Development and Testing of a New Active Steering System for Light Rail Transportation

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Abstract

Traila is focused on the development of an Active Steering solution for Light Rail vehicles and have recently built a test tram named the TX4 - Traila T2000 Test Tram. The purpose is to improve the wheel-rail interaction and improve wear, tear, noise, and vibration conditions. The TX4 is designed to accelerate the development and realization of the Traila Active Steering (TAS) technology. The TX4 enables practical field testing, data collection, and system demonstration of the TAS on the tram network in Zürich, in association with the Zürich city operator Verkehrsbetriebe Zürich (VBZ). The TX4 includes an array of vehicle sensors with which to support the direct operation of the TAS system, as well as integrating a wider arrangement of data collection architecture intended to further the development of the TAS technology. The collected field data is then analyzed against the testing requirements in addition to enabling the validation and optimization of novel Multi-Body-Dynamics modelling and Active Steering Control simulations respectively, developed in-house by Traila. Lucchini RS provided resilient wheels to match the requirements of the TAS system for use on the Zürich network.

Keywords: Active Steering, Sensors, Wear, Noise, Field Testing.

1. INTRODUCTION

The Swiss group Traila is developing a groundbreaking Active Steering technology for rail, based upon an onboard-sensor track-localization system. The continuous evolution of new types of electronic sensors, equipment and high-speed processors increasingly enables Active Steering systems to be developed and integrated into rail vehicles for practical use.

The Italy-based Lucchini RS Group, a worldwide leader in the design and supply of railway wheelsets and subcomponents, supported Traila in the design and supply of resilient wheels specified for use on a modified Tram 2000 (T2000) that is synonymous with the city of Zürich.

This collaboration was achieved following the meeting of these two groups at the 19th IWC congress that took place in Venice, 2019 [1].

2. HISTORY

Traila was established in 2018 and focuses on the development of Active Steering for light rail. Although Active Steering is not necessarily a new subject [2] early prototypes from Traila and laboratory-based test benches validated the functionality and suitability of various active steering solutions. Traila was able to successfully demonstrate the use of a functional active steering system [3] [4] that led to the establishment of a relationship with VBZ Zürich. In 2021 the relationship between Traila and VBZ resulted in the modification of a T2000 tram for the purposes of field testing a Traila Active Steering (TAS) on the Zürich network.

The foundation of the Zürich project was to optimise the running performance of the wheel-rail interaction and the optimisation of the steering controller attenable from the Zürich tests, using a 1-meter gauge, single axle bridge with independent wheels, with integrated track sensors and an onboard steering actuator.

3. TX4 TEST TRAM

The TX4 is a decommissioned Tram 2000 (T2000) taken out of service from Zürich in 2021, as shown in Figure 1. Essentially, Traila replaced a rear bogie with a new Traila TAS test system. The TAS takes the form of an axle bridge with independent wheels. Integrated into the TAS are a pair of Lucchini RS resilient wheels.

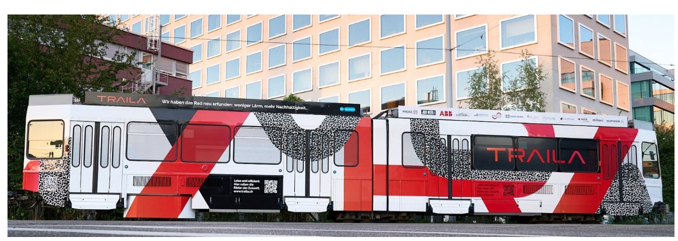

Figure 1 TX4 (Traila T2000 Test Tram) currently being tested on the tracks (1m gauge) at VBZ Zentrum, Zürich

Lucchini RS was able to design and supply these resilient wheels for the purpose of operating on the VBZ network, and in combination with a hub motor solution sourced from Traktion Services Austria (TSA). Traila and Lucchini RS Design and Engineering Departments worked closely together to design a compact solution of the fitting of these resilient wheels.

The onboard track detection sensors are of an inductive type and are mounted on the axle bridge in positions before and after the wheel, i.e. close to the wheel-rail contact zone. The TX4 also features optical sensors, accelerometers, angle sensors, and pressure sensors for the purposes of the field testing that are centralized in an onboard Data Acquisition (DAQ) system. The inductive sensors are arranged in a configuration to identify the edge position of the rail track relative to the vehicle on the tracks, whilst the onboard controller is then able to determine the optimal running line of the vehicle. The main purpose of the controller is to identify vehicle-to-track positional errors, and then counter and correct them through the use of an onboard steering electrohydraulic actuator. The description of the operation of the TAS technology is given in detail by the Traila patents [2] and [3] that describe a series of rail track detection sensors positioned around the wheel and rail contact area, using a tool chain as illustrated in Figure 2.

Figure 2 Traila tool chain – A) Track position detection, B) Correction for position errors, C) Mechanical adjustment

4. DEVELOPMENT AND DESIGN

The Traila wheelset takes the form of an axle bridge for the purposes of the development of the TAS Active Steering controller, as illustrated in Figure 3. The axle bridge configuration was chosen to simplify the turning point through the vertical center of axle system. This axle was designed to then have a minimum required turning force on the actuator and therefore minimize the turning inertia of the wheel set structure. The axle bridge features independent wheels, two levels of suspension, and the necessary supportive components that enables the integration of an Active Steering solution.

Lucchini RS was requested by Traila to provide a wheel solution for the TAS axle, which included a pair of matched TSA motors for the traction system. The outer diameter of these TSA motors was an obvious constraint for a wheel solution, in addition to a mandate from the VBZ that all tram wheels in operation on the Zürich network must be resilient.

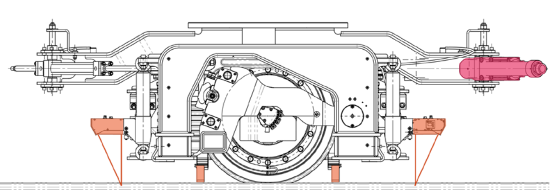

Figure 3 Side view of the TAS axle bridge (1m gauge)

Following a brief period of collaborative investigation between Lucchini RS Design Department and the Traila Engineering office, it was decided that a pair of resilient wheels could be designed and manufactured to fulfil the TSA motor geometries, as well as provide the performance requirements of Traila.

TSA was also included in these discussions, to make sure that all parties were satisfied with the design concept and assembly method, so that the wheels could be integrated into an Omega frame arrangement, as shown in Figure 4. This integrates a Knorr-Bremse HydroAct Caliper solution, which acts directly onto a brake disc mounted to the TSA motor housing.

Finally, the traction-wheel assembly shows a very compact and low-weight solution if compared with more conventional layouts that include a gearbox and resilient driving connections.

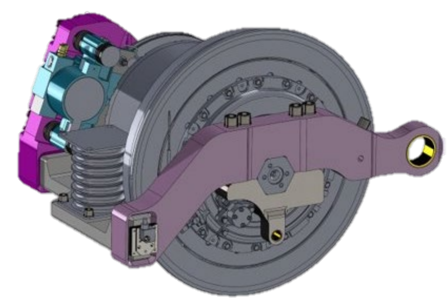

Figure 4 A Lucchini RS resilient wheel modelled on a TSA TMA 40-28-8 Motor integrated into a TAS Omega frame mounting braket. Also shown, the primary suspension, brake caliper and Omega frame hinge rotation point.

5. ASSEMBLY AND STIFFNESS TESTING

Lucchini RS performed a series of quality assessments and structural integrity analysis before delivery. High lateral positioning accuracy and response of the resilient wheel must be demonstrated for the Active Steering system to function as intended. Therefore, a significant request from Traila was to identify the lateral and vertical characteristics and behaviour of the newly designed resilient wheel, to complement the Active Steering controller development. Lucchini RS performed a series of static and dynamic stiffness tests post assembly. These physical parameters are critical input values in the TX4 Multi-Body Dynamic simulations, to achieve the safety and performance requirements.

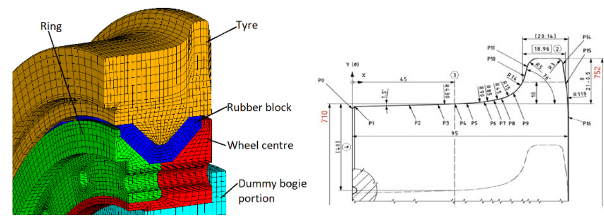

Figure 5 Lucchini RS resilient wheel (OD 710 mm) VBZ SD22475 wheel profile

Lucchini RS performed both FEA calculations for evidence-based calculations on the SD22475 wheel profile, shown in Figure 5, to be used in conjunction with a VBZ 60R2 grooved rail, shown in Figure 6. For the structural validation of the solution and for the definition of the design loads, the prescriptions of the European standard EN 13979-1 [5] were applied as far as possible (since such standard is formally applicable only to monobloc wheels), also considering the influence of the narrow-gauge track layout and, of course, of the driving actions applied directly onto the wheel. The physical measurement campaigns were made on a dedicated Test Bench, as illustrated in Figure 7, located at the Lucchini RS production facility in Italy.

The Active Steering system is designed to prevent any contact of the SD22475 wheel flange with the 60R2 grooved rail walls. This must be avoided.

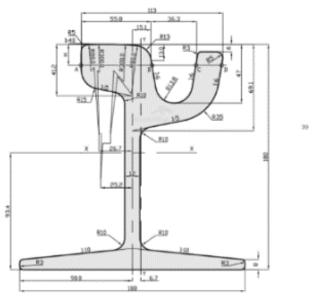

Figure 6 VBZ 60R2 grooved rail

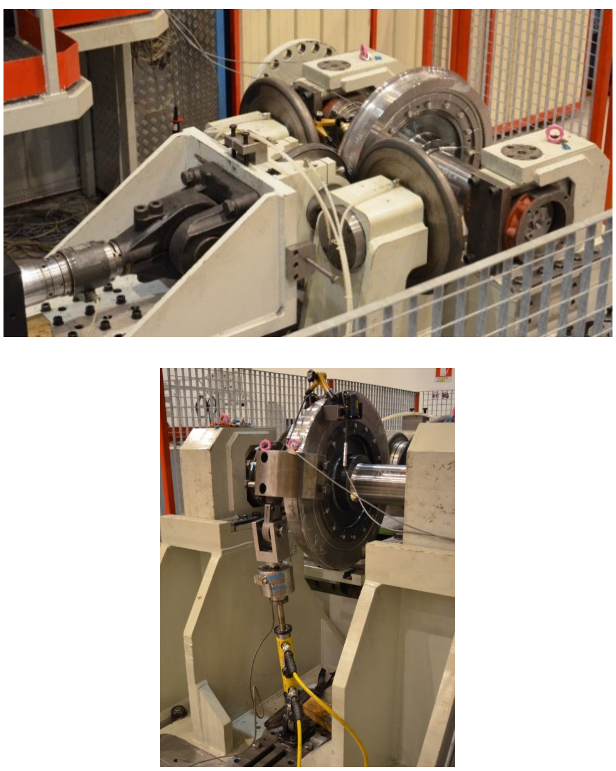

Figure 7 Lucchini RS test facilities (above and below), showing the TX4 wheel resilient wheel assembly during type testing to verify the wheel stifness in radial, lateral and torsional direction in new and artificially aged condition.

6. RESULTS

The integration of the Lucchini RS resilient wheels enabled Traila to develop an axle system for the Zürich network, shown in Figure 8. This enabled Traila to develop a physical and a virtual Active Steering system with an accelerated development cycle to capture the most amount of data from field testing scenarios. Installation of the Lucchini RS wheels together with the TSA motors went as intended to the design specification. The process took eight months from concept to production, to onsite delivery.

The design validation program of a new resilient wheel was performed on a full-scale test rig. The scope of the test was to verify the stiffness of the wheel in the radial and lateral direction in new and artificially aged conditions. The test rig is designed to apply to the wheel tyre combinations of radial and lateral loads used for the design and measurement of the tyre-to-center wheel relative movement, in the two directions by laser displacement sensors. A similar test was performed to estimate the torsional stiffness through the application of a tangential load; this load was then increased to a defined amount in order to ensure that in service there will be no relative slip between the tyre and the center wheel; this is, in fact, an event that must be avoided in order to maintain the integrity of the shunts that ensure the electrical continuity between the tyre and the center wheel and to the rails.

To validate the stiffness characteristics for the service life, the tests are repeated after the wheel assembly has gone through accelerated ageing at a temperature of 70°C for 10 days.

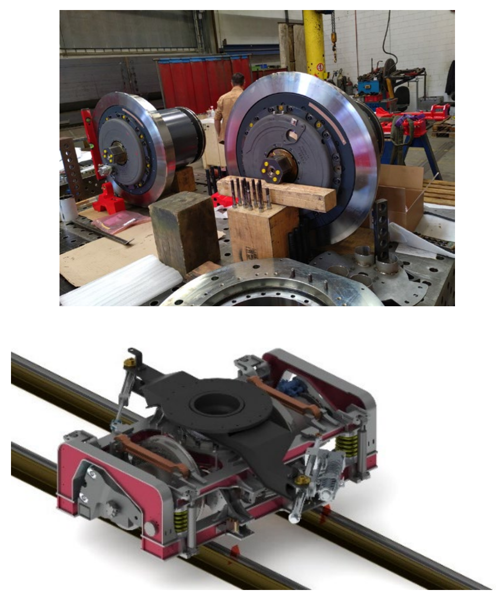

Figure 8 Installation of the Lucchini RS Resilient wheelset for the VBZ network (above) as according to the axle design (below)

On installation of the wheels to the axle bridge, the concentric alignment of the independent motors within the axle bridge design were measured-in using a FARO CMM arm. The wheel-to-wheel axis line is a critical dimension that was supported through the precise machining of the motor Omega frame hinge points on the lower TAS frame, relative to the Omega frame motor mounts. Once the motors were fitted, they were retained within the lower TAS frame. To maintain the motor and wheel assembly, the vehicle would need to be elevated, and the primary suspension and a retaining bracket removed. Under normal vehicle use the wheel and motor assemblies directly transfer the vehicle loads to the track, through the primary and secondary suspension systems.

The TX4 touched the Zürich tracks in August 2022. This was a true milestone for Traila as up to this point in time Traila had only handled the TX4 in a virtual world. The wheels touched the tracks just as intended and the TX4 was then standing back in its original city of use, Zürich, and was ready for the field test commissioning phase. The Lucchini RS wheels rolled directly on the tracks in a passive safe operation due to no overhead power supply being connected to the Active Steering system.

The TX4 includes a multitude of onboard vehicle sensors to support the TAS development, as shown in Figure 9. This sensor architecture was designed to collect and then post process the response of the TX4 under testing conditions, allowing Traila to develop a sensor-based localization position control intended for use on a dynamic vehicle.

The inductive track detection sensors are positioned before and after the wheels. Figure 10 illustrates the virtual simulation of the TX4 on the tracks in Zürich versus the actual TX4 on the tracks. As the TX4 moves along the track the rail detection sensors can determine the position of the vehicle and correct for the error with the onboard actuator. Figure 11 illustrates a sinusoidal test run that shows that there is a positive correlation of the sensor signals and the detection of the profile shape of the track. Additional optical sensors were also used, to verify the inductive sensor signals, and to determine the rail profile at the 'Edge point' which is central to the calculation of the optimum running line of the vehicle, shown in Figure 12. To date the inductive and the optical sensors are correlating well, with a high repeatability, therefore demonstrating success.

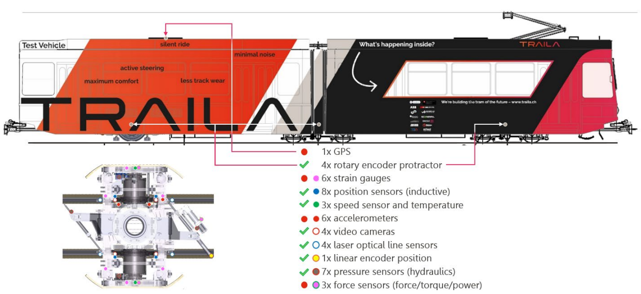

Figure 9 Integration of DAQ vehicle sensors to complement the performance analysis of the TAS system.

Figure 10 The TX4 on the tracks in Zürich, showing the Lucchini RS wheel in the center of the tram track groove (1m gauge) in addition to the Traila Sensor Units (red blocks) that are determining the lateral position of the vehicle relative to the tracks.

Figure 11 Sensor signals detected through a sinusoidal impulse to the active steering controller

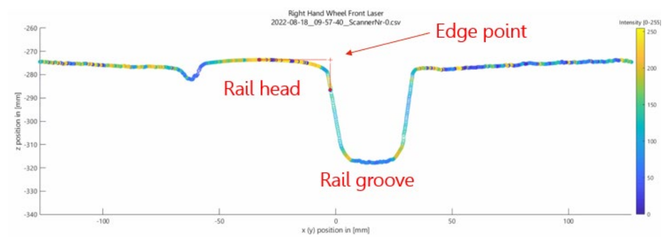

Figure 12 Identification of the edge using onboard lasers, used to validate the vehicle positioning.

7. DISCUSSION

The collaboration between Traila and Lucchini RS was extremely effective. Traila was able to benefit from the extensive knowledge and experience from the Lucchini RS Engineering Team. TSA were also involved in a series of design cycles, to guarantee that all the necessary requirements and specifications of the resilient wheels were communicated, understood, and integrated into the design. Particular attention was made to the interface design between the resilient wheel and the TSA motor connection flange.

The first stages of vehicle commissioning predominantly involved checking the communication between the digital TAS system with the historic analogue controls of the T2000 vehicle. Once the main power supply was connected and all systems activated, the Active Steering was ready for commissioning, in preparation for the testing campaign. Preliminary tests included sensor-mapping the inductive sensor movements relative to the track positions. This sequence of sensor motions was designed to determine the edge of the main rail profile using a set of calibrated inductive sensors.

The Traila Field Testing Team were quickly operational on the Altstetten Zürich tracks due to a high confidence in the Lucchini RS wheels. The team relied upon the stiffness and responsiveness of the wheels, which are crucial to the needs of the Active Steering system. As a result, the Traila Control Team were able to provide the necessary field data back to the dynamic simulations, then processed by the Traila Numeric team.

Field testing was designed to sequentially test and improve the performance and the effectiveness of the sensors, controller, and the actuator, under a variety of scenarios. This included straight track testing and curve testing. Each data set was collected and analyzed to then support the optimization the tuning of the actuator controller for the following tests.

The wheels and the rail are critical components operating under extremely aggressive tribological conditions. Therefore, the tests focused on positioning the wheel flange within the tram track groove and avoiding physical contact of the wheel flange with the groove. By reducing flange contact it is foreseen to increase the sustainability of the wheel rail contact zone and increase the lifecycle for wheel and rail. This also has the resulting effect of reducing the amount of energy consumed per passenger.

8. Conclusion

The rail industry demands an optimization of the wheel-rail interaction as it is a historical and systemic problem in the industry in general. Wear and tear, damage and vibration, noise and pollution are all resulting effects of ever worsening wheel-rail interaction conditions throughout the lifetime of vehicle operating on the rail infrastructure. Traila is solving this issue.

Traila is integrating active steering into rail vehicles and has the potential to disrupt the rail industry by opening avenues of technology to focus on the optimization of rolling stock and infrastructure interface. Although active steering systems have been developed before Traila is taking full advantage of modern sensors, controllers, and actuation technology.

Traila greatly benefited from the IWC in Venice in 2019, and a strong relationship with Lucchini RS was established who enabled a prototype resilient wheel to the specification of the Traila TAS Axle.

Traila has built a Test Tram (TX4) that is currently in operation in Zürich, Switzerland, in association with Verkehrsbetriebe Zürich (VBZ). In addition, Traila is building up a dynamic simulation and Hardware in the Loop (HIL) simulation capacity in order to accelerate the development of the active steering system. Field trails of the TX4 are expected to take place throughout 2023-2024.

The first phases of the TX4 testing have proved successful, and the TAS controller is able to maintain the position of the Lucchini RS wheels in the center of the VBZ groove.

Traila plans to attain a permit from the Bundesamt für Verkehr (BAV) to operate on extended sections of public track sections in Zürich, in order to collect data from challenging switch gear and crossing infrastructure components.

Acknowledgments

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- Lucchini RS
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- Prose AG
- ABB AG
- Brand Engineering AG
- Josef Meyer Rail AG
- Bucher Hydraulics AG
- Milani Design AG
- SWISSRAIL – Industry Association

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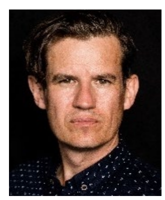

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