Lab #4 Name:____________________________
Forced Vibration (Experiment) Date:____________________________
Short Form Report Section / Group:____________________

Procedure:

1. Turn on the air supply as it will provide the air pressure needed to operate the air bearings of the setup. The air supply pressure to the bearing should be set to approximately 1 bar.

2. Execute the Forced Vibrations VI, you will use this tool to observe the system response.

Q1. (5%) Investigate the position sensors, X, Y and Z that are attached to the apparatus. Which displacements are measured with these sensors? (Hint: You think in terms of relative and absolute motions.)

Procedure:

3. Turn on the supply switch of the “FREE AND FORCED VIBRATION APPARATUS” to on position.

4. Turn on the LINE switch of the “TRIPLE OUTPUT POWER SUPPLY” to on position. The “Damper Control” of the main apparatus is out of order, thus you will be using this power supply to adjust damping. By varying the position of the “+6V” knob on the power supply, you will be able to alter the system damping.

5. Set the “Out of Balance” switch to on and make sure the “Base Motion” switch is turned off.

Q2. (5%) Try various values of ω (motor speed) and ζ (damping) by adjusting the knobs. Measure and observe the frequency and amplitude of mass for various rotating unbalance speeds. How is the angle (position) of the rotating unbalance related to the phase angle ϕ? (You should be able to see this by looking at the unbalance – particularly at very low frequencies). Next, set the damping to zero and leave the motor speed at a constant value. Observe the frequency of x(t), y(t), and z(t). Are the frequencies the same or different? Are the amplitudes of X, Y, and Z the same or different? Are these results what you would expect? Why? Do they fit with theoretical predictions?
Procedure

6. Continue using the rotating-unbalance set-up.

7. Set the damping control to approximately 1.0A.

8. Arbitrarily set the motor speed and note from the VI that the value of the input frequency.

Q3. (10%) Measure the steady-state system response amplitude at the frequency of excitation and compute the value of the rotating unbalance, \( m_e \). (Use the given values for \( k \) and \( M \))

Procedure

9. Shut off the damping and forcing to the system. Essentially we now have an undamped, freely (unforced) vibrating system.

10. Bring the mass up to its end position manually and release it so that it oscillates freely.

Q4. 3. (10%) Measure the natural frequency of the system using the “estimated frequency” on the \( z(t) \) time trace. Calculate the theoretical value and compare this to the experimental value (take care with the units)

<table>
<thead>
<tr>
<th>Theoretical</th>
<th>Experimental</th>
<th>Percent Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>( f_n ) (- ) Hz ( f_n ) (- ) Hz</td>
<td>( % \text{ diff} = )</td>
<td></td>
</tr>
</tbody>
</table>

\[ f_n = \frac{\text{Experimental Frequency}}{\text{Theoretical Frequency}} \times 100 \]
Show calculations:

Procedure

11. We will now study the response of the system to base excitation

12. On the control panel, switch the “Out of Balance” switch to “OFF” and the “Frame” switch to “ON”.

13. Use the Forced Vibrations VI to obtain data to plot the response curve $Z/Y$ versus $r$ (see Figure 4.2) for damping corresponding to 0.8A. It should be possible to plot this curve for $r$ values ranging from $r=0.6$ to 2.0 (recall $r = \omega / \omega_n = f / f_n$). Make hard copies of the time traces for values of $r = 0.8, 1.0, and 2.0$ as they will be needed to answer question #7.

14. Take approximately 10 data points ensuring that the peak (close to $r=1$) is well defined. Also ensure that $z(t)$ has reached its steady state value before its amplitude, $Z$, is measured (there are fast ways to accomplish this). Data should be entered in the Excel spreadsheet “Sys_Resp_Worksheet”. Note that since $Y$ is the amplitude of excitation, it is constant - it is not a function of $r$ and therefore doesn’t need to be measured each time. You may also have to change the “damping ratio” data value in the excel spreadsheet to correspond to your particular value used.
Q5. (10%) Provide sample calculations of $Z/Y$ for two values of $r$ and compare these results to the values in the spreadsheet.

Q6. (5%) Plot the experimental and theoretical response curves verses $r$. On the same plot, sketch what you would expect the theoretical response to be for a damping coefficient corresponding to 1.0A.

Q7. 5. (10%) Calculate the value of $\zeta$ used in procedure #13 (i.e., associated with 0.8 Amps) by considering the calibration plot provided. Calculate the theoretical value of the phase angle, $\phi$, for values of $r$ close to 0.8, 1.0, and 2.0 (i.e., the values you used when you made hard copies of the VI’s in procedure #13).

$$\zeta = \text{________}$$

$$\phi_{r < 1} = \text{________}$$

$$\phi_{r = 1} = \text{________}$$

$$\phi_{r > 1} = \text{________}$$
Q8. (10%) In order to better understand the meaning of the phase angle, sketch $a(t) = 1.0\sin(\omega t)$ and $b(t) = 2.0\sin(\omega t - \pi/4)$; and clearly mark the phase angle $\pi/4$ on your sketch.
Q9. (10%) We will now estimate the phase angle between the base excitation and the relative system response. Using the data printed in procedure #13, estimate the phase angle, $\phi$, (to within ±15 degrees or ±$\pi/12$ rads.) for each case. Compare these to the theoretical values computed in question #5.

<table>
<thead>
<tr>
<th>Theoretical</th>
<th>Measured</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\phi_1$ -</td>
<td>$\phi_1$ -</td>
</tr>
<tr>
<td>$\phi_2$ -</td>
<td>$\phi_2$ -</td>
</tr>
<tr>
<td>$\phi_3$ -</td>
<td>$\phi_3$ -</td>
</tr>
</tbody>
</table>

Q10. (10%) Run the system at an $r$ value close to 1.1 with a damping corresponding to a current of 1.0A. Suddenly reduce the damping to zero, and observe the time trace $z(t)$. Consult with your TA to ensure that you have observed the beating phenomenon. With reference to equations in the theory section, explain why the motion is no longer a pure sine wave.

Q11. (5%) Discuss some possible applications of single degree of freedom forced vibration.