



Engineering Encyclopedia

Saudi Aramco DeskTop Standards

BALANCING OF RIGID AND FLEXIBLE ROTORS

Note: The source of the technical material in this volume is the Professional Engineering Development Program (PEDP) of Engineering Services.

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INTRODUCTION

Excessive rotor unbalance may lead to large amplitudes of motion, or even failure of the shaft, bearings and foundation. Unbalance and shaft misalignment are recognized as the two major factors that can lead to machinery malfunctions and even catastrophic failure.

The unbalance in a machine may result from its initial manufacturing process, or may occur as a result of various operating factors such as machine erosion, thermal effects, and unbalance due to a build up of process material on the impellers and the surface of the rotor.

The object of balancing is to add or remove correction weights in one or more axial planes along the rotor to maintain permissible levels of vibration.

CLASSIFICATION OF ROTORS

Rotors may be classified as either rigid or flexible according to their dynamic behavior and operating speeds.

If the rotor is operating through one or more critical speeds, then it may be considered a flexible rotor, otherwise it is a rigid rotor.

The International Standard Organization (ISO) has classified rotors to describe the type and quality of balance needed for each rotor. Five basic classifications are presented by ISO:

- Class 1: Rigid Rotors - These rotors may be balanced in any two arbitrary axial planes and will remain in balance throughout the operating speed range.
- Class 2: Quasi-flexible Rotors - These are perfectly rigid but may be adequately balanced in a low speed balancing machine and will maintain smooth operation throughout the speed range.
- Class 3: Flexible Rotors - These rotors cannot be balanced in a low speed balancing machine and require one or more high speed trim plane corrections.

- Class 4: Flexible Attachment Rotors - These rotors can be categorized as class 1, class 2, or class 3 rotors but have components within themselves or are flexibly attached.
- Class 5: Single Speed Flexible Rotors - These rotors could be classified as class 3 flexible rotors but are balanced for operation at one speed only.

Single and two plane constant speed balancing is usually adequate for class 1 and class 2 rotors.

BALANCING TYPES

Balancing is generally classified in two broad areas: balancing in the shop on a balancing machine, and field balancing in which the rotor is balanced in place.

Workshops have procedures for balancing rotors. Sometimes components may be individually balanced as well as the final assembly balanced as a rigid rotor. If components are balanced before final assembly, as well as the final assembly, then even extremely long flexible rotors may operate very successfully without further adjustments in the field. A high speed balancing facility may be required for class # 3 rotors that operate through a number of critical speeds.

Field balancing can be single plane, two plane or multiple plane balancing of the rotor in its own bearing with vibration instrumentation to monitor shaft motion.

Single Plane Balancing By Influence Coefficients

The single plane, single influence coefficient method of balancing is the simplest of all procedures. Balancing instruments will have different conventions as to the initiation of phase measurement.

An influence coefficient represents the response of the rotor due to the placement of a unit trial weight at a particular speed. It is a vector quantity that results from dividing the change in vibration by the trial weight.

In single plane balancing by the influence coefficient method, the system is assumed to be linear and a single correction weight is placed on the shaft based on the computed influence coefficients.

Single Plane Balancing

When a vibration problem is correctable by balancing, the method of influence coefficients is usually used. In this method, it is assumed that the response is linearly proportional to the amount of residual unbalance. This assumption means that if, for example, 100 gram-in of unbalance is causing 1.0 mil difference in the vibration response, then 200 gram-in will cause a difference of 2.0 mils. This simple concept is applied to determine how much unbalance exist in a rotor. To do that, a known weight usually called a trial weight is attached to the rotor. The amount of vibration caused by this known weight is the difference between the vibration reading with the trial weight and before the trial weight. Now we know that a given unbalance weight causes a known level of vibration, it becomes easy to determine how much unbalance was causing the original vibration.

Lets put the previous discussion in a mathematical format. If we denote the vibration response as R in units of vibration parameter (i.e. mils pk-pk or in/sec pk, etc.), and the residual unbalance in units of vibration parameter (i.e. mils pk-pk or in/sec pk, etc.) as U in units of weight (gm or oz), then R being linearly proportional to U is mathematically written as:

$$R = K.U \quad [(1)]$$

$$\text{or} \quad U = R/K \quad [(2)]$$

$$\text{or} \quad K = R/U \quad [(3)]$$

where K is a constant and is usually referred to as the influence coefficient in terms of unit of vibration per unit of weight (mils pk-pk/gm).

Attaching a known weight W_t and measuring the difference in vibration response $R_1 - R_\phi$ and using equation (3), K can be calculated as:

$$K = \frac{R_1 - R_\phi}{W_t} \quad [(4)]$$

To calculate the original unbalance U_0 that caused the original vibration response R_ϕ , we use equation (2).

$$U_0 = R_\phi / K \quad [(5)]$$

To compensate for the original unbalance, a correction weight Wt_{corr} that is equivalent in magnitude to U_0 but at 180° away is attached.

$$\text{or} \quad Wt_{corr} = U_0$$

$$Angle_{corr} = Angle U_0 + 180^\circ \quad [(6)]$$

Remark: Equations (1) through (6) are vector quantities and all operations are handled vectorially.

Summary of Procedure

1. Take a vibration reading from the I/B & O/B proximity probes and record the highest running speed amplitude R_ϕ and phase θ_ϕ . This run is with no weights attached. This run is called the initial run.
2. Attach a trial weight close to the suspected unbalance location $Wt @ \angle \theta_t$.
3. Take a vibration reading $R_1 @ \angle \theta_1$ with the trial weight Wt attached.
4. Calculate the influence coefficient.

$$K \angle \theta_k = \frac{R_1 \angle \theta_1 - R_\phi \angle \theta_\phi}{W_t \angle \theta_t}$$

5. Calculate the original unbalance.

$$U_0 \angle \theta_\phi = \frac{R_0 \angle \theta_\phi}{K \angle \theta_k}$$

6. Calculate the correction weight.

$$Wt_{corr} \angle \theta_{corr} = U_0 \angle (\theta_0 + 180^\circ)$$

7. Attach the correction weight. The balancing job is complete.

Example:

Assume an initial vibration level of 3.0 mil $\angle 120^\circ$ when a trial weight of 100 gram was attached, the vibration level went up to 5.0 mil $\angle 240^\circ$. Perform balancing calculation.

Solution:

$$R_\phi \angle \theta_\phi = 3.0 \text{ mil } \angle 120^\circ \quad [\text{given or measured}]$$

$$W_t \angle \theta_t = 100 \text{ gram } \angle 0^\circ \quad [\text{given}]$$

$$R_1 \angle \theta_1 = 5.0 \text{ mil } \angle 240^\circ \quad [\text{given or measured}]$$

$$\begin{aligned} K \angle \theta_k &= \frac{R_1 \angle \theta_1 - R_\phi \angle \theta_\phi}{W_t \angle \theta_t} \\ &= \frac{5 \angle 240^\circ - 3 \angle 120^\circ}{100 \angle 0^\circ} = \frac{7.0 \angle 262^\circ}{100 \angle 0^\circ} \\ &= .070 \angle 262^\circ \text{ (mil/gram)} \end{aligned}$$

Original unbalance.

$$U_0 \angle \theta_\phi = \frac{R_0 \angle \theta_\phi}{K \angle \theta_k} = \frac{3.0 \angle 120^\circ}{.070 \angle 262^\circ} = 43 \text{ gram } \angle 218^\circ$$

Calculate correction weight.

$$Wt_{corr} = 43 \text{ grams}$$

$$\text{Angle} = 218^\circ + 180^\circ = 398^\circ - 360^\circ = 38^\circ$$

Attach the correction weight.

Graphical Solution for Single Plane Balancing

The graphical method was being intensively used not too long ago. Nowadays, however, computer solutions are more popular. Once understood, the graphical solution gives a good insight and leads to a better judgment during the whole balancing process. The best way to illustrate the graphical method is through an example (see Figure 1). Let's say that we have an initial vibration level, R_ϕ of 3.0 mils @ $\angle 120^\circ$. When we attached a 100 gram weight to the balancing plane, the vibration reading R_1 changed to 5.0 mils @ $\angle 240^\circ$. How much weight is needed to cancel out the original response R_ϕ ?

Procedure

- Step 1. Mark the shaft rotation, then number the phase angle on the graph against rotation.
- Step 2. Plot R_ϕ that is 3 mils at 120° on a graph paper. The graph is a 1 cm/mil.
- Step 3. Plot R_1 that is 5 mils @ 240°
- Step 4. $R_{trial} = (R_1 - R_0)$ is drawn from the arrow at R_ϕ to the arrow of R_1 . R_{trial} , the difference between R_1 and R_ϕ , is totally due to the trial weight.
- Step 5. Using a ruler, measure the length of R_{trial} which happens to be 7 mils. Now, we know that this difference of 7 mils between R_ϕ and R_1 is caused by the 100 gram trial weight attached to the balancing plane.

$$\text{correction weight} = \text{trial weight} \times \frac{R_\phi}{R_{Trial}}$$

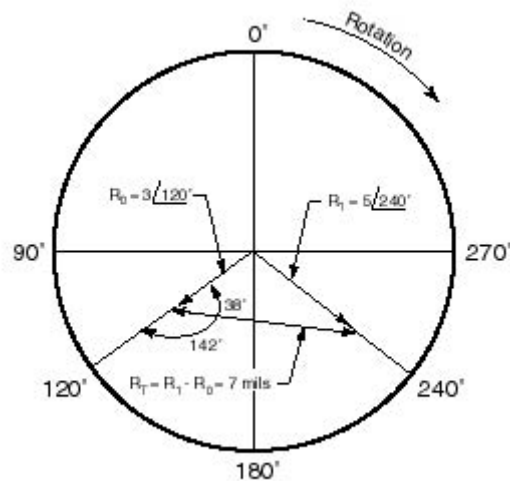


Figure 1. Graphical Solution for Single Plane Balancing

Elaboration

Since 100 grams made a difference of 7 mils, to cancel out our original response of 3 mils, we need

$$100 \text{ grams} \times \frac{3 \text{ mils}}{7 \text{ mils}} = 43 \text{ grams}$$

- Step 6. Measure the correction angle that is between R_T and a point exactly opposite to R_ϕ .

Elaboration

After knowing how much correction weight we need, the next step is to find where to locate this correction weight. By measuring the angles, we see that R_{Trial} is 142° away from R_ϕ and 38° from a point exactly opposite to R_ϕ . So, our correction angle is 38° against rotation from the trial weight.

General Comments in Balancing

Weight angles are measured against rotation. For example, the calculations showed that the correction weight is to be attached at 38° from location of trial weight. This angle should be measured going against rotation.

Excessive runout should be eliminated before balancing or at least subtracted out from all measurements.

Multiplane Balancing

When double plane or multiplane balancing is needed, usually the use of computer software is utilized. That's because the hand and the graphical methods become a bit more complicated and time consuming. Here are the steps of utilizing a computer program to perform a double plane balance.

- Step 1. Record initial data from at least two pick-ups. The pick-ups should be at different ends, i.e., inboard and outboard.
- Step 2. Attach a trial weight to plane No. 1 and record the first run vibration data.
- Step 3. Remove the trial weight from plane No. 1.
- Step 4. Attach a trial weight to plane No. 2 and record the second run vibration data.
- Step 5. Remove the trial weight from plane No. 2.
- Step 6. Enter data of initial run, first run, second run and trial weights, into the computer program and obtain correction weights.
- Step 7. Attach the correction weights.