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Wheel-Rail Profile Dynamic Interaction a Conditional Optimizing Methodology using Conicity Function

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Abstract*— Optimization methodology used by this paper has improved wheel – rail interaction in five of the most important dimensions characterizing railway dynamics, according the most prominent scholars. This paper combines conicity minimizing functions with dynamic simulations in order to achieve the conditional optimization of railway interactions between wheel and rail profiles. By using advanced algorithms, has been possible to prove that the optimization methodology designed from this paper achieves to optimize wheel – rail profile dynamics without making tradeoff between the above objectives of an optimized rail contact: Minimized stress contact, minimized wheel wear; reduced dynamic insecurities; appropriate conicity; encompasses the maximum possible segments across the railway.

***Index Terms*—Optimization, Conicity, Railway Interactions, Dynamics.**

I. INTRODUCTION

This paper aim to contribute to one of the most important problems identified in the railway dynamics: wheel rail profile interaction. As several scholars agree significant improvement has been achieved in several railway design dimensions, except that the mechanical dimension of railway wheel set is still problematic and has not yet come to a final optimum solution (Esveld, Markine, & Shevtsov).

The problem of optimizing wheel – rail optimization is one of the most difficult ones, that no prior analytical model has achieved to predict and include in itself all needed variables (Shevtsov, Markine, & Esveld, 2006).

II. OBJECTIVE

This paper objective is to optimize dynamic interaction between wheel and rail profile. But, what does it mean optimization? There are many definitions, if we refer to different authors. According Esveld, Markine, & Shevtsov (2009) have reduced the problem of optimization in minimization of wheel wear. Magel and Kalousek (2002) have defined optimization problem, more broadly by frame working it as the function that accomplish the following criteria:

- Minimizes stress contact
- Minimize wheel wear;
- Reduces dynamic insecurities;
- Establishes appropriate conicity;
- Adjust the maximum possible segments across the railway.

In this paper we will aim at designing a function which the five satisfaction optimizing criteria established by Magel and Kalousek (2002

III. WHEEL – RAIL INTERACTION CONCEPTS: PREREQUISITE OF A FUNCTION OPTIMIZATION APPARATUS

In order to be able to design an optimized function of train wheel profile we should first briefly discus the concept of the rolling radius. In the above picture most important characteristics of wheel – rail interaction are explained. Wheel rolling radius

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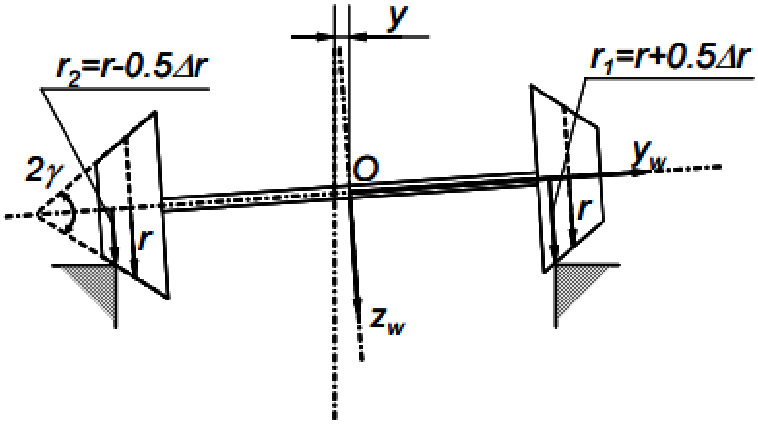

Fig 1 Wheel – rail interaction

In the above figure, we have

1 r - left wheel Rolling radius

2r - right wheel Rolling radius

Y - Wheel set displacement.

γ - Wheels conicity

RRD is described as the single contact point among wheel and rail profile Second, most important definition needed to be explained is: lateral displacement function. According Esveld (2001) it's analytical form is as following: Δr (y) (The rolling radius difference (RRD)) $\equiv r_1(y) - r_2(y)$ Thirdly, train wheels conicity according Burstow (2015 is the most important function concerning wheel- rail dynamics, because it numerically estimate the geometric relationship of the profiles[1] According Shevtsov (Wheel/Rail Interface Optimisation, 2008) it's analytical form is as following:

$$\gamma = \frac{r_1 - r_2}{2y} = \frac{\Delta r}{2y}$$

IV. MATHEMATICAL APARATUS OF THE PAPER

The wheel – rail profile optimization function, according to this paper derives from the function that describes the shape which has the so called: optimal equivalent conicity. Method of minimizing the difference between two functions is chosen Least Mean Square method. Given above background, the function needed to optimize in wheel rail profile interaction is:

$$f = \sum_{i=1}^{m} \left[\left(\lambda_j^{des}(y_i) - \lambda_j^{obs}(y_i) \right) \right]^2$$

λ_j^{des} - desidered conicities

(yi) - A lateral displacement

λ_j^{obs} – observed (factual) conicities

In order to optimize the above function, minimization between two curves is needed.

$$OPTIMUM = min \sum_{i=1}^{m} \left[\left(\lambda_j^{des}(y_i) - \lambda_j^{obs}(y_i) \right) \right]^2$$

In order to calculate and solve the problem of optimizing, Multipoint Approximations based on Response Surface fitting (MARS method) has been implemented. Conditions that restrain this optimization problem are: Minimizes stress contact, minimized wheel wear; reduced dynamic insecurities; appropriate conicity; encompasses the

[1] It is required to allow wheels to steer around curves ► Higher conicity allows vehicles to be guided round sharper curves without flange contact- reduced wear; High conicity leads to instability on straight track and shallow curves • Small perturbations in the track cause the wheelsets to oscillate

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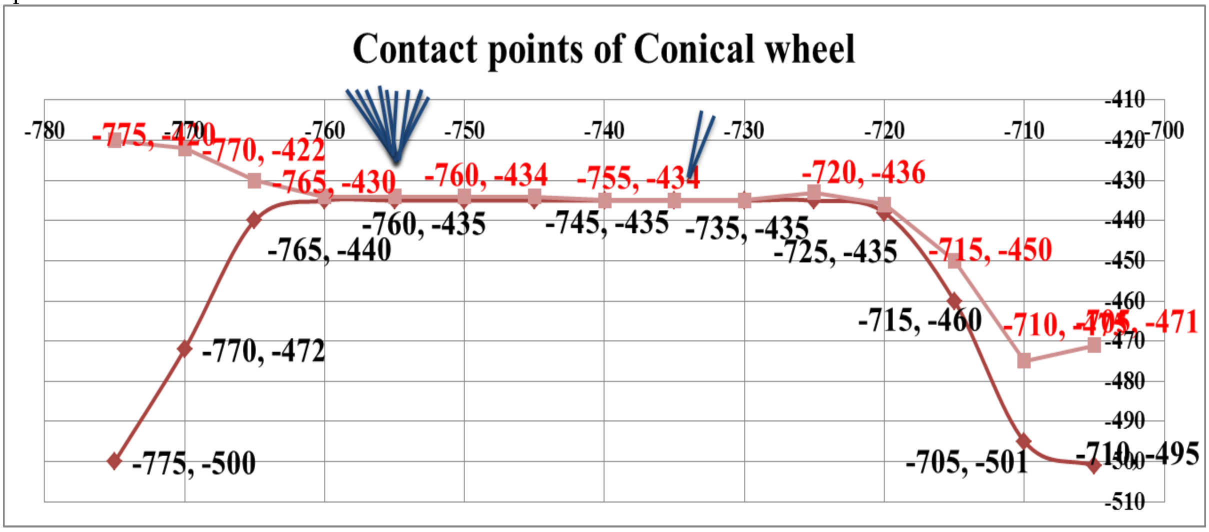
maximum possible segments across the railway. In general, in optimization problem, dynamic analysis follows a statistic analysis; but in this paper only dynamic procedure will be the focus.

V. RESULTS

A. *Contact surface*

As previously discussed contact between wheel and rail is one of the most important indicators revealing efficiency after applying an optimization methodology. The greater the contact between wheel and rail, the better the curving behavior of the wheel; when keeping into consideration that in such conditions we accept the speed and stability of the train in lower parameters. In the below pictures are visually demonstrated contact points of conical wheel before and after applying optimization procedure. After several dynamic simulations, the following case was judged to be representative[2] of the sample taken into consideration.

If we compare contact patches pre (original) and after optimization (desired) function, we can conclude that (1) the optimized wheel's has greater surface tread compared to that of the original wheel, and (2) the 2'nd contacting segment is positioned in a larger distance compared to that of the original wheel. Of course, these results indicate a positive development of wheel – rail interaction, derived from improvement and optimization of conicity function. Increase of assembly of contact points between wheel and rail profile implies several advantages, e.g. better curve handling of the road and decreasing wear wheel. In the following sections wear will be focus of specific discussions.



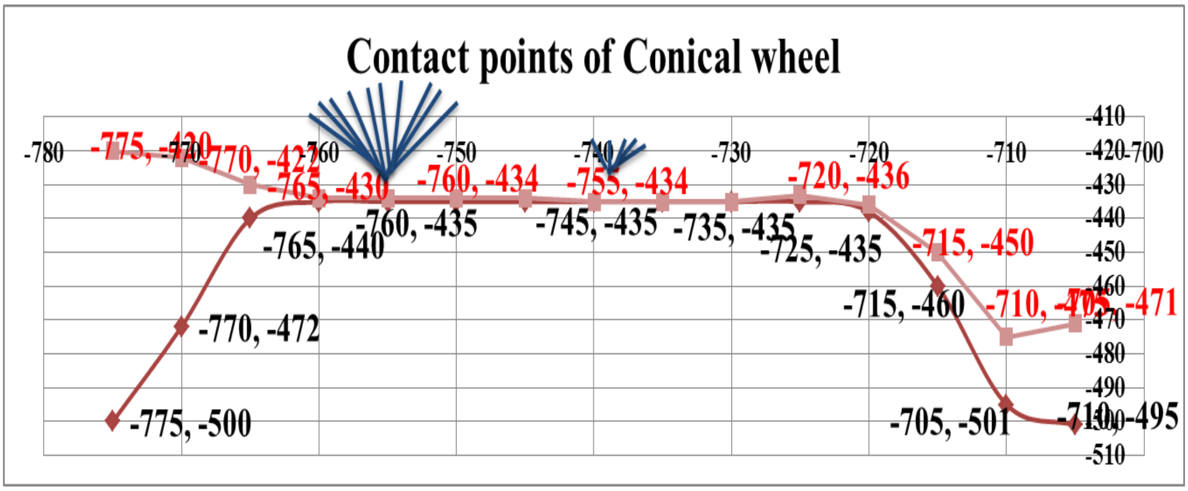


Fig 2 Contact points of Conical wheel in optimized and original conditions

[2] Representative here has the meaning of differences in the contact situation, and may be extrapolated to other curve radii analysed.

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Wear coefficient and derailment risk

Wear coefficient[3] is the coefficient indicating the material surrounding the contact surface of the wheel with the rail profile. While, derailment risk[4] is a measure of safety, it measures the probability of a derailment due to damage on rail and/ or wheels. In two pictures presented below it is visually presented RRD relationship with both: wear coefficient and derailment risk in original wheel and in optimized wheel.

The most representative wheel to be analyzed was decided to be those belonging to the first wheel set. Given the below results, it is clear that we have (1) decreased wheel wear after optimization according conicity function, and (2) decreased derailment risk after optimization according conicity function. As is showed, from the below table the maximum difference between original wear coefficient and optimized wear coefficient is 78.88% (Representing approximately 3/4 reduction in wear coeficient due to optimization process of the wheel), and the minimum difference between original wear coefficient and optimized wear coefficient is 20%% (Representing approximately 1/5 reduction in wear coefficient due to optimization process of the wheel). As may be observed the greater the RRD the smaller the improving effect of optimization of the wheel.

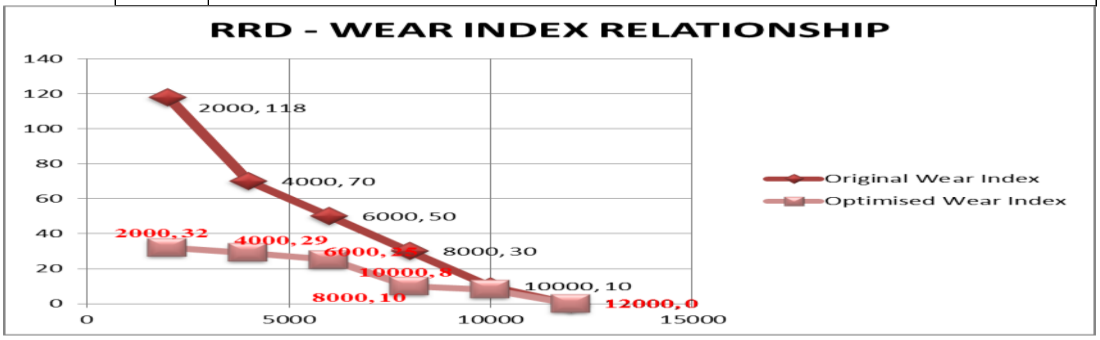
Table 1 Difference between Optimized Wear Index and Original Wear Index

RRD	**Difference between Optimized Wear Index and Original Wear Index**
2000	-72.88%
4000	-58.57%
6000	-50.00%
8000	-66.67%
10000	-20.00%

Furthermore, in terms of derailment risk we may say that significant changes have taken place after optimization of the wheel according this paper methodology. The maximum difference between original derailment value and optimized derailment value is 50% (Representing half reduction of the risk for derailment at a 12000 RRD due to optimization process of the wheel), and the minimum difference between original derailment value and optimized derailment value is 20%% (Representing approximately 1/5 reduction in derailment risk at 8000 RRD due to optimization process of the wheel).

Table 2 Difference between Original Derailment risk and Optimized Derailment risk

RRD	**Difference between Original Derailment risk and Optimized Derailment risk**
2000	-42.86%
4000	-41.67%
6000	-31.25%
8000	-20.00%
10000	-33.33%
12000	-50.00%



[3] *W* =**t** ***v. Where t** represent creep force and **v** represent creepage.

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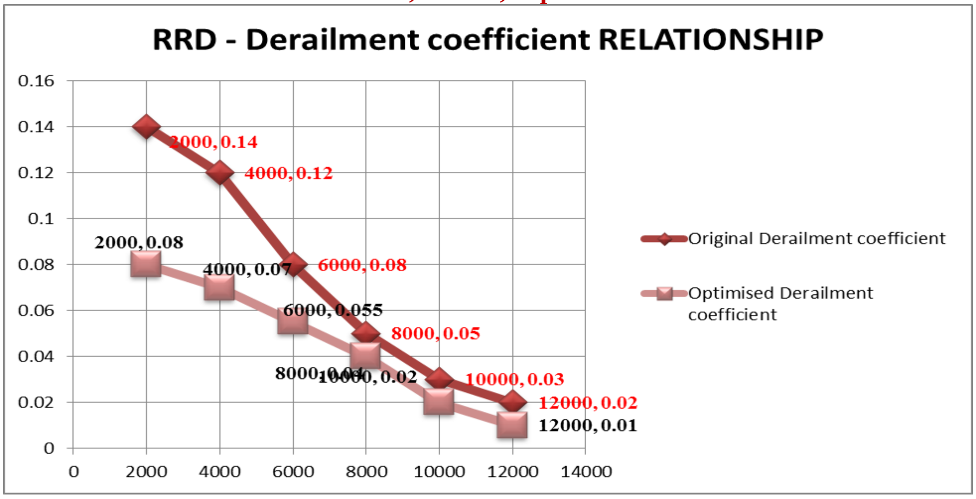

Fig 2 Wear coefficient and Derailment risk in original and optimized conditions

Stress contact

The indicator of contact stress is so important that some scholars have modeled wheel rail contact optimization by using contact stress as reference function to be minimized (Smallwood, Sinclair, & Sawley, 1990) The reason why stress contact among wheel and rail profile is intended to be minimized is because high values of this indicator may influence the creation of damages in the physical component material. As with the above indicators, visual and numerical comparisons between target and observed values of stress contact index has been conducted. From the below data (Table and Figure) it is clear that for all RRD rates, observed values of stress contact are greater than optimized values of stress contact. Even in terms of stress contact index optimization methodology used by this paper has improved wheel – rail interaction.

Table 3 Difference between Optimized stress contact and Original stress contact

RRD	Difference between Optimized stress contact and Original stress contact
2000	-36.36%
4000	-20.00%
6000	-25.00%
8000	-10.00%
10000	-20.00%
12000	-16.67%

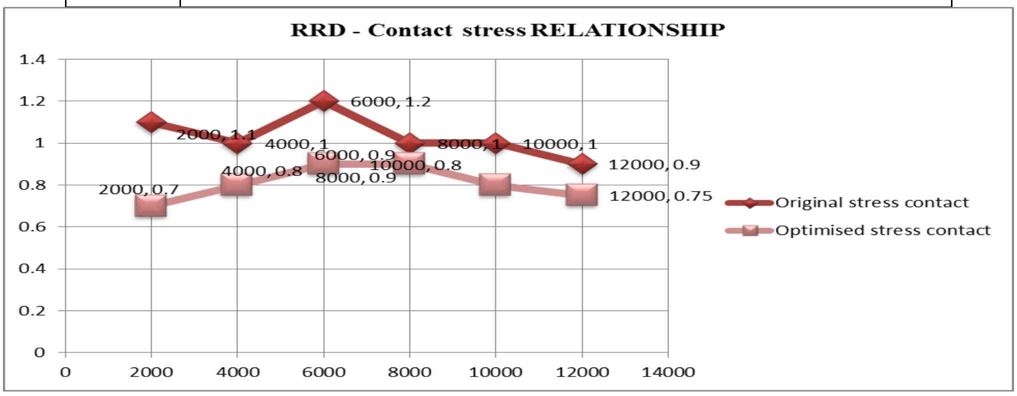

Fig 3 RRD - Contact stress RELATIONSHIP

[4] (*L*/*V*). Where L represent lateral force and V represent vertical force

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VI. CONCLUSSION

Due to conditional optimization of the analytical function based on conicity

$$OPTIMUM = min \sum_{i=1}^{m} \left[\left(\lambda_j^{des}(y_i) - \lambda_j^{obs}(y_i) \right) \right]^2$$

has been possible to optimize wheel – rail profile dynamic interaction in terms of Magel and Kalousek (2002) package of five criteria's.

Main achievements if this optimum methodology is used are:

- Greater surface tread of the optimized wheel's compared to that of the original wheel.
- Second contacting segment of rail wheel contact is positioned in a larger distance compared to that of the original wheel.
- Wear coefficient of optimized wear coefficient can be reduced from 20% to 78.88% due to optimization process.
- Derailment value of optimized wear coefficient can be reduced from 20% to 50% due to optimization process.
- For all RRD rates, observed values of stress contact are greater than optimized values of stress contact.

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