Study on High Speed Spin Test of Hydraulic Dynamometer by Test Rig Facility

Ashish R. Pawar[1], Kiran G. Shinde[1], Tapobrata Dey[1] and Kiran Narkar[2]

[1]*Department of Mechanical Engineering, D. Y. Patil College of Engineering, Akurdi, Pune-44, Savitribai Phule Pune University, INDIA*

[2]*Professor, Head, Dept. of Mechanical Engineering, D.Y. Patil Institute of Engineering Management & Research, Akurdi, Pune, Maharashtra, INDIA*

---***---

Abstract – *For checking the spin test, the purpose is to design the test rig for rotating elements. Due to checking the appropriate rotations during the actual application which need of work, whether it gives proper rotations or not or it have proper bearing alignment or not. The rotating elements while testing under spin test on test rig results to conclude that it has proper bearing alignment or not by giving it high speed rotations. So under this work a rotating element runs at different rpm for several time intervals. So we design the test rig for testing the rotating element by design calculations, numerical calculations and experimental calculations is used to build the test rig. Depends on this work, if finds to know the errors occur in rotating component at which it damages by temperature effect on it or by misalign bearing and at what rpm level it should be. Then appropriate remedies are taken by finding it to minimize the damages and give the proper rectification and again test the component.*

***Key Words*: 3 Phase AC Squirrel Cage Induction Motor (175KW), Dynamometer, Pulleys, Flat Belt, Plummer Blocks etc.**

1. INTRODUCTION

Dynamometer test is similar to blood test of human being that's why testing is being needed and hence concluded to design a Test Rig. Testing in general is associated with validation. Validation includes Design Validation, Performance Validation, Component Validation, Engine oil Testing, Production process Validation, Tribology Validation, Cold engine vs Hot engine Performance, Chassis Dynamometers due to this applications of high speed, test rig is being need to design. The spin test for rotating systems is necessary. Use of Dynamometer for testing as it tests at several speeds for several intervals, without testing it gets fail at application. Bearings of the dynamometer misalignment or loose contact in between parts of attachment or temperature effect so for overcoming these faults and rectify it under testing. [6] Test rig is used to develop and tests automatic transmissions under a variety of operating conditions. Check and measure dynamic performance including function, spin loss, noise, hydraulic stability, shift quality, oil level, oil foaming and basic cyclic durability. Usually testing is performed under no load condition i.e. output shaft is allowed to rotate freely.

For achieving test speed of dynamometer use of two phases over there by velocity ratio by means of motor speed increases to achieve it as required at the end. Phases are motor-shaft and shaft to dynamometer. Converting the speeds, use of belts in both phases over pulleys for achieving required speed. [4] Test Rig includes dynamometer, water temperature controller, oil temperature controller, speed indicator, test bed, motor, plummer blocks over which shaft rest under bearings. For validation it involves Analytical Analysis and Experimental Analysis used to develop this Test Rig [2].

By referring the paper includes Gearbox is an indispensable element of power transmission drives of most mechanical systems. Therefore, it is very essential to assure the performance of gearbox, it is important to check torque carrying capacity at rated speeds. This work presents the design and development of a torque testing rig for 0.5-10 KN-m capacity carried out for a gearbox having multi-plate brake system. While calibration of torque testing rig experimentally measured data is compared with theoretical calculations and a good agreement between experimental and theoretical calculations are observed. [4]

The summary of application of results and conclusion of brief program history regarding test rig for power transmission. Components are designed to assemble test rig facility by providing the operational checkout of drive system, high speed test components, instrumentation, etc. It gives results over supercritical shaft vibration control by damping where used of coulomb friction damper, squeeze-film dampers and its analysis with torquing systems assembly needed. Vibration which finds they are control by balancing where which influences coefficient balancing requires for final testing. After that comparison is between measurement and prediction whether it affects the torque or not even which check the non-synchronous vibrations are there or not and test the equipment. [1]

Technology based on Test Facilities-Project Descriptions. The Directors and Engineers have been involved in design and supply of "one-of-a-kind" test facilities and special engineering projects for over 30 years, for the facility includes aircraft tyre, wheel and brake high speed test dynamometers and static testers, automotive equipment, model ship and submarine towing carriages, aero engine component testers such as vacuum spin test rigs, blade testers, casing rigs. Special purpose rigs for military vehicle components such as main battle tank suspensions. It commenced operations in 1995. It works for the project such as follows- Aircraft Brake Test Dynamometer, National Airports Pavement Test Machine, Aircraft Tyre Test Dynamometer, Wheel and Brake Test Dynamometer, Development, design and build of automatic machinery for the assembly of fuel cells, Wind stream test rigs, and Fuel system test rigs for commercial and Military aircraft, Design motor and general based frames.[3]

Functional Design Specification for Spin Test Rig, Version 3.1 on 12th April 04 which includes the overview of design of test rig fundamentals from design to manufacture specification. It has Cimplicity System which consists of PC requirements, communications, Software's, Cimplicity Application, Database Convention, Test Certificate, and Network Connection. For loading and mounting they used to mounting seal and clamped it. It also used on concept of pneumatic control which works on transducers even which it also needs a motor and drive to operate and control the test rig design. It needs to operate on PLC Program Logical Controller for input description. At final stage safety circuits and electrical drawings are being necessary to complete the process of testing.[2]

Drag Torque, Lift-Off Journal Speed, and Temperature in a Metal Mesh Foil Bearing - Metal mesh foil bearings (MMFBs) are a promising low cost gas bearing technology for high performance oil-free micro-turbomachinery. Elimination of complex oil lubrication and sealing system by deploying MMFBs in rotorcraft gas turbine engines offers distinctive advantages such as reduced system weight, enhanced reliability at high rotational speeds and extreme temperatures, and extended maintenance intervals compared with mineral oil lubricated bearings. MMFBs for oil-free rotorcraft engines must demonstrate adequate load capacity, reliable rotor dynamic performance, and low frictional losses in a high temperature environment. The paper presents the measurements of MMFB breakaway torque, rotor lift-off and touchdown speeds, and temperature at increasing static load conditions. The tests, which were conducted in a test rig driven by an automotive turbocharger turbine, demonstrate the airborne operation (hydrodynamic gas film) of the floating test MMFB with little frictional loses at increasing loads. The measured drag torque peaks when the rotor starts and stops, and drops significantly once the bearing lifts off. The estimated rotor speed for lift-off increases linearly with the applied static load. During continuous operation, the MMFB temperature measured at the back surface of the top foil increases both with rotor speed and static load. Nonetheless, the temperature rise is mild, demonstrating reliable performance. Application of a sacrificial layer of solid lubricant on the top foil surface reduces the rotor break-away torque. The measurements give confidence on this simple bearing technology for ready application into oil-free turbo-machinery. [6]

1.2 Objective

- To eliminate the errors which is not at acceptable in Spin test of the rotating component / system / engine includes bearing misalignment, temp. Effect, vibrations.
- To design and develop a physically simpler, more reliable and less costly high spin test rig for testing.
- To ensure and maintain proper testing functionality of the prior art.

2. Architecture and Working of High Speed Spin Test Rig

An assembled layout of high speed spin test rig composed of basically prime mover as motor, test bed over which the rotating component is being placed for testing. But in this case when thinking on working of test rig and design layout of test rig the need is to achieve the speed of rotating component/system/machine.

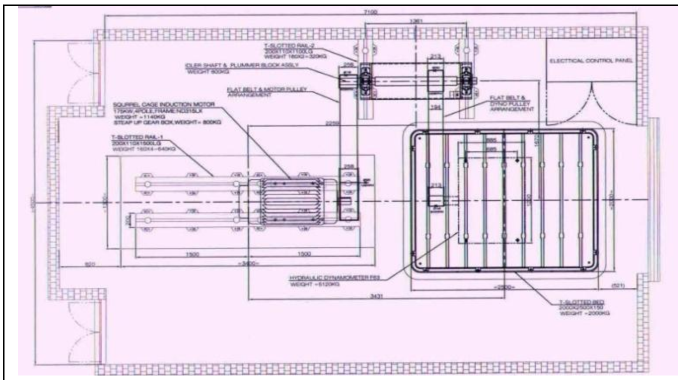

Fig -1: Proposed Assembled Layout of High Speed Spin Test Rig

2.1 WORKING:

By input the power through the prime mover as from Motor, the pulley which mount on shaft of motor should transfer the speed to next pulley situated on shaft and further on same shaft the other pulley is situated for converting the speed with velocity ratio by calculation below the same speed with that pulley transfers to rotating component say dynamometer for testing.

In this case use of rotating component to be tested is F-47 (SH-3300) Dynamometer as the company which develops it for the customer in CHINA for their application where they need this particular Dynamometer to operate at 7000 rpm.

So on this test rig which we develop, testing of dynamometer for spin testing and checking the bearing alignment of dynamometer whether they failed by spin testing, if they failed then gives remedies for the same.

Also on test rig, test the engine testing, shaft assembly etc.

As prime mover i.e. motor runs at 1350 rpm by considering power loss, convert speed towards the pulley situated on shaft under plummer block assembly with the vel. ratio of 2.98 and further on same shaft other pulley is situated which transmits the same speed as above have converts with vel. Ratio of 2 to the dynamometer pulley for achieving final speed.

3. Theoretical (Analytical) Analysis of Spin Test Rig

For achieving the speed of dynamometer at 7000rpm, use of velocity ratio there in between above component stages seen in figure 1.

3.1 Calculations & Selections:

3.1.1 Power Calculation:

Total Power Required = Rotational Energy + Linear Energy

$$V = \frac{\pi DN}{60} = 0.47\pi \frac{7700}{60} = 189.49 \frac{m}{sec}$$

$$\omega = \frac{V}{R} = \frac{189.49}{0.235} = 806.34\, rad/sec$$

Where, D = diameter of Rotor

N = speed expected (achieve)

A) Rotational Energy = $\frac{1}{2} I\omega^2$

Where, I = moment of inertia of Rotor (I = MK^2)
M = mass of Rotor = 250 kg
K = Radius of gyration = 0.1385m^2
I = 250 X $(0.1385)^2$ = 4.8 kg.mm^4
Response time = 15 sec

Therefore= $\frac{1560442.069}{15} = 104.029\ kw$

Rotational Energy = 0.5 X 4.8 X 806.34^2

= 1560442.069 watts

B) Linear Energy = Force X Velocity
= 250 X 9.81 X 189.49
= 464724.225 watts

$$Therfore\ = \frac{464724.225}{15} = 30.981kw$$

Total Power Required = 104.029 + 30.981= 135kw

3.1.2 Selection of Motor:

Motor of 175kw of Crompton Greaves of 3 phase AC squirrel cage induction motor by considering other loses.

Specification - Crompton Greaves works on 1488rpm but for factor of safety, assumed as 1350rpm for further calculation of other parameters by considering power losses during running.

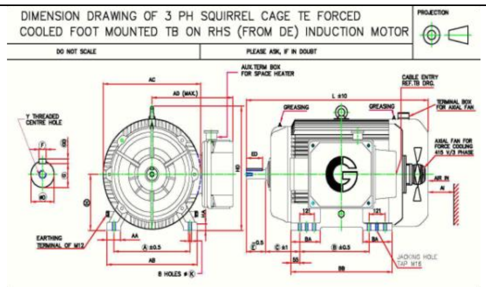

Fig – 2 : 3 Phase Squirrel cage Induction Motor

3.1.3 Pulley Calculation:

Speed ratio formula as – D1N1 = D2N2
Using conventional test rig dimensions-
Stage – 1: Motor Side

Pulley dia. of motor = D1 = 525

Pulley dia. of shaft = D2 = 176

Motor Speed = N1 = 1350

$$25\ X\ 1350 = 176\ X\ N2$$

$$N2 = 4026.98 \cong 4000rpm$$

$$velocity\ ratio = \frac{525}{176} = 2.98 \approx 3$$

By considering power losses take 4000 rpm.

Stage – 2: Dynamometer Side

As flange of Dyno-F47 (equipment to test) is 146mm (std.), design another pulley mounted on shaft for transferring speed.

$N3D3 = N4D4$ = Speed of shaft = N3 = 4000

Tested Speed of Dynamometer = N4=8000 (Apprx.)

$$4000\ X\ D3 = 8000\ X\ 146 = D3 = 290mm$$

$$velocity\ ratio = \frac{290}{146} = 1.98 \approx 2$$

By calculation, achieve dynamometer to be test at 7000rpm.

3.1.4 Belt Calculation:

Stage 1 – Motor to Shaft

Center distance = C = 3.18 X Larger pulley diameter

= 3.18 X 525 = 1669.5 ≈ 1670 mm.

$$length\ of\ flat\ belt(L) = 2C + \frac{\pi(D+d)}{2} + \frac{(D-d)^2}{4C}$$

D = 525mm; d = 176 mm;

L = 4459.36 ≈ 4460 mm

$$Belt\ thickness(t) = 0.02\ X\ d = 3.52 \approx 4mm$$

$$Belt\ width(b) = 1.33d = 1.3\ X\ 176 = 234mm$$

Stage 2 – Shaft to Dynamometer –

Center distance = C = 1875 mm

D = 290mm; d = 146 mm

Length of flat belt (L) = 4027.97 ≈ 4028 mm

$$Belt\ thickness(t) = 0.02\ X\ d = 2.92 \approx 3mm$$

$$Belt\ width(b) = 1.33d = 1..33\ X\ 146 = 194mm$$

Select flat belt as 4mm thick, 220mm width for Stage-1 & 3mm thick, 180mm width for Stage-2.

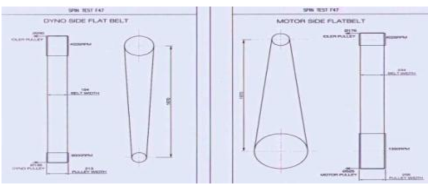

Fig. 3 : Flat Belt Arrangement

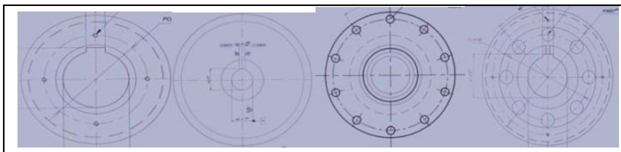

Fig. 4 : Motor side Pulleys & Dyno side Pulleys

3.1.5 Selection of Test Bed:

Test Bed Dimension – 2000 x 2500 x 150 mm

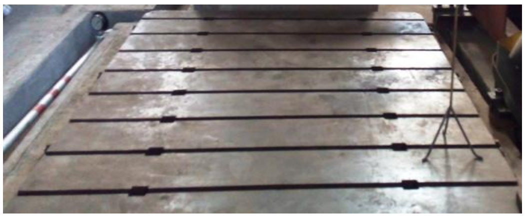

Fig. 5 : Test Bed

3.1.6 Shaft Calculation:

By drawing 2D diagram on Autocad Mechanical Software for calculating & design of length of shaft by randomly placed the entire component in the layout.
Maintains gap of 1000mm distance between motor & dyno for adjusting the belt by technician or workers.

$$T_{max} = \frac{(16x10^3)(M^2 + T^2)^{0.5}}{\pi D^3}$$

Material of shaft is EN8 – T_{max} = 340 Mpa
By Calculation of Moment= M = 5952726.22 N.mm
Similarly T = 10180000 N.mm Hence, D = 56.10mm
Take F.S. as 1.5 times greater of safety design.
D = 56.10 + 28.05 = 84.15 ≡ 90 mm (Apprx.)

3.1.7 Selection of Plummer Block:

Self-aligning ball bearings are selected as per diameter of shaft from the reference of SKF Bearings.

Table - 1: Description of Plummer Block Assembly

Sr. No.	DESCRIPTION	QTY
1.	Plummer Block Housing Size : SNA520 – 617 – MASTA	02
2.	Self Aligning Ball Bearing Size: 1220-ϕ100x180x34THK–SKF	02
3.	Adaptor Sleeve - SKF – H220	02
4.	Locking Ring - SKF –FRB18/180	04
5.	SEAL - SKF – TSN 520L	04
6.	Lock Nut M100x2 - SKF – KM20	02
7.	Locking Washer - SKF – MB20	02

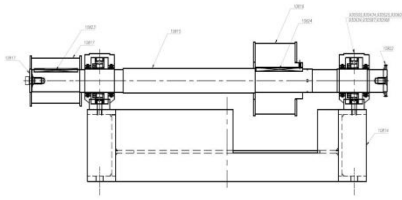

Fig. 6 : Plummer Block arrangement with pulley mounted on shaft

3.1.8 Design of T-Slotted Rail (Std.):

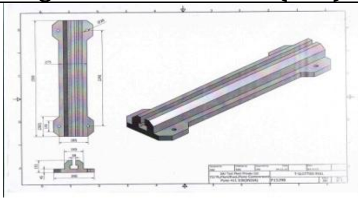

Fig - 7 : T-Slotted Rail

It gives supports to assembly of plummer blocks mounted on it as well as the motor which avoids vibrations and for a future scope it will be use to mount gearbox for high speed testing.

4. Experimental Analysis of Spin Test Rig

4.1 Cooling water - Provided for cooling the dyno as its application in Marine. It doesn't exceed 60˚C recommended. Higher temp. may affect control stability.

Table – 2: General guide for water quantity required –

Water Inlet Temp. ˚C (˚F)	Water Temp. Rise for 60˚C (140 ˚F) Outlet Temp.	Water requirement I/cvh (m^3/kw h) {gal/bhp h}
27 (80)	33 (60)	19.18 (0.0260) { 4.24 }
32 (90)	28 (50)	22.61 (0.0306) { 5.09 }
38 (100)	22 (40)	28.77 (0.0390) { 6.36 }

4.2 Electrical Supply – An AC mains supply-110 volt or 200-250 volt, 50 Hz, single phase for dynamometer & control equipment. Supply should be switched & fused at 5 Amp. Electric motor of 2.2 kW, 1435 rpm - power packed assembly, supply of 380 V, 3 Ph, 50 Hz is required.

4.3 Plummer Block Assembly – It gives support to shaft for spinning freely without a defect over which pulleys are properly fixed for making proper rotations while testing the equipment by velocity ratio which provides for testing spin test. T-Slotted Rails are used there; it also gives the scope of arrangement of adjusting it as equipment to be tested may be of complex sizes.

Fig - 8 : Plummer Block Assembly with Shaft

4.4 Equipment to be Tested:

Fig -9 : F47(SH300) Dynamometer

4.5 Vibration Meter:

Vibration meter is a contact type vibration meter. Used to check the vibrations of equipment to be tested i.e. Dynamometer in 3 directions as Horizontal, Vertical & Angular of Casing and Bed Plate.

4.6 Control Monitor Unit:

Assembled control unit is of electronic circuits and methods. Shows directly torque value as well as power at several speeds at different intervals of time and even bearing temperature at free and fixed end of the Dynamometer.

4.7 Assembly:

Fig - 10 : Assembly View of Test Rig (A)

Fig – 10: Assembly of Dynamometer on Test Rig for Testing (B)

5. Results and Discussion

Bearing temperature should not exceed 50˚C before stabilization & not exceed 60˚C during running. Vibrations should not exceed 4.6 mm/sec, even abnormal noise not occurs & casing temperature also not exceeds 60˚C during running.

It shows the all aspects clear and runs at various intervals without a fault as predicted. Not found any bearing misalign of both as fixed end and free end.

Values shows on control monitor unit while testing as-

Table – 3: Testing Results of Vibrations

RPM	Bearing Temp.		B. P. Vibrations			Casing Vibrations		
	Fixed	Free	Horizontal	Vertical	Angular	Horizontal	Vertical	Angular
1000	34	33	0.5	0.4	0.7	0.6	0.4	1.2
1500	35	34	0.4	0.5	0.4	1.0	0.4	1.2
2000	35	34	1.0	0.7	0.7	1.4	0.4	1.0
2500	36	34	0.9	1.0	1.3	1.8	0.7	1.6
3000	36	34	1.2	1.1	1.2	1.2	1.0	1.7
3500	36	34	1.8	1.9	2.1	1.9	0.6	3.6
4000	36	34	2.0	1.4	1.8	1.8	0.9	4.1
4500	36	34	1.6	1.6	2.0	1.8	1.4	2.0
5000	36	34	1.8	1.4	1.8	2.0	0.5	1.8
5500	35	34	2.0	2.2	4.6	2.4	1.8	4.0
6000	35	35	2.9	2.4	3.4	2.4	3.0	3.0
6500	36	35	2.6	3.6	3.8	3.2	3.6	3.2
7000	38	37	4.2	4.6	4.4	3.8	4.0	4.2

Vibrations should not exceed 4.6 mm/sec - standard as recommended for the F-47 Dynamometer while testing.

The current operates while testing gives values as-

Table - 4: Testing Results of Currents at RPM

Motor RPM	Rotor Current (Amp.)
620	51.5
800	60
885	65
978	78
1007	75

Values obtained while testing Dynamometer of torque & power as-

At different RPM the values are shown directly on monitor for torque and power which is being recorded for plotting the graph for Dynamometer F- 47 (SH-3300). Graphs of Torque and Power as follows-

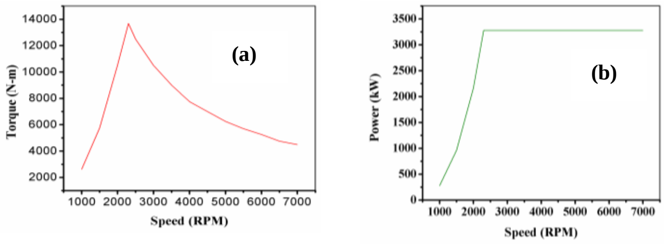

Fig – 11: Correlation between (a) speed vs torque and (b) speed vs power

6. Experimental Validation –

Includes the actual testing of Dynamometer on test rig as in all aspects which used to cover for development of test rig. From referring the literature for developing a test rig for gearbox, test rig is for testing the spins of rotating systems like Dynamometers, shaft assembly, etc.

Test rig fulfils the all need of spin test at high speed whichever needs to rotate by predicting all design aspects to development and construct without a errors. Foundation is also chemically grounded for fixing the test bed and for fixing the T-Slotted Rails. In running condition the test equipment on test rig fulfills the Experimental Validation.

Ensures that shaft rotates freely before test, all instruments are working and calibrated, conduct spin test for maximum standard/high speed. While testing the Dynamometer it starts from 1000rpm and increment it by

500 at each interval for finding & monitoring the bearing temperature of both sides as free & fixed end as well as torque & power values.

Problems predicts for failure of Dynamometer as follows-

- If coupling of shaft, rotor of Dynamometer is not Properly align then the temperature of the bearings will rise and fails the Dynamometer
- Balancing of Rotor, Shaft if not align then it fails
- Both bearings should be centrally lined if not then Dynamometer fails
- Bearing temperature exceeds 60˚C then it fails

Results and graphs of torque vs. rpm and power vs. rpm are shown in results part at which it gives at a maximum power i.e. 3280 KW while testing and also the maximum torque as 13695 Nm.

CONCLUSIONS

As we conclude that by considering the problem statement & innovative product development technique i.e. above title gives rise to failure of bearings to be tested under spin test & seen there is no failure as it can't exceeds the temperature as 60˚C. Also as from all aspects torque, power done above, vibrations not affects spin test, clearly seen the success of test rig which required at the earlier stage of design the project. Hence it is simpler, more reliable and convenient for spin test.

ACKNOWLEDMENT

It is privilege to express my deep sense of gratitude Vikrant Jagtap (Executive Director), SAJ Test Plant Pvt. Ltd. Pune whose words of expert provided me the valuable help for the same.
I also extend my appreciation towards valuable guidance from Raviraj Kumbhar, R&D, Mechanical, SAJ for showing the right way for the execution of project work.

REFERENCES

[1] Darlow M. and Smalley A., Design and Application of a Test a Rig for Super-Critical Power Transmission Shafts, Research Centre NASA, Hampton, Virginia. Report of NASA-CR-3155 19790023432

[2] Whiting Tony of Javelin Controls Ltd. – Functional design specification for spin test rig, Version 3.1, 12th April 2004

[3] Technodyne International Limited, Company No.3396849, EASTLEIGH, UK – Test facilities Project Descriptions

[4] Lomate Amruta, Mohite Suhas and Shinde Rahul – Design and Development of Torque Testing Rif for Gearbox, International Journal of Computer Communication and Information System (IJCCIS) – Vol2. No1. ISSN: 0976–1349 July – Dec 2010

[5] Mitchell Yuwono a,n, YongQin c, JingZhou a, YingGuo b, BrankoG.Celler b, StevenW.Su, Automatic bearing fault diagnosis using particle swarm clustering and Hidden Markov Model, ScienceDierct, www.elsevier.com/locate/engappai

[6] Kim Tae Ho, Andrés Luis San, Chirathadam Thomas

Abraham, Ryu Keun of Department of Mechanical Engineering, Texas A&M University, College Station, TX 77843-3123 on Measurements of Drag Torque, Lift-Off Journal Speed, and Temperature in a Metal Mesh Foil Bearing, NOVEMBER 2010, Vol. 132 / 112503-1, www.asme.org112503-1

[7] Siliang Lu, He Quingbo, Zhang Haibin, Hong Fanrang of Department of Precision Machinery and Precision Instrumentation, University of Science and Technology of China, Hefei, Anhui 230026, CHINA on Enhanced Rotating Machine Fault Diagnosis Based on Time-Delayed Feedback Stochastic Resonance, OCTOBER 2015, Vol. 137 / 051008-1, asmedigitalcollection.asme.org/ on 12/31/2015D. Kornack and P. Rakic, "Cell Proliferation without Neurogenesis in Adult Primate Neocortex," Science, vol. 294, Dec. 2001, pp. 2127-2130, doi:10.1126/science.1065467.

[8] Design Data for Machine Elements by B. D. Shivalkar.

[9] Design Data Book for by PSG.

[10]Machine Tool Design Handbook by CMTI.