Optimization of Needle Roller Bearing System by using Finite Element Analysis

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Abstract—**Most of the previous accidents of mechanical systems are majorly caused by bearing failure. Needle roller bearing is one of critical rotation components in mechanical systems. So it's significant meaningful for practical application to research failure feature detection and residual life prediction of key rotation components such as needle roller bearings. This paper is designed to analyze optimum life and strength of the vehicle differential lock system components (needle roller bearing and differential locking piston) and their effects. It is done by changing dimensions and analyzing the life of needle roller bearing and strength of differential lock piston. To achieve it analytical as well as experimental methodology is a good approach for several types of objective, which are minimized or maximized simultaneously. The optimization goal is to increase the life of needle roller bearing and the strength of differential lock piston. Performance parameters of needle roller bearing are analyzed with width and differential lock piston is analyzed with depth. The system is useful to eliminate failures of differential lock system components**

Keywords — Optimum Life, Differential locking system, Needle roller Bearing, Differential lock piston, HALT, Romax.

I. Introduction

Reliability of needle roller bearing is most crucial parameter in bearing life optimization. Reliability depends on various parameters like misalignment, vibration of the system, load carrying capacity of the bearing, space constraint, applied load on the bearing, application of the bearing, material property of the relevant component, etc. To do an optimization for reliability of bearing, the geometric or space constraint is playing vital role in a limited space. To optimize the bearing within limited space constraint and to enhance its life is key parameter.

The design of rolling bearings has to satisfy various constraints, e.g. the geometrical, kinematics and the strength, while delivering excellent performance, long life and high reliability. This invokes the need of an optimal design methodology to achieve an objective of optimization collectively. Rolling bearings are widely used as an important component in the most of the mechanical and aero-space engineering applications. It would be development of the house-hold appliance, automotive, aero-space, aeronautical, micro or nano-machine applications. All of them have given a boost to the advancement in the design technology of rolling bearings.

It is necessary to avoid the failure of rolling element of bearing or machine component due to availability of space limit. The optimization of given system have to do in limited space constraint. By doing the modification in the existing components like differential lock piston and needle roller bearing; there would be chances of failure of the components in the differential lock system. It would be possible to analyze the changes by analysis or experimental.

The differential lock system of off high-way vehicle failure issues due to failure of the thrust needle roller bearing, the failure of bearings are occurred in various ways like rollers coming out of cage, pitting of rollers, cage breakage of bearing, etc. The abrasive wear of the relative components are also occurred due to failure of needle roller bearing.

A off high-way vehicle is generally a heavy vehicle used in agricultural, forest or tree harvesting application. The off high-way vehicle is having differential lock system which plays vital role in these kinds of applications by distributing equal amount of power to each wheel.

Many of the expertise suggested modifications in bearing inner diameter, outer diameter and width variation, change in differential lock piston, spacer width variation, etc. to overcome the differential lock system failure.

As space is constraint to make the modifications in the system so by doing the modifications in dimensions of needle roller bearing may effect on differential lock piston dimensions and failure of piston may takes place and vice versa. By reducing the width of spacer there are chances to failure of spacer because of less cross sectional area over the application of load on it.

II. Related Work

A. Problem Definition

The case study has been prepared from field survey report where failures of off high-way vehicle due to thrust needle roller bearing of differential lock system. Various models of the vehicles failed before meeting the desired life. This data has been collected from various dealers from different countries. Out of that one of the off high-way vehicle machine model has taken for study purpose on which research work can be carried to resolve the failure of differential lock system before meeting desired life.

The application of off high-way vehicle is for heavy load so locking of differential system is more common in such a vehicle. Because of heavy load application the failure in the differential lock system aroused. The failure in needle roller bearing in various ways like breakage of cage, pitting failure, rollers coming out of cage, abrasive wear of relative components of system e.g. differential lock piston, spacers, etc. The current work is focused on failure of bearing and optimization of bearing dimensions in order to cope up with failure problem of bearing.

B. Working of System

The output of gearbox is connected to spiral bevel via propeller shaft and then spiral bevel to differential lock system. Generally differential lock system is used in off-highway vehicle like tractor, loader, backhoe loader, motor grader, etc. where loose or wet soil application is present in the field. In such a soil there are more chances of the wheel slippage due to less traction effect between tyre of wheel and soil hence relative power and speed of one wheel goes to another or no motion of vehicle in such a condition.

To avoid this effect designer placed differential lock system means locking of differential bevel gears. Once differential is locked then there is no relative speed between the differential bevel gears hence equal amount of power and speed is distributed to both the wheels though slippage of wheel may present.

The differential lock system is actuated by pressurized hydraulic oil which is applied on differential lock piston. As differential lock piston is fixed in directional rotation and it performs reciprocating motion during locking and unlocking of the differential lock system. There is relative motion of rotating thrust needle roller bearing with respect to differential lock piston and spacer which are present with actuator. Actuator consists of clutching arrangement with retraction springs and gets actuated with the application of pressurized hydraulic oil. Clutch plate arrangement locks the differential bevel gears hence the entire differential lock system is locked so there is equivalent distribution of power to each axle shaft. The system is unlocked by releasing pressurized oil supply and retraction springs retracts the clutch plates back to their position.

Many research works have been done in the field of optimization of bearing and its system analysis. The literature review of some papers giving more information about their contribution in various ways for optimization of rolling element bearing has been carried out and explained as below,.

Hongbiao Han, Jianzheng Li, Hongbin Liu [1] have presented FEA analysis of the shield machine main bearing under radial force. They worked on ANSYS software, one half of bearing and a single roll is respectively established under the action of the radial force. The contact stress distribution of a bearing and the position of the maximum load roller are confirmed by analysis of the half bearing model. Based on the finite element analysis of a single roller, the contact stress of a single roller is calculated. A single roller analysis results are close to the solution of hertz theory. This research makes the first step for optimum study on loading the moment and combined load.

Xiao Lin-jing, Sun Chuan-yu, Li Peng [2] have proposed bearing capacity of radial magnetic bearing (RMB) is determined through analyzing the radial loads of wind power generator, and upon this, the structure of radial magnetic bearing is designed. Then the electromagnetic characteristics of radial magnetic bearing are simulated by using finite element method (FEM), the phenomenon of electromagnetic coupling and magnetic flux leakage is analyzed, and the comparison between ANSYS solution and analytical solution is done. They concluded that by using the FEM analysis, the electromagnetic properties of RMB are simulated, and the phenomenon of electromagnetic coupling and magnetic flux leakage is analyzed.

Hamit Saruhan [3] has described a method based on an optimum design of rotor-bearing system stability performance comparing an evolutionary algorithm versus a conventional method. The intent of this paper is to formulate, demonstrate and validate a practical means of implementing an evolutionary optimization technique in a rotor-bearing system. The optimum design of a flexible rotor supported on three-lobe bearings is studied for the optimal performance considering system stability along with other design criteria such as fluid film thickness, power loss, film temperature, and film pressure using the genetic algorithm and the method of feasible directions. He did finite element model configuration of the rotor-bearing system.

Faruk Mendi, Tamer Baskal, Kurtulus Boran, Fatih Emre Boran [4] have presented an optimization of module, shaft diameter and rolling bearing for spur gear through genetic algorithm. They varied the parameters like module, number of teeth, shaft diameter, shafts length, bearing shaft diameter, bearing external diameter. Analytical method is used to facilitate the evaluation of genetic algorithm; a program was being developed on Borland Delphi 6.0 platform. They come to the solution that GA (Genetic Algorithm) is more efficient approach for the optimization of complex systems such as the gearbox made up of various elements.

Shantanu Gupta, Rajiv Tiwari, Shivashankar B. Nair [5] have done the work to satisfy various constraints, e.g. the geometrical, kinematics and the strength, while delivering excellent performance, long life and high reliability, three primary objectives for a rolling bearing, namely, the dynamic capacity (Cd), the static capacity (Cs) and the elasto-hydrodynamic minimum film thickness (Hmin) have been optimized separately, pair-wise and simultaneously using an advanced multi-objective optimization algorithm: NSGA II (non-dominated sorting based genetic algorithm).

The earlier research done by many of the researchers and showed considerable attention towards optimization of rolling element bearing to enhance life by optimizing the parameters like bearing diameter, max applied force, shaft length, etc. The analysis of the optimization of rolling element bearing is done by using various techniques like genetic algorithm, non-dominated sorting based genetic algorithm, FEA Software etc. They also developed experimental set up to optimize various parameters.

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Many of researchers considered load carried by bearing as radial load only, but it is necessary to consider axial load in case axial trust bearings. For this purpose it is necessary to design system which is having axial thrust load application and space constraint is a major parameter for limited space. It is necessary to improve the life of bearing by changing parameters like width of needle roller bearing in a limited space with respect to depth in differential lock piston in a differential lock bearing system.

III. Methodology

A. Analytical Study

1. Modeling of Components

The modelling of both the needle roller bearing and differential lock piston has done in the Pro/ENGINEER software. Pro-E is modelling software offers a range of tools to enable the generation of a complete digital representation of the product being designed. In addition to the general geometry tools there is also the ability to generate geometry of other integrated design disciplines such as industrial and standard pipe work, complete wiring definitions, castings, forgings, etc. Tools are also available to support collaborative development. It is used to optimize manufacturing, tooling and factory equipment design process. It simplifies and automates the transformation of engineering designs into manufacturing processes with the easy to use, powerful process manager for tool path definition, annotation features and other key capabilities in Pro/ENGINEER. It enhances the verification and validation process and also analyzes designs faster and easier with new tolerance analysis, improved meshing, support for nonlinear materials, better results analyses and smarter diagnostics

The modelling of both the components has been carried for every 0.5mm from 12 mm to 15 mm. The width of needle roller bearing and depth in differential lock piston has been increased step by step. The modelling of needle roller bearing and differential lock piston has shown in below fig 3.1 and 3.2,

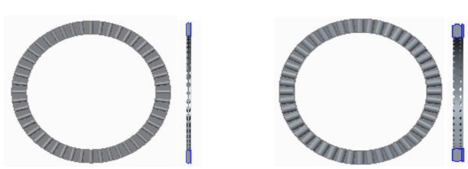

Fig. 3.1 NRB (Needle Roller Bearing)

(Width = 12 mm) (Width = 15 mm)

Fig. 3.2 Differential Lock Piston

(Depth = 10 mm) (Depth = 12.5 mm)

2. Finite Element Analysis

i. By Ansys Software

The finite element analysis of differential lock piston has done in Ansys software. ANSYS is general purpose software, used to simulate interactions of all disciplines of physics, structural, vibration, fluid dynamics, heat transfer, etc.

Ansys calculates the deformation or deflection, various types of stresses like max principal stress for steel material, various types of strains like max principal strain for grey cast iron, max shear stress, Von - Mises stress, strain energy, et.al.

Initially the modelling of differential lock piston is done in the Pro-E software and step file created which is used in Ansys software to do the various kinds of analysis for various materials.

Strain Analysis

The limit of max principal strain value for ductile and gray cast iron is 1500 μstrain and 800 μstrain for fatigue event and 3800 μstrain and 1500 μstrain for discrete event respectively.

As the material of differential lock piston is gray cast iron hence the limiting strain value is 800 μstrain for fatigue event and 1500 μstrain for discrete event respectively.

The contact between mating surfaces have given either frictional or bonded as per the relation between the mating parts. The meshing element is used in the analysis is patch confirming tetrahedron with body sized. The all over mesh size used for differential lock piston is 8 mm and at critical region the mesh size is 3 mm. The fixed support is provided at one end of assembly and pressure of 300 psi (2.0684 MPa) is applied on the differential lock piston and strain value result is shown in fig. 3.3 and 3.4.

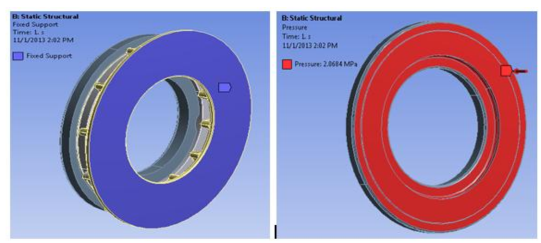

Fig. 3.3 Fixed Support and application of Pressure

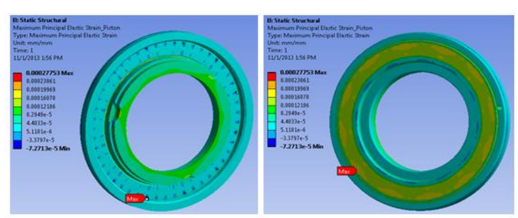

Fig. 3.4 Strain Value Results of differential lock piston

The analysis is carried out by varying the depth in differential lock piston from 10 mm to 12.5 mm. The fatigue event strain value is to be considered below 800 μstrain with desirable factor of safety.

ii. By Romax Software

The word Romax is self-explanatory "ROtating MAchinery eXperts" purely based on mathematical equations and modelling. This software founded in 1989 by Dr. S. Y. Poon, Romax has provided solutions to the world's leading companies in the transport and energy industries. It has offered technical consultancy, design services and software for gearboxes, drive trains and bearing analysis. The software suite, which includes Romax Designer, Romax Dynamics and Romax NVH, is a single environment which covers all major requirements for the modelling, simulation and analysis of geared and non-geared systems.

Bearing Life Analysis

Initially the modelling of entire system has done in the Romax software similar as that of real components, for that respective length and diameter is specified. The modelling is done for spiral bevel sets, differential bevel gears, taper roller bearings, differential housing, needle roller bearing, supporting components, etc. Then the connection nothing but doing an assembly between each component has given with respect to global or gearbox co-ordinate system. After giving proper connection between the components the differential lock system layout replicates the existing system. The stiffness of the system is enhanced by adding stiffened main housing in to the software. For doing stiffened housing the step file is created through Pro-E software and imported in Ansys software to do its meshing and bonded connection between the components. The Ansys data is stored in .cdb file and imported in Romax software to enhance the stiffness. Following figures give more information about the work.

The snaps of the Romax Analysis modelling are shown in below fig. 3.5 and 3.6 having section of differential arrangement and differential lock layout into housing contains differential arrangements and related parts as mentioned in previous section.

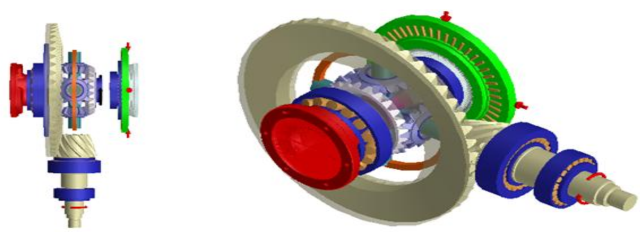

Fig. 3.5 Differential Arrangements

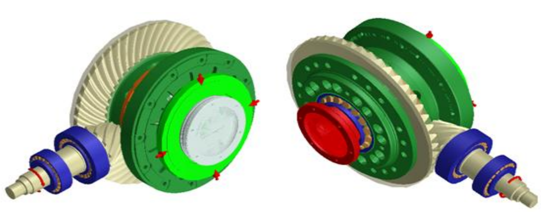

Fig. 3.6 Differential lock layout

The proper duty cycle is applied for the differential lock system and the axial load of 300 psi is applied on the differential lock piston shown in fig. 3.5 so that piston will have reciprocating motion to lock the differential lock system.

Then the bearing analysis is done to get the life of different bearings used in the system. But the more concentration is given to needle roller bearing and its life. Then the bearing analysis is carried out by varying width of needle roller bearing is shown below,

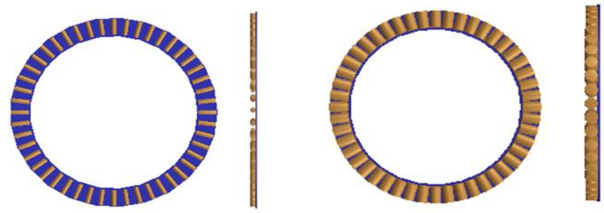

Fig. 3.7 Needle Roller Bearing

(Width variation from 12 mm to 15 mm)

The desirable life for the needle roller bearing is to be considered 15000 hrs as a design perspective. To meet the goal of life the variation in the width of needle roller bearing is made step by step. After doing an analysis for bearing life optimum needle roller bearing width is taken in to account to do experimental study.

B. Proposed Experimental Study

The system consists of motor, main housing called as mid differential housing in which sub-assemblies of spiral bevel set, quill assembly and differential lock system are present. In differential lock system the differential bevel gears, thrust needle roller bearing, pistons, spacers, actuator with clutch arrangement are present, which is shown in fig.3.8

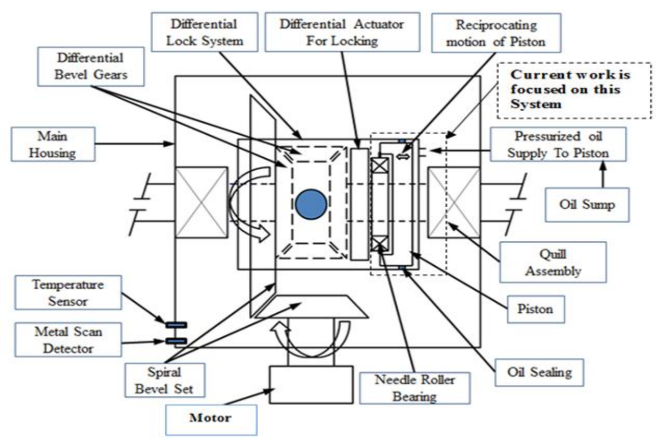

Fig 3.8 Proposed Experimental set-up

The output power of motor is connected to spiral bevel set and then spiral bevel set to differential lock system. An optimum changes will be made in the needle roller bearing and differential lock piston are considered for testing. The experimental study test will be carried under controlled atmospheric condition in testing laboratory. Both the modified needle roller bearing and differential lock piston will accommodate in the existing system to carry the testing on it and to perform more efficiently and reliable.

The readings will be obtained in the form of L10 life in hours and million cycles for needle roller bearing and differential lock piston respectively. One reciprocating motion of differential lock piston is nothing but a single cycle. The million cycles can be converted in to the strain values. The life of needle roller bearing will be calculated by using highly accelerated load test (HALT) of 600 hrs which is equivalent to 15000 hrs of duty cycle life. This test will be carried under heavy loads which may mostly leads to failure of components. If component sustains during HALT test will be considered that it can sustain in field application up to 15000 hrs of life. Suitable factor will be considered to convert HALT life in to field duty cycle life.

IV. RESULTS AND DISCUSSION

After doing an analytical study of both needle roller bearing and differential lock piston with the variation of only width and depth respectively an obtained result are mentioned in following table,

TABLE I. RESULT CHART

Sr. No.	Bearing Specification (mm)					Depth in Piston dp	L10 Life (Hrs)	Strain Value (µs)
	ID	OD	Roller Dia	Spacer Width	Total width			
1	190	236	10.0	2.0	12.0	10.0	60647	284
2	190	236	10.5	2.0	12.5	10.5	75746	321
3	190	236	11.0	2.5	13.5	11.0	93693	365
4	190	236	11.5	2.5	14.0	11.5	114870	448
5	190	236	12.0	2.5	14.5	12.0	139280	545
6	190	236	12.5	2.5	15.0	12.5	167190	594

As the increase in width of needle roller bearing increases L10 life and decreases the strength of differential lock piston (increase in strain values is nothing but reduced strength).

V. CONCLUSION

In this paper from the analysis, it found that optimization of space within the system may enhance the life of system. Needle roller bearing and differential lock piston finite element calculation model is established under the action of axial force. The optimized depth of differential lock piston will increase the strength and life of the system. The optimized width of needle roller bearing will increase the L10 life of the system. The warranty claims from customer may eliminate. It also provides theoretical base for optimization.

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