

# UNDERSTANDING ROUNDNESS AND RUNOUT

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Key Words: Roundness, Cylindricity, Circular Runout, Total Runout or TIR (Total Indicated Runout), Concentricity, Eccentricity.

## INTRODUCTION

Increased quality requirements by rolling mills in recent years have resulted in a need for both manufacturers and users to understand the basic form characteristics of roundness and runout. These characteristics help determine how rolls interact with strip to provide smooth, chatter-free surfaces to the final product. Roundness and runout as well as the related characteristics of concentricity and eccentricity are common requirements on drawings but are often misunderstood and misapplied.

The purpose of this paper is to clarify what each of these characteristics represents and to offer some suggestions in resolving common problems related to attaining customer requirements.

## DEFINITIONS

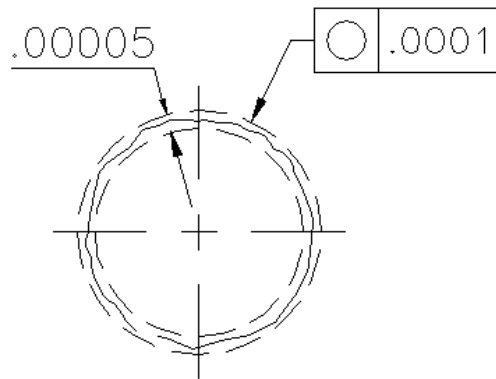
The geometric drawing symbols used to identify these characteristics are shown in Table 1. It is not uncommon for these characteristics to be specified on drawings using only text such as “TIR of bearing journals not to exceed .0002”, or “maximum

roundness deviation .0001”, or body to be concentric with journals within .0005”.

	Type of Tolerance	Characteristics	Symbol
For Individual Features	Form	Straightness	
		Flatness	
		Circularity (Roundness)	
		Cylindricity	
For Individual or Related Features	Profile	Profile of a line	
		Profile of a Surface	
For Related Features	Orientation	Angularity	
		Perpendicularity	
		Parallelism	
	Location	Position	
		Concentricity	
	Runout	Circular Runout	
Total Runout			

Table 1

**Roundness (Circularity)** is used to describe an object in relation to a perfect circle. In a circle each point on the circumference is the same distance from the centerline. If a diameter is specified with a roundness tolerance of .0001”, all points around the centerline of the diameter must be within .00005” of the centerline.



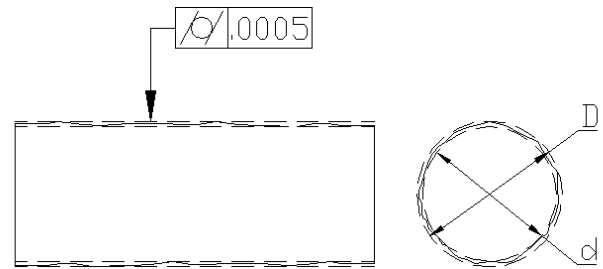
## ROUNDNESS TOLERANCE

Figure 1

Figure 1 is a diagram of roundness showing the symbol for roundness and using the tolerance of .0001". It shows a circle generated around the intersection of the centerlines, with all points on the circle being within .00005" of two theoretical perfect circles. It also requires that the size to be within .0001" across diameter on the plane being measured.

**Cylindricity** incorporates both straightness and roundness while asking for a true shape. It requires a cylinder to be both round and the same diameter at all points along the cylinder within the tolerance given.

Figure 2 is an illustration of cylindricity tolerance and the form the cylinder should be to conform to the tolerance. We are looking at a cylinder with the circular runout at any section of the cylinder staying true within .0005". With this, we have now moved into working with circular runout, straightness, and the true shape of the cylinder. If the total surface of the cylinder were indicated, all points would be within .0005" of all other points of the cylinder.



## CYLINDRICITY TOLERANCE

$$.0005 = \frac{D - d}{2}$$

ALL POINTS ON THE CYLINDER ARE WITHIN .0005 OF EACH OTHER

Figure 2

If we further qualify cylindricity with a roundness tolerance of .0001", we would restrict the cylinder to become an accumulation of planes making up the total length of a cylinder. The centerline of each plane is concentric and parallel with all other planes within 1/2 the roundness tolerance given. Each plane must be the same size within the roundness tolerance and the cylinder must be straight within the cylindricity tolerance. With an example of a cylindricity tolerance of .0005", and roundness tolerance of .0001", the combination produces a cylinder which may taper .0005", but must be round within .0001".

**Circular runout** is used to describe how true the surface of a cylinder is with respect to another or main cylinder. It does not necessarily describe the centerline of the cylinder being indicated, but does put a tolerance on the diameter across any plane, which is being indicated. As a related feature it is used to clarify a form (shape) and describes the roundness of the indicated surface.

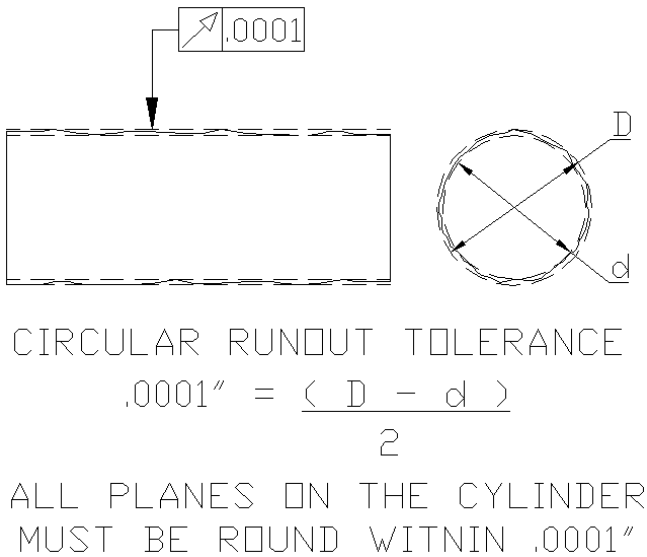


Figure 3

Figure 3 above is an illustration of the circular runout symbol with an explanation. It represents how the roundness of the cylinder is dependent upon the given tolerance and not the centerline of the cylinder. The diameter across any two points must not exceed the tolerance.

**Total Runout or Total Indicated Runout (TIR)** describes how a surface, as indicated, runs in relationship with the main cylinder. TIR may be used as a measurement between a face, taper, or another cylinder and the main object cylinder. All cylinders must be round or all faces must be perpendicular to the main object cylinder within the tolerance. Total runout or TIR does require roundness and/or straightness within tolerance.

Figure 4 illustrates how the solid cylinder line is rotating with respect to the dotted cylinder line, which is the main object cylinder. The solid cylinder being indicated must be round and concentric to the main object cylinder within

tolerance. This means that if a cylinder is checked on a steady rest, towards the end of the neck, or inside the steady rest, setting the indicator at the same angle, all the indications must be within the tolerance. The shape of the cylinder may taper, but the distance between points on the same plane must be within the tolerance.

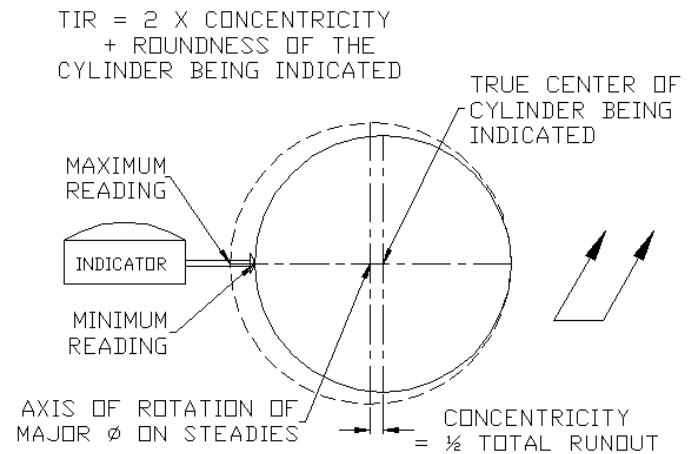


Figure 4

The difference between cylindricity and total runout (TIR) is that cylindricity describes the object cylinder and total runout describes a second object's surface relationship to the main object.

Most roll drawings will call for the journal diameters as the main object cylinder. The roll shop will set the roll on these cylinders to redress the body. However, some rolls will have tapered journals and use another cylinder for redressing roll bodies. These rolls may have the roundness and/or cylindricity geometric symbol on the redressing diameter and a related symbol, (TIR or Circular runout) showing how true the bearing journal must run with the redress cylinder.

Here the related symbol will describe the permissible difference between the roll redressing

location and the bearing journal. The grinding surface must then run true with the journal.

**Concentricity (Eccentricity)** is a related feature, and describes how concentric the centerline of one cylinder is with the object cylinder. Concentricity may be indicated at any position on the cylinder. It does not describe that the cylinder be straight, only that the centerlines be parallel within the tolerance. This means that the cylinder may be egg-shaped or multi-sided but within the tolerance desired.

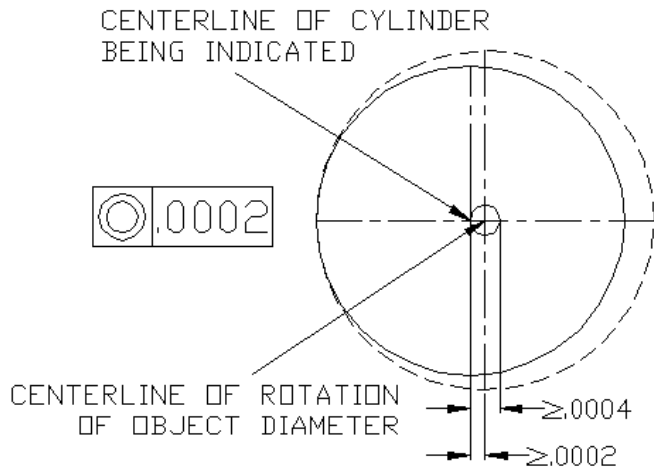


Figure 5

Figure 5 shows how the centerline of the smaller cylinder is being rotated around the centerline of the object cylinder. Notice that concentricity uses the centerlines of the cylinders be checked, and that the total movement of the part is twice the given tolerance. The smaller circle is still only .0002” **eccentric** although the total movement is .0004”.

**Datum Identifiers** are the symbols used to refer to each object on the drawing. These are letters in a box that is pointing to some surface on the roll. The main object will have the datum by itself beneath a form feature. A related feature should have the

datum behind its symbol to describe the reference surface. Together the symbols explain how accurate one cylinder must be with another.

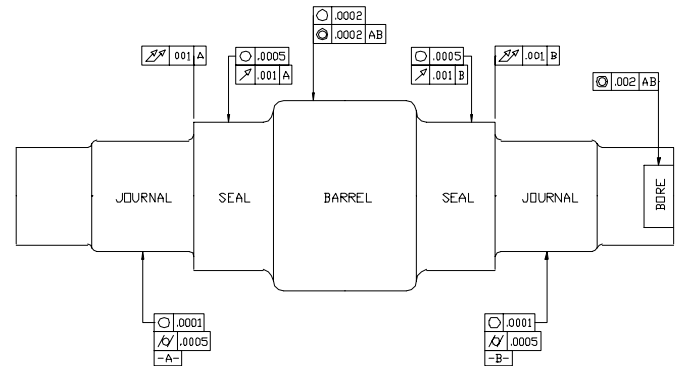


Figure 6

Figure 6 incorporates the aforementioned symbols on a simple drawing. The journals show roundness of .0001”, cylindricity of .0005” and are marked datum A and datum B. The barrel shows that it must be round within .0002” and concentric within .0002” (related feature) with both journals. The thrust faces must indicate within .001” total runout (TIR) with each respective journal. The seals must be round within .0005” and true within .001” (circular runout) to each respective journal and the bore must be concentric to both journals within .002”. The object cylinders are the journals A and B.

The geometric form symbol for roundness becomes the major factor in determining what is required on the roll. The form symbol for roundness on the body describes how round the barrel has to be. But because it has a related feature, the concentricity symbol, we must relate the eccentricity to the journals. Each seal and thrust face is individually related to its’ respective journal, indicating that the form feature is primary in fulfilling the tolerance requirement and may have to be checked with opposing indicators.

Measuring Equipment commonly used includes both mechanical dial indicators capable of reading to .0001" and electronic indicators employing LVDT (linear voltage displacement transducer) technology capable of reading to .000001". The LVDT's are attached to an electronic amplifier, which is also attached to a type of chart recorder. Viewing the amplifier permits the monitoring of movement and the ability to produce a hard copy recording of the movement.

### TYPICAL SETUPS

When grinding a new roll, the roll is set on centers in a roll grinder and we proceed to round up the spot diameters. This is to produce one true centerline through the roll. The spot diameters are the nearest diameters to the outboard end of each journal diameter. Once the spot diameters are brought close to finish size, the roll is taken off centers and set on steady rests on these diameters.

We are now ready to take a roundness reading to determine the actual shape of the spot diameters. Roundness as viewed by customers must be taken into consideration with the final product. Because the roll is resting on bearing pads and not on centers, the centerline of the diameter will be moving in an eccentric motion as the surface is running against the bearing pad. The indicator is set at 180° opposite the bottom-bearing pad and the roll is rotated to check the roundness.

To make the spot diameters more round, very lightly touch the surface with a grinding wheel. The eccentric movement of the centerline will diminish, as the surface of the diameter becomes a truer circle. The roundness is not indicative of the true centerline of the circle being indicated. We are actually measuring the change of the circle diameter from one side to the other with this diameter being affected by both the location of the indicator and the surface contact area of the bearing pads.

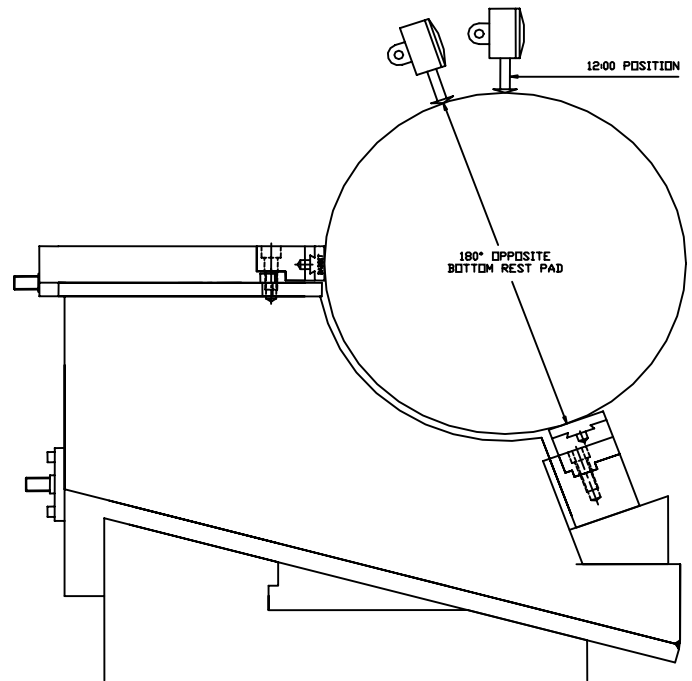


Figure 7

Figure 7 above illustrates the two locations used to determine the shape of the spot diameter. The measurement taken at 180° opposite the bottom bearing pad reflects a circular roundness or what is actually a difference in diameter from point to point as the roll is revolving on the bearing pads. A measurement taken at 12:00 will reflect a combination of differences of the diameter as is it being affected by both the bottom and side bearing pads. The 12:00 location will exaggerate the readings if a roll is three or more sided, and becomes easier to recognize than just measuring opposite the bottom pad.

Figure 8 on the next page is an illustration of a three-sided cylinder. This is what I am referring to when describing multisided cylinders or diameters. The diameter measurements taken appear to be on size at any two straight across points and within the tolerance. However if you try to slip a sleeve over it, it would catch on the highs because they are further away from the centerline.

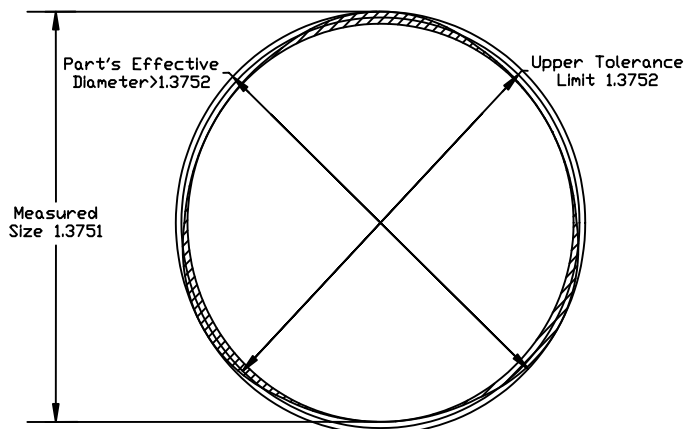


Figure 8

The roundness of a cylinder may change when grinding over steady rests and not on centers. They are illustrated in the above drawing of a three-sided cylinder. The shaded areas represent the three lobes generated by the grinding. When measuring across any two points, the micrometer readings appeared to be exactly the same size. However, when put on centers, the distance from the centerline varied over .0001" at every lobe. Two-point contact in a mill, backup roll on one side and the strip on the other, would not show any variance to the gage.

## Examples and Results

The following examples illustrate roundness readings and the shapes produced as we attempt to get closer and closer to a perfect cylinder.

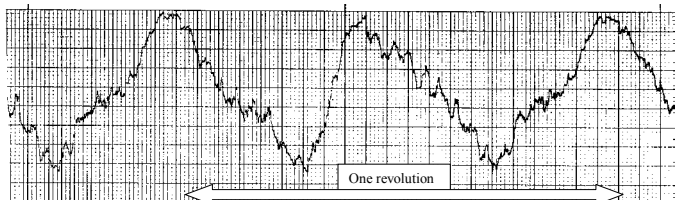


Figure. 9

In figure 9 the roll was started on centers and smoothed to the runout shown on the chart. The runout shows .00016 with two highs (egg shape). The roll was set on the steady rests and readings were taken with the indicator 180° opposite the bottom pad. The next step was to grind the cylinder round by just lightly touching the high humps so as to round the circle.

Figure 10 below shows how the sharp round at the first hump became steeper while the second hump started to flatten. The circle started to become more round with the runout changing to .00014".

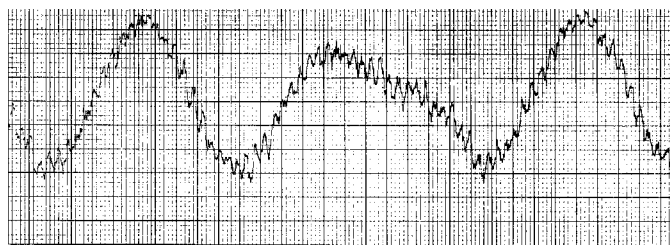


Figure. 10

With figure 11 below, the humps are flattened slightly more with the flatter hump becoming two separate humps. This is to say that the piece was beginning to go three sided. The runout decreased to .00012". The erratic movement is due to the grinding scratches being produced from the wheel.

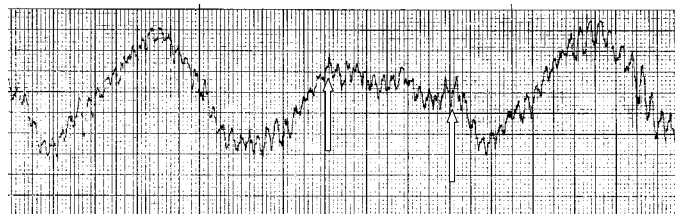


Figure. 11

In figure 12 below, the wheel was swept back and forth to smooth the surface and attain a better finish and at the same time the runout was decreased to about .00007".

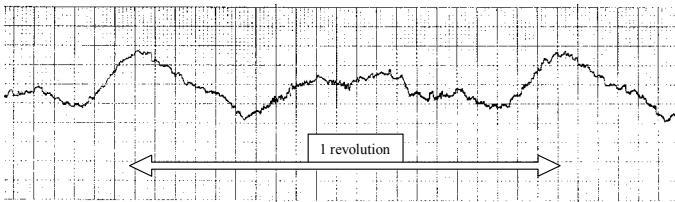


Figure. 12

Figure 13 below shows a neck that is starting to go 3 sided. The middle hump is opposite the lowest point recorded at the bottom of the graph. Runout is .00007".

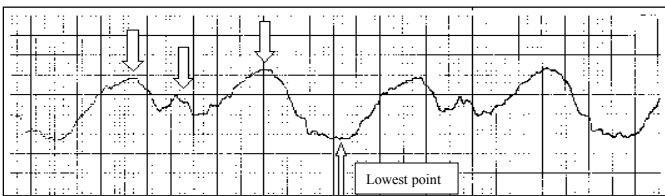


Figure. 13

Figure 14 shows changes as the humps are flattened down. However the roundness stayed at .00007" with the first 2 high spots being produced from the initial high hump, and the low point being opposite the second hump.

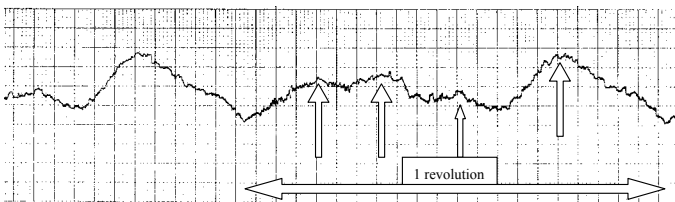


Figure 14

Figure 15 below shows the surface being smoothed down and the beginning of four high spots with a roundness runout of .00005".

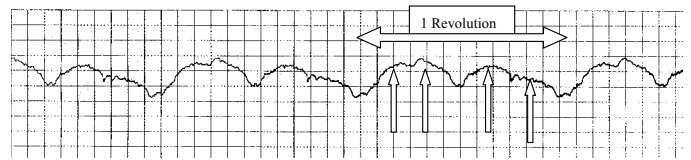


Figure 15

The strip chart recordings shown illustrate a total movement of .0002" from top to bottom which makes each large square on the chart represent .00002" movement of the electronic indicator and the small squares represent .000004" movement.

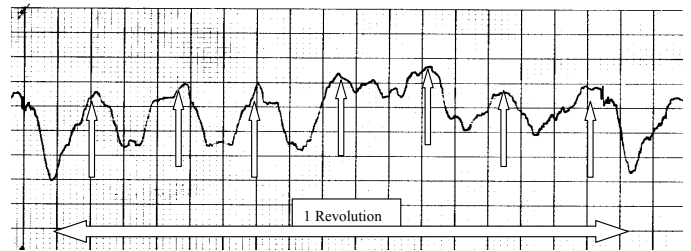


Figure 16

Figure 16 above is an example of a multisided cylinder. The roundness was within the tolerance at .00009" but the multiple humps appear as chatter on the surface and were very pronounced and visible. With so many sides to this surface, it became impossible to smooth down the chatter. When a surface starts to go flat (three sided, five sided, or more), it is better to start over at another location rather than continuing to fight the chatter. Go back up on centers roundup another area with minimum stock removal and then drop back down on the steady rests. Once this new surface is round, regrind the chattered surface.

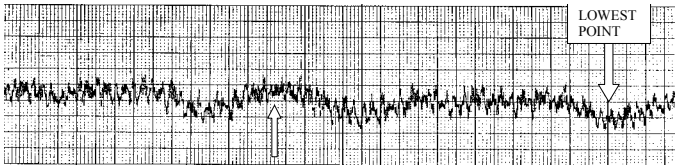


Figure. 17

Figure 17 shows a very quick erratic movement with the recorder needle moving up and down over a short distance. The roundness from the highest to lowest points total approximately  $0.00006''$ , with some of the quick movements being as much as  $0.00004''$ . These readings were taken on a journal, which had a rough finish.

Figure 18 shows the reading taken on the spot where the steady rest was riding. Notice that the configuration is the same, however the graph line is smooth and not jagged as in figure 17. With the surface riding against the Babbitt metal of the steady rest, the surface became burnished and smooth. As the surface in figure 17 was ground smoother, the jagged lines also smoothed down.

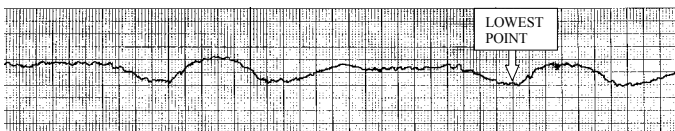


Figure. 18

The graph in figure 19 illustrates a tight chatter with about  $.00005''$  run out. The chatter will not cause a problem when regrinding due to the amount of surface that will be in contact with the steady rest. The lubricant used on the steady rest will fill most of the voids and create a hydrostatic condition at the same time the Babbitt will burnish the surface smoother while the roll body is being reground. This is acceptable, however a smoother continuous line is more desirable.

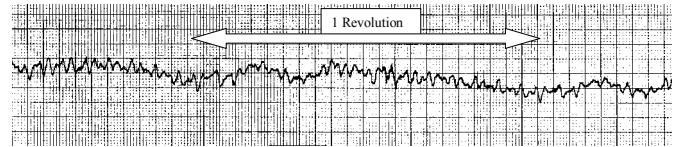


Figure. 19

In figure 20 below, the graph was shrunk length wise to illustrate two revolutions of the roll surface. The graph width still represents a total movement of  $.0002''$ . Each darker horizontal line is a measurement of  $.00002''$  movement of the LVDT. The Babbitt steady rest surface was being lubricated from an oil cup that was drip feeding very slowly.

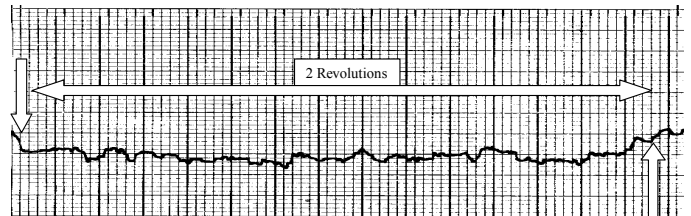


Figure 20

Notice that the graph is descending on the left side arrow, and starts to ascend on the right side arrow. The oil would raise the roll about  $.00002''$  for a revolution and then spread evenly to let the roll drop back down and occurred each time a drop of oil fell on the neck surface. Notice also that the total movement of the graph line is less than  $.00002''$  and does not appear to repeat. The surface is very close to being a true cylinder. The movement is just vibration and friction bounce. This is very close to a perfect cylindrical shape but it could go bad very quickly. If a cylinder is this round and still has stock, do not try to remove any more stock. It will go flat and will lose roundness very quickly. Finish the neck, move the steady rest to another finished fit and then come back and remove the rest of the stock from the spot fit.



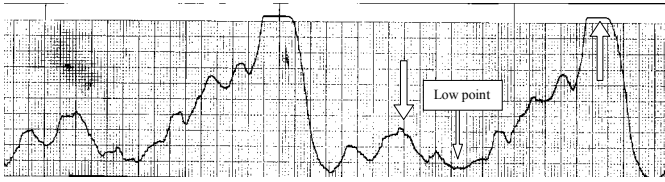


Figure. 21

Figure 21 above is an example of going from a very round cylinder to one with excessive run out. The downward arrow shows where the grinding wheel was fed into the piece and the upward arrow illustrates how the roll fell away from the wheel when the ground area came to the back steady rest pad. The low point is the area where the surface got warm, expanded, and extra material was removed. Then as this area cooled, it shrunk smaller than the original feed-in area. Notice that the feed-in is about 1/3 a revolution from the high, and the low point is 180° opposite the high. If we had attempted to round the high up again, the cylinder would have become three sided.

This cylinder was round within .00003” prior to the last feed in of the wheel. Now the cylinder is running .00024” with a flat spot at the downward arrow. The operator had rounded up another area on the neck before attempting to remove the excess stock on this cylinder and producing figure 21.

In figure 22, we see how he moved the steady rest to the rounded section, reground the original cylinder, and then moved the steady rest back to the first area. The roundness went from .00003” to .00006”. This illustrates that we can transfer roundness at least 1/2 as well as what was originally produced. He would have had better results had he spent more time finishing the first transfer spot, and again when he came back to finish the original spot.

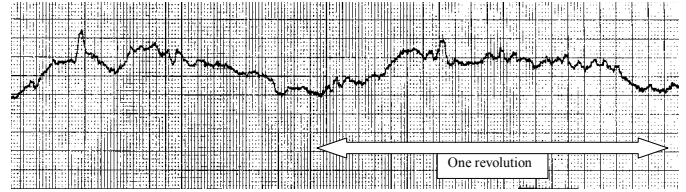


Figure 22

Figure 23 also represents a double transfer of the steady rests. The original run out was .00004”. The new run out is .00006” for one revolution. The cylinder was spotted on the steady rest and then a second cylinder was ground and permitted to “amp out”. The rest was moved to the second cylinder and the first diameter was ground to finish size and permitted to amp out. Upon moving the steady rest back to the first diameter, the graph in figure 23 was produced, illustrating an increase of about .00002” more runout.

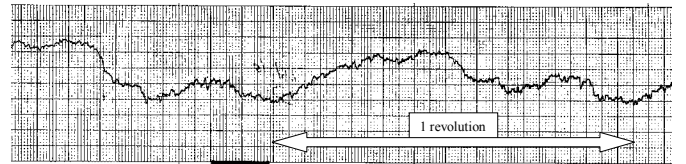


Figure 23

Figure 24 represents a three sided cylinder with approximately .0002” runout. Notice the three high indications within the one revolution and the amount of movement on both sides of the middle indication. With a situation this bad, move to a different area and start over. If you try to bring this three-sided cylinder into specification, you would need a lot of time and a very precise infeed on the grinder. Chances are that it would not come in to the .0001” requirement, of both being round and not multisided.

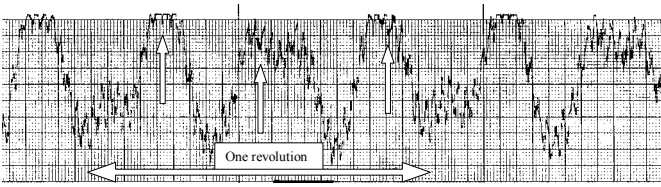


Figure 24

Indicator placement for checking roundness is critical for a true reading. When checking a roll on steady rests, the location of the indicator may produce a false reading with a three-sided cylinder. We make two readings at two different positions and analyze the graphs to determine the roundness of the cylinder.

Figure 7 illustrates the position for indicating roundness of the cylinder when checking the roll neck. The 180° opposite the bottom pad position will show the diameter roundness, even numbered multi-sidedness and chatter variation as the cylinder is rotated. The 12:00 position will show the roundness and will exaggerate any odd numbered multi-sidedness. The indication being taken at 12:00 will be needed for final verification and would be reported to the customer on an inspection certificate.

The strip charts shown previously required the operator to analyze the information. With the decreasing costs for computers, printers and technology, it is now possible to produce circular charts at a very reasonable cost. They are very self-explanatory and do not require much interpretation. Readings are given at six decimal places and the location of the highest reading is referenced from a "0" position. Figures 25 through 30 show a few of these graphs for reference.

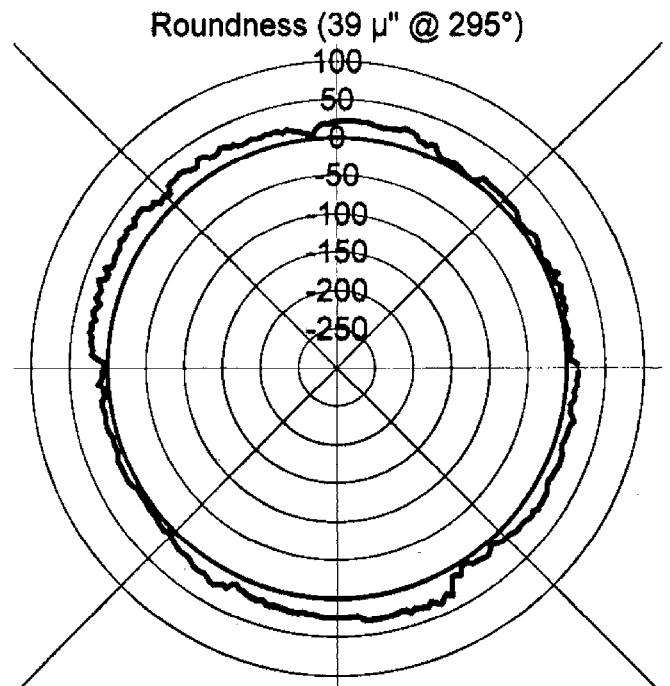


Figure 25 - Round

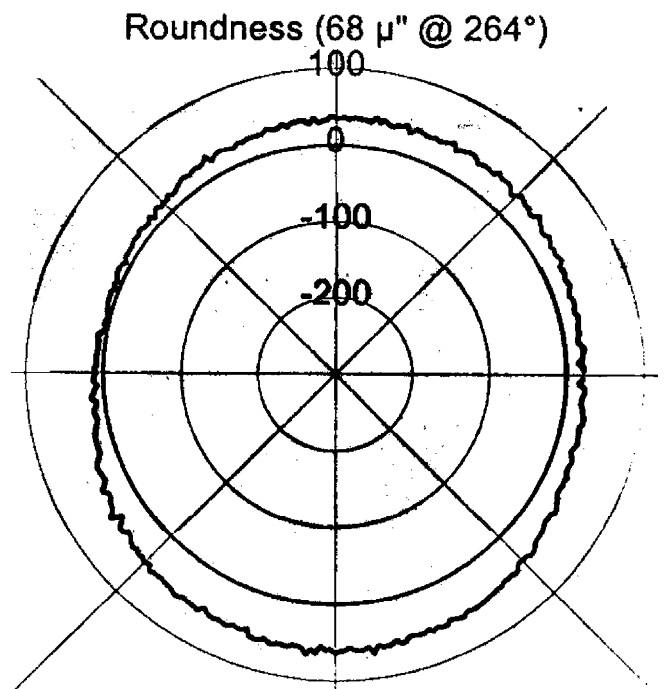


Figure 26 - Egg-shaped two-sided

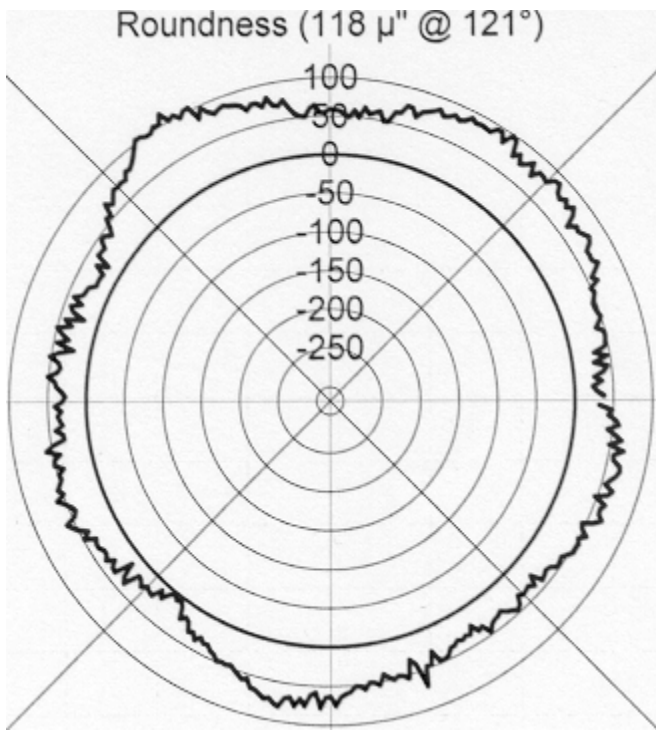


Figure 27 - Five-sided

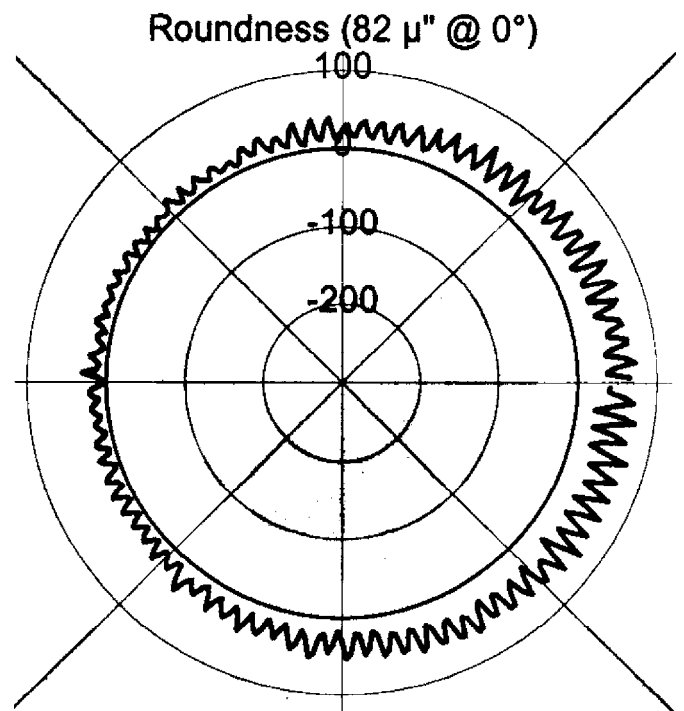


Figure 29 - Chatter

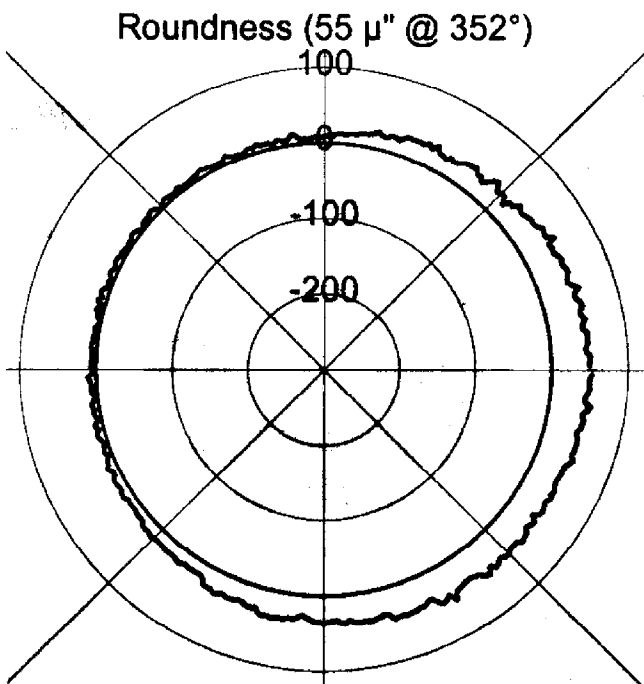


Figure 28 - Concentricity

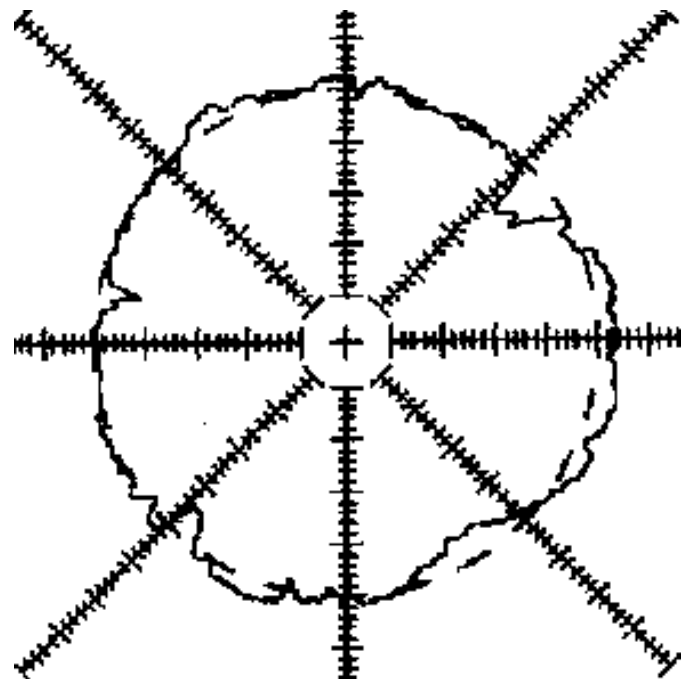


Figure 30 - Three-sided

## **Summary**

The intent of the paper was to clarify commonly used but often-misinterpreted terms used in customer specifications. Hopefully this paper has been helpful in explaining the terminology used in the roll making industry. The examples given are for illustration only, and are not intended to represent recommended roll tolerances for all roll applications.

## **Acknowledgments**

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