Title: Tachometer Replacement Analysis
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Description: This document determines what is required for a tachometer replacement in terms of voltage, speed, etc.

Directions

Fill in yellow highlighted regions.

Variables

$\mathrm{axis\_top\_speed} := 2000\,\frac{\mathrm{arcsec}}{\mathrm{s}}$ **Fastest movement of a telescope axis (includes margin: 1800+200 arcse/sec).**

$\mathrm{tracking\_rate} := 15\,\frac{\mathrm{arcsec}}{\mathrm{s}}$ **Tracking rate.**

$\mathrm{bull\_gear\_ratio} := 144$ **Ratio of motor shaft to telescope axis shaft.**

$\mathrm{safety\_board\_tach\_in\_gain} := \frac{10}{47.5} = 0.211$ **Input gain stage for tachometer on Safety Board.**

$\mathrm{velocity\_error\_goal\_pkpk} := 1.5\,\frac{\mathrm{arcsec}}{\mathrm{s}}$ **Peak to peak error velocity goal for TCS.**

$\mathrm{deg\_to\_arcsec} := 3600\mathrm{arcsec}$ **Conversion of degrees to arcsec.**

$\mathrm{arcsec\_to\_deg} := \frac{1\mathrm{deg}}{3600\mathrm{arcsec}}$ **Conversion of arcsecs to degrees.**

$\mathrm{tel\_arcsec\_s\_to\_motor\_rpm} := 6.667\cdot10^{-3}\,\frac{\mathrm{rpm}}{\frac{\mathrm{arcsec}}{\mathrm{s}}}$ **Conversion of telescope axis velocity to motor (and tach) rpm.**

$\mathrm{tel\_arsec\_s\_to\_tach\_volt} := 8.764\,\frac{\mathrm{mV}}{\frac{\mathrm{arcsec}}{\mathrm{s}}}$ **Conversion of telescope axis velocity to tach voltage.**

$\mathrm{PMAC\_servo\_update} := 2.26\mathrm{kHz}$ **PMAC servo loop bandwidth (update rate).**

$\mathrm{TCS3\_tach\_filter} := 152\mathrm{Hz}$ **Tach filter in use currently for the TCS3.**

Analysis section: Basic System Requirements (Mechanics and Tachs)

Determine what the maximum voltage output of the tach needs to be.

$$\mathrm{current\_TCS3\_tach\_volt\_max} := \mathrm{tel\_arsec\_s\_to\_tach\_volt}\cdot\mathrm{axis\_top\_speed}$$

$$\mathrm{current\_TCS3\_tach\_volt\_max} = 17.528\,\mathrm{V}$$

However, the first thing that the Safety Board does is to lower the signal. If this stage was replaced with a follower stage (gain=1), the voltage level could be lower.

$$\mathrm{tach\_after\_SB\_input\_gain} := \mathrm{current\_TCS3\_tach\_volt\_max}\cdot\mathrm{safety\_board\_tach\_in\_gain}$$

$\text{tach\_after\_SB\_input\_gain} = 3.69\,\text{V}$

This greatly reduces the voltage required and potentially allows more common electronics to be used without modification.

Another main specification is the rpm of the tach/motor shaft at tracking and max speed (just above slew).

$\text{tach\_shaft\_rpm\_tracking} := \text{tracking\_rate}\cdot\text{tel\_arcsec\_s\_to\_motor\_rpm}$

$\text{tach\_shaft\_rpm\_tracking} = 0.1\cdot\text{rpm}$

At maximum speed (including margin) it is:

$\text{tach\_shaft\_rpm\_max} := \text{axis\_top\_speed}\cdot\text{tel\_arcsec\_s\_to\_motor\_rpm}$

$\text{tach\_shaft\_rpm\_max} = 13.334\cdot\text{rpm}$

Take notice of the LOW speed and difference between the slowest and fastest rpm.

The industry standard specification for tachometer generators is in terms of volts per 1000 rpms.

$$\text{tach\_volts\_per\_rpm} := \frac{\text{tel\_arsec\_s\_to\_tach\_volt}}{\text{tel\_arcsec\_s\_to\_motor\_rpm}} = 1.315\cdot\frac{\text{V}}{\text{rpm}}$$

$\text{tach\_volts\_per\_1k\_rpm} := \text{tach\_volts\_per\_rpm}$

$$\frac{1300}{200} = 6.5$$

$$\text{tach\_volts\_per\_1k\_rpm} = 1.315\times 10^{3}\cdot\frac{\text{V}}{1000\text{rpm}}$$

This is a really high value in terms of industry standard, off the shelf tachometer generators. However, keep in mind that the first thing that occurs is a gain of around 1/5 is applied to the signal. So it is possible to find a lower value tachometer generator that won't require gain. Amplifying a low V/1000rpm tach would amplify the signal and noise. The tach shaft moves very slowly, so sensitivity may be an issue. So, keep this in mind. The higher the V/1000 rpm, the better. Regardless, using a gain of 1 would translate to:

$$\text{min\_ideal\_tach\_off\_shelf} := \text{tach\_volts\_per\_1k\_rpm}\cdot\text{safety\_board\_tach\_in\_gain} = 276.744\cdot\frac{\text{V}}{1000\text{rpm}}$$

Finally, determine the minimum resolution. Some solutions considered will likely involve A/Ds or D/As so it is important to have this value in terms of bits (using the full range) also.

$$\text{required\_percent\_full\_scale\_error\_max} := \frac{\frac{\text{velocity\_error\_goal\_pkpk}}{2}}{2\cdot\text{axis\_top\_speed}}$$

$\text{required\_percent\_full\_scale\_error\_max} = 0.019\cdot\%$

$\text{bits} := 0$

$$\frac{0.5}{2^{bits}} = \frac{\frac{velocity\_error\_goal\_pkpk}{2}}{2 \cdot axis\_top\_speed}$$

$Find(bits) = 11.381$

12 bits is the bare minimum. 14 bit or 16 bit converters would provide more margin.

Analysis Section: Encoder Basic Requirements

Determine how many pulses per second an encoder (plus quad decode) will need to produce (in terms of pulses/revolution) to match the tachometer as it is currently used in the system.

The tachometer has a low pass filter of:

$TCS3\_tach\_filter = 152 \cdot Hz$

At tracking, the shaft rate is:

$tach\_shaft\_rpm\_tracking = 0.1 \cdot rpm$

So, finally, the absolute, minimum encoder pulser per revolution should be:

$$min\_required\_pulses\_per\_revolution := \frac{TCS3\_tach\_filter}{tach\_shaft\_rpm\_tracking}$$

$min\_required\_pulses\_per\_revolution = 91195 \cdot \frac{1}{rev}$ **Pulses per revolution.**

The PMAC loop is actually operating at:

$PMAC\_servo\_update = 2.26 \times 10^{3} \cdot Hz$

Therefore the encoder should probably have a rate at least 3-4 times faster. If the encoder is significantly faster, digital averaging, and other methods could be employed.

Analysis Section: Gurley R158 Encoder

The Gurley R158 is an example of an off-the-shelf encoder that can provide 1,000,000 counts per revolution (after quad decode). There are similar encoders available from other manufacturers.

$Gurley\_R158\_counts\_per\_rev := 1000000$

At tracking:

$$counts\_per\_second\_tracking := Gurley\_R158\_counts\_per\_rev \cdot \frac{tach\_shaft\_rpm\_tracking}{rpm \cdot min}$$ **(Stripped off some units)**

$counts\_per\_second\_tracking = 1.667 \cdot kHz$ **(counts per second)**

Now determine the pulses at maximum speed (just above slewing):

$$\text{counts\_per\_second\_max} := \text{Gurley\_R158\_counts\_per\_rev} \cdot \frac{\text{tach\_shaft\_rpm\_max}}{\text{rpm} \cdot \text{min}}$$

(Stripped off some units)

$\text{counts\_per\_second\_max} = 222 \cdot \text{kHz}$ **(counts per second)**

Consideration #1: Encoder with Converter (US Digital - ETACH2)

US Digital makes an inexpensive and simple quadrature to analog converter.

The resolution should be analyzed. Incidentally, the ETACH2 can be set to use full resolution at 4kHz with its 12 bit A/D.

$\text{Etach2\_output} := 4.095\text{V}$

$$\text{max\_quantization\_error} := \frac{\left[\frac{(\text{Etach2\_output} \cdot 2)}{2^{12}}\right]}{2} = 1 \cdot \text{mV}$$

In terms of full scale percentage error:

$$\text{percent\_full\_scale\_error} := \frac{\text{max\_quantization\_error}}{2 \cdot \text{Etach2\_output}}$$

$\text{percent\_full\_scale\_error} = 0.012 \cdot \%$

Which is less than:

$\text{required\_percent\_full\_scale\_error\_max} = 0.019 \cdot \%$

$$\text{margin\_over\_requirement} := \left(\frac{\text{required\_percent\_full\_scale\_error\_max}}{\text{percent\_full\_scale\_error}}\right) - 1$$

$\text{margin\_over\_requirement} = 53.6 \cdot \%$

In absolute terms:

$\text{one\_quanta\_peak\_to\_peak\_error} := 2 \cdot \text{percent\_full\_scale\_error} \cdot \text{2axis\_top\_speed}$

$$\text{one\_quanta\_peak\_to\_peak\_error} = 0.977 \cdot \frac{\text{arcsec}}{\text{sec}}$$

So, the US Digital solution is very close to the minimum and most likely does not have adequate resolution.