# Precise High-Speed Hoist Way Scanning System in Super-Tall Buildings

Michael Eibel[1], Erich Spirgi[1], Daniel Roth[2], Dennis Aeschbacher[2]

[1] Lift Engineering Asia Pacific Limited, Hong Kong.
[2] PI Electronics AG, Switzerland

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**Abstract.** Accurate guide rail alignment is critical for ensuring ride quality, reliability and safety in high-rise and high-speed lifts. Misalignments can occur not only post-installation but also over the system's lifespan, posing significant challenges for measurement and rectification using conventional methods, which are often time-consuming and complex.

This paper introduces a high-speed hoistway scanning system that captures precise data on essential shaft elements, including guide rails, guide rail fixations, and landing doors. By enabling rapid, detailed analysis even in the tallest buildings, the system accelerates engineering workflows. This is particularly valuable when used as an integral part of rectification work on the shaft system.

To achieve high-speed scanning, the system employs specialised multi-channel data tracking and advanced signal processing. We provide a brief overview of its structure and performance, along with case studies and measurements from landmark buildings: one that was formerly Asia's tallest building and another with a hoistway exceeding 300 meters. These examples identify and quantify common patterns of rail misalignment observed in practice, demonstrating the system's usage.

## 1 INTRODUCTION

This paper presents a new tool and method for analysing the alignment of hoistway equipment, particularly landing doors and guide rails.

Traditional methods are often time-consuming and have other practical limitations. It is also difficult to record hundreds of measurements and assign them accurately to their locations in the hoistway. Maintaining a clear overview of the data is essential for planning any realignment work.

- **Guide rails.** The new method is particularly useful for high-rise lifts, where long rail stacks include hundreds of fixing points and rail joints. Accurate guide rail installation directly affects car vibration levels. In super-tall buildings, lift speeds often exceed 8 m/s, and at these speeds, even small rail misalignments can cause unacceptable car vibration.

- **Landing doors.** High-rise shafts also contain many landing doors, and accurate installation is essential for reliable operation. Misalignment can cause equipment failures, emergency stops, and entrapments. Good compliance with installation tolerances can therefore significantly improve reliability and passenger safety.

Ensuring that hoistway equipment in long shafts complies with the relevant standards is demanding. As a result, misalignments are often present immediately after installation.

Misalignments, particularly in the guide rails, can also develop during lift operation. Contributing factors include high loads caused by building settlement, building sway due to earthquakes or strong winds, and lift test procedures such as mandatory safety-gear testing.

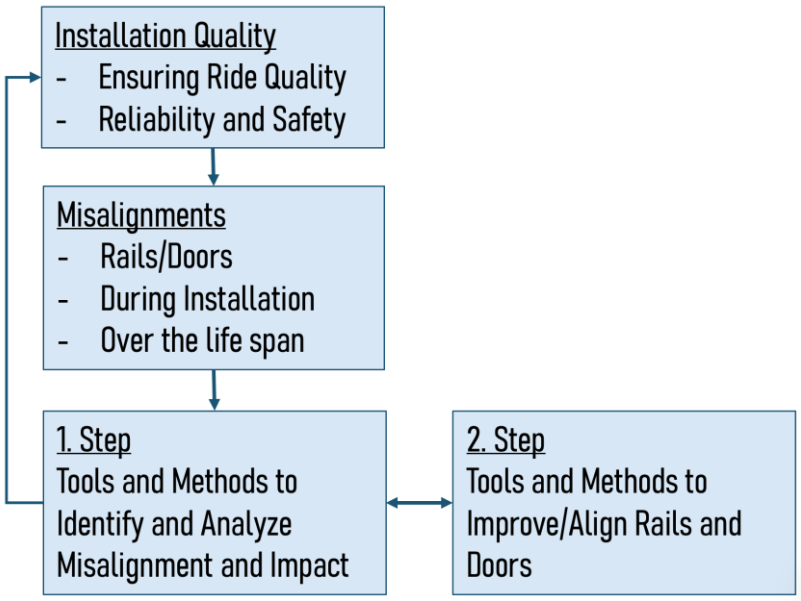



**Figure 1: Overview Installation Quality- Detection and Re-Establishing**

However, the focus of this paper is on the tools and methods used to identify and analyse such misalignments (Step 1) and to provide guidance for rectification work (Step 2).

The method can be applied repeatedly in a closed loop throughout the rectification process until the required alignment quality is achieved.

## 2 STATE OF THE ART METHODS TO ANALYSE HOISTWAY SYSTEMS AND THEIR LIMITATIONS

### 2.1 Conventional methods for measuring guide rail misalignment

Accurate alignment measurement of guide rails in high-rise hoistways remains a persistent challenge. In buildings exceeding 300 m, rail deviations accumulate over long travel distances, and conventional techniques struggle to deliver a sufficiently dense and reliable three-dimensional data set within acceptable downtime windows.

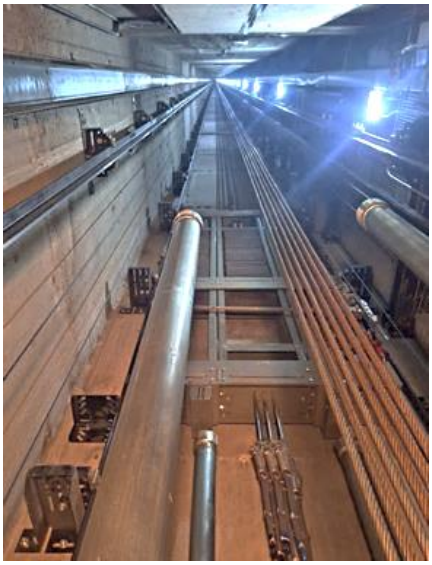


**Figure 2: Lift Shaft in Hong Kong (Travel Height > 300 m)**

Typical measurement scenarios involve either direct contact with the rail surfaces or optical reference lines established from the pit or machine-room level. These methods are applied sequentially, obtaining a comprehensive picture of rail straightness, bracket spacing, and door-zone geometry; often requires several hours or even days of lift shaft occupation.

## 2.2 State-of-the-art techniques and their practical constraints

Despite the availability of specialised instruments, current practice still relies on four principal families of methods:

**Table 1: Methods to Measure Hoistway Guide Rails**

| # | Method | Description | Advantages | Limitation |
|---|---|---|---|---|
| 1 | Manual gauging (Distance-gauge, spirit level, angle gauge, steel ruler) | Mechanical fixtures and manual readings taken at discrete points along the rail. | Low capital cost; simple to deploy on short rises. | Extremely time-consuming; low spatial resolution; operator-dependent accuracy; no continuous plane or twist information. |
| 2 | Piano-wire tensioned reference line with displacement sensors | A taut wire is installed as a datum reference; linear sensors or dial gauges measure rail-to-wire distance. | Provides a continuous reference line. | Complex and hazardous installation; significant shaft downtime; wire sag and vibration limit accuracy in tall shafts. |
| 3 | Single-point laser or optical plum-fixtures | A laser beam or optical plummet is projected vertically; offsets are recorded at selected landings. | Rapid setup for spot checks. | Only discrete points captured; beam divergence and air turbulence degrade results over long distances; no simultaneous multi-parameter acquisition. |
| 4 | Proprietary elevator-company systems (e.g., laser tool) | Motorised trolleys carrying laser sensors or inclinometers that travel along the rails. | Semi-automated data logging; better repeatability than purely manual methods. | Still requires physical contact rollers; limited to rail surfaces only; data fusion with door or bracket information is manual and slow. |

Literature on hoistway guide rail measurement is largely limited to internal manufacturer reports.

While laser-tracking or photogrammetric approaches have been proposed in isolated studies, none have reached widespread field deployment for complete guide rail shaft mapping.

Yang et al. [6] and Roberts [9] demonstrated that even minor guide rail misalignments significantly influence ride quality and vibration behaviour in high-rise elevators. Chen et al. [2] and Wang et al. [11] developed laser-based straightness measurement systems, while Li et al. [4], Zhang et al. [7] and Liu et al. [8] explored inertial, vision-based and structured-light approaches.

Although these methods improve accuracy, they remain limited in speed and completeness for very tall shafts. Kim & Park [5] and Onat et al. [10] emphasised the need for rapid, multi-sensor strategies in super-tall buildings. Wang et al. [3] further highlighted the potential of high-speed, multi-channel laser scanning to overcome existing constraints.

## 2.3 Problem statement and motivation for a new approach

The key requirements for modern high-speed elevators in super-tall buildings lie in the rapid and reliable detection of guide rail alignment. Existing methods do not adequately meet these requirements.

They either require the lift system to be shut down for several days or provide only sporadic and incomplete measurement data, which does not allow for a comprehensive assessment of guide rail deviations or a sound basis for targeted readjustment.

A contactless, multi-channel scanning system addresses these shortcomings by satisfying three essential criteria simultaneously:

1. **Efficiency**: acquisition of a full three-dimensional shaft model within minutes, thereby minimising downtime and enabling measurements during brief maintenance windows.
2. **Accuracy and reliability**: sub-millimetre resolution maintained over several hundred metres without mechanical contact, eliminating roller wear and rail-surface artefacts.
3. **Data fusion**: simultaneous recording of guide rail geometry, bracket positions, landing-door alignments and vibration signatures on a common time and position base.

By meeting these requirements, the system not only accelerates existing alignment tasks but also opens new use cases such as periodic condition monitoring, digital-twin generation, and data-driven rectification of entire hoistway systems; applications that remain impractical with today's state-of-the-art methods.

## 3 A NEW APPROACH TO ANALYSE HOISTWAY SYSTEMS

### 3.1 Requirements

The requirements for the system following the problem statement are as follows:

- Measurement of vibrations of the lift car to analyse ride quality
- Measurement of multiple positions of the guide rails to detect horizontal misalignments (x/y-axis)
- Simultaneous measurement of the vertical position of the lift car (z-axis). (This information shall be used as reference)
- System sampling rate to allow the 10 m/s lift car speed. Measurements shall be made with nominal speed.
- Modular and easy to install sensor setup
- Measurement logging for later analysis
- Visualisation and 1st level analysis of measured data including Frequency analysis (FFT)

### 3.2 Design

Our mobile measurement device is named LRQA (Lift Ride Quality Analysis System) and was developed to measure ride comfort. With position-based sampling, measurement data is recorded relative to the exact horizontal position, which offers significant advantages over time-based sampling. The core uses a cDAQ module (**C**ompact **D**ata **Acq**uisition) [13].

### 3.3 System overview

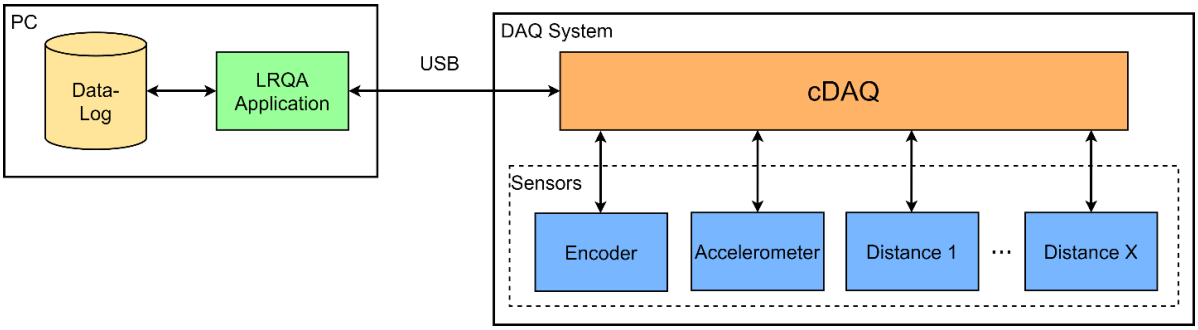



**Figure 3: Block diagram of the Measurement Device LRQA**

### 3.4 Hardware

To convert the analogue signals from the sensors, a cDAQ system was implemented. Measurement of the lift ride quality is done via different sensors. To detect the current position of the lift car, a decoder was built by utilising boreholes in the guide wheels for reference. To detect vibrations, a PI758 accelerometer [12] was used and mounted onto the lift car frame with magnets to measure the vibrations during travel.

The system has a sampling rate of 20 kHz. Because the lift speed is 10 m/s, a measurement of the rail conditions is made every 0.5 mm of distance travelled. The accelerometer has a frequency range from 0 Hz to 1.8 kHz. This means that the whole spectrum a lift passenger can perceive (from 1 Hz to 1 kHz) can be measured to analyse the ride quality. The distance sensor used for the guide rails has an accuracy of 0.01 mm and a processing delay of less than 1ms, to capture, for example, the guide rail clips with a speed of 10 m/s.

Misalignment and fixation of the guide rail are measured by using a laser distance setup. This enables the measurement of rail twisting (S1 and S2), distance between the guide rails (S3), and fixation (S4). The mechanical design is modular so it can be deployed quickly. There is a module with 4 sensors for both guide rails. The distance between the guide rails (DBG) can be calculated by adding the fixed distance of the modules to the S3 readings.

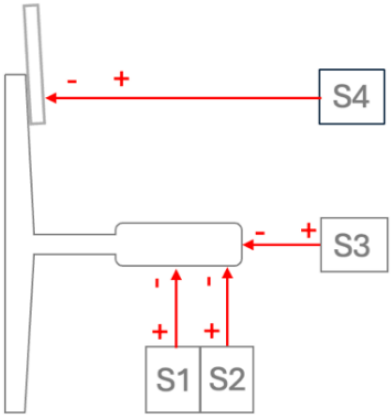



**Figure 4: Sensor Setup (left guide rail)**

The measurement of the misalignments and vibration in the lift car over the whole travelled distance (not over time) allows the problems with the rail that affect ride quality to be directly correlated to the vibration measurements in the analysis.

### 3.5 Software

The measurement sequence is controlled by a LabVIEW [13] application on a host PC that is connected to the cDAQ system via USB. Measurements are transmitted to the application, then converted and saved in a logfile. After the measurement, the logged raw data can be visualised and analysed further.

This could be expanded with further post-processing analysis, such as twisting of the rail. For the vibration measurement, raw values as well as the spectrum can be shown, see Figure 5.

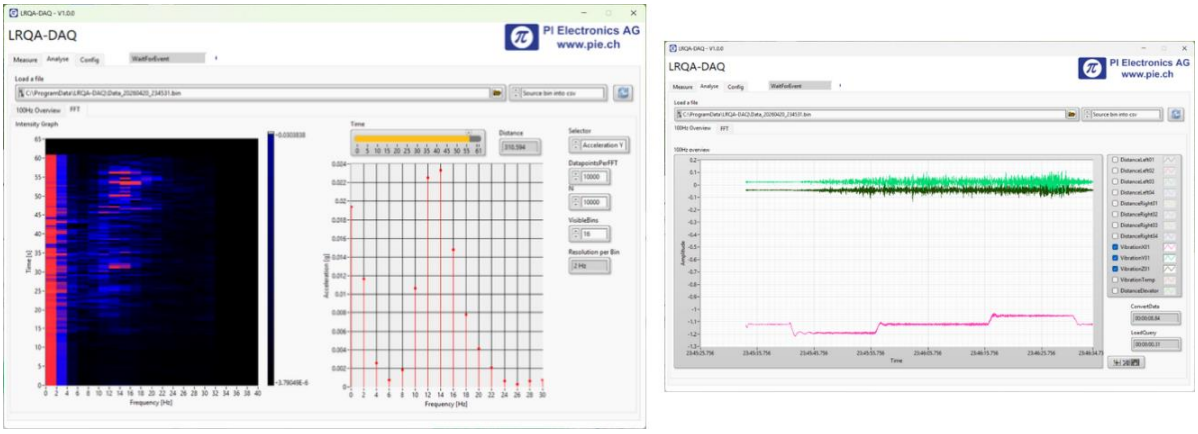



**Figure 5: Visualisation of the car vibrations with the LRQA application**

Time and FFT spectrum of the vibrations over the trip time can be visualised.

A map of the spectrum highlights relevant system resonances during the trip.

Above is a "real-world measurement" with a 9m/s trip in the upward direction. Intensified rope vibrations when the car approaches the top floor are visualised.

### 3.6 Definitions

We use the following naming and coordinates for the guide rail measurements.

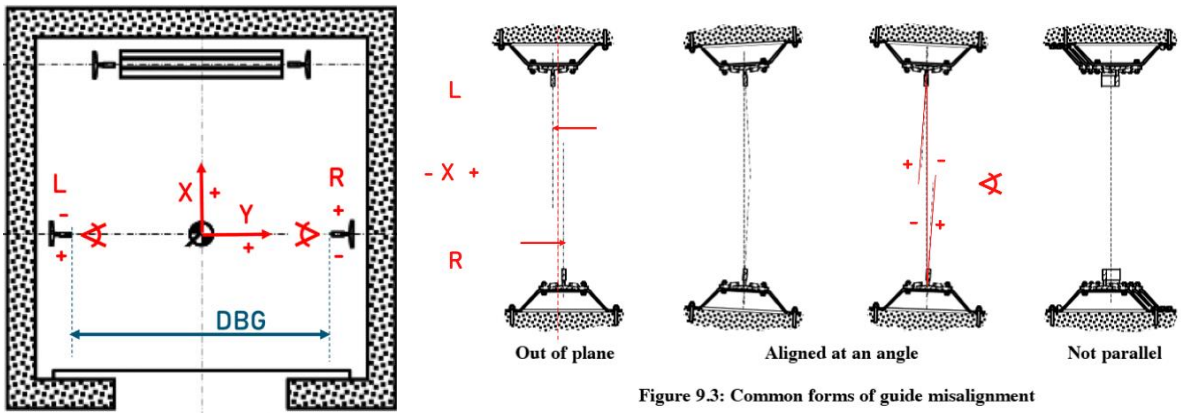



Figure 9.3: Common forms of guide misalignment

**Figure 6: Coordinates and Naming of the Different Guide Rail Misalignments [1]**

References are as follows:

- **Vertical:** Travel distance (Set to 0 at the beginning of the trip)
- **Horizontal:** Average of all measurements of the guide rail (x and y direction).

As an alternative, the offset to one fixed (calibrated) horizontal location can be used for each data point.

With post-processing, the sensor raw data has been scaled and translated to the understandable information of guide rail twist [degree] and "out-of-plane" [mm]. The out-of-plane value was calculated for each data point as a deviation from the average.

The distance between guide rails (DBG) is calculated as a deviation from the average.

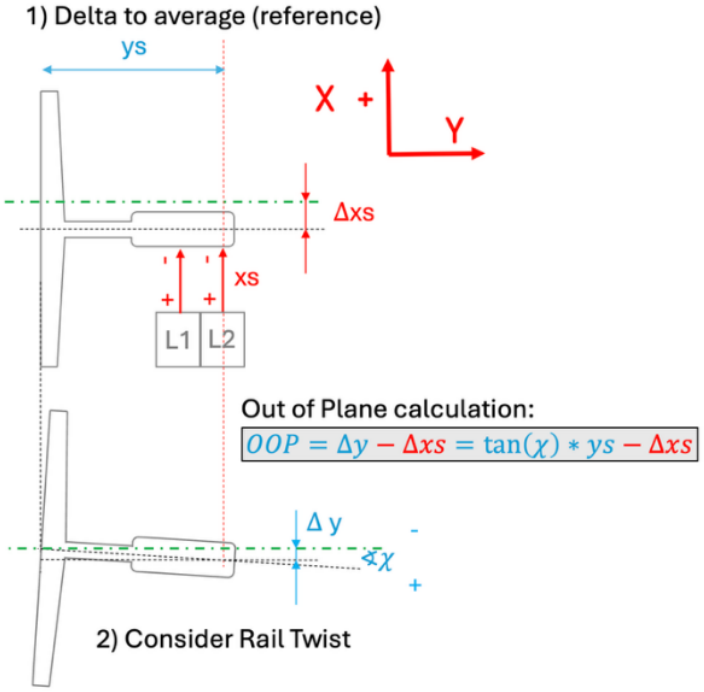



**Figure 7: Out of Plane Calculation**

### 3.7 Measurements from real installations/first findings

The device was installed and validated in two high-rise installations in Hong Kong. The selected lifts had hoist heights of 316 m and 158 m, with nominal speeds of 9 m/s and 7 m/s, respectively.

As required, data was recorded during full-speed trips in both directions. The captured data was then exported from the tool for post-processing and graph generation in Excel.

In the 2 trips in both directions, the following data was captured:

1. Car vibrations (3 axes)
2. Guide rail alignment (using 6 position sensors)
3. Guide rail fixation (using 2 position sensors)
4. Distance travelled (using the device's optical encoder)



**Figure 8: LRQA- one-side sensors, recording at full speed**

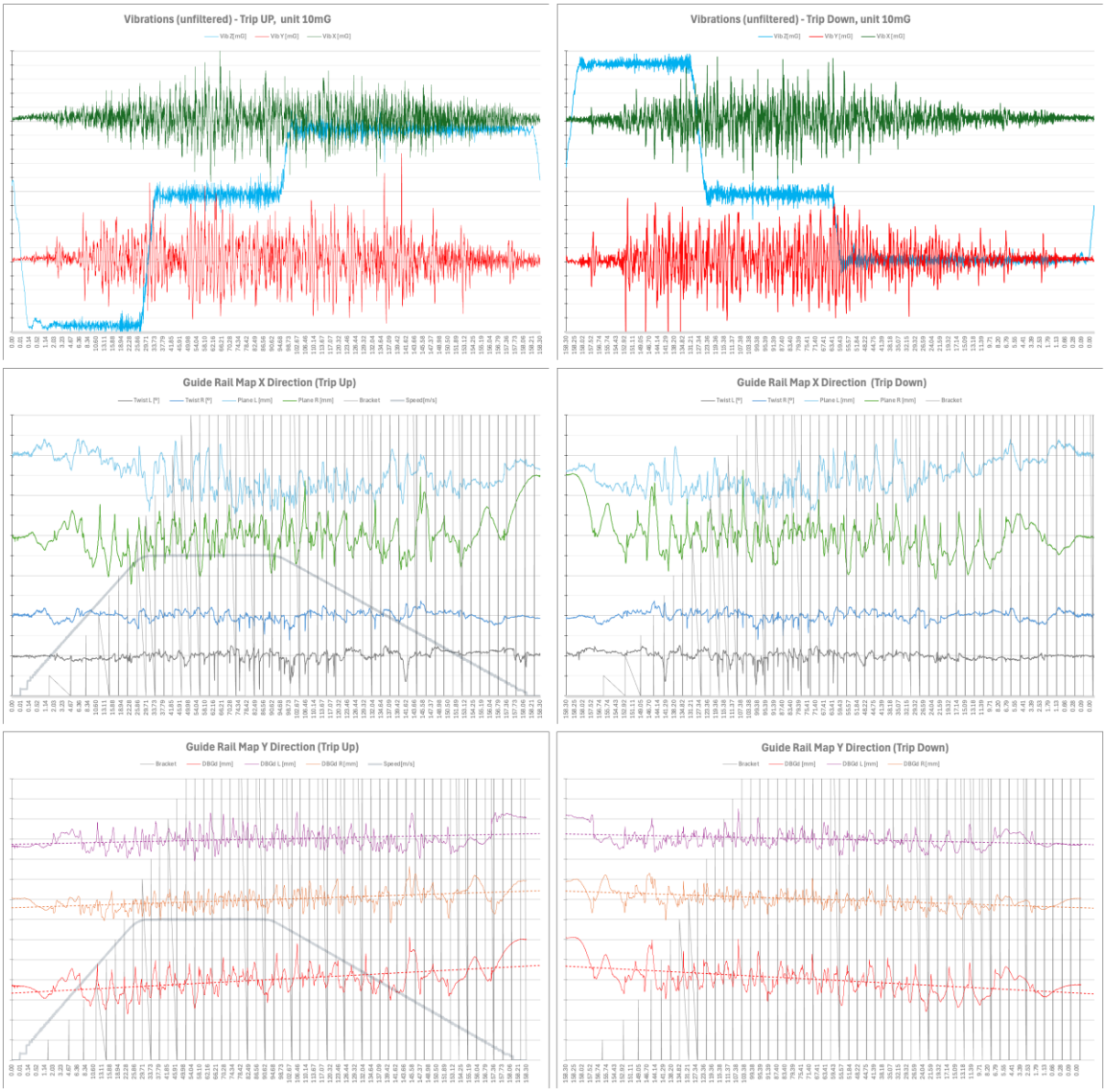



**Figure 9: Record of Full Shaft, Vibration and Guide Rail Maps**

The full shaft view gives an overview of the data. It helps to validate the data plausibility. The guide rail maps in both directions are highly correlated, and therefore reproducible.

For further analysis, for example of the guide rail alignment, a zoom/filter into a smaller section is needed. In this example, we chose the trip in the up direction, with a range from 80 to 110m.

Typical misalignment can be visualised and quantified as follows:

1. The right guide rail is out of plane for more than 1 bracket, by 1.5mm to 2mm. The peak is at the guide rail joint (fishplate).
2. Perfect alignment (no twist at this bracket left and right guide rail).
3. 1.5-degree twist at the right guide rail.
4. 1-degree twist at the rail fixation.
5. DBG is perfect at both rail fixation points (brackets)

6. DBG is almost more than 1mm too wide at the guide rail joints (fishplate)
7. DBG is too narrow by 1mm; each guide rail is about 0.5mm offset from the reference.

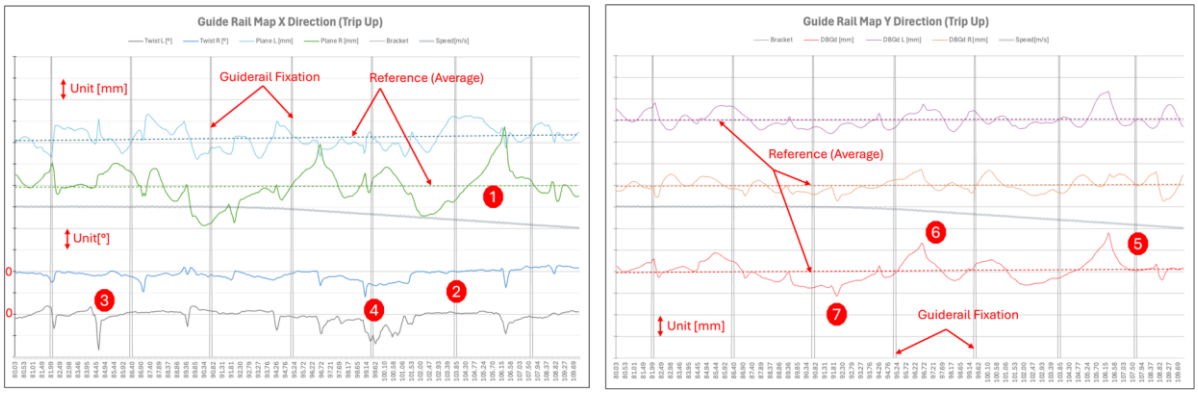



**Figure 10: Guide Rail Map, Shaft Section**

## 4 OUTLOOK: MORE USE CASES/RESEARCH

Potential future research and practical applications of the method include:

- Scanning landing door positions relative to walls or guide rails for rapid, accurate validation of installation quality.
- Scanning shaft wall accuracy.
- Combining the system with air-pressure sensors to quantify the dynamic effects of stack and piston effects.
- Combining the system with suspension-rope vibration data to assess the effect of rope vibration or uneven rope tension on ride quality.

A more compact device with remote access could also enable continuous or repeated monitoring of ride quality deterioration.

## 5 CONCLUSIONS

Lifts in super-tall buildings place exceptional demands on maintenance and inspection, and even brief downtime can have a major economic impact. Innovative and efficient solutions are therefore not just beneficial, but essential to sustain long-term ride quality, safety, and operational reliability.

The development of this high-speed, high-precision, contactless hoistway scanning system demonstrates the value of going beyond conventional methods.

By integrating advanced sensors, multi-channel data acquisition, and sophisticated signal processing, the system delivers comprehensive shaft analysis within minutes while maintaining the accuracy required for reliable alignment assessment and targeted rectification.

The result is possible only through close interdisciplinary collaboration across lift operations, lift engineering, and measurement/data-processing expertise.

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## BIOGRAPHICAL DETAILS



***Michael Eibel, Lift Engineering Asia Pacific Limited, Hong Kong***

Managing Partner, Vertical Transportation Consultant

Michael is an Austrian lift engineer who has held leading positions in global companies. He has been working in the field of lift technology for 20 years. Michael has expertise in planning, project management and installation, as well as extensive international lift experience in Asia. In addition, he runs his own consulting office for lift technology, is a lift inspector and a certified expert witness for lift technology. Michael graduated from the University of Northampton with a degree in Lift Engineering and has extensive experience in wire ropes.



***Erich Spirgi, Lift Engineering Asia Pacific Limited, Hong Kong***

Managing Partner, Vertical Transportation Consultant

Erich is a Swiss Engineer with more than 25 years of experience in the E&E industry in Asia and Europe.

He was a development engineer and team leader with expertise in motor control technology and was global product manager for electrical systems at a large OEM. Erich also completed an EMBA from Western University (IVEY), London, Ontario.

He found his passion to tackle complex technical and commercial topics in high-rise buildings and offers independent vertical transportation consulting services in Asia and Europe.



***Dennis Aeschbacher, PI Electronics AG, Baden, Switzerland***

Hardware and Software Engineer

Dennis is a Swiss Electrical Engineer developing hardware and software with a BSc from the University of Applied Sciences and Arts Northwestern Switzerland (FHNW).

He specialises in embedded Systems and FPGA circuit development. He combines hardware and software expertise to design and implement robust, high-performance electronic systems.

He develops measurement and validation systems at PI Electronics AG, focusing on high-speed data acquisition, signal processing, and robust system integration for demanding industrial environments.



***Daniel Roth, PI Electronics AG, Baden, Switzerland***

Daniel is an electrical engineer with 30 years of experience in high-end measurement technology, leading a team that consistently pushes the boundaries of what is physically achievable. The team develops solutions that make the previously unmeasurable measurable - integrating complex subsystems into robust, end-to-end architectures that transform technical challenges into reliable, real-world performance. His mission is precision and robustness that give our customers a measurable competitive advantage while significantly increasing their productivity.