Condition monitoring of train wheel wear and track forces: A case study

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ABSTRACT

One of the major failure modes in the railway industry is wheel wear. Wheel wear affects the dynamic characteristics of vehicles and the dynamic force impact on the rail, and can in worst cases scenario cause derailment. The wheel conditions also influences the wear and required maintenance on the rail. In this paper the correlation of wear rate and dynamic force between wheel and rail is studied to specify the most cost-effective wheel maintenance interval. Two cars, total of sixteen wheels, were selected. In order to calculate the wear trend, measurements have been performed, by MiniProf™, for a period of 12 months with the cars in traffic. During the same time period, the trend of track forces from the two cars has been obtained from the research station, outside Luleå, Sweden. Using the trends from wheel wear and track force in combination to form maintenance planning for wheels are discussed.

Keywords

Condition Monitoring, Railway, MiniProf, Wheel Wear

1. INTRODUCTION

Keeping the wheel profiles in an acceptable condition is one of the major railway's concerns. Not only because the dynamic behaviour of the rail vehicle is highly dependent on the shape of the wheel profiles but wheels conditions are also related to derailment safety. In addition, significant part of vehicle maintenance cost is allocated to maintenance of wheel sets.

Wear and fatigue are two main failure modes of wheel sets that are related to friction and dynamic forces respectively. Different condition monitoring techniques have been applied to monitor wear trend and crack propagation [9, 10]. Application of proper condition monitoring system helps to increase life length of wheel sets and reducing maintenance cost. MiniProf™ is one of the most reliable and accurate equipment for wheel profile monitoring and calculation of wear trend. Most of wheel profile monitoring equipments compares their results with MiniProf™ to check the accuracy [9].

There are several different methods to detect dynamic force impact on the rail track. The two most commonly used are strain- and accelerometer-based systems. Accelerometer-based systems measure the motion of the rail applied by the dynamic load from a passing wheel [2]. Strain-based systems measure the bending of the rail which is a direct measure of the applied load on the rail head. There are limitations to both of these methods. The registered acceleration does not give a quantitative measure of the size of the impact load [8]. The strain-based system can have difficulty to cover the whole circumference on all wheel diameters if not extended with sensors covering at least 3m of the track. Both of these monitoring methods are used on trains travelling at track speed and provide direct feedback of passing locomotive and rail car wheels to ensure safe train operations. The common railroad experience is that the impact load detectors are effective tools for monitoring high impact load producing wheels [11]. The research station used in this case study is equipped with a strain-based wheel impact monitor, situated in a curve with a radius of 484m.

In order to achieve maximum life length of wheel sets it is needed to execute maintenance practices based on the wheel's condition. Applying condition-based maintenance requires selecting proper condition monitoring system, a database for collecting condition data and appropriate data analyzing process to make maintenance decision from condition data.

This paper concentrates on how to make maintenance decision from condition data. This step is the most difficult part in condition-based maintenance strategy. In this paper, the correlation of wear rate and track force between wheel and rail is studied to specify the most cost-effective wheel maintenance interval.

2. CASE STUDY BACKGROUND

The case study is performed on iron ore freight cars belonging to LKAB mining company. The train cars are a Fanoo wagon with a three-piece AMSTEAD bogie and UNO wp4 wheel profile. Trains are transporting iron ore pellets on the iron ore line in northern Sweden, from the mine outside Gällivare to the port in Luleå, see figure 1. This line is trafficked by both passenger and goods trains. The trains are subjected to harsh climate condition such as snow and temperatures close to -40˚C in wintertime and +25˚C in summer time [7]. See figure 2 for a picture of a LKAB train.

In this case study, two cars (4043 and 4044), total of sixteen wheels, were selected. In order to calculate the wear trend, measurements have been performed with a MiniProf™ for a period of 12 months with the cars in traffic. During the same time period the trends of track forces from the two cars have been obtained from the research station, outside Luleå, Sweden.

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This research station is in operation to monitor track forces for all passing train wheels. Using the trends from wheel wear and track force and combine those with life cycle cost data a cost effective maintenance plan for wheels are achieved.

Figure 1. The iron ore line from Luleå to Narvik

Figure 2. LKAB iron ore train.

The designation on wheels and axles can be seen in figure 3, with our two cars always connected to each other at the A-end.

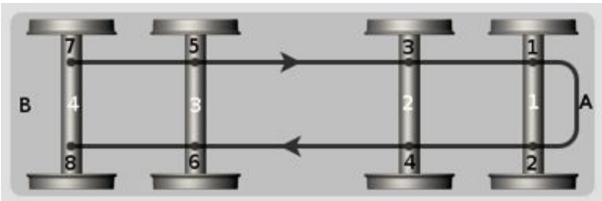

Figure 3. Measurement scheme and designation of wheels and axles.

Both of the test wagons in this case study are using three-piece bogies (AMSTEAD's Motion Control), see figure 4. It is called three-piece bogie since it comprises of one bolster and two side frames. This type of bogie uses non-linear frictional characteristic in the bogie suspension system. The suspension system in this structure is divided into primary and secondary suspensions [6]. The primary suspensions, or axle bearing connections, are acting in connection with the wheel sets and side frames. Meanwhile the secondary suspensions consist of some vertical nested springs in parallel with non-linear frictional damping component that is called “friction wedges” and are working in the coupling of bolster with two side frames. Efficient performance in track twist without loosing vertical wheel load is one of the advantages of this structure regarding vertical suspension [13]. In addition, it has cost advantages with respect to the number of suspension elements since suspension springs are limited to two nests. On the other hand, unsprung mass of side frames on the wheel sets and non-optimal dynamics of the bogie in lateral direction are main disadvantages of this structure.

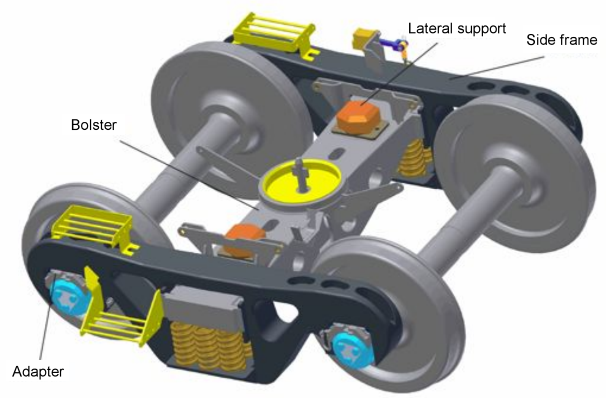

Figure 4. AMSTEAD's Motion Control [LKAB property]

The maintenance of the bogies is today mainly based on travelled distance. A computerised maintenance planning system uses RFID on the wagons and wayside antennas on their route to accumulate travelled mileage. The system can generate lists with wagons ready for overhaul. Daily manual inspection on the yard is used as a complement that identifies and pick out wagons not able to operate until next service based on mileage occur.

3. MEASUREMENT SYSTEMS

3.1 MiniProf^{TM}

The MiniProf^{TM} condition monitoring equipment is produced by Greenwood Engineering in Denmark. It is implemented by many railroads to monitor the wheel and rail profiles. The MiniProf^{TM} Wheel has the capability to calculate the flange thickness (S_d), flange height (S_h) and flange gradient (qR), see figure 5.

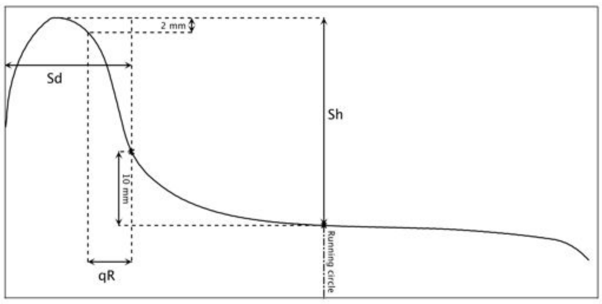

Figure 5. Explanation of Sh, Sd and qR calculation.

The MiniProf^{TM} has a sensing element that is connected to two joint elements, see figure 6. It measures the profile in polar coordinate with 2 degree of freedom but the computer calculates the profile in Cartesian coordinate [4].

In order to measure wheel profile, it is magnetically attached to the wheel. The back and top of the wheel are used as horizontal and vertical references respectively [4].

In this project, profile measurements of sixteen wheels were performed by MiniProf^{TM} to monitor wheel profiles regarding wear trend assessment, collecting information for wheel maintenance and optimizing profiles from the service life point, see figure 7.

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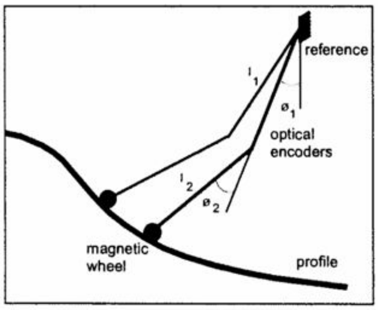

Figure 6. MiniProf™ measuring principle [4]

Figure 7. Wheel profile measurement by MiniProf™

3.2 Strain-based wheel impact monitoring

The strain-based system is composed of a series of strain gauges attached to the web of the rail [2, 12]. The strain gauges quantify the force applied to the rail through a mathematical relationship between the applied load and the strain caused to the rail web or rail foot. High-impact wheels are wheels that have an impact force of 400 kN or greater and most often they have a flat spot on the tread surface [12]. Other causes for high-impact forces are major defects in the tread surface and these have a higher probability of leading to catastrophic failure. The research station outside Luleå does not only measure impact forces from wheels but also lateral forces introduced by bad steering or by a non-optimal wheel-rail interaction. In figure 4 you can see how the measurement system at the research station is placed on the track. The outside rail of the track in a curve is called high rail and be seen as the closest rail in figure 8.

Figure 8. Picture of measurement system placement at the research station.

4. RESULTS

As it was discussed earlier, identical wheels with different ages were used in the case study. In figure 9, age distribution of the wheels after eight months (October 2009) from initiation of the test period is depicted.

At this time, October 2009, the train operator got an alarm concerning axle 3 in car 4044. When brought into the workshop for overhaul no clear indication of wheel wear was revealed. On axle 1 one wheel had loss of flakes of material from the wheel tread, called shelling. Hence these two axles were changed for newly turned wheels.

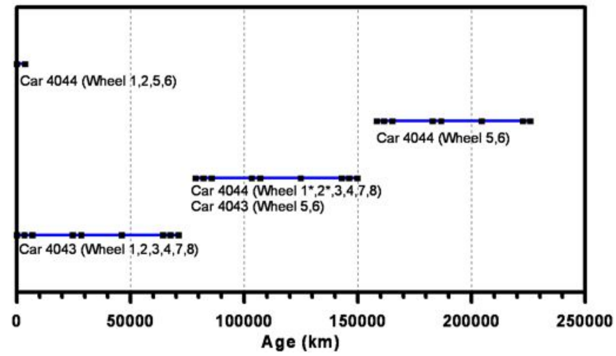

Figure 9. Age distribution of the wheels

To calculate the wear pattern from measurements data on each wheel, first of all, profiles should be aligned. For this purpose two points on flange section were selected to align along both x- and y-axis. Thereafter, vertical wear of each wheel profile was calculated compared to the new profile. To exemplify, vertical wear of wheels number 3 and 4 in car 4044 is illustrated in figure 10.

Despite of similarities between wheels, each wheel follows different wear pattern in the test, as it was shown in figure 10. Besides, our analysis confirmed severe wear magnitude in wheel tread section on wheels 5 and 6 in car 4044.

Afterwards, trend of wear criteria such as flange thickness (S_d), flange height (S_h) and flange gradient (qR) were assessed for all wheels. Figures 11 and 12 exhibit change of flange thickness (S_d) and height (S_h) of different wheels versus age. There is no obvious trend for S_d in figure 11 while particular raising trend in S_h is apparent in figure 12.

On the other side, the data from the research station tells us about the forces generated by the wheels into the track. The analysis has concentrated on evaluating the trend of quasi-static lateral forces based on the age of the wheels. As an example, changes in values of vertical and lateral forces versus age (km) are illustrated in figure 13 and 14.

Figure 13 shows vertical forces while figure 14 shows the lateral forces. The measurement of lateral forces in a sharp curve contributes with a lot of information about the steering performance of the vehicle and also changes in the wheel/rail contact point. However, the analysis must include knowledge of train speed, car travelling direction and weather conditions as they strongly influence the data. Newly turned wheels have a running-in behaviour where they start with medium high lateral forces of about 100 kN on leading axles with 30 tonnes axle load. That force drops and stabilises on a level of about 60-80 kN after 2-3 months in operation. These numbers all refer to a curve with radius of 484 m and a typical train speed of 60 km/h. When the wheel wear reaches a flange height (S_h) of about 34 mm the forces normally starts to increase once again. In this study we have not yet reached that limit.

Moreover, it is worth to mention that the analysis disclosed specific relation between variation of two criteria of S_d and qR. This relation is depicted in figure 15.

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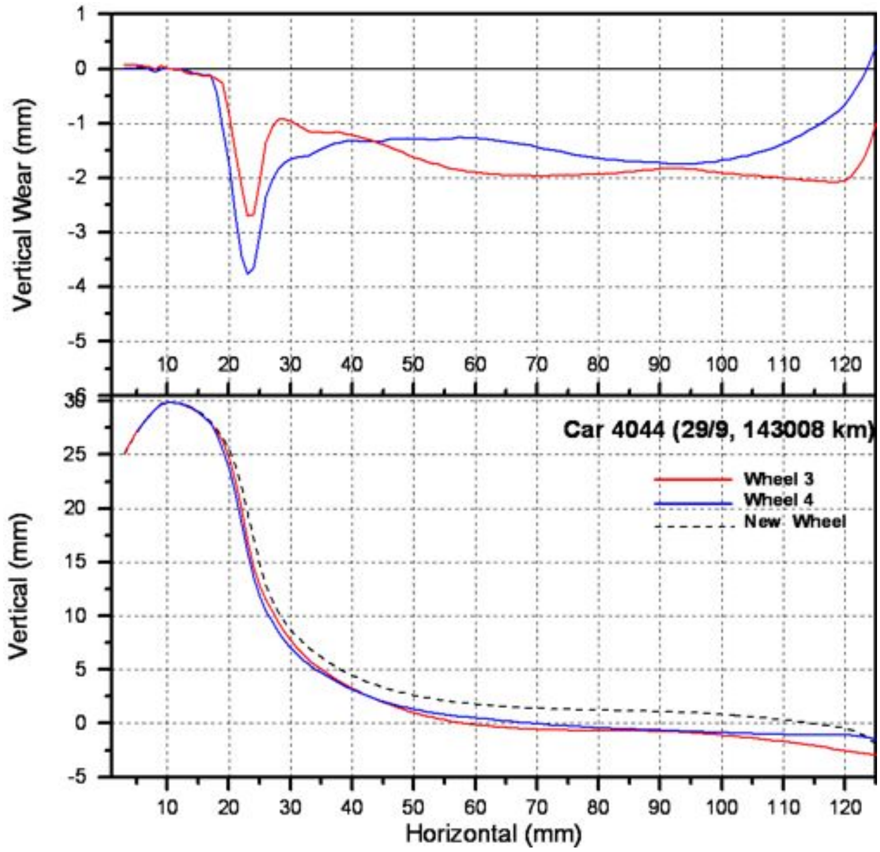

Figure 10. Vertical wear calculation of axle 2 in car 4044

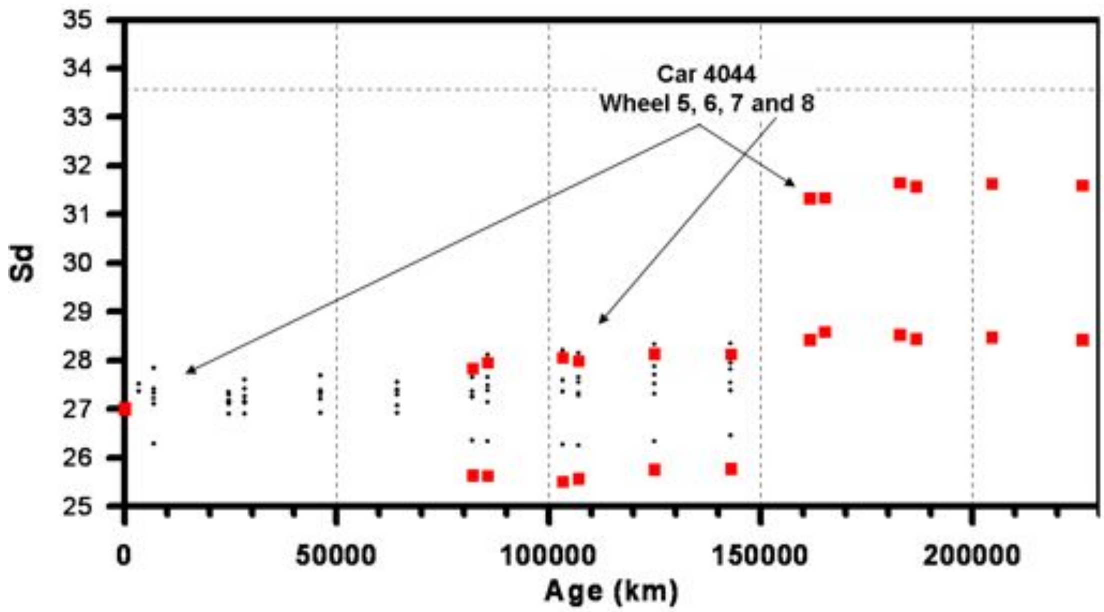

Figure 11. Flange thickness (S_d) versus Age (km)

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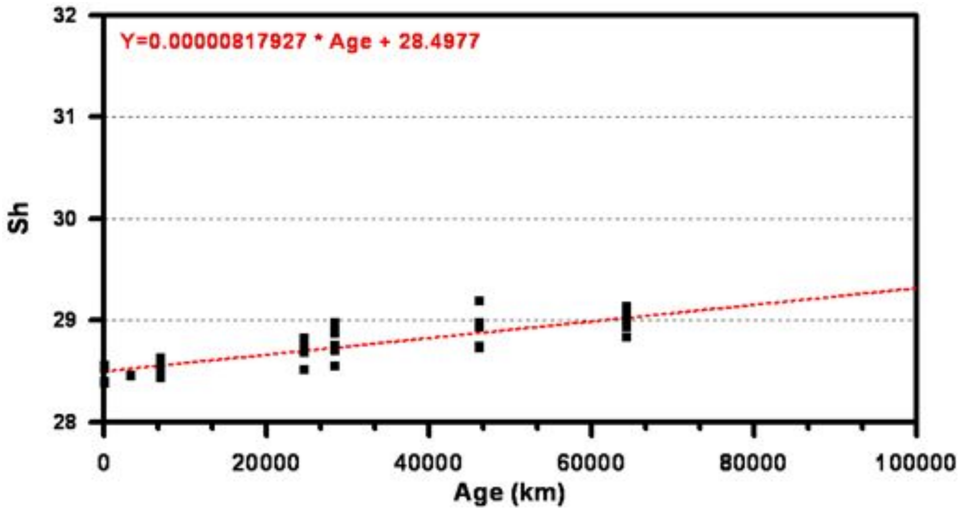

Figure 12. Flange height (S_h) versus Age (km)

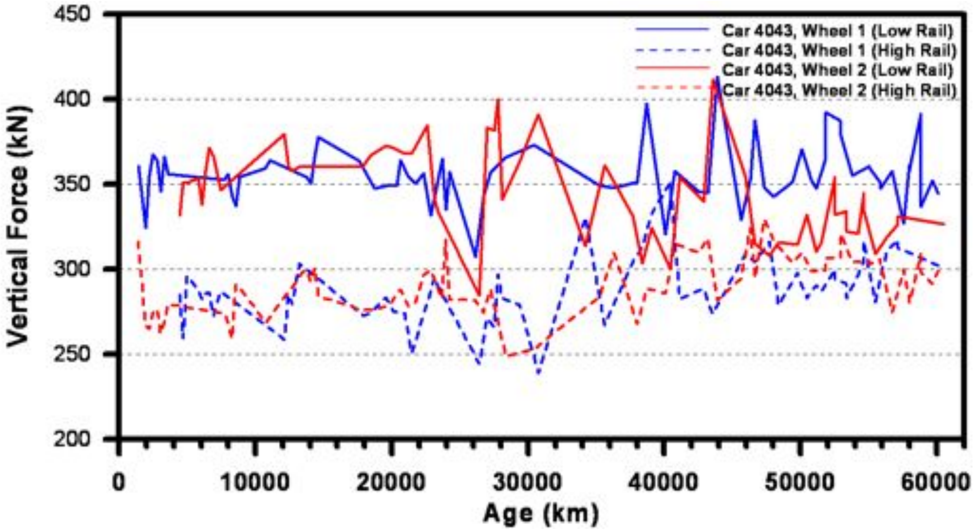

Figure 13. Vertical force (kN) versus Age (km)

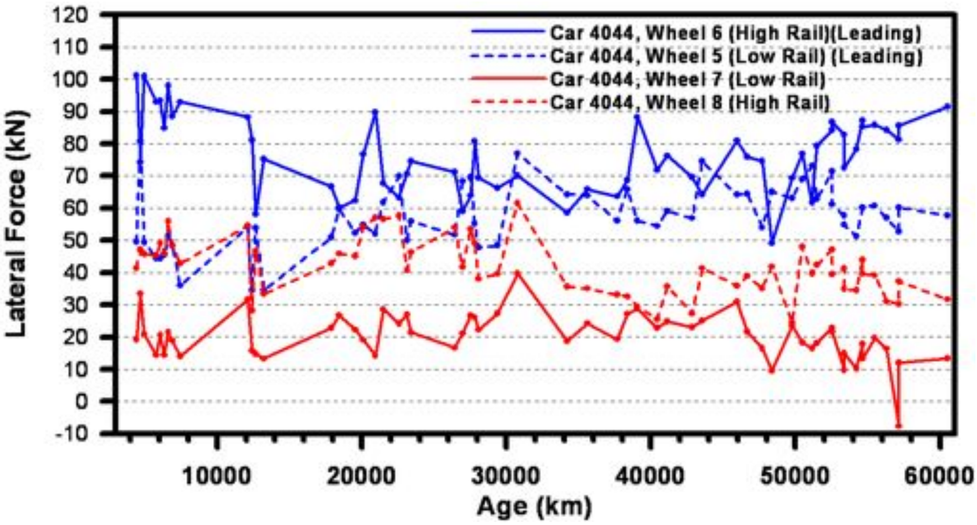

Figure 14. Lateral force (kN) versus Age (km) for a full bogie

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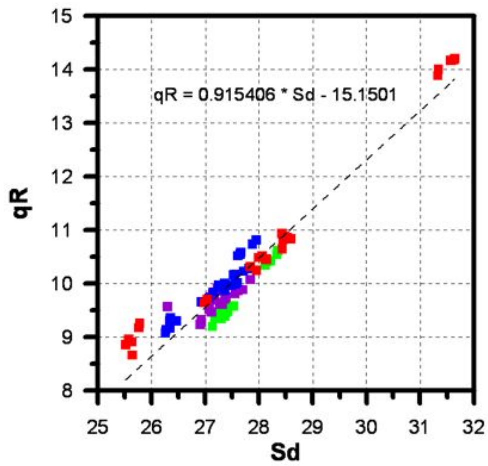

Figure 15. Flange thickness (S_d) versus flange gradient (qR)

5. DISCUSSION

Wear is a major failure mode in wheel sets and several researchers have tried to explore its mechanisms and proposed different models in order to predict wear rate [3, 5]. To foresee wear rate, it is required to have enough knowledge regarding wheel/rail interaction, track forces, track quality, track geometry (number of curves and their radiuses) and operating condition.

Result of analysis of wheel profile data disclosed that majority of the wheel sets have larger wear rate in flange region compared to wear rate in wheel tread area due to the contact between the flange and gauge face of the rail in curves. Flange region has a complex wear mechanism since it is subject to greater proportion of sliding than rolling contact [1]. On the other side, measurements data manifested hollow wear in tread region of some axles which the evident instance is axle 3 in car 4044, see figure 16. Our analysis confirmed that this axle had reached high level alarm for wheel change.

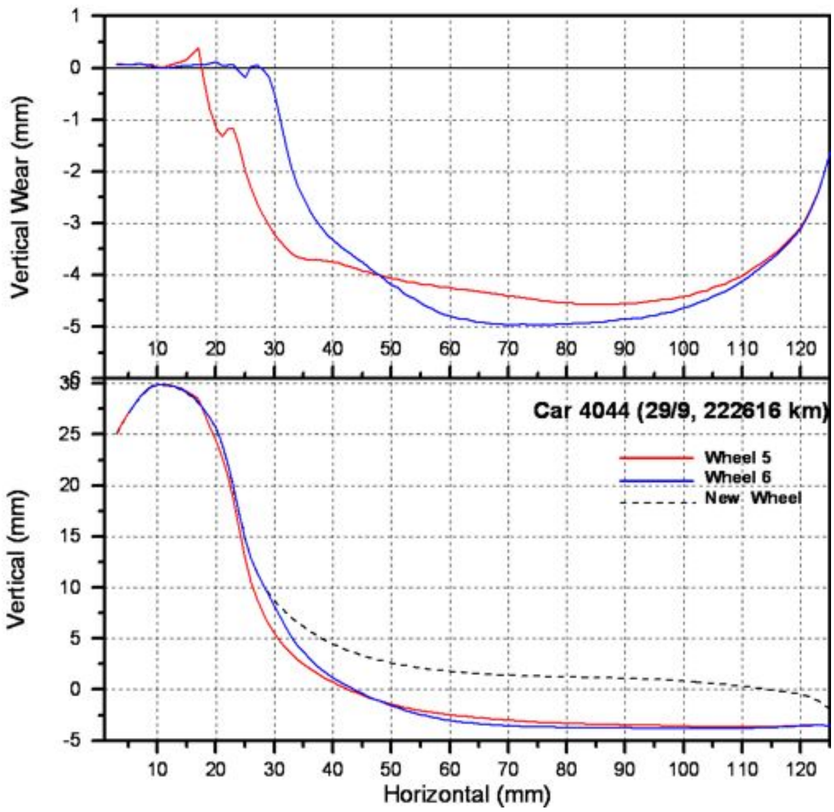

Figure 16. Vertical wear illustration of alxe 3 in car 4044

As it was discussed earlier, the wheel sets follow dissimilar wear pattern though they are similar. One of the potential causes of this phenomenon is bogie's effect. Axle position of wheel sets, which is dependent on bogie's type, has an important role on wear rate of wheel sets. In order to explore the effect of bogies, type of bogie, maintenance strategies for bogies and their degradation rate should be taken into account. Due to lack of data about these factors, the bogie's effect in this case study was not investigated and it can be a good subject for further research.

Our findings reveal that excluding of flange thickness which does not follow specific inclination; there is apparent rising trend in flange height through age increasing. This trend besides of relation between variation of S_d and qR can be implemented for maintenance decision making.

In general, an increase of track forces cannot be seen except of increasing trend of vertical force in some wheel sets. To enhance the life length of wheel sets it is essential to find the root causes of this specific trend on vertical forces and attempt to prevent or defer them.

By correlating trend of track forces and wear rate and considering their safety limits, the optimal maintenance thresholds for wheel sets can be identified. By implementing these thresholds and taking into account life cycle cost and risk factors, the cost-effective maintenance decision can be made.

6. CONCLUSION

Wear pattern of sixteen similar wheels were obtained by analysis of profile measurements data. Findings show that wheel sets follow different wear pattern. Moreover, flange wear was dominant wear on majority of wheel sets because of the

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contact between flange region and gauge face of the rail in curves.

Variations of wear criteria (S_d, S_h, qR) through running distance were discussed. Track forces were gathered from research station in order to assess any trend on them. The wheels seem to have a running-in behaviour during the first 2-3 months in operation where after the forces become quite constant. Weather conditions and train speed can influence the data. Wheel surface defects such as shelling do not influence the steering ability and the measured lateral forces.

7. FURTHER RESEARCH

The focus of this paper has been on wheel wear as a function on track forces either lateral or vertical. The only data available is from the research station and from the MiniProf™ condition monitoring equipment. There are no data regarding the condition of the bogie during this case study. The effects on wheel wear dependent on the condition of the bogie would be a start for further research.

8. ACKNOWLEDGMENTS

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