# A Vector Approach to Single Plane Balancing

By Michael Keohane | February 7, 2019

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Unbalance (Imbalance) is often defined as the unequal distribution of the weight of a rotor about its rotating centerline. A rotor can be balanced either in-place or in a balancing machine assuming unbalance is the issue and weight can be added or removed. Modern balancing instruments will do the math for you. I originally learned by plotting on polar graph paper with an analyzer with a strobe light phase input.

Definitions

**Vector** – a quantity having both direction and magnitude

**Polar Graph Paper** – graph paper with equally spaced concentric circles divided into small arcs

**Mils** – Peak to Peak vibration displacement, 1 mil = .001 inches. Often used in field balancing

**Trial Weight** – Amount of weight added to a rotor that changes the unbalance condition

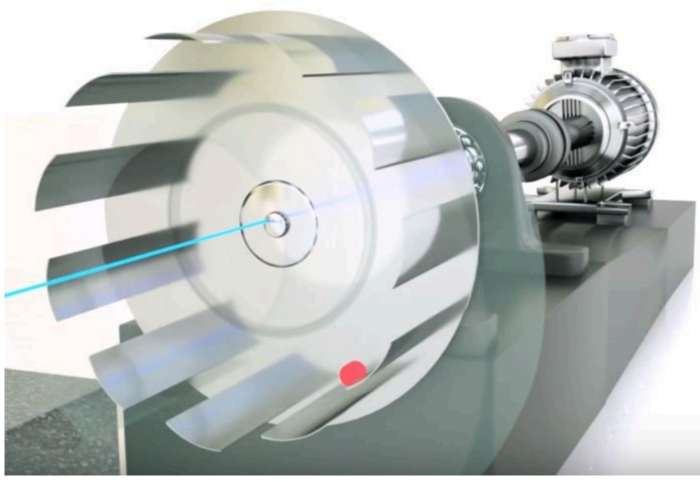
O – Vector representing the original unbalance

O + T – Vector representing the original plus trial weight unbalance

T – Vector representing difference between "O" and ("O"+"T") This is the effect of the trial weight

Solving a single plane balance using vectors and polar graph paper

1 – At running speed measure the amplitude and phase at 1 x rpm. This is plotted as the "O" vector



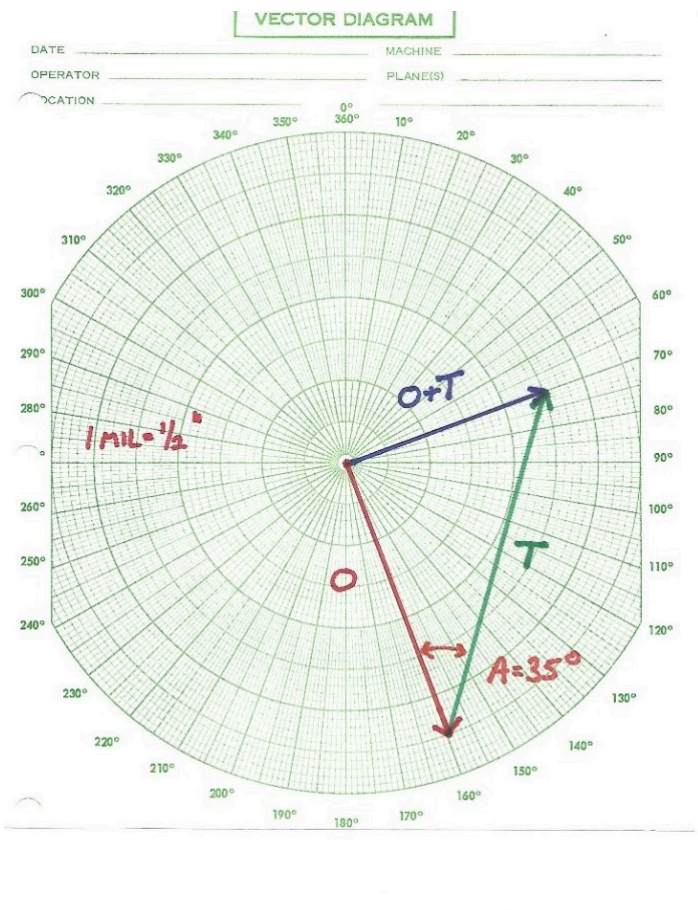
"O" = 7 mils at 160 degrees

2 – Shut down the machine and add a trail weight of a known amount

Trial Weight = 100 grams (3.53 oz)

3 – Run the machine and record the new amplitude and phase. A rule of thumb is look for either a 30 degree phase change or a 30% change in amplitude. This vector is plotted as "O" + "T"

"O" + "T" = 5 mils at 70 degrees




4 – Connect the end of the "O" vector to the end of the "O" + "T" vector and label this as "T"

5 – Measure "T"

"T" = 9 mils

6 – Use the formula Correction weight = Trial weight x "O"/"T"

CW = 100 x 7/9 = 77.77 grams

7 – Measure the angle between "O" and "T" with a protractor

"A" = 35 degrees

8 – The goal is to adjust vector "T" so it is equal and opposite vector "O"

9 – Remove the trial weight and add a correction weight of 77.77 grams 35 degrees from the location of the trial weight

10 – For this example, the correction weight is shifted in the direction opposite the shift of the reference mark from "O" to "O" + "T"

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## 5 Comments

**Roberto Colaneri** on February 26, 2019 at 4:07 am

Hi Michael,
in the formula Correction weight = Trial weight x "O"/"T"
CW = 100 x 7/9 = 77.7 grams and not 55.5 grams.
Thank you for share this article.

**Michael Keohane** on March 1, 2019 at 11:48 am

Roberto,

Thank you for reading and catching my error and taking the time to reply! Keeps me on my toes! We will correct it. If you have an ideas for future blog posts please let us know. We love to hear from our readers.

Regards,

Michael

**Richard Steinberger** on February 22, 2020 at 2:22 pm

Hello Michael
Thanks for your very simple and easy to understand of single plane balancing using a vector plot.
I would appreciate a clarification on one point that shows up in many articles on using vibration measurements to solve balance problems. That is, in your first step, you say "measure the amplitude and phase at 1x rpm". Suppose one is using a 3-axis accelerometer to measure the vibrations, and the x and y axes define the plane that is perpendicular to the axis of rotation. Then what exactly is meant by phase angle? Usually phase refers to the angle between a reference point and the maximum of the vibration wave. In the test you describe, are you using some reference marker on the spinning disk, then looking at the time between that marker and the sine wave max of the vibration? If so, then it seems you would need some sort of display such as a o-scope. Or is the phase calculated as the angle defined by the x and y components of the accelerometer readings, e.g. arctan(ay/ax) — which really gives the direction of the unbalanced force, though it's still not clear to me where 0 deg is defined — unless for these purposes it really doesn't matter because in the end you just want the angle between the two vectors O and T.
Could you please explain a bit about what you mean here as phase? Thanks a lot.

**Michael Keohane** on February 26, 2020 at 9:55 pm

Richard,

Thank you for the question.

Phase is defined as the position of a rotating part at a given instant with reference to a fixed point or another vibrating part. The vibration sensor is telling you how much vibration is present with the phase measurement giving you the direction.

For purposes of balancing we are measuring absolute phase which is measured using an instrument with a vibration sensor and a phase input such as a strobe light, photocell or laser tachometer that references a mark on a rotating shaft. To obtain phase readings with a strobe, a reference mark is placed on the rotor at the end of the shaft or some other observable position. You can often use an existing keyway or other mark. An angular reference scaled in degrees can be superimposed around the shaft (often times with 12 o'clock designated as zero) and phase angles are observed using the strobe. The strobe is being triggered by the 1 x vibration on the machine. Most modern balancing tools such as the Acoem Smart Machine Checker use a laser tachometer as the phase input. This provides a voltage reference pulse at the desired vibration frequency (1x for balancing). A common method of preparing the shaft is to attach a small piece of retro-reflective tape to the shaft. Zero is where the tape and tach line up.

Here is a video that might be helpful – Concepts of balancing – rotational imbalance

When using a triaxial sensor and an instrument that measures cross channel phase you are measuring relative phase between positions. Phase is a very useful, and often underutilized, diagnostic tool and among other things can help confirm a diagnosis of imbalance since you would expect about a 90 degree phase shift when looking at the horizontal and vertical positions. It isn't used for balancing since it doesn't provide the direction of the force.

Hope this helps.

**Lee Kernich** on June 11, 2020 at 8:26 pm

Hi Michael,

marked position (giving us just the amplitude of "O + T"). So far, that's just as you did. Next, repeat the last run, but with the trial weight placed 180 degrees from the first position. This gives us the amplitude of "O + Topposite".

We now have 3 vectors of unknown direction, but we do know they have a common intersection point, and that the arrowhead of O will bisect the straight line representing "T" and "Topposite".

Arranging the vectors will reveal the magnitude of T and the angle between O and T.

In your example, my proposed extra run would have given an amplitude of 15.3 mils.
(If you draw a vector on your diagram opposite to T, you will find the vector "O + Topposite" of length 15.3 completes the polygon.)

If you had just known the 3 amplitudes (5, 7 and 15.3) you could have arranged the vectors in this way, and deduced the size of T, and the angle between T and O. The direction of the angle would then be determined by one or 2 trial runs with the correction weight either side of the marked starting point.

I'd be interested to hear your opinion on this.





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