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СОДЕРЖАНИЕ

СЕКЦИЯ *"ЖЕЛЕЗНОДОРОЖНАЯ ТЕХНИКА И ТРАНСПОРТ "*

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TRACK CONDITION DIAGNOSTIC SYSTEM

СИСТЕМА ДИАГНОСТИКИ СОСТОЯНИЯ РЕЛЬСОВОГО ПУТИ

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Abstract:

The paper explains the philosophy of the track line-speed dependent geometry parameters presenting methods of the track condition evaluation in the form of synthetic quality coefficients is described. Requirements for geometry data collection are discussed and the relevant equipment design features needed for its collection are presented. Analysis of the temporal trend of the track and switch geometry change calls for measurement data storage and analysis. The relevant database system is described along with the examples of queries. Real life examples and experience with this methodology of track and switch geometry parameters analysis in Poland and other EU countries are presented.

KEYWORDS: TRACK GEOMETRY, SYNTHETIC ASSESSMENT, DATABASE, RAILWAY INFRASTRUCTURE, TRACK DIAGNOSTICS

1. Introduction

Regular, scheduled track geometry control features the basis for the contemporary track diagnostic. The issue is to develop the systems capable of generating early warnings of the developing "weak locations" in the track, thus enabling the maintenance services to carry out the preventive maintenance to the track [1, 5, 6]. The routine track geometry checkup carried out by the track recording cars or diagnostic trains ranges from 14 days to 6 months, depending on line load and speed [2, 4, 10]. Spotting the "weak locations" requires a dedicated track geometry database making it possible to align precisely the measurements collected using various systems and to draw conclusions, based on track parameters' temporal trends. The paper is focused on the GeoTEC database system with the dedicated track maintenance dashbboard, developed to assist track maintenance tasks [9].

*The **GeoTec Visual** module is a part of the **GeoTec** package used for the acquisition and extensive analysis of the track geometry measurement data collected using the TEC/TEE trolleys and track recording cars [3, 7, 8]. The package's operation is based on the network definition and measurement data databases. **GeoTec Visual** is an application to be used for the presentation of data stored in the measurements database. The data are exported to the database by means of a **GeoTec Writer** tool.*

The framework supporting the package operation is the network definition database. The network of measured tracks is defined in the aforementioned database. The structure of the database is relatively flexible. The network definition is a hierarchical one. The two main levels are regions and routes used as informative units of certain areas (sets of single track sections). A region may define any area (geographical or political one – subject to a certain executive unit, managing authority etc.). A route may be a set of tracks lying, for instance, between two locations and may run across several regions.

Two lower hierarchical units are a section and a measurement sector. A section is a subset of a route, which may consist of many sections. A section is closely connected with a railway track (with the track ID), which means that a section may be defined only within a track having the same ID. Changing a track ID entails the change of a section. The last organisational unit is a measurement sector i.e. a track fragment of up to 250m in length. Sectors are subsets of sections.

This computer tool makes it possible to forecast track defect development, being able to detect these track geometry deviations that – so far - are still well within their relevant tolerance limits, yet whose development trends turn out to be hazardous for the safe track operation. It should be borne in mind that all track parameters keep deteriorating all time, so it is essential to use special equipment making it possible to collect track geometry data not only in selected locations, but along the track. Computerised trolleys feature the very useful instruments, as the quality of the maintenance tasks carried out can be effectively checked at any time before the track recording task will pass on it scheduled date.

Track gauge measured 14 mm below the rail running surface rails features one of the fundamental geometrical parameters of the track. It turns out that even at the 40-50 Tg load per year measurements made with the geometry cars twice a year – in Spring and in Autumn – give enough diagnostic information about the track gauge, provided the sleepers or elements fixing the rails to them are not in a very bad condition. The expected track gauge increase is about 2 mm for the straight tracks and curves with radii down to 700 m subjected to 20 Tg load [1].

Track twist may be measured using one reference length and then re-calculated to another length – in this way microprocessor track gauges with body length of 1 m can measure twist on base lengths as big as 5 m or 6 m. The main reason for diagnostics taking into account twist has been introducing heavy cars with high torsional rigidity so in some cases twist as low as 4‰ (20 mm per 5 m base) may turn out to be unsafe. All allowable deviations of the track structure are specified taking into account evenness of running. Nevertheless, fast passenger lines allow even larger twist than low speed cargo lines [1, 2, 5].

Each horizontal irregularity of the track curvature results in acceleration of the train travelling through it. Local curvatures of the straight track also affect normal train movement. Horizontal irregularities tend to grow intensively after reaching certain value. For example, the allowable differences of versed sine measured for the 20m long chord are 8 mm for speeds up to 120 km/h, 6 mm for speeds up to 140 km/h, and 4 mm for speeds above 140 km/h, for transient curves these differences are 6.4 and 3 mm. It is important to note that the smallest practically feasible accuracy of track location in horizontal plane is not much more accurate, therefore, accuracy of the technological process features an important factor for line speeds of 120 km/h and more[2].

*While measuring, the user marks the beginning and end of the sector by pressing the appropriate button on a trolley control panel. Such measurement is then exported to the database (**GeoTec Writer**). While being exported, the sectors marked during the measurement are overlaid onto the measurement sectors defined in the track definition database.*

2. Synthetic coefficients of track condition

The coefficients used by the Polish Railways are presented below. The calculated values of synthetic assessment are as follows:

coefficient J *– calculated basing on standard deviations of four track parameters:*

- *standard deviation of vertical irregularities* σ_z;
- *standard deviation of horizontal irregularities* σ_y;
- *standard deviation of track twist* σ_w;
- *standard deviation of track gauge* σ_e;

$$J = \frac{\sigma_z + \sigma_y + \sigma_w + 0.5 \cdot \sigma_e}{3.5}$$

standard deviations *of all track parameters:*

$$\sigma = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2}$$

where: n – the number of samples registered on a given section
x_i – i-th sample value,
$\bar{x}$ - average signal value for the assessed section

five-element defectiveness W5 *– calculated using the defectiveness values of five parameters:*

- *track gauge defectiveness -* W_e;
- *cant defectiveness -* W_g;
- *twist defectiveness -* W_w;
- *vertical defectiveness -* W_z;
- *horizontal defectiveness -* W_y;

$$W_5 = 1-(1-W_e)(1-W_g)(1-W_w)(1-W_z)(1-W_y)$$

parameter defectiveness W:

$$W = \frac{k}{c}$$

where:
W – coefficient of parameter defectiveness,
k – number of samples of assessment section which exceeded the allowed value
c – total number of section samples

The five-parameter defectiveness is calculated basing on exceedings of the maximum allowed – limit - values (i.e., it depends on the selected class of allowed deviations). The values of J and W5 coefficients exceeding the allowed values are displayed in red in the table.

2.1 Additional coefficients

The additional coefficients are the ones that describe the tolerance range, i.e., area under the parameter plot curves:

average overshoot *of the toleration range (S_p):*

$$S_p = \frac{\sum_{i=1}^{k}\frac{x_i}{g}}{k}$$

where:
x_i –the i-th sample value exceeding the allowed deviation,
g – value of the allowed deviation,
k – number of samples exceeding the allowed deviation (for k=0, S_p= 0),

maximum overshoot *of the allowed deviations (S_{pm});*

$$S_{pm} = \frac{x_{i\max}}{g}$$

where :
x_{imax} – the maximum value of the sample exceeding the allowed deviation, ,
g – value of the allowed deviation,
**(S_{pm}=0 if there are no measurements exceeding allowed deviations)*

utilisation of the tolerance range *(S_i);*

$$S_i = \frac{\sum_{i=1}^{m}\frac{x_i}{g}}{m}$$

where:
x_i – the i-th sample value not exceeding the allowed deviation,
g – value of the allowed deviation,
m – number of samples whose measured values do not exceed the allowed deviation

maximum signal/ allowed deviation (T) ratio;

$$T = \frac{x_{i\max}}{g}$$

where:
x_{imax} – the maximum value of a sample in a section,
g – allowed deviation,

utilisation of 75 % of the tolerance range *(P_{75});*

$$P_{75} = \frac{k}{c}$$

where:
k –number of samples (readings) of the assessment section, whose value exceeded 75% of the allowed deviation value,
c – total number of section samples (readings)

2.2 Auxiliary coefficients

The auxiliary coefficients, as an example of the other approach to the track condition assessment, used by the Hungarian Railways, are as follows:

parametric area *– the area between the plot and zero lines (the coefficient value depends on the section length);*

$$P = \sum_{i=1}^{n}|x_i| \cdot l$$

where:
x_i – the i-th sample value,
l – measurement increment,
n – number of samples in the analysed section

parametric peak-peak coefficient *– the maximum value of the difference between two adjacent extrema found for the analysed section;*
parametric coefficient of projection *– the sum of the horizontal projection lengths (from maximum to minimum) of the geometric parameter edges (the value of a coefficient also depends on a section length).*

In addition, for each type of coefficient, the cumulative coefficient Q is calculated according to the formula:

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$$Q = \frac{W_z + W_y + W_x}{3}$$

where:

- W_z - *vertical parametric coefficient; this coefficient is calculated as the sum of parametric coefficients for both rails or as the double value of a parametric coefficient of one rail;*
- W_y - *horizontal parametric coefficient; this coefficient is calculated as the sum of parametric coefficients for both rails or as the double value of a parametric coefficient of one rail;*
- W_x – *twist parametric coefficient; this coefficient is calculated as the sum of parametric coefficients calculated for the twist on the base length A (usually 2.5m) and B (usually 6m)*

3. Results of defect and peak-peak analysis

The analysis of defects examines the values of geometrical parameters by assigning the parameters values to one of the three classes: A – values exceeding 50% of the maximum allowed value, B - values exceeding 75% and C - values exceeding 100%. In addition, readings overshooting 125% of the allowed value are logged.

Summary report - list of dangerous defects and engineering objects

Section [km]: 213.000-214.000 Serie: 03.12.1999-03.12.1999

Parameter/Object	Beg. mileage [...	End.mileage [k...	Length ...	Max value at mileage		AV	CV	AC	L
Curve	213.000								
Gradient	213.059	213.059	0	2.5	213.059	2.5	160 k...	50 km...	C
Gradient	213.076	213.076	1	3.0	213.076	2.5	160 k...	50 km...	C
Gauge	213.086	213.086	1	6.3	213.086	6.0	160 k...	150 k...	C
Gradient	213.197	213.197	1	3.3	213.197	2.5	160 k...	50 km...	C
Gradient	213.289	213.291	2	-2.7	213.291	-2.5	160 k...	50 km...	C
Gradient	213.494	213.495	1	-3.0	213.495	-2.5	160 k...	50 km...	C
Cant	213.524	213.525	1	-9.2	213.524	-8.0	160 k...	150 k...	C
Cant	213.546	213.548	2	-8.3	213.548	-8.0	160 k...	150 k...	C
Cant	213.554	213.554	1	-9.1	213.554	-8.0	160 k...	150 k...	C
Cant	213.561	213.568	7	-9.0	213.564	-8.0	160 k...	150 k...	C
Gauge	213.654	213.654	1	6.3	213.654	6.0	160 k...	150 k...	C
Cant	213.613	213.665	53	-15.5	213.644	-8.0	160 k...	90 km...	C
Gradient	213.859	213.859	0	-2.6	213.859	-2.5	160 k...	50 km...	C
Gradient	213.914	213.916	2	2.7	213.916	2.5	160 k...	50 km...	C
Gradient	213.958	213.959	1	2.7	213.958	2.5	160 k...	50 km...	C

☑ Show defects zero -peak ☑ Show defects peak-peak Close

Figure 1. Detailed results of defects analysis – list of faults in the track

The list (Fig.1) contains the logged defects of C class (over 100% of the maximum allowed value). The first column contains information about the logged defect or object and the information about a section location (curve or a straight track). The STOP icon in the first column indicates that the defect exceeds 125% of the maximum allowed value. One can also display the detailed information for the defects analysis, peak-peak analysis or on both types of analyses.

Track condition assessment

Summary statistics | Synthetic coefficients | Additional coefficients | Auxiliary coefficients | Defect analysis | Peak-peak analysis | Diagnostic comments

		Coefficients for linguistic assessment								
Section [km]	Time period	Coeff. name	Gauge	Grad.	Cant	Twist	Vert.	Horiz.	Accel.	Acc. rise.
212.000-213.000	03.04.2001-03.04.2001	Quality level	0.00	0.00	0.00	0.00	0.00	0.00	0.75	5.18
		P75	0.00	0.00	0.00	0.00	0.00	0.00		
		T	0.58	0.94	0.74	0.49	0.58	0.86		
	High probability of exceeding the allowed limits.									
	Trip comfort bad.									
	03.12.1999-03.12.1999	Quality level	0.00	0.00	0.01	0.00	0.00	0.00	0.73	8.89
		P75	0.03	0.01	0.05	0.00	0.00	0.01		
		T	0.92	1.06	1.18	0.61	0.56	0.88		
	Routine repair neccessary.									
	Trip comfort bad.									
213.000-214.000	01.10.2001-01.10.2001	Quality level	0.00	0.00	0.00	0.00	0.00	0.17	1.13	4.98
		P75	0.00	0.01	0.00	0.00	0.00	0.21		
		T	0.84	1.00	0.59	0.66	0.89	1.28		
	Routine repair neccessary.									
	Trip comfort not good									
	12.06.2001-12.06.2001	Quality level	0.00	0.00	0.00	0.00	0.00	0.11	0.91	5.35
		P75	0.00	0.01	0.00	0.00	0.00	0.19		
		T	0.82	1.10	0.49	0.68	0.92	1.08		
	Routine repair neccessary.									
	Trip comfort bad.									

Calculated for 1000 [m] + - Calculate OK

Detailed diagnostic assessment - launch SOHRON.

Figure 2. Detailed results of analysis of defects with diagnostic recommendations

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The selection is made by marking the appropriate check boxes: ***Show defects zero-peak*** *or* ***Show defects peak-peak.*** *The results of peak-peak analysis in a summary table and in the table listing faults found in the track (fig.2) take the same form as the results of analysis of defects; however, this analysis makes use of the peak-peak analysis deviation classes.*

4. Diagnostic comments

The GeoTEC system has been designed with the data reduction needs in view; therefore, all essential results of the defect analysis and track condition assessment are presented in one screen – table (fig.3).

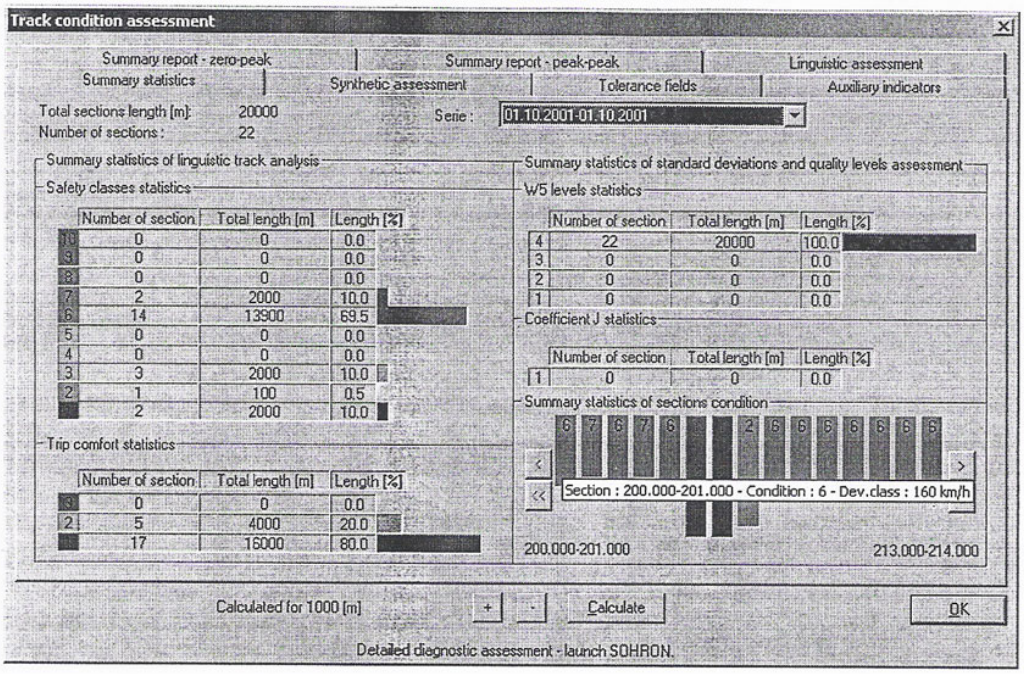

Figure 3. Summary of the assessed track section

Moreover, the integrated expert system generates maintenance recommendations. The table contains also coefficients on which diagnostic comments are based. Moreover, two kinematic parameters are calculated to supplement the track assessment:

lateral acceleration a:

$$a = 6.17 \cdot 10^{-4} \cdot \frac{V^2 \cdot f}{c^2} - 6.54 \cdot 10^{-3} \cdot h$$

where:

a – acceleration value [m/s²],
V –maximum train speed [kph],
f – versine [mm],
c – horizontal irregularity base measurement length [m],
h – cant (difference in heights of rails) [mm],

acceleration increment over a segment Ψ*:*

$$\psi = \frac{3.429 \cdot 10^{-4} \cdot V^3 \cdot (f_{i+1} - f_i)}{c^3} - \frac{V(h_{i+1} - h_i)}{275\ c}$$

where:

V – train speed [km/h],
f_i *– versine at the assessed location [mm],*
f_{i+1} *– versine value half the measurement base length away [mm],*
c – versine measurement base length [m],

5. Conclusions

The GeoTEC database/expert system, developed in MS Access, has made it possible to detect weak locations in the track and to track their development. The results of the multidimensional analysis of track geometry data, apart from the traditional tabular reports and plots, are reported in one "dashboard" screen giving the comprehensive overview of the track section in question. The system has been successfully commissioned in Poland, The Netherlands and is being deployed in Russia. The database system can store and analyse about 6 years worth of geometry measurements data collected with track recording cars and trolleys.

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