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Design and Development of High Speed Spin Test Rig Facility for Rotating Systems

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Abstract — **Under this paper the main purpose is to design the test rig for checking spins of rotating elements. The need of work is due to checking the appropriate rotations during the actual application whether it gives proper rotations or not or it have proper bearing alignment or not. As the rotating element by testing it on this test rig we can 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 is used to build the test rig. Depends on this we should 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 finding to minimize the damages and give the proper rectification and again test the component.**

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

I. INTRODUCTION

System/machine/an engine test is similar to blood test/BP check 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 necessory. Use of Dynamometer for testing in this paper. As it tests at several speeds for several intervals, without testing it gets fail at application. May be misalignment of bearings or loose contact in between parts of attachment or temp. effect so for overcoming these faults and rectify it under testing. 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 dyno 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 dyno. Converting the speeds, use of belts in both phase over a pulleys for achieving required speed.Test Rig includes Dyno, water temp. controller, oil temp. 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.

I.1 LITERATURE REVIEW

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]

From Research Centre NASA, Hampton, Virginia. Report of NASA-CR-3155 19790023432 on Design and 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 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]

Technodyne 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, Windstream test rigs, and Fuel system test rigs for commercial and Military aircraft, Design motor and general based frames.[3]

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, 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 microturbomachinery. 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 oilfree turbomachinery. [6]

I.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.

II. 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.

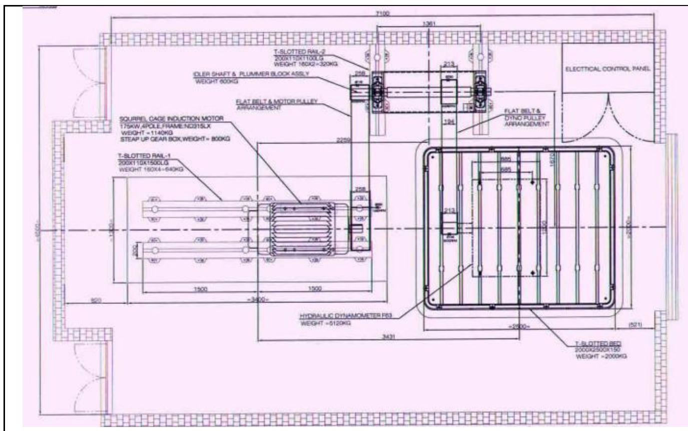


Fig. 1 : Proposed Assembled Layout of High Speed Spin Test Rig

- 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 Dyno 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.

III. THEREOTICAL (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.

- Calculations & Selections –

1. Power Calculation –

Total Power Required = Rotational Energy + Linear Energy

$$V = \frac{\pi DN}{60} = \pi * 0.470 * \frac{7700}{60} = 189.49 \frac{m}{sec}$$

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

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 * $(0.1385)^2$ = 4.8 $kg.mm^4$
Response time = 15 sec

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

Rotational Energy = $0.5*4.8*806.34^2$
= 1560442.069 watts

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

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

Total Power Required = 104.029 + 30.981= 135kw

2. Selection of Motor –

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

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.

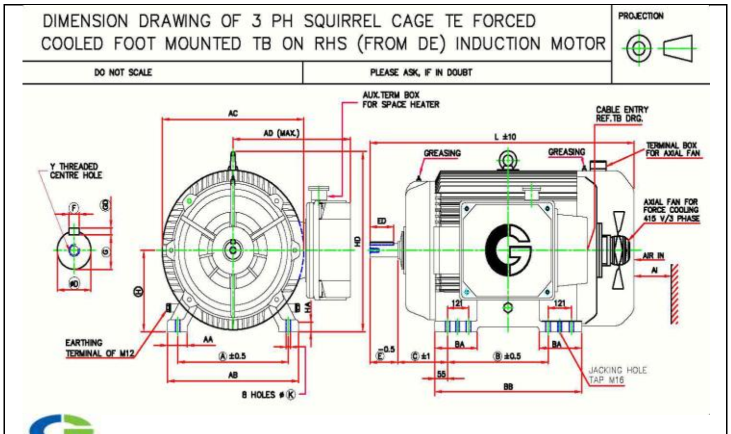


Fig. 2 : 3 Phase Squirrel cage Induction Motor

3. 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
Speed of motor = N1 = 1350
$25 * 1350 = 176 * N2$
$N2 = 4026.98 \cong 4000rpm$

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

By taking power losses take 4000 rpm.

Stage – 2 : Dyno 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
Speed of Dynamometer which tested = N4=8000 (Apprx.)

$$4000 * D3 = 8000 * 146$$

$$D3 = 290mm$$

$$velocity\ ratio = \frac{290}{146} = 1{,}98 \approx 2$$

By this above calculation, achieve dyno to be test at 7000rpm.

4. Belt Calculation –

Stage 1 – Motor to Shaft
Center distance = C = 3.18 * Larger pulley diameter
= 3.18 * 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

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

$$Belt\ width(b) = 1.33d = 1..3 * 176 = 234mm$$

Stage 2 – Shaft to Dynamometer –

Center distance = C = 1875 mm

D = 290mm; d = 146 mm

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

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

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

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

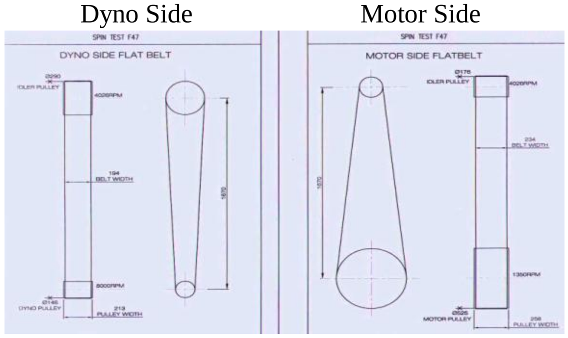


Fig. 3 : Flat Belt Arrangement

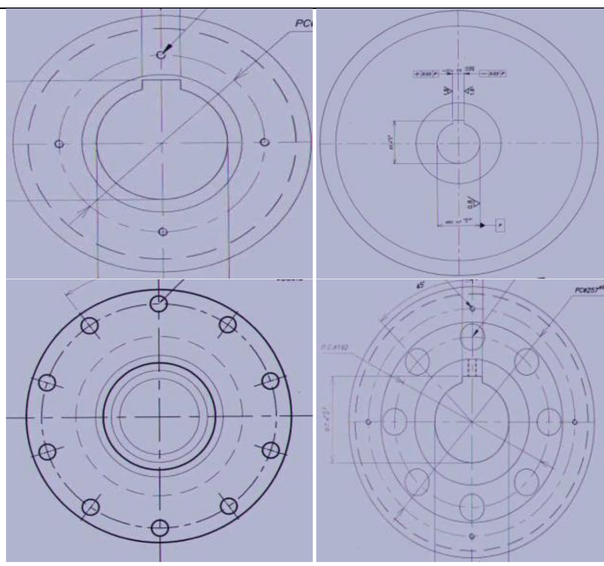


Fig. 4 : Motor side Pulleys & Dyno side Pulleys

5. Selection of Test Bed –

Test Bed Dimension – 2000 x 2500 x 150 mm

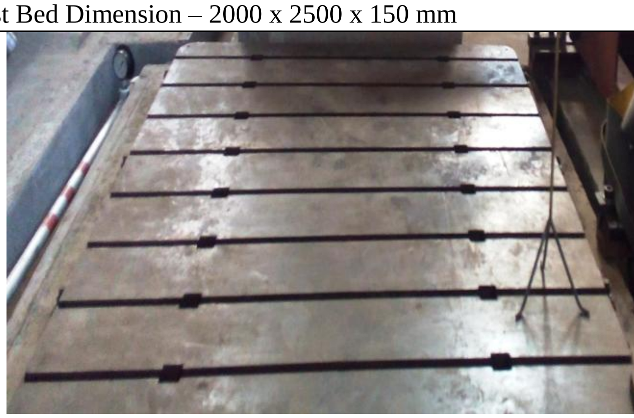


Fig. 5 : Test Bed

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.

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

Material of shaft is EN8 – τ_{max} = 340 Mpa

By Calculation of Moment= M = 5952726.22 N.mm

Similarly T = 10180000 N.mm

Hence, D = 56.10

Considering F.S as 1.5 times greater of safety design.

D = 56.10 + 28.05 = 84.15 ≡ 90 mm (Apprx.)

7. Selection of Plummer Block –

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

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

Table 1 : Description of Plummer Block Assembly

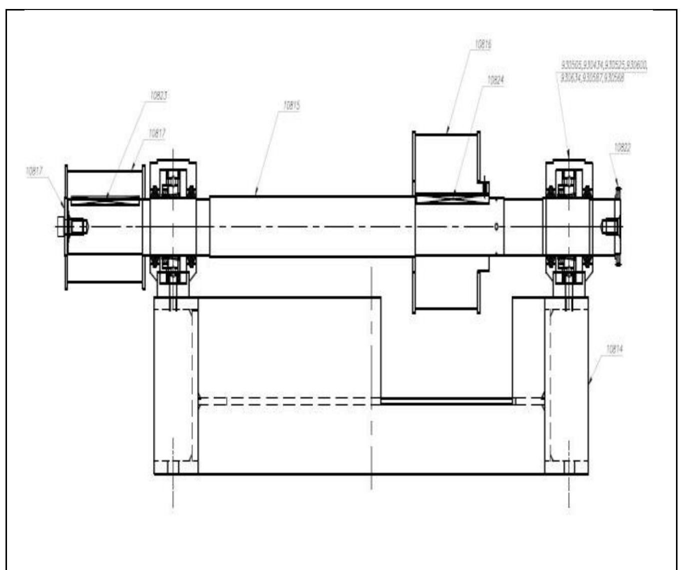


Fig. 6 : Plummer Block arrangement with pulley mounted on shaft

8. Design of T-Slotted Rail (Std.)

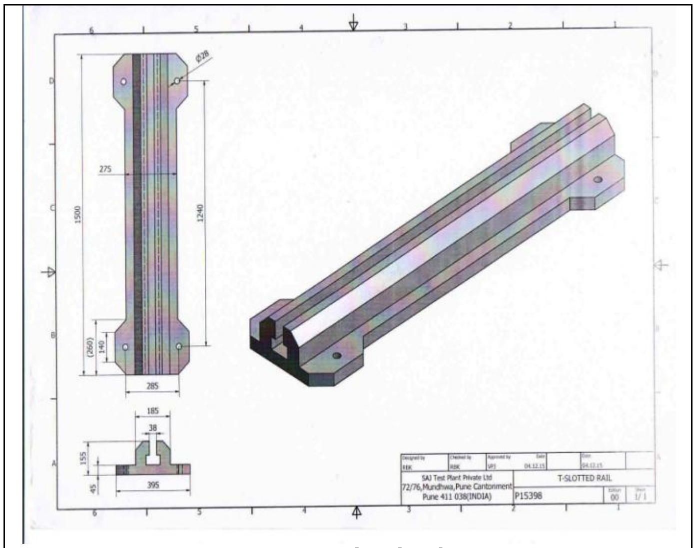


Fig. 7 – T-Slotted Rail

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.

IV. EXPERIMENTAL ANALYSIS OF SPIN TEST RIG

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 below referred as general guide for water quantity required –

Water Inlet Temp. ˚C (˚F)	Water Temp. Rise for 60˚C (140 ˚F) Outlet Temp.	Water requirement I/cv h (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 }

Table 2 – Water quantity Description along Temp.

Electrical Supply – An AC electrical mains supply of 110 volt or 200-250 volt, 50 Hz, single phase is required for the dynamometer & control equipment. The supply should be switched & fused at 5 amperes.

For an electric motor of 2.2 kW, 1435 rpm used in power packed assembly, an electric supply of 380 V, 3 Ph, 50 Hz is required.

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.

As 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

Equipment Tested -

Fig. 9 – F47(SH300) Dynamometer

Vibration Meter –

Fig. 10 – 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.

Control Monitor Unit –

Fig. 11 – Control Monitor Unit

It is an assembled control unit by using some electronic circuits and methods. For showing directly the torque value as well as power at several speeds at different intervals of time and even bearing temp. at free and fixed end of the Dynamometer.

Assembly –

Fig. 12 : Assembly View (A)

Fig. 13 : Assembly of Dynamometer on Test Rig for Testing (B)

V. 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 occur & casing temperature also not exceeds 60˚C during running.

As per problem statement which test the component i.e. Dynamometer for spin test, under this test we are finding the misalignment of rotor shaft and bearing misalignment and also the temperature of bearing which do not exceeds 60°C while operating at high speeds.

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.

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

Values which shows on control monitor unit while testing as-

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

Table 2: Testing Results of Vibrations

Vibrations are also check for the result, it checks in three directions as in horizontal, vertical as well as in angular while spin test of the Dynamometer with the help of Vibration meter which should not exceed 4.6 mm/sec which is standard as recommended for the F-47 Dynamometer while testing by the customer recommendation data.
Allowable upto 4.5 mm/sec, as it cannot cross the given value hence it is in safer side.

Some alternate current data is also finds during testing the Dynamometer under spin test, which gives the fluctuating values at different interval of speeds.

The current operates while testing gives some results as-

MOTOR RPM	ROTOR CURRENT (AMP.)
620	51.5
800	60
885	65
978	78
1007	75

Table 3: Testing Results of Currents at RPM

Values obtained while testing Dynamometer of torque & power as-

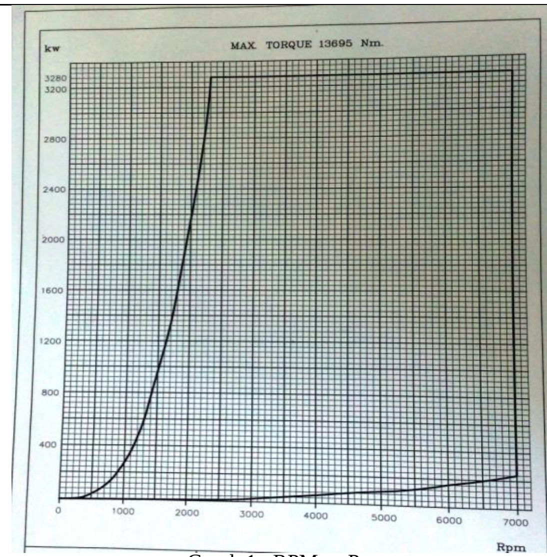
At different RPM the values are shown directly on monitor for torque and power which is being recorded for plotting the graph for Dynamometer F- 47 (SH-3300).

RPM	TORQUE	POWER
1000	2625	280
1500	5750	960
2000	10500	2160
2300	13695	3280
2500	12500	3280
3000	10500	3280
3500	9000	3280
4000	7750	3280
4500	7000	3280
5000	6250	3280
5500	5700	3280
6000	5250	3280
6500	4750	3280
7000	4500 / 250	3280 / 240

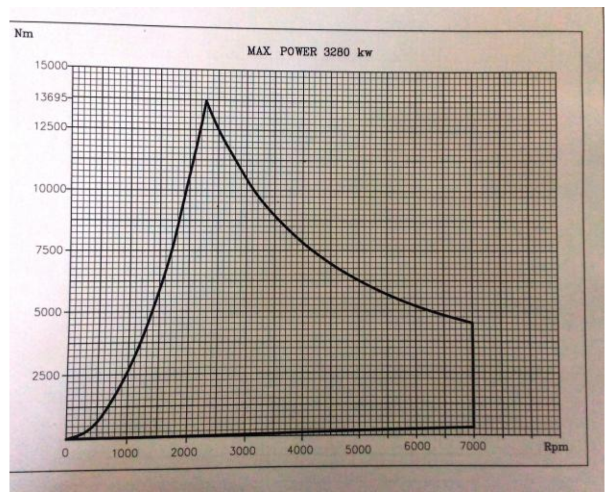
Table 4: Torque & Power at several RPM

Graphs of Torque and Power as follows-

Graphs shows the different values of torque and power which plots and find some curve which seen in below graph.



Graph 1 : RPM vs Power



Graph 2 : RPM vs Torque

VI. EXPERIMENTAL VLIDATION -

Validation includes the actual testing the Dynamometer on test rig as in all aspects which used to cover for development of test rig.

As from referring the literature for developing a test rig for gearbox, this 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 with predicting by all design aspects for development and construct without a errors.

Even foundation is also chemically grounded for fixing the test bed also for fixing the T-Slotted Rails.

While running the test equipment on test rig it fulfills the Experimental Validation here.

It 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.

Main problems which 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

The 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.

CONCLUSION

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 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 it is simpler, more reliable and convenient for spin test.

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