

Impact of deteriorated tram tracks on the current collectors of trams

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ABSTRACT

This article presents the results of a measurement campaign conducted during the summer of 2025 in Sofia. The study aims to determine the impact of deteriorated tram tracks on the current collectors of trams. Measurements were carried out on sections of the tram network where the tracks are in emergency or pre-emergency condition. The measured parameters include linear accelerations, angular velocities, and magnetic field values along the three axes. The sensors were positioned on the tram roof and on the collector strip holder. The analysis of the findings includes a comparison of the parameter values recorded at both locations, a general assessment of their impact on the current collector, and a comparison with results from a previous study conducted in 2019. Based on the obtained data, conclusions have been drawn regarding the influence of the tram's lateral sway on the current collector.

KEYWORDS

Trams, Electrical current collector, Railroad, accelerometer, Gyroscope, Magnetometer, Kalman filter

1. INTRODUCTION

The measurement conducted in 2025 is part of a long-term and comprehensive study on the impact of tram track conditions on the current collectors of tramcars in the city of Sofia [1, 2]. To determine the causes of failures and emergency breakdowns of the current collectors, a series of measurements were performed in track sections under emergency and pre-emergency conditions. It was found that current collectors are most vulnerable to the lateral rolling of the tramcars caused by track subsidence. The primary cause of failure is the destruction of the middle joint of asymmetric current collectors and the rods above the joint. The novelty lies in the fact that the measurement was carried out using two independently operating systems located at the base of the current collector and on the collector head frame.

2. MATERIALS AND METHODS

The measurement was conducted on August 22, 2025, along the route shown in Figure 1. This section provides detailed information regarding the track segment on Hristo Botev Boulevard, extending from Struga Street to Pirotska Street. In this section, the tram track underwent major overhaul in 1998, and currently exhibits severe rail subsidence with a random distribution. The operation of tramcars in this segment is characterized by significant lateral rolling.

A T6A2-BG type tram with inventory number 3027 was used for the measurement. The measurement was conducted at night under a regime corresponding to actual operating conditions. The tramcar is a single-section, four-axle vehicle with rigid axlebox guiding. The current collector is a symmetrical type KE28 - original for this tram model - featuring a modified design of the collector head frame. Following the installation of the sensor unit, the current collector was adjusted to bring the contact wire force to its standard value of 70 N.

The accelerations generated within the current collector during the tramcar motion are used to determine the forces acting upon it. In the method described in [2], the accelerations were measured on the ceiling of the tramcar passenger compartment and analytically mapped to its individual components.



Figure 1: Test route

To avoid this mapping procedure and its associated inaccuracies, two fully autonomous sets of measurement systems were utilized. One system was installed on the cab roof (Photo 1.), while the second was mounted on the collector head frame (Photo 2.). The specific positioning of the second module imposes additional requirements on its design. To provide protection against the magnetic field of the contact wire, it is housed in an enclosure fabricated from a steel section.

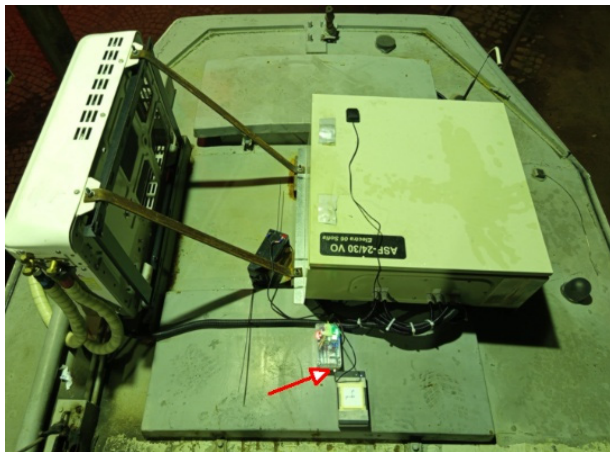


Photo 1



Photo 2

Figure 2: Sensor placement

Both systems are identical and comprise: a triaxial accelerometer, a triaxial gyroscope, a triaxial magnetometer, a navigation receiver, and a microcontroller for data processing and storage. The BNO055 inertial measurement module from Bosch [4] was selected, in which all three sensors are integrated into a single package. It is manufactured using MEMS technology. To fuse the data from the three sensors, it features an embedded 32-bit microcontroller running the proprietary BSX3.0 Fusion Lib software. This enables the sensors to be programmed in various modes to determine either relative or absolute orientation, outputted as quaternions or Euler angles. The ESP32-WROOM-32D [5] module was utilized to read and store the information from the BNO055. Out of the diverse interfaces it provides, two serial interfaces were used: I2C for communicating with the BNO055 and SPI for connecting the SD card module. The system is integrated onto a Spark-Fun IoT RedBoard-ESP32 [6] development board.

A navigation receiver was utilized for the geographic referencing of the measurements. The sensor data, sampled at a frequency of 40 Hz, were appended to the coordinates received every second. The information integrated in this manner was recorded onto an SD card. Since the navigation receiver located inside the steel enclosure could only acquire a time synchronization signal, this resource was utilized to synchronize its time with that of the receiver on the roof. Consequently, the corresponding geographic coordinates were determined by aligning these timestamps.

Photo 3. shows the orientation of the axes in the coordinate system of the instruments. The Y-axis is directed forward along the direction of travel of the tramcar, while the X-axis is directed to the right relative to the direction of travel.

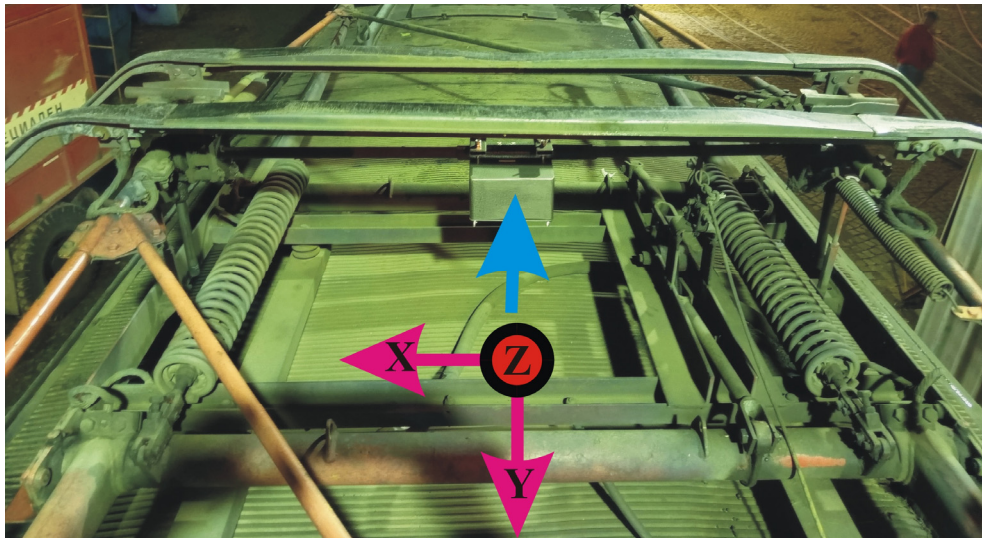


Photo 3. Orientation of the axes in the measuring instruments coordinate system

3. MEASUREMENT RESULTS

The sensors generate 40 readings per second along all three axes for all monitored parameters. To track the impact on the current collector in the lateral direction, the accelerations along the transverse axis of the vehicle were taken into account - specifically, the acceleration values and the root-mean-square (RMS) acceleration values. Table 1. presents the acceleration values obtained from the sensors on the cab roof and the current collector head, as well as the calculated root-mean-square (RMS) acceleration values.

Table 1: Measurement Results

	on the roof	on the current collector
Maximum acceleration values on the X-axis, ms^{-2}	$-1,36 \div 2,42$	$-11,6 \div 12,67$
Equivalent values of acceleration on the X-axis, ms^{-2}	2,84	24,27
Average equivalent values of acceleration along the X-axis, ms^{-2}	1,06	5,08

Figure 3 shows the diagram of the accelerations measured on the roof of the tram.

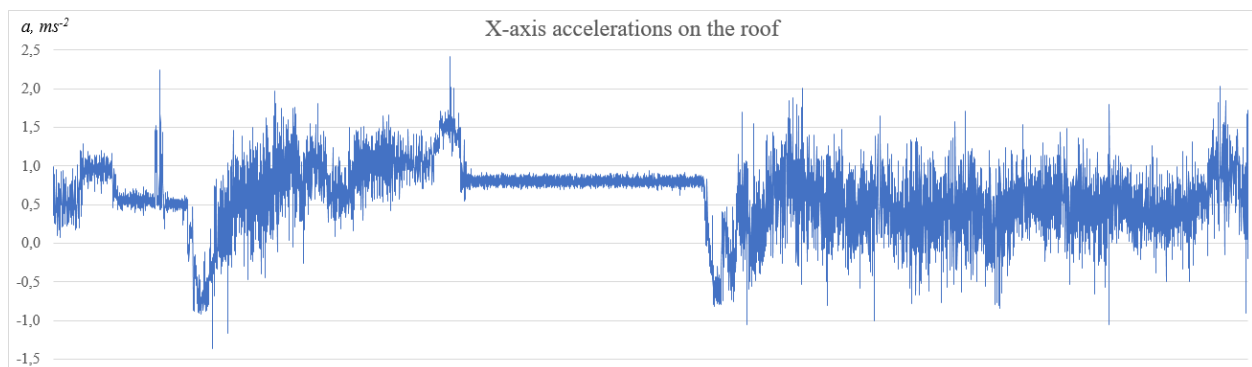


Figure 3: The diagram of the accelerations measured on the roof of the tram

Figure 4 shows the diagram of the accelerations measured on the collector head frame.

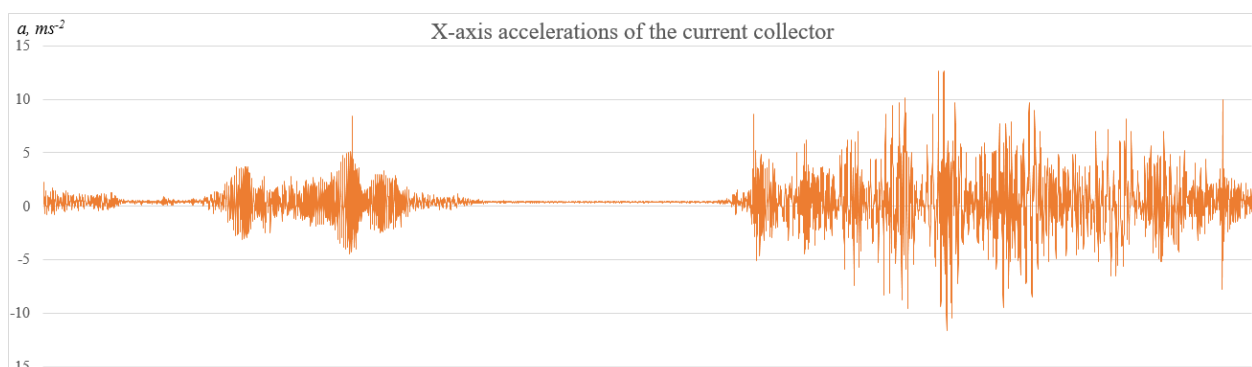


Figure 4: The diagram of the accelerations measured on the collector head frame

The diagram presented in Figure 5. shows the results of the measured accelerations - specifically, on the roof in blue and on the current collector head in orange.

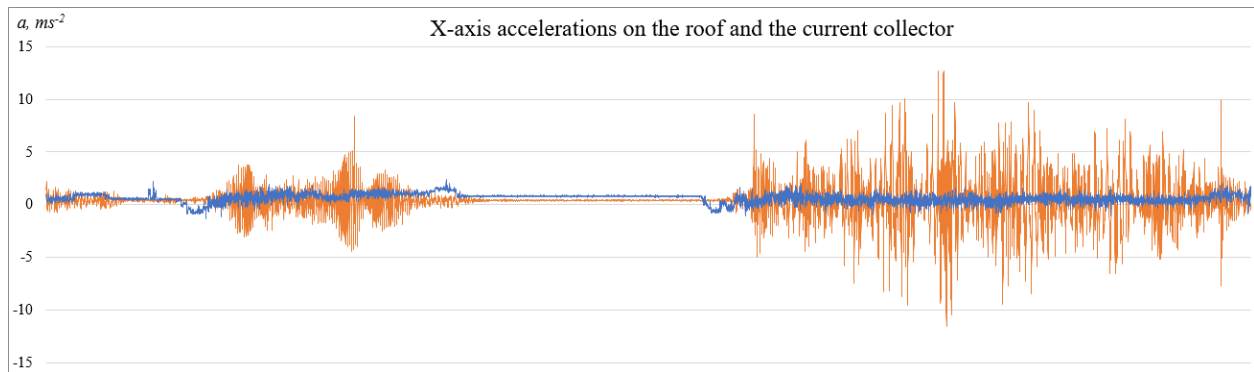


Figure 5: The diagram of the accelerations measured on the roof and on the collector head frame

The intervals with very low values recorded by the sensors correspond to the tram's dwell time at traffic lights. Significantly higher acceleration values were registered in the second part of the section, along Hristo Botev Boulevard from Slivnitsa Boulevard to Pirotka Street. Figure 6 shows the diagram for this section, presenting the results from both measurement points.

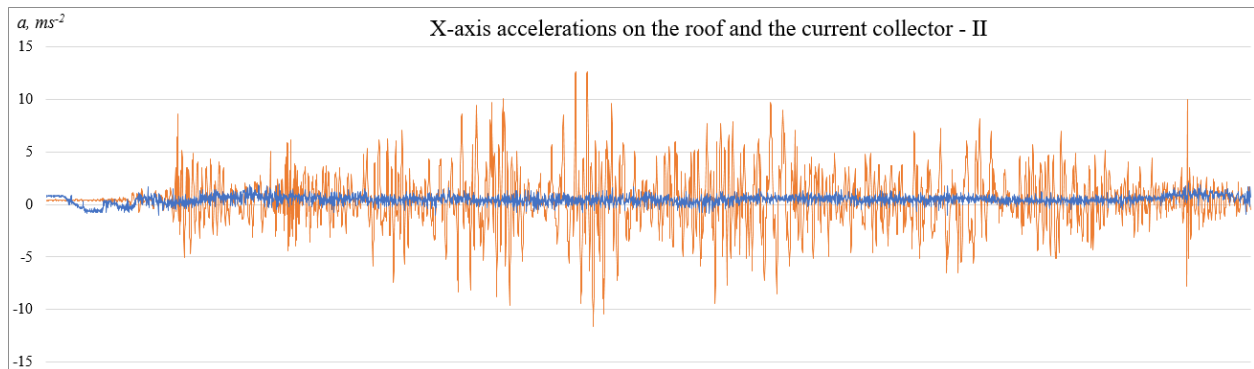


Figure 6: The diagram of the accelerations measured on the roof and on the collector head frame in the second part of the section, along Hristo Botev Boulevard from Slivnitsa Boulevard to Pirotka Street

The diagram with the calculated root-mean-square (RMS) acceleration values for this section is shown in Figure 7.

The presented diagrams clearly illustrate the discrepancy in acceleration magnitudes between the two measurement points. The acceleration magnitude at the current collector head is significantly greater than that at its base. A detailed review reveals that, in addition to exhibiting a larger amplitude, the accelerations at the current collector head display more frequent directional fluctuations. Furthermore, they are phase-shifted, indicating a certain delay in changing direction.

Considering the worst-case scenario, where consecutive maximum accelerations occur in both directions along the X-axis, summing the peak values yields $3,78 \text{ ms}^{-2}$ at the base and $24,27 \text{ ms}^{-2}$ at the current collector head.

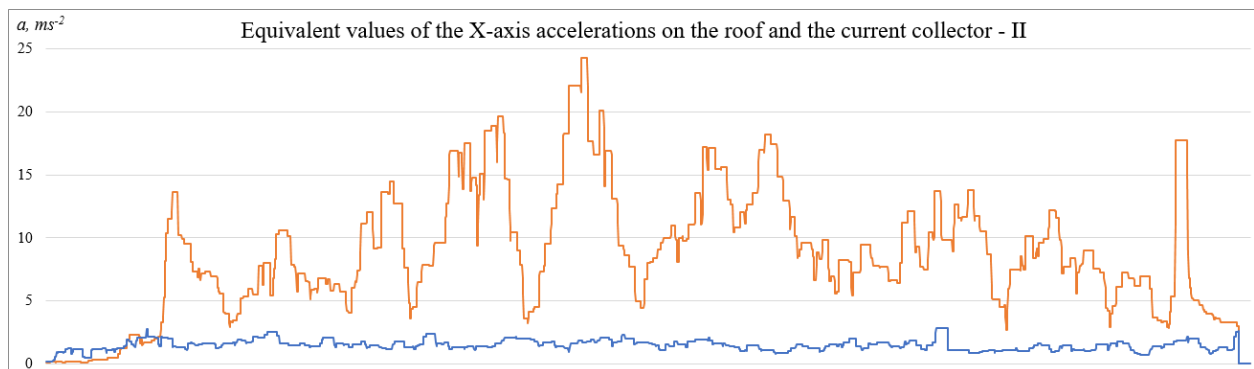


Figure 7: Diagram of the Root-Mean-Square (RMS) Acceleration Values for the Second Part of the Section along Hristo Botev Boulevard from Slivnitsa Boulevard to Pirotka Street

4. IMPACT ON THE CURRENT COLLECTORS

The prevailing acceleration values measured at the current collector head are on the order of $\pm 5 \text{ ms}^{-2}$, corresponding to a peak-to-peak amplitude of 10 ms^{-2} . Taking into account the discrepancy between the values obtained at the two measurement points, this value can be considered close to the effective acceleration acting on the current collector head during most of the travel time along track sections under emergency or pre-emergency conditions.

To determine the degree of impact on the current collector and its components, the methodology developed in [1, 2] can be applied with minimal modifications. Instead of mapping the parameter values to the current collector head, they can be calculated using the acceleration values obtained during the 2025 measurement.

Figures 8. and 9. show the geometric dimensions of the current collector involved in the calculations. In the figures: B_{bi} - represents the center of gravity locations for each component of the current collector; S_i - denotes the centers of the joints; C_i - indicates the sensor placements; G_i - represents the common centers of gravity for the individual stages of the current collector; d_i - represents the distances from the centers of gravity to the current collector base; ρ_i - denotes the distance of the characteristic points to the rotation axis of the tram; and x_p - represents a point on the X-axis of the tram rotation.

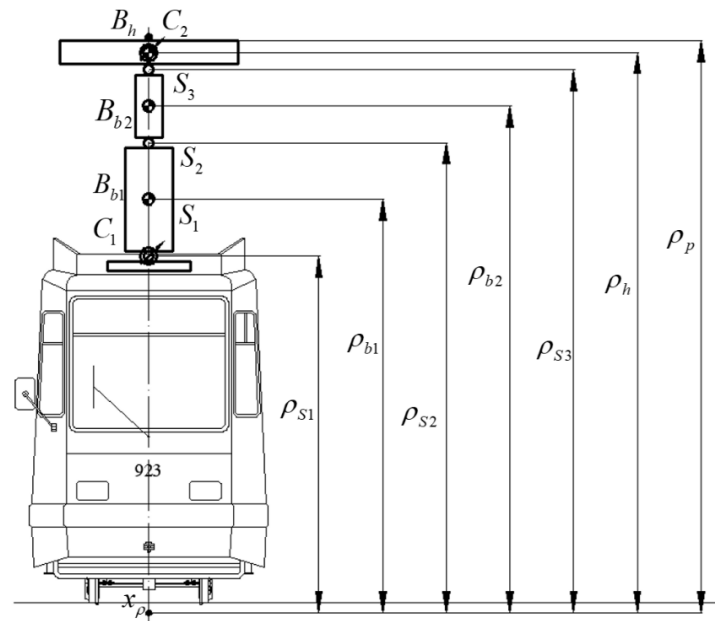


Figure 8: Distances from the current collector components to the rotation axis

Considering that the current collector joint connections are their most vulnerable areas, emphasis has been placed on the forces arising at these points. The calculation results are listed in Table 3 and compared with the calculation results obtained following the 2019 measurement.

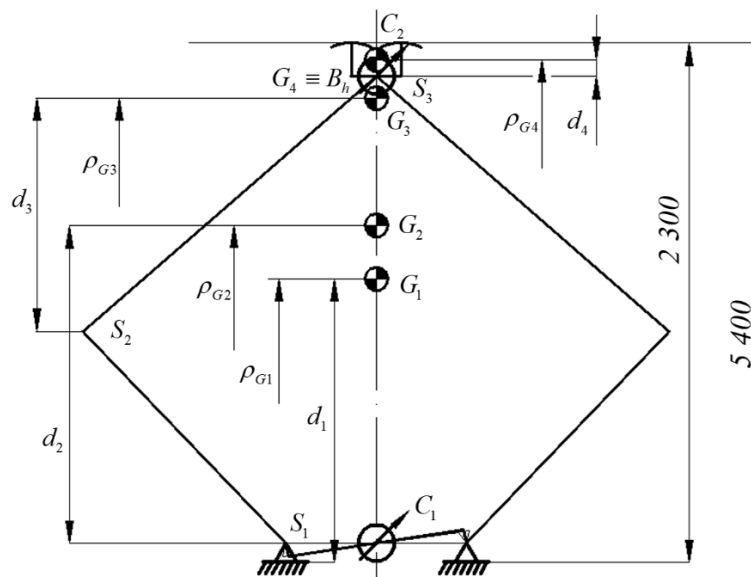


Figure 9: Characteristic points and the distances between them

5. COMPARISON WITH DATA FROM THE PREVIOUS MEASUREMENT

In the measurement conducted in 2019, the sensors were positioned on the ceiling of the passenger compartment, directly beneath the current collector base [1, 2]. Based on the obtained results, conclusions were drawn regarding the accelerations and forces acting on the various current collector components. For this purpose, the corresponding analytical relationships were derived. In 2019, the measurements were performed using two types of trams equipped with Pf-80 and KE28 current collectors. In 2025, the measurement was carried out exclusively with a T6A2-BG type tram featuring a KE28 current collector; therefore, it is appropriate to make the comparison specifically with the data for this type of current collector. In the calculations performed in [1, 2], it is assumed that the angular velocities and accelerations of the entire current collector are uniform. Based on this assumption, calculations were carried out regarding the loads in the joint connections between the current collector components. The 2025 measurement indicates that the accelerations at the current collector head are approximately 5 times greater than those at the base. Consequently, the corresponding loads within the joints are significantly higher. Table 2 presents the results of both acceleration measurements, obtained from the sensors at the base and the current collector head, respectively.

Table 2: Acceleration measurement results from the base and collector head sensors

	measurement in 2019	measurement in 2025
Acceleration values on the X-axis on the roof, ms^{-2}	0,95	2,42
Acceleration values on the X-axis on the current collector, ms^{-2}	-	12,67

The discrepancy between the acceleration values at the current collector base in the two measurements can be attributed to the different routes and, consequently, the varying track conditions. The 2019 measurement was conducted in a track section characterized predominantly by parallel rail subsidence. In contrast, for the 2025 measurement, a section with a staggered or random distribution of rail subsidence was selected. Table 3 presents the values calculated from the 2025 measurements and compares them with the mapped values computed based on the 2019 measurement.

Table 3: Values calculated from the 2025 measurements and mapped values computed following the 2019 measurement

	measurement in 2019	measurement in 2025
Bending moment at the current collector head hinge, Nm	3,62	482
Bending moment of the current collector middle joints, Nm	78,14	726
Bending moment of the current collector base joints, Nm	188,22	1297

A comparison of the data in the table indicates that the 2025 measurement yielded higher values for the bending moments in the current collector joint connections.

6. CONCLUSION

The presented results of the acceleration measurements in tram current collectors, arising from the tram track conditions, demonstrate significant values. These findings can be considered to account for the frequent failures of current collectors on trams operating on lines whose routes traverse track sections under emergency and pre-emergency conditions. The presented measurement validates the conclusions drawn in [1, 2] and provides a clearer understanding of the loads acting within tram current collectors.

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