Optimisation of Rolling Stock Wheelset Life through Better Understanding of Wheel Tyre Degradation

I. Vermeij, T. Bontekoe, G. Liefting, and J. Peen

Abstract

Since the 1990's the fleet of the Dutch Railways showed a dramatic decrease in wheel tyre life. This lifetime reduction led to an unacceptable increase in life cycle costs. Therefore Lloyd's Register Rail has proposed to NedTrain to investigate the possibilities of improving the wheel tyre life.

Three improvements were determined as most promising and relatively easy to achieve:
- Profile optimisation for Rolling Contact Fatigue (RCF) reduction - a new wheel profile has been developed with a better resistance against rolling contact fatigue of the wheel tread. The profile has been implemented on single deck intercity trains and shows an increase in wheel tyre life of 30%.
- Selection of improved wheel tyre materials - combining information from literature and experiences of manufacturers five alternative wheel tyre materials have been selected and are now being tested in practice.
- Optimisation of the maintenance strategy - an alternative, preventative maintenance regime has been developed. With this Scraping regime, during short term maintenance every wheel is reprofiled. Higher mileages are reached and savings on life cycle costs up to 50% and more have been achieved. Unplanned maintenance goes down with 30~60%.

The results from field tests, using a reference group for comparison, and preliminary results after implementation show that the increase in wheel tyre life that is achieved with this project is significant. The results will continue to be monitored using the asset management tool 'WheelWatch', that was specially developed for this project and is also described in this paper.

Keywords : Rolling contact fatigue, Maintenance strategy, Asset management tool

1. Introduction

In the Netherlands, the passenger transportation on the main network is the responsibility of the Dutch Railways. Their fleet consists of approximately 150 electrical locomotives, 900 coaches, 580 EMU's and 100 DMU's which are maintained by NedTrain (part of the Dutch Railways). Unlike most countries, the majority of the wheelsets are tyred. Analysis of the maintenance data showed that the wheelset lifetime has decreased significantly during the last decade. This is shown in Figure 1.

The decrease in lifetime has resulted in higher life cycle costs for NedTrain. Lloyd's Register Rail investigated the possibilities for life cycle cost reductions of wheelsets.

The life of wheel tyres is influenced by a large number of parameters, but most parameters cannot be altered by the maintainer. The following three important parameters, which can be influenced by the maintainer, were selected by Lloyd's Register Rail:
1. Wheel profile
2. Wheel tyre material (currently B5T is used for most tyres)
3. Maintenance strategy

For these parameters an improved solution has been sought and found in order to significantly reduce the life-cycle costs. In this paper the results are presented.

2. Wheel Profile Optimisation

On some types of intercity rolling stock, cracks have been found left and right of the wheel running surface. These cracks are caused by rolling contact fatigue (RCF) and are strongly related to Head Checks (gauge corner
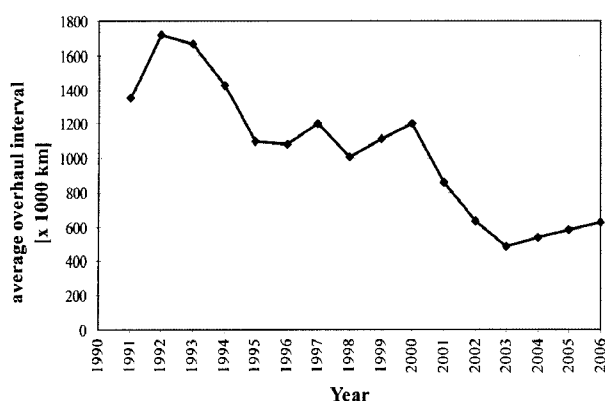
Lloyd's Register Rail Europe, Utrecht, The Netherlands

Fig. 1. Average Tyre Lifetime from 1990 - 2006 for NS Fleet

cracking) found in curves in the track. On wheels these cracks are a reason to reprofile the wheel tread. Because the cracks sometimes occur as soon as the first short term maintenance interval, this significantly influences the wheel tyre life. To increase wheel tyre life Lloyd's Register Rail has developed a new wheel profile to best match the track conditions.

For the development of the new wheel profile, an efficient combination of practice and theory has been used. Theoretical analysis is important to make sure that only feasible profiles are tested in practice. Practical analysis is inevitable, because it is impossible to simulate every aspect of the outside world, especially with limited resources.

Simulations have been performed using computer modelling. Measured wheel profiles, after different mileages, were used as an input to the models. These wheel profiles are not only considered to be stable, i.e. no excessive wear, but they also do not lead to unstable vehicle behaviour.

For a first selection of profiles, an in-house developed program (using Matlab) was used to simulate the quasi-static effects. The commercial multi-body software ADAMS/Rail was then used for the final selection of the profile, putting dynamic effects into the equation. The selected profile was tested on two types of intercity trains to establish the actual delay of crack growth in the wheel. The results of these field tests showed a significant improvement and were reason for NedTrain to introduce the new profile (HIT-profile) in the workshops.

From September 2005 the HIT-profile has been the default profile for all intercity train sets. The introduction of the HIT-profile has led to an increase in wheel tyre life of up to 30% for the entire single deck intercity fleet. This has mainly been achieved by reducing RCF cracking, but also by reducing flange wear. Because the additional costs of turning a different profile are minimal, the cost reduction is of the same magnitude.

3. Selection of Improved Wheel Tyre Materials

In order to specify an improved wheel tyre material, it is necessary to know which material properties determine the lifetime, i.e. which degradation type you are optimising for. From the available information it turned out that for the majority of the wheels "out of roundness" and "squats" are the main cause for a limited tread lifetime. Based on information in literature, together with experiences of railway operators, wheel tyre manufacturers and research institutes, the properties of the desired wheel tyre have been formulated. In general terms materials are sought with an improved homogeneity, a fine grain size, a high degree of purity and a high fatigue resistance. However, the development of such a new steel grade would be too complicated, time consuming and costly. Therefore promising existing steels have been selected based on the identified improvement directions. Next five batches of 120 wheel tyres have been ordered at three different manufacturers. As the alternative wheel tyre materials are not strictly within the UIC standards, an amount of mechanical testing has been performed to determine safety related properties as strength, fracture toughness and crack growth properties.

Currently all 600 tyres have been placed on a variety of rolling stock. The behaviour of the different batches is being monitored using a specially developed software tool. This tool is described in more detail later in this paper. As a reference material B5T tyres will be monitored in the same way. Before statistical reliable data can be obtained, the wheelsets should at least have passed a few maintenance intervals. It is estimated that in the course of 2008 the first results will become available. Based on the field test results a Life Cycle Cost analysis will be performed for all materials and the optimal material will be selected for implementation.

4. Optimisation of the Maintenance Strategy

4.1 Current maintenance concept

The general maintenance concept for tyres at NedTrain is shown in Figure 2. It shows the situation in 2004, when one out of five wheelsets with wheel defects is overhauled every short term maintenance (top flow). The remaining wheelsets are reprofiled on the wheel lathe. Overhaul takes place because the wheel tyre is too thin.

The maintenance is condition based and may take place planned during short term maintenance or unplanned when wheel defect levels are exceeded. In both cases, the input from the track based wheel impact monitoring system
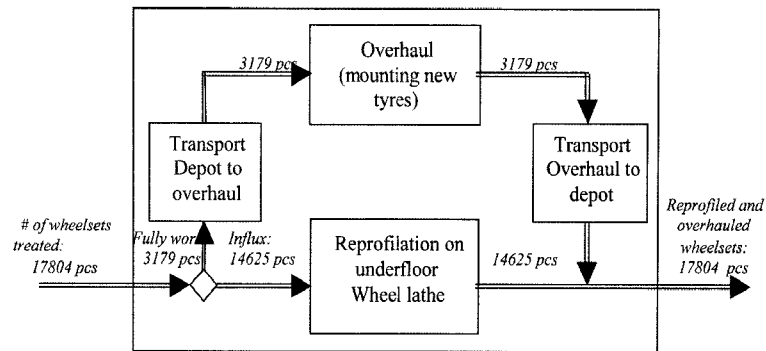
Fig. 2. Flow Diagram of Wheelsets in the NedTrain Organisation

Gotcha is used (Figure 3). See www.gotchamonitoringsystems.com for more information on this system.

With the Gotcha system the wheel quality of the trains is measured at least once per day during normal operation. If the wheel quality gets below a certain level, wheelset maintenance will be planned. Within a predefined time the train will be sent to the wheel lathe.

During short term maintenance all wheels are visually inspected on surface defects. Additionally the data of the Gotcha system are analysed. When defects lie outside the acceptance criteria, the corresponding wheels are turned on the wheel lathe.

In case the tyre thickness is insufficient for another reprofiling, the wheelset is removed and sent to the overhaul workshop of NedTrain (see Figure 2).

The maintenance concept described above has two disadvantages:

1. it is not optimised for life cycle cost
2. there is no closed control loop present

The second disadvantage has no direct influence on the maintenance, but it is very important to monitor the performance of wheelsets on a regular basis in order to make timely adjustments when mileages decrease.

4.2 Life cycle cost analysis
The current maintenance process as shown in Figure 2 is

not optimised for life cycle costs, but is does give an impression of where the highest costs are being incurred. To determine the most important cost drivers and their sensitiveness to changes, a life cycle cost model has been produced.

The model showed that the wheel reprofiling costs are more or less fixed and are composed of personnel and machines. In this model the personnel expenses at the wheel lathe are considered to be fixed because the wheel lathe has to be available the entire day. The overhaul costs on the other hand have a very high component of variable costs, composed of mainly personnel and materials.

Another interesting finding was that the wheel lathe was occupied less than 50% of the time. This opened up the possibility to change the wheel lathe regime in order to increase the lifetime of wheelsets until overhaul.

5. Scraping Concept

The condition based maintenance at NedTrain was developed to maximise the reprofiling intervals. This does not necessarily lead to the maximum wheelset mileage and
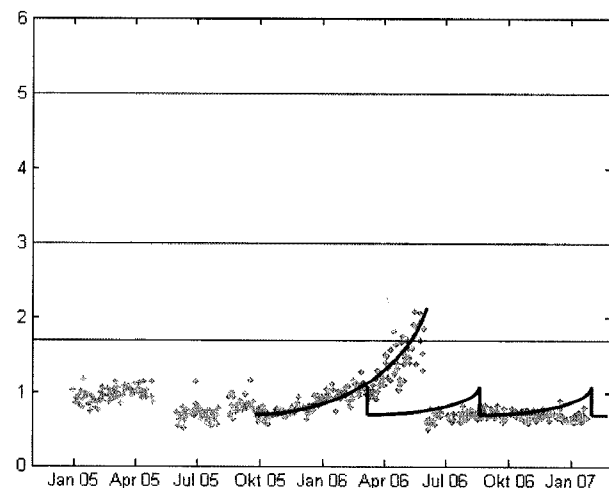

Fig. 3. Gotcha Track Based Monitoring System

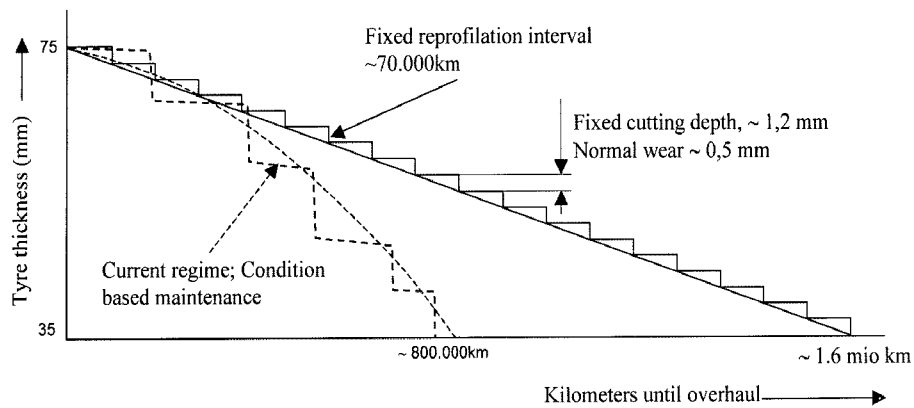**Fig. 4.** Progressive Growth of a Wheel Defect (as Measured by Gotcha System)

Fig. 5. Scraping Principle (Dashed Line Represents Current Regime)

minimum life cycle costs because more material has to be removed during the reprofiling. Especially during the last part of the degradation curve accelerated wheel tread degradation is normally observed. This can be nicely viewed in Figure 4.

The figure shows data from the Gotcha system. The dots all represent a single measurement. Maintenance on the wheel lathe took place in June 2006, after the wheel defect value crossed the first horizontal line. If the wheel would have been turned in March 2006, during short term maintenance, significantly less material would have had to be removed (black "saw tooth" line). During condition based maintenance, the average cutting depth is 6 to 7 mm.

The scraping principle belongs to the preventative maintenance category. Every short term maintenance all wheels are reprofiled, with a cutting depth of around 1 mm. The result is that wheels remain round and consequently the dynamic load during their life cycle is lower. Defect initiations like small cracks and pitting are removed in an early stage. Relative large cutting depths due to damage accumulation are prevented. Using a small cutting depth, the work hardened layer is not removed and this results in a slower development of out of roundness. The scraping principle is shown in Figure 5.

Besides the benefits of the scraping principle described above, there are some additional benefits. One benefit is that due to the small cutting depth it is now possible to use more of the tyre thickness. With an average cutting depth of 6 to 7 mm, tyres will in most cases not be used until their lower thickness limit of 35 mm. With an average cutting depth of 1 mm it is still possible to run another few terms after the tyre becomes thinner than for instance 40 mm. This leads to an estimated mileage increase of 15%.

Another benefit of scraping is a reduction of unplanned maintenance. Due to the scraping principle a significantly higher wheel roundness is achieved. Damage accumulation by small wheel flats does not lead to unplanned main-

tenance, because wheels are reprofiled timely. Field tests with the EMU intercity fleet of NS have shown a reduction in unplanned maintenance of approximately 40%.

Summarising, the scraping principle has several economic advantages compared to the condition based maintenance regime used by NedTrain:

- reduction of unplanned maintenance and consequently increase in availability of trains
- better utilisation of wheel lathe capacity where extra costs are marginal
- significant decrease in wheelset overhaul costs due to increased wheelset life time
- short term maintenance becomes more planable

6. Practical Verification

In the first quarter of 2006 a field test was started with the scraping regime. Two VIRM double deck intercity EMU's (24 axles, average axle load of 14.3 ton) and four ICM single deck intercity EMU's (16 axles, average axle load of 12.3 tonnes) were being maintained according to the scraping principle. Both vehicle types are shown in Figure 6.

In Figure 7 the defect value growth for a single wheel, as measured by Gotcha, is shown. In February 2006 this wheel was introduced into the scraping regime. In the situation of condition based maintenance, the defect value increases in time, while with scraping the defect value

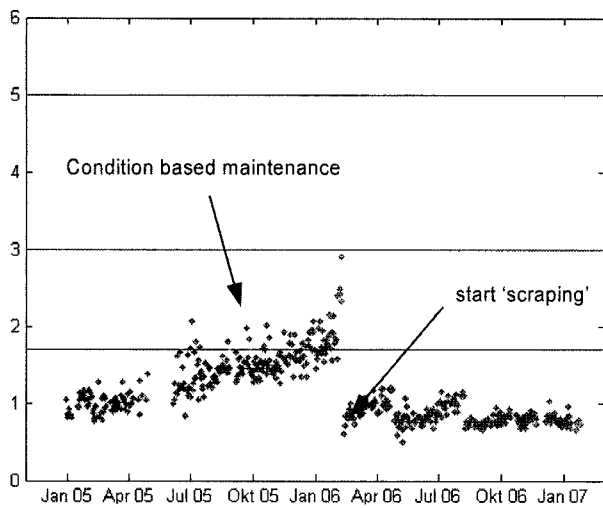**Fig. 6.** VIRM Double Deck Intercity (left) and ICM Single Deck Intercity (Right)

Fig. 7. Defect Level Growth for Single Wheel before and after Introduction of Scraping

continues to be on a low level. This is observed in almost all wheels in the field test.

During the same field test it was also discovered that there have been train sets with malfunctioning Wheel Slip Protection (WSP) systems. This was observed in the Gotcha data. The WSP problem can be recognised by extremely fast increasing defect values. An example is shown in Figure 8, where five or six different occasions of WSP failure can be observed. After each failure the wheel has been reprofiled but the WSP problem was not detected.

After this successful field test more intercity trains have been introduced into the scraping regime. These train sets have been monitored with a specially developed asset management tool. Again very good results were obtained and as a result NedTrain decided to introduce scraping for all intercity train sets. The total increase in wheelset life is established to be 61% for VIRM double deck train sets and 35% for ICM single deck train sets. The reduction of unplanned maintenance was also proven to be significant,
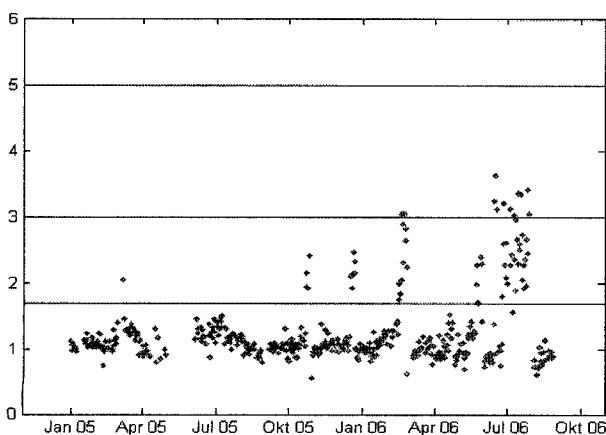
around 36% for VIRM and 54% for ICM.

7. Asset Management Tool WheelWatch

The control loop for wheelset maintenance is currently not closed (there is no feedback) and so a method had to be designed to measure the achieved wheelset life increase. For this purpose a special asset management tool has been developed for NedTrain: "WheelWatch".

For the WheelWatch tool, existing data sources are used as input. Within NedTrain the following databases were available for this purpose:

· R5 database; contains maintenance and overhaul data (most important for WheelWatch are the measured tyre thickness and mileage)

· Gotcha database; contains the wheel quality as measured by the Gotcha system for all wheelsets

Using these data sources, different graphs were generated. Important for these graphs was that changes in achieved life time should become visible as quickly as possible. For instance, the graph shown in Figure 1 is not sensitive to sudden changes. Changes can be visualised much quicker when plotting the average wheel tyre thickness of a predefined batch of wheelsets against the mile-
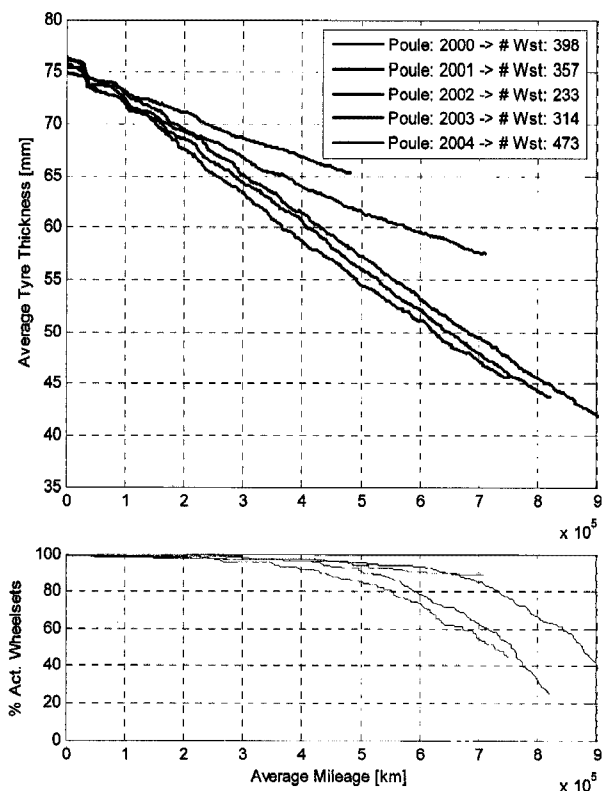

Fig. 9. Example of Average Reduction of Tyre Thickness for Different Batches of Wheelsets as a Function of the Mileage [Different Colours Represent Different Batches (Poule) of Wheelsets (Wst)]
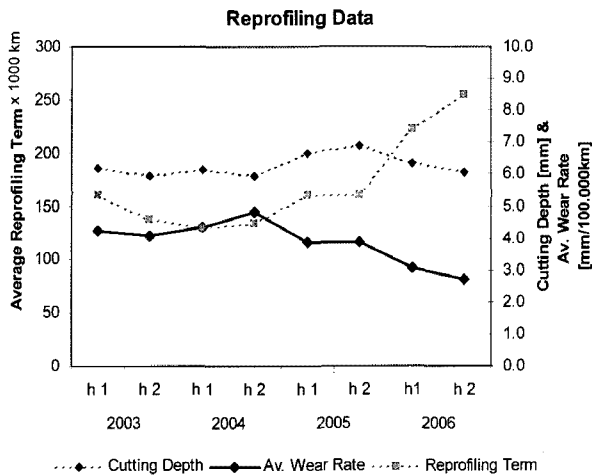

Fig. 8. Detected WSP Problem

Fig. 10. Average Reprofiling Data (Per Half Year)

age. An example is shown in Figure 9. The upper part of the figure shows the decrease of the tyre thickness (starting around 75 mm, with a minimum allowed thickness of 35 mm) for five different batches of wheelsets. It can be clearly seen that the batches from 2003 and 2004 show significantly better results than the older batches. The lower part of the figure shows the percentage of wheelsets in a batch that are still active. This provides information on the statistical distribution of life time within a batch.

Using these graphs it is possible to compare the performance of different types of rolling stock or different wheel tyre material batches. Another method of presenting performance data that is used in the WheelWatch tool is shown in Figure 10.

The figure shows the average cutting depth, reprofiling term and wear rate in millimetres per 100.000 km. This is averaged for every half year. The wear rate is comparable to the derivative of the line shown in Figure 9.

With the 'WheelWatch' tool it is also possible to gener-

ate plots of Gotcha data. An example of such a plot is shown in Figure 8: detected WSP problem for a single wheel. These plots can also be made for batches of wheels, clearly showing the differences in wheelset performance.

8. Conclusions

Part of the work described in this paper has already been implemented and the results show that an impressive reduction in life cycle costs have been more than achieved.

The alternative wheel profile for single deck intercity trains has led to an increase in wheel tyre life of 30%. This is mainly achieved by reducing the RCF cracks next to the running surface and by reducing flange wear.

Use of alternative wheel materials is still in the phase of field testing, but significant improvements are expected. Five batches of wheel tyre materials have been placed on different train series. The first results will become available in 2008.

The alternative maintenance regime using 'Scraping' has been developed and implemented. With this preventive maintenance regime all wheelsets are reprofiled during short term maintenance. Monitoring results with the asset management tool 'WheelWatch' show an average increase of wheel tyre life of 48% and an average decrease in unplanned maintenance of 45%.

This project has been successful because a life cycle cost model has been used as a basis to determine the aspects to improve. The research was not purely theoretical, but it had to be possible to implement results in practice. This has already been shown, because the wheel profile and the Scraping regime are partly implemented in the NedTrain organisation. The final key to success is that the research has been performed in an integral project - the influence of one aspect on the other has been analysed.