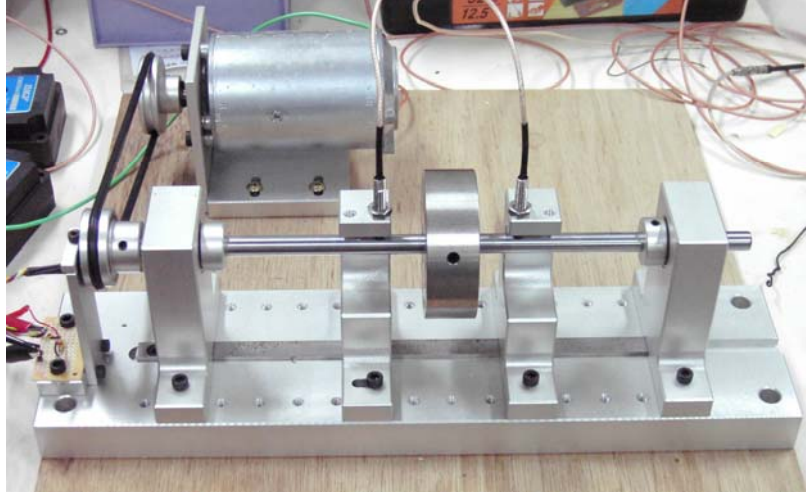# Dynamic Balancing of Rotating Machinery

Objective: To learn a dynamic balancing method that can be used in the field

Preparation: (i) Rotor kit, (ii) Eddy current proximity probes (see Appendix B), (iii) CNY70 (Reflective optical sensor with transistor output, see Appendix A), (iv) DC power supply, (v) Oscilloscope, (vi) PC. (vii) Correction masses and a balance.

Background:

Production tolerances used in the manufacture of rotors are adjusted as closely as possible without running up the cost of manufacturing prohibitively. In general, it is more economical to produce parts, which are not quite true, and then to subject them to a balancing procedure than to produce such perfect parts that no correction is needed. Some common causes of irregularity are machining error, assembly tolerances, distortions due to heat treatment, and material non-homogeneity. Because of these irregularities the actual axis of rotation does not coincide with one of the principal axes of inertia. It produces variable disturbing forces proportional to the rotating speed. In order to remove these forces and establish proper operation, a rotor balancing task has to be done.

A new machine when assembled at its permanent location will need balancing or a machine already in operation will need re-balancing. The system of balancing used in this experiment was developed to satisfy the need to perform field balancing of equipment. Although there are many possible causes of vibration in rotating equipment, this technique will deal only with that caused by the mass unbalance.

For a rigid long rotor, the unbalance can be in different axial planes. As a result, while in rotation, the unbalanced forces form a couple and a lateral force, which rocks the axis of rotation and causes undesirable vibration of the rotor, mounted in its bearings. It can be shown that for the correct balance of such a rotor, two masses placed in different radial planes of the rotor are necessary and sufficient to balance the rotor. There are the amount and position of these two correction masses to be dealt with when balancing any rigid rotor. This technique deals with these four variables simultaneously.

The data necessary to determine the magnitudes and position (angle) of the two correction masses are obtained by test runs at the same speed. The vibration amplitude and phase angle are measured by each proximity probe. An important and reasonable assumption made by this technique is that the system is linear. Most simple rotors/systems can be balanced by applying this technique iteratively.
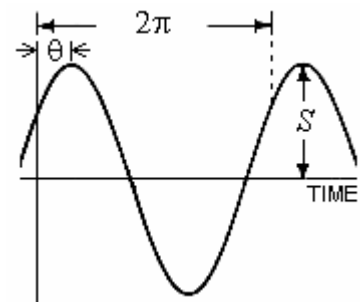
Experimental setup:

The rigid rotor is driven by a DC motor whose speed can be controlled by the DC power supply. The voltage supplied to the DC motor should not exceed 24*V*. The gap between the proximity probe and the shaft is 0.9*mm*. Vibration amplitudes and the phase angles are measured by proximity probes which signals are connected to the CH1 and CH2 of the oscilloscope respectively. The oscilloscope is triggered by CNY70 that provides a phase reference. The CNY70 is powered with the +5*V* voltage source of the DC power supply. Rotating speed is also measured using the oscilloscope.Choose AC coupling for both CH1 and CH2. Setting for external trigger: Edge trigger, DC coupling, Slope "+", trigger level "+2.4V".
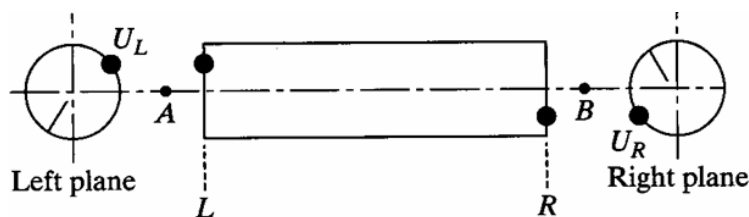
Procedure:

The procedure to acquire the required data and balance the rotor is as follows:

1) Run the rotor at a speed of 360*rpm* (6*Hz*) to measure its *static runout*. Use "single sweep" to freeze the trace. Record the static runout as a vector $Se^{i\theta}$. **This value should be subtracted form all other measurements**.

2) Run the rotor at a speed of 3000*rpm* (50*Hz*) which will be held constant throughout the experiment. With only the original mass unbalances of the rotor, record vibration amplitudes and phases at both proximity probes.

3) Arbitrarily choose a trial mass W_L and mount it on the left plane *L* of the rotor at an angle of 0°. Record readings of both proximity probes.

4) step 3 with the difference that the trial mass W_R is now mounted on right plane *R* of the rotor.

5) Using the equations determine the 2 masses required at both planes *L* and *R* of the rotor to dynamically balance the rotor.

6) Run the rotor with the correction masses added. Record the vibration amplitudes at both probes.

7) Repeat the processes from step (2) to (6) until a satisfactory result is obtained.

Equations for dynamic balancing

$$\vec{V}_A = \vec{A}_{AL}\vec{U}_L + \vec{A}_{AR}\vec{U}_R$$
$$\vec{V}_B = \vec{A}_{BL}\vec{U}_L + \vec{A}_{BR}\vec{U}_R$$

$$\vec{V}'_A = \vec{A}_{AL}(\vec{U}_L + \vec{W}_L) + \vec{A}_{AR}\vec{U}_R \qquad\qquad \vec{V}''_A = \vec{A}_{AL}\vec{U}_L + \vec{A}_{AR}(\vec{U}_R + \vec{W}_R)$$

$$\vec{V}'_B = \vec{A}_{BL}(\vec{U}_L + \vec{W}_L) + \vec{A}_{BR}\vec{U}_R \qquad\qquad \vec{V}''_B = \vec{A}_{BL}\vec{U}_L + \vec{A}_{BR}(\vec{U}_R + \vec{W}_R)$$

Find

$$\vec{A}_{AL} = \frac{\vec{V}'_A - \vec{V}_A}{\vec{W}_L}, \qquad \vec{A}_{BL} = \frac{\vec{V}'_B - \vec{V}_B}{\vec{W}_L}, \qquad \vec{A}_{AR} = \frac{\vec{V}''_A - \vec{V}_A}{\vec{W}_R}, \qquad \vec{A}_{BR} = \frac{\vec{V}''_B - \vec{V}_B}{\vec{W}_R}$$

Calculate the unbalances

$$\vec{U}_L = \frac{\vec{A}_{BR}\vec{V}_A - \vec{A}_{AR}\vec{V}_B}{\vec{A}_{BR}\vec{A}_{AL} - \vec{A}_{AR}\vec{A}_{BL}}$$

$$\vec{U}_R = \frac{\vec{A}_{BL}\vec{V}_A - \vec{A}_{AL}\vec{V}_B}{\vec{A}_{BL}\vec{A}_{AR} - \vec{A}_{AL}\vec{A}_{BR}}$$

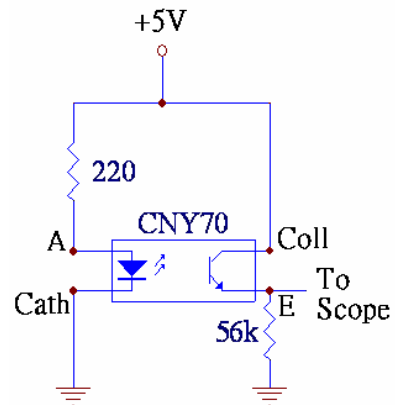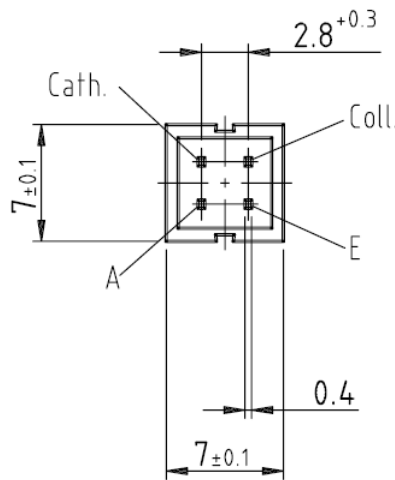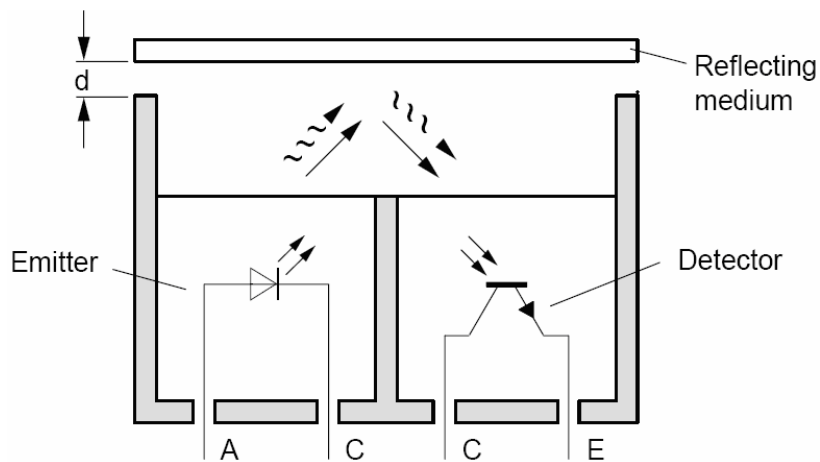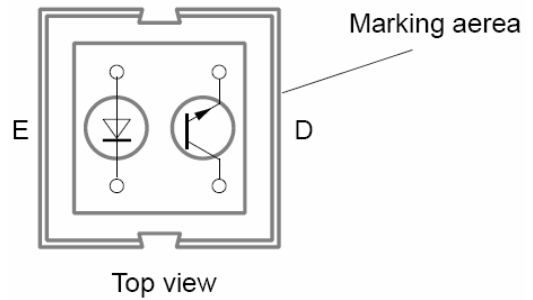For convenience, express all vectors with complex quantities $re^{i\phi}$.

Report:

(1)   Plot vibration amplitudes of the unbalance rotor versus the motor speed. Explain this behavior.

(2)   Use different trial masses to find the influence coefficients A_{IJ}. Do they change? Explain.

(3)   Determine the percent reduction of the vibration amplitude at the location of each probe. How can these results be improved further?

(4)   If the angular coordinate on the rotor is rotated a certain angle, discuss all the consequences.

Appendix A:
The CNY70: Reflective optical sensor with transistor output

The CNY70 has a compact construction where the emitting light source and the detector are arranged in the same direction to sense the presence of an object by using the reflective IR beam from the object. The operating wavelength is 950 nm. The detector consists of a phototransistor.

Top view

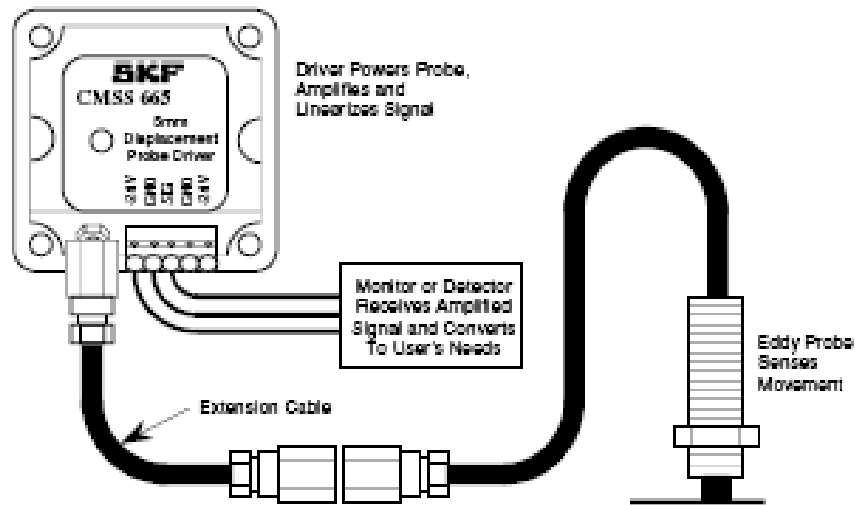Appendix B:
The eddy current probe
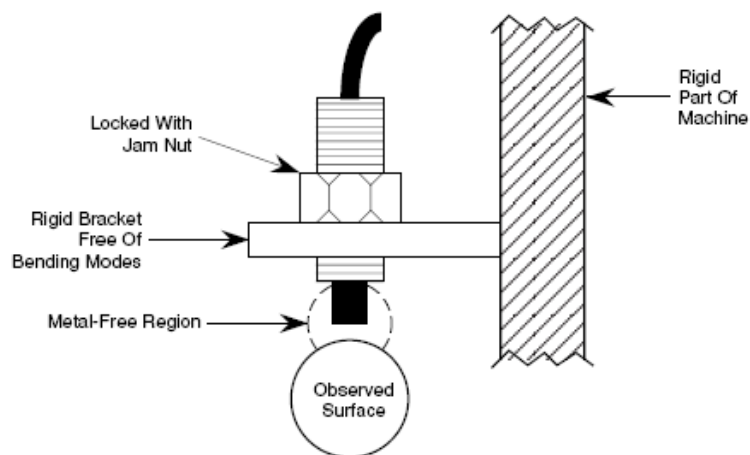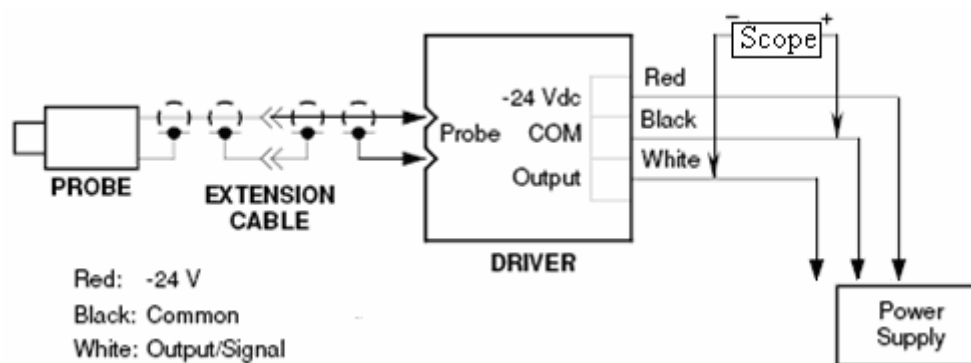

Fig. 1 An eddy current probe system.

Fig. 2   Probe mounting on bracket.

Fig. 3   Interconnect to displacement monitor system.