger than the X Range of the “small” runout holes.

## Study Results - Standard Deviation

Figures 6 and 7 summarize the 3 sigma results for the ,018 and .0135 inch.

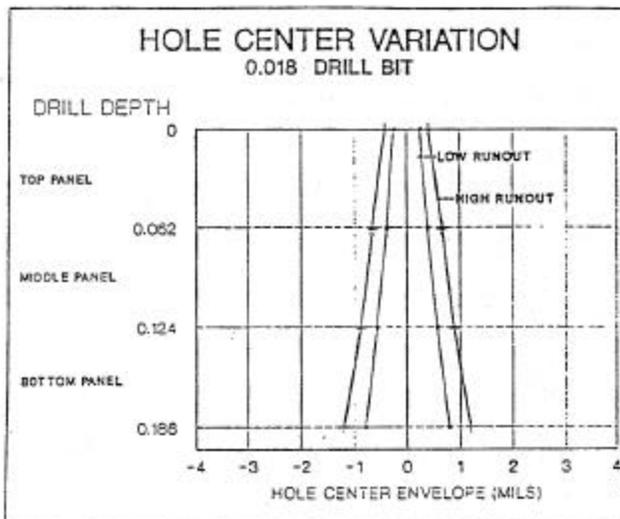


Figure 6

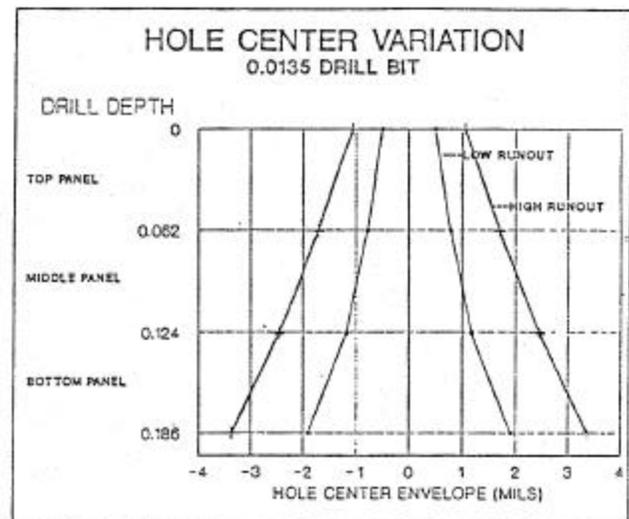
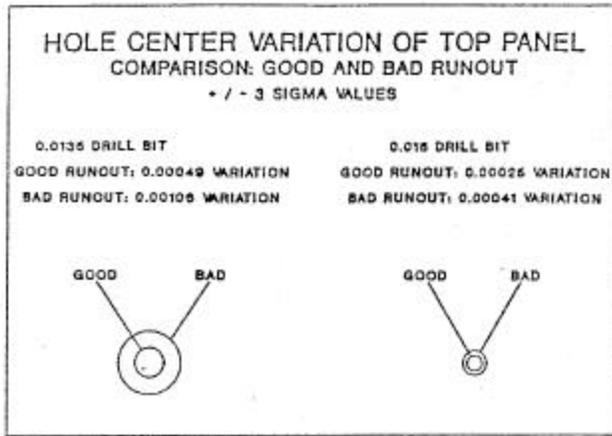


Figure 7

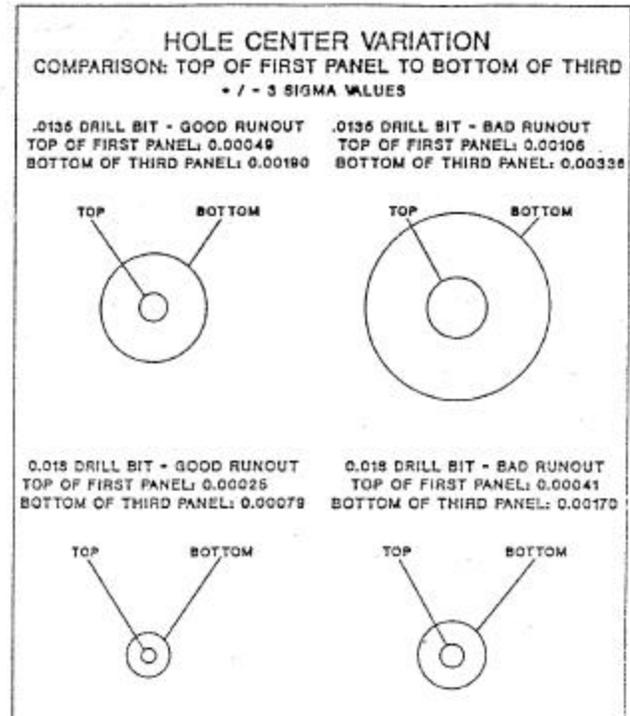
Figure 8 presents the data collected from the top panel, comparing the “large” and “small” runout hole center variation. Figure 9 is a similar graph, but compares data from the top of the first panel compared to the bottom of the third panel. The “wander” of the drill bit through the various panel layers can be seen.

The following conclusions about the hole center locations can be drawn:

- The total standard deviation of the “large” runout .035 inch drilled holes is about 100 % larger than the “small” runout holes. This is consistent throughout the layers, no matter what the position of the panel (bottom or top).
- The total standard deviation of the “large” runout .018 inch drilled holes is 25 to 50 % larger than that of the “small” runout holes.
- The total standard deviation does get larger as the drill bit proceeds through the layers, with the deviation of the top layer for the .0135 inch hole increasing over three times by the bottom of the third layer: The total standard deviation also grows for the .018 inch hole, although not as much around 150 % growth from the top of the first panel to the bottom of the third panel.



**Figure 8**



**Figure 9**

## Conclusions

For small hole and microhole drilling, spindle/collet runout does impact hole registration. The importance of runout grows as the drilled hole size gets smaller. Both range and standard deviation are negatively impacted by increased runout. For example, the  $\pm 3$  sigma value for the .0135 inches drilled hole in this study was as high as .0106 inches, almost the diameter of the drill bit. As expected, the standard deviation for the hole center does increase as the drill bit proceeds through the layers, independent of runout. However, runout does cause a larger increase, especially when looking at smaller holes. In other words, the drill bit will “wander” more as it is drilled through successive layers, with more “wander” occurring with larger runout. Runout at operating speeds is typically larger than runout monitored statically and the runout usually increases as speeds increase. However, it has been observed in the field this trend is not always the case. Most deviations from this pattern have occurred on air bearing spindles. Runout measurements using a dial indicator have some repeatability and accuracy concerns. However, the biggest problem with this approach is it is not a good predictor of runout performance at operating speeds. And has been seen by this study, runout can affect hole registration. The ability to monitor dynamic runout has increased the printed circuit board manufacturer’s ability to improve board quality. The dynamic runout system is a tool which allows the driller to both better understand his drilling process as well as easily monitor the process on an ongoing basis, so that the proper corrective action can be taken when needed.