

CHARACTERISTIC PARAMETERS OF NONLINEAR WHEEL/RAIL CONTACT GEOMETRY

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Abstract

Equivalent conicity is widely used to characterize the wheel/rail contact geometry; however, it does not consider the contact nonlinearity. There is a need for an improved but still simple description which considers the most important effect of the contact nonlinearity on the running dynamics of railway vehicles. This paper demonstrates the influence of the contact nonlinearities on the behaviour of railway vehicles at stability limit and proposes a description of wheel/rail contact geometry using two parameters. The proposed characteristic parameters are compared on examples of wheelset/track pairs and the correlation between the proposed parameters and the vehicles' behaviour presented.

1. INTRODUCTION

The contact geometry between wheel and rail or wheelset and track, respectively, has an important influence on the running dynamics of railway vehicles. The real contact geometry wheelset/track changes not only due to variations of the rail profile shape on different track sections but also due to the deviation of track gauge, rail inclination, rail irregularities in vertical and lateral directions as well as by the flexibility of rail support.

The main parameters influencing the contact geometry wheelset/track are the profiles of wheels and rails, rail inclination, back-to-back distance of wheels and track gauge. These parameters are typically used for an assessment of the contact geometry or as the input data for multi-body simulations of railway vehicle dynamics. Because of large scatter of the wheel/rail contact geometry due to wear of wheels and rails and due to track gauge deviations, a suitable, simplified parameter is required to assess the contact geometry. The equivalent conicity – a parameter originating from the linearization of the wheelset/track coupling – is widely used by the railway community to characterize the contact geometry. This parameter is introduced in EN 14363 [1] and UIC Code 518 [2] dealing with the wheel/rail contact geometry assessment during the testing for vehicle acceptance. It is also used in Technical Specifications for Interoperability [3–5] to characterize the track (combining the measured rail profiles with theoretical wheel profiles) or the geometry of worn wheel profiles (combining the measured wheel profiles with theoretical rail profiles), respectively.

In last decades, the progress in nonlinear dynamics of railway vehicles has contributed to recognize the effects of the nonlinearities wheelset/track on the behaviour of vehicles. Several papers present investigations related to the influence of nonlinear wheel/rail contact geometry on the stability of railway vehicles. The parameters used to change the wheel/rail contact geometry are usually the wheel and rail profiles, inclination of rails and track gauge [6–9]. These parameters, however, do not allow any generalized conclusion regarding the relationship between the wheel/rail contact nonlinearity and the vehicle's behaviour. A simplified characterization of the contact geometry wheelset/track will remain an important topic for the assessment of tracks and vehicles and also as the input for multi-body simulations. There is a gap between the progress of nonlinear dynamics and the practical assessment of wheel/rail contact geometry. This paper is an attempt to start the work on closing this gap. It shows the effects of wheel/rail contact nonlinearities and proposes a new characterization of wheel/rail contact geometry consisting of two parameters.

The paper is organized as follows: The traditional characterization of wheel/rail contact geometry using the quasi-linearization is described in Chapter 2. Chapter 3 demonstrates the effect of nonlinearity and non-smoothness of the contact geometry wheelset/track on the behaviour of vehicles at the stability limit. Chapter 4 presents the proposed definition of new parameters characterizing the contact nonlinearity. This description is compared on six examples of contact geometries wheelset/track with three different levels of equivalent conicity. The relationship between the characteristic parameters, the bifurcation at the stability limit and the dynamic behaviour of a vehicle running on measured track irregularities is shown. A summary and an outlook regarding further investigations are given in Chapter 5.

2. CHARACTERIZATION OF WHEEL/RAIL CONTACT BY LINEARIZATION

The equivalent conicity represents an established assessment criterion for the contact geometry wheelset/track. The most widely used quasi-linear wheel/rail contact model [10] consists of three parameters

- equivalent conicity λ
- contact angle parameter ε
- roll parameter σ .

The linearization according to Maurer [11] describes those linearization parameters as a function of the wheel profile cross section radius R_W , the rail profile radius R_R , the contact angle δ_0 in nominal position, a half of the tape line distance e_0 and the nominal wheel radius r_0 , see Figure 1.

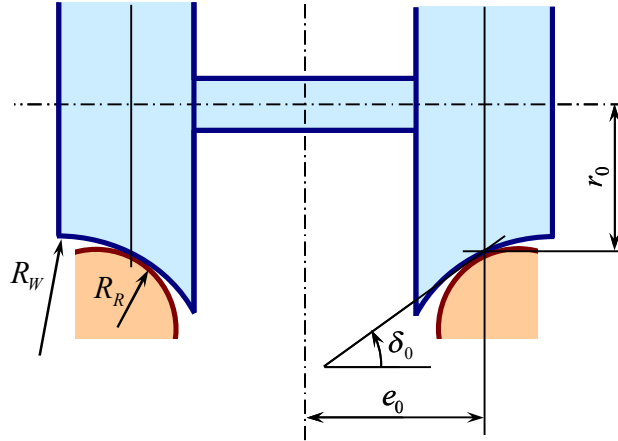


Figure 1. Linearized model wheelset/track.

Applying a linearization around the nominal position, the equivalent conicity λ reads

$$\lambda = \frac{R_W \cdot \sin \delta_0}{R_W - R_R} \cdot \frac{e_0 + R_R \sin \delta_0}{e_0 \cos \delta_0 - r_0 \sin \delta_0} \quad (1)$$

The difference of the contact angles on the left and right wheel is described by the contact angle parameter ε

$$\varepsilon = \frac{e_0}{R_W - R_R} \cdot \frac{e_0 + R_W \sin \delta_0}{e_0 \cos \delta_0 - r_0 \sin \delta_0} \quad (2)$$

The roll angle around the longitudinal axis is characterized by the roll parameter σ which reads

$$\sigma = \frac{e_0 \sin \delta_0}{e_0 \cos \delta_0 - r_0 \sin \delta_0} \quad (3)$$

Assuming a small contact angle ($\sin \delta_0 \approx \delta_0$, $\cos \delta_0 \approx 1$) and neglecting the term

$$\frac{e_0 + R_R \delta_0}{e_0 - r_0 \delta_0}$$

which is very close to 1, the Equation (1) for the conicity linearized around the nominal contact point can be simplified into

$$\lambda = \delta_0 \frac{R_W}{R_W - R_R} \quad (4)$$

From the Equation (4) one can observe that the value of equivalent conicity is influenced by

- contact angle
- conformity of wheel and rail profile.

Both effects mentioned lead to a change of conicity; the first one with rather small lateral shift of the contact area across the profiles, the second one with a large shift of the contact area across the wheel and rail profile, see Figure 2. The first case leads to rather small contact angle difference and a large roll angle, the second one to a large contact angle difference and small roll angle. The more conformal contact can be often observed on worn wheel and rail profiles. However, there is no correlation between the contact geometry and either new (theoretical) or worn profiles.

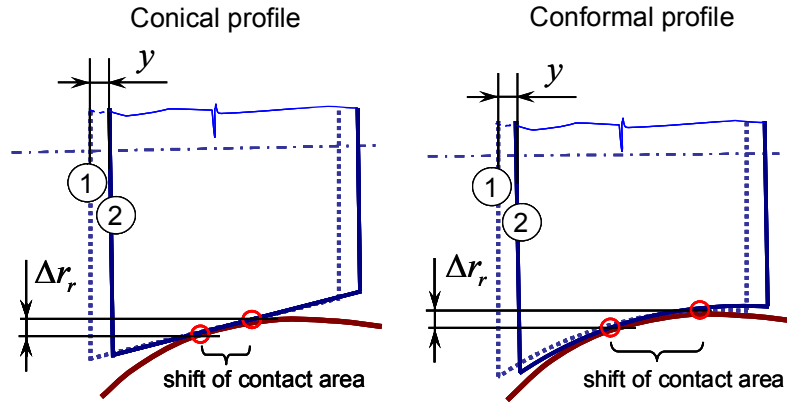


Figure 2. Shift of the contact area across the conical and conformal wheel profiles due to wheelset displacement leading to the same difference of rolling radii.

The parameters of a quasi-linear contact model wheelset/track are calculated by harmonic linearization [11], whereby this linearization considers not only a very small wheelset displacement around the nominal position, but the specified wheelset displacement inside of the clearance between the wheelset and track. A sensitivity of the critical speed calculated using quasi-linear wheel/rail contact to the variation of contact angle parameter and roll parameter was presented by the author in [12]. All in all, the sensitivity of the running stability to the contact angle parameter and roll parameter is low compared with the sensitivity to the equivalent conicity. The equivalent conicity influences the other parameters, so that the conicity is the only parameter usually mentioned in frame of the wheel/rail contact geometry assessment.

The value of equivalent conicity for a wheelset's amplitude of 3 mm is typically used to describe characteristic properties of wheel/rail contact geometry in railway applications [1, 2]. Therefore, if there is no other reference, the equivalent conicity is understood as the conicity for the amplitude of 3 mm.

There are several definitions and methods for conicity calculation. The wheelset movement considered in the calculation of the equivalent conicity is either periodic or stochastic [13]. While a stochastic movement with the specified standard deviation is used to calculate equivalent conicity in UK, a periodic sinusoidal wheelset movement is traditionally used in the countries of continental Europe and has been introduced in the standards dealing with the determination of equivalent conicity [14, 15].

The methods frequently used to calculate the equivalent conicity are

- harmonic linearization [11]
- equivalent linearization by the application of Klingel formula [14]
- linear regression of the function of rolling radii difference [14].

Different methods can certainly lead to deviations in the calculated conicity values. This topic has not been analysed in publications yet; the only publication known to the author about the differences between the different conicity calculation methods is the article by Bonadero [16].

The application of the equivalent conicity for a wheelset's amplitude of 3 mm to characterize the contact geometry wheelset/track considers linear contact geometry relations. The rolling radius difference and consequently also the equivalent conicity are, however, influenced by the nonlinearity of wheel/rail contact geometry. Consequently, the vehicle behaviour can differ even when wheel/rail contact geometries possess the same equivalent conicity for the specified amplitude. The following investigations concentrate on the influence of the contact geometry nonlinearities on the equivalent conicity. The aim of this contribution is to propose parameters suited to characterize the nonlinear contact geometry from the point of view of the effect of this nonlinearity on the railway vehicle dynamics.

3. EFFECT OF WHEEL/RAIL CONTACT NONLINEARITY ON RAILWAY VEHICLE DYNAMICS

It is well known that the wheel/rail contact geometry has an important influence on the running stability of railway vehicles. A detailed stability assessment of a nonlinear system can be achieved by a bifurcation analysis. In case of railway vehicles, the bifurcation diagram displaying the amplitude of wheelset lateral displacement is typically used to assess the vehicle's stability, see e.g. [17] for more detailed explanation. The author's investigations as well as comparison with other publications have allowed an identification of the relationship between the shape of the bifurcation diagram and the nonlinearity of the wheel/rail contact geometry functions. This relationship between the equivalent conicity in function of wheelset displacement amplitude and the bifurcation diagrams can be seen on multi-body simulation results in Figure 3 for three different vehicles and

two different wheel/rail contact geometries. Both examples of wheel/rail contact geometry represent the same equivalent conicity for the amplitude of 3 mm, however different values for other wheelset amplitudes. For the contact geometry A, there is a progressive equivalent conicity in function of wheelset amplitude. The bifurcation analysis displays a subcritical Hopf bifurcation. In contrast, for the contact geometry B there is a strongly declining equivalent conicity function for amplitudes up to 5 mm (i.e. in the wheel tread away from flange contact). A supercritical Hopf bifurcation can be observed for this wheel/rail contact geometry. Such different behaviour on contact geometries with the equivalent conicity function of “Type A” and “Type B” was described for the first time in [18] and outlined more in detail in [17, 19].

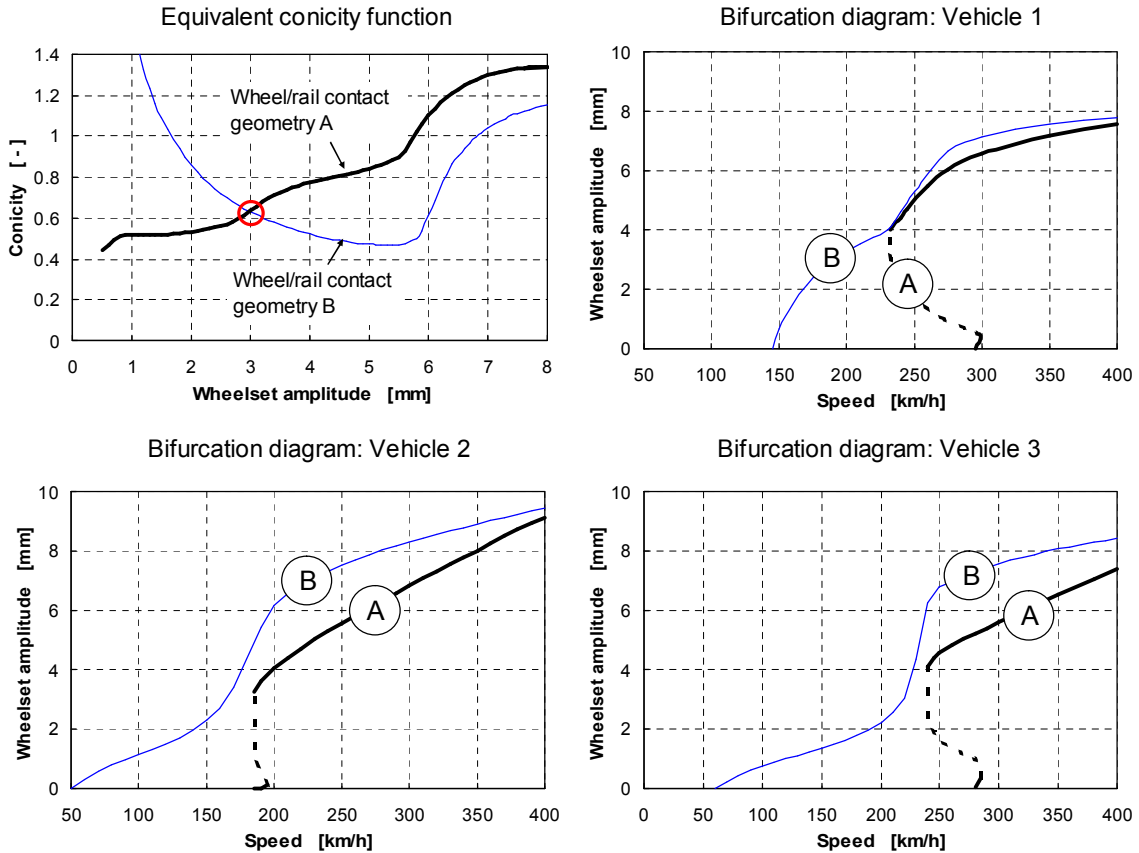


Figure 3. Effect of wheel/rail contact nonlinearity on the bifurcation diagram. Vehicle 1: Articulated EMU, Vehicle 2: Double-decker coach without yaw dampers, Vehicle 3: Double-decker coach with yaw dampers.

A wheel/rail contact with rather low conicity at small wheelset’s amplitudes and a positive slope of equivalent conicity function typically results to a sudden occurrence of a limit cycle with large amplitude leading to an exceedance of safety limit. This behaviour is represented by the subcritical Hopf bifurcation: the nonlinear critical speed and the exceedance of the safety limit are very close due to a sudden appearance of the oscillation. A wheel/rail contact resulting to high conicity for small wheelset’s amplitudes and a negative slope of the equivalent conicity function usually leads to the limit cycle with an amplitude slowly growing with increasing speed. The bifurcation analysis delivers a supercritical Hopf bifurcation. In this case, a limit cycle with small amplitude usually occurs at speeds far below the safety limit according to EN 14363 [1] and will not necessarily lead to an exceedance of the instability limit, see Figure 4.

The nonlinearity of the contact geometry often determines the type of Hopf bifurcation of railway vehicles as shown in the presented examples. The nonlinearity of a vehicle model can supersede the abovementioned effect of wheel/rail contact and eventually also change the type of Hopf bifurcation as described in [20]. The tendency of the modification of bifurcation diagram will, however, remain similar.

The bifurcation diagram showing the subcritical Hopf bifurcation can identify the risk to underestimate the critical speed. The vehicle will run stable even at speeds higher than the nonlinear critical speed, if the track irregularities during the tests or the irregularity data applied in simulations are too low. A system showing the supercritical Hopf bifurcation possesses nonlinear critical speed which is lower than the speed at which the safety limits are reached. An assessment of such system can deliver too low critical speed with the criteria below the safety limits specified for vehicle acceptance. So, the stability assessment can either underestimate or overestimate the safety relevant critical speed. Hence, an understanding of the vehicle’s behaviour at the stability

limit is an important part of railway vehicle stability assessment.

No correlation between the shape of the bifurcation diagram and the wear of wheels and rails has been identified either by the author or by Chung and Shim [21]. Hence, it is important to find out characteristic parameters of wheel/rail contact geometry which express the aforementioned effect of the nonlinearities on the behaviour of vehicles at stability limit.

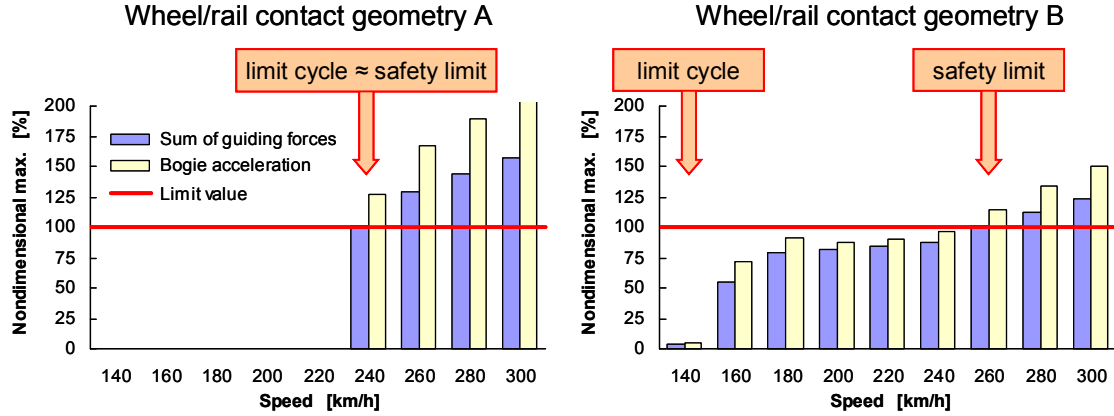


Figure 4. Simulation results displaying a relationship between nonlinear critical speeds identified by a presence of a limit cycle and by an exceedance of the instability safety limits according to EN 14363 after an excitation by a single lateral disturbance (Vehicle: Articulated EMU).

4. NONLINEAR WHEEL/RAIL CONTACT GEOMETRY PARAMETERS

4.1 Proposed parameters to characterize the wheel/rail contact

The equivalent conicity value for a wheelset amplitude of 3 mm is used today for characterization of wheel/rail contact geometry [1, 2]. The experience with use of this parameter in railway community confirmed this parameter as useful information regarding the instability safety limits according to the standards for vehicle acceptance. The equivalent conicity, however, does not consider the nonlinearity of wheel/rail contact.

As an approach to describe the nonlinear wheel/rail contact geometry, a new description is proposed consisting of two parameters. The equivalent conicity as used today is extended with a second parameter related to the slope of the conicity function. This second parameter allows assessing the contact geometries with the same conicity level. Whereas the equivalent conicity provides a level (quantity) assessment regarding the instability, the proposed nonlinearity parameter characterizes the quality or the performance at this level. The equivalent conicity is related to the critical speed with respect to instability safety limits, whereas the nonlinearity parameter allows distinguishing if the critical speed can be expected to occur as a sudden flange-to-flange limit cycle or as a limit cycle with a small amplitude which grows with increasing speed.

The proposed characterization of nonlinear wheel/rail contact geometry hereby consists of:

- Level parameter expressed by the equivalent conicity as used today, i.e. the conicity value for the wheelset amplitude of 3 mm
- Nonlinearity parameter λ_N related to the slope of the conicity function in the neighbourhood of the value for the wheelset's amplitude of 3 mm.

The definition of the nonlinearity parameter has been selected with the aim to allow an easy assessment applying the tools used today, so that the calculation of the nonlinearity parameter is possible with only a small extension of the conicity assessment carried out by many railway operators and infrastructure companies today. According to the latest revision of UIC 518 [22], the conicity values for the wheelset amplitude of 2 mm and 4 mm should be assessed together with the conicity for the amplitude of 3 mm. Those three conicity values can certainly be proposed to calculate a nonlinear parameter characterising an increase of the conicity function related to an increase of the wheelset amplitude by 1 mm for the range of wheelset amplitudes between 2 and 4 mm

$$\lambda_{N,1} = \frac{\lambda_4 - \lambda_2}{2} \quad (5)$$

with λ_2 equivalent conicity for a wheelset amplitude of 2 mm

λ_4 equivalent conicity for a wheelset amplitude of 4 mm.

The second proposed definition of the nonlinearity parameter covers a wider range of wheelset amplitudes

between 1 and 5 mm

$$\lambda_{N,2} = \frac{\lambda_5 - \lambda_1}{4} \quad (6)$$

with λ_1 equivalent conicity for a wheelset amplitude of 1 mm
 λ_5 equivalent conicity for a wheelset amplitude of 5 mm.

The parameter definitions (5) and (6) consider a sufficient lateral clearance between the wheelset and track before a flange contact occurs. To avoid a misrepresenting characterization in case of a tight track gauge, an adaptation of the proposed parameters could be introduced analogue to the definition of the equivalent conicity in TSI High Speed [3] in regard to the maximum clearance wheelset/track. The Equation (5) will then read

$$\lambda_{N,1} = \frac{\lambda_{(y_\lambda+1)} - \lambda_{(y_\lambda-1)}}{2} \quad (7)$$

with

$$\begin{aligned} y_\lambda &= 3 \text{ mm} && \text{if } (TG - FG) \geq 7 \text{ mm} \\ y_\lambda &= \frac{(TG - FG - 1)}{2} && \text{if } 5 \text{ mm} \leq (TG - FG) < 7 \text{ mm} \\ y_\lambda &= 2 \text{ mm} && \text{if } (TG - FG) < 5 \text{ mm} \end{aligned} \quad (8)$$

where TG track gauge in mm
 FG distance between the active faces of a wheelset in mm.

For the nonlinearity parameter according to (6), an application of the same principle could lead to conicity assessment for wheelset amplitudes $\rightarrow 0$. To avoid this singularity, it is proposed to reduce the range of the wheelset amplitudes for $(TG - FG) < 7$ mm. The Equation (6) will then read

$$\lambda_{N,2} = \frac{\lambda_{(2y_\lambda-1)} - \lambda_1}{2y_\lambda - 2} \quad (9)$$

4.2 Assessment of wheel/rail contact geometry examples

The proposed characteristic parameters were compared and analyzed on six examples of wheel/rail profile combinations. The investigated pairs wheelset/track were selected to represent three levels of equivalent conicity and at the same time two different contact nonlinearities for each conicity level. The selected profiles consist of theoretical as well as worn profiles. They do not necessarily represent any typical or standard profiles. They were rather selected to reach completely different contact geometries and therefore different nonlinearity effect while obtaining the selected conicity level for the nominal track gauge value of 1435 mm.

The following methods to calculate the equivalent conicity were applied:

- harmonic linearization, elastic wheel/rail contact with a wheel load of 70 kN
- harmonic linearization, rigid wheel/rail contact
- equivalent linearization by application of Klingel formula according to UIC 519 [14], Appendix B
- linear regression of the Δr -function (difference of rolling radii) according to UIC 519 [14], Appendix C
- UK-method for a stochastic wheelset displacement with a standard deviation of 1.25, 2.50 and 3.75 mm.

The calculations were carried out using the tools RSGEO [23] and VAMPIRE® [24] for a wheel diameter of 850 mm, wheelset back-to-back distance of 1360 mm and track gauge 1435 mm. A comparison of the equivalent conicity functions of the investigated wheelset/track combinations can be seen in Figure 5. There is a large difference in some cases for wheelset amplitude greater than 6 mm. The difference observed is related to the rotation of wheel profile about an axis longitudinal to the track (roll movement) due to the lateral wheelset displacement. This effect concluded to be negligible in the description of the Ayasse's method in [25] and also in the article by Gerlici and Lack [26] is neglected in UIC Code 519 [14] and prEN 15302 [15]; the profiles are only shifted laterally and vertically. However, this rotation is considered when using simulation tools to calculate the equivalent conicity. This leads to a difference of the Δr -function, whereby this difference is very small for wheel tread contact but not negligible in case of a flange contact. For the contact in the wheel tread area, the equivalent conicity functions possess similar shapes. Differences can be observed between the rigid and elastic wheel/rail contacts, namely in examples 1b, 2a and 3a (Figure 5), because the jumps of the contact point which are present in case of the rigid contact, are smoothed by a widening of the contact area when using elastic contact. Surprisingly, the equivalent conicity values calculated using the UK-method are also comparable with other methods, in spite that this method uses a stochastic instead of a periodic wheelset movement.

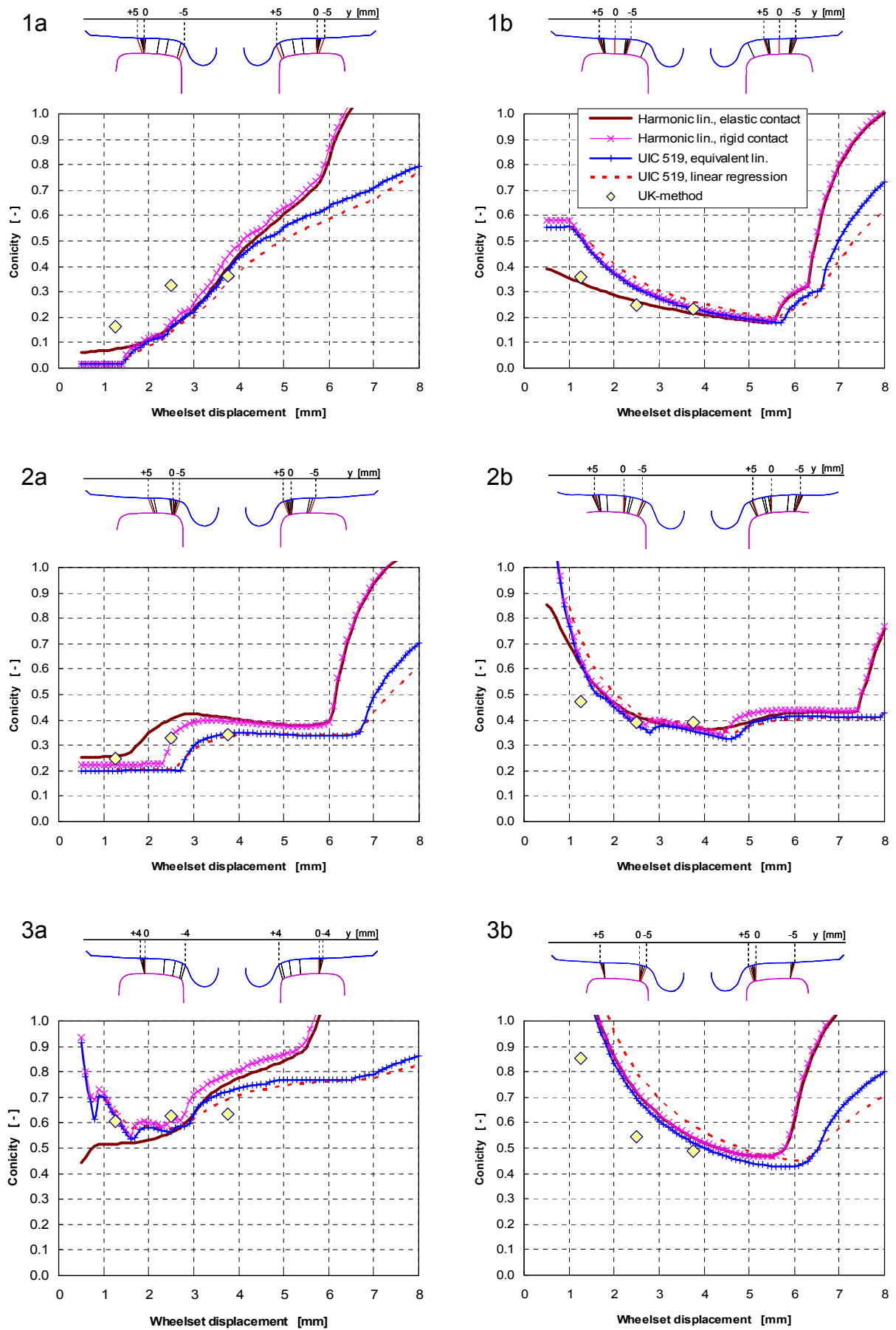


Figure 5. Conicity functions of the investigated wheel/rail contact geometry examples.

A comparison of the equivalent conicity values for the wheelset amplitude of 3 mm calculated using different methods is shown in Figure 6. In spite of similar shape of conicity functions, the conicity value for 3 mm deviates dependent on the calculation method. Unsurprisingly, the largest differences occur between the conicity values calculated by the UK-method for the standard deviation of wheelset displacement of 2.5 mm and other methods calculated for a periodic wheelset displacement with an amplitude of 3 mm. However, the results calculated under the assumption of a periodic wheelset displacement deviate as well. In the investigated examples, the difference reaches up to 0.14 which is more than 30% of the conicity value. A comparison of both methods described in UIC 519 results to differences 0.02-0.03 except in case 3b where a difference of 0.085 occurs. Such difference is higher than the value 0.05 which is specified in EN 14363 as a maximum conicity increase to avoid new tests if the vehicle has been tested with new instead of worn wheel profiles. Even if the two methods described in UIC 519 are closer to each other we have to keep in mind the simplifications applied in those methods (rigid contact, neglected roll movement of wheel profiles during the wheelset displacement). The equivalent conicity value calculated using the methods described in UIC 519 is therefore less representative for the vehicle's behaviour than the equivalent conicity value calculated using the elastic wheel/rail contact and considering the complete movements of wheel profiles including the rotation about an axis longitudinal to the track.



Figure 6. Comparison of the equivalent conicity for the wheelset amplitude of 3 mm of the investigated wheel/rail contact geometry examples.

As a conclusion from this comparison we can state that the equivalent conicity value for the wheelset amplitude of 3 mm as used for the specification of wheel/rail contact conditions during the vehicle acceptance is only an indication. It is only comparable as long as the same method and calculation tool is used. The limit for the conicity increase due to wheel wear as used today in EN 14363 is too small; it is even smaller than the deviation which can occur when assessing the same pair wheelset/track by different conicity calculation methods used in railway community.

The proposed characteristic parameters of the investigated combinations wheelset/track are shown in Figure 7. This description consists of the nonlinearity parameter according to (5) or according to (6), respectively, together with the equivalent conicity calculated by harmonic linearization using the elastic contact. As can be seen, the analyzed pairs wheelset/track represent three conicity levels, whereby there is one pair with a negative and one with positive nonlinearity parameter for each conicity level.

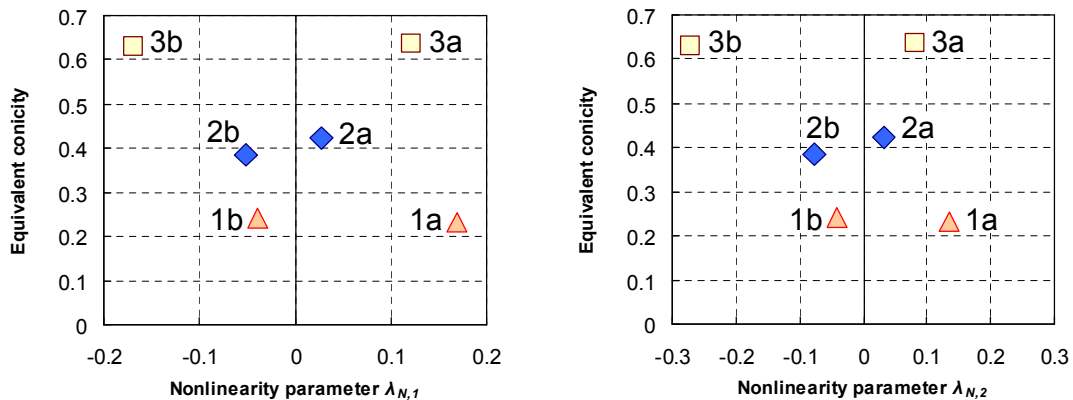


Figure 7. Characteristic parameters of the investigated wheel/rail contact geometry examples for two definitions of the nonlinearity parameter λ_N .

4.3 Characteristic parameters and vehicle dynamic behaviour

The influence of wheel/rail contact nonlinearity on the bifurcation diagram of a nonlinear double-decker coach model and the investigated wheelset/track pairs is illustrated in Figure 8. Large wheelset amplitudes above approximately 5 mm are reached at similar speeds for both wheel/rail contact geometries with the same level parameter (equivalent conicity λ), so that the instability safety limits will be achieved at similar speeds for the same conicity. However, the shape of the bifurcation diagrams and the appearance of a limit cycle vary significantly due to the different nonlinearity parameters $\lambda_{N,1}$.

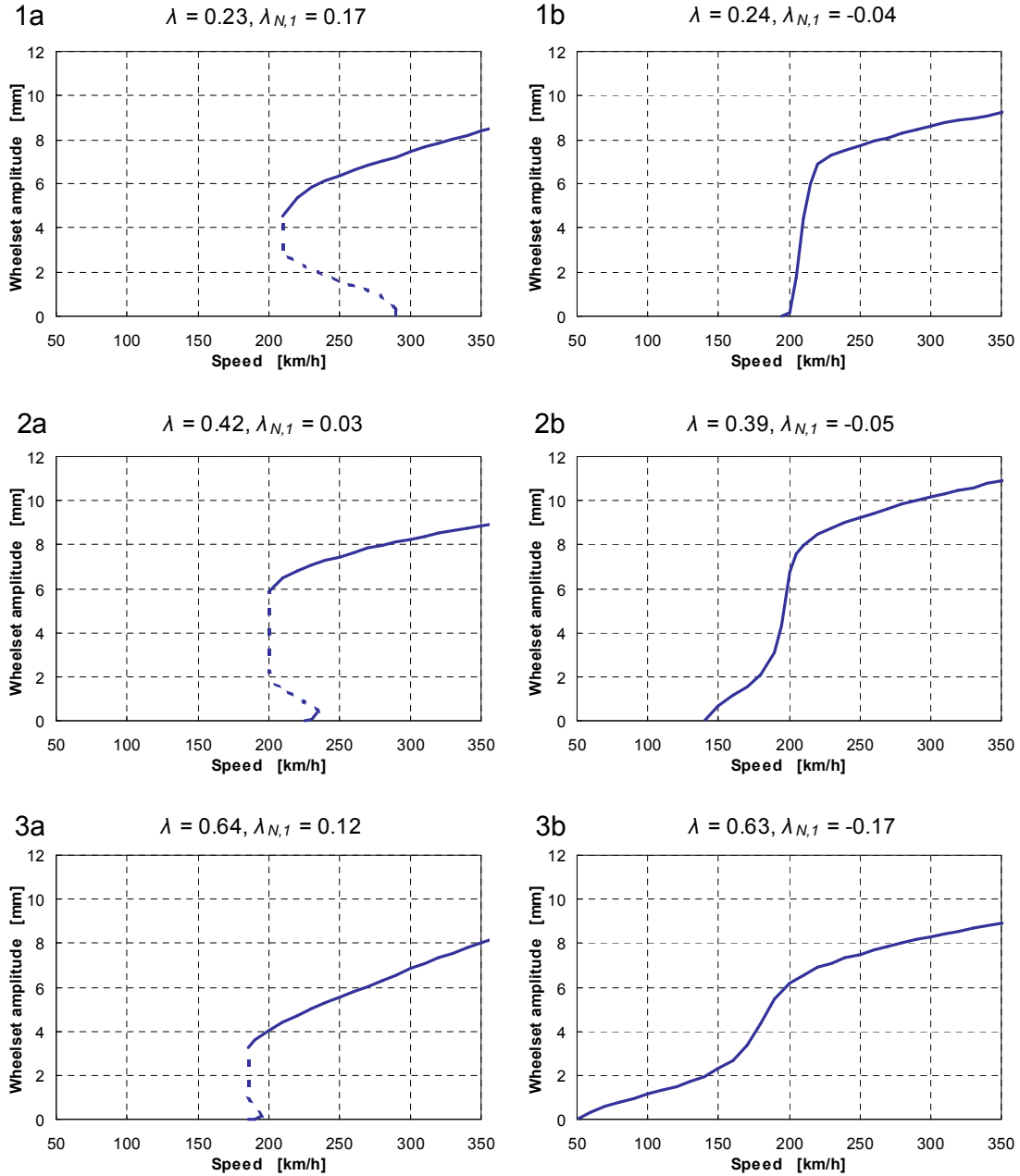


Figure 8. Bifurcation diagrams as results of stability analysis using the investigated wheel/rail contact geometry examples (Vehicle: Double-decker coach without yaw dampers).

The trends of alterations of bifurcation diagram due to changes of the wheel/rail contact characteristic parameters are shown in Figure 9. An increase of the level parameter (equivalent conicity) leads to a decrease of speed at which the instability safety limits will be exceeded. An increasing nonlinearity parameter promotes the bifurcation diagram with the subcritical Hopf bifurcation. A sudden occurrence of a limit cycle with large amplitude can be expected at the stability limit. The running dynamics of vehicles is certainly dependent on all nonlinearities of the system vehicle/track; hence, the bifurcation diagrams can significantly differ for other

vehicles. However, similar trends in relation to the proposed wheel/rail characteristic parameters observed by the author in simulations of other vehicles confirm the presented tendencies to be rather general.

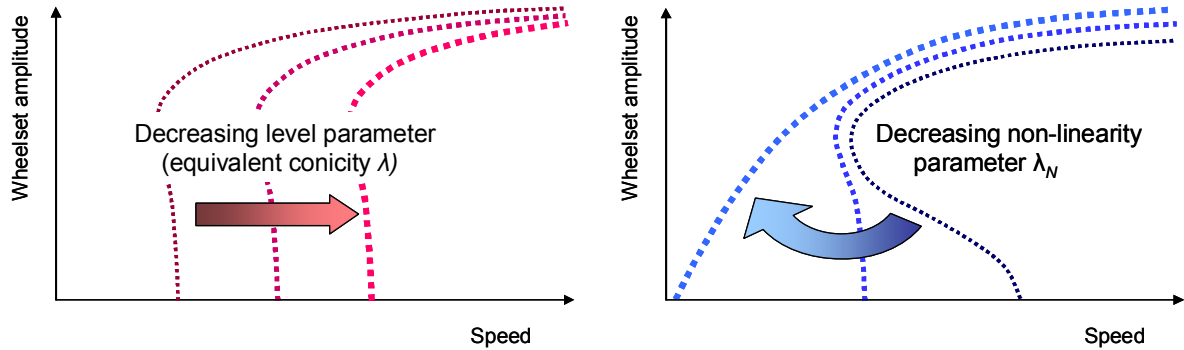


Figure 9. Influence of wheel/rail contact geometry on the bifurcation diagram. Trends due to the variation of the level parameter (equivalent conicity λ) and the nonlinearity parameter λ_N .

Figure 10 presents the relationship between the simulation of running behaviour on a straight track with measured irregularities and the wheel/rail characteristics using the nonlinearity parameter $\lambda_{N,1}$. The results show higher values of lateral bogie accelerations and of the sum of guiding forces in simulations with the wheel/rail contact geometry “Type B”, i.e. with the negative nonlinearity parameter, as also confirmed in [27]. The rms values of the lateral acceleration on a bogie frame and the sum of guiding forces are decreasing with decreasing conicity, but also with increasing nonlinearity parameter, whereby the effect of the nonlinearity parameter is even more important than the effect of the conicity. The relationship between the wheel/rail characteristic parameters and the maximum values of accelerations and wheel/rail forces show less obvious, but still similar tendency. The assessment using the nonlinearity parameter $\lambda_{N,2}$ is not displayed because it shows similar diagrams as using the parameter $\lambda_{N,1}$. Further studies would be required to compare both variants of the proposed nonlinearity parameter.

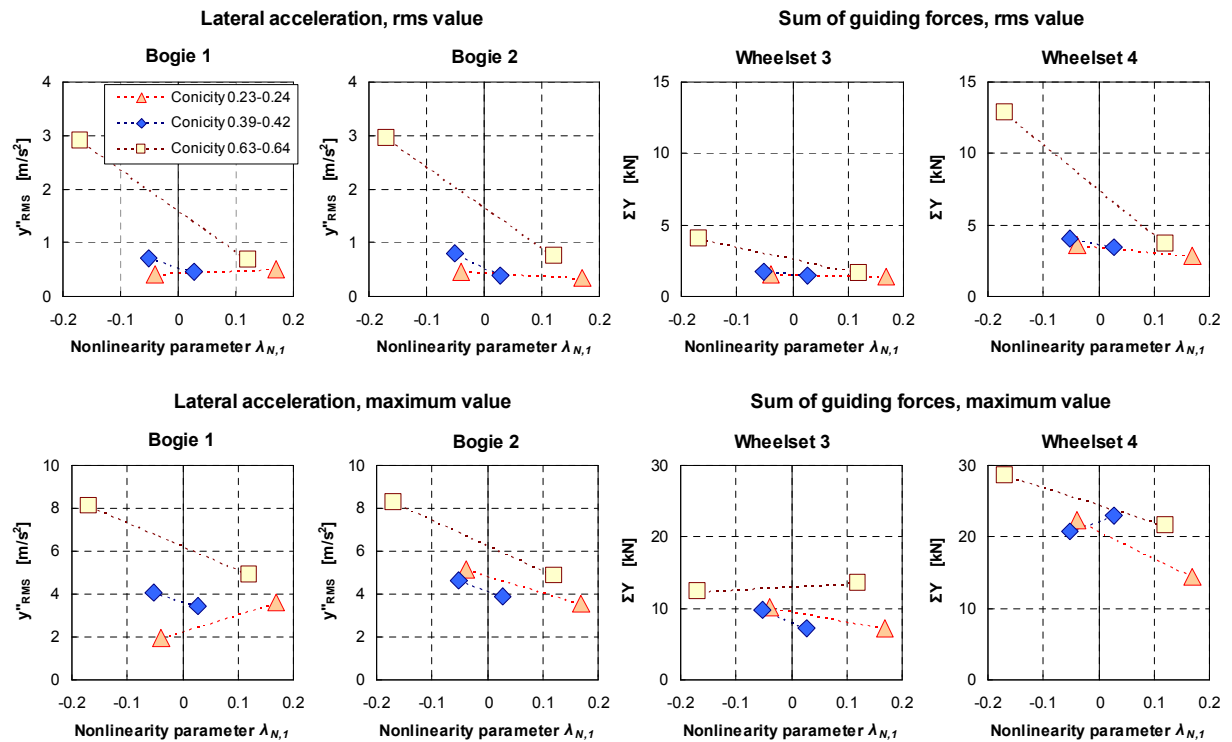


Figure 10. Relationship between the proposed wheel/rail characteristic parameters and the vehicle behaviour as a result of simulation on measured track irregularities (Vehicle: Double-decker coach with yaw dampers, speed 160 km/h).

5. SUMMARY AND OUTLOOK

The paper deals with the characterization of wheel/rail contact geometry in frame of assessment of measured or theoretical wheel and rail profiles during the vehicle testing or for the specification of multi-body simulations. First, the traditional characterization of wheel/rail contact geometry using the quasi-linearization and its limitations are presented. Then, the effect of the nonlinearity and non-smoothness of the contact geometry wheelset/track on the behaviour of vehicles at the stability limit is shown.

A new description characterizing the wheel/rail contact geometry by two parameters is presented. The first parameter allows to assess the vehicle performance regarding to the instability safety limit as specified in EN 14363 [1]. The newly introduced, second parameter allows assessing the expected behaviour at the stability limit: either a sudden flange-to-flange limit cycle or a limit cycle with a small amplitude growing with increasing speed. This parameter also shows the sensitivity of the vehicle to the lateral excitation by track irregularities. The proposed wheel/rail contact geometry description is compared on six examples of contact geometries wheelset/track with three different levels of equivalent conicity. The relationship between the characteristic parameters, the bifurcation at the stability limit and the dynamic behaviour of a vehicle running on measured track irregularities is presented.

The proposed definition of characteristic parameters allows an improved but still comprehensive description of nonlinear wheel/rail contact geometry. It could be applied for better understanding of railway vehicle behaviour on different wheel/rail contact conditions during testing, for a more exact assessment of wheel conditions (check for need for wheel maintenance), rail profiles (check for need for rail maintenance) and more detailed specification of the wheel/rail contact geometry in multi-body simulations.

This paper is only the first step on the way to improved generalized characterization of wheel/rail contact geometry. Further assessments of measured data, extensive simulations using measured wheel/rail contact geometries and additional analyses of on-track tests are required to confirm the observed relationships, to assess the applicability of the proposed characterization or to identify better suited parameters. This effort would provide the knowledge necessary to establish an improved but still simple characterization of wheel/rail contact geometry. A closer relationship of these characteristic parameters to running dynamics of nonlinear railway vehicle systems would increase the value of the wheel/rail contact geometry measurements and assessments.

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