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Creep and Warping (Including Gauge Widening) Analyses of Hot-Running Loco Wheel and Track Towards Development of Design Guidelines Against Gauge Widening

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ABSTRACT: When vehicles travels through curves, forces that increase the wear and tear of the track are generated and thus the potential for derailment. These forces need to be minimized by designing the curve using maximum practical radius, together with one or more of the following additional measures if necessary gauge widening, super elevation of the outer rail, check rails fitted to the inner rail lateral forces on the wheels in curves with small radius, the track gauge gets widened and the rails get inclined outward. To prevent the tendency of outward inclination of the rails, the track gauge in curves with small radius is designed with appropriate widening. The amount of gauge widening including creep and warping depends on the curve radius, type of track and rigid wheel base of the vehicles.

Keywords: *Bogie, Creep, Curvature, Gauge, Locomotive, Railway, Track, Warping*

INTRODUCTION

At high temperatures, such as the one encountered in hot running loco wheel, steam boilers, turbines and piping, the deformation of materials ceases to be elastic and becomes plastic with a continuous increase under a constant load. The equilibrium between stress and load is not established even after a very long time. The material under tensile stress continues to stretch or creep. Creep is measured in terms of plastic deformation during a certain time. The limiting creep stress for a certain temperature is the maximum stress under which the material will not fail during a prescribed length of time. Creep is more severe in materials that are subjected to heat for long periods and generally increases as they near their melting point. Sometimes creep called cold flow is the tendency of a solid material to move slowly or deform permanently under the influence of mechanical stresses. It can occur as a result of long-term exposure to high levels of stress that are still below the yield strength of the material.

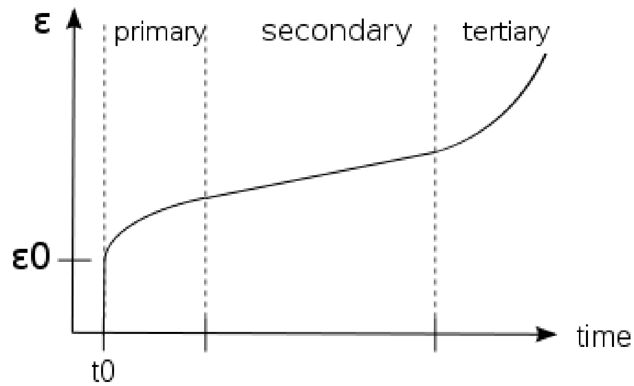

Fig: 1 Stages of Creep

In the initial stage or primary creep, the strain rate is relatively high, but slows with increasing time. This is due to work hardening. The strain rate eventually reaches a minimum and becomes near constant. This is due to the balance between work hardening and annealing (thermal softening). This stage is known as secondary or steady-state creep. This stage is the most understood. The characterized "creep strain rate" typically refers to the rate in this secondary stage. Stress dependence of this rate depends on the creep mechanism. In tertiary creep, the strain rate exponentially increases with stress because of necking phenomena or internal voiding decreases the effective area of the specimen. Fracture always occurs at the tertiary stage. In weaving cloth, the warp is the set of lengthwise yarns that are held in tension on a frame or loom. The yarn that is inserted over-and-under the warp threads are called the weft, woof or filler. Each individual warp thread in a fabric is called a warp end.

Very simple looms use a spiral warp, in which a single, very long yarn is wound around a pair of sticks or beams in a spiral pattern to make up the warp. Because the warp is held under high tension during the entire process of weaving and warp yarn must be strong, yarn for warp ends is usually spun and plied fiber. Traditional fibers for warping are wool, linen, alpaca and silk. With the improvements in spinning technology during the Industrial Revolution, it became possible to make cotton yarn of sufficient strength to be used as the warp in mechanized weaving. Later, artificial or man-made fibers such as nylon or rayon were employed.

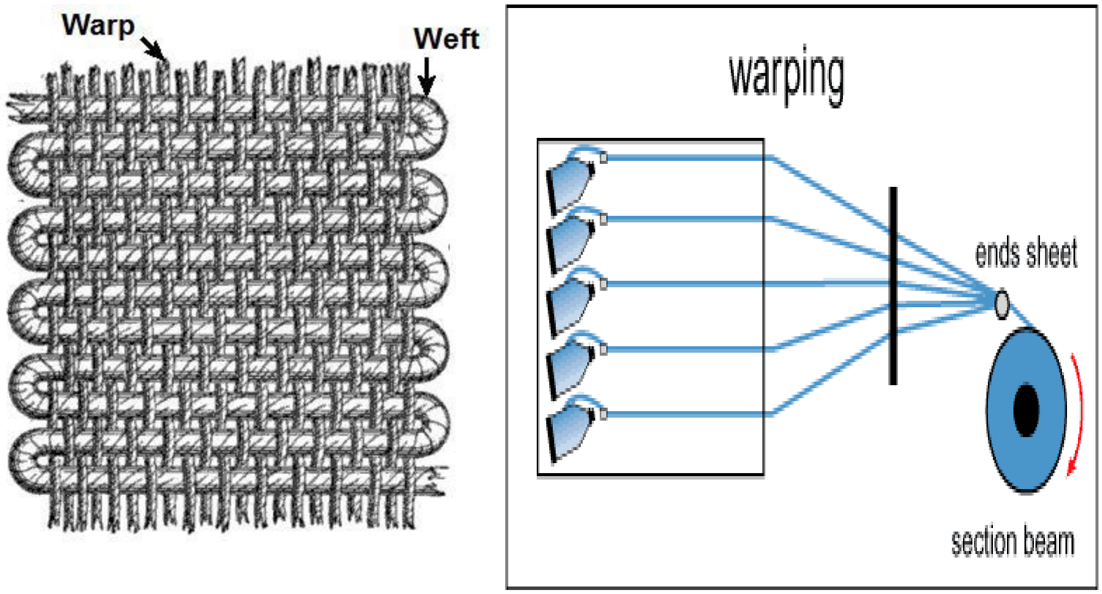

Fig: 2 Warps and Weft in Plain Weaving

While most people are familiar with weft-faced weavings, it is possible to create warp-faced weavings using densely arranged warp threads. In warp-faced weavings, the design for the textile is in the warp, and so all colors must be decided upon and placed during the first part of the weaving process and cannot be changed. Warp-faced weavings are defined by length-wise stripes and vertical designs due to the limitations of color placement.

METHODOLOGY

- **Gauge**

Gauge shall be able to maintain the safe and stable car operation, given the structure of rolling stock, the maximum design speed and other relevant factors into consideration.

- **Gauge Widening**

Gauge widening shall be provided at circular curve sections to prevent excessive lateral force to the track, taking the curve radius and bogie wheelbase of rolling stock into consideration. This rule does not apply however, to those cases where the radius of curve is large, the wheelbase of rolling stock is short and there is no chance for the excessive lateral force to be generated. Gauge widening shall be gradually decreased over the considerable distance in order not to interfere with safe car operations, taking the bogie wheelbase of rolling stock into consideration.

Gauge shall be as follows in order to ensure the safe rolling stock operation and shall take the structure of the rolling stock such as width and past performance records into consideration.

- ✓ Gauge of ordinary railways (excluding Shinkansen railways) shall be 0.762m, 1.067m, 1.372m or 1.435m.
- ✓ Gauge of Japanese railways (Shinkansen) shall be 1.435m.

In this paper it was performed analysis of curve negotiation of three axle bogie of hot running locomotive type. This hot running locomotive has two bogies, both with three axles. Distance between bolsters of bogies is 10.3 m. Bogies are connected with elastic diagonal links for the purpose of better curve negotiation. Technical documentation of this hot running locomotive states that minimal track radius is 90 m. Due to large distance between first and middle i.e. middle and last axle, it occurs increased lateral forces during curve negotiation as it is shown in consideration below.

- **Analysis of Curve Negotiation in Hot Running Wheel Gauge Widening**

It was investigated necessary geometrical conditions for curve negotiation of three axle bogie of hot running locomotive curves with radius from R=300 m to R=500 m. Among other performances of this hot running locomotive, the most important for curve negotiation analysis are bogie axle distance 2700 mm, mass of hot running locomotive 120t ± 2% and axle load 200 kN ± 3%.

During curve negotiation, tree axles remain parallel or nearly parallel. Due to rigid guiding in rolling direction, it occurs additional friction force between hot running loco wheel and rail. Additional friction is the consequence of longitudinal creep of hot running loco wheels on the same axle due to path length difference, lateral slip of hot running wheels on inclined track level, increased slip between hot running loco wheel flange and rail due to forced guidance of hot running loco wheel set and centrifugal force. Force which occurs during curve negotiation is influenced by condition of hot running wheels and rail head, track curve radius, length of rigid wheel base, track width and other parameters impurities of contact surfaces, climate conditions and similar.

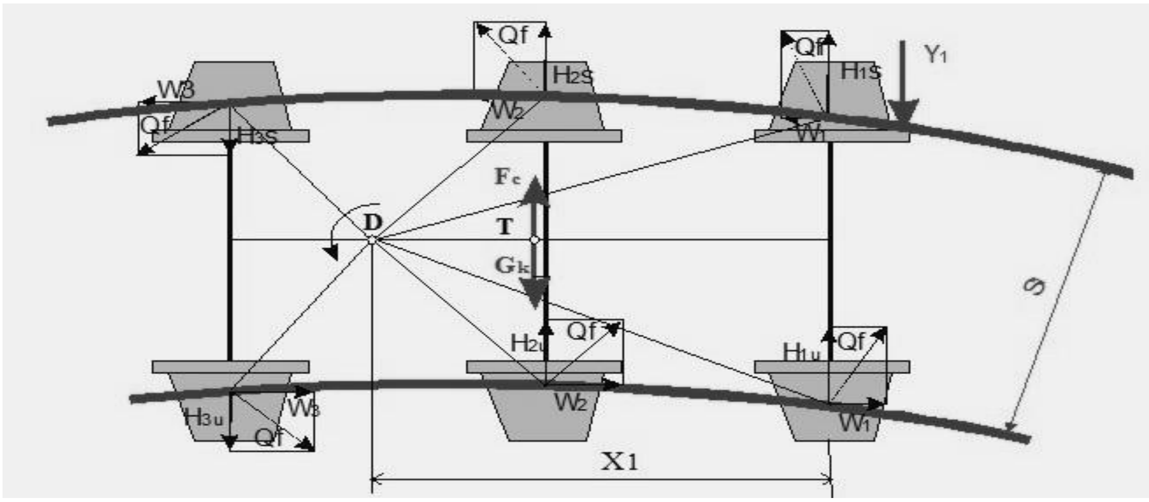

Fig. 4 Gauge of Hot Running Loco Wheel Set (q), Gap (d), Track Gauge and Flange Thickness.

In above fig 4 shows inclined loose position of three axle bogie in curve guiding force Y1 that acts on the outer wheel of the first axle, lateral forces Hi and longitudinal friction forces Wi, centrifugal force Fc, weight G and current centre of rotation D.

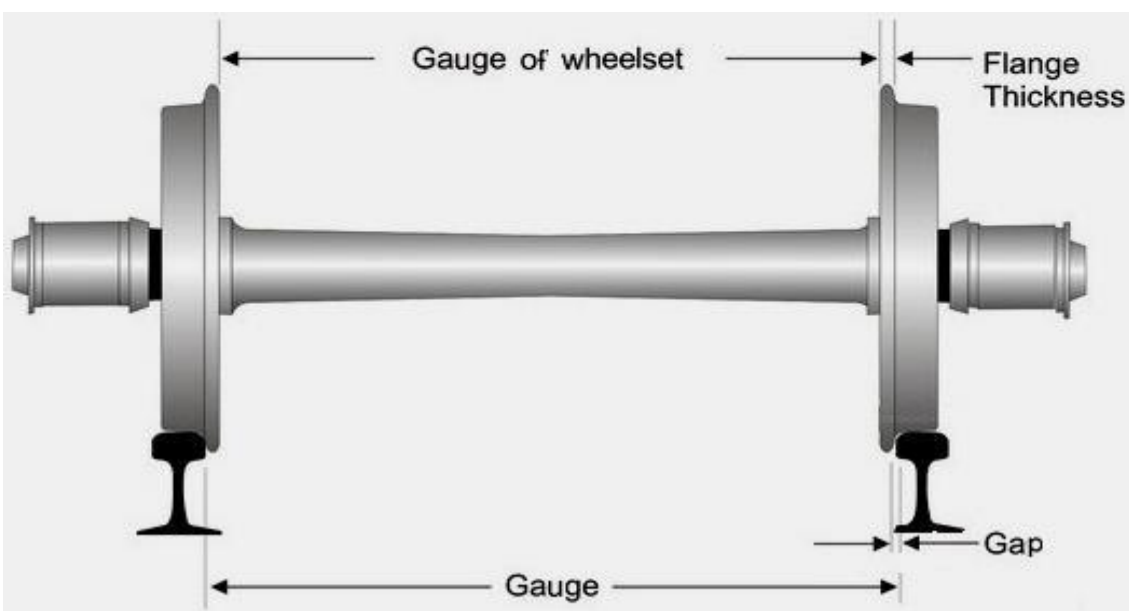

Fig 5 Principal Geometric Parameters of Hot Running Loco Wheel Set and Track

In above fig 5 shows the preferred inclined loose position of three axle bogie in curve as well as lateral forces and longitudinal friction forces, which affect the vehicle during curve traversing. Unfortunately, the three axle bogie with long rigid wheelbase (distance between first and last bogie axle of locomotive is 2x2.7=5.4m) is usually in the chord position due to lack of track gauge in curve.

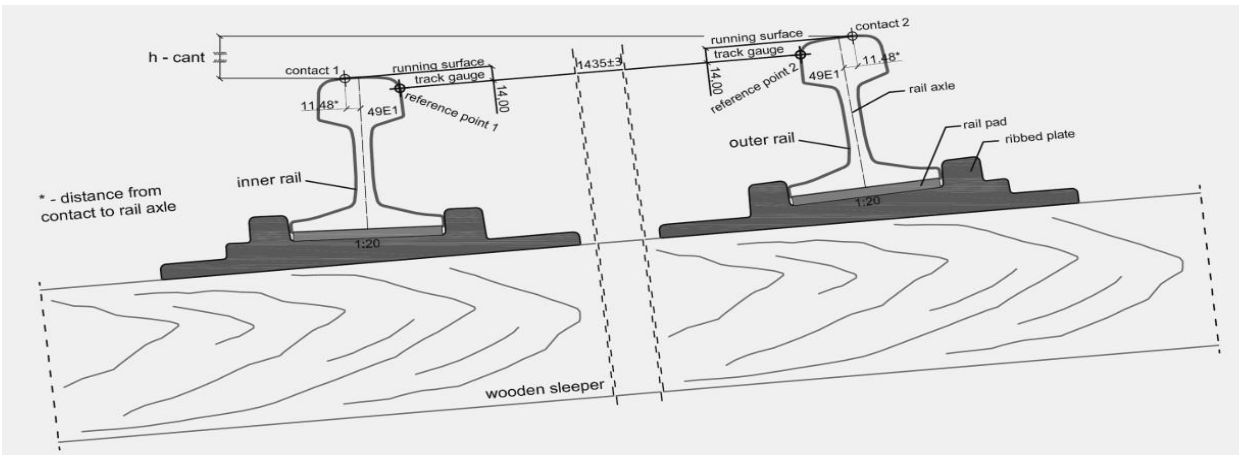

Fig 6 Initial Position of Track Rails in Curve without Track Widening

Fig 6 shows initial position of track rails in curve with nominal track gauge according to defined tolerance 1435±3mm.

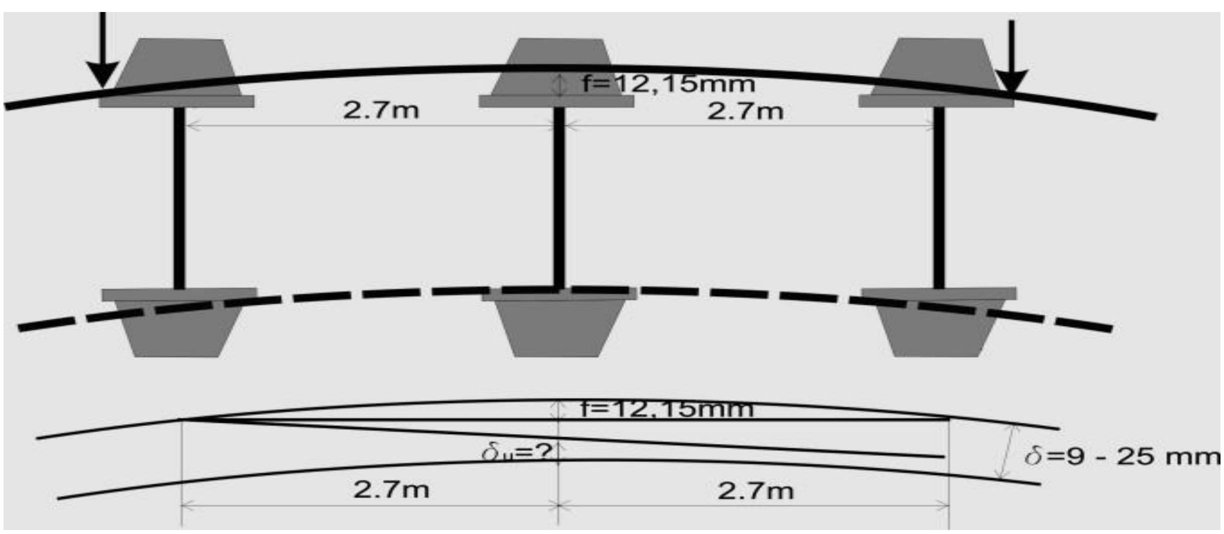

Fig 7 Necessary gaps (up) ʓS=ʃ between flange of outer wheel on the mid axle and outer rail (down) ʓu between flange of inner wheel on the mid axle and inner rail locomotive, radius R=300 m chord and inclined position.

Fig 7 shows calculated gap value ʒS=f=12.5 m between flange of outer wheel on the mid axle and outer rail in curve with radius R=300 m for chord position according to formula (1). Also, it shows total available gap in track is = 9–25 mm.

$$ʃ = (L^2) / (4×2×R) \text{……………………………… (1)}$$

$$= (5.4)^2 / (4×2×300)$$

$$= 12.15m$$

According to calculated gap value ʃ=12.15 mm in curve with radius R=300 m (Fig 7), it is obvious that inner wheel doesn't have sufficient track gauge for curve traversing in inclined position neither in chord position with total available gap ʒ<12.15 mm.

Necessary gap value between inner wheel of mid axle and gauge face of inner rail was calculated according to Fig 6 using the equation (2).

$$ʒ_{2u} = ʒ - ʃ - 0.5 × ʒS \text{………………………………………… (2)}$$

Where

ʒ2*u* = Gap between inner wheel of mid axle and gauge face of inner rail.

ʒ = Total ʒ2*u* = ʒ - ʃ - 0.5 × ʒS al gap.

ʃ = Gap between flange of outer wheel on the mid axle and outer rail.

ʒS = Gap between flange of outer wheel on third axle and outer rail.

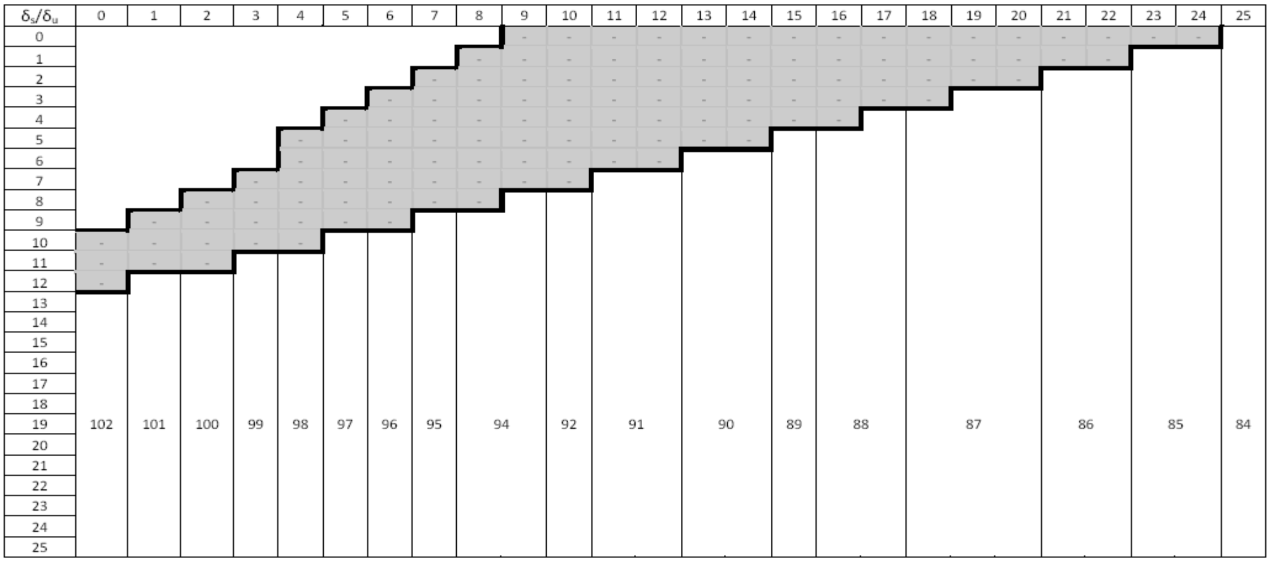

Fig 8 Possible Traverse Speeds for Bogie in Inclined Position, without Track Widening, in Curve with Radius R=300 m.

Input Data	**R=300 m**	**R=500m**
Measured track gauge widening (mm)	10	9
Range of available total gap ʒ (mm)	19-35	9-25
Gap between flange of inner wheel on third axle and inner rail ʒu (mm)	3	1.5
Gap between flange of outer wheel on third axle and outer rail ʒs (mm)	32	23.5
Creep coefficient	0.22	0.22
Output Data	**R=300m**	**R=500m**
Guiding force Y1 that acts on the outer wheel of the first axle (KN)	91.98	84.55
Guiding force Y1u=H1 on the inner wheel of the first axle (KN)	21.69	21.74

Y1r = Y1 - 2H1 Force that acts on the first axle(KN)	48.59	41.06
Centrifugal force Fc (KN)	101.74	60.67
Vehicle speed in curve (KN)	80.42	80.17
Uncompensated lateral acceleration ps (m/s^2)	0.68	0.40

Table 1 Curve Traversing of Three Axle Bogie through Curve with Radius R=300 m and R=500 m, as well as Vehicle Speed V=80 km/h.

- **Analysis of Track Gauge Widening**

According to calculation, due to large distance between first and middle i.e. middle and last axle, it occurs increased lateral forces during negotiation of curve, as it was shown in calculation Table1. These lateral forces are not hazardous for derailment, but they have significant influence on the track in small radius curve. Axle load of locomotive is 200 kN ± 3%. This load is distributed on both wheels, but this distribution is not equal during curve negotiation. For example, in case of cant excess, load on inner rail in curve might be significantly larger than 100 kN. With increase of operational load (MGT-Million Gross Tones), it can be expected track gauge widening and deviation of designed geometry.

In addition, gauge-face wear of rails, rigid rail fastening system, plastic deformation of rail pad, the embedment of ribbed plate into upper side of wooden sleeper, convexity of a twin block concrete or wooden sleeper etc. influence the track gauge widening. This deformation is more significant on rail pads under inner rail due to cant excess, when ordered speed was lower than designed speed, and due to chord position of three axle bogie. Infrastructure manager makes a decision on the track gauge widening in small radius curve according to the performance of the vehicle and characteristics of the track. Table. 2 shows the values of the track gauge widening in small radius curve prescribed by the infrastructure manager according to the local specifics.

Radius R, [m]	Gauge Widening [mm]	Concrete Sleeper	
	Wooden Sleeper	Twinblock	Monoblock
R>600	0	0	0
600>R>400		5	5
400>R>350	5		
350>R>300	10		
300>R>250	15		10
250>R	20		

Table 2 Gauge Widening in Small Radius Curve Prescribed by the Infrastructure Manager according to the Local Specifics.

Speed [km/h]	Track Gauge (IAL) Immediate Action Limit			
	Isolated defects Nominal track gauge to peak value Isolated defects Nominal track gauge to peak value [mm]		Nominal track gauge to mean track gauge over 100 [mm]	
	Maximum	Minimum	Maximum	Minimum
V<40	-11	+35	Not Applicable	+32
40 < V<80			-8	+32
80 < V<120	-11	+35	-7	+27
120 < V<160	-10	+35	-5	+20

160 < V<230	-7	+28	-5	+20
230< V<300	-5	+28	-3	+20

Table 3 Gauge Widening

Derailments caused by gauge widening usually involve a combination of wide gauges and large lateral rail deflections or rail roll as shown in Figure 9. The maximum 31.5 mm gauge widening include the rail gauge wear measured under an unloaded condition from the standard value is allowed for a freight vehicle operating in the speed range from 40 to 60 km/h, if a maximum permissible wear of wheel flange is 15 mm. It is obvious that values in Table. 3 match with values from considerations.

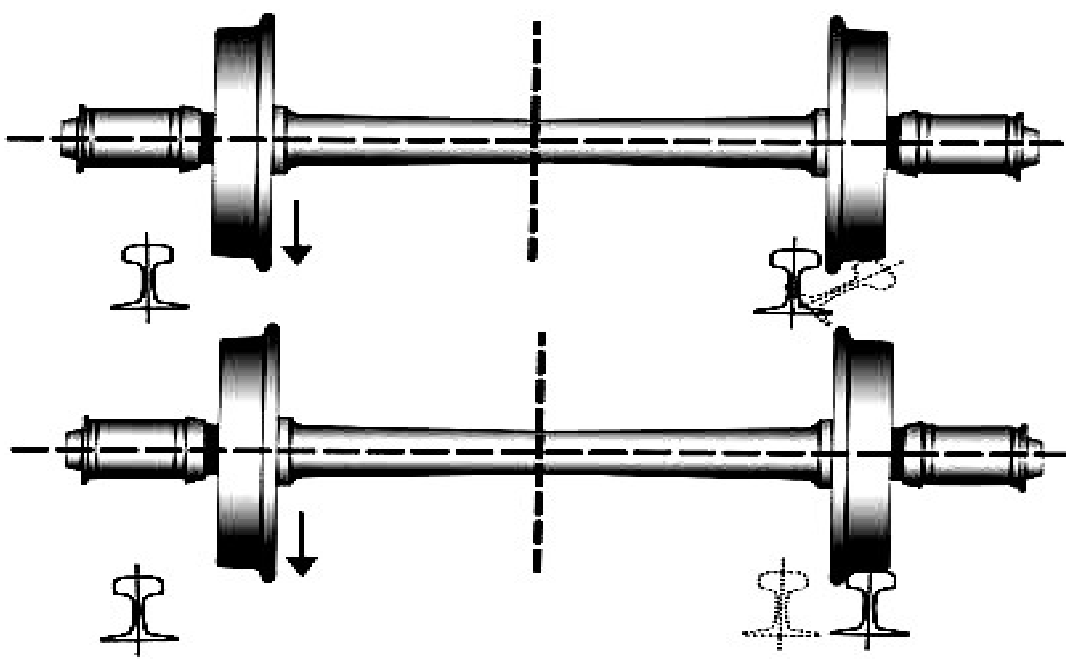

Fig 9 Possible Derailment due to Gauge Widening

- **Hot Running Rail Wheel Gauge Widening and Failures**

Railway wheel is one of important and intensively loaded components in trains. They experi ences mechanical and thermal loads during operation. As failure of railway wheels may lead to several damage or failure of other components, it is important to ensure safety at all stages of manufacturing, assembly with axle and in field. To ensure optimum safety, wheels need to be replaced immediately whenever any fracture is observed. Here are frequently observed wheel failures in Indian Railways given below,

- ✓ Wheel shelling
- ✓ Wear from flange and tread regions.
- ✓ Formation of wheel at from continuous dragging of wheel against rail
- ✓ Thermal and mechanical fatigue due to higher temperatures and mechanical loads
- ✓ Wheel tread plastic deformation from higher wheel running temperatures
- ✓ Wheel gauge widening
- ✓ Worn-out due to frequent re-profiling of wheel tread
- ✓ Breakages at rim-disc and disc-hub interfaces due to excess heating or from residual stresses from wheel heat treatment
- ✓ Excess wheel wear from tread region

Chemical Composition of Locomotive Wheel

Element	Percentage	Element	Percentage
Cr + Ni + Mo	0.5	Mn	0.60-0.85
C	0.57-0.67	Si	0.15
P	0.03	Ni	0.25
S	0.03	Cr	0.25
Cu	0.28	Mo	0.06
V	0.05	Al	0.02

Table 4 Chemical Composition of Locomotive Wheel

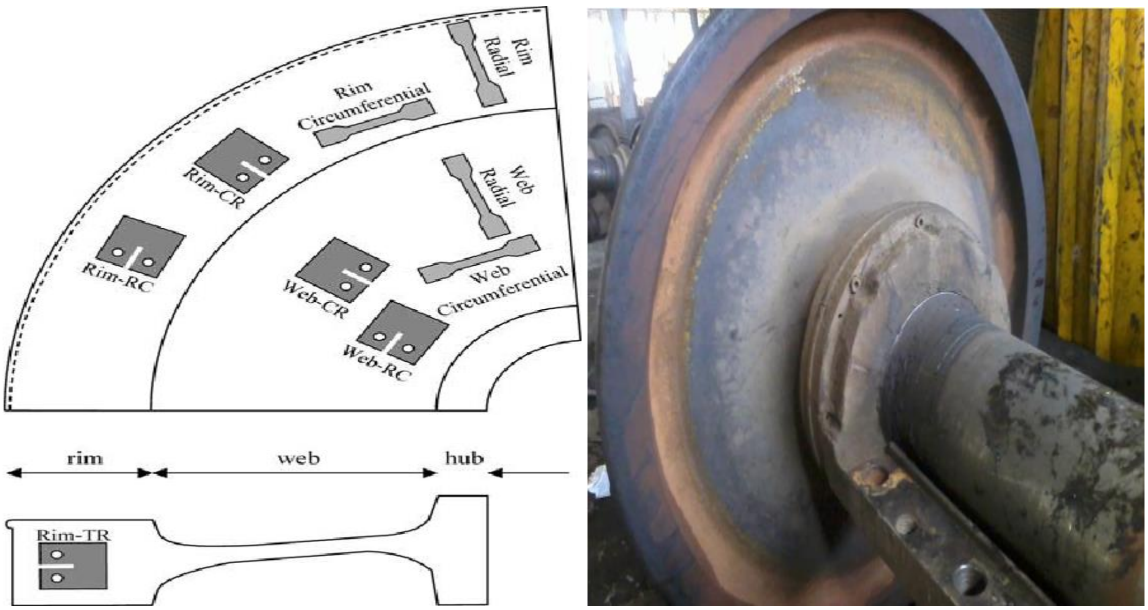

Fig 10 Gauge Widened Locomotive Wheel with Values of Circumferential Gauge Increases

Wheel Gauge Widening

Locomotive wheel gauge is checked when the locomotives go to maintenance sheds. During inspection, the locomotive is at rest and the wheels are nearly at room temperature. Gauge widening is normally axial symmetric and no axial shift of wheel on axle was observed. Maximum gauge increase observed was about 20 mm. It is noteworthy that in essentially all reported cases, failure occurred from gauge widening and not from condemning. Several changes were made to control locomotive wheel gauge widening. They are reduction of brake cylinder pressure, ensuring friction characteristics to satisfy prescribed limits, by passing braking to coach or wagon wheels without application on locomotive wheels. Nonetheless, the problem still persists. Several hundreds of wheel gauge widening cases were reported in various types of diesel and electrical locomotives.

Guide Way Alignment

Radius of curve and gradient of the main track shall be able to ensure the high-speed and large capacity performance of the rail transport, taking the maximum design speed and tractive effort into consideration.

The curve radius of the main track (excluding the curves inside a turnout and in the vicinity of a turnout (hereinafter referred to as a "curve incidental to a turnout")) and the gradient of the main track taking the performance of the rolling stock and other factors into consideration, shall be determined so as to attain at least approximately 80% of the maximum design speed of said line, excluding cases that are prohibited by topography. However, the gradient of the main track for the line on which operation is carried out by locomotive traction shall be such that will enable the designed traction load of this line taking the performance of the locomotive and other factors into consideration.

CONCLUSION

- Analysis of cause and mechanism of track gauge widening phenomenon in curve radii from 300 m to 500 m indicates that track gauge widening is influenced by bogie construction, reduced speeds in relation to the designed speed and cant excess as well as rigid fastening system and type of sleeper.

- Gauge widening shall be gradually increased over the adequate distance in order not to impair safe car operations taking the bogie wheel base of rolling stock into consideration.

- Gauge widening shall be provided at circular curve sections to prevent excessive lateral force on the track taking the curve radius and bogie wheelbase of rolling stock into consideration. This rule does not apply however to those cases where the radius of curve is large, the wheel base of rolling stock is short and there is no chance for the excessive lateral force to be generated.

- Gauge widening cases are more in tread broken locomotive wheels with composite brake blocks. Gauge widening is axial symmetric and reported in straight plate wheel profiles only.

- Wheel heat treatment and axle wheel fitment leaves residual stresses in wheels.

- Wheel failures from thermal cracking and wheel gauge widening are important failures observed in Indian Railways.

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