CHAPTER 3

Test Rig and Experimental Setup

3.1 Test Rig

The test rig designed and constructed for this research is shown in figure 3.1. The system was designed to represent a typical rotating machine with flexible rotor and compliant stator. The rotor shaft is supported by ball bearings at both ends. There are two disks mounted on the shaft at the location of an active magnetic bearing (AMB) (plane 1) and a stator contact mechanism (plane 2). The rotor is driven by DC motor through the timing pulley, which connects to the rotor by a flexible coupling. The designed speed range of the system is 0-6,000 rpm (0-100 Hz). The AMB at plane 1 can be used to apply control forces to the rotor or excite vibration of the disk at plane 2. It can also be used to generate a simulated unbalance disturbance at the disk at plane 1. The stator interaction mechanism at plane 2 involves a circular surround supported by four thin horizontal rods, the length of which can be varied in order to change the stiffness. The test rig is installed on a heavy (135 kg) based plate fixed rigidly to ground by four steel posts. The influence of the base structure on overall system dynamics is therefore negligible.

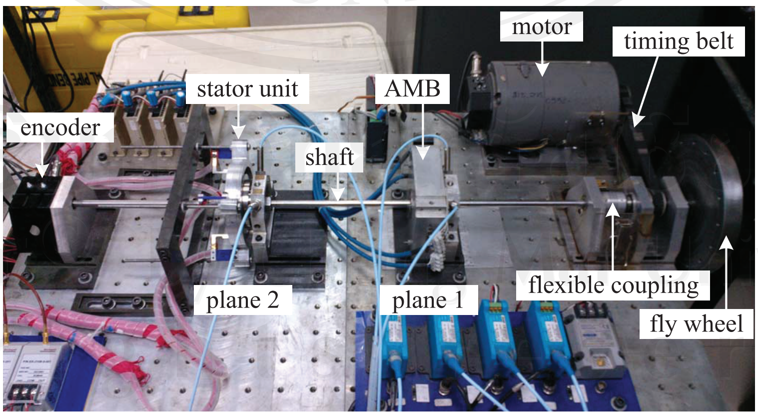


Figure 3.1: Experimental test rig

The system has been designed with an aim to reproduce both the forward whirl and backward whirl vibration response behaviours, as introduced from a theoretical perspective in Chapter 2.

3.2 Rotor

The rotor shaft is 800 mm in length and with diameter of 10 mm. The shaft is supported by ball bearings at both ends. The length between the bearing supports is 700 mm. Disk 1 and disk 2 are mounted at 232 mm and 475 mm respectively along the length of the shaft from the driven-end bearing, as shown in figure 3.2.

Disk 1 is made of a laminated ferromagnetic material. The mass of disk 1 is 0.36 kg and the diameter is 48 mm. Disk 2 has a mass of 1.12 kg and 16 equally space holes of M3 screw thread are located at radius of 28.5 mm from the center of the disk. Small masses can be placed in these holes in order to balance the rotor or to produce a required vibration at disk 1 and disk 2. A ball bearing with radial clearance of 600 μm to the stator is fitted on disk 2. This bearing is used to reduce tangential friction forces at the rotor-stator interface and thereby prevent friction-driven response modes. In a backward whirl test, the ball bearing is replaced by an aluminium ring with radial clearance of 400 μm in order to increase the friction force and to establish friction-driven response modes.

The lateral vibration of the disk at each plane is measured by non-contact displacement sensors (Bently Nevada model 3300XL). A pair of sensors at each plane are arranged perpendicular to each other and at 45 degree to the horizontal (x- and y-axis).

There is an encoder using a photo sensor at the non-driven end of the rotor that is used to

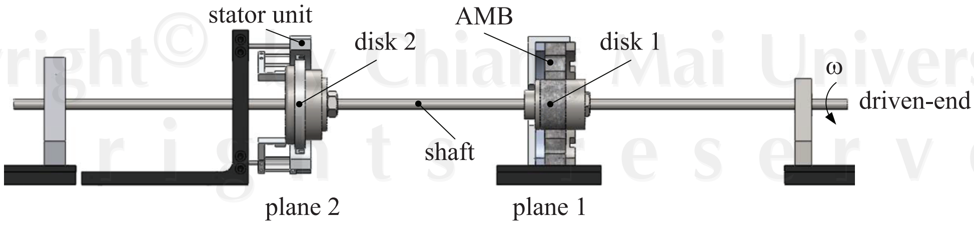
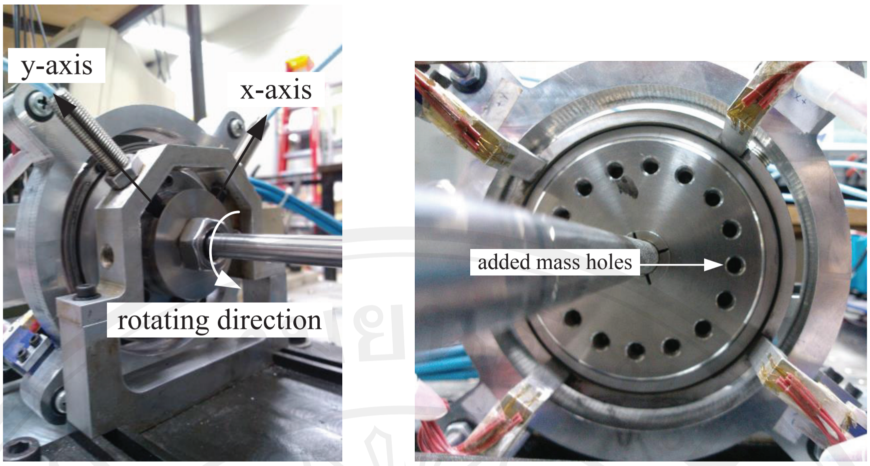


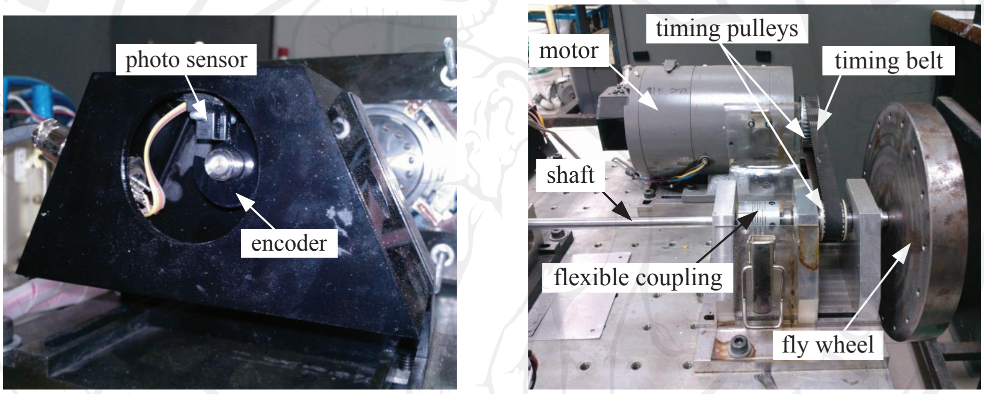
Figure 3.2: CAD model of rotor part



(a) Contact disk with displacement sensors

(b) 16 holes for added mass

Figure 3.3: Contact disk



(a) Encoder using a photo sensor for rotational speed measurement

(b) Driving unit

Figure 3.4: Rotational speed measurement and driving unit

measure key phasor pulse of rotating rotor which is at one pulse per revolution. The motor is controlled by PID current control using a DC brush servo amplifier (Copley Controls Corp model 412).

3.3 Active Magnetic Bearing

An active magnetic bearing (AMB) is a device that consists of electromagnetic unit, power amplifiers, non-contact position sensors and electrical control system as shown in figure 3.5. The signals from position sensors are used as the input signals to the controller to determine the control signals which are transmitted to the amplifiers. The amplifiers drive

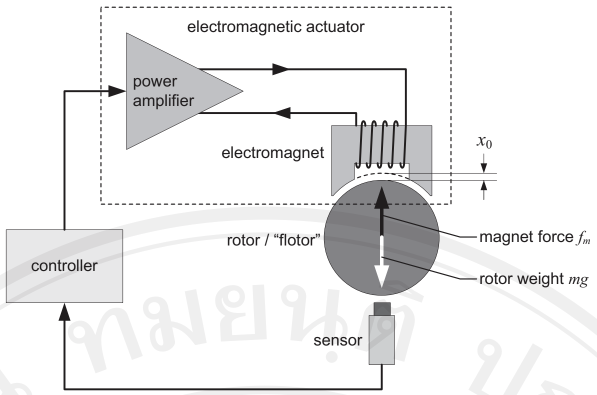
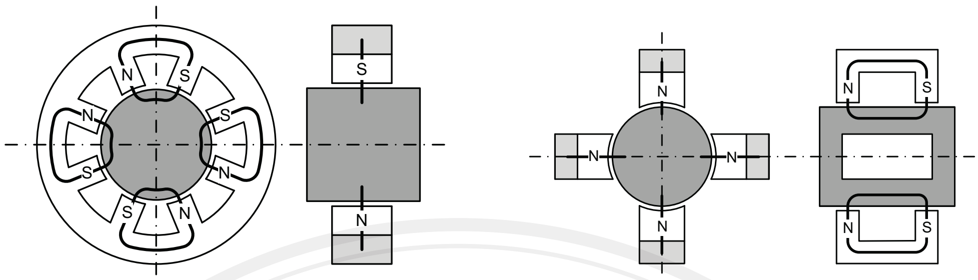


Figure 3.5: Basic concept of an active magnetic bearing.[1]

the current through the electromagnet coils to generate forces which act on the suspended rotor. For the AMB, there is no contact between rotor and bearing. In practise, this allows machines to operate with no lubrication and hence no mechanical wear. Another important advantage of AMBs is that the rotordynamic behaviour can be controlled actively through the bearings. There are two types of structural configurations for radial active magnetic bearing. Heteropolar is named for the structural configuration where all of the lines of magnetic flux are confined to a plane perpendicular to the axis of rotation as shown in figure 3.6a. The heteropolar type can be manufactured in a manner similar to that for electric motors. The rotor must be laminated in order to keep the eddy current losses as low as possible. Another structural configuration type is called homopolar. For this type, some portion of the magnetic flux can pass axially along the rotor as shown in figure 3.6b. There is much less field variation around the circumference of the rotor and so the eddy current loss due to rotation of the rotor is reduced. Homopolar configurations are commonly used in conjunction with permanent magnets (PM).

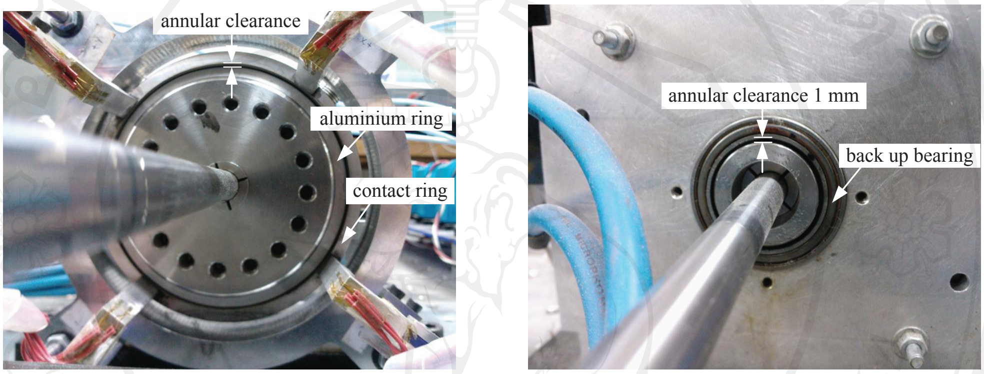
The AMB designed for the test rig is showed in figure 3.8 and is located at plane 1. The AMB used in the test rig is a conventional heteropolar design having 2 sets of opposing pole pairs. The magnetic coils are driven by pulse-width modulation (PWM) switching amplifiers of Copley Corporation Corp (model 2122z) and operate with bias currents of 1 A. The back up bearing is inserted on the AMB housing in order to prevent the contact between the disk and AMB housing with radial clearance of 1 mm.



(a) Heteropolar: polarities of the stator poles in a given rotational plane vary. The sequence shown here is N-S-S-N-N-S-S-N

(b) Homopolar: in any given rotational plane stator poles have the same polarities (N in the left plane and S in the right plane

Figure 3.6: Structural configurations of radial bearings.[1]



(a) Radial clearance at contact plane

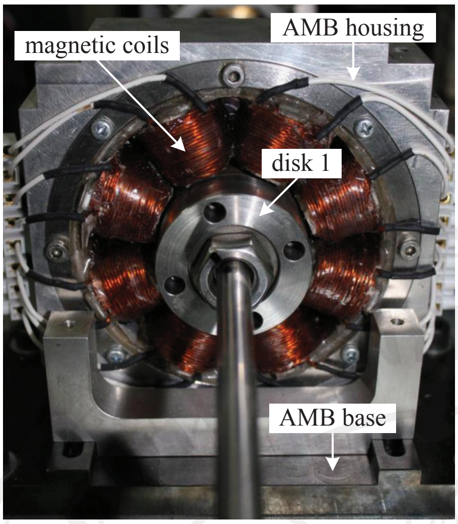
(b) Radial clearance of 1 mm at AMB back up bearing

Figure 3.7: Radial clearance between rotor and stator/AMB housing

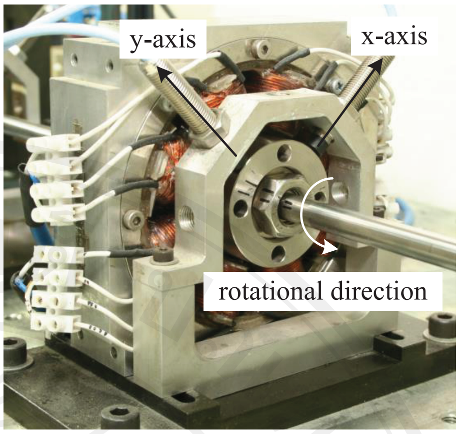
In normal operation, proportional and derivative (PD) feedback of local rotor displacements is used to stabilize the bearing and the AMB may be simply modelled as a linear spring and damper support. In the experiments, control forces can be applied to the rotor through the AMB in order to control/influence the vibration response within the limits of linear operation of approximately 15 N.

3.4 Stator and Force Sensing Device

The rotor surround/stator has a mass of 0.46 kg and is compliantly supported by four horizontal rods (figure 3.9). The length of the rods can be varied in order to change the natural frequency of the stator within the range 25 to 200 Hz.



(a) Active magnetic bearing



(b) Active magnetic bearing with displacement sensors

Figure 3.8: Active magnetic bearing

An interaction force sensing device is fitted within the stator unit. This device consists of a contact ring, which has clearance to disk 2, mounted on four sensing elements as shown in figure 3.10. Each sensing element consists of one cantilever with strain gauges, connected in series with another cantilever designed to give compliance to the element in an orthogonal (non-sensing) direction. The four sensing elements are arranged circumferentially in opposing pairs to maximize symmetry of the device. The strain measured at the four sensing elements can be converted to lateral $(x - y)$ force components via a linear transformation. The contact ring and sensing elements are designed to have low mass in order to maximize bandwidth of the device, which is limited by the natural frequency of the contact ring. Finite element modeling was used to optimize the design in order to achieve good sensitivity while maintaining a sufficiently high natural frequency (> 400 Hz). The maximum force that the device can withstand is estimated to be 50 N.

3.5 Instrumentation and Data Acquisition

The test rig is controlled using the xPC Target computer system. The connection diagram of xPC Target system and the test rig is shown in figure 3.11. The xPC Target computer system consists of two separate personal computers which are called “host computer” and

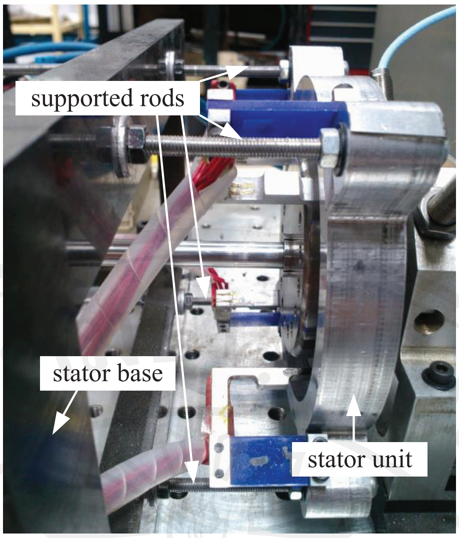
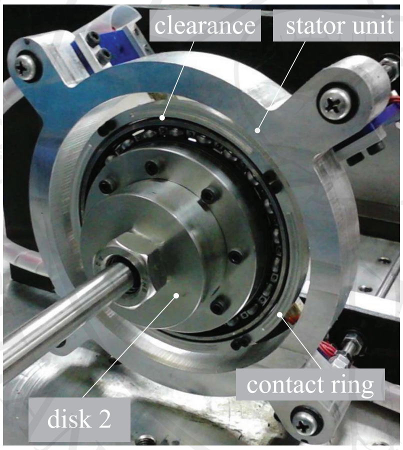
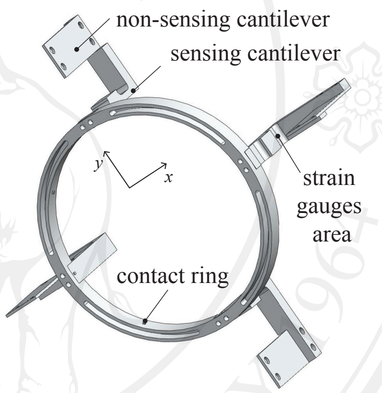


Figure 3.9: Horizontal supported rods



(a) Stator unit with force sensing device



(b) CAD model of force sensing device

Figure 3.10: Force sensing device

"target computer". The host computer is used to compute, analyse and/or create the controller and also to transfer input/output data. The target computer is used as a real-time processor to control and/or monitor real-time input/output data. The host computer is 1.8 GHz Intel Pentium 4 Processor and the target computer is 800 MHz Intel Pentium 3 Processor. The target computer uses analog input board model PC104-DAS16JR and analog output board model PC104-DAC06. These boards are made by Measurement Computing company which are compatible with Matlab xPC toolbox in the host computer. The analog input board has a maximum sampling rate of 150 kS/s with 12-bit resolution and there are 16 single-ended analog to digital input channels or 8 analog to digital input channels

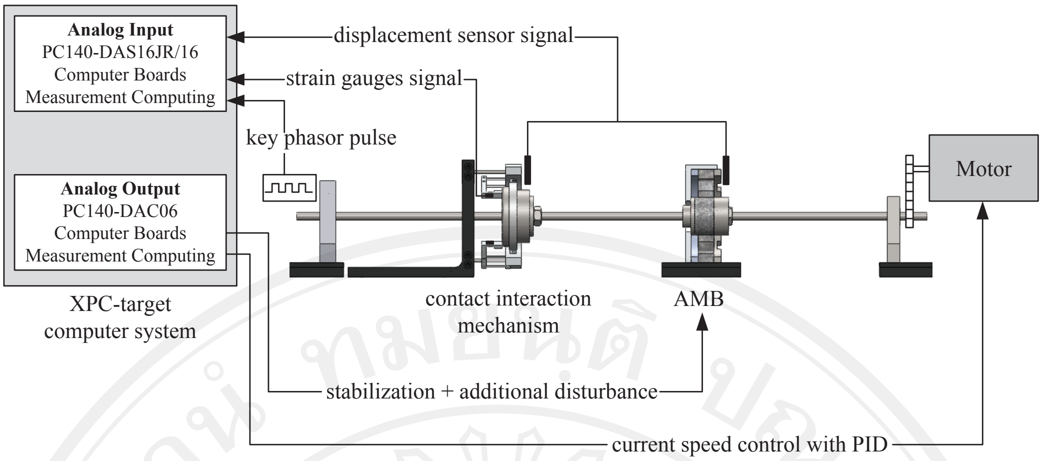


Figure 3.11: xPC Target system and test rig connection diagram

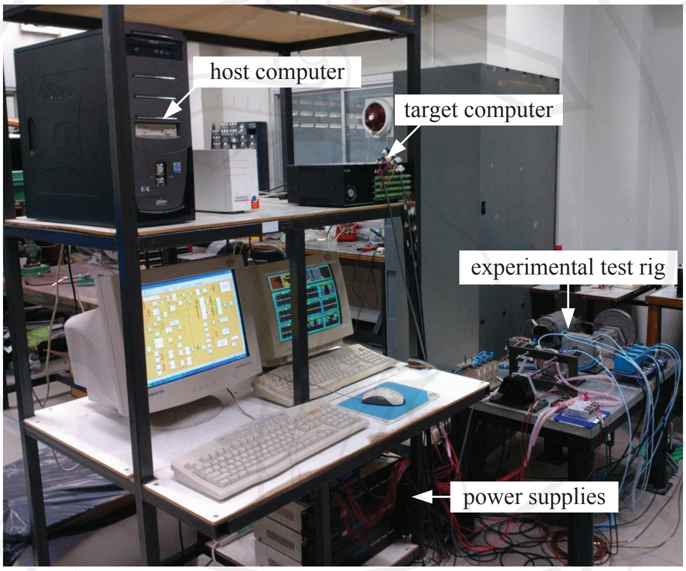


Figure 3.12: Experimental test rig and xPC target computer system connection

in differential configuration. The digital to analog board has 6 output channels with 12-bit resolution.