EXPERIMENT DESIGN FOR
SIMULATING DIFFERENT FAULTS IN A ROTOR KIT

JUNE 2005

ENAYET HALIM

Objective

The objective of this report is to explain the experimental setup configured to generate
data for different simulated fault of a rotating machine, using the experimental Rotor Kit
model 24750 designed by Bently Nevada. The simulated faults are unbalance of the rotor,
shaft bow (overhung configuration of the rotor), and oil whirl of the bearing and rub on
the rotor by the stator. Radial shaft vibration is measured using proximity transducers and
Siglab vibration analyzer, designed by DSP Inc., at different rotating speed. Vibration
from the shaft would change with a change in configuration (including change of position
of load) and rotor speed.

Literature review

A brief literature review was performed on the experiments conducted using a rotor kit to
simulate the different faults mentioned earlier but not too many papers could be found.
Also the papers failed to provide any detailed information on the procedure the
experiments were conducted. Details about previous experiments conducted using the
same experimental setup can be found in paper [9].
Paper [1] and [6] explains the generation of unbalance in a rotor kit. In [1], the rotor kit
consisted of a steel shaft 1.1m long with a nominal diameter of 38 mm, holding 2 shrink-
fitted balancing discs. The shaft was supported at both ends by journal bearings of 100
mm. Table 1 and 2 gives the different configurations used in [1] and [7] to generate the
desired unbalance respectively.
Paper [2] indicates the experimental setup to produce an overhung rotor condition where
an 8 kg weight was hung on the outer side of the outer bearing on a steel shaft 540 mm
long and 10 mm in diameter. Two discs of 0.8 kg were also used.
using a copper block whereas in [3] a device has been designed to produce equal rub
from 4 sides. But there is no mention of the measurement of severity of rub in the two
papers.
Paper [4] gives a brief idea about producing oil whirl fault in rotor kit, but a better
procedure has been outlined in the manual of the rotor kit [8]. The main frequency feature
of oil whirl is the increase of 1/2X component.
Paper [5], [6] and [7] also briefly describes experiments with rotor kits though not much
detail can be obtained. Figure 1 indicates the dimensions used in [6]. Table 2 indicates
the rotor kit configuration parameters in details for [7].
Figure 1: Dimension used in rotor kit experiment in [6]

Table 1: Table of rotor rig physical properties and unbalance configuration used to excite rotors as mentioned in [1]

<table>
<thead>
<tr>
<th>Station</th>
<th>Length (mm)</th>
<th>Diameter (mm)</th>
<th>$E$ (GPa)</th>
<th>$\rho$ (kg/m$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shaft properties</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>63.5</td>
<td>38.1</td>
<td>200</td>
<td>7850</td>
</tr>
<tr>
<td>2</td>
<td>25.4</td>
<td>77.57</td>
<td>200</td>
<td>7850</td>
</tr>
<tr>
<td>3</td>
<td>50.8</td>
<td>38.1</td>
<td>200</td>
<td>7850</td>
</tr>
<tr>
<td>4</td>
<td>203.2</td>
<td>100</td>
<td>200</td>
<td>7850</td>
</tr>
<tr>
<td>5</td>
<td>117.8</td>
<td>38.1</td>
<td>200</td>
<td>7850</td>
</tr>
<tr>
<td>6</td>
<td>50.8</td>
<td>116.8</td>
<td>200</td>
<td>7850</td>
</tr>
<tr>
<td>7</td>
<td>76.2</td>
<td>38.1</td>
<td>200</td>
<td>7850</td>
</tr>
<tr>
<td>8</td>
<td>76.2</td>
<td>109.7</td>
<td>200</td>
<td>7850</td>
</tr>
<tr>
<td>9</td>
<td>76.2</td>
<td>38.1</td>
<td>200</td>
<td>7850</td>
</tr>
<tr>
<td>10</td>
<td>50.8</td>
<td>102.9</td>
<td>200</td>
<td>7850</td>
</tr>
<tr>
<td>11</td>
<td>117.8</td>
<td>38.1</td>
<td>200</td>
<td>7850</td>
</tr>
<tr>
<td>12</td>
<td>203.2</td>
<td>100</td>
<td>200</td>
<td>7850</td>
</tr>
<tr>
<td>Balancing discs</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>25.4</td>
<td>203.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>25.4</td>
<td>203.2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Unbalance configurations used to excite rotor

<table>
<thead>
<tr>
<th>Unbalance configuration</th>
<th>Balance disc</th>
<th>Unbalance (kg/m)</th>
<th>Phase (deg lead)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>0.0013</td>
<td>75</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.0013</td>
<td>-150</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>0.0013</td>
<td>-105</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.0013</td>
<td>120</td>
</tr>
</tbody>
</table>
Table 2: Table with accompanied figure indicating the dimensions used in the rotor kit for experiment of [7].

<table>
<thead>
<tr>
<th>Run</th>
<th>Weight</th>
<th>Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.3 grams</td>
<td>225 and 270 degrees</td>
</tr>
<tr>
<td>2</td>
<td>0.4 grams</td>
<td>90 and 337.5 degrees</td>
</tr>
</tbody>
</table>

Configuration of the test rig

Configuration parameters of the rotor–bearing system

<table>
<thead>
<tr>
<th>Configuration parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Balancing planes C and D</td>
</tr>
<tr>
<td>Diameter 60 mm, thickness 25 mm, mass 800 g</td>
</tr>
<tr>
<td>Bearings</td>
</tr>
<tr>
<td>Stiffness $5.75133 \times 10^3$ N/m, damping 17.51 kg/s</td>
</tr>
<tr>
<td>Shaft</td>
</tr>
<tr>
<td>Diameter 10 mm, density 7800 kg/m$^3$, modulus of elasticity $2.1 \times 10^{11}$ N/m$^2$</td>
</tr>
<tr>
<td>Coordinates of nodes</td>
</tr>
<tr>
<td>L1 = 0 mm, L2 = 32 mm, L3 = 72 mm, L4 = 139.5 mm, L5 = 229 mm, L6 = 306 mm,</td>
</tr>
<tr>
<td>L7 = 383 mm, L8 = 423 mm, L9 = 468 mm, L10 = 515.5 mm, L11 = 553 mm</td>
</tr>
</tbody>
</table>

Setting up the Proximators

There are 4 probes in the rotor kit setup – 2 on the XY probe bearings and 2 on the motor joint to detect rotation speed. Figure 2 shows the proximator setup with connections to 3 probes. The remaining probe from the motor joint (right) goes to the motor speed controller.
Unbalance can be generated in the rotor kit by adding extra weight to one or both of the rotor discs at certain phases. The rotor kit can be configured to carry one or two weight discs on the rotor. According to [1], two weight discs can be used effectively to produce unbalance. Table 1 summarizes the unbalance produced in [1]. In [6], a mass of 0.5 grams was added to the groove of the disc. According to [7], the masses can also be varied with the phase and Table 2 summarizes the configurations.

One-Disc Configuration
To start off, one weight disc is mounted in the middle of the rub-screw mount and the inboard bearing with a spacing of 15 cm from each. Figure 3 shows the rotor and the position of the discs and the bearings. Table 3 summarizes the unbalanced produced with different arrangements for the simulation.

**Figure 3: One-disc rotor configuration.**

**Table 3: Table indicating the different arrangements used in the rotor kit for one-disc unbalance simulation.**
<table>
<thead>
<tr>
<th>Configuration</th>
<th>Weight used</th>
<th>Phase</th>
<th>Data no.</th>
</tr>
</thead>
<tbody>
<tr>
<td>ODU-N</td>
<td>0</td>
<td>0</td>
<td>en_1_n1,n2,n3,n4</td>
</tr>
<tr>
<td>ODU-1</td>
<td>Large</td>
<td>90</td>
<td>en_1_c1,c2</td>
</tr>
<tr>
<td>ODU-2</td>
<td>Large</td>
<td>135</td>
<td>en_1_c3,c4</td>
</tr>
<tr>
<td>ODU-3</td>
<td>Small</td>
<td>90</td>
<td>en_1_c5,c6</td>
</tr>
<tr>
<td>ODU-4</td>
<td>Small</td>
<td>135</td>
<td>en_1_c7,c8</td>
</tr>
<tr>
<td>ODU-D</td>
<td>Large+Small</td>
<td>90+225</td>
<td>en_1_c9,c10</td>
</tr>
</tbody>
</table>

Two-Disc Configuration

The rotor kit can be prepared to support two weight discs on its rotor. The rub-screw mount can be moved and re-positioned in the middle, maintaining approximate equal distance of 17.5 cm from the inboard and outboard bearings. The two discs can then be mounted on the rotor with equal distance of 8 cm from the rub-screw mount. Figure 4 shows the rotor and the position of the discs and the bearings. Table 4 summarizes the unbalanced produced with different arrangements for the simulation.

![Figure 4: Two-disc rotor configuration.](image)

Table 4: Table indicating the different arrangements used in the rotor kit for two-disc unbalance simulation.

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Disc</th>
<th>Weight used</th>
<th>Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>TDU-1</td>
<td>L</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TDU-2</td>
<td>L</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TDU-3</td>
<td>L</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Shaft Bow (overhung rotor)

Overhung rotor condition can be produced by putting only one weight disc between the rub-screw mount and the inner bearing where the rub-screw mount is located at one end of the base. Figure 5 shows the overhung mass configuration with the dimensions. A preload or rub condition can also be considered as an addition to this configuration. In [2], the overhung rotor condition is produced by using 8 kg weight at one side of the shaft outside the outer bearing, but for this experiment no such configuration is used.
Rub
The rub screw housing is used to produce a rub condition to the rotor using the screw attached. Rub condition in [3] has been produced using special device, which produces a uniform rub between the stator and rotor from all 4 sides. The rotor is made of steel whereas the stator is made of soft aluminum alloy. But in literature, there is no mention of measure of the rub produced between the rotor and stator. To produce a uniform rub the following steps has to be taken:

1. Adjust the screw so that it barely touches the rotor.
2. Thread the screw upward making it rotate X times on its axis completely.
3. Run the rotor and adjust the desired speed and vibration condition.
4. Thread the screw downward X times. Rub should now be generated at the minimum level.
5. Thread the screw more downward recording the amount rotated (measuring the angular distance the screw has been turned) and the number of complete rotation of the screw on its axis.
6. Produce the desired level of rub and record the angular distance and the number of turns of the screw each time along with the data.

Since there is no measure of rub given in literature therefore rub of different severity should be produced depending on the amount of vibration generated by the rotor due to the rub. The One-Disc Configuration should be used when producing rub in the rotor.

Oil Whirl
For a rotor-bearing foundation system, the self-excited vibration of the oil film force between the bearing and the journal may cause the film to collapse. Under certain conditions, vibration will increase suddenly at that position and spread over the whole system in short time, which will cause strong vibration. [4]
The steps taken to produce a oil whirl in the rotor kit is given below.

1. Remove the outboard bearing housing and the shaft from rotor kit. Remove the rotor masses from the shaft.
2. Remove end cap from oil bearing and slide it over oil shaft. Install preload frame, typically within 1 inch of the bearing. Install a rotor mass approximately centered on the oil shaft and install the shaft fully into the motor coupling. For fluid
instabilities at very low speed it may be necessary to either move the rotor mass fully inboard (toward motor) or remove it from the shaft.

3. Position the oil bearing housing on the base, insert the journal, and slide the bearing housing outboard to provide approximately 1/16 inch (1 to 2 mm) axial clearance. Ensure that the oil stand is perfectly aligned in the base keyway and secure the housing. Install end cap into oil bearing.

4. Check that no rub, preload, unbalance, or bow greater than 0.001 inch (25 micron) exists along the shaft.

5. Fill the reservoir with light viscosity dyed turbine lube oil.

6. Connect the proximators.

7. Open the oil flow valve until oil drips from the bearing, then close the valve. Turn the motor up to about ¼ to 1/3 (approximately 3000 rpm) and open the oil flow valve. If instability does not begin immediately, lift the shaft lightly at the oil stand end using the nylon preload rod. Operate the oil return pump as necessary to maintain a supply in the reservoir.

The rotor will develop oil whip when the frequency of an existing oil whirl vibration (approximately 0.48X shaft rpm) excites the natural resonance of the rotor. During oil whip the frequency of the whip is nearly constant as the rotor rpm is increased.

**Operation Speed and adjustment**

According to [3] and [4], the rotation speed of the rotor should be set to 3000 rpm. [6] indicates a speed of 1500 rpm whereas [7] reports result between 1900 rpm to 3100 rpm. In [2], the speed of the rotor was 3500 rpm for which the critical speed varied from 1720 rpm to 4025 rpm. The manual of the rotor kit [8] indicates a speed of 3000 rpm as a suitable speed for rotation. The speed should be controlled properly and initiated in the following sequence.

1. Put the RAMP/SLOW ROLL switch to SLOW ROLL. The SLOW ROLL Control should be set to 250 rpm.
2. Turn on ON/OFF power switch to ON.
3. Rotor should start turning and stabilize at the slow roll speed.
4. Put the RAMP UP/DOWN switch to UP and set the RAMP RATE Control to 3000 rpm.
5. The rotor should start turning at the desired 3000 rpm.

Operation should also be operated at other speed conditions which may initially be selected as 2000 rpm, 2500 rpm and 3500 rpm.
Data Acquisition

According to [3] and [4], the data acquisition should be conducted at a frequency of 1600 Hz. Siglab can handle a data acquisition frequency of 2560 Hz. Therefore, it is better to use 2560 Hz as the data acquisition frequency. Data collection time should be minimum 3 seconds to acquire sufficient data to analyze, but in this case time duration of 6 seconds should be preferable.

The sequence of experiment should be as follows.
1. Unbalance using One-Disc Configuration
2. Rub
3. Unbalance using Two-Disc Configuration
4. Shaft Bow
5. Oil Whirl

References