A Simplified Electronic Edge Finder with CNC Compatible Outputs, Version 1.5

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Conclusion

This Electronic Edge Finder (EEF) is my best design so far:

- It recognizes when the spindle resistance is too small to detect touchdown, preventing probe crashes during automatic touchdown[2].
- It is compatible with Computer Numerical Control (CNC) systems for use in the automatic touchdown function[3]. See Appendix I for a manual version.
- It uses the fewest components and costs the least, coming in under $3.
- Its mechanical accuracy is the same as the more elaborate EEFs I have designed.

I employ a 100 mA test current. See Appendix II on page 12 for why I do not believe this damages the spindle bearings.

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[2] This does assume that the spindle clip has been installed on the spindle and the enclosure is solidly on the table or ways. Now, is that too much to ask?

[3] I do not have the automatic probing function but it should work there too.

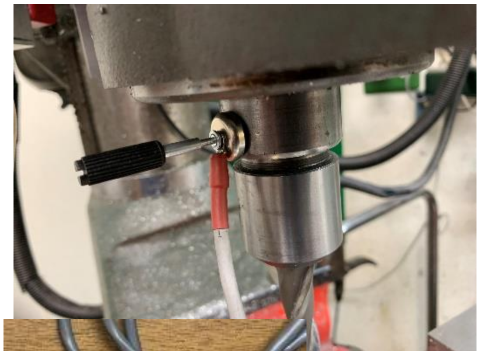
Can It Work For You?

This Electronic Edge Finder depends on having at least 1 ohm between the spindle and the machine body. Most multimeters can perform this measurement. First, touch both probes to the machine's body and record the number. Then move one probe to the spindle and record that number. Subtract the first number from the second. Is it at least 1? If not, see Appendix III for how to increase sensitivity.

Contents

Operation

The spindle connection is via a magnetic clip placed on the spindle.



The bottom of the enclosure, which rests on the mill table or lathe ways, provides the machine body's electrical connections. Two magnets inside the enclosure ensure good electrical contact is made with the table or ways.

The Computer Numerical Control (CNC) interface is via a ¼ inch diameter stereo jack.

Power comes from a USB wall wart.

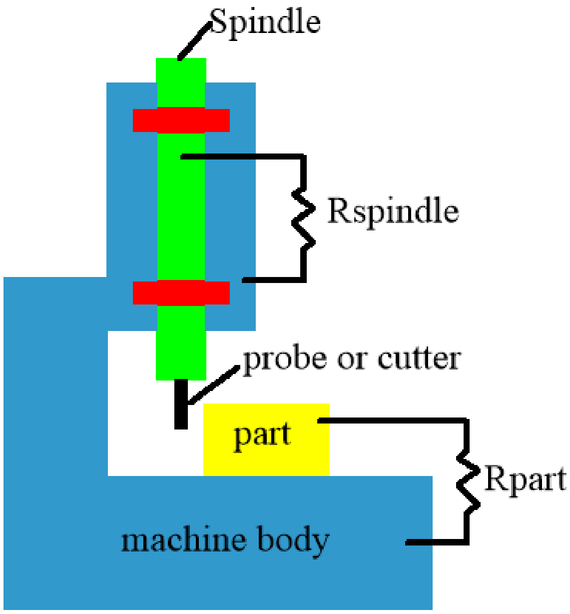
After making these connections, if the red LED is on, the spindle resistance is too small to proceed, and the CNC display will show probe contact. A few degrees of spindle rotation clear this fault on my mill.

1. If the LED is off, it is safe to proceed. However, if power is not connected, the CNC system will indicate that there is no probe.
2. Optionally[4], run a functional test
    a. Move the probe close to the reference surface.
    b. Momentarily bridge the gap with a piece of metal[5]. The CNC display should report touchdown.
3. The automatic touchdown process can now begin. Typically, the LED will flash when the initial touchdown occurs and remain on at the end of the process.

If the spindle resistance drops below 1 ohm during the touchdown process, a false touchdown will be generated, stopping further movement and preventing a crash.

[4] Your past experience will dictate if this is necessary.
[5] Soft metal, like plumber's solder, will not harm the cutting edge of an end mill if one is used as the probe.

Theory



Two resistances are involved in detecting touchdown using a non-insulated probe and an Electronic Edge Finders (EEFs). The spindle resistance, $R_{spindle}$, is the total electrical resistance inside the two spindle bearings. It varies from many ohms down to almost zero. The part resistance, R_{part}, ranges from about 0.05 ohms to nearly zero[6]. They are read by measuring the resistance between the spindle and the machine body.

Before touchdown, the EEF measures just $R_{spindle}$. After touchdown, it reads the parallel combination of $R_{spindle}$ and R_{part}.

If $R_{spindle}$ is more than 1 ohm, detection of touchdown is assured.

If $R_{spindle}$ is less than 1 ohm, a false touchdown results, which alerts the user and the CNC system that $R_{spindle}$ is too small. If $R_{spindle}$ drops below 1 ohm during the automatic touchdown process, the false touchdown will stop further movement and prevent a crash.

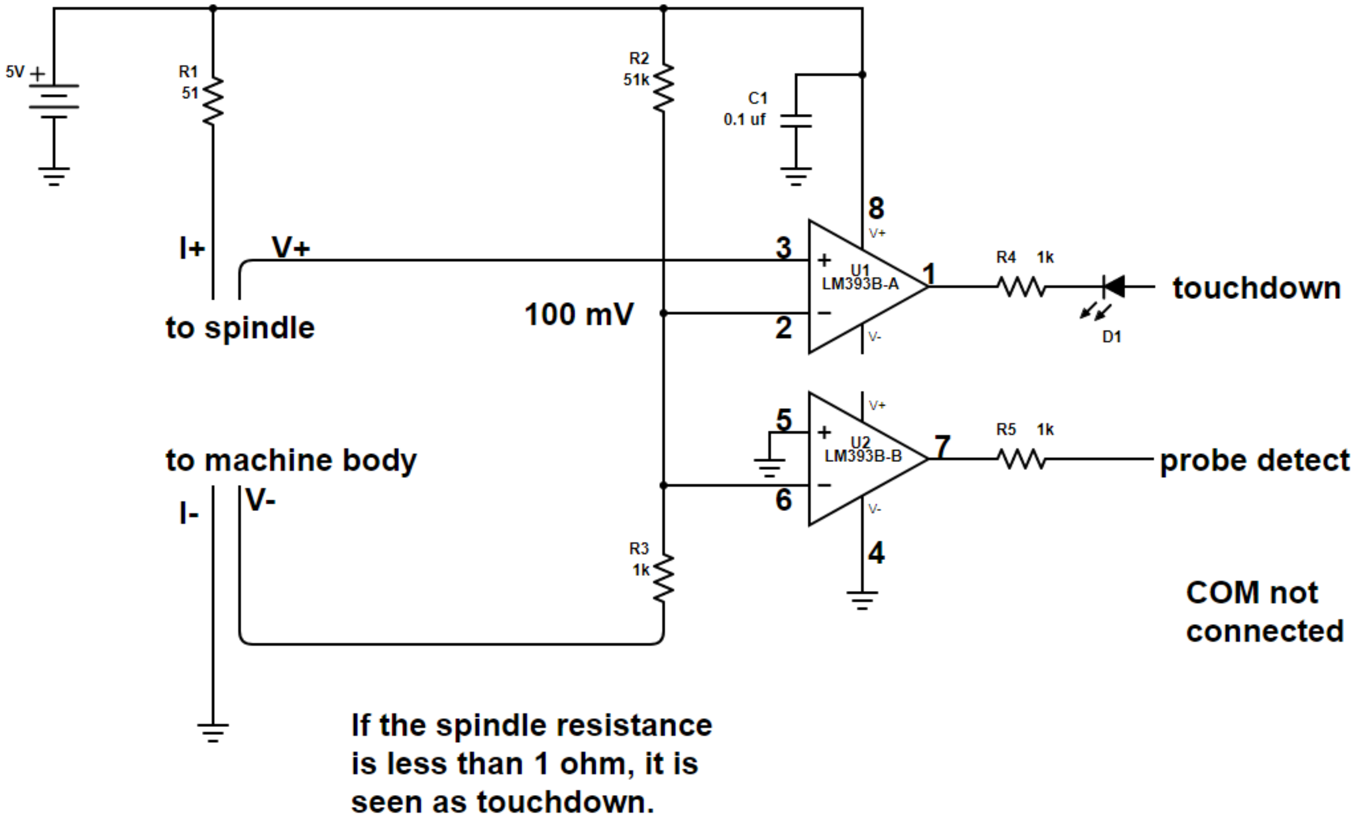
Rotating the spindle a few degrees returns the resistance to a usable value.

The EEF circuit contains two ancient inventions. Accurate sensing of the unknown resistance uses a Kelvin Connection, invented by William Thomson, 1st Baron Kelvin, in 1861. Measurement of this unknown resistance independent of supply voltage is accomplished with a Wheatstone Bridge, created by Samuel Hunter Christie in 1833.

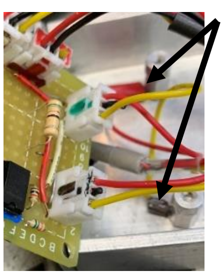
The output of the Wheatstone Bridge feeds a voltage comparator which, in turn, drives the CNC system.

[6] For more background on these resistances on a lathe, look here. For a mill, look here, page 6.

Schematic



Two wires, I+ and V+, run to the magnetic clip that holds onto the spindle.



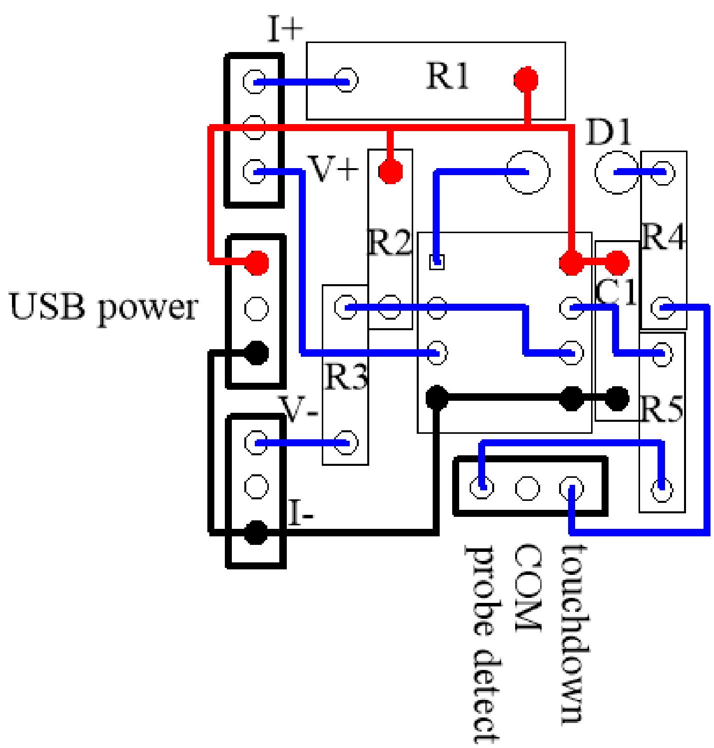
I- and V- are separate wires that run to the metal enclosure of the EEF. When this enclosure is placed on the mill table[7], a low resistance connection to the machine's body is made. These four connections form the Kelvin Connection.

[7] Two magnets located inside the enclosure ensure good electrical contact. If the enclosure was heavier, these magnets would not be necessary.

Bill of Materials

Name	Type	Value	Digi-Key Part Number	Quantity	Description
R1	RESISTOR	51	A138198TB-ND	1	RES 51 OHM 5% 1W AXIAL
R2	RESISTOR	51k	P51KJTR-ND	1	RES SMD 51K OHM 5% 1/10W 0402
R3, R4, R5	RESISTOR	1k	A126400TR-ND	3	RES SMD 1K OHM 5% 1/5W 0603
U1	LM393B-A		296-LM393BIDGKRTR-ND	1	DUAL COMMERCIAL GRADE STANDARD C
D1	LED		516-2231-2-ND	1	LED RGB CLEAR 4PLCC SMD
C1	bypass	0.1 uf	399-C1206S104K5RACAUTOTR-ND	1	SMD AUTO X7R FE, CERAMIC, 0.1 UF

A Possible Layout



I have assumed all through-hole devices and connectors. The board is 1.2" by 1.2".

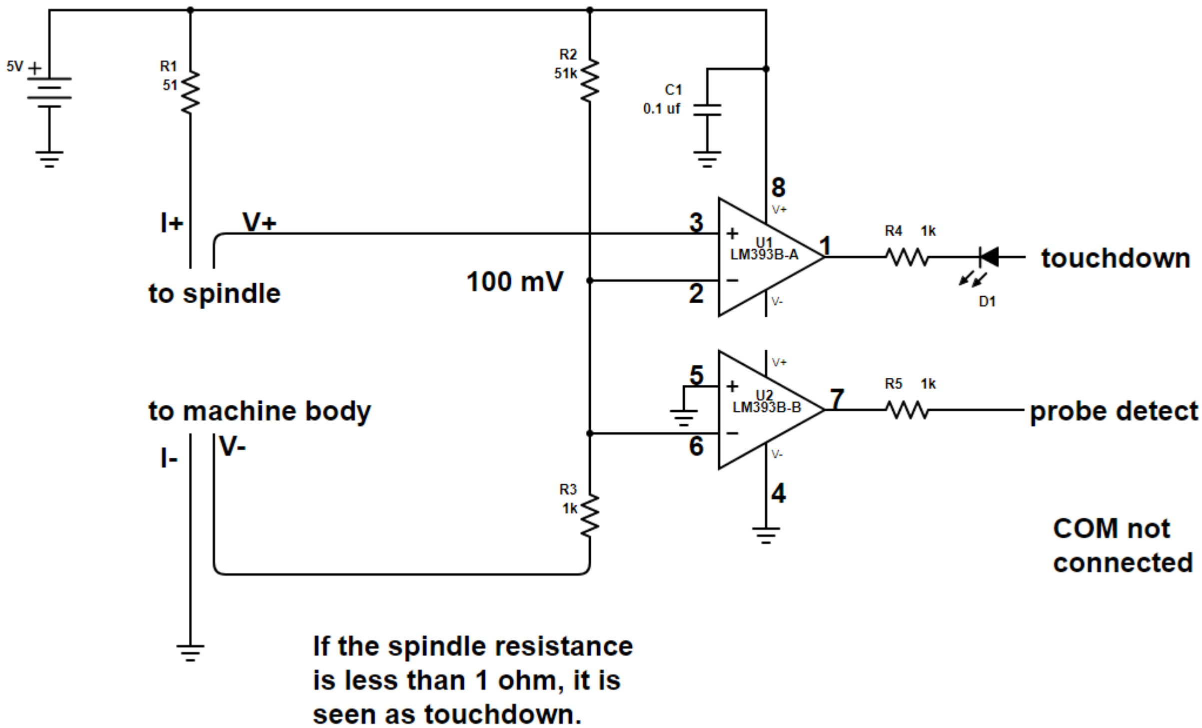
I used four connectors[8]. In the upper left corner is the termination of the spindle cable, containing I+ and V+.

Below it is USB power. Next down is the termination of the enclosure wires, V- and I-.

Along the bottom is the CNC interface with touchdown and probe detect. Note that COM is not connected, as explained on page 9.

[8] I only had 3 pin connectors on hand but 2 pin would have done the job.

High-Level Circuit Description



The Kelvin Connection, described on page 5, consists of I+, I-, V+, and V-. A poor connection here will cause a false reading.

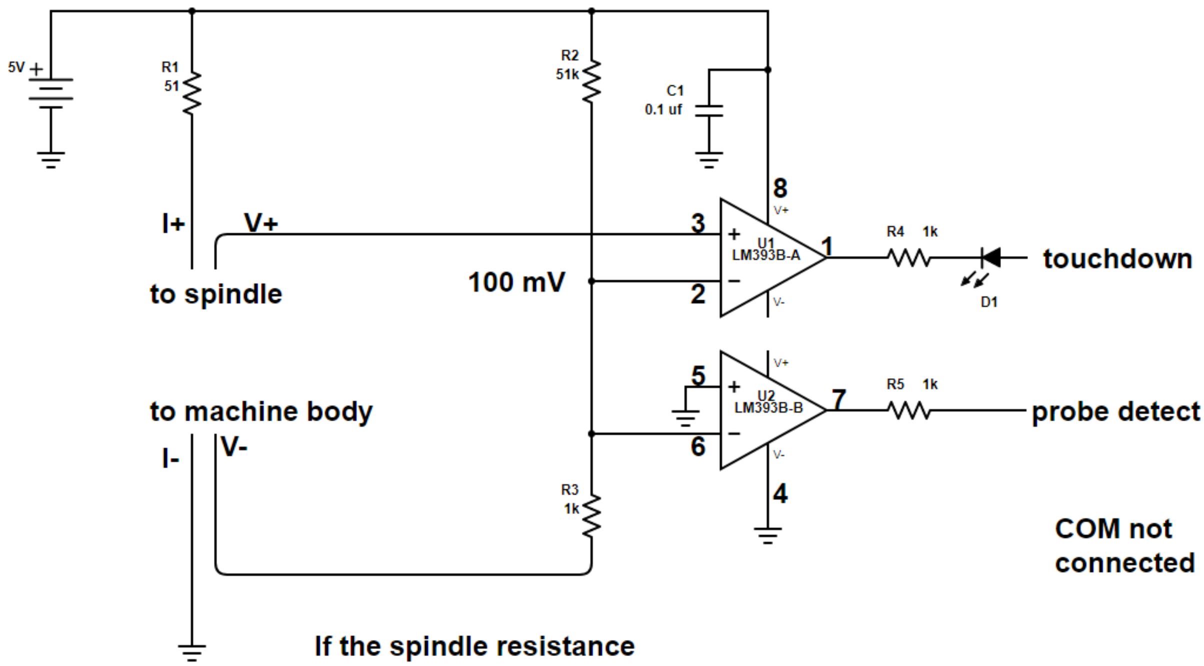
R1, the unknown resistance Rx, R2, and R3 are the Wheatstone Bridge. The threshold, R_{th}, is when $\frac{R1}{Rth} = \frac{R2}{R3}$ so $R_{th} = R1 \times \frac{R3}{R2} = 51\ ohms \times \frac{1k}{51k} = 1\ ohm.$

U1 performs the comparison. When Rx is greater than R_{th}, pin 3 is at a higher voltage than pin 2, and no current flows into pin 1. When Rx is less than R_{th}, pin 3 is lower than pin 2, and current flows into pin 1, which lights the LED and tells the CNC system that touchdown has occurred.

Current flowing in touchdown and probe detect flows back to the CNC hardware via machine body and the safety ground. More on this on page 9.

Power comes from a USB wall wart.

Low-Level Circuit Description



The test current is $\frac{5V}{Rx+R1}$ where Rx is the unknown resistance. This large current causes a voltage drop in the wires associated with I+ and I-. This voltage drop is small compared to 5V, so it has a minimal effect on the test current.

The resulting voltage, $(Rx)\left(\frac{5V}{Rx+R1}\right)$ appears at V+ relative to V-. A tiny current flows in V+ and V- so the voltage drop in the associated wires is insignificant.

The current through R3 is $\frac{5V-V_{-}}{R2+R3}$ so the voltage across R3 is $(R3)\left(\frac{5V-V_{-}}{R2+R3}\right)$. However, V- is much smaller than 5V, so we can say that the voltage across R3 is $(R3)\left(\frac{5V}{R2+R3}\right)$.

The comparator, U1, sees

$$(Rx)\left(\frac{5V}{Rx+R1}\right) - (R3)\left(\frac{5V}{R2+R3}\right) + V_{os} \quad (1)$$

where V_{os} is the comparator's input offset voltage of ±3 mV.

$$(Rx)\left(\frac{5V}{Rx+R1}\right) - (R3)\left(\frac{5V}{R2+R3}\right) + V_{os} \qquad (1)$$

Touchdown is detected when

$$(R_{th})\left(\frac{5V}{R_{th}+R1}\right) = (R3)\left(\frac{5V}{R2+R3}\right) + V_{os} \qquad (2)$$

where R_{th} is our threshold.

$$R_{th} = \frac{R1}{\left(\frac{R2}{R3}+\frac{V_{os}}{5V}\right)} \qquad (3)$$

$$R_{th} = \frac{51\ ohms}{\left(\frac{51k}{1k} \pm \frac{3\ mV}{5V}\right)}$$

$$R_{th} = \frac{51\ ohms}{(51\ \pm 0.0006\ )}$$

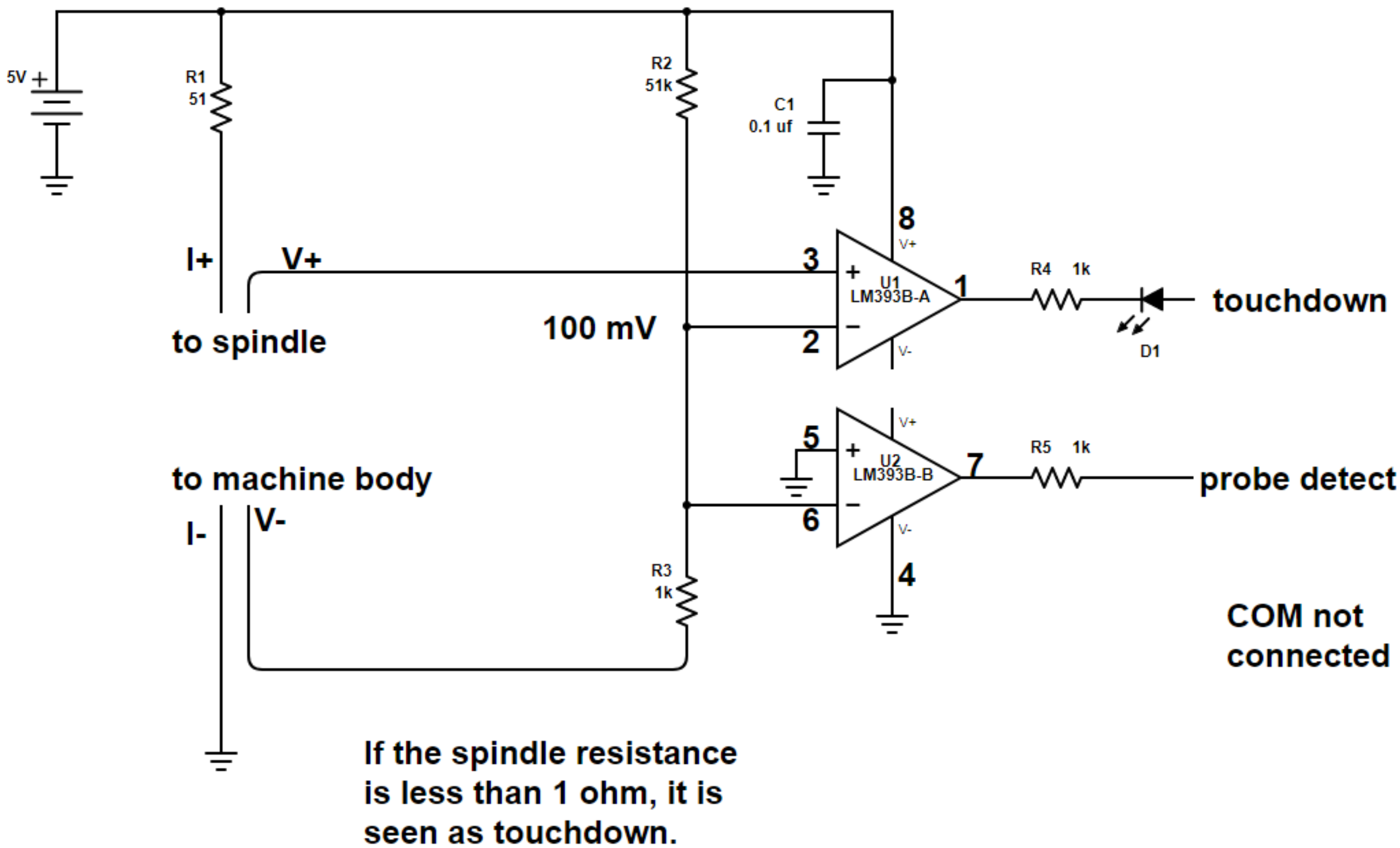
$$R_{th} = 1 \text{ ohm}$$

Notice that 5V and V_{os} have minimal effect on the threshold. All resistors are 5%, so the absolute worst-case tolerance of the threshold is ±15%. That may sound like a lot, but given the large variability of $R_{spindle}$, it doesn't matter.

U1 and U2 are part of an LM393B dual comparator. R4 and R5 limit the current from the CNC hardware to about 10 mA. This is necessary because the maximum current the comparators can sink is 16 mA. Empirically, I found that the CNC hardware has a threshold of around 5 mA.

Machine body is ultimately connected to ground via a power cable. COM is similarly connected through the CNC system. A voltage difference may be present due to ground currents. If I connected COM directly to circuit ground, an unknown and potentially significant current might flow.

Without connecting to COM, the current comes in on the touchdown and probe detect leads, through the comparators, into circuit ground, and onto the machine body. It then flows through the ground of the mill's power cable, the ground of the CNC system, and into COM within the CNC system. I measured – 7 mV on COM relative to machine body. This has minimal effect on of the current flowing from touchdown and probe detect.



R1 continuously dissipates ½ watt, so I have specified a rating of 1 watt. R2 is 0.1 watts. R5 continuously dissipates 120 milliwatts, so I have specified a rating of 1/5 watts. To minimize the diversity of part types, R3, R4, and R5 are the same value and power rating.

All of my previous designs had a low pass filter at the input. Since I do not latch the touchdown signal, I did not bother to filter it—the CNC software deals with any noise and contact bounce.

The voltage from the USB wall wart is stiff enough that I do not need a low frequency bypass capacitor. C1 provides instantaneous current to the dual comparator during switching.

Operational Test Results

As can be seen in [this video](), I used a finger Dial Test Indicator to measure the repeatability of the EEF. During my testing, the pre-touchdown voltage never went below 122 mV. If it had dropped below 100 mV, I would have received a false touchdown indication. That would have prompted me to turn the spindle a few degrees, bringing it above 100 mV. At touchdown, the voltage was always below 8 mV.

I ran seven passes, and the DTI read 0.0 every time.

I welcome your comments and questions.

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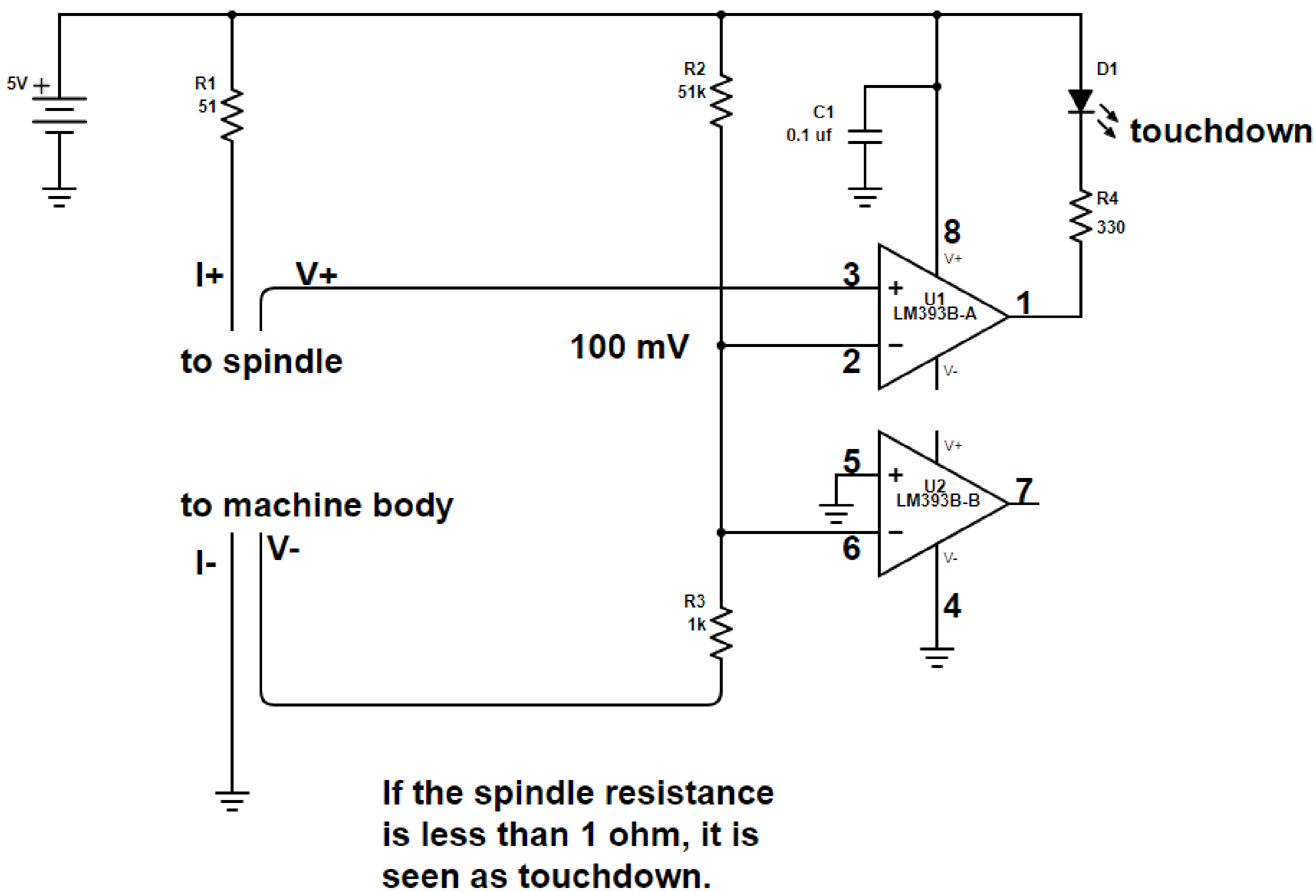
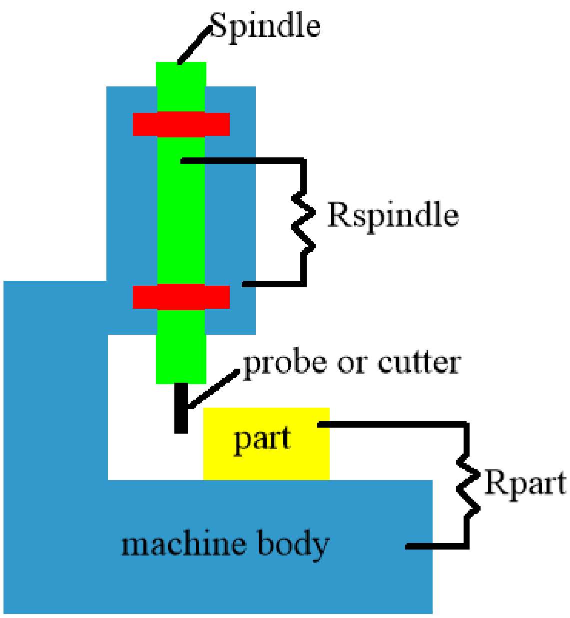
Appendix I: A Manual Version of the EEF



To maintain the same LED brightness, I have reduced the value of R4. I removed R5 because Probe detect is not needed.

Appendix II: Potential Bearing Damage Caused by the EEF

If you do a web search using "arcing on ball bearings," many papers address how arcing on the surface of ball bearings causes damage. Voltage is generated across these bearings, and periodically current conducts, causing arcs. These arcs pit the surface and lead to failure. In all cases, the motor is running, and these arcs occur millions of times. One reference says that damage can result with as little as 6V across the bearings.



With the EEF's enclosure sitting on the machine body, my magnetic probe can have no more than 5V on it. When connected, it is typically less than 0.2V. Then a current of less than 0.1 amps flows through the bearings.

At touchdown, the probe contacts the part. This diverts most of the 0.1 amps away from the bearings as the voltage drops to near 0.

If there was going to be arcing, it would be between the magnetic contact and the spindle during setup or at touchdown between probe and part. It would not be within the bearings.

Therefore, I do not believe my EEF can cause damage to my spindle bearings.

Appendix III: Changing Sensitivity

You can change the circuit's threshold via R3. This threshold equals $\frac{R3}{1,000}$. Conversely, $R3 = 1,000 \times R_{threshold}$. For a threshold of 0.5 ohms, R3 equals 500 ohms. Due to limitations in the comparator and the part's resistance, do not go below a threshold of 0.2 ohms.