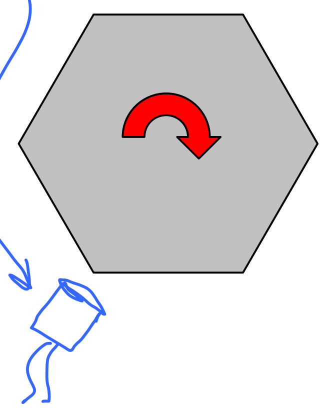
- Continue to review the pdf module: **Mechanical Measurements**, and do some examples
- Do a demo – stroboscopic tachometer

Example: RPM measurement

Given: A "poor person's" magnetic pickup tachometer is made from a standard hex nut on an automobile turbocharger to measure the rpm of the turbocharger.

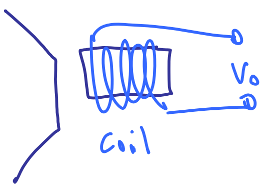


(*a*) To do: If the observed pulse rate is 5,000 pulses per second, calculate the rpm of the rotating hex nut.

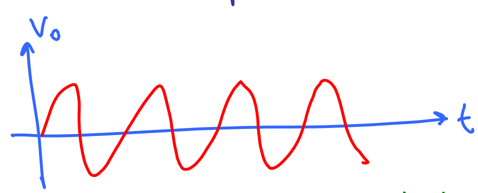
(*b*) To do: Calculate the multiplaction factor to convert from P to N_{rpm}.

Solution:

Note: This is not a gear, but it should still produce a voltage spike every time a corner of the bolt passes by the magnetic pickup.



→ Expect



[We expect some kind of periodic saw-tooth-like pattern]

(a) From the learning module,

(unity conversion factor)

$$N_{rpm} = \frac{P}{n_{teeth}} = \frac{5000 \text{ pulse/s}}{6 \text{ pulse/rot}}\left(\frac{60 \text{ s}}{\text{min}}\right) = \boxed{50{,}000 \text{ rpm}}$$

(b) The factor is obviously 10 $\left[5000 \frac{\text{pulse}}{\text{s}} \rightarrow 50{,}000 \text{ rpm}\right]$

So, $\boxed{N_{rpm} = 10P}$ where P is in units of pulse/s

Example: RPM measurement

Given: A shaft is rotating at 2400 rpm. A single dot is painted on the end of the shaft, and a stroboscope is used to measure the rpm.

To do: For each case, determine how many dots you will see, whether they are moving or "frozen," and if you are fooled (infer the incorrect rpm). The strobe flashes at:
(***a***) 800, (***b***) 1600, (***c***) 3000, and (***d***) 4800 rpm.

Solution:

Procedure: [Here is the easiest way to solve these kinds of problems]

(1) Calculate the $\frac{\#\text{rot}}{\text{flash}}$ (number of rotations per flash)

(2) Factor the numerator & denominator to get the simplest fraction that has integers for both the numerator & denominator

If the final fraction is $\frac{1}{1}$, it is the correct rpm

(3) The denominator is the number of "frozen" dots that you see.

☆ (4) If denominator = 1 & numerator > 1, we are fooled

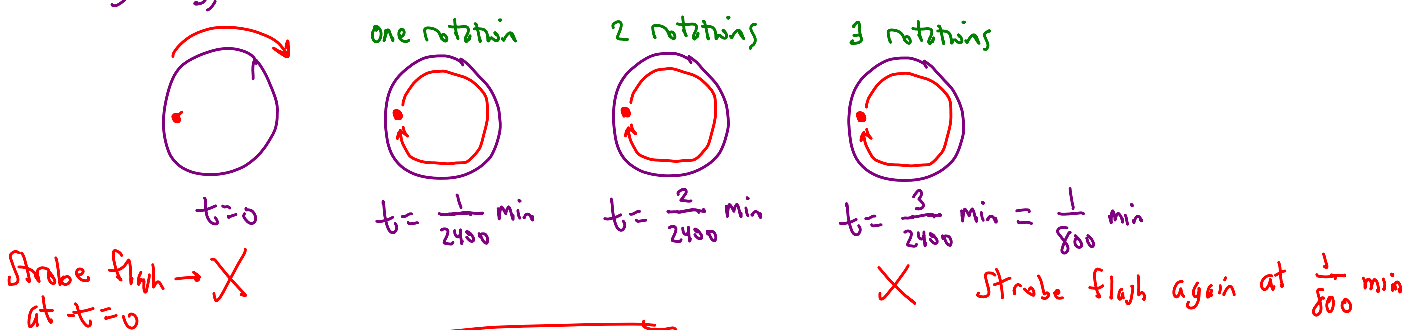
(this is another way of saying that the strobe flashes at an integer fraction of the actual or true rpm)

(a) $\frac{\#\text{rot}}{\text{flash}} = \frac{2400 \text{ rot/min}}{800 \text{ flash/min}} = \frac{24}{8} = \frac{3}{1} \frac{\text{rot}}{\text{flash}}$ [rpm] [÷100] [÷8]

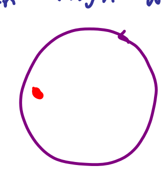
denominator = 1, but numerator > 1, so we are fooled

see 1 "frozen" dot

• Physically, the shaft rotates 3 times for every strobe flash



We are fooled (see 1 "frozen" dot) when flash at 800 rpm — we think the shaft is rotating at 800 rpm



All we see is one "frozen" dot @ 800 rpm flash rate (we are fooled)

(b) Strobe @ 1600 rpm, shaft @ 2400 rpm

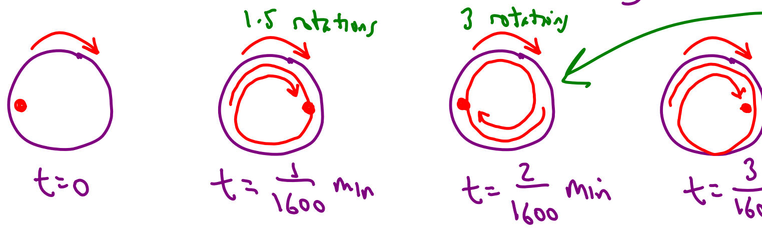
$$\frac{\#\text{rot}}{\text{flash}} = \frac{2400 \text{ rot/min}}{1600 \text{ flash/min}} \underset{[\div 100]}{=} \frac{24}{16} \underset{[\div 8]}{=} \frac{3 \text{ rot}}{\textcircled{2} \text{ flash}}$$

→ **We see 2 "frozen" dots**

We are not fooled, since we see more than one dot.

[Note: Actually, the dot appears on the left, then on the right, then on the left, etc. each time the strobe flashes. If our eyes were fast enough, we could see this. But our eyes (& brain) are too slow, so it looks like two "frozen" dots.]

• Physically, the shaft rotates 3 rotations for every 2 strobe flashes.



3 full revolutions have occurred when $t = \frac{2}{1600} = \frac{1}{800}$ min since shaft @ 2400 rpm

Strobe flash X X X X

NOTE: We are not fooled, but this is a kind of aliasing → we see the dot move one time around (left-right-left) in $\frac{1}{800}$ min → we think the shaft rotates at 800 rpm $\left[\frac{1 \text{ rot}}{1/800 \text{ min}} = 800 \frac{\text{rot}}{\text{min}}\right]$ [Just like with data acquisition, we can have aliasing if we don't "sample" (i.e., flash) fast enough.]

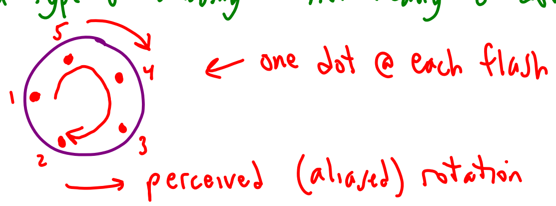
(c) Strobe @ 3000 rpm, shaft rotates @ 2400 rpm

$$\frac{\#\text{rot}}{\text{flash}} = \frac{2400 \text{ rot/min}}{3000 \text{ flash/min}} \underset{[\div 100]}{=} \frac{24}{30} \underset{[\div 6]}{=} \frac{4 \text{ rot}}{\textcircled{5} \text{ flash}}$$

→ **We see 5 "frozen" dots**

Not fooled since > 1 frozen dot

Again, this is a type of aliasing — not really 5 dots, but the dot appears to rotate backwards



(d) Strobe @ 4800 rpm, shaft @ 2400 rpm → $\frac{\#\text{rot}}{\text{flash}} = \frac{2400}{4800} = \frac{1}{\textcircled{2}}$ → **2 frozen dots, Not fooled**

(e) (Extra) Strobe @ 1400 rpm, shaft @ 2400 rpm →

$$\frac{\#\text{rot}}{\text{flash}} = \frac{2400 \text{ rot/min}}{1400 \text{ flash/min}} = \frac{24}{14} = \frac{12 \text{ rot}}{\textcircled{7} \text{ flash}}$$

→ **We see 7 "frozen" dots, not fooled**

Some additional comments and notes about measuring rpm with a strobe:

Procedure: How to properly measure the rpm using a strobe:

1. Start at ***low*** flash rate, and slowly ***increase*** the flashing rpm until you see one "frozen dot" for the ***last*** time. This will be the correct rpm.

OR

2. Start at ***high*** flash rate, and slowly ***decrease*** the flashing rpm until you see one "frozen dot" for the ***first*** time. This will be the correct rpm.

THEN

3. For either case, ***double*** the flash rate at which you see one "frozen dot" and verify that you now see two "frozen dots". If so, then you are confident that half of this rpm is the correct rpm.
   [E.g., at 600 rpm see *one* frozen dot, and at 1200 rpm see *two* frozen dots. We are confident that the correct rotation speed is 600 rpm.]

Additional comments:

1. ***Any strobe flashing rate above the correct rpm cannot fool you***. [You will never see only one "frozen dot" and be fooled at that rpm. You will either see two or more "frozen dots", or you will see the shaft rotating at some (incorrect) rotation speed, either forward or backward, or you will see some other pattern of dots – you will not be fooled.]
2. ***Any strobe flashing rate that is an integer fraction below the correct rpm will fool you***. [You will see only one "frozen dot" and be fooled at that rpm. In other words, you will think the actual rpm is the strobe flashing rpm, but this will be incorrect.]
   [E.g., if the true rpm is 600, you will see one "frozen dot" at 600 rpm (correct), but also at 600/2 = 300 rpm, 600/3 = 200 rpm, 600/4 = 150 rpm, … etc. If you are not careful, you could be fooled into thinking the correct rpm is at one of these lower (incorrect) rotation rates.]
3. Things get a little more complicated when there are identical spokes, as in a wagon wheel.

Example: RPM measurement

Given: A wagon wheel has 12 identical spokes, and rotates at 600 rpm. The rpm is measured with a stroboscopic tachometer in a room where it is dark except when the strobe light flashes. There are no painted dots anywhere, and *there is no way to distinguish one spoke from another*.

To do: Calculate the maximum strobe flashing frequency at which you could be fooled. In other words, calculate the maximum strobe flashing frequency at which you would see a wagon wheel that appears to be frozen (not rotating), and therefore you could be fooled into thinking that this is the correct rpm. *Give your answer as in integer in units of rpm.*

Solution:

Solution to be provided next lecture