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Track and gauge geometry measurements – the present and future

Abstract

The acts, regulations and technical instructions in force imply the obligation of regular monitoring of the railroad condition at the railroad management institutions. This monitoring consists of several types of measurements, most important of which – railroad surface diagnostics – covers the assessment of the technical condition of tracks by measuring the key parameters specifying the rail track position. This paper presents the currently applied solutions, new technologies and potential directions of measurement method development.

Keywords: railway gauge measurements, railway track measurements, track gauge, mobile mapping systems.

1. Introduction

The railroad management institutions both in Poland and the other European states are obliged to perform measurements as well as technical and diagnostic tests of the railway infrastructure elements. These actions aim at determination of the actual condition of facilities and devices. Information collected within this process form a basis for approving the decisions on continued exploitation, taking preventive measures or commencing the repair works. Such measurements require specialist tools of construction adjusted to the specific nature of the rail environment and of accuracy meeting the requirements specified in the sectoral instructions.

2. Rules for Basic Rail Infrastructure Elements Monitoring

Tracks are the key elements of rail infrastructure. Satisfactory technical condition of the tracks is decisive for rail transport safety. The "Instruction of taking measurements, testing and evaluating the state of the rails Id-14 (D-75)" that is in force in Poland specifies in detail the geometrical parameters of the tracks to be determined in order to prepare the synthetic assessments of their condition. These assessments are then used to draw-up the track condition analyses for the individual rail lines. Determination of track width, cant and vertical, as well as horizontal, rail track irregularities is necessary in both indirect measurements performed with the use of measuring vehicles and in direct measurements using mobile measuring devices. Additional parameters to be determined on the basis of the data recorded by the measuring vehicles include track twist and gauge gradient. Measurement with the use of a mobile device provides information on the vertical and horizontal position of track against track alignment indicators and gap values at the contact points of a standard track [1].

Track geometry inspections are performed on a regular basis and combined with the measurement of structure limit gauge. Pursuant to the Polish Ordinance of the Minister of Infrastructure and Development of 5th June 2014, the structure gauge is the outlined area determining the minimum distances between the railway vehicle and the facilities and devices of rail infrastructure, necessary to ensure safe and non-collision rail traffic [2]. In the horizontal plane, this outline is determined against the track axis, whereas in the vertical plane – from the upper level of railhead. The structure gauge may cover only the track and devices directly cooperating with the railway vehicle [3]. Determination of the potential collision elements enables undertaking the relevant measures by the authorized competent authorities before the identified phenomenon becomes dangerous and poses a threat to rail freight traffic.

3. Mobile measuring devices in railroad surveying

The Id - 14 instruction classifies the track geometry measurements into the measurements performed with the use of mobile measuring devices or measuring vehicles.

Mobile measuring devices include among others conventional devices, such as calipers, versine gauges, profile gauges or universal track gauges. These analogue devices require manual recording of the measurement results. Pursuant to the classification of devices intended for rail infrastructure elements inspection, these devices are included into Group I. This classification was proposed by the Swiss Commission for Technology and Innovation (CTI) and is based on measuring efficiency of the devices used in the rail sector [4]. The proposed ranges of measurement rate are up to 0.5 km/h for Group 1, between 0.5 km/h and 5 km/h for Group II and between 5 km/h and 250 km/h for Group III.

a)

b)

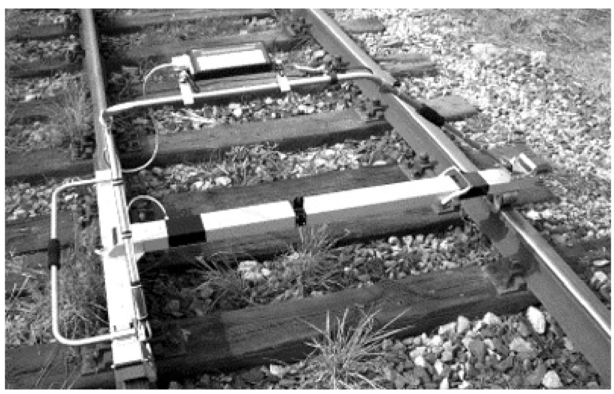

Fig. 1. Electronic track gauges: a) manual track gauge DTG [7], b) trolley TEC - 1435 [7]

Group II includes electronic track gauges [5]. These automated tools enable integration of measurement techniques, carrying out analyses and automatic result recording. Electronic devices are the dominating group on the diagnostics tool market, which results from both technological development and reduction of measurement time at a given section. In opposite to universal track gauges, the electronic trolleys are equipped with recorders enabling storage of the measured parameter values. This group includes manual track gauges e.g. RTE 2® by Proventus [6] or DTG by P.U.T Graw [7]. Both gauges enable the measurement of track gauge, cant and turnouts. The tool included in this group is presented in Figure 1a.

The a/m devices perform the measurement on point-basis at the point of application. To enable seamless recording of track parameter, the trolleys have been introduced. Readings from measurement sensors are recorded automatically in the memory of the devices in real time, subject to time-measurement step and resolution specified by a manufacturer. Such devices provide the complete set of data necessary to determine the parameters required by the Id – 14 instruction. The trolley market is dominated by the devices offered by Polish manufacturers and constructors. TEC - 1435 by P.U.T Graw [7], presented in Figure 1b, is the most common tool used in Polish railroads and is also applied in Holland and Lithuania. Proventus offers the innovative laser trolley LASERTOR XTL 2® [6], whereas TQM is marketed by the British R.A.I.L and designed by Edward Len under his PhD thesis [8].

The available track gauges differ in terms of structure, measurement technology, time-measurement step or accuracy. The common feature is collecting all the required data with the average error not exceeding 1 mm.

Clearance measurements performed simultaneously with the track geometry inspection forced the gauge manufacturers to extend their inspection systems by the new measuring devices. No sectoral instruction specifies the accuracy for determination of the location of the potential collision points. Absence of applicable provisions prevented the testing of individual technologies and devices.

One of the implemented solutions is the application of a reflectorless laser rangefinder dedicated to determining the distance of the facilities situated along the track. All values are converted to the reference system determined against the track axis. Orientation of such reference systems is presented in Figure 2.

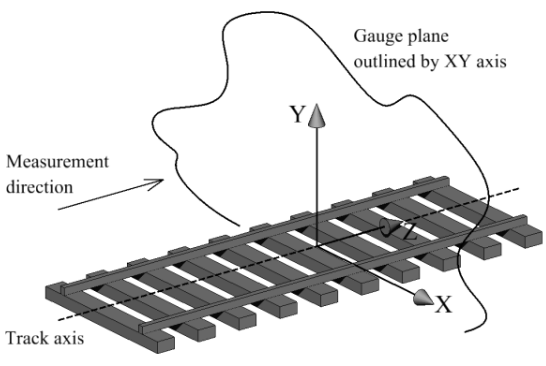

Fig. 2. Orientation of rangefinder system against the track

The range and accuracy of measurement depend on the applied rangefinder. The presented method was used for the construction of a track gauge designed at the Department of Civil and Surveying Engineering of the AGH University of Science and Technology in Krakow [9]. Also P.U.T Graw introduced the LaserTEC – 1435 on the market, based on TEC – 1435 in terms of track geometry surveying and supplemented with rangefinder overlay [7]. The presented track gauge uses the DISTO rangefinder by Leica of 5 mm measurement average error at 7 m distance. The GRP 3000 track gauge produced by the Amberg Group, presented in Figure 3a, is equipped with a Profiler 100 FX with measurement capability of the facilities located in a distance up to 5 m with 3 mm average error [10].

Application of rangefinders forces the trolley operator to stop and target the measured facility. Enhancing the measurements and ensuring continuous recording of elements situated along the track were enabled by introduction of the laser scanning technology. This solution was applied in the Swiss Trolley system designed by the Institute of Geodesy and Photogrammetry in Zurich [4], or GEDO SCAN by Trimble, presented in Figure 3b [11]. The devices used in the discussed cases are profile scanners. The prism rotating around its own axis forces the emission of laser spot in a single plane and generates the profile. Track gauge movement prevents overlapping of the profiles and makes them positioned in a certain distance depending on the trolley speed. In this way the 3D point cloud is generated. The differences between the implemented devices (SICK LMS 200 and Trimble TX5) include scanning range (180° and 360°) and mirror rotation speed (75 Hz and 97 Hz), which translates directly into the number of points recorded by each device (27000 point/sec and 976000 point/sec). Recording the entire space around the track frequently requires the use of two or more laser scanners assembled at different angles as in the case of the Swiss Trolley gauge.

a)

b)

Fig. 3. Trolleys with installed clearance measurement devices: a) laser rangefinder [10], b) laser scanner [11]

Track and gauge geometry surveys performance in the track gauge + laser measuring device configuration enables acquisition of information in the local coordinate system determined against the track axis. Positioning of the starting and ending point of the data record has been based on a combination of mileage information placed on the traction poles and readings of the distance sensor e.g. odometer. To ensure more accurate positioning of the measured section in space and determination of its location in the surveying system, total stations were introduced. In most surveying systems applying this solution, the total station is placed outside the railroad and the measurements are performed to the mini-prisms assembled on the trolleys. This technology is used in TOTAL-TEC trolleys by P.U.T Graw [7], GRP 1000 by

Amberg Group [10] or Hergie by Rhomberg Bahntechnik [12]. A slightly different positioning concept is offered by the Track Quality Measuring (TQM) trolley. In this case the total station is assembled on the trolley body and the measurement is performed to the prisms located on the traction poles and to the reference points of known coordinates [8].

The described method of determination of trolley location features a high measurement accuracy, however due to the limited range of total station records and pursuing towards increased work efficiency, the GNSS (Global Navigation Satellite System) measurement technique has been introduced. A GPS antenna is assembled on the track gauge arm. The measurement is performed using the RTK (Real Time Kinematic) method based on temporary reference stations in the geodetic reference network or permanent nation-wide network stations. This satellite-based measurement may be performed in the stop&go mode, with temporary antenna stoppage over the point and in true kinematic mode at continuous antenna motion.

To ensure sufficient accuracy, the GPS measurements must be made in strictly defined conditions, key of which is visibility of at least 4 satellites. Impaired sky visibility by high land development or vegetation cover may result in connection loss. Another factor influencing the correctness of the acquired results is the multipath effect. Avoidance of such disturbances requires exclusion of the areas with large, flat structures, tin roofs or in-land water reservoirs. Therefore, many manufacturers and constructors implement both positioning methods to enable interchangeability depending on the surroundings of the inspected railroad. These include Trimble (GEDO REC track gauge) [21], Amberg Group (GRP 3000 track gauge) [10] or the employees of the Institute of Geodesy and Photogrammetry in Zurich (Swiss Trolley) [4]. Application of satellite technology in rail infrastructure surveying translates into better efficiency however poorer accuracy.

4. Measuring vehicles

Suitability and reasonability of the track gauge use in track geometry surveying is reflected (in particular) in auxiliary measurements at short distances. Track gauges are not suitable for inspecting the entire railroads, in particular due to the fact that such inspections must be performed up to several times a year. Geometry cars are the perfect solution for such an option. These cars combine the entire measurement, recording and data processing systems in one motorized vehicle. Track geometry cars currently used throughout the world may be categorized in two groups. The first one includes the cars dedicated to the determination of track geometry parameters, whereas the second one consists of cars equipped with clearance measuring devices. The specific feature of the track inspection cars is analysis of the acquired data in motion. The systems of the second group process the acquired data in the offices upon completion of field surveys.

The measurement systems determining the track geometry parameters in real time include EM - SAT 120 by Plasser&Theurer [13] and PALAS by Sersa Group [14]. The first one, presented in Figure 4a, uses the laser long chord method, feasible thanks to a double modular structure of the system. The first module is a track geometry car recording measurements, whereas the second one consists of a trolley emitting the laser beam. The PALAS system is installed on tampers. Using the gyroscopes and a laser scanner, the system collects information on the track axis position in real time, enabling its simultaneous correction. Despite certain differences in measurement technique, both systems were compared due to their efficacy. Although these are assembled on the motorized platform, their speed is app. 5 km/h – 7 km/h (EM - SAT 120) and app. 1 km/h (PALAS), which classifies them into the second measurement efficacy group together with trolleys. There are also other measurement systems that reach much greater speeds even up to 120 km/h and determining the track geometry parameters with the accuracy required by the sectoral instruction. One of them is installed in the EM 120 track geometry car [15], used on Polish railways, whereas the other example is the US Track Geometry Measurements System implemented on the T2000 geometry car [16]. The first vehicle is equipped with electric linear transmitters as well as measuring slides and wheels providing information on track geometry parameters in vertical and horizontal planes (electro-mechanical system). TGMS is a laser-optical system. It consists of a scanner emitting the laser beam perpendicularly to the track axis installed on a bar placed diagonally to the track axis and video cameras of known orientation recording the generated light profile. TGMS is presented in Figure 4b.

The measurement systems dedicated to clearance surveying include the systems using the stereophotogrammetry, laser scanning or light profile recording technologies. Due to the amount of received data and complexity of processing the information acquired with the use of the a/m technologies, all calculations and analysis are carried out upon completion of field surveys.

a)

b)

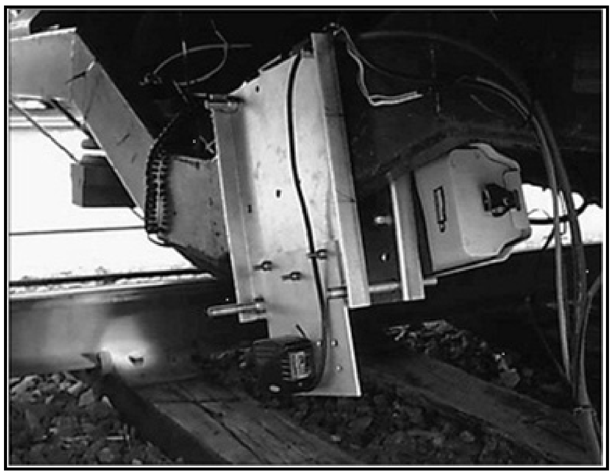

Fig. 4. Track geometry systems installed on geometry cars: a) EM - SAT 120 system [13], b) TGMS system [16]

Detecting the collision facilities at the clearance inspection with the use of the simultaneously acquired image pair is the solution implemented in the LIMEZ II system by Technet [17]. The discussed geometry car with the installed set of tools and measuring devices is presented in Figure 5a. Knowledge of mutual position and models of cameras enables the acquisition of the spatial location of the inspected facilities against the track axis [18]. LIMEZ II formed the reference basis for the Polish UPS - 80 system by P.U.T Graw [19]. The high resolution of cameras used in both systems and their known parameters enabled delivery of highly accurate measurements at the speed of app. 20 km/h.

The laser scanning technology replaced stereophotogrammetry and has dominated the mobile measurement sector. As in the case of track gauges, the geometry cars apply profile scanners. In motorized vehicles, these devices usually have higher point measurement frequencies. This option is necessary for the high speeds of geometry cars. The first rail system using these scanners was LIMEZ III [20]. It is equipped with two or optionally three measuring heads. Clearance measurement is made via CPS (Clearance - Profile - Scanner) devices, whereas the recording of small facilities is performed by a HSP (High - Speed Profiler) device. This tool uses two laser beams instead of a single one as in the case of conventional scanning devices. Application of such device configuration enables acquisition of even up to 1200 profiles per second with 3600 points in each profile. At the maximum vehicle speed of 100 km/h, one is able to acquire the profiles every (2÷3) cm.

The a/m solution was developed with a view to measurements in the rail environment. However the trend towards adapting mobile measuring platforms designed for road measurements has been increasingly visible. This was the case for the Riegl company, transforming the VMX – 450 system [21] and IGI [22] adjusting its StreetMapper to rail conditions. Both measuring platforms are equipped with two Riegl profile scanners. VMX - 450 RAIL is able to record 200 profiles/sec., which gives 1100 million of points per second in total. Laser devices embedded in the RailMapper, deliver 100 profiles/sec., acquiring 600 000 points per second. The average error of points acquired by this measurement technology is in a range between 6 mm and 8 mm. The RailMapper system is presented in Figure 5b.

The photogrammetric light profile recording method is the technology common for track geometry rather than gauge surveying. However the Balfour Beatty Rail Technologies company decided to use a fast LaserFlex scanner with HD Video cameras to detect the collision points [23]. The applied laser device emits a beam in a 360° arc, perpendicularly to the track axis. The light plane delivered by the scanner generates the profile lines at the crossing with the facility, which are then recorded by Video cameras of known location against the generated plane. The discussed measurement system along with the generated light profile is presented in Figure 5c. The camera records the profiles every 2 cm at 120 km/h speed.

Both when using the mobile devices and geometry cars in the measurements, positioning the measured section of the railroad in space is of the utmost importance. Determination of the location based on mileage is certainly the least accurate method. Such solutions have been applied in the gauge surveying systems using the stereophotogrammetry method [17, 19]. In this case, all measurements were referred to the track axis and the collision points were identified based on information placed on the traction pole, which was found via recording with an additional video camera.

When determination of the position of measuring devices with 1 mm average error was necessary, as in several systems dedicated to track geometry surveying, one should use a total station or laser scanning and gyroscope. Such an approach was adopted in the EM - SAT 120 [13] and PALAS [14] systems. Application of this method implies the use of prisms or boards of known coordinates and situated along the railroad. As the specific PALAS system has no option to enhance the work efficiency due to the speed of the applied tampers, determination of the position in the EM - SAT 120 system with the use of a total station is restricted by the distance of the measured route covered per hour.

Application of satellite measurement technology was supportive here. This solution acts as the golden mean between the time-consuming determination of the position with high accuracy and fast, however imprecise positioning. EM - SAT 120 [13] or T2000 [16] cars have been equipped with GPS. As in the case of using this method of determination for the location in trolleys, we must face the problem of signal loss and multipath effect.

a)

b)

c)

Fig. 5. Gauge surveying systems: a) Balfour Beatty Rail system [23], b) RailMapper [22], c) LIMEZ II [17]

To avoid decreased measurement efficacy, a solution consisting in complementing the navigation system with the inertial unit (IMU) was applied. This device is structured of three mutually perpendicular gyroscopes, accelerometer and magnetometer. It replaces the satellite measurements when crossing the tunnels or highly urbanized areas, however it cannot operate alone. This device is actually a dead reckoning navigation sensor, in which the new position is calculated against the previous result. If no new data is supplied to determine the position, there is no correction of errors, which increase in time. The GPS/IMU cooperation-based navigation system was applied to the LIMEZ III [20], VMX-450 RAIL [21] or RailMapper [22] gauge surveying systems.

5. Summary

Low weight and small dimensions of mobile measuring devices are their unquestionable advantages. These properties enable fast and easy removal of a device from the track, which enhances the measurement effectiveness on railroads with high traffic intensity. It seems more complicated in the case of inspections performed by specialist vehicles, since operation of such a measurement system must be included in the time-schedule. However, with a view to obligatory monitoring of the entire railroads even up to several times a year, application of geometry cars becomes the only feasible solution. Enhanced works efficiency related directly to implementation of faster technologies and measuring devices, both to determine the track geometry parameters, gauge surveying or positioning of the inspected railroad sections. Introduction of the laser technique and satellite measurements proved to be the best solution. Both technologies enable surveying in constant movement.

In track geometry measurements, the laser-optical systems have been gradually replacing the electro-mechanical ones. Clearance surveys, both direct and indirect, have withdrawn from reflectorless rangefinders forcing the operator to stop the vehicle. The stereophotogrammetry technology could be used during car movement, however insufficiently developed automatic methods of collision point identification on the images forced the operators to verify each stereogram manually. In effect, photogrammetric cameras or video have been only supporting the systems using the laser scanners, documenting the measurement and facilitating the interpretation. The available solutions are dominated by laser profile scanners in various configurations and settings, enabling measurements of the entire area surrounding the measuring platform to be collected. The greater the vehicle speed, the higher the measurement rate of the applied scanners that is required. Measuring sections are localized in space thanks to the satellite positioning technology. To avoid signal losses and multipath-related errors, the navigation units are complemented with an IMU device. Impact of the introduction of this technology on the efficiency and accuracy of the measuring devices and vehicles is presented in Table 1.

Tab. 1. Parameters of the selected measuring devices and vehicles

	Measuring devices			
	GEDO CE trolley [11]	EM – SAT track geometry car [13]	Limez III track geometry car [20]	VMX - 450 RAIL track geometry car [21]
Average error of track geometry parameters determination	Width:			
	0.3 mm	1 mm	2 mm	-
	Cant			
	0.5 mm	-	2 mm	-
Positioning of the point using a total station	Average error			
	1 mm * 3 mm **	1 mm - 3 mm	-	-
	Measurement rate			
	0.5 km/h - 1.2 km/h	1.5 km/h	-	-
Positioning of the point using the satellite measurement technique	Average error			
	20 mm - 40 mm *	10 mm - 12 mm	< 0.1 m	20 mm - 50 mm
	Measurement rate			
	1.2 km/h	5 km/h - 7 km/h	100 km/h	120 km/h

*stop&go method
**true kinematic method

As we can see, this method is faster compared to the conventional positioning methods and may be applied during the continuous movement of the track gauge or mobile mapping systems, however impairs the measurement accuracy.

The systems used for clearance surveying additionally determine the track geometry necessary to outline the track axis against which the gauge is surveyed. In most cases it is determined with lower accuracy than required. In effect, the rail diagnosticians must use two independent measurement systems.

6. Conclusions

This paper presents the track geometry and gauge measurements applied in the past and at present. The performed analysis formed the basis to conclude on the future of measurements in the rail sector. It seems that the key element will be the efficacy of data acquisition. Thus the applied technologies will be dominated by the track geometry cars equipped with devices recording both track geometry and structure gauge parameters with the accuracy required by the sectoral instructions, whereas the measuring sections will be positioned using the GNSS technology supported by the IMU device.

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