

Backlash and Gear Profile Analysis of Railway Axle Gearbox - a Case Study

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ABSTRACT: Axle gearbox, an important component of urban rail vehicles working in the most severe conditions, plays a crucial role in the urban rail vehicle transportation. It is necessary to detect the fault of axle gearbox at an early stage to prevent human casualties and reduce maintenance costs. In this paper, a new method is developed based on dimensional accuracy and precision for measurement of gear profile and backlash. The temperature distribution test on gear profile take confirmations about the failure on gear tooth therefore if any fault occurs in the axle gearbox it will totally affect the working of railway axle, reduce the speed of locomotive and produce vibration on it. so it is important to study the various faults occurring in the gear box and modeling of that faults. On the basis profile accuracy decision is take place regarding replacement of gear. Gears and gearboxes are generally robust and reliable devices.

KEYWORDS: axle gearbox, dimensional accuracy, precision, gear profile, backlash.

I. 1.INTRODUCTION

The modern diesel locomotive is a self-contained version of the electric locomotive. Like the electric locomotive, it has electric drive, in the form of traction motors driving the axles and controlled with electronic controls. It also has many of the same auxiliary systems for cooling, lighting, heating and braking for the train. It can operate over the same routes (usually) and can be operated by the same drivers. It differs principally in that it carries its own generating station around with it, instead of being connected to a remote generating station through overhead wires or a third rail. The generating station consists of a large diesel engine coupled to an alternator producing the necessary electricity [5]. Axle gear box is used to power transmission from traction motor to axle through spur gear. locomotive gearboxes including axle mounted and nose suspended designs which offer strength, reliability and flexibility. We understand that need of maximum availability[11].

a. Traction Motor Mounting Arrangement

Traditionally, the biggest challenge for traction motor designers is to design an appropriate mounting arrangement of the motor in the bogie frame. The correct geometric arrangement between rotor shaft and the axle of the wheel set is maintained to make sure that the efficiency and smooth functioning of the transmission between the two (motor shaft and wheel set axle) are fully maintained under all operating conditions. The traction motor output torque is required to be transmitted to the vehicle axle through reduction gears. The complete power transmission from traction motor through pinion set of gear is called drive arrangement and traction motor can be treated as driver. Based on the fact how traction motor and drive arrangement is mounted in a bogie, following two types of traction motor mounting arrangement in bogies are generally considered worldwide:

- Axle hung nose suspended Traction Motor
- Nose Suspended Drive

However, there are other types of traction motor mounting arrangements such as underframe mounted traction motor, where traction motor is mounted in vehicle underframe, driving one or more axles through a flexible drive and gearless drive where axle of the wheel set is used as shaft of the rotor, while stator is rigidly mounted to the vehicle body [12].

b. 1.2 Axle Gearbox bearing arrangements

Rolling bearings in gearboxes stabilized the shaft and support the transmission of forces. In doing so, they must withstand extreme loads under complex environmental influences. The bearing types principally used for gearboxes are tapered roller bearings, four points contact bearings and cylindrical roller bearings. Bearing types used less frequently include deep groove ball bearings, spherical roller bearings and angular contact ball bearings.

The main requirements for bearings in gearboxes

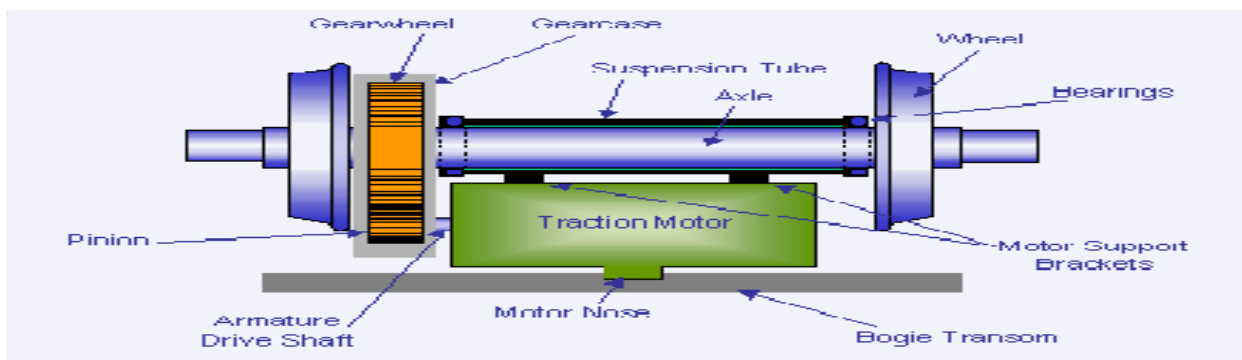


Fig. a. Diagram of DC Suspended Traction Motor and bearing arrangement [6]

- high speeds
- high loads
- vibrations and shocks
- high temperatures
- high guidance accuracy
- compact construction

Based on these characteristics, bearings are selected in consultation with the gearbox manufacturer.

c. Axle box materials

Axle box housings and covers are commonly manufactured as castings. Depending on use and customer specifications, a range of materials can be used. For housings, mainly spheroidal cast iron GJS is used. This very ductile iron is also known as nodular cast iron, spheroidal graphite iron, spherulitic graphite cast iron and SG iron. The main advantage is much more flexibility and elasticity due to its nodular graphite inclusions. In addition to spheroidal cast iron, light alloy is used in specific cases at the customer's request to achieve a lighter design. However, this material is much more expensive. Older designs were based on cast steel material, which is much more difficult to cast and machine than spheroidal graphite iron [16].

d. Gear tooth failure

The failure of any gear tooth falls into one of two forms:

(a) complete fracture of the gear tooth; this usually occurs at the root of the tooth

(b) damage or destruction of the working surfaces of the gear tooth Either of these forms of failure may be the result of one or a combination of any of the following factors:

- Initial stresses.
- Poor tooth design.
- Use of an incorrect material.
- Incorrect heat treatment for the selected material.
- Defective case or surface hardening.
- Poor mounting and casing design.
- Surface damage in final machining or grinding operation.

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- Excessive operating temperatures.
- Misalignment of mountings.
- Tooth overloading, either from internal or external forces.
- Poor lubrication - either lack of lubrication or excessive lubrication.

II LITERATURE REVIEW

Dechen Yao et.al [1] proposed a new technique for detecting faults in the railway gearbox by applying the time frequency parameters and genetic algorithm neural network to deal with railway gearbox fault signals. In this method, wavelet analysis and empirical mode decomposition (EMD) are carried out on gearbox vibration signals for extracting the time-frequency feature parameters. Then genetic algorithm neural network (GNN) is used for the classifications of the time-frequency feature parameters. The analysis results show that the effectiveness and the high recognition rate in classifying different faults of railway gearboxes.

Ferhat Dikmen et.al [2] address life value of axle related to reliability and compare it with the realized life value up to fracture. The activity firstly deals with the definition of critical section in the axle. The location of the fracture is the section between the wheel and gear. The research then addresses determination of the wagon loading cases based on statistical data related to the number of passengers. First, minimum life value of the axle was determined considering full load, then effective life values were calculated by using Palmgren- Miner's theorem as a cumulative failure theorem for real loading conditions in the case of different distributions.

Jean-Luc Dion et.al [3] develops an experimental and numerical study of dynamic phenomena involving gear impacts with one loose gear inside an automotive gearbox. A dedicated test bench was designed for this study. Signal processing tools, based on the Order Tracking Method, were specially developed in order to clarify the underlying phenomena

Josef Kolar et.al [4] describes trends in individual wheelset drive and drives of the independently rotating wheels of modern low-floor trams and railway vehicles. It documents the way of a constructive design of the individual wheelset drive (without gearbox) and wheelset drive with gearboxes.

Marianne Mosher et.al [5] show a detailed analysis of the vibration signal from the destructive testing of a spiral bevel gear and pinion pair containing seeded faults. The vibration signal is analyzed in the time domain, frequency domain and with four time-frequency transforms.

Mark Lee Johnson et.al [6] explore how oil selection can affect gearbox efficiency. According to the US Energy Information Administration, the United States generated 1,006 billion kWh of electricity in 2007. (EIA) It is generally accepted that electrical motors account for about seventy percent of industrial electrical power consumption.

Mr. Vijay kumar et.al [7] contains the study about vibration analysis for gearbox casing using Finite Element Analysis (FEA). The aim of this paper is to apply ANSYS software to determine the natural vibration modes and forced harmonic frequency response for gearbox casing. The important elements in vibration analysis are the modelling of the bolted connections between the upper and lower casing and the modelling of the fixture to the support. This analysis is to find the natural frequency and harmonic frequency response of gearbox casing in order to prevent resonance for gearbox casing. From the result, this analysis can show the range of the frequency that is suitable for gearbox casing which can prevent maximum amplitude.

Nxiukun Wei et.al [8] analyze a new method based on SIMPACK is proposed and confirmed efficient by testing, which can overcome the disadvantages of the experimental platform. Meanwhile, MATLAB was applied to time-frequency domain analysis and wavelet packet analysis. These analysis results demonstrated the feasibility and reliability of this method.

Paula J. Dempsey et.al [9] developed diagnostic tool for detecting fatigue damage to spur gears, spiral bevel gears, and rolling element bearings. This diagnostic tool was developed and evaluated experimentally by collecting oil debris data from fatigue tests performed in the NASA Glenn Spur Gear Fatigue Rig, Spiral Bevel Gear Test Facility, and the 500hp Helicopter Transmission Test Stand. During each test, data from an online, in-line, inductance type oil debris sensor was monitored and recorded for the occurrence of pitting damage. Results indicate oil debris alone cannot discriminate between bearing and gear fatigue damage.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 6, June 2016

Prashant Bagde et.al [10] analyses about the gearbox is an important element of any machine so it is very important to make study on that and finding out faults accoutering in the gearbox. It is possible every time to observe the gearbox for its faults so the vibration changes in the gearbox is used for the possible faults. In this thesis the faults accoutering in the gears are studied and how the vibrations are changes for a particular fault are studied. The modelling of the elements will be done on the CATIA.

R. Sharma et.al [11] discusses a testing and commissioning model for a typical light rail project. The paper does not propose a new methodology or concept, but the idea is to consolidate different testing and commissioning exercises into a generic structure of stages, which can be applicable to any light rail project. The various stages depend on the level of testing and integration required as a project progresses from supply of equipment and installation to integration and actual operation. Systems integration is a vital aspect of the testing and commissioning program, and is discussed in brief in this context. The documentation and control necessary to complete the testing and commissioning program are also outlined.

R.N.Lal et.al [11] describe about motor suspension arrangement is of paramount importance for the reliability of traction motors. Another vital input for the selection of traction motor for given motor suspension arrangement is its rotational speed. Non-availability of any complied information on the relationship of rotational speed of traction motors and their mounting arrangement makes the jobs of Rolling Stock Engineers difficult. After study of various relevant literatures, various systems followed worldwide and interaction with leading locomotive manufacturers, an effort has been made.

Rusmir Bajric et.al [12] presents the results of an evaluation of vibration analysis techniques as a method for the gear and gear pairs condition assessment. The origin of vibration in gear pairs and useful definition of damage identification techniques are presented.

Satoshi koizumi et.al [13] describe the trade-off problem between the curve negotiation and the high speed running stability is a basic issue for bogie design technology. But today, by the use of simulation techniques, we can design the suitable rolling stock for the various applications.

III. 3.DIMENSIONAL ANALYSIS OF GEAR PROFILE AND BACKLASH OF RAILWAY AXLE GEAR BOX

Steps Involved

Maintenance schedule proposed to perform an audit on the axle gear box to determine the cause of failing. During these schedules, vibration measurements, visual inspections foundation are performed. Besides this, the maintenance planning, technical data use of wearable parts is reviewed. These comprehensive compressors schedule allow us to draw up the condition of axle gear box and propose potential solutions. The schedule showed that a measurement of cracks of axle gear box was necessary to prevent wear of moving parts and auxiliaries would lead to an unplanned shutdown. Additionally, it was advised to renew the axle gear box foundation. To ensure its continuous operation, scheduling the overhaul becomes necessity.

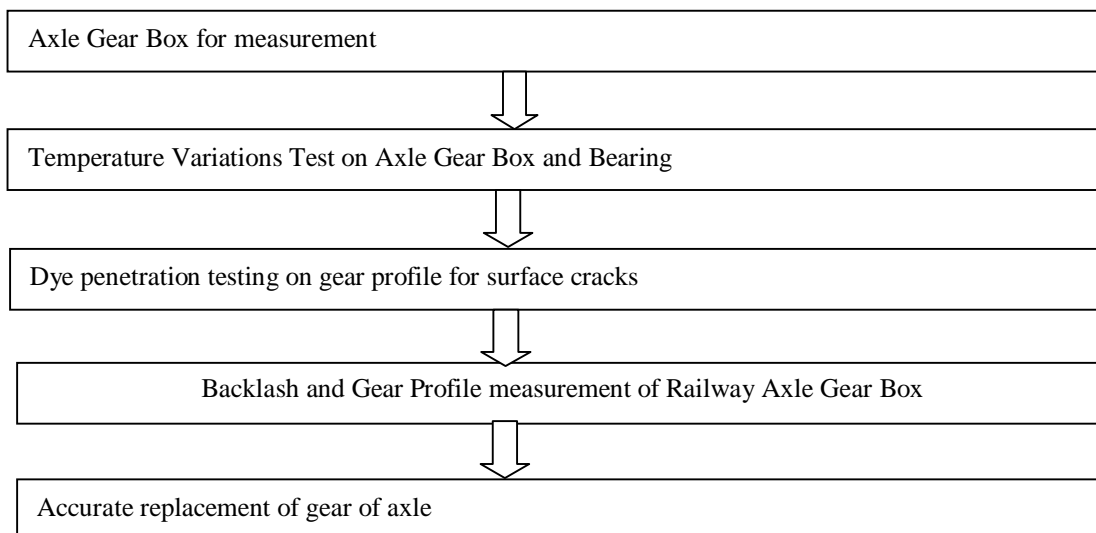


Fig. b steps involved in Analysis of Gear Profile and Backlash of Railway Axle Gear Box

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

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a. Temperature Variations Test for Axle Gear Box, Bearing case and Motor Suspension Unit

Axle box temperature is to be measured at the front cover rather than at the crown of axle box. The maximum temperature limit of bearing case is

$$T_{max.} = 2 * T_{atmosphere}$$

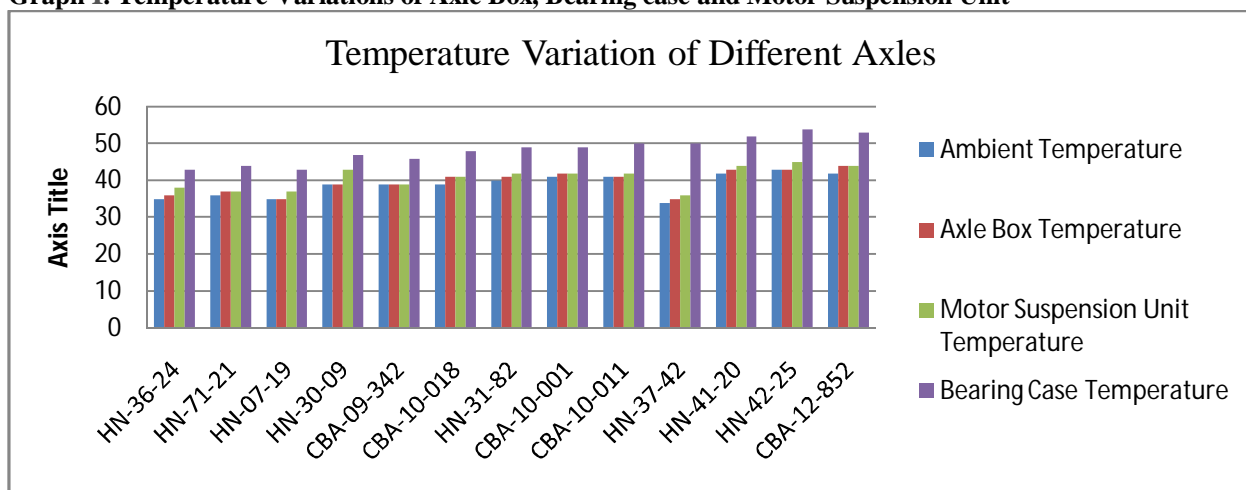
But for safe condition $T_{max.} = T_{atmosphere} + 12^{\circ}C$

By temperature gun. If temperature of Axle Box is increase above $T_{atmosphere} + 12^{\circ}C$ during test. Then it is vibrant that Axle Box meeting with traction motor by gear, generate heat due to failure and cracks on tooth profile. This variation of temperature decides the failure in meeting gear.

Table. I. Temperature Variations of Axle Box, Bearing case and Motor Suspension Unit

Axle number	Ambient Temperature	Axle Box Temperature	Motor Suspension Unit Temperature	Bearing Case Temperature
HN-36-24	35	36	38	43
HN-71-21	36	37	37	44
HN-07-19	35	35	37	43
HN-30-09	39	39	43	47
CBA-09-342	39	39	39	46
CBA-10-018	39	41	41	54
HN-31-82	40	41	42	49
CBA-10-001	41	42	42	49
CBA-10-011	41	41	42	50
HN-37-42	34	35	36	50
HN-41-20	42	43	44	52
HN-42-25	43	43	45	56
CBA-12-852	42	44	44	53

Graph I. Temperature Variations of Axle Box, Bearing case and Motor Suspension Unit



After the observation of Table. I. temperature of bearing case axle number CBA-10-018, HN-37-42 and HN-42-25 generate more heat with specific speed and time of rotation of axle. Therefore, in these axle it is possible that axles are defective and the gear profile of the assembly is damaged. Therefore, it is required to measure the cracks and profile of the gear before replacement.

b. Dye penetration testing on gear profile for surface cracks

After the dismantling Dye penetration testing is done on gear profile for surface cracks. This method is frequently used for the detection of surface breaking flaws in ferromagnetic non ferromagnetic materials. The subject to be examined is first of all chemically cleaned, usually by vapors phase, to remove all traces of foreign material, grease, dirt, etc. from the surface generally, and also from within the cracks. Next the penetrant (which is a very fine thin oil usually dyed bright red or ultra-violet fluorescent) is applied and allowed to remain in contact with the surface for approximately fifteen minutes. Capillary action draws the penetrant into the crack during this period. The surplus penetrant on the surface is then removed completely and thin coating of powdered chalk is applied. After a further period (development time) the chalk draws the dye out of the crack, rather like blotting paper, to form a visual, magnified in width, indication in good contrast to the background. The process is purely a mechanical/chemical one and the various substances used may be applied in a large variety of ways, from aerosol spray cans at the simplest end to dipping in large tanks on an automatic basis at the other end. The latter system requires sophisticated tanks, spraying and drying equipment but the principle remains the same.

c. Dimensional Analysis of Gear Profile and Backlash of Railway Axle Gear Box

Set of profile deviation measuring gauge p-value and k-value with feeler gauges for bull gear 65 teeth mating pinion 16 teeth is used for measurement. The gears are periodically checked for wear with involute profile gauges. The gauges are used by railroad and railroad repair shops to determine the amount of deviation from the original tooth profile. The main purpose of the gauge is to measure involute wear. It may also be used to measure involute error on new and re-profiled gears and pinions. The gauge mirrors the original tooth profile. In Fig. c. the gauge is place on the gear (or pinion) with the gauge resting against one side of the tooth profile. A feeler filler gauge through the gap indicates gear profile wear of 0.24mm or greater. Generally, 0.24mm is used as the benchmark for maximum allowable wear. Usually, gears and pinions are taken out of service with gaps of 0.24mm and greater. The gears are typically re-profiled if they are not beyond the tooth thickness condemning specification. The pinions are usually replaced.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 6, June 2016



Fig. c. Measurement of P-Value, K-Value and Backlash of Axle Gear Box

P-Value is measured by profile deviation measuring gauge and feeler gauge.

P-value= feeler gauge reading

Limit of P-Value is up to 0.24mm.

K-value is measured by checking gauge. Limits of K-Value is 276.568 to 276.429mm.

Backlash=Tooth space – Tooth thickness

Tooth space= (minimum limit of K-value – 8*Tooth thickness)/7

Tooth thickness= 38.62mm

Backlash is 0.2 to 0.7 for smooth running of gear. If these range of values is not find during measurement then it is necessary to replace the gear, because damaged profile of gear is not refurbished again.

Table II. Observation of P-Value, K-Value and Backlash of Axle Gear Box

Axle Number	P Value (mm)	K Value (mm)	Backlash (mm)	Dye Penetration Testing of Gear	Dye Penetration Testing of Motor Suspension Unit
HN-36-24	0.20	276.50	0.60	Done	Done
HN-71-21	0.20	276.45	0.70	Done	Done
HN-07-19	0.20	276.50	0.60	Done	Done
HN-30-09	0.22	276.35	0.70	Done	Done
CBA-09-342	0.21	276.50	0.40	Done	Done
CBA-10-018	0.20	276.50	0.70	Done	Done
HN-31-82	0.25	276.40	0.74	Done	Done
CBA-10-001	0.28	276.35	0.75	Done	Done
CBA-10-011	0.22	276.50	0.72	Done	Done
HN-37-42	0.26	276.38	0.70	Done	Done
HN-41-20	0.20	276.45	0.70	Done	Done
HN-42-25	0.21	276.46	0.60	Done	Done
CBA-12-852	0.21	276.55	0.65	Done	Done

After the observation of Table II.the axle number HN-31-82, CBA-10-001and HN-37-42, backlash and P-valve increase and K-value for standard 8 teeth is decrease. There for the profile of these gears is damaged and required to replaces the following gears.

IV. CONCLUSIONS

A rail vehicle drive works with variable operating conditions (changing of a drive mode with braking mode, bidirectional traffic, variable load) and climatic conditions (temperature changes, snow, dust, humidity). it is necessary to define correctly a requirement on the vehicle acceleration and maximum vehicle speed.

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- 1.The accurate measurement of gear profile and testing of axle gear box provide accurate repair and replacement of gear assembly.
2. Temperature distribution offer the exact location of damaged section of gear, bearing and axle.
3. The most serious factor that affects the systematic backlash is the inherent error of gear, which cannot be inevitable. However, improving the precision of machine tools and assembly accuracy can decrease the inherent error effectively. Transmission ratio has great influence on the backlash of transmission chains, so the number of transmission stages should be reduced. The transmission ratio should be as large as possible and be allocated reasonably.
- 4.Backlash of gear train has a large relationship with gear meeting. Therefore, the pitch circle diameter of ring gear should be accurate according to design. if the requirements for design is not satisfied. Thenjamming of teeth generate the heat during running and damage profile of gear.

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