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Development and Testing Of Wheel Bearing Preloading Machine for Off-Highway Trucks

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ABSTRACT

Preloading of a bearing is an essential method to make sure that the bearing runs perfectly well under its dynamic working conditions. Preloading value of a bearing is decided upon forces applied on it in its working condition. When the preload is applied correctly, it reduces all possible causes of bearing failure. This paper deals with the development of a bearing preloading machine for heavy duty OHT's (Off Highway Truck's) wheel bearing. As the working conditions and load carrying capacities of OHT's are extreme, wheel bearing becomes the major cause of onsite failures and it leads to repairs, rework and wastage of man hours and cost. In order to overcome these failures, the bearing preloading machine perfectly ensures required preload on each wheel bearing, which reduces the onsite bearing failures by about 30% – 40%. As precision of applying preload is very accurate and process is automated to avoid human errors, which give excellent results in short time period.

Keywords *– Bearing, Preload, Automation, Precision.*

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I. INTRODUCTION

The industrial revolution in the 20th century which is exponentially increasing the economic growth of the developing nations and humanity is also demanding a huge load of energy requirements with different levels of efficiencies. A study by Perticas Diana, states that, between 1970 and 1997 world energy consumption was almost doubled and it is projected to grow by about 57% during next two decades. [8] Hence, harvesting of the available energy resources to the maximum with best pace and low materialistic and monetary resource has become a need of the day. Off highway trucks (OHTs) also called as Haul Trucks is one of the best and most used ways of earth moving on mining sites. These kinds of trucks have been developed specifically for mining, quarry and construction applications. The OHTs keep material moving at high volumes; they are optimized to ensure minimum haulage cost per ton. [9] These are the next generation transport machines having adaptability to the worst kind of roads and hard working conditions. Apart from the working conditions they also have exceptionally large load carrying capacities compared to the regular dump trucks running on the roads.

To be able to drive off the mining sites, they need several characteristics. These include low ground pressure so as to not sink in the soft ground, good ground clearance to not get hung up on obstacles and the most important resist breakdown to the maximum extent while working. The construction of these trucks is rugged to create a durable machine. The mining trucks generally have net power between 1350 to 3800hp produced by diesel engines. They have incredible pay load capacities between 150- 370 ton. [14] The build quality of these trucks needs to be superior like its perfect design. A mining truck costs nearly $500,000 and for such high price the machine failure can result into increased payback time period and also causing inconvenience and reduced production.[14] Hence the aim is also to have very good production repeatability apart from good design. The aim of this project was derived from this demand of perfect production, repeatability and its pre and post requisites. Various causes of the onsite failure were previously examined by many authors and it was clearly seen that engine and wheels were the critical parts in case of time consuming repairs and rework.

So considering the wheel-end of an OHT, the most critical part of it was identified to be the wheel bearing. Determining the causes of bearing failure and a proper solution for it. It was found that preloading of a bearing was essential. [2] On a more specific note this paper aims at preloading the bearing of the trucks wheel-end to perfection so as to increase the bearing life and minimize failures.

II. REVIEW OF LITRETURE

The intent of this paper is to explain a method of bearing preloading by a fully automated process giving the wheel end bearings excellent fatigue life and induce minimum failures or breakdowns. One of the basic requirements of taper roller bearing manufacturers has been exact preload, that must be applied while the assembly of wheel [3]. Earlier, after determining the exact preload required, a torque wrench was used to manually load the bearings. This method could not attain the required perfection and cater to the policy of zero failure and hence has become obsolete [7]. We also know that the bearing preloads significantly affects the vibration characteristics of shaft-bearing assembly due to major changes in stiffness matrix [2]. In the application of off highway trucks, the need of preloading to perfection is a basic requirement as onsite failures are undesirable. The cost of rework or repair is extremely expensive in this particular application. Hence the need of perfection is amplified. Generally speaking the desirable performance of the wheel end bearing is going to maximize the life of the working system [1].

The bearing clearance needs to be adjusted to its precise value in case of bearing preloading. Mechanical preload and bearing clearance are major factors reducing frictional losses.[4] The bearing preload value and its accuracy makes sure that in case of heavy loads on the bearing it does not deform [11]. Accurate preload also ensures control of noise and vibration, ensuring suppressed runout shaft [18]. The temperature inside the bearing also plays a vital role in the bearing life which is controlled by friction which directly depends on the bearing clearance [10]. The expansion of bearing due to different changes in temperature is hence accounted while preloading the bearing which obviously increases its accuracy and precision demand [16]. Scoring is a major problem seen in case of bearings which again is successfully solved by accurate preloading [15]. As a result we can see that there is a need of next level automation, required for faster speeds and accuracy.

III. THEORY AND BASIC COMPONENT DETAILS

3.1 Bearing

In this case the bearings used in the wheel end assembly were the tapper roller bearings. However, magnetic bearings was an option but they are too costly for many low- and medium-speed, high-load applications.[5] Taper roller bearings were used because it can withstand radial as well as axial forces. The inner race is called cone and outer race is call cup. Since there were axial forces acting on the bearing the cup and cone may get separated. In order to avoid this separation the axial force must be balanced by an equal and opposite force. They were either arranged in face to face or back to back configuration. In this case face to face arrangement was used. Figure 1 shows a taper roller bearing.

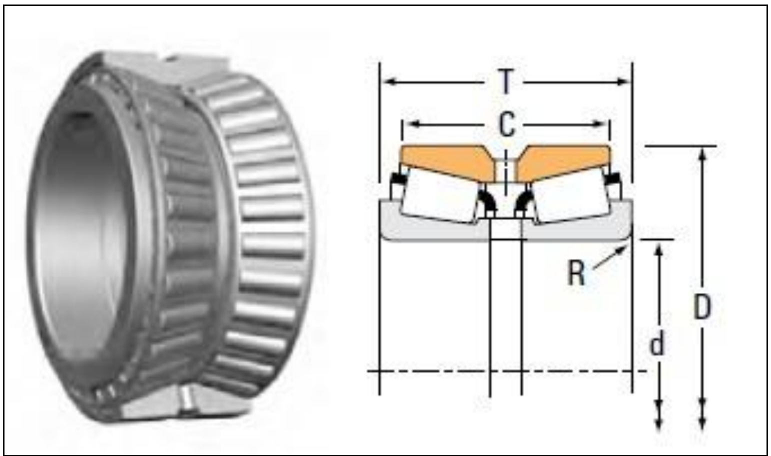

Figure 1 Taper Roller Bearing

3.2 Bearing Preloading

Bearing preload **is** related to issue of internal clearance in the bearing and could be critical for the proper functioning of the bearing. The preload essentially described the process where in a permanent thrust load was applied to the bearing. This permanent thrust ensured perfect contact between rollers and races and had no axial clearance. The bearing preload process helped in getting rid of all the unwanted clearances, creating high stiffness and reducing noise and vibration. An added benefit was that reducing the clearances could help control the rotational accuracy of the bearing and reduce run out. The preload also helped in preventing the rollers in the bearing from skidding on the races.

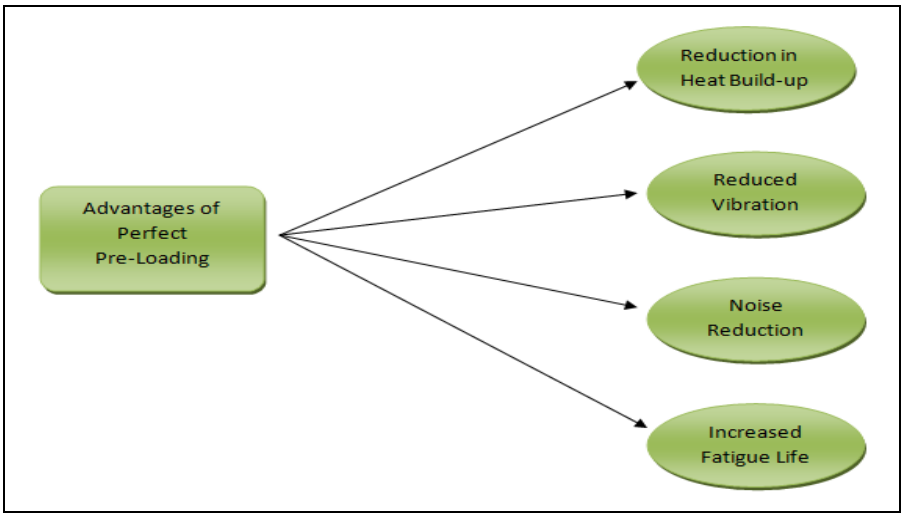

Figure 2 Advantages of Preloading

An optimum preload should be individually specified for each type of roller bearing. If the Preload was applied excessively, excess heat could be generated in the bearings, which would result in short Bearing Fatigue Life and would increase raceway noise as well. Bearing starting and running torque would also be high by necessity, to overcome the tightness in the bearing. This increases the power demands of the system. On the other hand if the applied Preload was insufficient, fretting corrosion could occur. This happened as a result of vibration causing the rollers to resonate and abrade on the raceways. Therefore, obtaining the correct Preload was of great importance.

The purposes of preloading can be stated as follows.

[1] To maintain the bearing in exact position radially and axially.

[2] To maintain bearing rigidity.

[3] To reduce noise created by axial vibration and resonance.

All these result into increased bearing life and smoother working without maintenance.

3.3 Preloading Methods

There are mainly 2 main types of preloading ‘Position Preloading’ and ‘Constant Pressure Preloading.’ Position preload can be further divided into several sub groups namely a method of tightly fitting a pair of preloaded bearings, a method of adjusting the dimensions by using a shim pack or a spacer to obtain optimum preload, a method of employing the direct control of proper degree of fastening force to apply the appropriate amount of preload by measuring the starting friction moment without using spacer or shim. These kinds of preloads allow a bearing to keep constant relative position irrespective of its operation status.

[1] Influence on the increase of bearing rigidity : Constant pressure preload < Position preload
[2] **Variation of bearing rigidity by bearing load :** Constant pressure preload > Position preload
[3] **Variation of preload by temperature and load :** Constant pressure preload < Position preload

The constant pressure preload is a method that uses any of coil spring, plate spring or board spring to apply required amount of preload. Because the rigidity of preload springs is generally and sufficiently smaller than that of the bearing, the preloads are kept almost constant although bearings relative positions vary during operation. The comparisons between Position Preload and Constant Pressure Preload are listed below.

IV. OBJECTIVE AND PROBLEM STATEMENT

The objective of our project was derived from the need of the project that was, preloading the wheel bearing of an OHT. It can be stated discretely as follows:

- To ensure perfect preloading of wheel bearing.
- Simulation of actual loading condition.
- Accurate **shim** selection for precise preload.

In order to achieve these objectives, proper equipment was designed and build based on the problem statement and design variables derived from it. The problem statement was as follows:

"To preload a wheel bearing of an OHT with heavy load (Value stated in kN) and simulate its actual working condition by rotating the wheel-end at the same time of loading. Also to measure the gap with the help of precise electronic probes which was produced during preloading and to select perfect shim pack thickness while simulating conditions."Based on these parameters a concept drawing was prepared which had all the components placed at various locations, satisfying all the objectives developed in problem statement.

V. PROPOSED CONCEPT

As seen before preloading the bearing to an exact specified preload is very necessary in case of OHTs. The need for specific and accurate preload gets amplified due to the heavy loads and extreme working environments. For better production rate at specified quality and low manufacturing cost, automation can be the best solution. In the specific application of OHTs the wheel bearing was one of the most critical components. It takes all the working as well as static loads acting on the wheels. Wheel bearing not being an auxiliary member, the vehicle cannot function in case of its failure. Hence the idle time of the vehicle goes on increasing and exponentially increasing the capital recovery time. As the vehicles cannot run on roads, the maintenance takes time, all resulting into a vicious circle of losses.

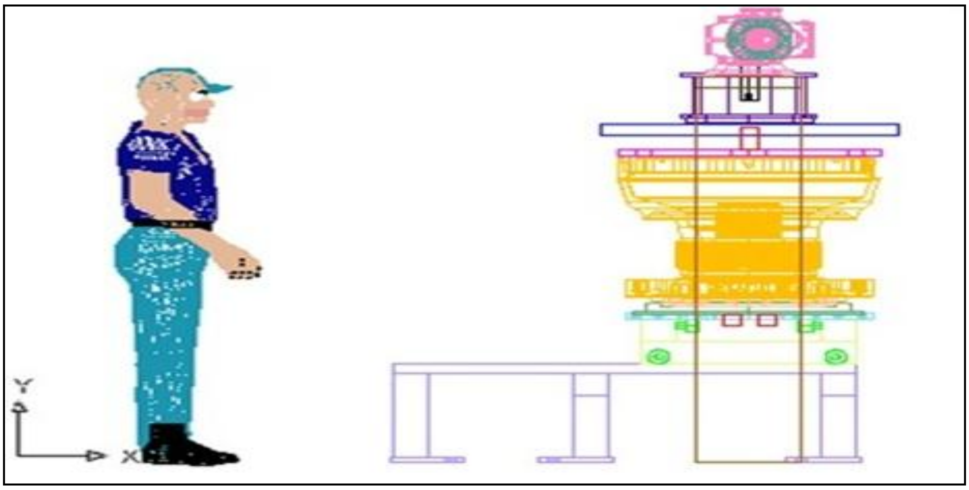

Figure 3 Concept Drawing of the Mechanism

This was the concept proposed to achieve perfect preloading, the layout shown in **figure 3** was finalised. The component was locked in its place by using mechanical locks. The hydraulic ram was used to apply different loads on the bearing during the preloading process. An Electric motor and a pair of gears to rotate the bearing and simulate its exact dynamic condition while taking different readings in order to increase accuracy. A rigid Frame, Stool and Pallet design to support heavy loads up to 176kN were manufactured. A shim pack of appropriate thickness was selected by the process explained in the further section.

Preloading of the bearing was achieved by tightening of Bolts in order to control the preloading force. Shim pack was used to restrict the bolts from exerting extra force. The concept drawing clearly indicates positions of different components in the equipment. As the frame is the major part of the equipment, it supports all other parts. The hydraulic ram was placed on top of the frame because force required for preloading was to be generated in the vertically downward direction. Pair of gear was placed on the frame below the top surface so as to give rotating facility for the wheel-end and to simulate it to actual working condition. Test component was placed on pallet for easy movement in the shop. In this manner the proposed concept was further taken in consideration to actually build the equipment with restriction of designing parameters and factor of safety for various components of it.

VI. DESIGNING THE EQUIPMENT

Equipment consists of following main components:

[1] Frame
[2] Hydraulic Ram
[3] Gear Pair
[4] Motor

These were the main components which were designed with great accuracy and safety standards. Various design data books and references were used to ensure perfect an optimum design of each component in the equipment.

6.1 Frame Design

Frame is one of the most crucial part of the equipment. Frame needs to support and transfer heavy loads of 176kN with negligible deflection. If the deflection in the frame were not negligible it might affect the readings required for accurate shim selection. Frame also houses all the major components viz. Hydraulic ram; drive motor, gear pair etc. Hence a robust frame was designed in order to assure reliability of the equipment.

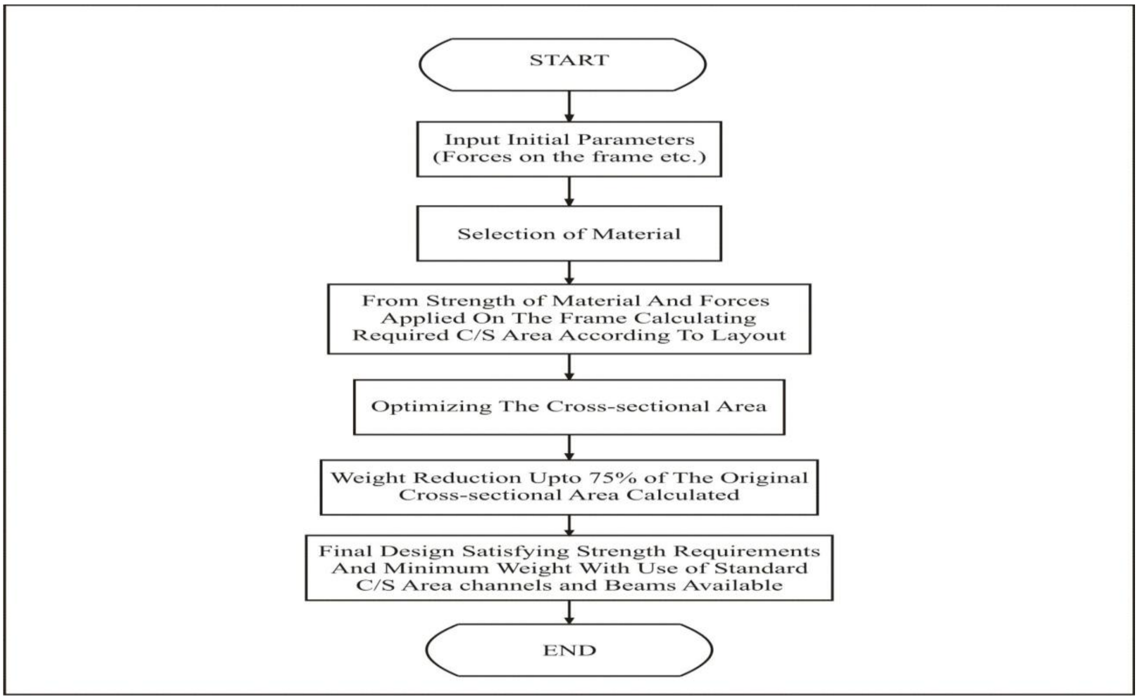

Figure 4 Frame Design Procedure

[1] While designing a frame the most important parameters to be considered are the various forces acting on the frame and the space considerations.
[2] By considering the strength requirements, dimensional constraints, and the cost an appropriate material was selected.
[3] From strength of material and the forces acting on the frame calculating the cross section area of the frame according to the layout. The members of the frame were tested against crushing failure, bending failure

and buckling failure. The deflection in the frame was limited to 1mm under the maximum forces acting on the frame.

[4] Optimizing the cross section area by making the frame hollow there by reducing material required and weight of the frame but keeping the strength and area moment of inertial constant (or greater than obtained in step 3).

[5] Weight reduction up to 75% was achieved by doing number of iteration.

[6] Standard cross section area beams and channels were selected in order to reduce the cost of manufacturing.

6.2 Selection of Hydraulic Ram

Hydraulic ram was the second most important component on the equipment as it provides the heavy force required to preload the bearing. Hydraulic rams utilize high pressure hydraulic fluid to generate extremely high forces. Hydraulic fluid is pressurized and sent to the ram which pushes the rod out of the ram casing and does desired work. Therefore, we know the preloading force to be generated and depending on the same we selected appropriate ram so as to make sure pressure generated inside the ram was limited to a value equal to (max. pressure in ram / F.O.S.) [12][13]. The major influencing parameters for ram selection were – 1. Force to be generated. 2. Max. Working Pressure inside the ram. 3. General dimensions of the ram. 4. Face flange for mounting. After selecting ram from "Achieve Hydraulics & Pneumatics" catalogue, we backed it up with proper hydraulic power pack which supplies the ram with pressurized fluid.

The ram was placed on top of the frame and it directly gets in contact with the component under test by vertically downward movement of the rod. The head of the ram rod was fitted with proper attachment so as to incorporate sensors required for measuring the shim pack thickness. Hydraulic ram was the most economic and easy to use option for force generation. Although it had a bit dirty environment due to fluid used for pressurizing but it was the most easy to use device as electronically operated hydraulic valves were directly connected with PLC programmer. This made working of the hydraulic ram at a push of a button ensuring perfect movement of fluid inside the ram and producing exact preloading force. In this manner the hydraulic ram was used as the main component for preloading the wheel-end assembly.

6.3 Design of Gear-Pair

[1] The first step of gear design is the selection of proper type of gear for the given application. The parameters considered while selecting type of gear are general layout of the shaft, speed reduction, power to be transmitted, input speed and cost considerations. Selecting here 20 degree full depth involute gear system [12][13].

[2] Appropriate material as per required strength and cost considerations is selected.

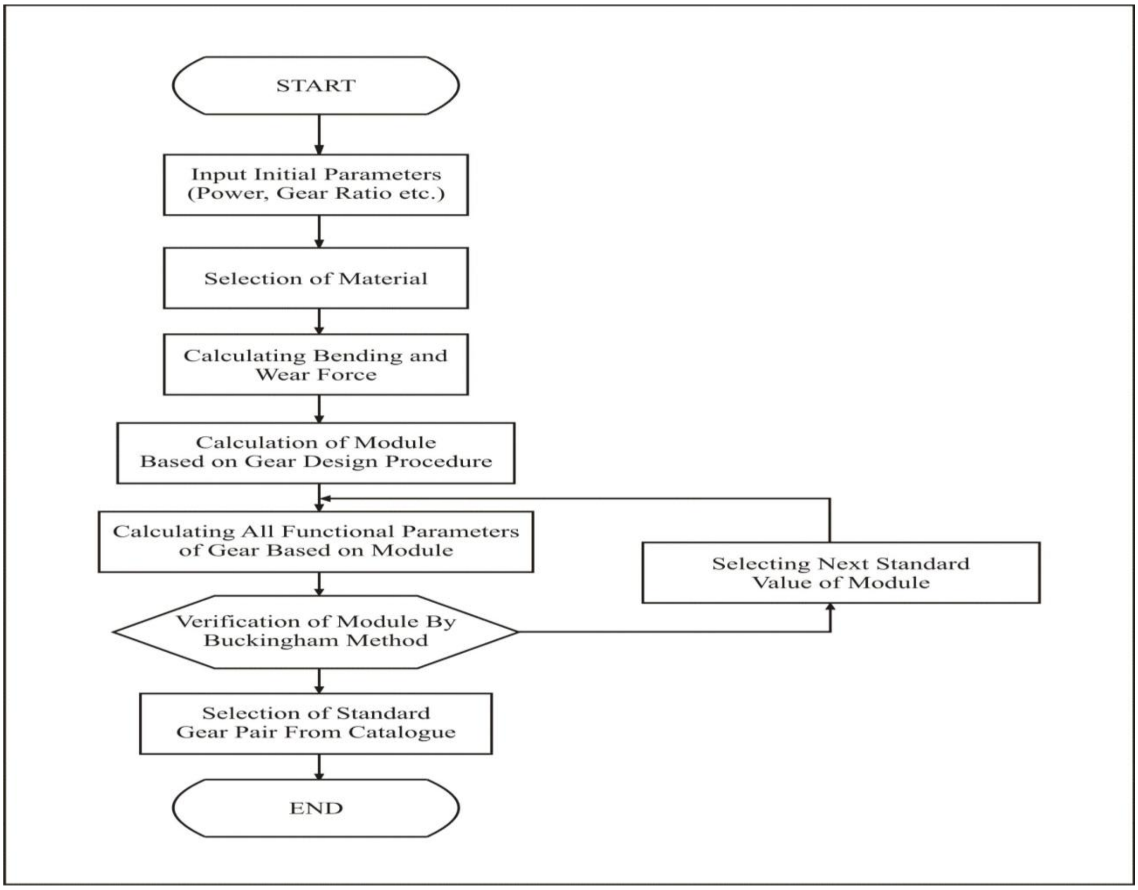

Figure 5 Gear Design Procedure

[3] Calculating the maximum bending force and wear force acting on the gear while transmitting the required power at the required RPM.
[4] Calculating the module depending on the weaker element in the above step (step no. 3).
[5] Calculating all functional parameters of the gear based on module such as addendum, dedendum, clearance, pitch circle diameter, face width, working depth and whole depth.
[6] Verifying the calculated module as per Buckingham theorem, if the obtained factor of safety is less than the required factor of safety then repeating Step 6.
[7] Selecting a standard gear from the manufacturer's catalogue as per required specifications.

6.4 Motor Drive

Motor drive was required as the component was to be rotated at the same time of preloading because, it simulated the actual working condition of the wheel as well as it made sure that the readings taken for the shim pack thickness were uniform throughout the trial process. In order to rotate the wheel-end a gear pair was used (designed in 6.3) to transmit required torque and r.p.m. As discussed in earlier part the gear ratio of the pair was so selected so that the torque requirement would be limited to a certain value. Due to which the required motor power and its size were limited to as low as possible. Saving procurement cost, space and weight at the same time.

After calculating the torque and r.p.m. requirement based on calculations and problem statement. Power of the motor was calculated based on:

Power (P) = $\frac{2\times\prod\times n\times T}{60\times1000}$ kW Where, n = rotations per minute and T = Torque required (N-m)

Motor was selected from SEW catalogue that satisfied the power requirements. Motor was also mounted on top f the frame. Stepwise procedure of motor use is described in further context.

6.5 Digital Probes For Measurements

Measuring probes were of high priority. All the data input coming from the equipment was collected through measuring probes mounted on the ram head with proper mounting arrangement for it. The required experimental readings that we recorded were in microns, due to which the need of extremely accurate measuring probe was a necessity. As the load generated by tightening the bolts on the retainer pads exerted preloading force on the bearing assembly, it was crucial to select accurate shim pack, because even a small change in thickness of shim pack would result in change in preloading force. Therefore, measuring probes selected were of higher accuracy of the order in microns. Probes were of make – TESTAR and product was under the category of "Red Crown Pencil Probe".

Full Bridge (LVDT) measuring probes were used on the equipment. Sensitivity (mV/mm/V) 114÷ 122, Linearity error (μm) ≤ 38 (0,4%), Energizing frequency range (kHz) 4÷ 9. It was able to measure as minimum as less than a micron with great precision. These probes were fitted on equal circumferential distance on the attachment provided on the rod of ram.

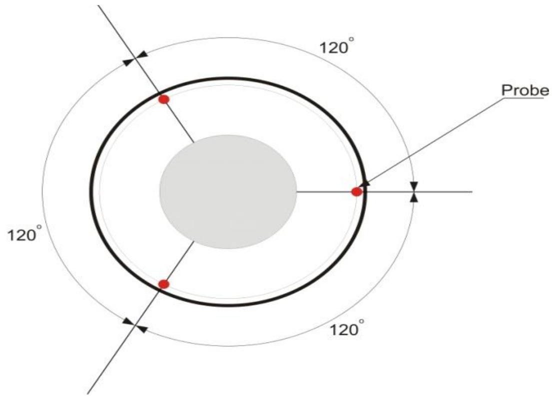

Figure 6 Probe Arrangements on Ram Head

VII. TRIALS CONDUCTED ON THE EQUIPMENT WITH DETAILED PROCEDURE

[1] The wheel bearing to be preloaded moves along the assembly line to the preloading equipment.

[2] The component was loaded on a pallet and moved to the preloading station. Then the pallet was locked in place, just before going under the ram with the help on pneumatically actuating mechanical-stopper locks.

[3] Master plates A, B and C were placed so that the geometry of the wheel end can be superposed on the surface so that it replicates the inside of the bearing and does not damage the component from direct load.

[4] The pneumatic locks were unlocked after placing master plates, so that the pallet could move under the hydraulic press to continue with the process.

[5] Again the pallet holding the component was locked in place with the help of pneumatically actuating mechanical-stopper locks, so that it won't be able to move under the hydraulic ram and increase the accuracy of the reading, also the stability of overall moving pallet and component.

[6] The motor was started and the wheel started rotating through gear pair. Then the hydraulic ram was taken down, the wheel was rotated because the gap produced was variable in the bearing assembly. By rotating the wheel-end, the average gap was measured which in turn increases the accuracy of the process.

[7] Reading R1 was taken at 0 kN force, this reading was the basic reading and was considered as the reference reading in the remaining process.

[8] The motor was stopped and the ram was taken up. First part of the process was finished. [9] Master A is removed and only B & C were placed for further process.

[9] Then ram was again taken down and a specified load of 176kN is applied and reading R2 is recorded.

[10] The force on the bearing was removed by taking the ram up and again the ram is taken down on the bearing and reading R3 is recorded.

[11] The difference between R2 & R3 was calculated, the difference should not exceed 50 microns if the difference was found out to be more than 50 micros then the bearing was rejected under the category of false bearing assembly.

[12] The ram was then again placed on the bearing and a load on 50kN was applied on the bearing and reading R4 is recorded.
[13] The difference between R4 and R1 is the required shim pack thickness.
[14] The major process was ended at this point.
[15] Then the pallet was unlocked and the equipment is moved back away from the hydraulic ram. [17] Master plates B and C were removed.
[16] Then shim pack of required thickness was selected as per value calculated is step 14.
[17] The shim pack thickness is verified in the shim pack verification equipment and was compared with thickness achieved in step 14.
[18] If the selected shim pack thickness was as per the shim pack thickness received then green light is signalled on the control panel.
[19] This shim pack was placed on the spindle.
[20] Then the whole setup was assembled in the following sequence as spindle then shim pack and then retainer plate and it was tightened with the help of washers and bolts.
[21] Then the bolts are torqued with 520 Nm.
[22] These bolts apply the required preloading force on the bearing and the shim pack thickness prevents the bolts from exerting excess preloading force.

This explains the detail procedure of preloading the wheel bearing of an OHT. Master plates are used on top of the hub assembly (at the place where the retainer is placed afterwards.) in order to avoid any direct damage to the component at the time of preloading as force generated by the hydraulic ram at the time of preloading is of a very higher value. Shim pack thickness value was calculated as a result of the step wise preloading procedure. Shim pack selected was verified under the verifying unit which cross-checks the thickness value from the experiment and the actual shim pack thickness selected. The selected shim pack was placed on the spindle and retainer plate was placed on it. Retainer plate was loaded with bolts with a specified torque value, ensuring perfect preload on the bearing assembly.

VIII. RESULTS

8.1 Result Table

Set No.	Readings	Probe1 Counts	Probe2 Counts	Probe3 Counts	Avg (P1,P2,P3)	Reading In Micron	R2-R4 Micron	Shim Size Micron
1	R1	11368	11000	11656	11341	6342	-1	**2119**
	R2	4760	4256	4880	4632	8506		
	R3	5880	5288	5944	5704	8160		
	R4	4776	4224	4888	4629	8507		
	R5	4904	4400	5016	4773	8460		
2	R1	11520	11040	11744	11435	6311	7	**2125**
	R2	4736	4320	4864	4640	8503		
	R3	5880	5392	5984	5752	8145		
	R4	4824	4304	4856	4661	8496		
	R5	5008	4488	5048	4848	8436		
3	R1	11568	11104	11640	11437	6311	12	**2120**
	R2	4784	4320	4912	4672	8493		
	R3	5960	5416	5992	5789	8132		
	R4	4872	4336	4920	4709	8481		
	R5	5008	4504	5080	4864	8431		
4	R1	11296	11072	11864	11411	6319	5	**2143**
	R2	4824	4232	4944	4667	8495		
	R3	5768	5176	5928	5624	8186		
	R4	4840	4232	4976	4683	8489		
	R5	4929	4312	5064	4768	8462		
5	R1	11664	11080	11704	11483	6296	10	**2157**
	R2	4720	4280	4888	4629	8507		
	R3	5880	5352	6093	5775	8137		
	R4	4784	4240	4960	4661	8496		
	R5	4912	4360	5120	4797	8452		

Table 1 Test Result Data

The result table clearly shows the shim pack thickness required to be put in to ensure perfect preloading of the wheel bearing. Two important parameters were observed during the trials. As follows:

[1] The gap retained after applying a load of 176kN
(This should be within the tolerance limit of 50 microns)
[2] The shim pack thickness generated from the procedure described above.

As seen from the above procedure of preloading (VII), it is clearly seen that 5 readings were taken for each trial on a single component. (R1, R2, R3, R4, R5). Each reading has its own significance in order to calculate final shim pack thickness. 3 probes are used to measure the same parameter. As in the actual simulation process the wheel-end is rotated while the load is applied on it, Due to rotation and loading the assembly tends to vibrate slightly which affects the readings taken by the electronic probes. So as to ensure no mistake in the readings taken, 3 probes continuously monitor required parameter and the final value was taken as an average of the three. The probe count (Specified in above result table) has a direct relation with the final reading. The formula for converting the probe count into microns was given by the probe manufacturer. By using the same final readings were found out to be (R5-R1), which is the actual required shim pack thickness.

Conclusive graphs were plotted according to the results. They are as follows:

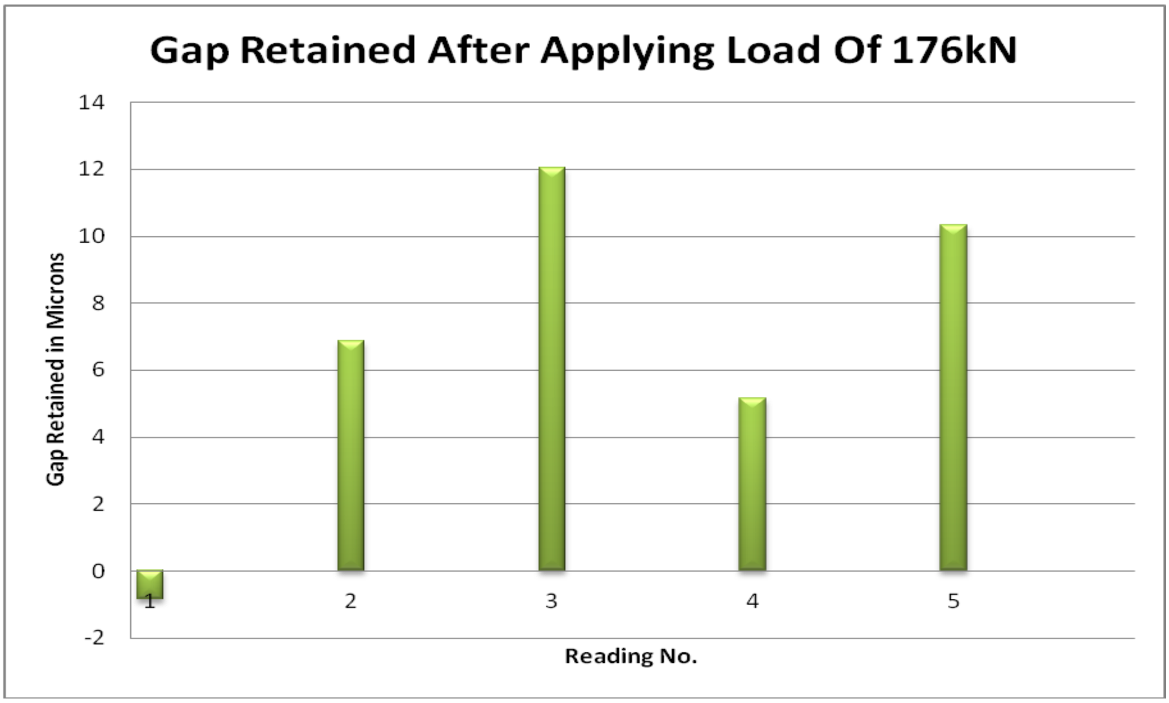

Figure 7 Reading Number Vs Plot of Gap Retained After 176kN Load

As seen from the procedure of preloading (VII), the bearing must retain its gap within 50 microns under application of load to ensure perfect assembly of bearing and hub. The results were plotted as per (R2-R4) and it can be clearly seen from the graph as the results obtained were well within the limit. The gap was found out to be ranging from -1 micron to a maximum of 12 microns. All the test components were successfully tested under the equipment.

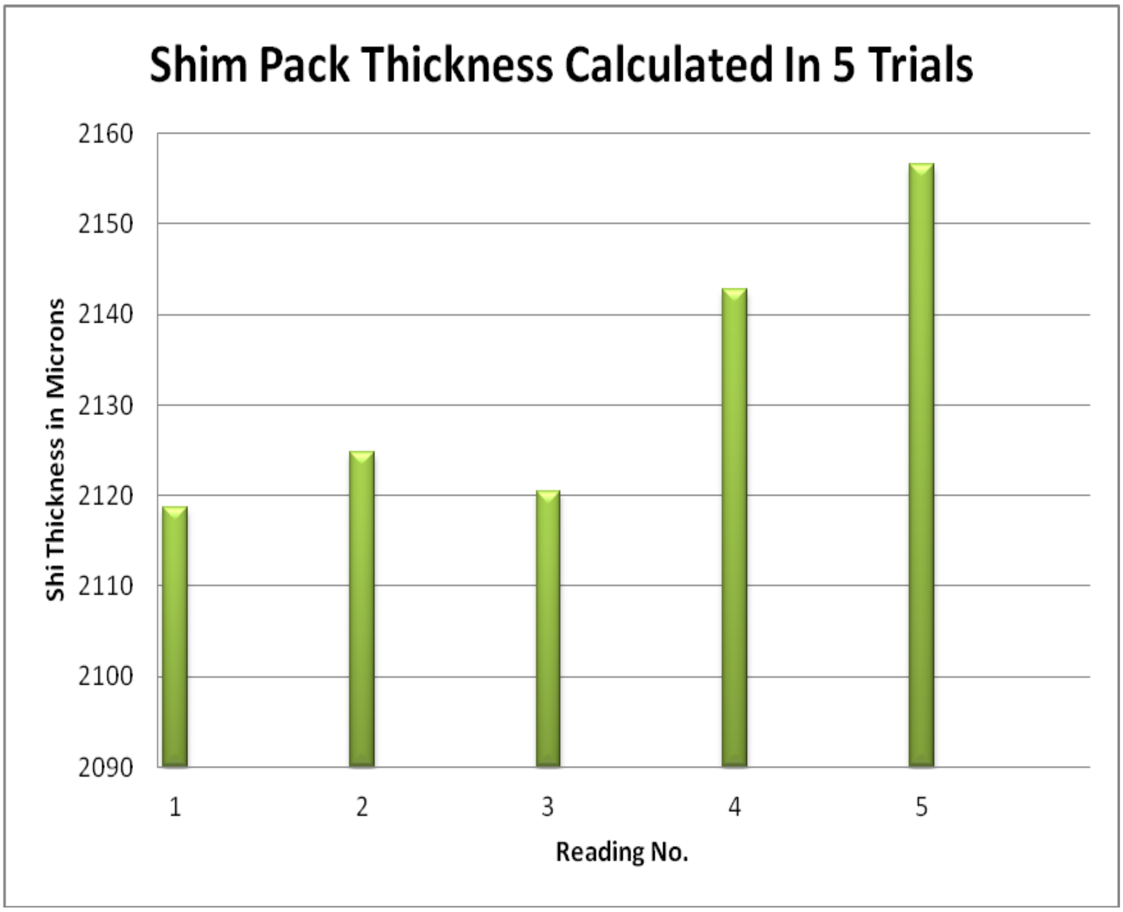

Figure 8 Reading Number Vs Shim Pack Thickness

Shim Pack thickness was calculated for each of the test component according to the result table. The shim pack was verified under "shim verification unit" (compares thickness of actual shim and shim thickness obtained from preloading procedure) and then placed in the wheel-end assembly. The graph shows various shim thicknesses found out during the trials, ranging from 2119 microns to a maximum of 2157 microns. These graphs were helpful in keeping the inventory of various shim thickness.

IX. CONCLUSION

[1] As seen from the result table there was a positive gap generated after preloading the wheel bearing to its given values. So in order to limit the travel of the retainer bolts over the bearing assembly, certain shim packing was adopted to assure perfect preloading.

[2] Due to exact preload and simulation technique the bearing was precisely installed and assembled in the wheel end.

[3] Accurate preload directly resulted into increased fatigue life of bearing, smooth working of the wheel assembly and low temperature build-up in the wheel end.

[4] These advantages were able to reduce the onsite failures by about 30-40%. Major capital cost, repair and rework time and cost were saved as a result of precise preloading of the wheel bearing.

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