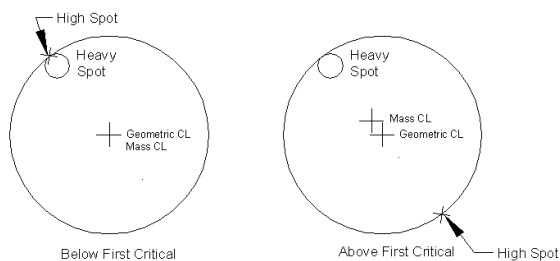


## Balancing

Unbalance is a very common source of high vibration that is identified by excessive levels of vibration amplitudes at a frequency that is synchronous with machine speed. Possible sources for this malfunction may be uneven product deposits around a fan or pump impeller, damaged or missing blades or vanes, improper shaft component assembly, or any other uneven mass distribution around the rotor axis. A machine that is operated within design conditions and is clean should not experience severe unbalance vibration levels.

Correction of unbalance situations involves characterizing the heavy spot. The heavy spot is the radial location at which the excessive radial mass distribution exists. This heavy spot is always a location that is opposite the location where weight needs to be added. Unfortunately the location of the heavy spot cannot be identified directly. However, we can identify the high spot location, which is the point of maximum displacement. The high spot is a radial location where the shaft experiences its maximum displacement, or excursion, due to the unbalance force(s).

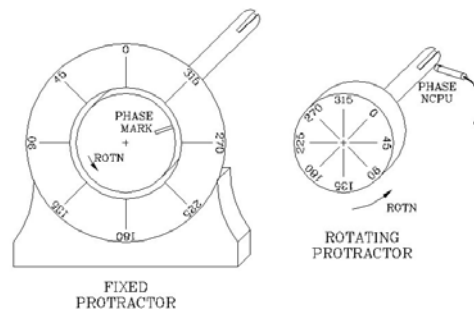


A definable relationship exists between the heavy spot and the high spot, which depends upon the rotor critical speed. If a rotor never experiences a critical speed throughout its operating range the heavy spot will always be the exerting force resulting in the high spot coinciding with the heavy spot, just as a weight being swung on a string exerts a displacing force on the rotation axis.

As the rotor surpasses the first critical speed the heavy spot and high spot split apart until they are separated by about 180°. This phenomenon occurs because the rotor now rotates around its mass centerline instead of its geometric centerline, forcing the high spot to be the location of maximum displacement. If the rotor continues to increase its speed and experiences another critical speed the high spot rotates another 180° until the high spot coincides with the heavy spot. This 180° shift in the high spot's relationship to the heavy spot continues as subsequent critical speeds are surpassed. For further discussion about the relationship between critical speeds and the associated phase shift, see STI Application Note, System Response (F=MA).

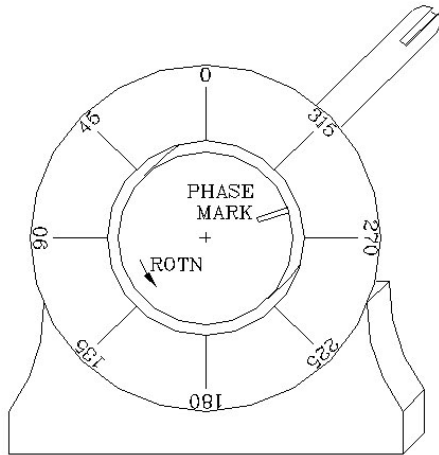
speeds and the associated phase shift, see STI Application Note, System Response (F=MA).

Correcting an unbalance condition involves using phase measurements to locate the high spot orientation, determining the relationship of the high spot to the heavy spot, and finding the magnitude of the unbalance by measuring the influence of correction weights. Careful observation of the machine vibration level and phase angle as it progresses from stand still to full operating speed will identify whether the trial weight should be installed at the high spot phase angle or opposite the high spot phase angle. Following this observation the vibration amplitude levels will almost always be reduced during the first balance run, which usually impresses the machine operators.



Two balancing procedures prevail: the fixed protractor method where a mark on the rotor is used for phase measurements with a strobe light; the rotating protractor method where a phase transducer observing a once-per-turn event is used for phase measurements. Both methods are a trial weight balancing procedure where an initial weight is installed to determine how the rotor responds to it.

### Fixed Protractor Method

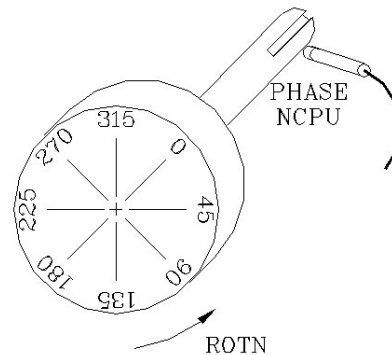


FIXED  
PROTRACTOR

In the fixed protractor method a strobe light is usually used to measure the phase angle by observing a single mark, or unique item, such as a key or machined hole. Some procedures use an optical tachometer, instead of a strobe light, to obtain phase measurements. Phase angle markings are made on the stationary part of the machine. This method counts increasing phase angles in the direction of rotor rotation. Phase measurements are taken by observing a single mark on the rotating shaft using the strobe light which is tuned to the machine speed or using the photo-tach which observes a piece of highly reflective tape placed on the shaft.

This method is commonly employed on machines that do not operate above their first critical speed because the high spot and the heavy spot are coincident meaning that the final balance weight location will be opposite the measured high spot. Also, instrumentation setup is easy, usually using surface mounted vibration transducers.

### Rotating Protractor Method



ROTATING  
PROTRACTOR

The rotating protractor procedure utilizes a phase Eddy Probe or an optical tachometer to determine the phase angle.

The trigger for this method comes from a pulse signal observing a once-per-turn event, such as a keyway or a key. Phase angle measurements are the relation between the keyway and the high spot, with increasing phase angles measured against shaft rotation.

Setup for this method requires that the phase transducer be installed observing a once-per-turn event. An existing key or keyway is ideal, but if non-existent a temporary key may be epoxied in place.

The rotor will require phase marks installed, not to directly obtain measurements, but to assist in weight placement. A simple method for marking the shaft is to use a permanent marker to label the rotor with the zero degree angle aligned with the keyway that the phase transducer observes. When marking the rotor remember that phase increases against the rotor rotation direction.

### **Trial Weights**

Regardless of which balancing procedure used a "trial weight" is must be installed to measure how the rotor will respond to this weight. This weight will induce a different balance condition with an accompanying change in the vibration level and/or phase angle. This change, once introduced into balance calculations, will dictate how much weight is required to be added and the radial location for weight placement.

If the vibration levels are not acceptable after a balance weight has been placed on the rotor, a further weight called a trim weight can be installed. Sometimes this weight will be required to be located at a slightly different location than the previous weight.

### **Balance Weights**

Trial, balance, and trim weights may be made from any material. Common materials are bolts, washers, or C-clamps. Strong tape, such as duct tape, is sometimes used to temporarily attach a trial weight. Some machines will require an imagination to devise an attachment method. Other machines, such as turbo-machinery, have balance weight holes provided which may require some machine disassembly to access them.

If the weight must be located at the same location as a previous weight both weights (previous balance weight and trim balance weight) should be combined into a single weight by making a larger weight or using a material of greater density.

All weights, regardless of material or attachment method, must be held rigidly in place. This may be accomplished by staking, welding, etc. Relying on a bolt and nut with split washer should not be considered. If a bolt and nut configuration is used the bolt should have its threads staked to prevent the nut from shifting.

### **Balancing Speed**

Operating speed has a drastic effect upon the measured unbalance vibration level since the centrifugal force due to unbalance is proportional to speed squared ( $\text{rpm}^2$ ). During the balancing procedure the operating speed at which amplitude and phase measurements are gathered must be held steady at a predetermined speed. All subsequent balance attempts should be made with the machine operating at the same speed as previous attempts. Future balance activity should be made at this same speed so that the balance response coefficient(s) can be include into calculations to reduce the number of machine restarts.

### **Balance Response Coefficient**

Once a rotor has been balanced, or has had a trial weight installed that produces a change in vibration amplitude or phase, an unbalance constant can be calculated which can be used in future balance attempts. Each rotor will have a different unbalance constant, given in units of weight per amplitude (lbs/mil, oz/mil, gm/in/sec, etc.). A single plane balance procedure will produce one balance response coefficient. Multiple plane balancing will produce any number of coefficients depending upon the number of balance planes. A three-plane balance procedure will produce nine balance response coefficients. This number is because as the trial weight is moved to each subsequent balance plane two additional response coefficients are calculated.

### Correction Weight Calculations

Once the vibration levels and phase angles have been collected with and without a trial weight, the required correction weight can be calculated. Basically, the correction weight must be sized to counteract the centrifugal force generated by the existing unbalance mass. The method for calculating the weight differs depending upon the whether the rotor experiences a critical speed and the number of balance planes.

One plane balance, operation below 1<sup>st</sup> critical speed

$$CW = (G \times CF) / (R \times SPD^2)$$

Where  $CF = (V \times K) / 2$   
And  $K = WR^2 \times M$

Two plane balance, operation below 1<sup>st</sup> critical speed

$$\text{Inboard } CW_i = (CF_i \times G) / (R_i \times SPD^2)$$

Where  $CF_i = (V_i \times K_i) / 2$   
And  $K_i = (WR^2 \times M) / 2$

$$\text{Outboard } CW_o = (CF_o \times G) / (R_o \times SPD^2)$$

Where  $CF_o = (V_o \times K_o) / 2$   
AND  $K_o = (WR^2 \times M) / 2$

One plane balance, operation above 1<sup>st</sup> critical speed

$$CW = (CF \times G) / (R \times SPD^2)$$

Where  $CF = (WT \times V \times SPD^2) / 2 G$

Two plane balance, operation above 1<sup>st</sup> critical speed

$$CW_i = (CF_i \times G) / (R_i \times SPD^2)$$

Where  $CF_i = (1/2 WT) \times V_i \times SPD^2 / 2 G$

$$CW_o = (CF_o \times G) / (R_o \times SPD^2)$$

And  $CF_o = (1/2 WT) \times V_o \times SPD^2 / 2 G$

CF = Centrifugal force due to unbalance (lbs)  
WR = First critical speed (rpm)  
K = Rotor spring constant (lb/in)  
M = Rotor mass (rotor weight (lb/G))  
G = Acceleration of gravity (386.4 in/s<sup>2</sup>)  
V = Peak-peak vibration (in)  
SPD = Balance speed (rpm x 0.1047 rad/s)  
CW = Correction weight (lbs)  
R = Balance weight radius (in)  
WT = Rotor weight (lbs)  
CF<sub>i</sub> = Inboard centrif. Force due to unbalance (lbs)  
K<sub>i</sub> = Inboard rotor spring constant (lb/in)  
V<sub>i</sub> = Inboard pk-pk vibration (in)  
CW<sub>i</sub> = Inboard correction weight (lbs)  
R<sub>i</sub> = Inboard balance weight radius (in)  
CF<sub>o</sub> = Outboard centrif. Force due to unbalance (lbs)  
K<sub>o</sub> = Outboard rotor spring constant (lb/in)  
V<sub>o</sub> = Outboard pk-pk vibration (in)  
CW<sub>o</sub> = Outboard correction weight (lbs)  
R<sub>o</sub> = Outboard balance weight radius (in)

### Balancing Checklist

1. Balancing Method
2. Trial Weight(s)
3. Weight Material
4. Balancing Speed
5. Response Coefficient(s)
6. Final Weight Placement Documented