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Design Of Experimental Setup For Machinery Component Failure Diagnostics And Dynamic Life Prediction By Signal Acquisition

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Abstract: Machinery diagnostics is used for predicting existing defects and used to prevent catastrophic failures in mechanical systems. During operation, the mechanical parts are subjected to heavy and dynamic loads generated by machines and transmitted through the components of rolling element bearings. There are different methods for the diagnosis of these defects in the bearings viz. acoustic measurement, temperature monitoring, wear debris analysis and vibration measurement. A combination of these techniques can predict an upcoming failure with a certain level of confidence and accuracy. The main aim of our project is to design a machine that enables finding out potential defects in a machinery and be able to predict the remaining life of components.
Diagnosing wearing parts of machines and engines, improve the availability, safety and help to reduce material usage and refurbishing efforts. Primary operational parameters like pressure, flow, and material temperature can be measured and a relationship can be established for each type of component. These relationships can then be monitored for a consistency and predict the changes in machinery behaviour.
Keywords: Reliability, Predictive Maintenance, Wear and Tear, Variable loads, Vibration analysis, FFT analysis, Machinery component failures, Component life diagnostics, Condition monitoring

I. INTRODUCTION

Detecting a failure early helps the manufacturing industry to avoid heavy losses in production and maintenance of machinery. Rotating machineries are complex and have numerous components that could potentially fail. At the same time failures of stationary equipment can lead to huge safety and environmental risks. This research will be very helpful to find the working life of the various components and be able to continuously monitor any equipment that is subject to static and dynamic loads.

Bearing is heart of any rotating machinery, and has a minimum desired rated life, which depends on the loads and usage frequency of the equipment. Hence a permanent monitoring program can be designed such that the time to next failure and the mode of failure of machinery can be predicted.

Undetected failures become more expensive as those have potential to become catastrophic and may damage other parts or nearby equipment after the failure, leading to high maintenance costs. In some cases, it can also lead to safety breaches. Predicting equipment life will restraint the sudden failures and avoid further loss to human safety and environmental damages. The remaining life of the components can be estimated by analyzing the mathematical relationship between different measuring parameters and immediate actions can be taken to prevent the damages.

Predicting the problems in advance helps to keep in control the key performance indicators like equipment Mean Time To Repair (MTTR) and Mean Time Between Failures (MTBF).This design of experimental setup is also aimed to provide basis for researchers and end users to generate a database and algorithm which can identify dynamic relationship between various measurements to find the remaining life of different components.

II. LITERATURE REVIEW

Qun Chao, Junhui Zhang [1] proposed Test rigs and experimental studies of the slipper bearing in axial piston pumps: A review. In this paper, the slipper behaviour has been predicted by developing many theoretical models and numerical simulations. The validation was done between the Experimental measurements and simulation results. Also, they offer a unique opportunity to monitor the slipper behavior online and thus to identify the slipper's factors behind the pump failure. The main aim of project is to present a systematic review on the slipper test rigs used for experimental measurements. In terms of Fundamental Principles, merits and demerits, all the test rigs were presented which will give the experimental results. The future scope of the slipper test rig is also discussed.

Guo Chen, Meijiao Qu[2] proposed Modeling and analysis of fit clearance between rolling bearing outer ring and housing. The change of temperature of bearing and installation prestressing forces will lead to raise the fit clearance between housing and bearing outer ring. Now the fit clearance fault may lead to friction between bearing and bearing housing, causing strong non-linear vibrations. The rolling elelment bearing and the entire rotor system will be subjected to vibrations, leading to impact reliability as well asthe service life of bearing and rotor system. The main aim of this paper is to make the rolling bearing dynamic model with fault inclearance of bearing fit. The influence of physical factors typically during assembly are studied by time-domain numerical integration method. The defects can be like fit clearance, rotor unbalance, bearing outer ring tightening torque which can give clear response on the vibrations. Simulation results were verified by bearing fit clearance fault test gaining significance for understanding the diagnosis and to prevent bearing fit clearance fault between housing and bearing outer ring.

Alessandro Paolo Daga, Alessandro Fasana[3] proposed the Description and analysisof open access data on bearing test rig. Machinery diagnostics using non-destructive techniques such as vibration monitoring has always been of interest due to large quantity and accurate health information, that is extracted by raw data collected from sensors like accelerometers. Time data records provide enough information about Damage severity, fault, location etc. The scope was to present massive amount of data acquired on the rolling bearing test rig of DIRG - Dynamic and Identification Research Group, in Politecnico di Torino at the Department of Mechanical and Aerospace Engineering. It also intended to define conclusions and to share with scientific community. To establish a statistical approach analysis and its performances such that it is simple technique and can be fruitfully adopted. The test rig comprehends to different working conditions and can be raised to 30,000 RPM, and is flexible to incorporate differnet damage types and levels, data can be collected at different sensor positions and orientations. The test rig can be operated at prolonged durations for endurance tests. Once data was gatherd, tried-and-tested statistical tools are applied to exploit the information about bearing damages. ‘Data mining’was performed using inferential statistical techniques such as ANOVA - Analysis of Variance, applied on usual statistical features, which characterize of the signal. LDA - Linear Discriminant Analysis proposed by Fisher was also used in the configuration. Mahalanobis distance also used to perform an Outlier Analysis, so as to statistically distinguish a damage condition from the healthy state, and wherever possible compensating for environmental and operational variations like temperature, speed and load.

Jing Liu, [4] proposed statistical feature investigation of the spalling propagation assessment for a ball bearing. One of the the main reasons for fatigue failure in Ball bearing is spalling and in other words spalling is the result of fatigue. Propagation of spalling changes the vibration patterns and features, which can be fully utilized to locate and identify the damage level due to spalling in the bearing. The main aim of this project is to assess an algorithm that is dependent on FFT spectrum comparison by analysis of of amplitude using statistical calculations to identify the spalling damage location and level. The damage level is compared and determined by the sample faults in the listed test works. The spectrum (from Fast Fourier Transformation) amplitude ratio is extracted from the fault frequencies of bearing faults and spectrum amplitudes, which is then used to identify the damage location. They calculated about 25 statistical features of the time-domain signal, and used Pearson correlation coefficient (PCC) to determine the effective ones. Then the effective statistical features are used to estimate the damage level and the location. The test data given by the previous workswasalso utilized to verify the developed spalling propagation assessment algorithm. The results drawn indicated that the established method can give a new approach to identify the level of damage due to spalling in a ball bearing and closest damage location.

F.Y. Saket, M.N. Sahinkaya, P.S. Keogh[5]“Measurement and calibration of rotor/touchdown bearing contact in active magnetic bearing systems”. Transient faults, overloads, or other disturbances may occur under certain operational conditions. Prevention of contact between rotor and stator laminations is achieved by touchdown bearings or bushings. The rotor dynamics may become persistent if rotor contactsthe touchdown bearing, inturn becoming transient. Appropriate control strategies should be formulated through the magnetic bearings to restore contact-free rotor operations, which may further extend the life of touchdown bearings and minimise operational downtime.To minimise the operational downtime, an understanding of the contact dynamics is required, together with the relationship between contact and magnetic bearing forces. The main aim of this project is investigation of rotor/touchdown bearing contact conditions by using an active magnetic bearing system with a flexible rotor. They also presented a design methodology of a measurement system which is capable to provide rotor /touchdown bearing contact related data, based on strain measurement. Force and phase measurements are evaluated to verify the frequency dependent behaviour of active magnetic bearing.Strain induced contact signals are calibrated against applied magnetics bearing forces. The measurement data represent system identification for the potential of active magnetic bearing force-based contact control.

Ram Bihari Sharma [6]proposed Modelling of acoustic emission generated in rolling element bearing. Different component failures and defects like bearings, gears etc. can be detected by condition monitoring method like Acoustic Emission (AE). In this paper defects of bearing were detected by experimental studies. The presence of defect directly influences Accoustic Emissions. The main aim of experimental testing is to find out the effect of operating parameters such as load, speed, etc. on AE generated during operating condition of bearing. In this study, a theoretical model has been presented to enable understanding the energy released from Accoustic Emmissions generated from rolling element bearing due to the influences of operating parameters. Severity of defects in interfacing between the surfaces of inner race to rolling element and between outer race to rolling element in the bearing had been the basis of model development. This has been carried out by analyzing contact load distribution while in the load zone and effects of lubrication, using Hertzian contact approach and statistical concepts,. The same model has been extended for analysis of defective bearing by considering the physics Accoustic Emmission due to influence of defects on inner race, outer race and rolling element. The validation was done between the experimental studies and developed model and the results were drawn.

Yongwei Chi [7] proposed Spectral DCS-based feature extraction method for rolling element bearing pseudo-fault in rotor-bearing system. The pseudo-fault is a common phenomenon in a system, which is defined as the faulty feature of a healthy component caused by a defective component. Pseudo-fault signals, coupled with signals of both faulty component and healthy component, may lead to false diagnosis for healthy component. The challenging task is to decouple pseudo-fault feature based on the single-channel pseudo-fault signal of rotating machinery. The main issue is presented for feature extraction of the pseudofault signal of a rolling element bearing (REB) in a rotor-bearing system. A method is proposed for feature extraction of a REB pseudo-fault in a rotor-bearing system based on spectral degree of cyclostationarity (DCS). Firstly, a dynamic model of the rotor-bearing system is established to produce pseudo-fault signals, considering different deflection exponents and slippage of bearings caused by both outer race and inner race defects. The dynamic and time-frequency characteristics are then analyzed to show the amplitude modulation of pseudo-fault signals. The cyclostationary analysis is implemented for pseudo-fault extraction and verified by numerical simulation. The spectral DCS method is proposed to capture the cyclostationarity of filtered signals ordered by kurtosis, evaluated by the crest factor upon the spectral kurtosis gradient. An experimental system, under four assembly modes and three rotating speeds, is constructed based on a machinery fault simulator (MFS) to verify effectiveness of the proposed spectral DCS method. Experiment results show that quasicyclostationarity distribution with respect to kurtosis remains almost constant in the spectral kurtosis and degree of cyclostationary (SK-DCS) spectrogram and that the crest factor upon the spectral kurtosis gradient is closer to zero.

Jiewen Deng [8] proposed Does magnetic bearing variable-speed centrifugal chiller perform truly energy efficient in buildings: Field-test and simulation results. The Magnetic Bearing Centrifugal Chiller with variable-speed control (MBCC), also known as an oil-free chiller, is highly recommended as a remarkable energy-efficientsolution for space cooling in buildings by manufactures. But, MBCCs have to work co-ordinately with cooling demand of buildings as well as local climate.The energy performance of MBCCsfrom factorymust be evaluated in operation for future applications. The main aim of this paper is to examine actual performance of MBCCs in diff erent buildings and cities through whole year and comparesthe results toconventional screw chillers and centrifugal chillers. Itwas disclosed clearly that MBCCs performed much efficiently especially at part load ratio of cooling demand as well as part compression ratio demand.Based on time-series operational data log, an empirical model of MBCC was conducted which can help optimizing chiller plant design and operational strategy through annual hourly simulation of energy performance of MBCCs.

III. PROBLEM DEFINITION

Not being able to predict the life of machinery components and any upcoming failures can lead to human safety and environmental risks beyond heavy material and efforts cost.

It is vital to identify the defect, location and severity of a problem before it reaches to catastrophic level.

a) INDUSTRY NEED:

To be able to predict and avoid machinery failures, secondary damages and avoid heavy costs due loss of production.

To monitor equipment reliability, consistency and predict changes in machinery behavior.

b) TECHNOLOGY NEED:

To take benefit of latest technology to develop models using machine learning and artificial intelligence for predictive analytics.

c) ACADEMIC NEED:

To generate theoretical mathematical model for different failure modes with various measurement parameters on equipment.

To conduct various researches on heavy industry machinery enabling identification of different equipment failure modes.

IV. OBJECTIVES

The design shall enable to manufacture experimental setup machines which can be used to:

- To determine correlation between all measurable parameters and components life.
- To validate the developed characteristic equations and ensure the established relationship between various parameters affecting component life through Experimentation.
- To generate database for various modes of failure that could occur in the life of machinery.

V. SCOPE

The scope of this project is to design of the experimental setup that enable diagnostics and investigation of potential defects on industrial machinery at scale. The boundary is limited to design and clearly defined at the start of project to prepare a:

- Detailed design of individual components selected
- Design and analysis of overall system / assembly
- Define the measurement parameters and instrumentation
- Design the control panel with online and offline sensors

VI. METHODOLOGY

CRITICAL SUCCESS FACTORS of the project which is basis of this paper was to strictly follow the parts selection and design assembly procedure throughout the duration. Below tenets were defined during the project initiation and critically followed:

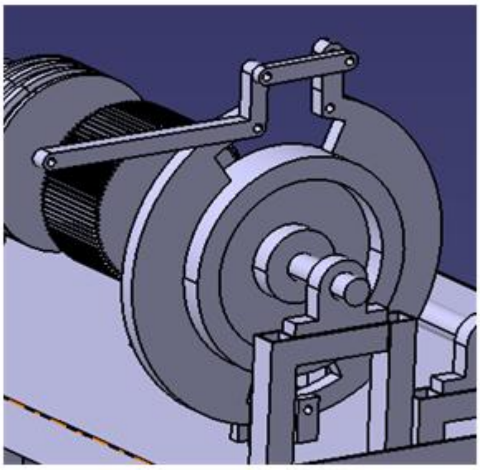
1. Select parts easily available in market as standard.
2. Design for fabrication of only those components that are not available from the market.
3. Follow standards where ever applicable.
4. Design overall assembly such that the maintenance, dismantling, and assembly is easy.
5. All the parts should be replaceable.
6. Arrange for non-destructive testing - measurement and data collection where ever possible.
7. Since some parts are designed for quicker wear and tear, those assembly should be available for procurement.
8. Overall design should be flexible and scalable.
9. Later when the entire setup is fabricated, every measurement should be traceable and recordable for in-depth analytics.
10. Visit industries and different laboratory setups for defining use cases

VII. SELECTION OF PARTS

There are multiple small and miniature components like electrical panels, power block, frame, foundation, fixtures etc, which are not mentioned in this paper, however are part of the overall design.

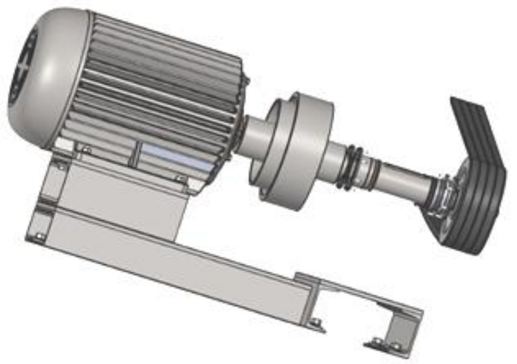
A. Dynamic load:

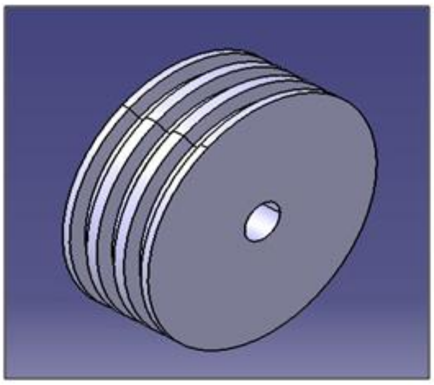
The basic intention around providing a dynamic load is to allow the users and researchers to apply a proportional load to the equipment that they want to test. Multiple assemblies were envisaged, and the simplest assembly selected as a brake drum.



Total Torque applied on shaft drum (200 mm dia) = Torque on left arm + Torque on Right arm
Total design torque = 373 Nm
With the arm length design = 200mm
A limiting lever force of 501 N can be applied i.e., approx. 50Kg of load can be applied on the breaking mechanism

B. Pulley and V-belt drive:
Pulley drive is designed such that the users can replicate a set of equipment where they have varying speed and soft loads. For example, machinery like Fans / blowers / compressors etc. The user will have option to select the drive by either v-belt where for varying speed, and timer belt as well. However, in this study we have selected the most appropriate v-Belt pulley.



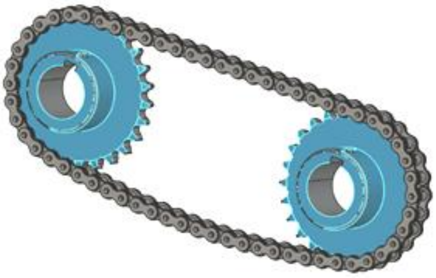


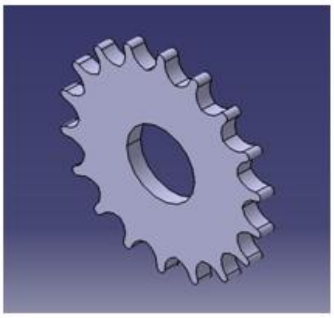
Drive pulley is 3-inch diameterwith 3 no of grooves.

Driven pulley is 6-inch diameter with 3 no of groove.

V type of belt

C. Chain and Sprocket drive:
The setup shall also have an option to replace the drive to chain and sprocket type. This will allow the researchers to study and experiment a sprocket drive mechanism. The design takes care to replace any other drive mechanism to chain and sprocket.





D. Motor:

The selection of motor was dependent on the type of loads that will be applied, and the most generic use case. There were no calculations applied during selection of motor, rather it was based on availability, ease of mounting and standard sizes.

Power, P = 1.5 HP

Speed, N = 1500 RPM.

E. Shaft Calculations:

Shaft is subject to combined bending and torsion moments, hence dimeter of shaft calculated as:

$D = (\frac{16}{\pi \tau per}((k_b\ M_b)^2 + (K_t\ M_t)^2)^{1/2})^{1/3}$

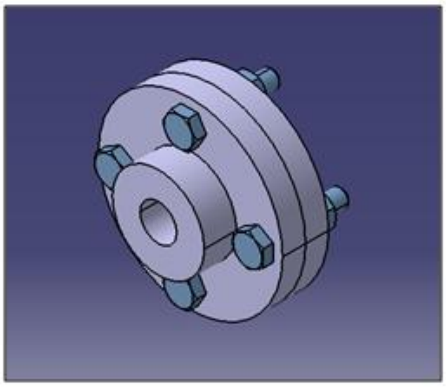
= 23.4 mm

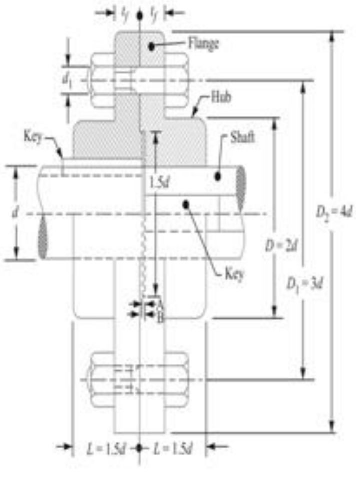
Considering standard size of bearings available, the shaft selected is of 25 mm

F. Bearing Selection:

Single row deep groove ball bearings are used in a wide variety of applications, they are simple in design, non-separable, suitable for high speeds and are robust in operation, and need little maintenance. Deep raceway grooves and the close conformity between the raceway grooves and the balls enable deep groove ball bearings to accommodate axial loads in both directions, in addition to radial loads.

Hence, we have selected Bearing no: 6005ZZ for all the support bearings.





G. Coupling design:

Shaft dia = 25 mm

Dia of hub = 50mm

Outer dia of flange = 100mm

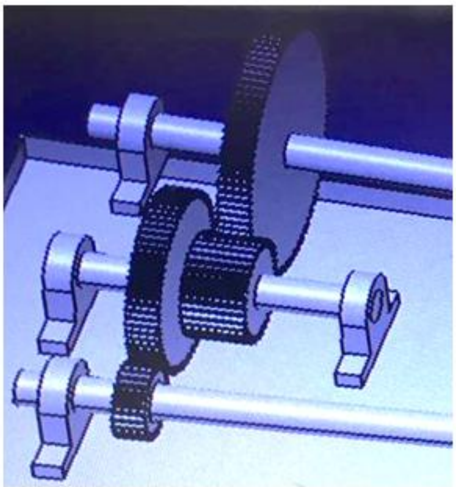
Shear stress in Flange: $T = \frac{\pi}{16} \times \tau \times d^3$

= 23.22 N/mm2

Number of bolts = 4
Key width = 6.25 mm
Key Length = 37.5 mm

H. Gear box design:

A two-stage spur gear transmission has been designed for industrial heavy load equipment testing.

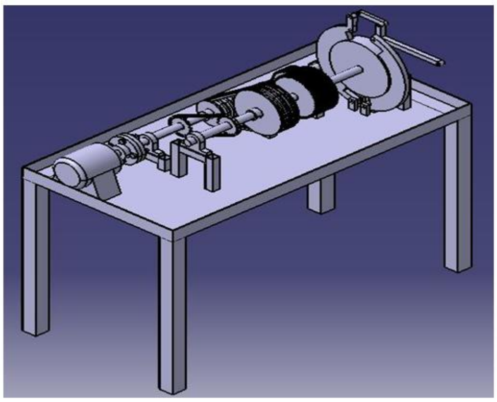


1st stage reduction:
No. of teeth of pinion is 27
No. of teeth of wheel is 76
Centre distance between two gear is 80 mm
PCD of pinion is 40
PCD of wheel is 120
Transmission ratio is 2.814

2nd stage reduction:
No of teeth of pinion is 34
No of teeth of wheel is 94
Normal module of gear is 1.5
Centre distance between two gear is 100mm
PCD of pinion is 60
PCD of wheel is 140
Transmission ratio is 2.794

I. Complete Assembly:

The assembly has been designed such that each of the transmission mechanism can be separated by the user, as and when required. This will enable the user to test the system with individual transmissions, as any practical industrial machinery would be operated.



J. Instrumentation:

Sensors are designed to be permanently mounted on individual parts and for collecting online measurements. There are measurements which need to be collected discretely using portable instruments. The below table mentions the instrumentation required to be able to collect relevant data for analysis.

S No	**Sensor**	**Type**	**Measurement Location**	**Orientation**
1	Vibration	Accelerometer	Motor drive end	H
2	Vibration	Accelerometer	Motor drive end	A
3	Vibration	Accelerometer	Motor Foot	V
4	Vibration	Accelerometer	3 No Support Plummer blocks	H
5	Vibration	Accelerometer	3 No Support Plummer blocks	V
6	Thermography	Thermal imager	Motor, dynamic load, Pulleys	
7	VFD	Speed control	Motor	
8	Proximity probes	Transient data and ODS	2 no shafts	X, Y
9	Temperature	RTD	4 nos, motor, plummer block	X
10	Current Spectrum	Current probe	Motor input cables	
11	Noise	Microphone	1 on bearing	
12	Data recorder	Computer	1 No	

K. Software:

The machine shall be in operation for many continuous hours, and data will have to be collected continuously for entire duration. This data shall be collected in the form of time series and then converted into FFT (Fast Fourier Transformation) spectrums for detailed analysis.

Although the machine is being designed agnostic to the software, it is recommended to utilize Labview software by National Instruments, because of the flexibility it provides.

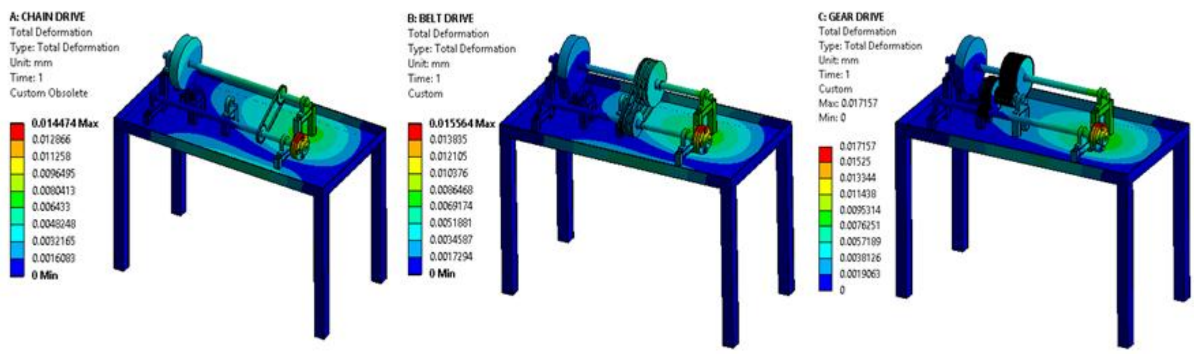
In many use cases the setup shall be operated continuously until some of the components fail. The software shall be able to capture transient data as well as discrete data for complete in-depth analytical study.

VIII. ANALYSIS

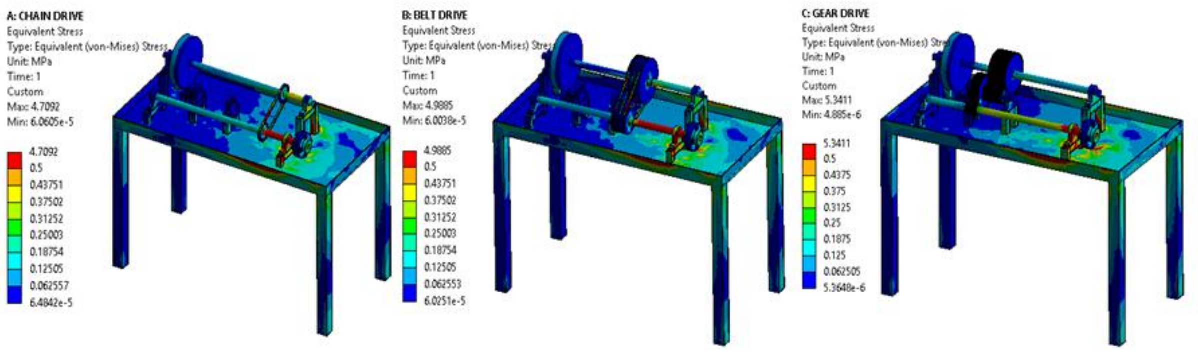
For each mode of transmission, a meshing is created in ANSYS application:

Transmission	Chain Drive	V-Belt drive	Gear Drive
Nodes	48723	66967	109725
Elements	21873	30616	32205

A. Total deformation computed out for each of the transmission modes:



B. Equivalent Stress computed out for each of the transmission modes:



IX. CONCLUSION

The equivalent stress obtained after the analysis for different transmission systems is within the yield strength, so the design is safe. The experimental setup design can be used to fabricate a machine with flexible configuration.

Data from online measurements and offline measurements can be collected and analyzed for failure. Following research possibilities are envisaged from the setup by experimentation:

1. Analyze and detect failures for each failure type by acquiring FFT.
2. Create a failure pattern for each physical failure. This shall enable to create a predictive model for isolated failure mode.
3. Empirical modeling by establishing correlation between different parameters for each failure.
4. Create database of various failures that can occur on a specific type of machine configuration.
5. Prove by experimentation that each failure mode has a specific pattern and prove the P-F curve supplied by manufacturers.
6. Analyze effects of an induced failure mode.
7. Recommend corrective actions that can resolve the identified defects, thereby increasing the overall life of the components.
8. Create a database of various failure modes on equipment with different drive configurations.
9. Establish life cycle of components under stress to impact the remaining operational life of equipment.
10. Identify changes happening in machinery and understand the root causes for driving corrective actions.

Future enhancement possibilities:

a. The system with designed instrumentation is a step towards latest technology for IIOT – industrial internet of things.

b. The setup can further be used for driving predictive maintenance programs within any heavy manufacturing industry.

c. Predictive models can very easily be built by using AI (Artificial Intelligence) and the models can then be trained by using ML (Machine Learning)

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REFERENCES

[1]. Qun Chao, Junhui Zhang, Bing Xu, Qiannan Wang, Hsinpu Huang et al., "Test rigs and experimental studies of the slipper bearing in axial piston pumps: A review" Measurement 132 (2019) 135–149

[2]. Guo Chen, Meijiao Qu et al., College of Civil Aviation, Nanjing University of Aeronautics and Astronautics, Nanjing, PR China, "Modeling and analysis of fit clearance between rolling bearing outer ring and housing" Journal of Sound and Vibration 438 (2019) 419e440

[3]. Alessandro Paolo Daga, Alessandro Fasana, Stefano Marchesiello, Luigi Garibaldi, Politecnico di Torino, Dipartimento di Ingegneria Meccanica e Aerospaziale – DIMEAS, Corso Duca degli Abruzzi, 24, I-10129 Torino, Italy, "The Politecnico di Torino rolling bearing test rig: Description and analysis of open access data" Mechanical Systems and Signal Processing 120 (2019) 252–273

[4]. Jing Liu, State Key Laboratory of Mechanical Transmission, Chongqing University, Chongqing 40 0 044, P.R. China; College of Mechanical Engineering, Chongqing University, Chongqing 40 0 044, P.R. China;

[5]. Zidan Xu, Li Zhou, Yimin Shao,State Key Laboratory of Mechanical Transmission, Chongqing University, Chongqing 40 0 044, P.R. China;

[6]. Yuwen Nian, Department of Mechanical and Materials Engineering, Queen's University, Kingston ON K7L 3N6, Canada;

[7]. "A statistical feature investigation of the spalling propagation assessment for a ball bearing" Mechanism and Machine Theory 131 (2019) 336–350

[8]. F.Y. Saket, M.N. Sahinkaya, P.S. Keogh, Department of Mechanical Engineering, University of Bath, Bath BA2 7AY, UK; "Measurement and calibration of rotor/touchdown bearing contact in active magnetic bearing systems", Mechanical Systems and Signal Processing 122 (2019) 1–18

[9]. Ram Bihari Sharma, Anand Parey, Mechanical Engineering Department, School of Engineering, Indian Institute of Technology Indore, Indore, India; "Modelling of acoustic emission generated in rolling element bearing" Applied Acoustics 144, (2019) 96-112

[10]. Yongwei Chi, Shixi Yang, Xiwen Gu,Jun He, The State Key Laboratory of Fluid Power and Mechatronic Systems, College of Mechanical Engineering, Zhejiang University, Hangzhou 310027, China; The Key Laboratory of Advanced Manufacturing Technology of Zhejiang Province, College of Mechanical Engineering, Zhejiang University, Hangzhou 310027, China

[11]. Weidong Jiao, Department of Electromechanical Engineering, College of Engineering, Zhejiang Normal University, Jinhua 321004, China

[12]. Evangelos Papatheou, College of Engineering Mathematics and Physical Sciences, University of Exeter, Exeter EX4 4QF, UK

[13]. "Spectral DCS - based feature extraction method for rolling element bearing pseudo-fault in a rotor-bearing system", Measurement (2018), doi: https://doi.org/10.1016/j.measurement.2018.09.006

[14]. Jiewen Deng, Qingpeng Wei, Yangyang Qian, Hui Zhang, Department of Building Science, Tsinghua University, Beijing 100084, PR China; "Does magnetic bearing variable-speed centrifugal chiller perform trulyenergy efficient in buildings: Field-test and simulation results", Applied Energy (2018), doi: https://doi.org/10.1016/j.apenergy.2018.08.062

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