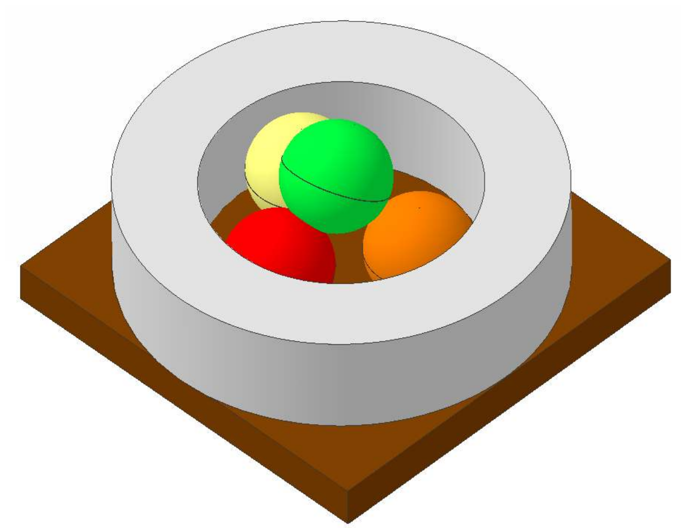
A Four Ball ID Gage, version 3

By R. G. Sparber



Take 4 balls of identical diameter and place them in a known diameter hole that is perfectly round.

Measure the height of the top ball above the surface of the brown plate.

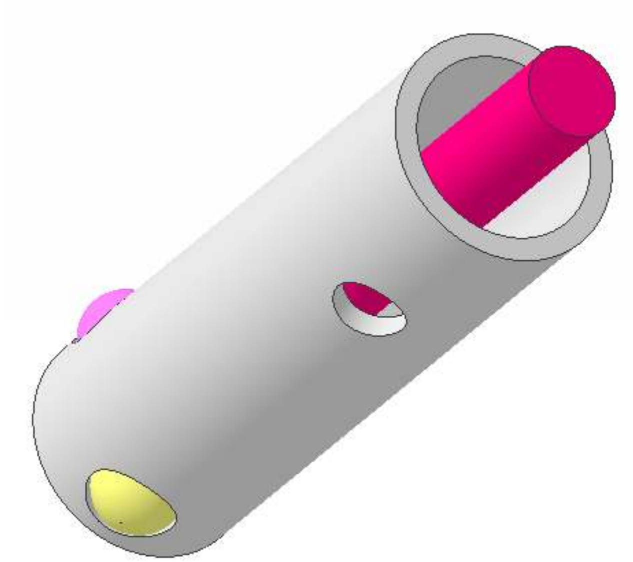
Then place the balls into a hole that is also perfectly round but of unknown diameter. Note the change in distance of the top ball above the brown plate.

You can then accurately calculate the ID of the unknown hole using the equations provided in the Theory section of this article. There is a bit of math there but if put into a spreadsheet, you will only have to input the change in distance of the top ball and will get the ID.

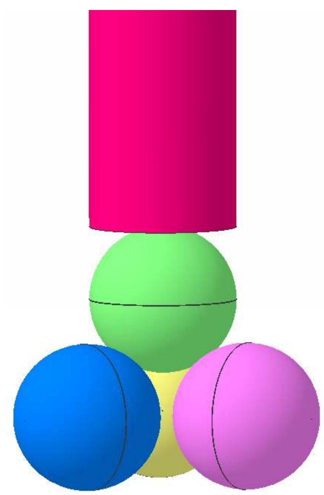
The one limitation is that the top ball must stay in contact with all 3 bottom balls. This means that the instrument is best suited for inspecting small variations of the given bore. However, you can use this gage for very deep holes which is hard to do with a telescoping gage.

You can detect out of round conditions by simply holding the gage at a given depth and rotating it. If the bore is asymmetric, elliptic or any multiple of 3 lobes, you should see the error.

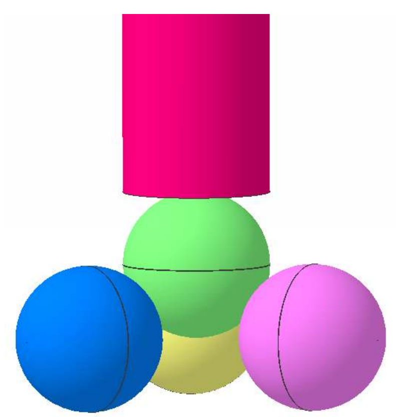
The Instrument



The red cylinder in the center is my Dial Test Indicator push rod. At the bottom you can see two of the 3 balls that contact the ID being measured. The hole in the side of the body takes a locking screw for holding the DTI in place.

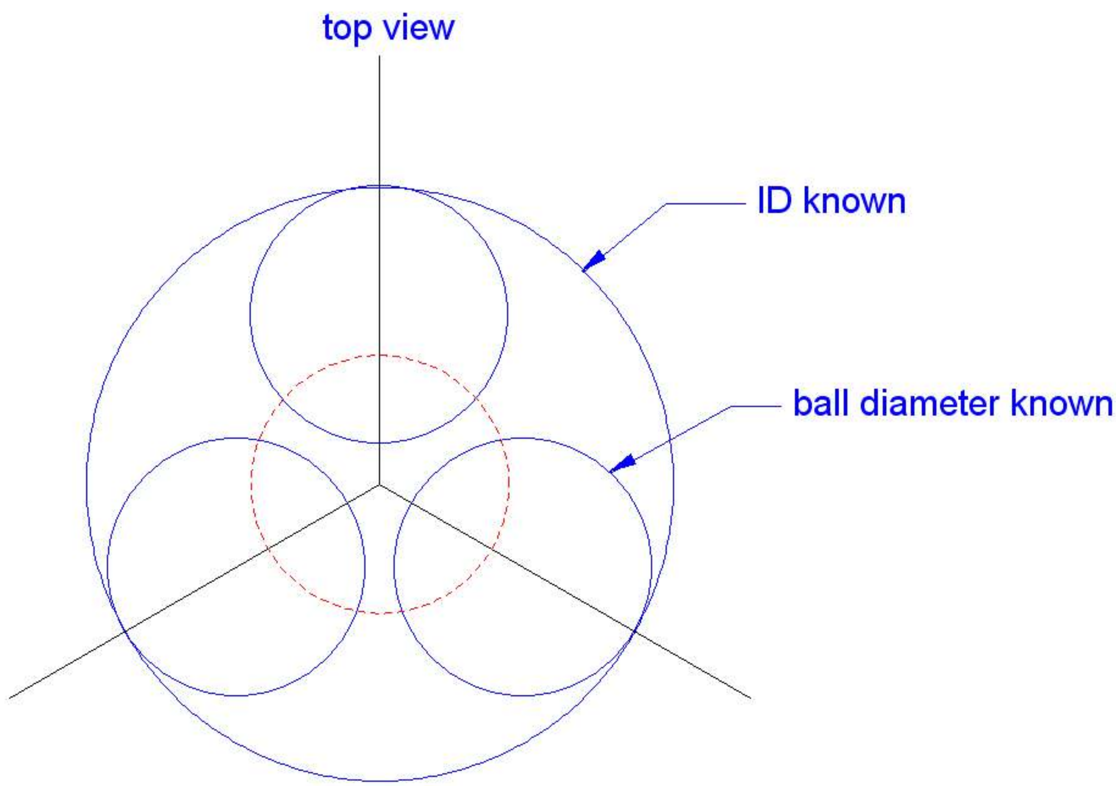


With the body of the instrument made invisible, you can again see the four balls.



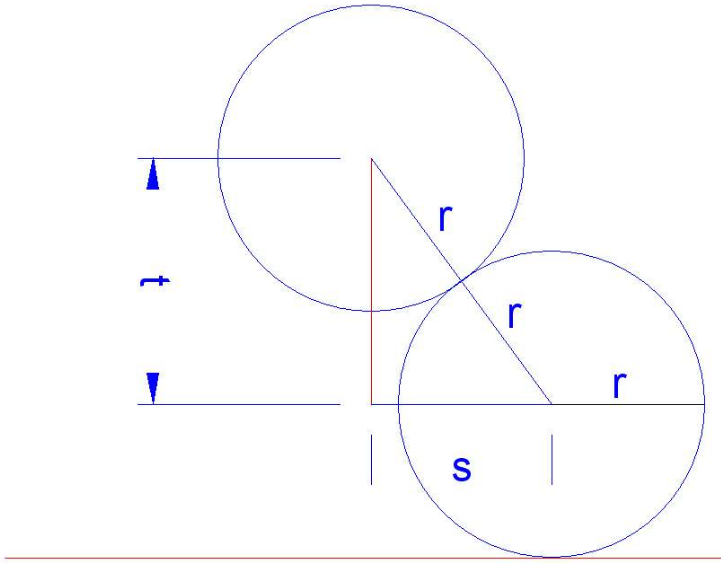
As the top ball is lowered, the bottom three balls move out. The precision of the instrument depends on the precision of the balls plus the holes that guide these balls in the body. All holes are reamed for a close sliding fit and precisely set 120° from each other.

Theory



Here is a top view of the 4 identical balls. The bottom 3 balls are on a plane and the forth ball rests on top (shown as a dashed red circle). The 3 balls are constrained by a cylinder with a known ID as shown.

Notice that the center of the top ball is at the center of the known ID.



A side view of just one of the 3 bottom balls and the top balls is shown here. All balls have a radius of "r".

Note that I can form a right triangle with hypotenuse of 2r.

Recall from the last page that the center of my top ball is at the center of the known ID. This means that my vertical red line must be at the center of my known ID. It also means that the distance s+r must equal half of my known ID. This lets me say

$$s = \frac{ID}{2} - r \qquad \text{(equation 1)}$$

S is the base of my right triangle. This means that I know the hypotenuse and base of the right triangle so can find the rise, "t" with

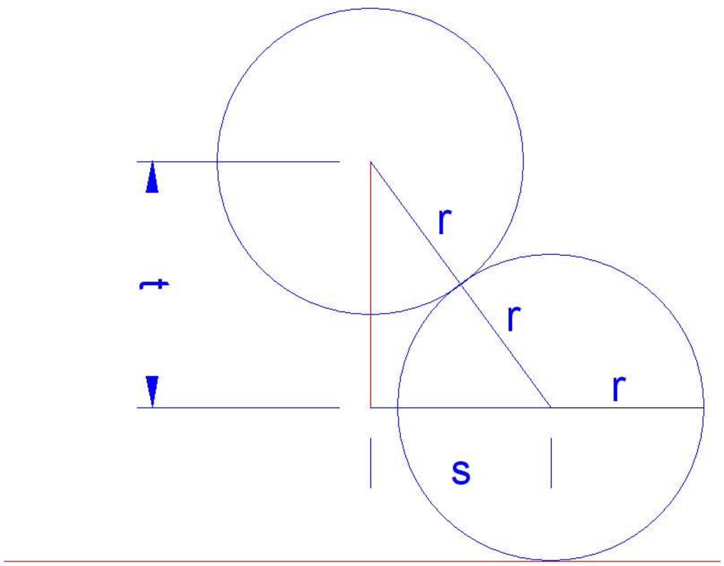
$$t = \sqrt{(2r)^2 - s^2} \qquad \text{(equation 2)}$$

Now, say I have a Dial Test Indicator pressing down on the top ball. With the 4 balls inside of my known ID, I zero the DTI.

Then I move the 4 balls to an unknown ID that is larger than the known ID and the top ball is still in contact with the bottom 3. I will see a change in DTI reading as the top ball lowers into its new position as the bottom 3 move out to contact the new ID. Call the new reading on the DTI "q". Equation 2 told me the old value of t. My new value of t, call it t_{new}, would be

$$t_{new} = t - q \qquad \text{(equation 3)}$$

Where t comes from equation 2 and q is the new reading on the DTI.



Looking again at the figure, note that I have a new value for t but the same value for the hypotenuse, 2r. So I can calculate the new value for s by rearranging equation 2.

$$s_{new} = \sqrt{(2r)^2 - {t_{new}}^2} \qquad \text{(equation 4)}$$

By rearranging equation 1 I get

$$ID_{new} = 2(s_{new} + r) \qquad \text{(equation 5)}$$

I could combine equations 1 through 5 for a single equation that relates the new ID to the change in DTI reading plus known ID, but don't see much point in it. Instead, I will just put it in a spreadsheet.

Four Ball ID measurement	
known ID	0.6250
ball diameter	0.2499
DTI reading	0.0390
measured ID	0.6813

The procedure then becomes:
1. Slide ID gage into known ID
2. Zero DTI
3. Slide ID gage into unknown ID
4. Read the DTI (including sign if unknown ID is smaller than known ID)
5. Enter DTI reading into spreadsheet (yellow box)
6. Read out measured ID (green box)

Bench Work

All of this theory is all well and good, but does it actually work?

I put a 1” piece of aluminum round stock in my lathe and bored out a hole to a depth of about ½”. Then I backed out the boring bar and opened up the top ¼” of the hole by a few thou.

After cleaning and deburring, I measured each diameter five times using my telescoping gage and my best mic[2]:

	ID 1	ID 2
	0.65190	0.65795
	0.65115	0.65810
	0.65165	0.65895
	0.65255	0.65855
	0.65175	0.65840
	3.25900	3.29195
av	0.65180	0.65839
deviation +/-	0.00065	0.00044

You can see I have calculated the average and deviation from this average for each ID.

Next, I discarded the largest and smallest value to see if they had much of an effect.

	ID 1	ID 2
	0.65190	0.65810
	0.65165	0.65855
	0.65175	0.65840
	1.95530	1.97505
av	0.651767	0.65835
deviation +/-	0.00002	0.00025
diff in averages	0.00003	0.00004

[2] See http://www.use-enco.com/CGI/INSRIT?PARTPG=INSRAR2&PMAKA=510-2292&PMPXNO=8915860

Note that the average changed by no more than 0.0004" which tells me the outliers were about equidistant from the average. My deviation went down by around half. This tells me that my average measurements are close to the "truth".

I bought 100 ball bearings that were about ¼" in diameter. From the group, I selected four balls that were 0.24930" in diameter.

My 4 ball ID gage was equipped with a low cost push rod DTI that has tick marks every 0.001". I can easily read to 0.0005" and with a bit of hope, to the nearest 0.00025". Going way out on a limb, I attempt to read to the nearest 0.0001" but accuracy is dubious.

The spreadsheet was then populated with known values:

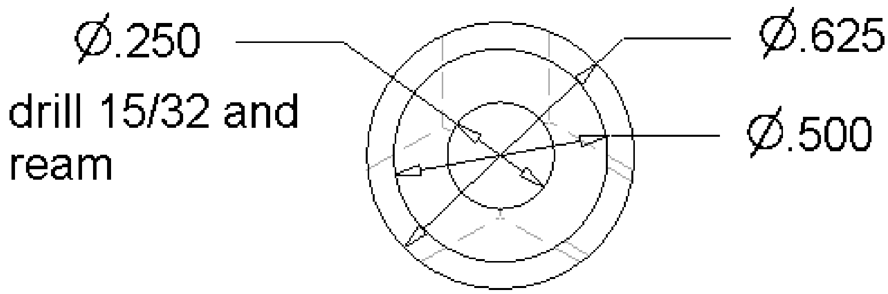
Four Ball ID measurement

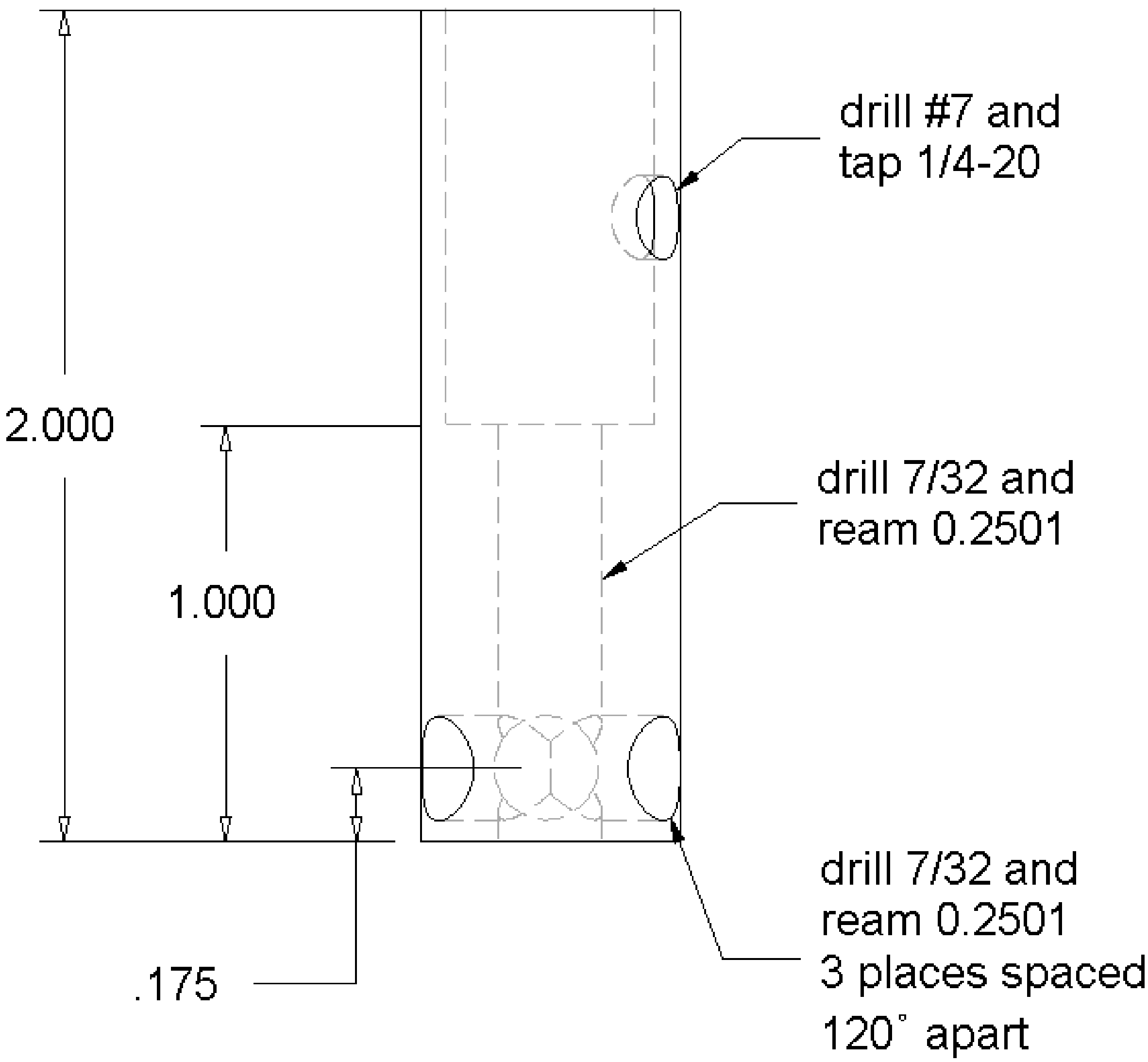
known ID	0.65177		
ball diameter	0.24930		
DTI reading	0.00450	0.00464	would give exact result
measured ID	0.65820		

Reading the DTI to the nearest 0.0005" gave me a calculated measured ID that was 0.00015" under the value found by using the telescoping gage. If I had read the DTI to be 0.00464", I would have calculated an ID exactly equal to the average value found with the telescoping gage.

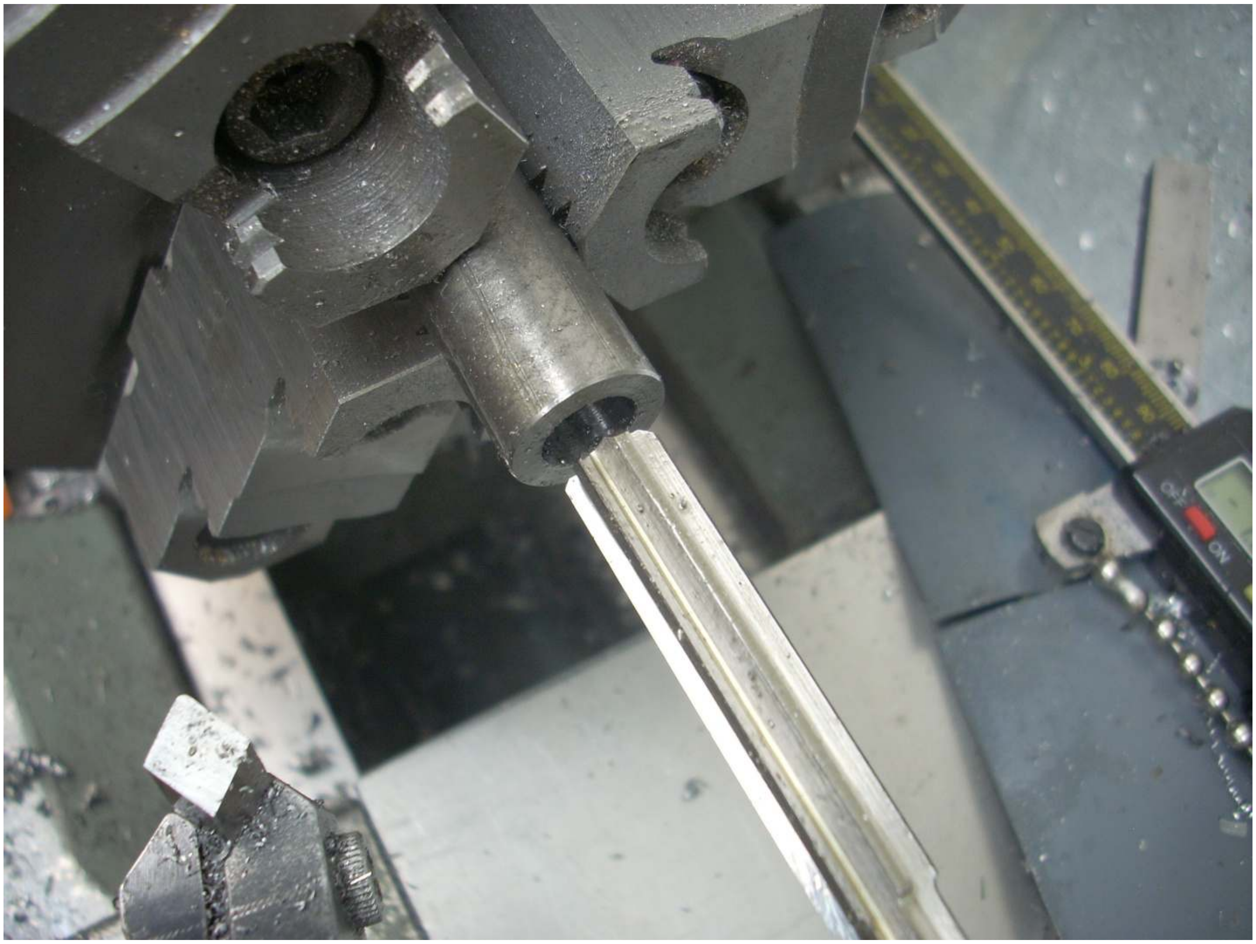
This is far from a rigorous proof that the instrument works, but does hint in that direction.

Construction



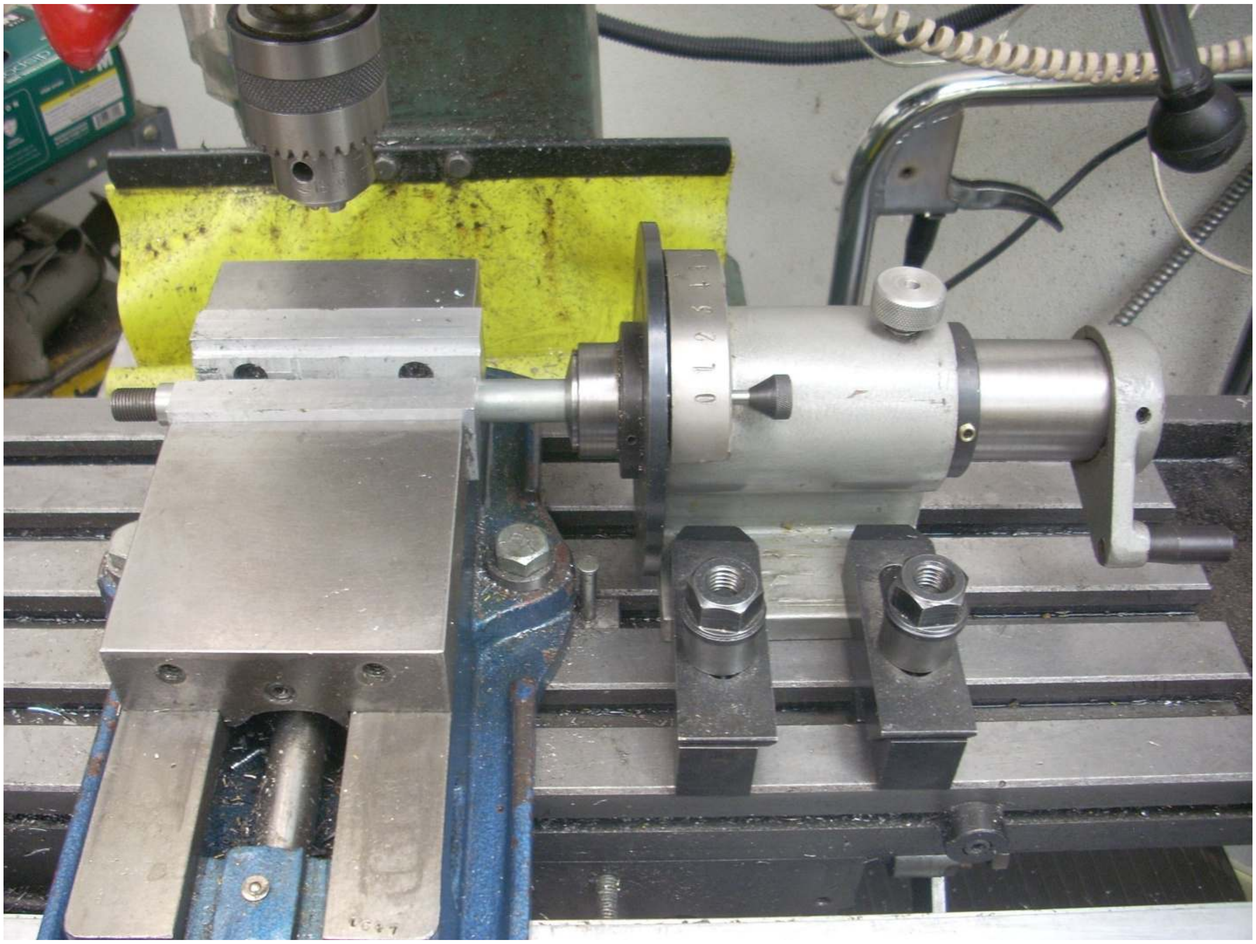


The gage is shown to be 2” long but by placing a longer push rod down the center, you could make the gage just about any length you want.

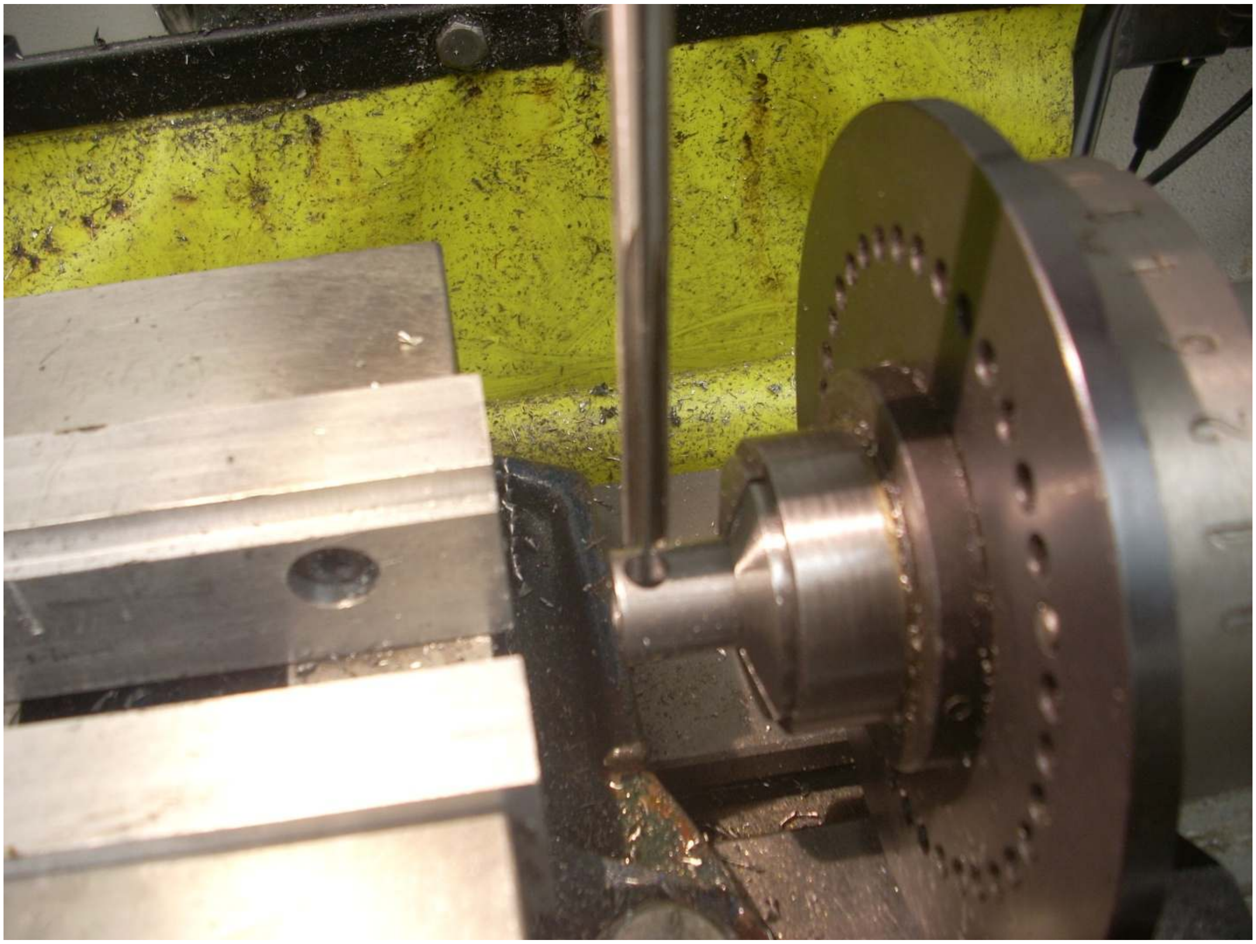


After facing the end of the body, I drilled 7/32" and reamed to 0.2500. It was a bit snug so I have specified using a 0.2501" reamer. I then drilled 15/32" to a depth of 1" and ran a 0.500" reamer as shown here.

I then deburred the part and cleaned it up before moving to my mill.



I will use my 5C collet spinner to position the 3 holes exactly 120° apart. The first step is to align the center of rotation of the spinner with the X axis of my mill. Since my vise is already aligned, I just chucked up a pice of ½” bar stock and clamped it in the vise and spinner. Then I tightened the clamps on the spinner.



The body was then clamped in the spinner using a 5/8” 5C collet and the spinner’s rotation locked. I used my DRO to find the centerline of the part and the end. Then I moved in 0.175” and locked my X and Y axes. For each hole I started with my spot drill, then a 7/32” drill, and finally my reamer. Rotated the part 120°, locked the spinner, and repeated the process two more times.

I then flipped the part over and drilled the hole for the set screw.

The knurled set screw came out of my junk drawer. I bought 100 of these ¼” ball bearings for about $3.50 from Enco©.

There is a small amount of friction between the balls and the reamed holes so the balls don’t just fall out.

Here is the gage sitting in my calibration ID. Note that the dial has been zeroed.

I placed a spacer in the calibrated ID cylinder to raise the gage up so it would contact the upper ID. The gage reads 0.004” and not 0.0045” because it is not straight.

Improvement

One factor that affects accuracy is the orientation of the gage in the hole. It must be as aligned with the central axis of the hole. This can be done fairly well by eye but by adding a tapered collar, the guess work is taken out.

The collar was made of aluminum. The hole down the center should be a close fit to the body of the gage. The taper angle is not critical but I chose to set my compound at 10° and it seems to work well. Do take care when cutting the taper to produce a sharp edge at minimum diameter. The taper must fit into the hole.

When the 3 balls are in contact with the wall of the hole and the taper is contacting the top edge of the hole, the gage will be centered.

Conclusion

It is certainly far easier for me to measure the bore with this gage than with the telescoping gage. If you had a deep bore and needed to measure variations in diameter at various depths, this instrument might do the trick. I would recommend using a better quality DTI to measure top ball movement. I would not recommend using a mic barrel because it would not permit the balls to freely move as the ID changed. This could jam the instrument and give false readings.

Acknowledgements

This has been a group design project. From the Valley Metal club, I wish to thank John Herrmann, Bob Sanders, Brian Lamb, and JR Williams. From the Atlas_Craftsman group, I wish to thank JT, Glenn N, James Irwin, Jon Elson, Philip Sutcliffe, Bruce Freeman, Donald Lewis, Aaron Silver, and Russ Kepler. From the metal_shaper group, I wish to thank Alan Lapp, Ian Newman, and John Kiely. My apologies if I forgot anyone.

These generous people again demonstrate that "all of us are smarter than any one of us".

I welcome your comments and questions.

Rick Sparber
Rgsparber@aol.com
Rick.Sparber.org