DESIGN AND DEVELOPMENT OF SPIN TEST RIG FACILITY FOR F47 HYDRAULIC DYNAMOMETER

Design and Development

[1]Prajakta Y. Chavan, [2]Ganesh E. Kondhalkar
[1]PG Scholar, [2]Assistant Professor
[1]Mechanical Engineering Department,
[1]ABMSP's Anantrao Pawar College of Engineering & Research, Parvati, Pune, India

Abstract: Article suggests the main purpose to design and development of the speed spin test facility for confirmation of bearing alignment of rotating system for that we design test rig for checking spins (speeds) of rotating elements. Need of work would be is due to checking the appropriate rotations during the application used whether it gives proper rotations or not or bearing alignment or not. The rotating element by testing it on the test rig, conclude that it has proper spin tests and bearing alignment or not by giving it on highest speed rotations. Actual work include 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 not experimentally is used to build the test rig. Depends on this we should know the accounting errors occur in rotating component at which it damages by due to temperature effect on it or by improper misalign bearing and at what rpm level it should be. Then appropriate remedies are finding to minimize the damages or effects and give the proper rectification and again test the component. The features of this project is its speed as speed of motor increases by velocity ratio in two phases which finally gets appropriate speed of rotating system which is being needed.

Index Terms: **3 Phase AC Squirrel Cage Induction Motor (175KW), Hydraulic Dynamometer, Pulleys, Flat Belt (Open belt), Plummer Blocks, Shaft, Test Bed etc.**

I. INTRODUCTION

Any type of rotating machine or an engine or any fundamental system test is similar to Blood Test/ BP Check of human being that's why testing is usually needed and resulted to design a Test Rig. Validation testing associated that the product actually meets clients need. Also Validation actually which include smoke testing, functional testing regression testing, system testing Cold Engine Vs. Hot Engine Performance; Chassis Dynamometers due to these applications of high speed Test Rig is being need to design any component. The Spin Test of the rotating system should be necessary for the machine or a system where the rotating component i.e. going through under testing should be required. As the application where it uses the component say Dynamometer being used it should be tested under testing equipment for rotation checks by checking it under several speeds. Without testing the dynamometer it gets fail at application where it used.

Achieve test speed of dynamometer use of two phases over there. By the use of velocity ratio of motor speed increases to achieve it as per required at the end. Phases are divided into 2 modes such as motor-shaft and shaft-dynamometer. Transferring the speeds, use of belts in both phases over the pulleys for achieving required speed. Test Rig includes Dynamometer, water temperature controller, oil temperature controller, speed indicator, test bed, electric motor, Plummer block assembly which includes ceilings, bearings, etc. over which shaft rest under bearings. For validation paper includes Analytical Analysis and Experimental Analysis used to develop this Test Rig for specific Dynamometer.

II. LITERATURE REVIEW

This report includes Research Centre NASA, Hampton, Virginia. Report of NASA-CR-3155 19790023432 on Design and development Application of a Test a Rig for Super-Critical Power Transmission Shafts – It includes 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 torqueing 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]

Whiting Tony of Tony Whiting Javelin Controls Ltd. – 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, simplicity 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]

Techno dyne International Limited, Company No.3396849, EASTLEIGH, UK – It includes the 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]

Next 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 KNm 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]

II.1 OBJECTIVE

To eliminate the actual errors during conducting spin test is not acceptable during testing. Spin test of the rotating component/system/engine includes improper bearing alignment, temperature rise effect, noise and vibrations. To design and develop a simple and accurate, more reliable and less costly set of high spin test rig for testing. Also to ensure and maintain proper testing functionality of the prior art.

III. ACTUAL CONSTRUCTION AND WORKING OF SPIN TEST RIG

An actually construction of high speed spin test rig facility composed of component such as prime mover as motor, the rotating component is being placed in test bed for testing. In that case actual working of spin test rig and layout of test rig which needed is to achieve greater the speed of rotating element/system/any machine.

Fig. 1: Layout of Speed Spin Test Rig

IV. 1 WORKING –

Given input power through the basic component such as prime mover as from Motor, the first pulley which is mounting on the shaft of motor which is transferring the speed to next pulley at situated on shaft of motor .further on same shaft of motor the other pulley is situated at for converting the speed with relevant actual velocity ratio by further calculation given below the same speed with the pulley transfers to rotating component say dynamometer for testing. In actual case use of rotating component to be tested for F-47 hydraulic Dynamometer in that company which develops it for the another customer in CHINA for their specific application such as heavy engineering operations where they need this particular Dynamometer to operate at 7000-8000 rpm. Further this test rig which develop, testing of dynamometer for high spin testing and checking the proper bearing alignment of specific dynamometer whether they damaged by spin testing, if they damaged then gives remedies for the same.
Test the engine testing in test rig shaft assembly etc. As basic prime mover i.e. motor runs at considering safety by at 1350 rpm also by considering total power loss, changing the speed towards the pulley situated on shaft of motor under Plummer block assembly with the actual velocity ratio of 2.98 considering rpm and further on same shaft other pulley is situated for transmits the same relevant speed as above we have converts with velocity Ratio of 2 to the dynamometer pulley for achieving total final speed.

IV. ANALYTICAL CALCULATION OF SPIN TEST RIG

Achieving the actual speed of dynamometer at 7000-8000rpm, use of linear velocity ratio there in between above component seen in figure 1.

Calculations & Selections.

V. 1. Total power calculation-

Given data from design book: 1) Diameter of rotor (D) =0.470m, 2) Radius of rotor(R) =0.235m,3)Speed expected(achieve)=7700 4) Mass of rotor (M) =250kg, 5) Radius of gyration (K) = 0.1385m2.
SO Moment of inertia for rotor (I) = MK^2= 250 * (0.1385)2 = 4.8 kg.mm4.
6) Response time (T) =15Sec.
Calculating linear and angular velocity by following formula;
$V = \pi DN/60 = \pi * 0.470 * 7700/60 = 189.49 m/s$,
$\omega = V/R = 189.49/0.235 = 806.34\ rad/sec$.
Total power =Rotational energy during rotor + Linear energy
=0.5*$I\omega$2+ (Force*Velocity)
Rotational Energy=0.5*4.8* (806.34) ^2=1560442.069 watts.
So considering response time, Rotational energy=1560442.069/15= 104.029 kw.
Linear velocity=Force*Velocity=M*g*V=250*9.81*189.49=464724.225 watts.
Also considering response time, Linear energy=464724.225/15= 30.981kw

Total power=Rotational energy + Linear energy
=104.029+30.981
=135kw

IV. 2. Motor selection-

For considering other losses obtained this stage choose Crompton Greaves of 3 phase squirrel cage induction motor of 175kw Desired specification: In 3 phase squirrel cage induction motor, Crompton Greaves works on 1488rpm but for considering factor of safety, it assumed as 1350rpm for next part of calculation of another parameter related to this type of design component by considering power losses during running.

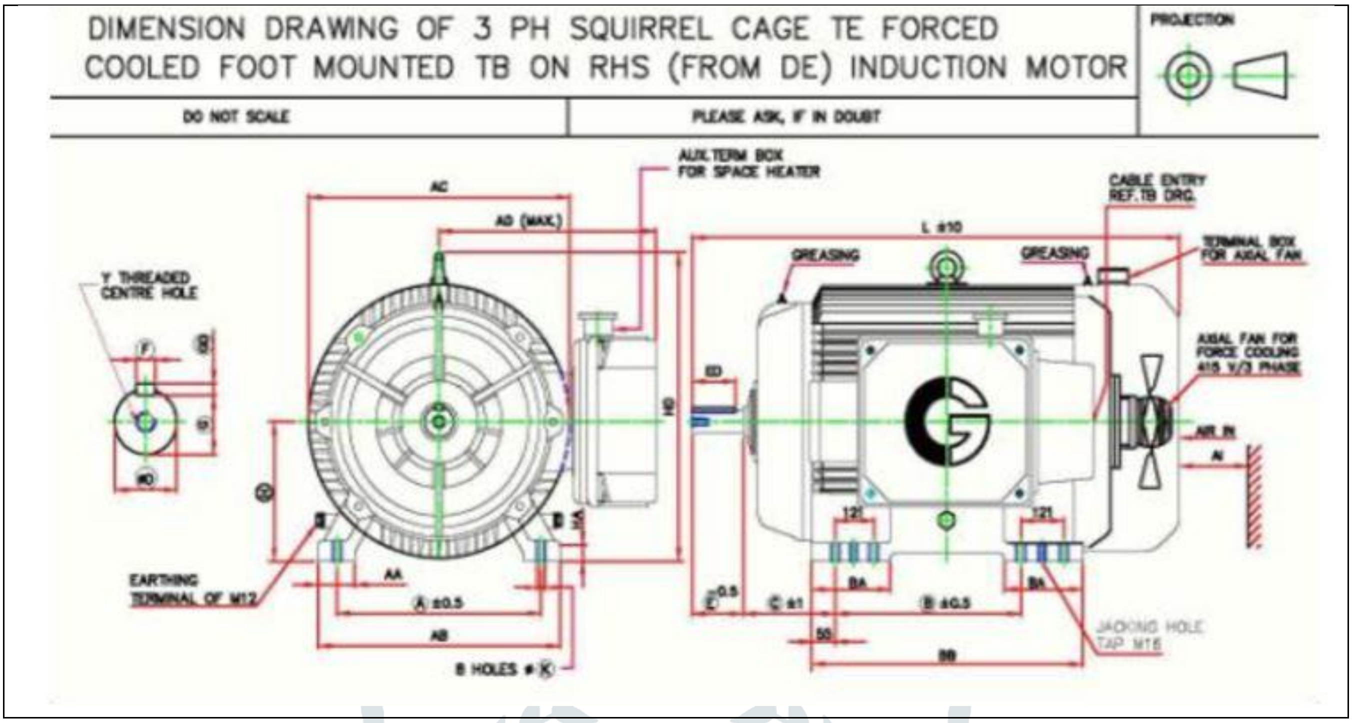


Fig. 2: 3 Phase Squirrel Induction Motor (Crompton Greaves)

IV.3. Belt calculation-

Here motor to shaft is connected by using flat belt and also shaft to dynamometer is connected by using flat belt.

IV.3.1 Phase 1: Motor to Shaft

Center distance = (C) = 3.18 * Larger pulley diameter (D1)
= 3.18 * 525 = 1669.5 ≈ 1670 mm

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

Diameter of motor (D) = 525mm; diameter of shaft (d) = 176 mm
So, Length of flat belt is (L) = 4459.36 ≈ 4460 mm.
Following formulae are taken by design data book;
So, i) Belt thickness (t) = 0.02 $* d$ = 3.52 ≈ $4mm$
ii) Belt width (b) = 1.33d = 1. .3 $*$ 176 = 234mm

IV.3.2 Phase 2: Shaft to Dynamometer

Center distance = C = 3.18*290 = 1875mm.
Diameter of dyno (D3) = 290mm; d = 146 mm
So, Length of flat belt is (L) = 4027.97 ≈ 4028 mm
So by using design data book
i) $Belt\ thickness\ t$ = 0.02 $* d$ = 2.92 ≈ $3mm$
ii) $Belt\ width\ b$ = 1.33d = 1. .33 $*$ 146 = 194mm
Now, Select for Phase 1 as flat belt is 4mm thick and 220mm width. & 3mm thick, 180mm width for Phase 2

IV.4. Pulley calculation-

Used speed ratio formula is- D1N1=D2N2
Conventional test rig dimensions are used.

IV.4.1 Step-1 Motor side (first stage):

Pulley diameter of motor = (D1) = 525mm
Pulley diameter of shaft = (D2) = 176mm
Speed of squirrel cage induction motor = N1 = 1350rpm
25 $*$ 1350 =176 $* N2$
$N2$ = 4026.98 ≅ 4000rpm (assuming)
velocity$y\ ratio$ =525/176= 2.98
Considering power loses at 4000rpm.

IV.4.2 Step -2 Dynamometer side (last stage)-

Hydraulic Dynamometer-F47 (Model to test) is taken as 146mm diameter (std.), design another pulley mounted on same shaft for transferring speed to dyno.

So using speed ratio formula for another side as, $N3D3 = N4D4$
Same speed is achieving on both side of shaft, so N2 = N3 = 4000rpm
We tested the speed of dynamometer is approximately at 8000rpm.
Using speed ratio formula, $4000 * D3 = 8000 * 146$

$$D3 = 290mm$$

$velocity\ ratio$ =290/146= 1,98 ≈ 2(approximately taken)
From this above calculation achieve dynamometer to be tested as 7700rpm.

IV.5. Shaft Calculation-
As the distance in between motor shaft and equipment to be tested i.e. Dynamometer should be at least 1000 mm for adjusting the belt by the technician or worker who works on spin testing that's why it needs above clearance value in between Dynamometer and motor shaft.

$$\tau_{\max} = \frac{\sqrt{\left(16\times10^{3}\right)\times\left(M^{2}+T^{2}\right)}}{\pi D^{3}}$$

Shaft of Material is EN24 T – Ʈmax = 340Mpa

Torque = T = $\frac{Power\times60\times10^{6}}{2\pi N}$ = $\frac{175\times60\times10^{6}}{2\pi\times1350}$ = 1237872 N.mm

Taking Factor of safety as 1.5 times greater for safety design.
Diameter of shaft = 56.10 + 28.05 = 84.15 ≡ 90 mm (approximately)

IV.6. Selection of Test Bed-
This test bed is selected as a future scope too for the testing of a big size dynamometer and a big assembled component which will to be tested in future on the same test bed that's why company decided to buy a big size i.e. mentioning above as 2000 X 2500 X 150 mm Bed which is ordered by JASH PRECISION TOOLS LTD.

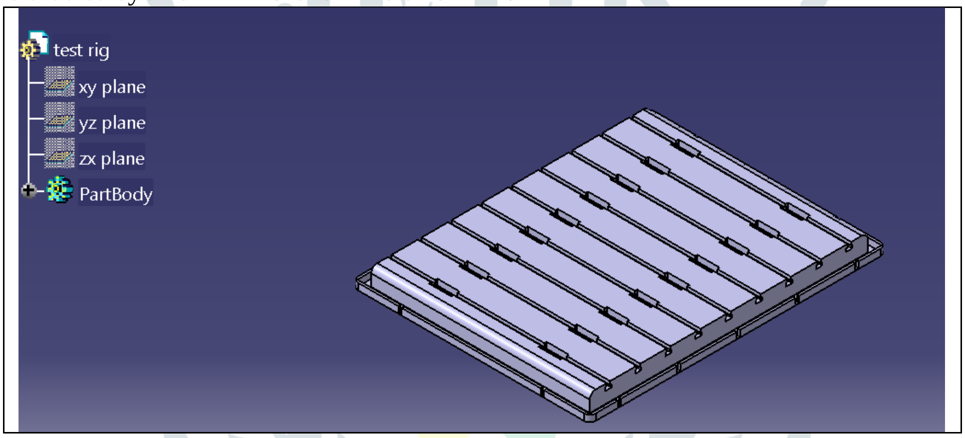


Fig. 3: Catia Model of Test Bed

IV.7. Plummer Block selection-
As per calculation and selection of shaft size there is a need of Plummer Block assembly in which shaft is situated under bearings and transfers the speeds as per needed.
Selection of Plummer blocks elements as:
Table 1: Details of Assembly Parts-

Sr. No.	Description (Components)	Qty.
1	The Housing of Plummer block at Size : SNA520 – 617 – MASTA	02
2	Self-Alignments of Ball Bearing Size: 1220 - ϕ100x180x34THK–SKF	02
3	Lock Nut M100x2 - SKF – KM20	02
4	SEAL - SKF – TSN 520L	04
5	Locking Ring - SKF – FRB18/180	04
6	Adaptor Sleeve - SKF – H220	02
7	Locking Washer - SKF – MB20	02

IV.8. Design and Selection of T-Slotted Rail-
As T-Slotted Rail is being selected to mount the Plummer Block assembly on it for providing the support to rest on assembly. As well as it also used to mount the Motor on it for adjustment purpose of motor and for future scope to achieving the high speed there is scope of gearbox, that's why T-Slotted Rails are using there as shown in assembly layout of spin test rig.

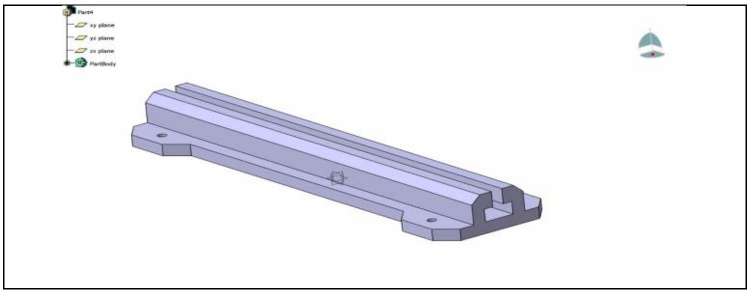


Fig.4: Catia model of T-Slotted Bar

V. ACTUAL EXPERIMENTAL ANALYSIS OF SPIN TEST ARRANGEMENT-

V.1 Plummer block assembly for test rig-

These are actual assembly of shaft, pulleys includes motor side driven and Dynamometer side driven which held in a Plummer block assembly. The Plummer block assembly with stool held on a T-Slotted Rail which used here for the resting purpose of all the assembly on it for providing the support to it. There is a scope of fine adjustment for this Plummer block assembly on Rails if and only if required but in this case no need.

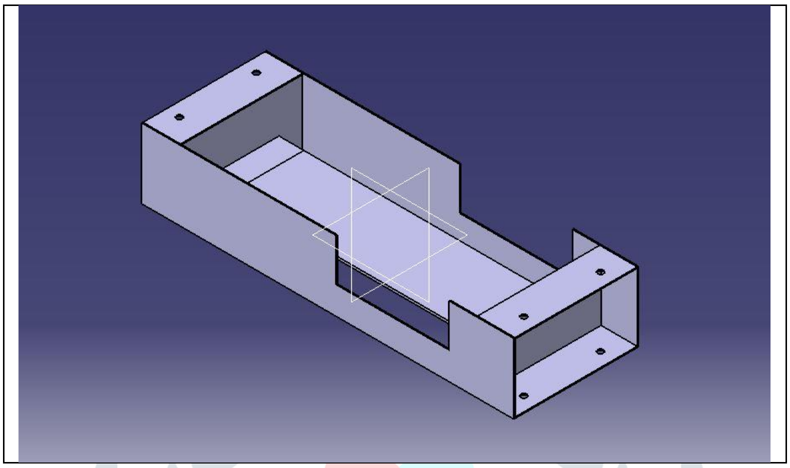


Fig. 5: Catia Model of Plummer Block

Fig 6: Arrangement of Plummer Block Assembly with Shaft and Pulleys

V.2 For Dynamometer Equipment to be tested-

The F47 Hydraulic Dynamometer (SH 3300 {9} CROP ROTOR) is being tested as the requirement of company which has the client as CHINA SHIPBUILDING INDUSTRY EQUIPMENT AND MATERIALS CO. LTD. BEIJING, CHINA. They use this configured Dynamometer F47 (SH 3300) in there Marine application as the dynamometer has in the category of hydraulic it uses at that rpm which we need to test on test rig.

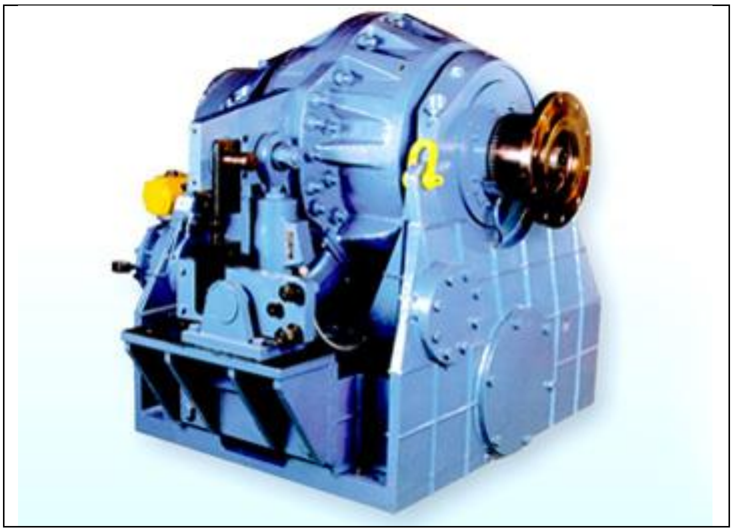


Fig 7: F47 Hydraulic Dynamometer

V.3 Control Monitor Unit-

The control monitor unit shows the actual speed which is to be provided by the prime mover and gives rise to change by the velocity ratio in between motor side and dyno side.

The toque required by the dynamometer while testing on spin test rig is shown in this unit.

V.4 Vibration meter-

For checking the vibrations presented on Dynamometer which is being tested on high Spin Test Rig for this purpose, used Vibration meter. Such type of applications in marine, the customer don't want any kind of vibration in machine due to Dynamometer.

V.5 Typical view of assembly-

Fig 6: Dynamometer assembly for spin Test Rig

VI. RESULT AND DISCUSSION-

Temperature of bearing should not be exceed 50˚C before stabilization & not exceed 60˚C during running condition. Even abnormal noise not presenting due to temperature exceed 60˚C and The casing temperature do not exceeds 60˚C during running condition, So vibration occurring should not exceed 4.6mm/sec.

The Problem statement which test of the component like Dynamometer (rotating machine) for spin test, this test finding the misalignment of bearing and also rotor shaft. Also finding the bearing temperature which not exceeds 60°C while operating at high speeds. It gives all the aspects clear and runs at various intervals of speeds without a fault as predicted. Bearing misalignment not to be found on both as fixed end and free end.

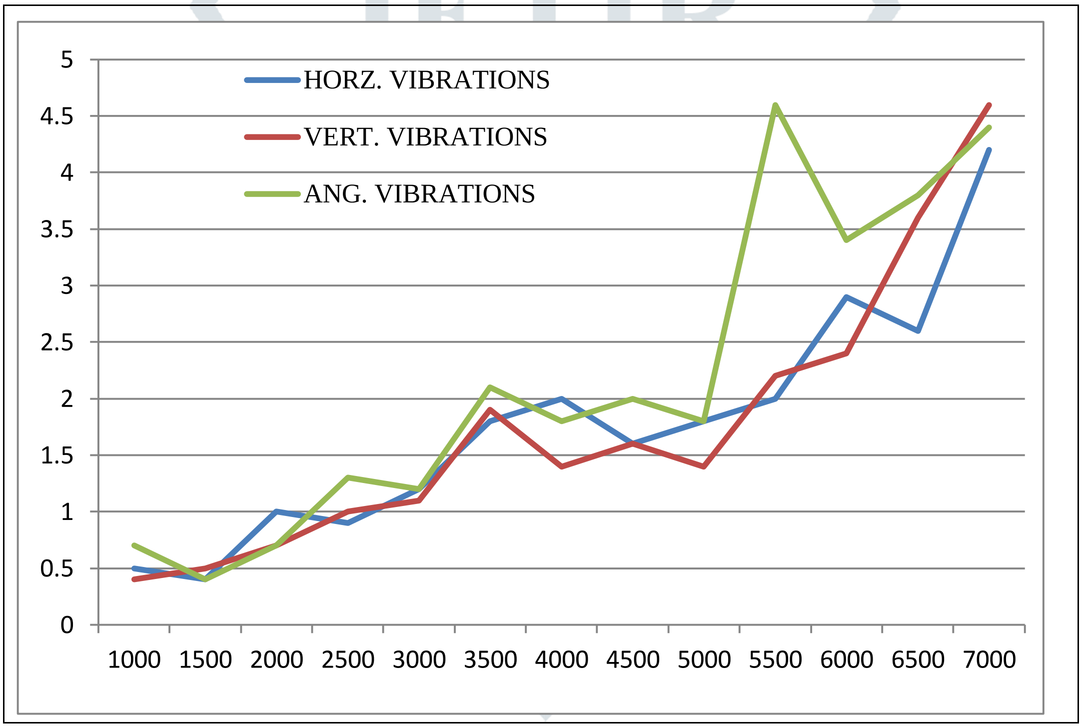
It shows temperature of bearing at both end is free and fixed is good and under safe condition which not exceeds 60°C as per standard allowance of the Dynamometer testing.

The relative values which shows on control monitor unit while dynamometer testing as-

Table 3: Vibration testing result

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



Graph 1: RPM vs. B .P. Vibrations

Graph 01 shows the RPM vs. B.P.Vibration.

The alternate current data is find during testing the Dynamometer under spin test, which gives proper values at different interval of speeds.

Table 4: Testing Results of Current at RPM

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

The values obtained while testing the Dynamometer of torque and power at several rpm are as follows in the table:

Table 4: Torque and Power at several RPM:

RPM	POWER IN KW	TORQUE (Nm) ANALYTICAL	TORQUE EXPERIMENTAL	ABSOLUTE ERROR
1000	280	2674	2698	24
1500	960	6112	6139	27
2000	2160	10313	10341	28
2300	3280	13618	13650	32
2500	3280	12529	12558	29
3000	3280	11396	11426	30
3500	3280	8949	8990	41
4000	3280	7830	7850	20
4500	3280	6960	7000	40
5000	3280	6264	6290	26
5500	3280	5695	5720	25
6000	3280	5220	5250	30
6500	3280	4819	4850	31
7000	3280	4475	4500	25
8000	3280	4013	4230	23

VII. EXPERIMENTAL ANALYSIS-

Verification includes the actual testing of Dynamometer on test rig as in all aspects which used to cover for design and development of test rig. The literature review shows for developing a test rig for gearbox and this test rig is for testing the spins test of rotating machines like Dynamometers, shaft assembly. Test rig provide the all need of spin test at highest speed which needs to rotate with predicting by all design aspects for development and construct without an any errors. Also foundation is chemically grounded for fixing the test bed which is mounted on T-Slotted Rail. At working condition the test equipment on test rig it provide the Experimental Verification here. The shaft rotates freely before test, all equipment's are working and calibrated at given condition so conduct spin test facility for maximum standard/high speed.

Important problems which obtained for failure of Hydraulic Dynamometer as follows-

1) If shaft coupling, rotor of Dynamometer is misalign then the bearing temperature will rise and fails the Dynamometer
2) Balancing of Rotor, Shaft misalign then rotor will fails.
3) Bearings should not be centrally lined then Dynamometer gets fails.
4) Bearing temperature should rise at 60˚C then it fails.

VIII. CONCLUSION-

The suitable fabrication process is finalized for the fabrication and manufacturing of Design and Development of High Speed Spin Test Rig Facility which is simpler, more reliable and convenient for spin test.

So we conclude that by seeing the problem statement & innovative product development technique there is no failure as it can't exceeds the temp. 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 this test rig is simpler, more reliable and convenient for highest spin test.

REFERENCE

[1] K. Kawasaki, Patent No. 5819141 US 4694689, Publish on Sept 22 1987 on Method and Device for Spin Testing of Turbocharger Rotor.

[2] 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

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

[4] 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

[5] 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

[6] Design Data Book for by PSG

[7] Machine Tool Design Handbook by CMTI

[8] Machine Design book by V.B.BHANDARI

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