Electronic Edge Finder Run-out Compensation, Version 1.0

By R. G. Sparber

Scope

For some milling machine[2] operations, the Center Of Rotation (COR) of the spindle must be known relative to some reference surface attached to the table. This measurement can be done with a non-rotating Electronic Edge Finder[3] (EEF). Read on for a procedure that minimizes error due to run-out.

Conclusion

Using a non-rotating Electronic Edge Finder and the procedure presented here, it is possible to measure the distance between COR and a reference surface with an error much smaller than the repeatability of my milling machine.

In other words, the Electronic Edge Finder probe run-out error has essentially been eliminated.

[2] In all cases, I am talking about vertical milling machines.
[3] See, for example, https://rick.sparber.org/SDEF.pdf which is used in this article.

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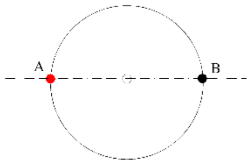
The Procedure

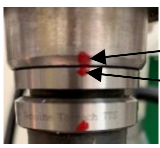
One Time Calibration

1. Place a single colored dot on the perimeter of the collet that holds the EEF probe[4].



Call this mark "***A***". Call the radial point 180° from this mark "***B***".

2. With the highest accuracy available, measure the diameter of the probe between the ***A*** and ***B*** reference marks. Call this the ***actual diameter***.
3. Install the probe in the spindle.



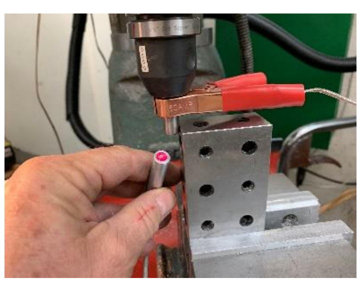
4. Place a single colored dot on the spindle that lines up with ***A***. I have added a second dot on the top of the collet to ease alignment.

5. Turn the spindle so ***A*** faces the reference surface.
6. Feed in the probe until touchdown is detected.
7. Record the position and call it $\mathbf{D_A}$.
8. Back the probe away from the reference surface.
9. Rotate spindle to ***B***.
10. Feed in the probe until touchdown is detected.
11. Record the position and call it $\mathbf{D_B}$.
12. Calculate the ***effective diameter***

$$\textbf{\textit{Effective diameter}} = \textbf{\textit{actual diameter}} + (\mathbf{D_A} - \mathbf{D_B})$$

13. Use the ***effective diameter*** as the the probe diameter.

Routine Procedure



Proceed with finding zero on the X and Y axes. Always turn the spindle so the ***A*** reference mark faces the reference surface. If the probe is removed from the spindle, reinstall with the colored dots lining up.

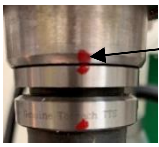
[4] Yes, the probe is just a short length of 3/8 inch drill rod.

An Example

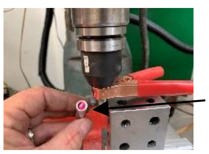
One Time Calibration

1. Placed a single colored dot on the perimeter of the collet that holds the EEF probe. Called this mark "***A***". Called the radial point 180° from this mark "***B***".

2. Measured the diameter of the probe between the ***A*** and ***B*** reference marks. Called this the ***actual diameter***. I measured 0.37465 inches.
3. Installed the probe in the spindle.



4. Placed a single colored dot on the spindle that lined up with ***A***.



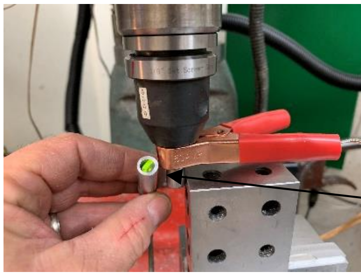
5. Turned the spindle so ***A*** faced my reference surface.
6. Fed in the probe until touchdown was detected (LED red).
7. Recorded the position and called it $\mathbf{D_A}$. I read a machine position of 5.2653 inches[5].
8. Backed the probe away from the reference surface.
9. Rotated the spindle to ***B***.
10. Feed in the probe until touchdown was detected.
11. Recorded the position and called it $\mathbf{D_B}$. I read a machine position of 5.2647 inches.
12. Calculated the ***effective diameter***

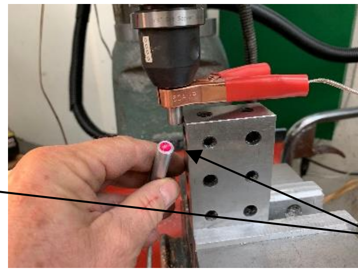
Effective diameter = ***actual diameter*** + $(\mathbf{D_A} - \mathbf{D_B})$
Effective diameter = 0.37465 + (5.2653 - 5.2647)
Effective diameter = 0.37465 + 0.0006 (so run-out is 6 tenths)
Effective diameter = 0.3753

13. Set the probe diameter to 0.3753.

[5] I took 10 readings for D_A, tossed the largest and smallest, and averaged the rest. This number was then rounded to 4 places after the decimal point. Did the same for D_B.

Routine Procedure





I was setting zero on my X-axis. The spindle was rotated so the ***A*** reference mark faced the reference surface, my 123 block. Then I had the CNC program automatically feed in until touchdown. Note that the LED changed from green to red.

Test Result Evaluation

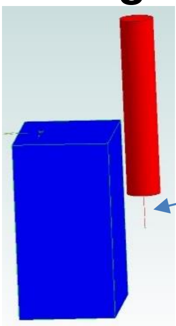
Reading the machine coordinates using my EEF and correcting for the probe radius, touchdown occurred at 5.4523 inches.

Using my Starrett mechanical edge finder[6] and again correcting for its probe radius, I read 5.4525 inches. Unpublished position repeatability of my machine has been measured at ± 0.0005 inches. Absolute accuracy with screw mapping enabled is ± 0.001 inches[7]. This means that error due to machine variation dominates and EEF error, with run-out compensation employed, is not significant.

[6] I consider this edge finder my "gold standard". Sadly, it is not compatible with my CNC program. The EEF is.

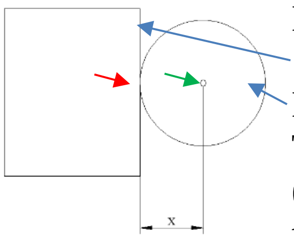
[7] See https://rick.sparber.org/CSMX.pdf

Background



My Electronic Edge Finder is represented here by the red cylinder.

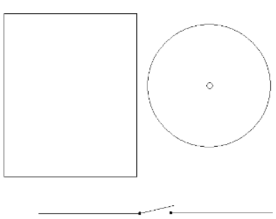
This thin line extending out the bottom is the Center Of Rotation. The blue block has a surface facing the EEF which I can define as my reference surface. The goal is to measure the distance from the COR to the reference surface. Knowing this value permits me to replace the EEF with a cutter and position it precisely relative to the reference surface in preparation for machining.



Here is a top view of the reference surface and the EEF.

The basic idea is to move the EEF until it touches the surface (red arrow). Given that we know the EEF's radius, we know the distance, *X*, from COR (green arrow) to reference surface. A few conditions must be true and these will be addressed later.

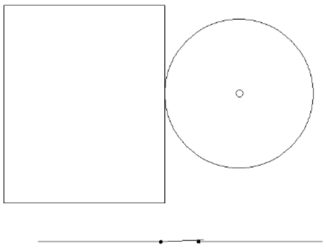
Don Bailey of SuburbanTool Inc has done a masterful[8] job of explaining the various types of edge finders along with their strengths and weaknesses. See https://www.youtube.com/watch?v=bga7y4infIo



Given that the reference surface and EEF probe are clean, there is no more accurate method for sensing touchdown. We essentially have an electrical switch which is either open or closed[9]. The reference surface is one contact of our switch and the probe is the other. When the EEF is not touching the reference surface, the switch is open.

[8] With one exception: he addresses repeatability but not relative accuracy. It would have been interesting if he had shown machine coordinates while comparing types of edge finders.

[9] The voltage difference across the contacts is too small to cause arcing.



The instant the probe contacts the reference surface, we transition from an open circuit to a closed circuit.

The switch can be connected to a battery and light bulb or fed into complex CNC software. In both cases, when the we have touchdown, the switch closes, and an indicator becomes active.

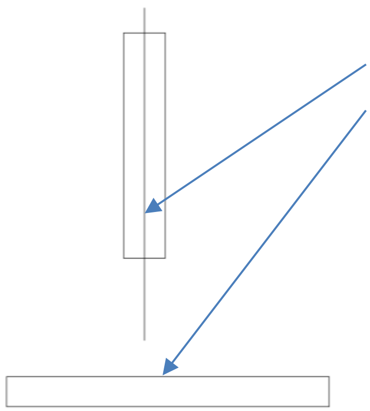
Any variation in touchdown position is due to repeatability error in the milling machine. This error increases with applied force as the machine flexes a tiny amount.

Imagine that the mill is made from overcooked macaroni. It will have one alignment when not being touched but will distort under even the lightest pressure. This is why you must never rest your hand on the head of a mill while it is cutting. No matter how massive, the machine will unnecessarily distort due to this added weight.

Even with zero error while using an EEF, there will be error during cutting. The best we can do is not contribute error due to using an EEF.

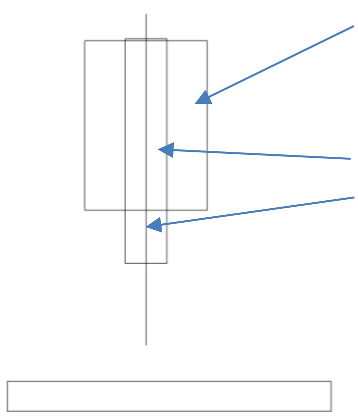
Error Sources

Many factors reduce the accuracy of the EEF. All but one are related to how the milling machine is fabricated and/or aligned. We can identify these error sources but correction is beyond the scope of the article. The remaining factor can be identified, measured, and minimized.



An ideal mill has its Center Of Rotation perpendicular to its table. The table's surface is parallel to the XY plane while the COR is parallel to the Z axis. In this way, a cutter rotating in alignment with the COR can be moved in XYZ space to cut precise shapes.

Sorry, but you can't buy an ideal mill. The COR will never be exactly perpendicular to the table and the table will never perfectly move along the X and Y axes. These error sources can be minimized but as far as the EEF is concerned, are just facts of life. I will deal with these imperfections the best I can: ignore them.

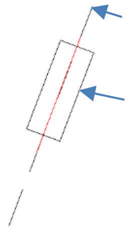


The mill has a Quill which ideally moves move up and down. It carries the Spindle which ideally rotates around the COR. This enables the spindle to rotate plus move up and down.

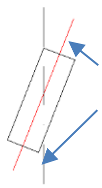
Attached to the bottom of the spindle is a means[10] by which cylinders like EEFs and cutters can be attached. Ideally, they attach in perfect alignment with the COR.

[10] Examples include drill chucks, end mill holders, and collets.

Of course, there will always be some misalignment.



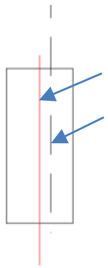
The COR can never be exactly perpendicular to the mill's table. Here you see that the
EEF or cutter is perfectly aligned to the COR but the COR is tilted[11] with respect to the table.



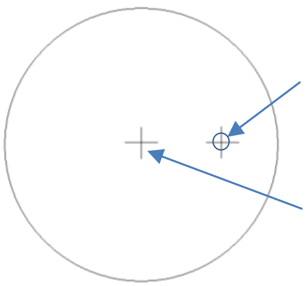
To the extent that the
major axis of the EEF or cutter is not parallel to the
COR, it will trace out an hourglass shape while turning. This is a defect in the mill or attachment tooling.

Look elsewhere for how to reduce these errors. I'll be ignoring them here.

[11] Look up traming.

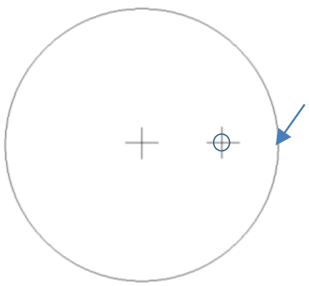


A third error is called ***run-out***. This is when the major axis of the cylindrical EEF or cutter is not coincident with the COR. They are, however, assumed to be parallel.



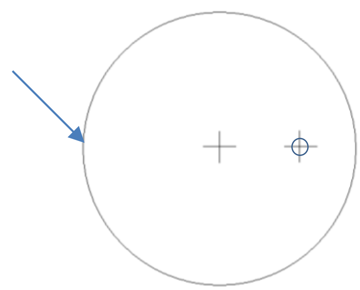
Looking from above, we see the COR and

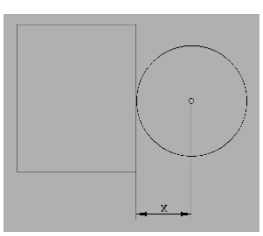
the major axis of the cylinder.



If I use this point to touch down on my reference surface, I'm closer than the radius of the probe.

If I use this point to touch down on my reference surface, I'm further than the radius of the probe.





The important point here is that run-out causes the EEF probe[12] to act like it has a radius different than actual. When detecting touchdown, this misalignment can directly contributes to error in the COR to reference surface distance. That causes our zero point on this axis to shift.

The trick is to measure the run-out and cancel it.

Refer to page 3 for the procedure.

[12] Remember, the EEF is not rotating.

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Rick Sparber
Rgsparber.ha@gmail.com
Rick.Sparber.org