M+P | Member of Müller-BBM group
The solution people

ARRoW

Acoustic Track Monitoring System

Introduction

Rail noise levels can tell you a lot about the condition of your rail infrastructure. Corrugation, rail roughness and defects in the rail or fastening systems are revealed through the noise of the wheel/rail interaction. ARRoW operates on the basis of these principles. To quickly and accurately assess the quality of your railway network, ARRoW is the perfect solution.

ARRoW stands for 'Acoustic Rail Recording on Wheels' and consists of a measurement system on the train and analysis software.

ARRoW records the noise (and vibrations) from the rolling wheels together with the train's speed and geographical position. The noise levels that are measured fluctuate due to the changing properties of the railway track. By measuring the noise, one can chart the changes in typical rail properties such as rail roughness or rail defects. This information can be used for many purposes:

- Monitoring of track **roughness** for noise mitigation measures
- Early detection of rail **corrugation**
- **Noise mapping**
- Very early detection of rail **squats**
- Reduction of cost-of-ownership through **direct maintenance** on problematic areas instead of global maintenance at regular intervals
- Identification of noisy **"hotspots"** in urban areas that can be rectified before residents file complaints.

ARRoW is a product developed and actively maintained by M+P. This brochure offers detailed information on the system.

M+P (member of the Müller-BBM group) is a world-leading provider of road and rail-related measurement solutions, with a special focus on acoustics and vibration. As such we have contributed significantly to the development of the various measurement methods and regularly participate in related working groups of the International Organization for Standardization (ISO) and European Community (EC).

In addition to developing and manufacturing ARRoW, we also have vast experience in using ARRoW to create railway surveys, research and development (R&D) on railway noise, performing noise tests according to the technical specifications for interoperability (TSI), and certifying test tracks in accordance with ISO specifications.

Background

Rolling noise and roughness

Rolling noise is the main source of noise along railway mainlines. This noise is produced by surface roughness at the point of contact between the train wheel and rail. Since the wheel and the rail are never entirely smooth, the wheel vibrates as it passes over the rail and the rail vibrates as the wheel passes over it. This vibration is subsequently emitted as noise to the surrounding area. This noise is directly linked to the level of unevenness or roughness. Thus, the smoother the wheel and the rail track, the lower the noise.

Grinding

The rails can be ground to reduce their surface roughness and hence diminish rolling noise. This effectively eliminates the problem at its source. This is a measure that infrastructure managers can take irrespective of the train operator.

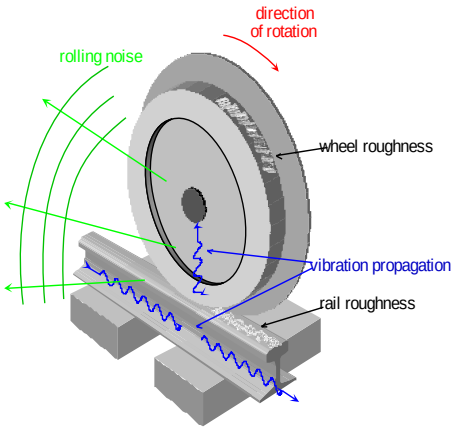
The rail is first ground at the construction stage to remove mill scale and eliminate irregularities from the surface of the rails. The initial grinding is performed so that the railway meets acoustic requirements. The rail roughness is the criterion used to determine the acoustic quality of the rail.

In Europe, it is common practice to grind the rails to keep them in optimal condition. Acoustic grinding, as it is known, is an established method of reducing noise emissions from the rails as trains roll over them.

Track inspection

A profilometer is used to directly and accurately measure the rail roughness of a track prior to and following grinding. These results relate directly to the achievable noise reduction. However, rail roughness can only be measured over a short section of track. Secondly, rail traffic must be interrupted to perform these measurements and the measurements themselves are rather labour intensive.

The direct method of measuring roughness is appropriate for assessing test sections in accordance with ISO 3095 that requires these specific values.



To overcome the disadvantages of directly measuring the surface roughness on long sections of track, ARRoW derives the roughness indirectly by recording the rolling noise over time and translating these into roughness levels. The system is calibrated using direct rail roughness measurements.

ARRoW measures the sound levels in close proximity to the wheels. For a given (low) wheel roughness and track system, there is a direct relationship between changes in rail roughness and rolling noise levels. In fact, all noise variations can be assumed to derive from variations in rail roughness for a given dynamic track behaviour and vehicle speed. Thus, when we measure the noise fluctuations along a certain track we also learn how the rail roughness varies along its length.

It is important to note that this indirect method yields only relative noise variations that cannot be directly equated with absolute rail roughness values. Therefore, the results of direct surface roughness measurements are used to calibrate the noise measurements. The results of both measurements can be used to calculate the absolute rail roughness along an entire section of track.

Roughness measurement along a test section of the high-speed line in the Netherlands. The Müller-BBM m|rail system was used for the measurement.

ARRoW system

ARRoW consists of an on-board measurement system and the *RailInspector* analysis and visualisation software. Both components work together hand in hand to capture and analyse the rail quality.

Properties

With more than 10 years of experience in acoustic rail monitoring, we have identified the most important aspects of rail quality monitoring. We designed ARRoW with the following attributes in mind:

- **Portable**: can be installed on existing vehicles with no need for a dedicated measurement vehicle
- **User-friendly**: built with standard components, our analysis software is intuitive to use
- **Autonomous**: no need for external power supplies or additional sensors for measuring vehicle position and speed
- **Robust**: built-in redundancy in measurement chain makes measurement errors nearly impossible
- **Reliable**: after nearly 10 years of use in the Netherlands and EU, ARRoW has been tried and tested in the field
- **Wide application range**: applications include light rail, conventional rail and high-speed rail

On-board measurement system

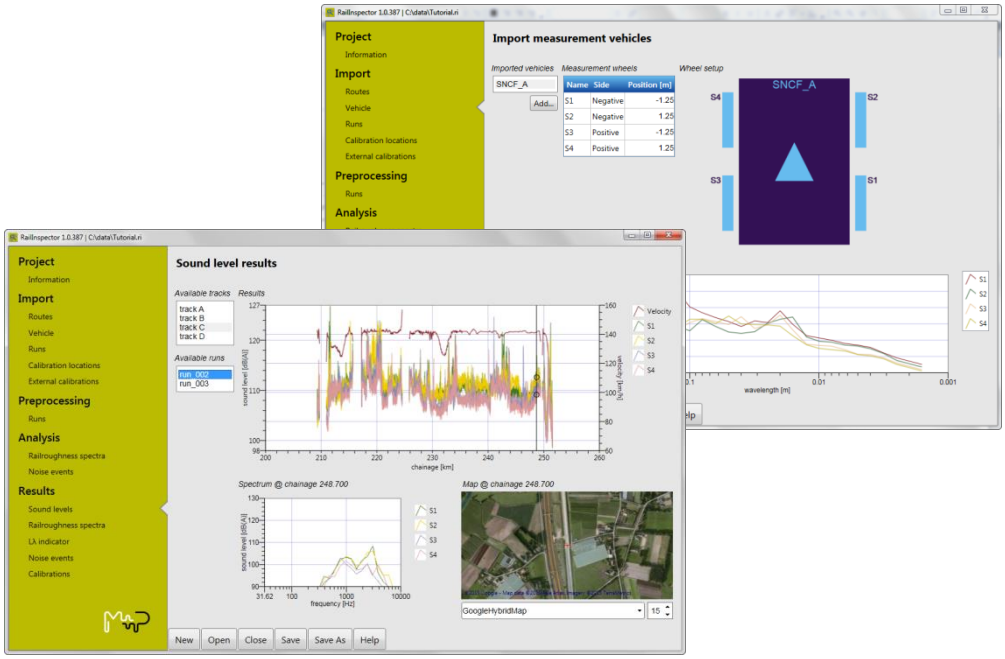
The on-board measurement system for ARRoW consists of a PAK MKII multichannel data acquisition system which simultaneously measures sound levels, position and speed.

With four class 1 measurement microphones, the sound levels are measured at close proximity to the wheels as they roll over the rails with one microphone next to each wheel on the measurement bogie. This makes it possible to measure the left and right sides of the rail separately.

The use of multiple microphones introduces redundancy into the measurement chain, thus making the system highly robust. The geographical position and speed are recorded using a GPS receiver so that this data is also available for post-processing

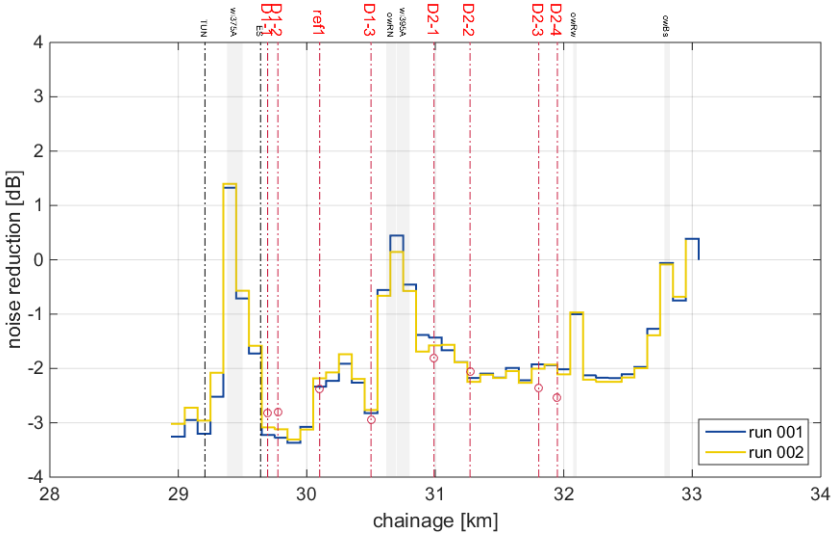
RailInspector

Our proprietary RailInspector software was developed to analyse and present the results captured by ARRoW, and allows you to combine the position and speed data of the railway network with the noise measurements. RailInspector simplifies this task so that you can easily analyse and visualise the results.



Some screenshots of RailInspector analysis and visualisation software.

Typical results from ARRoW: noise reduction in dB from acoustic grinding.



References and example applications

Over the last ten years, ARRoW has been tried and tested in in many applications in Europe and abroad. In the following, we discuss some of these applications.

Compliance of rail roughness on high-speed tracks to customer requirements
The Dutch section of the high-speed railway line running between Amsterdam and Paris was built by Infraspeed. Before the high-speed track could be taken into operation, the track constructor had to prove that it complied with all requirements, including rail roughness. ARRoW was used to verify that the track was compliant. ARRoW was installed in a Thalys train (made by Alstom) and the track roughness was measured at speeds up to 160 km/h.

The ARRoW system mounted on a bogie of the Thalys high speed train.

An ARRoW system is installed here on a Dutch rail measurement platform in a back-to-back comparison with the German Schallmesswagen of Deutsche Bahn.

Direct comparison of track monitoring systems: ARRoW and Schallmesswagen
ARRoW and Schallmesswagen (SMW) from Deutsche Bahn are both monitoring systems that assess track quality by measuring the noise. SMW is an officially accredited measurement platform in Germany. In 2008, ProRail, the Dutch rail infrastructure provider, requested a comparison between ARRoW and SMW. This undertaking demonstrated that ARRoW was a good match for SMW. Both systems offer highly reproducible measurement results that are indeed very close to each other. In fact, ARRoW would appear to offer some advantages over SMW: it can distinguish between the left and right rails and, with four microphones instead of only one, is more robust.

ARRoW in France: SNCF-LECAV project

ARRoW was evaluated in the framework of SNCF's LECAV project. This project was to characterise the acoustic condition of the railway network in with the following three goals:

- to **provide** a map of track roughness throughout the entire railway network;
- to **monitor** the acoustic performance of the track for the grinding policy ;
- to easily **identify** and locate possible TSI-compliant measurement locations.

For this task, ARRoW was tested together with other on-board measurement systems. More specifically, ARRoW was used to measure rail roughness levels and spectra during a 2000 km measurement campaign, with this resulting in a global network map of rail roughness. At some test and reference sites, more detailed results were obtained by repeating measurements multiple times in order to to verify the reproducibility and accuracy of the ARRoW results with respect to direct measurements. The results of this campaign were presented at the International Workshop on Railway Noise (IWRN 2010) in Japan (a copy of the paper is available).

The ARRoW system mounted on the SNCF measurement train for the LECAV project.

Type A (top) and type C (bottom) squat rail defects

Rail defect detection

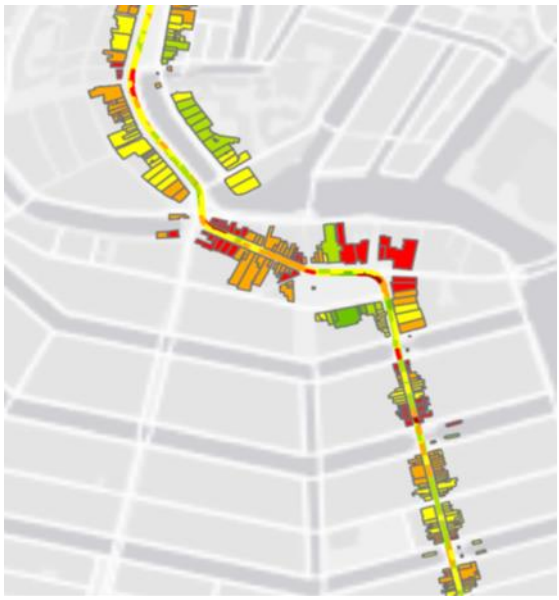
In 2010, we worked with the Delft University of Technology to investigate a means of detecting rail defects using ARRoW. Because of the measurement configuration with four microphones (two on either side of the vehicle) ARRoW can measure the left and right rails separately. Through correlation analysis, we can distinguish rail defects from random rail roughness. In this case, we discovered small rail defects (type A, see above) at a very early stage. This was an excellent result because it is difficult to visually spot these minor defects. If still small in scale, these defects can be removed by grinding. Once they become more readily visible (e.g., type C squat), it is likely too late to grind and the rail must be replaced. The results of this study were presented at the third international conference on Railway Technology: Research, Development and Maintenance (RW2016) in Cagliari.

Light rail track monitoring

The city of Amsterdam wanted to obtain insight into the quality of their light rail network and to detect (potential) noise and vibration hotspots. ARRoW was used to provide these insights.

ARRoW was installed on a regular tram vehicle and the vibration - and noise levels were measured on two lines. In addition, pass-by measurements were used to calibrate the results of the on-board measurements by determining the transmission loss from the sound levels measured at the tram to levels at the façade of the buildings.

The results of the ARRoW measurements were used to make maps indicating (potential) hotspots.



Client applications

In the past years we have sold several ARRoW systems. This is what our clients do with it.

China

The China Academy of Railway Science (CARS) purchased ARRoW to monitor the high-speed lines in China. ARRoW is used to detect and analyse corrugation of the rails.

Canada

A consultancy company in Vancouver purchased RailInspector to determine the (acoustical) quality of a local light rail line to optimize the maintenance of the track.

They used the 'noise event' analysis in RailInspector to localize spots with impulse-like noise levels. Visual inspection of these locations confirmed the findings of the ARRoW inspection. All locations showed damage to the track. Using RailInspector enabled them to perform the track inspection in less time than before. The results were used as input to schedule the track maintenance.

Specifications

The ARRoW base package consists of a custom measurement system (data acquisition front end, measurement computer, microphones, GPS receiver) and the analysis and presentation software RailInspector.

Hardware

ARRoW's on-board measurement system consists of the following components:

- PAK MKII data acquisition system
- Measurement laptop
- Four measurement microphones and related equipment
- Microphones, mounts, cables

PAK MKII (2-slot) is an 8-channel measurement and analysis system that includes a GPS-module. PAK MKII can also be configured for other (sound) measurements beyond ARRoW applications. You can also order extra modules to extend the number of measurement channels. PAK MKII is made by Müller-BBM VibroAkustik Systeme GmbH in Munich, Germany.

The standard measurement computer is a state-of-the-art rugged notebook running Microsoft Windows 8.1 English. This notebook is fully configured and comes with PAK MKII and RailInspector pre-installed, configured and tested.

The four measurement microphones come with four pre-amplifiers and a sound pressure calibrator, all performance category class I according to IEC 61672-1. Calibration certificates are included. The microphones and pre-amplifiers are provided by Microtech Gefell in Germany. Other microphones are available upon request. Of course, you can also use your own microphones if you have suitable types at your disposal.

The microphone mounts and cables (lengths) depend on the measurement vehicle. We can deliver general purpose clamp mounts for the microphones and the necessary cables. But if these are not suitable for your vehicle, we can also provide adapters for different bogie types or you can send us your specifications and we will provide you with a custom adapter.

Software

The RailInspector software can process and present all of the data you have captured during on-board measurements. It provides the following functionality:

- Projects: all data from a project or client are stored together for ease of management
- Combined analyses: multiple measurement routes can be grouped together for each railway network
- Post-processing: sound levels, industry standard 3rd-octave roughness spectra, noise reduction in dB, $L_{\lambda CA,}$ noise event detection etc.
- Use of GIS measurement routes in shapefile format
- Flexible data processing with:
  - Multiple measurement runs
  - Multiple calibration locations
  - Multiple measurement vehicles

Including

In addition to the ARRoW measurement hardware and RailInspector software, the base package includes:

- One day training (at our office)
- One year software support and updates

Options

Besides the standard components above, we optionally provide the following services:

- In-house or on-the-job training: how to use ARRoW and RailInspector efficiently to achieve the results you require
- Design, production and installation of additional ARRoW hardware on your vehicle
- Advice on how to interpret results for your asset management, noise mapping and maintenance purposes
- Development of additional software modules according to your specifications (e.g., additional analyses, custom coupling with databases or GIS systems etc.)

Conditions

Delivery time

ARRoW will be delivered approximately 3 months after ordering. We will provide you with an exact delivery date when you place your order.

Support

The standard support period for ARRoW is one year after delivery. In this period you will have free access to the support hotline and receive all software updates for RailInspector and PAK MKII. After this period, an ARRoW software maintenance package can be purchased that entitles you to software updates, bug fixes and hotline access for the duration of the maintenance contract.

Since RailInspector and PAK are closely integrated in ARRoW, installation of unsupported PAK software releases may cause problems with RailInspector. We therefore test each new release of these products to ensure that they work together correctly before releasing them to our customers. We will always inform you when to update the PAK or RailInspector software.

Warranty

The manufacturer's warranty applies for any third-party products such as the microphones, auxiliary hardware and PAK MKII measurement system. The term of warranty for most equipment is 12 months.

In the rare cases of faults in the PAK MKII system, the entire system or faulty component can be returned to the manufacturer. In most instances, the system or component will be repaired or replaced and returned within a few days. It is also possible to purchase a PAK hardware maintenance contract.

The warranty for RailInspector software is stipulated in the license agreement. We guarantee to rectify any software problems for a period of 12 months subsequent to delivery. After this period, a RailInspector software maintenance contract will be required to cover software claims.

About M+P

For over 40 years, we have studied and developed solutions relating to noise, vibration and air quality. With our expertise and communicative approach, we are a respected consultancy firm that is always open to our customer's specific needs. Based in the Netherlands, our team of 40 professionals are trained in a range of fields to serve our clients. We are backed up by more than 1000 specialists in the Müller-BBM companies. M+P is a member of the Müller-BBM Group.

The Solution People

At M+P, we use a four pillar approach to projects:

- **There is always a solution:** When doing business with us, you will notice our dedication. Your project becomes our project. From environmental permits, reports, complex calculation models to policy advice, we always work with you to find a solution and how to achieve it. Our path to the solution may be fast and direct, or it could be winding and filled with new discoveries. And should we discover that a new path should instead be pursued, we will always inform you about what we have learned.

- **If it doesn't exist, we'll invent it:** We love to be at the forefront and we employ state-of-the-art technology in our work. And we never shy away from new approaches when the situation demands it. Is it something that's never been done? We won't hesitate to try our hand at it. Where possible, we contribute to the behind-the-scenes development of new standards and methods. We actively participate in ISO, national and European committees. This way, we can help boost developments that are beneficial to all parties in the industry. And we are the first to apply these innovations in practice.

- **Versatile and agile:** Although we conduct large (government) projects, we are and always will be a small-scale enterprise with a personal approach: direct communication with no intermediates, clear reports, and tangible results. We are a pool of experts specialising not only in measurement technology and services but also in the development of instruments, software and geographic information systems. We have the team that your project needs.

- **We will step into your world:** We are eager to understand your work so that we can find the solutions you need. It makes no difference whether or not you are knowledgeable in the area of acoustics, vibration, or air quality. We will work with you to find the best way of accomplishing your goals.

For more on M+P, visit us at www.mplusp.eu and for more on the Müller-BBM Group, visit www.mbbm.com.

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