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Written by André Van Leuven D2S
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PROJECT CO-ORDINATOR	Dynamics, Structures & Systems International	D2S	BE
PARTNERS	Bari Fonderie Meridionali	BFM	IT
	Vossloh – Cogifer	COGI	FR
	Vlaamse Vervoersmaatschappij De Lijn	De Lijn	BE
	Frateur de Pourcq	FDP	BE
	JEZ Sistemas Ferroviarios	JEZ	ES
	National Technical University Athens	NTUA	GR
	Politecnico di Milano	POLI	IT
	Régie Autonome des Transports Parisiens	RATP	FR
	Société des Transports Intercommunaux de Bruxelles	STIB	BE
	Université Catholique de Louvain	UCL	BE

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TABLE OF CONTENTS

1	Objectives of the project.....	4
2	Contractors involved	6
3	Work performed and end results.....	8
3.1	WP 1: Modelling procedures for determining impact forces of turnout systems and sensitivity of these forces to changes in track and vehicle parameters.....	9
3.1.1	Selection and measurement of the 'reference' turnout systems	9
3.1.2	Preliminary evaluation and comparison of two different approaches for modelling the dynamic forces in a turnout.....	11
3.1.3	Validation and comparison of both models on different turnouts.....	15
3.2	WP 2: Conceptual design of measures to reduce impact forces	17
3.2.1	Listing and selection of design measures to reduce the impact forces and the stresses.....	17
3.2.2	Sensitivity analysis of contact forces to design parameters	28
3.3	WP 3: Modelling and optimisation of new turnout systems for use in selected field conditions.....	31
3.3.1	Selected test sites	31
3.3.2	Review of the selected designs and iterative optimisation	32
3.4	WP 4: Manufacturing of new turnout systems.....	34
3.4.1	Two low profile rail turnouts from COGI	34
3.4.2	One turnout from BFM.....	36
3.4.3	Embedded FDP turnout with discrete rail fixations	37
3.4.4	One turnout from D2S	38
3.4.5	Jez turnout with movable point frog	39
3.4.6	One industrial turnout with casted manganese steel crossing from FDP	41
3.5	WP 5: Lab testing and on site installation and testing of the new turnout systems.....	42
3.5.1	Lab testing.....	42
3.5.2	Turnout installations.....	43
3.5.3	Validation measurements	51
3.6	WP 6: Final assessment	66
4	Comparison of initially planned activities and work actually accomplished	68
5	Impact of the project on its industry or research sector	69
6	Plan for dissemination and use	70
6.1	Exploitable knowledge and its use	70
6.1.1	JEZ – moving nose frog	70
6.1.2	De Lijn – Moving nose frog and FDP foundation damping	71
6.1.3	BFM – Welding process for manganese frogs.....	72
6.1.4	D2S.....	73
6.1.5	FDP.....	73
6.1.6	COGI	74
6.1.7	NTUA	74
6.1.8	POLIMI	76
6.1.9	RATP.....	76



6.2	Dissemination of knowledge	77
6.2.1	JEZ – Moving nose frog	77
6.2.2	De Lijn	77
6.2.3	BFM	77
6.2.4	D2S	77
6.2.5	FDP	77
6.2.6	COGI	77
6.2.7	NTUA - 3D finite element modelling methodology	77
6.2.8	POLIMI	78
6.2.9	RATP	78



1 OBJECTIVES OF THE PROJECT

The objective of this project was to improve the vehicle-track interaction in the turnout systems for urban rail transit, and therefore improve their efficiency, enhance their safety levels, reduce the required maintenance, and restrain the emitted noise.

These objectives were to be reached by reducing the loads and stresses in the frog and in the switch point/stock rail sections in comparison with a conventional turnout. The modern conventional turnout is of tangential geometry design and equipped with clothoidal transition curves. These eliminate the steady state flange contact-based form of curving condition in the diversion curve.

The following turnout systems were to be considered:

- ✧ turnouts with cast manganese and welded frogs;
- ✧ turnouts on concrete slab and on sleepers in ballast;
- ✧ turnouts with grooved rail and with vignole (T) rail;
- ✧ embedded turnouts (tram);
- ✧ free surface turnouts.

Mathematical models were to be established in order to quantify the loads and stresses. The modelling procedures were to be validated by means of measurement results on existing turnouts. The mathematical simulation of turnout negotiation poses three major problems:

1. the rail profiles vary along the track;
2. the track flexibility varies along the track;
3. the dynamic forces are complex: a horizontal force during curve negotiation and a vertical loading caused by gapping of the wheel at the flangeway gap. The forces depend on the geometry of the turnout, the stiffness and damping of the turnout fixations and of the foundation, and the dynamic properties of the vehicle.

Two different simulation approaches were to be compared:

1. The first approach is based on a multi body dynamics model, which includes rails, fixation systems, foundation and vehicle. Some bodies are described using 3D finite elements and other bodies using lumped parameters. A numerical procedure was to be used to reproduce vehicle-track interaction whereby the equations of motion of track and vehicle are integrated simultaneously evidencing wheel-rail contact forces. This numerical simulation includes all non-linear effects and transient phenomena, which are relevant to turnout negotiation.
2. The second approach is based on a non-linear 3D finite element analysis of the turnout system where the performance of the turnout (without vehicle) is calculated through a non-linear transient dynamic analysis. The input forces and finite element model parameters are derived from lumped parameter models, which are updated using experimental measurement results (static and dynamic).



The objective was **to obtain models capable of predicting the input forces within a margin of 3 dB** considering known input data such as new or used wheel treads, track geometry, fixation characteristics, etc.

The models were then to be used to evaluate the effect on the impact forces of some important parameters:

- ✧ inertia of the frog section;
- ✧ wear of wheel tread;
- ✧ stiffness of the elastic components.

Seven test sites had to be selected for evaluating the newly designed turnout systems. These sites had all to have different site specific characteristics such as concrete or ballast foundation, geometrical constraints, embedded or free running, tram or metro, requirement for manganese frog or welded frog, type of rolling stock, grooved rail and vignole rail.

In function of these actual site specific conditions, some of the above selected design measures had to be evaluated for each selected test site in terms of impact force reduction performance, using the validated models.

For each test site, a different specific design had to be selected iteratively in function of its overall technical performance, cost, end-user preference and manufacturer preference.

The selected systems were to be constructed and tested in laboratory before installing and testing them on site. If possible, the systems were to be installed in a double turnout system with one turnout of the conventional design and the other one adopting the new design.

The newly designed turnouts had to show a **reduction of the impact force by at least 6 dB (factor of two)** in comparison with the conventional ones. A conventional turnout exhibits a 10 dB increase in the vibration level (and hence impact force) in comparison with normal running on a tangent track. The newly designed turnouts were then to exhibit an increase in vibration level, which is no more than 4 dB in comparison with running on tangent track.

In other words, by reducing the impact force to 6 dB, this project targeted **to increase the life time of the turnouts at least by a factor two and to reduce maintenance costs by 50 %**.



2 CONTRACTORS INVOLVED

As summarised in the table below, the consortium consists of 3 end-users, 1 engineering consultancy SME (project co-ordinator), 1 track contractor (SME) having a production facility for welded turnouts, 3 turnout manufacturers (welded and manganese frog turnouts) and 3 universities (see table here below).

The consortium includes the two most important European turnout manufacturers: COGIFER and VAE (through its subsidiary JEZ).

Number	Organisation Name	Short name	Country	Main mission /Business Activity/ Area of activity	RTD Role in project
1	D2S International	D2S	B	Engineering consultant for rail transportation	Co-ordinator
2	Bari Fonderie Meridionali	BFM	I	Turnout manufacturer	Principal contractor
3	COGIFER	COGI	F	Turnout manufacturer	Principal contractor
4	Vlaamse Vervoersmaatschappij De Lijn	LIJN	B	Urban public transportation network	Principal contractor
5	Frateur-De Pourcq	FDP	B	Track contractor	Principal contractor
6	JEZ Sistemas Ferroviarios	JEZ	E	Turnout manufacturer	Principal contractor
7	National Technical University of Athens	NTUA	G	University	Principal contractor
8	Politecnico di Milano	POLIM I	I	University	Principal contractor
9	RATP	RATP	F	Urban public transportation network	Principal contractor
10	STIB	STIB	B	Urban public transportation network	Principal contractor
11	UCL-LGC	UCL	B	University, Laboratory of the Civil Engineering Department	Principal contractor



The complementarity of the partnership is best illustrated by the well-balanced task repartition:

- ✧ The universities and engineering consultant had to handle the modelling and testing work.
- ✧ The industrial partners had well distinct design tasks:
 - BFM had to work on steel quality/type and welding methods for manganese frogs (metro).
 - FDP had to work on switch point designs with head hardened vignole rails for embedded tram tracks.
 - JEZ had to work on improved wheel/rail contact and better production tolerances for manganese frogs.
 - Cogifer had to work on welded switches with low rail profile and on integration of turnouts in concrete structures.
 - RATP had to work on longitudinal running profile correction for new and existing turnouts.
 - D2S had to develop a passive isolation system for the turnouts.
- ✧ The end-users provided their know-how and they provided their network for evaluation and validation.

This project also used the results of recent studies by Cogifer, D2S and National Technical University of Athens on crossovers exhibiting fatigue related problems in the metro of Athens.

STIB, RATP, FDP, UCL, POLIMI and the project co-ordinator had already co-operated in previous research projects with very satisfactory results.

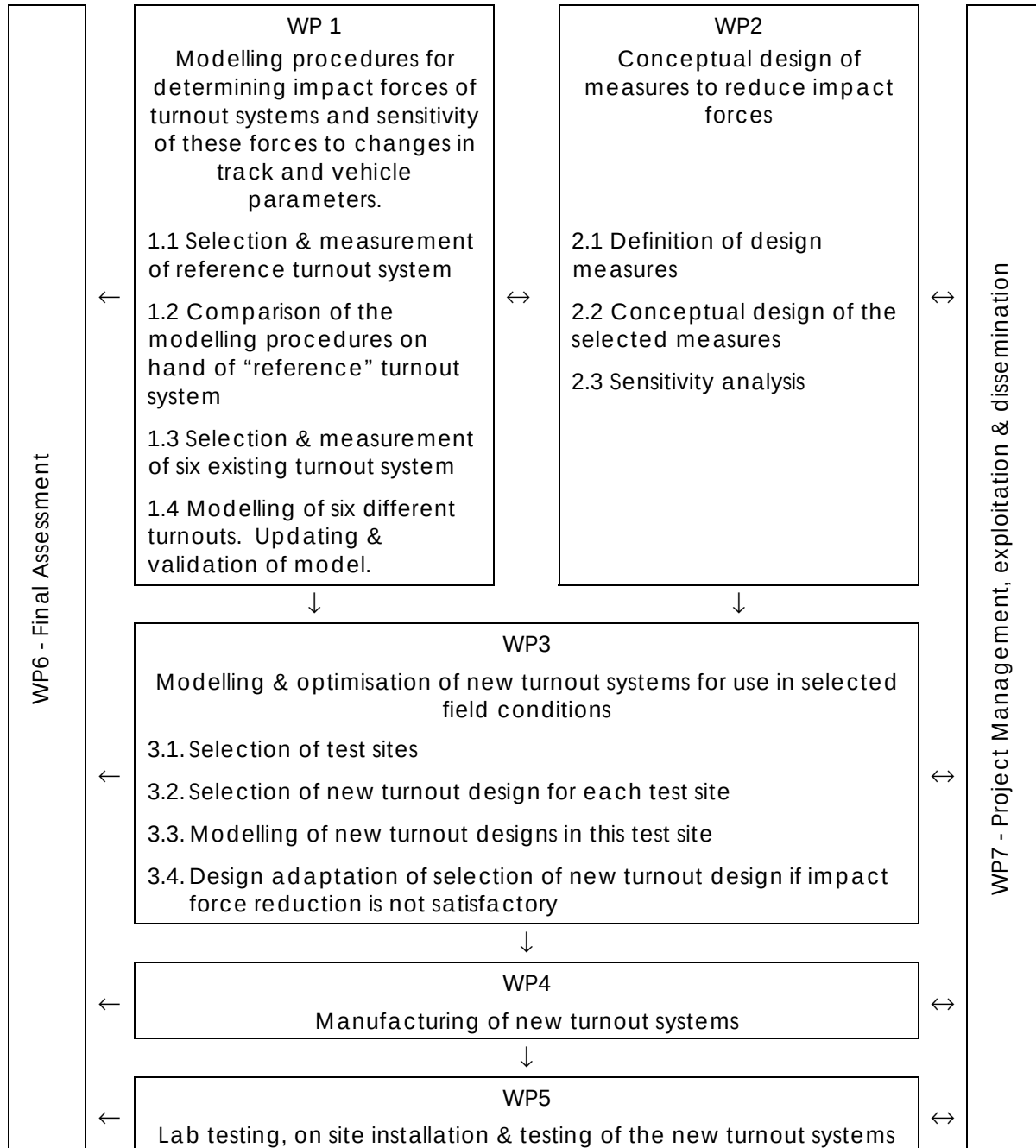
JEZ, FDP and LIJN had a long lasting working relationship in this area. COGI is the main supplier to STIB and RATP.

Partners were not new to each other. This enhanced the collaboration and the achievement of successful developments.



3 WORK PERFORMED AND END RESULTS

A graphical presentation of the workpackages is given below:



3.1 WP 1: MODELLING PROCEDURES FOR DETERMINING IMPACT FORCES OF TURNOUT SYSTEMS AND SENSITIVITY OF THESE FORCES TO CHANGES IN TRACK AND VEHICLE PARAMETERS

3.1.1 Selection and measurement of the 'reference' turnout systems

The objective of this subtask was to measure the exact geometry of the turnouts, their static and dynamic behaviour during vehicle crossing and to collect or measure all required vehicle characteristics, in order to validate the modelling procedures.

Two reference turnouts have been selected:

- ✧ one tramway turnout in STIB's network, located boulevard Louis Schmidt (Brussels):



Figure 3.1.1

STIB's reference turnout

- ✧ one metro turnout in RATP's network, located Porte de Vanves (Paris):

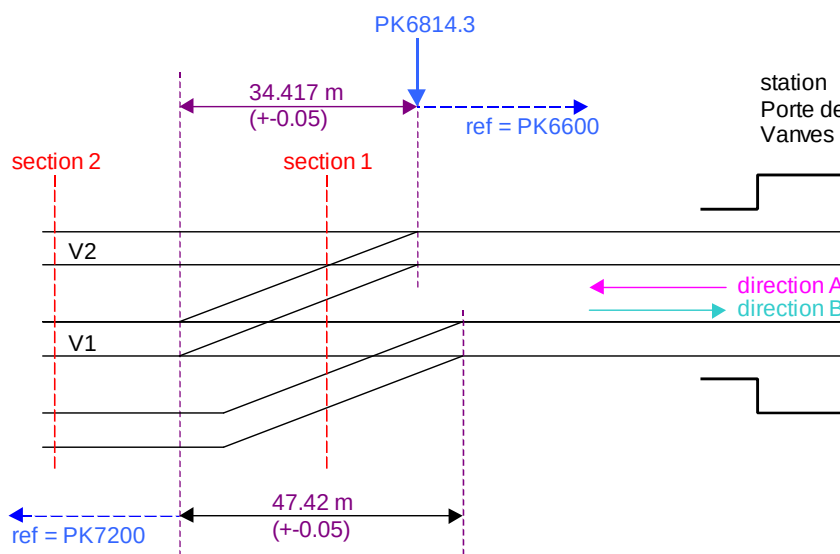


Figure 3.1.2

RATP's reference turnout



The following measurements have been carried out:

✧ on STIB's reference turnout:

- inside vehicle, for different movements (stay on track BACKWARDS and FORWARDS, change of track BACKWARDS and FORWARDS), measurement of vibration levels in the following points:
 - axes, near bearings;
 - bogies, after primary suspension;
 - floor;
 - relative displacements between vehicle and bogies.
- on track:
 - rail;
 - displacements (horizontal + vertical);
 - accelerations (horizontal + vertical).
- on soil:
 - accelerations (vertical at 2 m and 4 m from track heart).

✧ on RATP's reference turnout:

- inside vehicle, measurement of vibration levels in the following points:
 - axes, near bearings;
 - bogies, after primary suspension;
 - floor;
 - relative displacements between vehicle and bogies.
- on track, in two sections: on the frog and outside the turnout (normal rail):
 - vibration levels in horizontal and vertical directions: at the highest speeds in vertical direction on the frog, peak levels of 130 g are measured (RMS levels: 195 dB re.1*10⁻⁹ or 5 g RMS).
 - horizontal and vertical impedance measurements by means of an impact hammer and load cell.

The measurement results have been collected in a technical deliverable and disseminated to all partners.



3.1.2 Preliminary evaluation and comparison of two different approaches for modelling the dynamic forces in a turnout

The mathematical simulation of turnout negotiation poses three major problems:

- ✧ the rail profiles are varying along the track;
- ✧ the track flexibility is varying along the track;
- ✧ the running in the frog section and switch sections is complex to model.

Despite the very large number of publications available on this subject, only few scientific papers dealt, up to now, with the problem of turnout negotiation, which is indeed one of the most demanding running conditions for the vehicle and therefore should be deserved special attention.

Most of the papers concerning the particular problem of turnout negotiation tackled the problem from the point of view of rail vehicle dynamics in presence of a rail whose shape is variable with the distance run. In most cases, this was done by introducing some crude approximation like e.g. neglecting the gap in the frog. In other cases the approach was more general, but the results were quite far from reality and showed a high sensitivity to numerical errors. Moreover, in all the papers, track flexibility was neglected, so that the validity of the results was limited to the low frequency range (0-20 Hz) and the forcing effect due to the spatially varying flexibility of the track was neglected. Therefore, none of these models seemed to be completely satisfactory for the purposes of the TURNOUTS project.

On the other hand, a few papers were found where the spatially varying flexibility of the turnout was taken into account, but these references only considered the vertical dynamics of the train-track system, and totally neglected the lateral loading due to the curvature of the diverging track.

In conclusion, the state of the art review evidenced the need for a new model, combining an appropriate description of lateral dynamics, impact dynamics and wheel/rail contact along the turnout with a model of the spatially varying track flexibility.

Two different simulation types have been compared in terms of their performance.

3.1.2.1. Multi-body dynamics model of POLIMI

The mathematical model of train-turnout interaction was obtained starting from an existing model for train track interaction, previously developed at the Department of Mechanical Engineering, Politecnico di Milano, and introducing new developments and extensions to represent the peculiar situation of a train negotiating a turnout. The extension of the model mainly concerned:

- ✧ the representation of wheel-rail contact, where the variation of the rail profile along the turnout was introduced;
- ✧ the model of track flexibility, where the spatially varying stiffness of the turnout was introduced.



The mathematical model of train-turnout interaction is defined in the time domain, in order to account for several non linear effects that typically arise at wheel-rail interface, namely the non-linear geometry of wheel-rail contact and non-linearities arising in the relationship between the relative motion of the wheel on the rail and the resulting contact forces.

The motion of the train-turnout system is therefore represented by means of several different sets of second order differential equations of motion, one for the turnout and one for each vehicle in the train assembly. The equations of motion for each single vehicle are obtained using a multi-body approach, linearised only with respect to kinematical non-linearities. Wheel-rail contact forces act as coupling terms between turnout and vehicle motion. It is therefore necessary to solve the problem of train-turnout interaction by solving simultaneously the equations of motion for all subsystems. This is done using a modified version of the Newmark time-step algorithm.

The general overview of the train-turnout interaction model reported above does not differ from the approach that could be used to simulate train-track interaction on a standard section of line (i.e. not involving a turnout). Nevertheless, in order to consider the situation of a train negotiating a turnout, some specific phenomena need to be taken into account:

- ✧ First of all, it is necessary to consider that the shape of the rail profiles is changing along the turnout: this requires the use of a more complicate model of wheel-rail contact forces, where the number and position of wheel-rail contacts is changing not only as a function of the relative motion between the track and the wheels, but also as a function of the distance travelled by the wheelset along the track.
- ✧ A second important consequence of the spatial variation of rail profile is that in some sections of the turnout, especially on the frog nose, the wheel will be subjected to a vertical displacement, that does not take place on a standard rail track. This effect must be properly taken into account in the model, because it is the source of impact forces arising on the train-turnout system, that may have a large influence on wheel and rail durability as well as on noise and vibrations produced during turnout negotiation.
- ✧ A third problem to be dealt with is the spatially varying flexibility of the track along the turnout. In particular, on the switch blade and on the frog nose the travelling wheel is transferred from one rail to another, and these different rails are characterised by different flexibility in vertical and lateral directions. This issue is also very important in order to correctly represent impact loads during turnout negotiation and, according to the available state of art, until this project was only given an approximate solution, by using a fictitious beam element transferring the wheel from the stock rail to the frog nose. In this project, a different and more accurate approach has been proposed to simulate this effect.
- ✧ Finally, an important issue to be taken into account is represented by the sudden changes of track curvature that occur when the train is negotiating the diverging line of the turnout, while on the standard track step variations of track curvature are normally avoided by the use of cubic transitions. This effect is also very important, since it may have important consequences on ride safety, passenger comfort, damage of wheel-rail surfaces and long term behaviour of the turnout. From the point of view of mathematical modelling, sudden



variations of track curvature may be taken into account quite easily, but this issue must be considered very carefully with respect to the possible consequences on the stability and accuracy of the numerical integration procedure.

The schematisation of the track is based on the Finite Element (FE) approach, therefore a FE model was defined for the whole turnout, including a section of standard track before and after the turnout, to establish proper boundary conditions for the passage of the train.

A Multi-Body (MB) model was defined for each rail vehicle in the train assembly. For each vehicle type, the equations of motion were linearised (with respect to kinematic non-linear effects only), assuming the motion to be a small perturbation around that of a moving reference, travelling along the track centreline with constant speed. When the train negotiates the turnout along the main line, the motion of the moving reference is a translation along the longitudinal direction with constant speed, and therefore the resulting equations of motion for the vehicle are the same as if they were written in a fixed reference. On the other hand, when the vehicle travels along the diverging line, the moving reference travels along a curved path, and therefore a vector of inertial forces is added in the vehicle's equations of motion, to account for the inertial forces on the different bodies associated with the motion of the reference.

A new "general shape curved track" option was implemented in the TDS software, used for all modelling activities, where the geometry of the curve is defined by a lookup table which is interpolated during time step numerical integration. In this way, the peculiarities of any specific kind of turnout may be included in the analysis.

Wheel rail contact is represented in the train-track interaction model by means of a non-linear description where the presence of multiple contacts between the same wheel-rail couple is accounted for. In order to speed-up simulation time, a geometric analysis of wheel-rail contact is performed before running the time-step integration, based on the geometry of wheel and rail profiles, and the relevant parameters of all the candidate contact points are stored in a contact table. During time-step integration, the geometric parameters of the actual contact points are obtained by the interpolation of the contact table. In order to deal with the simulation of wheel-turnout interaction, this procedure was extended, to introduce the peculiar effects related to turnout negotiation.

3.1.2.2. Multi-body dynamics model of NTUA

The model developed by NTUA incorporates the whole turnout, including sleepers, rails, guardrails, heart, railpads, baseplates and guardrail support plates. The analyses are carried out with the finite element code ABAQUS. All components are modelled through 3D hexahedral brick-type elements. While the central sleepers are modelled three-dimensionally, to incorporate the effect of the neighbouring sleepers as well as of the longitudinal continuation of rails and guardrails, a composite boundary is introduced to the model. It comprises beam elements to model both the neighbouring sleepers and the rail continuation. This way the central 3D model is neither assumed fixed at its boundaries, nor taken as free. Waves



propagating longitudinally through rails and guardrails are allowed to realistically radiate outside the 3D model, not affecting its performance. If the boundary was either assumed to be fixed or free, then such longitudinal waves would be forced to reflect at the boundaries and get trapped inside the model. The same holds for vertically propagating waves. In this case, the ballast is the one letting them radiate. The ballast is modelled through springs and dashpots in all directions (X, Y, and Z). The springs represent the resiliency of the ballast, while the dashpots capture the radiation damping through the ballast and the supporting soil. If the ballast was placed on top of a rock-type material then the radiation damping would be minimal. On the other hand, if the ballast is placed on top of a deformable soil layer, then radiation damping can be quite significant.

If the geometry of both the turnout's running surfaces as well as of the wheels of the vehicles was perfect, then the passage of the wheels over the turnout should almost be of a smooth transition. In real conditions, the wear of the wheels and turnout running surfaces makes the passage of the wheel over the turnout will be dominated by impacts and "jumps" of the wheels while passing over the heart of the turnout, instead of a smooth transition. In NTUA model, the corresponding load applied on the model is an impact velocity and not a contact force, allowing the system to dynamically respond naturally.

To compute the impact velocity of the wheel as well as the impact point, an analytical procedure based on a simplified lumped-mass model has been developed. A simplified model takes into account the primary suspension characteristics, the wheel mass, the total weight and the running velocity of the vehicle and the degree of the relative wear of the wheels of the vehicle and of the running surfaces of the turnout. The model simulates the "fall" of the wheel (which is due to the inherent imperfections) to the flangeway gap.

The 3D non-linear model has been applied to the RATP and STIB turnouts. It has been used to conduct a parametric numerical study and a back-analysis of the measurements. Assuming a "jump" of the wheel while passing over the heart of the turnout, instead of a smooth transition, an analytical procedure based on a simplified lumped-mass model has been developed to compute the impact velocity of the wheel as well as the impact point. The model takes into account the primary suspension characteristics, the wheel mass, as well as the total weight and the running velocity of the vehicle. This way, the loading is an impact velocity and not a contact force, allowing the system to dynamically respond naturally. A similar 3D model has been developed to simulate the performance of each turnout and back-analyze the relevant measurements.

In general lines the analysis reveals the significantly lower distress level of the STIB turnout (in view of the peak accelerations) compared to the RATP turnout. The dramatic differences are mainly attributed to the "softer" composite wheels of the STIB vehicles as well as on the complete embedment of the STIB turnout that leads to increased levels of damping. The distress of the turnout (in terms of the peak accelerations) is a function of the train velocity, in agreement with the measurements on both turnouts. Moreover, the computed accelerations reflect the same trends as the measurements. The simulated accelerations are slightly higher than the measured ones, confirming the conservative assumptions of the model.



3.1.3 Validation and comparison of both models on different turnouts

The numerical modelling developed by POLIMI is based on a detailed multi-body model of the trainset and on a detailed model of wheel-rail contact geometry and contact forces in presence of spatially varying rail profiles, while for the turnout structure a simplified finite element model, mainly based on the use of beam elements and concentrated/distributed visco-elastic elements, is used.

On the other hand, the NTUA approach defines a detailed finite element model for the turnout, by using a discretisation into 3D solid elements (plus beams and springs to introduce appropriate boundary conditions at the extremities of the modelled track section), whereas the passing train and the mechanism of train-turnout interaction are modelled in a simplified way, by assuming that a single rigid wheelset in series with a Hertzian spring impacts the turnout over the frog.

Both approaches are complementary, since the first one concentrates on the phenomena of wheel/rail interaction but in order to keep reasonable simulation times requires a simplified representation of the track/turnout, while the second one represents in full detail the turnout system, but relies on a simple model of train/turnout interaction. It is thus particularly important to perform a direct comparison between the two modelling approaches, to define the respective ranges and scopes of applicability. This kind of comparison was performed considering as test cases three reference turnout systems:

- ✧ a turnout with vignole rail, negotiated at relatively high speeds by a “commuter type” trainset (RATP);
- ✧ two turnouts with grooved rail, both negotiated by a tramway trainset at relatively low speed (STIB and De Lijn), one of them based on the “flange bearing” concept, i.e. during the passage over the crossing nose, the wheel/rail contact occurs between the outer part of the flange and the bottom of the rail groove.

Comparisons were performed between the results of the NTUA and POLIMI models, and between these numerical results and the results of measurements performed by D2S on the three systems.

All comparisons were performed in terms of vertical rail acceleration on the crossing nose. Lateral accelerations were not considered since the NTUA model does not take into account lateral excitation on the turnout, while other quantities provided by both models were not considered since an experimental measure was not available to compare with that kind of output. Finally, all signals (measurements and results of numerical simulations) were low-pass filtered to confine the comparison to the 0-500 Hz frequency range, that is the range of validity of simplifying assumptions introduced in the turnout finite element model in the POLIMI approach.

All comparisons performed have shown that both modelling approaches provide comparable results and are in very good agreement with the corresponding measurements. In particular, both models fully satisfy the ± 3 dB accuracy requisite set as a target for modelling techniques being developed in the TURNOUTS project.



In the case of the STIB turnout, the low speed of the trainset together with the very good quality of the turnout geometry, lead to particularly low values of rail acceleration and very small impact effects. Under these conditions, the POLIMI model is able to reproduce the non-negligible effect of rail irregularity, which is not accounted for in the NTUA approach. However, the NTUA approach is still able to achieve a very good accuracy on predicting the extreme vibration levels also in this case.



3.2 WP 2: CONCEPTUAL DESIGN OF MEASURES TO REDUCE IMPACT FORCES

3.2.1 Listing and selection of design measures to reduce the impact forces and the stresses

The following design measures have been selected for further evaluation:

3.2.1.1. Low profile turnout for integration in concrete

In 2001, Vossloh/Cogifer created a new rail section within the framework of a European project named EUREKA. It consists in a new innovating type of track using a new rail profile, the 35 GPB, laid on continuous support to reduce the height of the railway infrastructures.

Conclusions were that:

- ✧ the 35 GPB embedded track is economically very competitive;
- ✧ its installation is very fast;
- ✧ the vibro-acoustic attenuation is higher than the current standards;
- ✧ maintenance is not very constraining;
- ✧ all types of road coatings are possible.

A tramway turnout is now designed using the same rail profile (35GPB - height 85 mm). This turnout will be incorporated in prefabricated concrete slabs by STIB. During this incorporation, the turnout will be equipped with insulating components.

The objective is to develop a concept offering:

- ✧ a reduction of the global thickness of the platform (reduction of the excavations) allowing the installation even in particular locations such as bridges;
- ✧ a reduced installation time (reduction of the harmful effects to the residents);
- ✧ a reduction of the vibro-acoustic emissions.

The following pictures show a general view and a detail of the turnout components before its integration in concrete slabs:



Figure 3.2.1

General view of the single crossover (sight towards the 35 GPB rail)

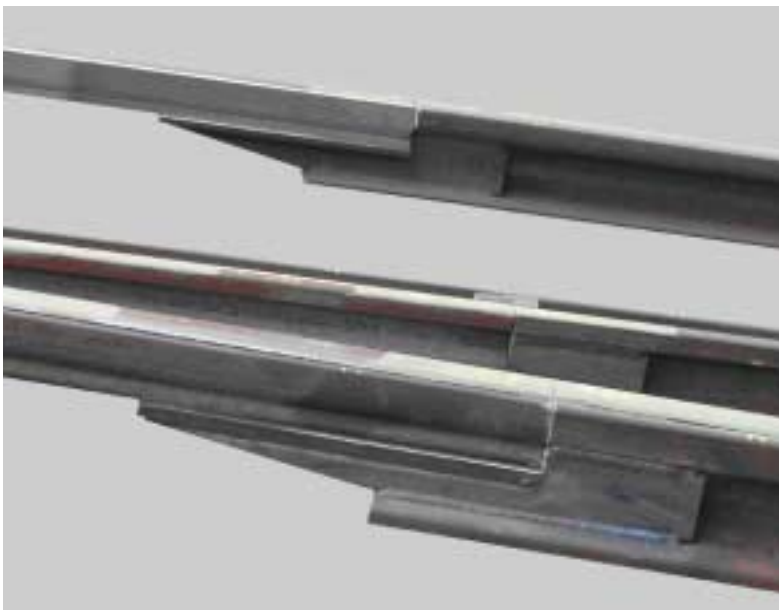


Figure 3.2.2

Transition rails (with 35 GPB rail)



3.2.1.2. Standard and moving nose turnouts with improved wheel/rail contact, geometry and tolerances

The objective of this research is to study from a geometrical point of view the interaction between the wheels and the critical parts of the turnout, which are the switch device and the crossing. The critical areas of the study are the transition between tongue and stock rail at switch device and the crossing gap.

Two types of wheels are to be used, the main difference between both being the conicity (1:40 against 1:14.5, where the wheel with 1:40 conicity conforms to the crossing rolling table, whereas the wheel with 1:14.5 conicity does not).

This research was carried out using the 3D CAD system Unigraphics.

In existing turnouts, the rolling surfaces at the switch device present the following characteristics:

- ✧ gauge radius at tongue $R = 6$ mm in the existing switches;
- ✧ stock rail gauge corner and head machined as NP4aM head profile;
- ✧ tongue and stock rail profile not coincident at the toe and the heel (there is a step at the rolling surface);

and at the crossing:

- ✧ gauge corner as NP4aM profile;
- ✧ wing wheel riser inclined 1:40.

The new design is based on 1:6 NP4aM crossings and new wheels (no data was available on worn wheels).

The research at the crossing led to the following results:

- ✧ the wheel trajectory on the crossing is not flat in any case: the wheel “falls” when rolling on the crossing gap, at the nose;
- ✧ the most favourable cases are the ones with the wheel 1:40, with a slight depression at the trajectory of about 0.3 mm; the reason is because the crossing wing wheel riser conforms the shape of the wheel 1:40;
- ✧ the wheel 1:14.5 and the crossing wing wheel riser do not conform, as the inclinations are very different; the wheel 1:14.5 “falls” more than 1 mm at the crossing gap on the nose: there is an important impact source;
- ✧ the wheel 1:14.5 also “climbs” about 0.4 mm before the crossing gap, as the wheel thread and the wing wheel riser do not conform.

These results are given in (new) ideal conditions. The reality could be worse because of worn out wheel profiles and crossing surfaces.



Research was also carried out at present R = 50 NP4aM switch device, with one wheel profile (1:14.5) at average wheel flange clearance, this wheel passing by closed tongue on curved and straight tongue, with three different sorts of tongue machining at the gauge side:

- ✧ R = 6 mm (present);
- ✧ R = 8 mm;
- ✧ NP4aM head machining;

leading to the following results:

- ✧ the wheel trajectory on the present switch device is not flat: the tongue and the adjacent rail NP4aM have not the same head profile;
- ✧ there is a step of more than 1 mm at the tongue tip and heel, this is cause of impact and noise;
- ✧ if the gauge corner at the tongue is to be machined to 8 mm (first assumption), the step at the tongue tip and heel is reduced to 0.9 mm;
- ✧ if the gauge corner of the tongue is to be machined to NP4aM rail head, the trajectory of the wheel is flat, without any step.

These results are similar for both half switches and any type of wheel profile.

The conclusions of this research phase are that:

- ✧ The present design of the rolling surfaces at the turnouts does not take into account the predominant wheel profiles.
- ✧ The sources of impacts at the switch are the steps between tongue and stock rail at the tip and heel of the tongue, due to the different rolling profiles.
- ✧ The solution at switch device is to machine the tongue head and gauge line the same as the standard profile NP4aM.
- ✧ The main sources of impacts at the crossing are the gap and the different shape of the wheel thread (1:14.5) and the crossing wing wheel riser (1:40).
- ✧ Machining the crossing rolling surface with 1:14.5 inclination will help to reduce the impact forces, but it will not eliminate them, as both surfaces, the wheel and the crossing, wear out in service.
- ✧ To eliminate impact forces at the crossing gap, a swing nose crossing could be the best solution.
- ✧ Swing nose crossings are not sensitive to different types of wheels or worn wheels, as the rolling surface is continuous.

The implementation of these solutions to eliminate the sources of impact forces leads to a new concept of tram turnout. The turnout selected to test these design measures is a NP4aM R = 30 turnout, left hand side. The implemented design measures include:

- ✧ modification of the machining of the tongues, i.e.:
 - modification of the machining profile of the tongue at the gauge corner;
 - machining profile of the rolling surface coincident with that of the NP4aM profile;
 - elimination of the step between rolling surfaces of stock rail and tongue;
- ✧ use of a swing nose crossing to eliminate the crossing gap;

with the following consequences:

- ✧ the check rails are no longer necessary to guide the axles through the crossing gap, avoiding the lateral movement of the vehicle, which leads to a higher riding comfort and lower requirement for maintenance;
- ✧ use of a swing nose crossing also reduces the requirement for maintenance due to quite reduced plastic deformation and wearing on the rolling surface at the crossing, and increases the lifespan;
- ✧ a very low sensitivity to the circulation of different wheel profiles or worn wheels.

The corresponding main features are illustrated below:

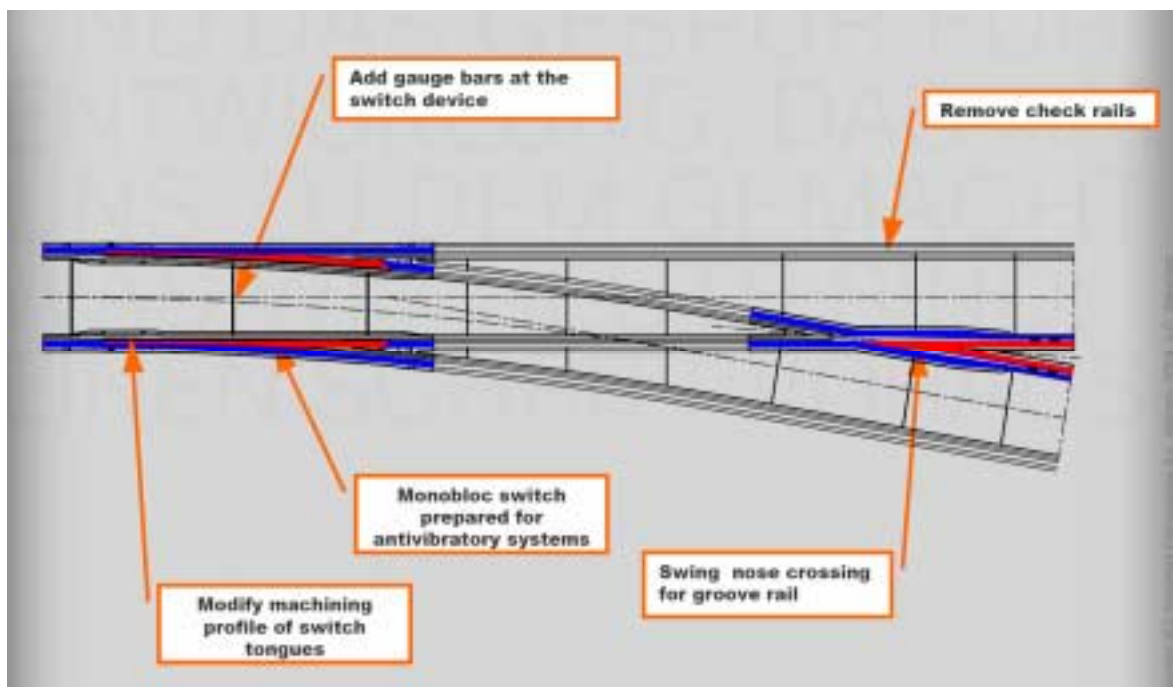


Figure 3.2.3

Main features of the new concept turnout

The main elements (cradle and point) are made of cast manganese steel, fully machined. Point rails are moved by electrical Hanning & Kahl motor. The rolling surfaces are machined according to standard rail profile NP4aM. The point rails are easy to replace in case of damage.

These solutions, combined with the installation of the turnout with elastic antivibratory systems developed by FDP (see §3.2.1.3 below), will reduce the noise and vibrations transmitted to the infrastructure and adjacent buildings. This new concept of tram turnout will be compared with the conventional design installed under the same conditions, i.e. FDP antivibratory system described below.



3.2.1.3. Elastic mounting

The objective of this solution is to reduce noise and vibrations transmitted to the environment by using a proper insulation of the turnout.

The main characteristics of existing turnouts at De Lijn in Antwerp are:

- ✧ gauge 1000 mm – NP4aM;
- ✧ geometries in $R = 18, 30, 50$ and 100 m at the branch line;
- ✧ usually installed on wooden sleepers;
- ✧ monobloc switch device with direct fastening, out of cast Mn steel;
- ✧ fixed crossing out of cast Mn steel;
- ✧ check rails out of cast Mn steel.

The selected geometry for this test is a $R = 50$ m turnout 1:6 tangent. A turnout will be manufactured with this existing design and installed on a concrete plinth with antivibratory damping system. It will be compared with the new concept turnout described above (see §3.2.1.2), also installed on a concrete plinth with antivibratory damping system. In both turnouts, the main components are made out of cast austenitic Mn steel.

The existing design has to be adapted:

- ✧ fixation on metallic sleepers;
- ✧ fixation with clips or screws;
- ✧ shuttering of the rails;
- ✧ closing openings on foot of the rail.

Due to the fact that the turnout is fixed on a concrete foundation, following problems had to be solved:

- ✧ adaptation of the turnout for switchboxes;
- ✧ turnout in concrete needs a water carry off system;
- ✧ boxes for tongue control, tongue heating system, short-circuit (if necessary);
- ✧ necessary fixation of cables.

A first design was produced after 12 months. It was further refined under the following aspects:

- ✧ determination of the geometry of the switchboxes: tongue control, tongue heating system, short-circuit;
- ✧ fixation of cables: due to the fact that the turnout will be installed in concrete, the electric command of switchbox and the short-circuit (shuntage) has to be removable or changeable:
 - the cables are installed in PVC-tubes;
 - two supplementary cables have to be installed just before and after the switchbox;



- the cable system of De Lijn needs not only fixations in the electronic turnout, but also before and after it;
- ✧ isolation of the switchbox: the turnout is installed on elastic pads. The down movement of the turnout must also be secured at the place of the switchboxes. Installation of a damping material at the underside of the switchbox is necessary.

The set up of the turnout on the foundation of the concrete slab required also a detailed study of the following aspects:

- ✧ determination of the quality of the concrete;
- ✧ determination of the thickness of the concrete foundation;
- ✧ determination of the reinforcement of the concrete slab;
- ✧ mounting of the turnout with levelling and alignment;
- ✧ isolation of the turnout: there was a direct contact between the concrete reinforcement bars and the steel parts of the turnout. This requires isolation between the mounting bridges and the reinforcement bars. This is solved by placing a PVC tube over the mounting bridges.

The damping material put in next to the rail had the following functional requirements:

- ✧ the static deflection of the rail in the turnout must be lower than 1 mm in order to limit the wear of the turnout;
- ✧ for a good vibration isolation and reduction of the effect of impact, the first wheel-rail resonance frequency must be lower than 50 Hz.

Tests were carried out on different products:

- ✧ prefabricated formed bodies of different types and materials;
- ✧ polyurethanes;
- ✧ resins;
- ✧ mixed Expansion PU;
- ✧ mixed polyurethanes with cork;
- ✧ mixed polyurethanes with rubbergranules of different diameters;
- ✧ mixed polyurethanes – resins and granules.

3.2.1.4. Booted under sleeper pads with ballast mat

The objective of the TURNOUTS project is to improve the vehicle-track interaction in the turnout systems for urban rail transit, and therefore to improve their efficiency, enhance their safety levels, reduce the required maintenance, and restrain the emitted noise. These objectives are to be reached by reducing the loads and the stresses on the frog and in the switch point/stock rail sections in comparison with a conventional turnout.

A solution is defined with increased foundation damping that is designed to absorb the impact from the wheel passing over the gap in the frog, which will reduce impact wear and thus



increase the longevity of the frog. In addition, the impact absorption will provide a significant reduction in noise and vibration.

The design covers the treatment of a turnout that is embedded in the roadbed. The whole turnout is built over a concrete slab covered with a ballast mat. The sleepers on which the turnout is mounted are treated with booted under sleeper pads that cover their entire bottom surface.

The booted under sleeper pads consist of three layers:

- ✧ the vibration damping pad;
- ✧ the boot made of a relatively rigid material:
 - protects the vibration damping pad;
 - allows the sleeper to move freely up and down in the ballast;
- ✧ the distribution plate:
 - provides uniform load distribution over the ballast;
 - optimises performance of the vibration damping pad;
 - completely eliminates the possibility of ballast penetration (short-circuiting between the ballast and the sleeper).

The rail is completely separated from the roadbed to allow it to move freely. This is achieved by covering the rail with jackets made from pre-moulded rubber epoxy. The internal profile is shaped to fit the rail web and foot. A separate section covers the foot of the rail between the sleepers.

Since concrete is poured between the rails over the ballast and also over the sleepers, the sleepers themselves must also be separated from the roadbed. This is achieved with a stiff separation layer that is capable of withstanding the loads on the roadbed.

3.2.1.5. Improvement of crossing geometry

Most vibrations occurring on crossings are due to running discontinuities generating shocks on passing wheels. Those discontinuities are of two kinds: crossing joints and crossing gap. Shocks due to joints have been greatly reduced by the spread of welding: research presently focuses on an improvement of their realization with smaller stainless steel inserts.

As far as the gap is concerned, tests have been carried out on devices closing this one. Those systems did not prove effective to reduce vibrations on wide deviation angle switches commonly used on urban systems. Researches carried out have shown that it was possible to reduce the vibratory impact on crossings cast in one piece without altering their design, thanks to an improved geometry. The expected benefit could reach 7 to 9 dB.

To maximize the vibratory reduction, the geometry of crossings should be realized with an accuracy better than 0.3 mm providing the most rectilinear possible trajectory to the wheel. It is difficult to perform this measurement with the required accuracy because the wheel

successively runs the different parts of the crossing whose running surfaces are different from each other.

RATP has designed a measurement device able to measure the trajectory followed by a wheel in the vertical plane with an accuracy of 0.1 mm. This device is said « crossing measuring cradle ». It includes a solid rectangular frame run by two girders perpendicular to each other, and a measuring head fitted with a displacement transducer. The original feature of this device is the shape of the contact piece, obtained from a wheel tyre. That way, the displacement of this piece along the crossing accurately reproduces the vertical movements of a vehicle wheel running along the same path. Those movements are recorded, which makes it possible to determine the running profile of the crossing. The analysis of those profiles makes it possible to locate flaws accurately and to measure their depth.

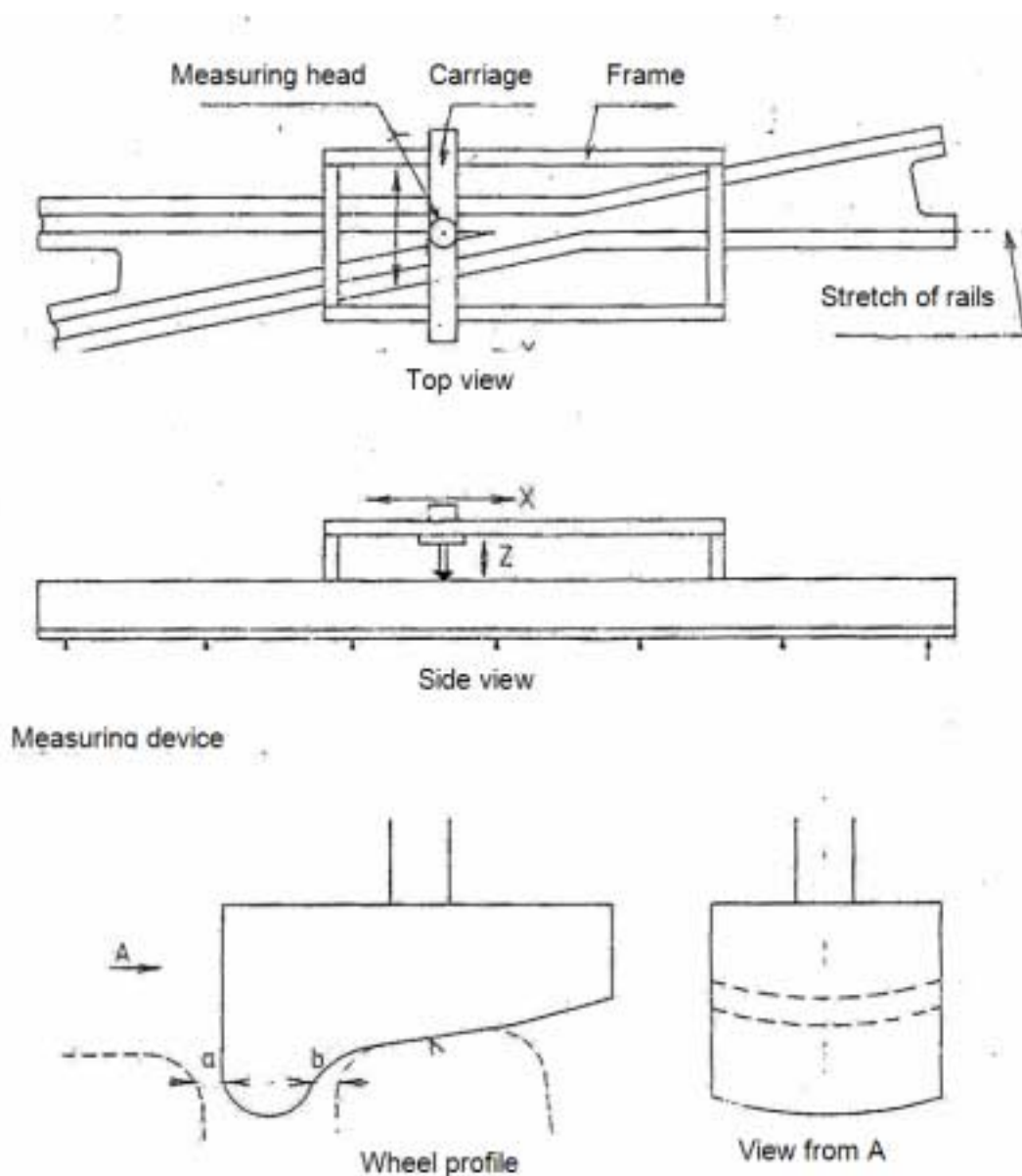


Figure 3.2.4

Crossing measuring cradle

Correction of the running surface of a crossing consists in filling hollow areas with metal and then grinding modified surfaces and bumps. Metal filling is a common operation, generally well performed by the maintenance staff, grinding does not provide the 0.2 or 0.3 mm accuracy despite the care brought to that operation.

To reach this result, a guided grinding system has been designed whose concept is similar to that of the measuring cradle. This device is said « grinding cradle ». It includes a rectangular frame rigidly connected to the crossing, which serves as a guide for an electric grinding machine. The whole device is adjustable in transverse direction and in rotation, which provides a grinding of the whole upper surface of the heart, including the fillet.

3.2.1.6. Improved process and new welding procedures: Flash Butt Welding Technique

Joining turnout components by the flash butt method is an automated, electrical resistance welding process, performed without the use of any filler metal. The process comprises a sequence of up to five different operations:

1. square-flash;
2. preheating;
3. flashing;
4. upsetting;
5. cooling.

Flashing, upsetting and cooling are characteristic of the process and are always necessary.



Figure 3.2.5

Flash Butt Welding Technique

When two wires which are charged with electricity, are put in contact with each other, they crackle with sparks. The flash-butt welding is a welding method which harnesses this heat of which sparks generate, to melt and to weld metals.

The potential between two poles of transformer is 12 volts and the current is about 1000 amperes. The touched faces to be welded are melted in a moment with this electricity



which has higher current with lower voltage. The contact faces are touched and untouched until all parts of contact faces are melted uniformly.

Typical welding problems that may occur when dealing with very thin brinox sections are:

- ✧ Brinox section ejected from weld (aligning problems: the thinner the section the higher the alignment precision)
- ✧ welding heterogeneities, as shown by thermal gradient (Flash-Butt parameters).

The following improvements have been brought to the process:

- ✧ more precise alignment between rail, brinox and frog with:
 - hydraulic system;
 - mechanical clamping;
- ✧ electronic control of flashing time: system optimized (PLC) in order to better control flashing frequency.

Acting on control parameters for pre-flashing, flashing, forging and final tempering, several trial welds have been attempted. Trial samples with a Brinox length around 3 mm have been produced.

Metallurgical analysis of these samples has shown that:

- ✧ HAZ is very limited (less than 0.3 mm);
- ✧ Hardness gradient confirms the limited HAZ;
- ✧ Hardness values are in accordance with the requirements.

Non destructive penetrating testing and radiographic testing do not evidence any defect.

Bending tests have shown that new joints with reduced Brinox length to 3 mm show a higher stiffness when compared to 20 mm Brinox joints. Moreover, the initial yielding moment is two times higher than for 20 mm Brinox joints (this is due to the higher yield strength). This does not allow to reach a permanent deflection of 18 mm, as required by the standard Certifer for the homologation.

Fatigue tests were also carried out, leading to the following conclusions:

- ✧ according to Certifer standard, the fatigue tests at 200 MPa have been passed
- ✧ moreover, at 220 and 240 MPa, welded joints failed after 4.000.000, far from welding.

Frogs with 3 mm welded joints will be tested in service on RATP network.



3.2.2 Sensitivity analysis of contact forces to design parameters

This sensitivity analysis is intended to validate some of the proposed design measures, and also to allow an optimisation of the main relevant parameters involved (e.g. stiffness and damping of the different resilient layers in the track), in view of achieving detailed specifications for new turnout systems to be developed in the project.

Two types of turnout were considered for the sensitivity analysis:

- ✧ a turnout with vignole rail type V52;
- ✧ a turnout with grooved rail type NP4aS.

Sensitivity analyses on the turnout with vignole rail type have led to the following conclusions:

- ✧ As far as rail acceleration is concerned, it can be concluded that the only measure that is actually effective in reducing rail vibration is the correction of rail profile. The correction of track geometry bears negligible (in some cases even negative) advantages, both when applied alone or in combination with rail profile correction. Modifications in track resilience are totally ineffective in reducing rail vibration if applied below the ballast (ballast mat), and provide only a limited benefit if applied above the ballast (under sleeper pad). The combined use of rail profile correction and of an under sleeper pad provides the best results, but the improvement with respect to the case of rail profile correction only is limited.
- ✧ When the reduction of soil vibration is considered, both the effects of rail profile correction and of track resilience modification turn out to be effective (but in different frequency ranges). In this case, both the use of a ballast mat and of an under sleeper pad may be effective, and the combined use of these two resilient layers may provide remarkable reductions of soil vibration and thus of ground borne noise.
- ✧ Quite obviously, the reduction of soil vibration obtained by the combined use of rail profile correction and improvement of track resilience bears the highest benefits among those considered in the sensitivity analysis, and the amount of soil vibration reduction (10-11 dB) is highly promising for future implementations of this concept.
- ✧ Rail profile correction is the measure that mostly affects the reduction of contact forces and in the considered case is the only mean to avoid the loss of wheel-rail contact during the passage of the wheel over the crossing nose.
- ✧ As for rail accelerations (that are indeed strictly related to wheel-rail contact forces), a slight improvement may be obtained by the use of an under sleeper pad, due to the additional damping introduced by this component. The highest reduction of contact forces is then obtained for cases where rail profile correction is used in combination with the modification of track resilience.
- ✧ Finally, the improvement of track geometry turns out to be totally ineffective in improving wheel-rail contact forces; this is due to the fact that track geometry correction only affects



the long-wavelength components of the vertical displacement that the wheel undergoes when passing through the crossing panel.

- ✧ In terms of maximum stress cycle amplitude, the largest reduction is in the range of 3 dB and is obtained by correcting the rail profile geometry and at the same time modifying the track resilience properties. According to the results of the simulation, the same result may be obtained also by using a ballast mat in combination with an under sleeper pad. This result could be produced by a high sensitivity of the stress calculation to the specific point where the wheel impacts the crossing frog, and therefore the actual benefit provided by the modification of track resilience alone should be carefully considered.
- ✧ It is important to observe that none of the proposed corrective measures leads to an increase of the stresses in the rail, except the case of track geometry modification where the increase of the stress amplitude is anyway almost negligible (below 1 dB).
- ✧ As far as rail acceleration is concerned, it is observed that the use of a stiff (200 MN/m) railpad with high damping may lead to a decrease of the peak and r.m.s. vibration of the rail up to 3.5 dB. Using softer pads a reduction of rail vibration is still achieved, though by a lower amount (1.5 dB for the r.m.s. with the soft pad). By considering low damped pads the reduction of rail vibration is lower, and becomes negligible in the case of the soft and low damped pad.
- ✧ On the other hand, the highest reduction of soil vibration (more than 3 dB on both r.m.s. and extreme value) is obtained using the softer pad, which obviously increases the filtering properties of the track. For the same value of pad stiffness, lower values of railpad damping are associated to lower reduction of soil vibration levels with respect to direct fastening. In all cases considered in the sensitivity analysis, the reduction of soil vibration introduced by the use of the railpad is much lower than the one that could be achieved by the use of a ballast mat in combination with an under sleeper pad.
- ✧ The effect of fastener properties on the reduction of the r.m.s. value of dynamic wheel-rail contact forces is not so marked, except in the case of soft, highly damped pad on a rail with corrected profile, in which case the non negligible reduction of 2.5 dB is obtained. In general, low values of pad stiffness and high values of pad damping have a favourable effect on the reduction of wheel-rail contact forces.
- ✧ For what concerns the sensitivity analysis on fastener properties concerning the reduction of bending stresses in the crossing panel, the reduction with respect to the nominal case is for this quantity positive in the case of the stiff pad, due to damping introduced by the pad. However, increasing the pad deformability, a larger portion of the contact force is transmitted by the rail, resulting in higher bending moments. In conclusion, the choice of a very soft pad may result in non negligible increases of the stresses in the rail, that in turn might negatively affect the durability of the crossing panel.
- ✧ Another important parameter to be evaluated concerning the effect of railpad stiffness on train-turnout interaction is the reduction of the force transmitted by the rail to the sleeper. In fact, the railpad acts as a mechanical filter between these two bodies, hence protecting the sleeper from excessive impact loads generated at wheel-rail contact. The



reduction of the maximum force on the sleeper is much higher in the case of a railpad with high damping and is higher for softer pads. The largest reduction of the force transmitted is 1.4 dB, but it should be considered that this reduction is computed on the whole transmitted force, including the quasi-static component produced by the wheel load, so that in absolute terms the reduction of the transmitted force is definitely relevant in view of the sleeper durability.

- ✧ Finally, though the use of a soft railpad leads to a relevant increase of the rail vertical displacement, the maximum deflection of the rail relative to the sleeper always remains below 1.6 mm, which is a quite reasonable value and should not be cause of particular problems in view of ride safety.
- ✧ In conclusion, it may be stated that the use of a railpad instead of direct fixation is advisable for several reasons: reduction of rail vibrations, reduction of impacts on the sleepers, reduction of wheel-rail interaction forces. In the case of a stiff track like the one considered, some minor benefits may also be introduced on soil vibration. If the protection of the sleepers for extra loads is the main issue, a soft pad with high damping should be chosen, though being careful about the fact that this choice will introduce additional stresses in the rail. On the other hand, the use of a stiff pad with high damping will reduce rail vibration without increasing the stresses in the rail, but will not be as efficient as the soft solution in limiting the maximum force on the sleepers.

Sensitivity analyses on the turnout with grooved rail type have led to the following conclusions:

- ✧ As far as rail accelerations are concerned, quite small variations of the performance indexes are observed, with the r.m.s. generally being slightly reduced and the maximum amplitude being sometimes increased (especially in the case when a soft under sleeper pad is used).
- ✧ Soil accelerations are quite remarkably reduced by all the measures considered in the sensitivity analysis, the best improvement, close to a 10 dB reduction of vibrations, being provided by the combined use of a ballast mat and an under sleeper pad. Also the use of a soft ballast mat without under sleeper pad may provide very good results (vibration reduction close to 8 dB), while not introducing the additional costs for the under sleeper pad.
- ✧ The dynamic component of wheel rail contact forces is reduced by the increase of track flexibility introduced in the sensitivity analysis. This is due to the fact that a reduction of track impedance produces a lower amplitude of vertical vibration of the non-suspended vehicle masses in response to track irregularity and wheel out-of-roundness, thereby producing lower inertial effects associated to the vibration of the non-suspended masses. The maximum reduction of r.m.s. wheel-rail contact forces is in the range of 1.5 dB.
- ✧ Finally, the nominal bending stresses in the crossing panel are increased due to the increased flexibility of the track, leading to a higher portion of wheel load being transferred through the rail to adjacent rail supports. This increase reaches in the worst case 2.5 dB and should be considered in the choice of track properties.



3.3 WP 3: MODELLING AND OPTIMISATION OF NEW TURNOUT SYSTEMS FOR USE IN SELECTED FIELD CONDITIONS

3.3.1 Selected test sites

The following test sites have been selected for the different designed solutions:

3.3.1.1. D2S Concept

The D2S concept of foundation damping using ballast mat and under sleeper pads is to be installed in rue G.J. Martin in the network of STIB in Brussels. This site was selected as it was part of a renovation project and the existing turnout was creating a serious annoyance in the nearby German Embassy. As the vibration reduction predicted by the modelling at POLIMI would solve this problem, it was an ideal location to evaluate the concept.

3.3.1.2. COGI/KIHN Low Profile with deep groove

The low profile turnout is specifically designed to be incorporated in thin concrete slabs such as those used in prefabricated track designs. The low profile turnout will be mated to a standard profile turnout. Both turnouts will be integrated in prefabricated slabs with continuously supported rail. Having the two turnouts side by side provides the opportunity to not only compare their performance with the tangent track, but also with each other. Rue Baeck in the network of STIB in Brussels provided the opportunity to have both turnouts installed for an effective comparison.

3.3.1.3. COGI/KIHN Low Profile with flange bearing

Flange bearing turnouts are typically installed where the deviating track must part at a relatively large angle. In a tramway network these are typically installed at the entrance of return loops. As this turnout is designed to be incorporated in a prefabricated concrete slab, it has to be installed in a return loop that is embedded in the street. Place Van Gehuchten in the network of STIB in Brussels matched up with these design criteria and was chosen for this turnout.

3.3.1.4. Embedded FDP turnout with discrete rail fixation

The FDP concept of foundation damping is based on an embedded rail with discrete fastenings that are solidly anchored in the concrete slab. The total thickness of the slab from soil to surface is about 0.6 m, which implies a relatively deep excavation for the track construction. Hence such an installation will only be executed during a major construction project. The rehabilitation of the St. Bernardse Steenweg in Hoboken provided the opportunity to install this concept in conjunction with tangent track of similar construction.

3.3.1.5. Jez turnout with movable point frog

The JEZ moving nose crossing so far has never been used for tramway. In view of this aspect, it was decided to put the turnout in open ballast and not in an embedded configuration. Since the turnout promises great gains in noise and vibrations, it would be most welcome to replace high angle flange bearing crossings. In view of these restrictions and benefits it was decided to install the turnout at the entrance of the tram return loop in Antwerpen Linkeroever.



3.3.1.6. BFM cast manganese frog

Cast manganese frogs are typically installed for their longevity. Line 13 of the Paris RATP is a heavily travelled line where the new frog would be intensively crossed. In addition, it was the turnout that was to be replaced that served as a reference turnout, making direct comparisons easy.

3.3.1.7. RATP longitudinal profile correction

The turnout selected for these experiments is the turnout that feeds directly into the BFM turnout and has the same nominal geometry as that one and also as the reference turnout.

3.3.1.8. FDP industrial turnout

The FDP industrial turnout is to be installed at the BASF facility in the port of Antwerp. It was decided that it would replace the first turnout of the BASF depot so it would see immediately high traffic volumes, guaranteeing quick results for evaluation and durability.

3.3.2 Review of the selected designs and iterative optimisation

The new concepts to reduce vibration effects arising during train passage on a turnout have been assessed and optimised, using the modelling techniques developed and validated in WP1. The corresponding findings are summarised below.

A first important conclusion of the calculations performed is that all the new concepts considered provide a relevant reduction of solid vibration transmitted to the foundation of the turnout, hence reducing substantially the annoyance produced on the environment by train passages over the turnout.

The D2S solution based on combined use of under sleeper pad and ballast mat is able to reduce soil vibration by 10 dB or more in the high frequency range. On the other hand, rail vibration and wheel-rail interaction are less affected by the introduction of resilient layers below the sleepers and below the ballast, and hence the reduction achieved in the overall levels of rail vibration and of wheel-rail contact force are in the range 1-2 dB.

As far as the Kihn-Cogifer concept is considered, relevant reductions of soil vibration are to be expected for both the standard rail and low height rail versions, due to the presence of the massive slab. The overall reduction of soil vibration is expected to be in the range of 6 dB. Calculations indicate a reduction also in the levels of vertical rail vibration. For this quantity the reduction with respect to the considered reference is predicted in 3-4 dB approximately.

For the same concept, a reduction in the stiffness of the continuous rail support is expected to bring as a benefit a reduction of wheel-rail interaction in the high frequency range, which could turn out in a reduction of emission of rolling noise. However, the same measure will produce higher levels of rail vibration and hence higher levels of noise emission from the rails. A reduction of the slab-soil interface layer stiffness should produce, according to the calculations performed, a reduction of ground borne noise and vibration, however, the effects on the design of the concrete slab and of track foundation are to be considered carefully.



For the Frateur de Pourcq turnout concept also, a relevant reduction of soil vibration levels, in the range of 6-7 dB, is predicted by the calculations performed. Rail vertical acceleration is also reduced with respect to the reference, in the range 5 dB. For this track concept a parametric analysis was performed concerning the stiffness properties of both the concentrated and distributed rail support elements, resulting in a low impact of these parameters on vibration transmitted to the soil. On the other hand, a slight reduction of rail vibration may be expected by increasing the stiffness of either the concentrated or distributed rail support.

3.4 WP 4: MANUFACTURING OF NEW TURNOUT SYSTEMS

Based upon the new designs as selected and optimised in WP3, seven new turnout systems have been manufactured for later in field installation and testing. An eighth turnout has been transformed, from an existing turnout, by RATP.

3.4.1 Two low profile rail turnouts from COGI

COGI has manufactured two low profile rail turnouts:

- ✧ One to be installed rue Baeck in Brussels:

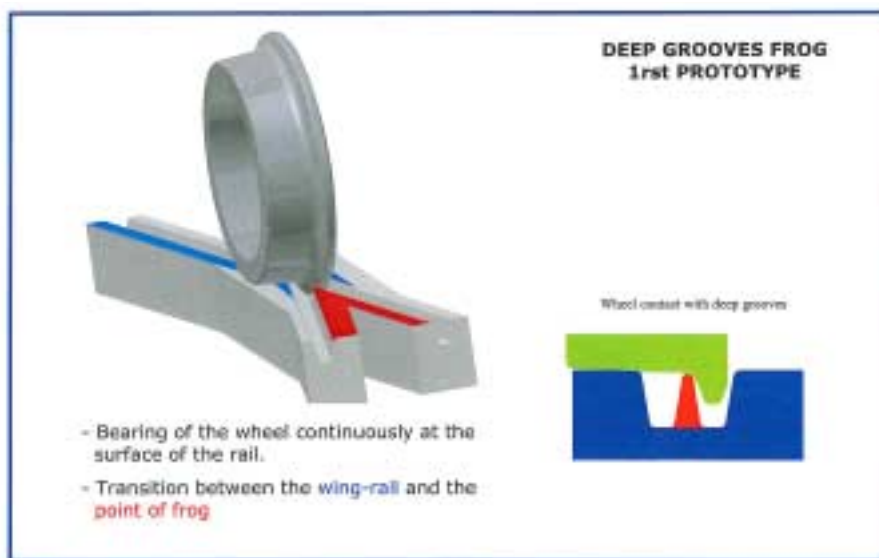


Figure 3.4.1

- ✧ One wheel flange bearing turnout, to be installed place Arthur Van Gehuchten in Brussels:

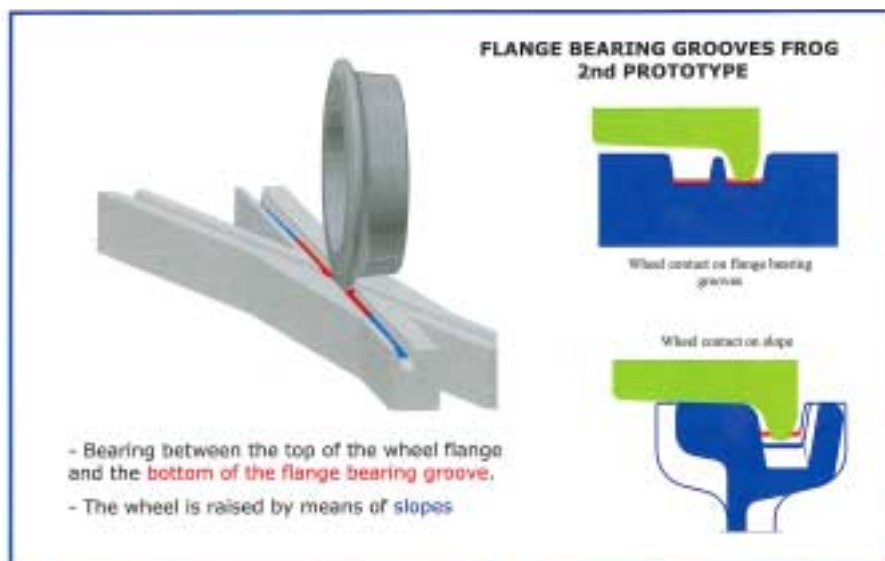


Figure 3.4.2



The manufactured low profile rail is shown below:



Figure 3.4.3

3.4.2 One turnout from BFM

One turnout has been manufactured in BFM factory, in Bari, to be installed in RATP network, Porte de Vanves. It is shown below during its installation:



Figure 3.4.4

3.4.3 Embedded FDP turnout with discrete rail fixations

One existing design turnout has been manufactured by FDP, to be installed on a concrete plinth in St-Bernardsesteenweg in Hoboken (Belgium). A general view of this turnout is given below:



Figure 3.4.5

3.4.4 One turnout from D2S

One existing design turnout has been manufactured to be mounted on under sleeper pads in rue G.J. Martin in Brussels. It is shown, during installation, below:



Figure 3.4.6

3.4.5 Jez turnout with movable point frog

The pictures below show some of the major steps of the manufacturing in JEZ factory in Bilbao:

- ✧ pouring of the manganese steel:



Figure 3.4.7

- ✧ turnout components before and during machining:



Figure 3.4.8



Figure 3.4.9

✧ assembling of the turnout and switch devices:



Figure 3.4.10

3.4.6 One industrial turnout with casted manganese steel crossing from FDP

One industrial turnout with casted manganese steel crossing and tongue in ZU2-49 profile has been manufactured, to be installed by FDP at BASF site in Antwerp.

Some pictures of the manufacturing of fixation components are shown below.



Figure 3.4.11



Figure 3.4.12



3.5 WP 5: LAB TESTING AND ON SITE INSTALLATION AND TESTING OF THE NEW TURNOUT SYSTEMS

The seven new prototype turnouts manufactured in WP4, together with the longitudinal running profile correction on a RATP turnout, are installed and validated during normal operation (three end-users).

Before installation, the prototype turnouts underwent extensive lab testing.

After installation, their static and dynamic behaviour (including impact forces) was measured by D2S.

3.5.1 Lab testing

Lab tests have been carried out by UCL on different products, parts and assemblies of some of the new turnout systems. The objectives of these tests were:

- ✧ to acquire experimental data to quantify the input parameters of the numerical models;
- ✧ to control if the characteristics of selected products, parts or assemblies were compliant with the technical specifications;
- ✧ to insure their long term behaviour (mainly due to their use in the network).

The two first purposes are reached by static and dynamic tests.

The static test consists in loading slowly the product, part or assembly, and measuring the response (deformations versus load). Static properties (typically the static stiffness) can be extracted from the recorded curves.

The dynamic test consists in loading the product, part or assembly, alternatively between two load limits, following a sinusoidal wave, with chosen frequencies (5 to 20 Hz), and to measure the dynamic response. Dynamic properties (dynamic stiffness, natural frequency, ...) can be determined from the measurements.

The long term behaviour is controlled by fatigue testing.

The fatigue test consists in a sinusoidal load applied by a pulsating actuator. The load varies between two fixed limits. The frequency of the loading depends on the conditions (load limits, deformation of the tested system, used material, ...). During the tests, some measurements are performed, such as the load by a dynamometric cell and selected deformations by strain gauges and/or LVDT captors.

The parameters of the tests are fixed in accordance with the real operation conditions in the concerned network.

All these tests are carried out either on a machine (100 kN or 1000 kN capacity) or with an electro-hydraulic actuator attached to a frame fixed on the test floor of the laboratory.

The results of the tests have been supplied step by step to the involved partners and included in their design work.

3.5.2 Turnout installations

Seven new turnout installations have been installed on selected test sites. An eighth turnout has been treated by RATP: longitudinal running profile correction by refurbishment. These operations are described below.

3.5.2.1. Installation of an embedded turnout with discrete rail fixation (St-Bernardsesteenweg, Hoboken-Belgium)

A map of the installation site is shown below:

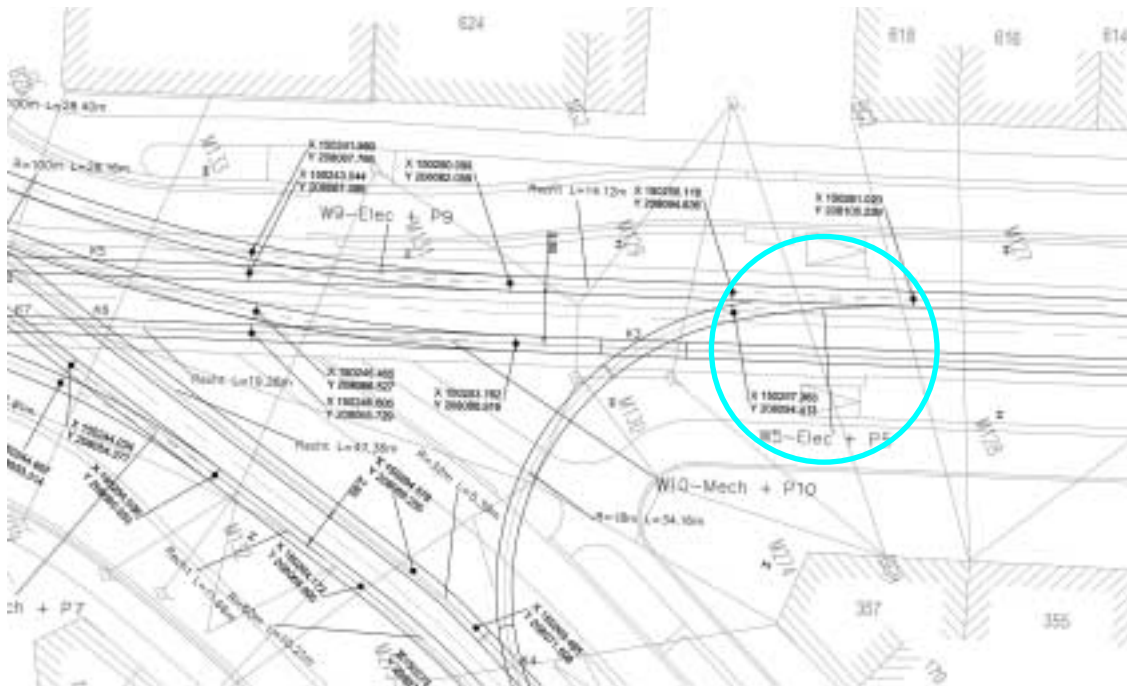


Figure 3.5.1

The turnout is installed and poured in concrete, as shown below:



Figure 3.5.2

3.5.2.2. Installation of a Jez turnout with movable point frog (Linkeroever, Antwerp)

A map of the installation site is shown below:

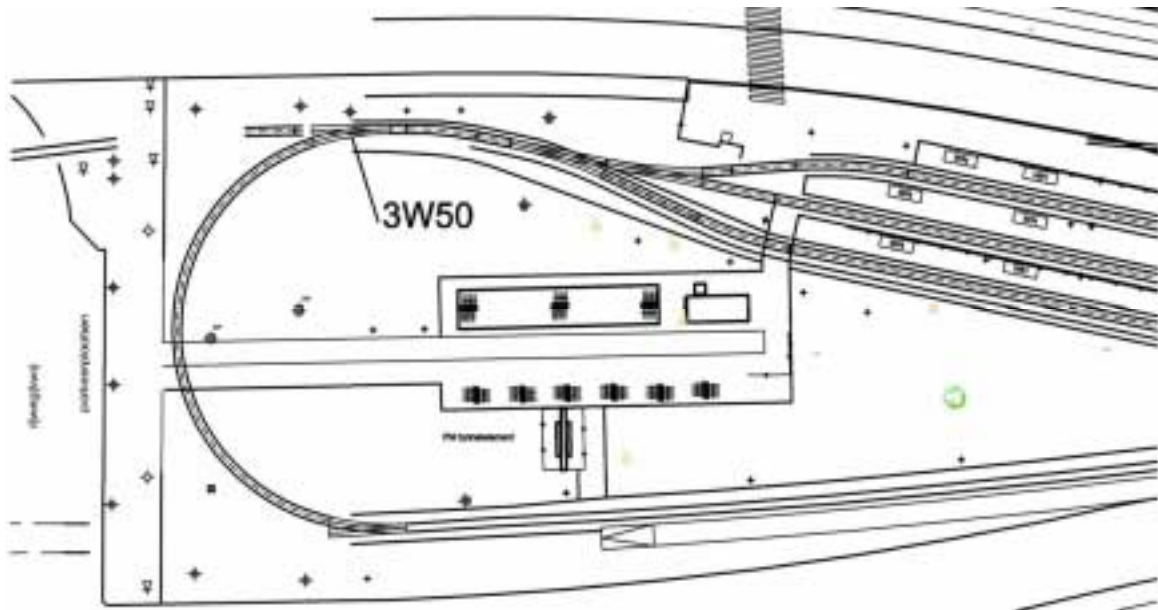


Figure 3.5.3

On this site, one tram transits every 5 minutes. The existing turnout was removed, the new one is installed. During the first runs, the tram driver switches the movable point of the turnout manually, as shown below:



Figure 3.5.4

In a later stage, the control unit is installed, enabling the automated use of the turnout.

3.5.2.3. Installation of a new design turnout with low profile rail (rue Baeck, Brussels)

The low profile rail turnout with deep groove is installed rue Baeck in Brussels. A picture of the installation process is shown below, together with a zoom on the transition between the low profile rail and the adjacent standard rails:



Figure 3.5.5



Figure 3.5.6

3.5.2.4. Installation of a new design turnout with low profile rail running on wheel flange (place Van Gehuchten, Brussels)

A map of the installation site is shown below:

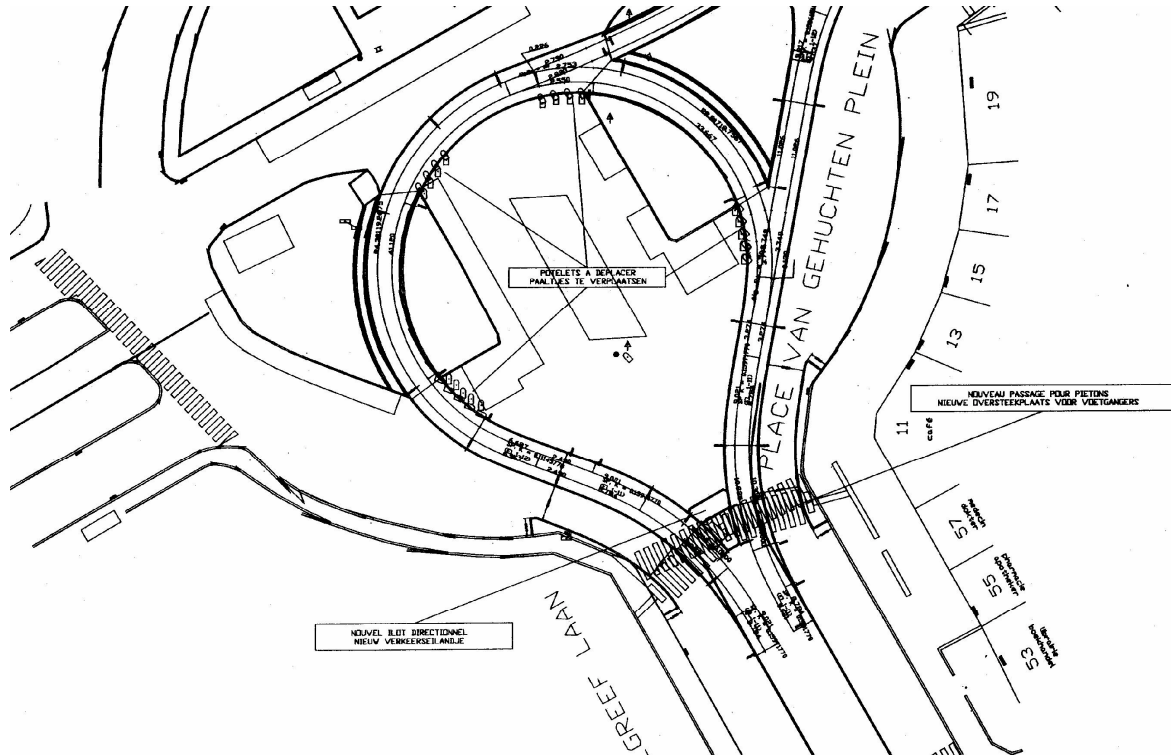


Figure 3.5.7

3.5.2.5. Installation of an existing design turnout mounted on under sleeper pads (rue G.J. Martin, Brussels)

A map of the installation site is shown below:

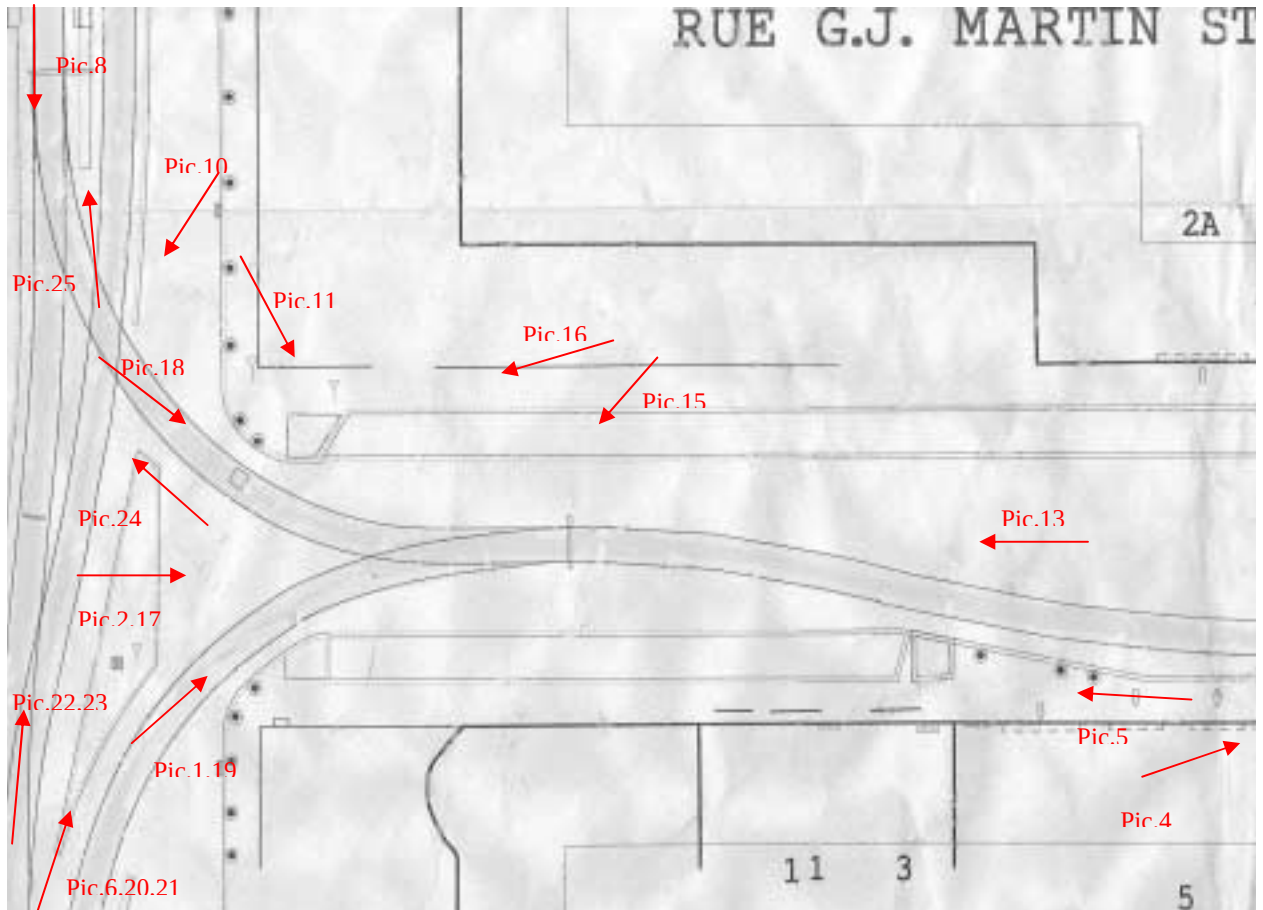


Figure 3.5.8

The installed turnout is shown below:



Figure 3.5.9

3.5.2.6. Installation of an existing design turnout with new crossing and elastic railpads (porte de Vanves, Paris)

A map of the installation site, on RATP line 13, is shown below:

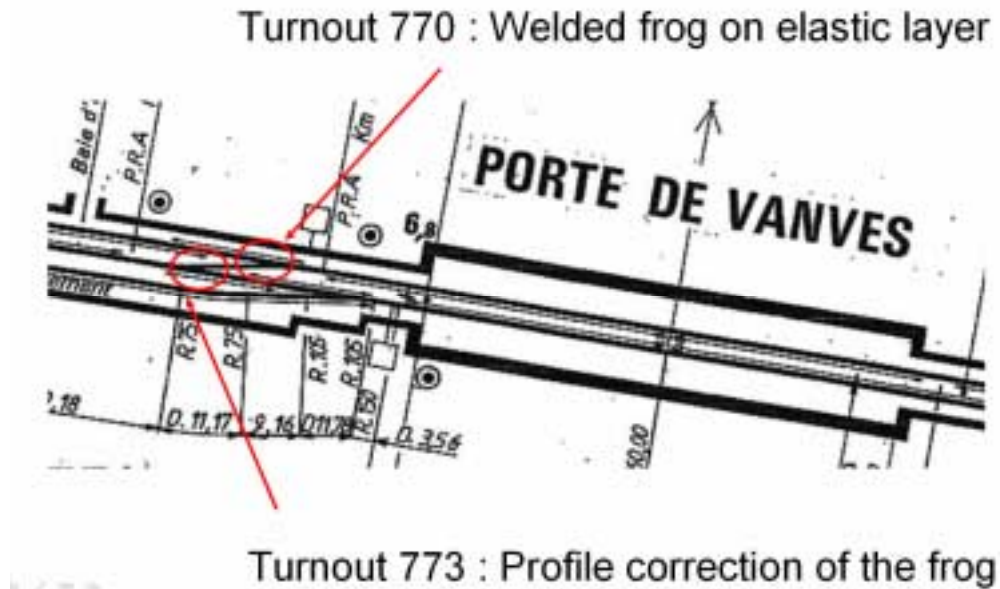


Figure 3.5.10

A picture of the installation is given below:



Figure 3.5.11

3.5.2.7. Installation of a turnout with recharged crossing (porte de Vanves, Paris)

The test site is the same as for the previous turnout (see §3.5.2.6). Reprofiting of the frog is carried out by recharging of the point and the wing rail, as shown below:



Figure 3.5.12

After that, the geometry is controlled as shown below:



Figure 3.5.13

3.5.2.8. Installation of an industrial turnout with casted manganese steel crossing (BASF plant, Antwerp)

A map of the installation site is shown below:

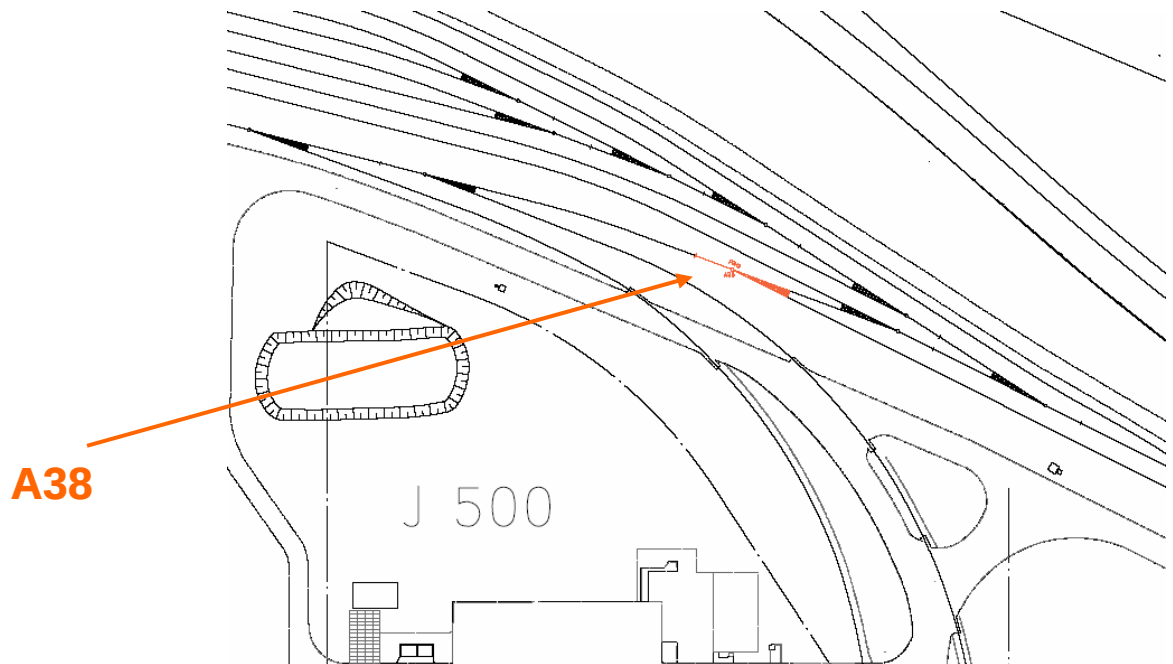


Figure 3.5.14

The installed turnout is shown below:



Figure 3.5.15



3.5.3 Validation measurements

The impact forces and static and dynamic behaviour of the new turnout systems have been measured during vehicle passages. The gain in vibration reduction and noise emission and in reduction of impact forces in comparison with a conventional turnout installed in the same network under the same operating conditions and in identical field conditions has been evaluated. These results are summarised below.

3.5.3.1. State of the art turnout, avenue de Tervuren, Brussels

Noise and vibration levels were measured during pass-by of a test vehicle at 10, 15 and 22 km/h on a new (state of the art) turnout (with under sleeper pads and ballast mat) and on adjacent normal tangent ballasted track. In both measurement sections, vibration and noise levels were measured at 3.6 m from the external rail, leading to the conclusion that, for pass-by noise and vibration levels, a turnout installed with under sleeper pads and ballast mat generates an increase of these levels with 10 to 12 dB in comparison with a straight ballasted track.

3.5.3.2. RATP test site

Measurements were performed on the turnouts of line L13 Porte de Vanves on 2 dates: 8 July '04 and 21 December '06. In between this period the two turnouts are changed (recharged) or replaced.

In July '04 only one turnout was instrumented (turnout 770) and measured (reference case). In December '06 two frogs were instrumented and measured after modification. This brings the number of studied frogs on three, named:

- ✧ FROG (turnout 770, track V2) July '04 (reference)
- ✧ FROG (turnout 770, track V2) renewed in June '06: new frog developed by BFM and railpads with $k = 50 \text{ kN/mm}$, measured in December '06
- ✧ FROG2 (turnout 773, track V1) : geometry correction by recharging in October '06, measured in December '06.

Comparisons have been made, for the frogs described above, between vibration levels when passed by a MF77 vehicle at different controlled speeds: 20, 45 and 55 km/h. A detailed analysis of the measured vibration signals is done in acceleration in the maximum frequency range (0 - 2500 Hz). A second complementary analysis is done in vibration velocity in (0- 200 Hz) band, which is a more dominant zone for transmission to the surroundings. Track impedances were also measured in the different cases.

The different systems are compared in terms of:

Time domain peak accelerations (up to 2500 Hz):

During pass-by of the MF77 vehicles, shocks are induced onto the frog. The peak acceleration of the frog in the time domain are compared, as shown below:

- ✦ Comparison of the frog of turnout 770 on track V2 before and after modification (BFM frog with railpads of 50 kN/mm):

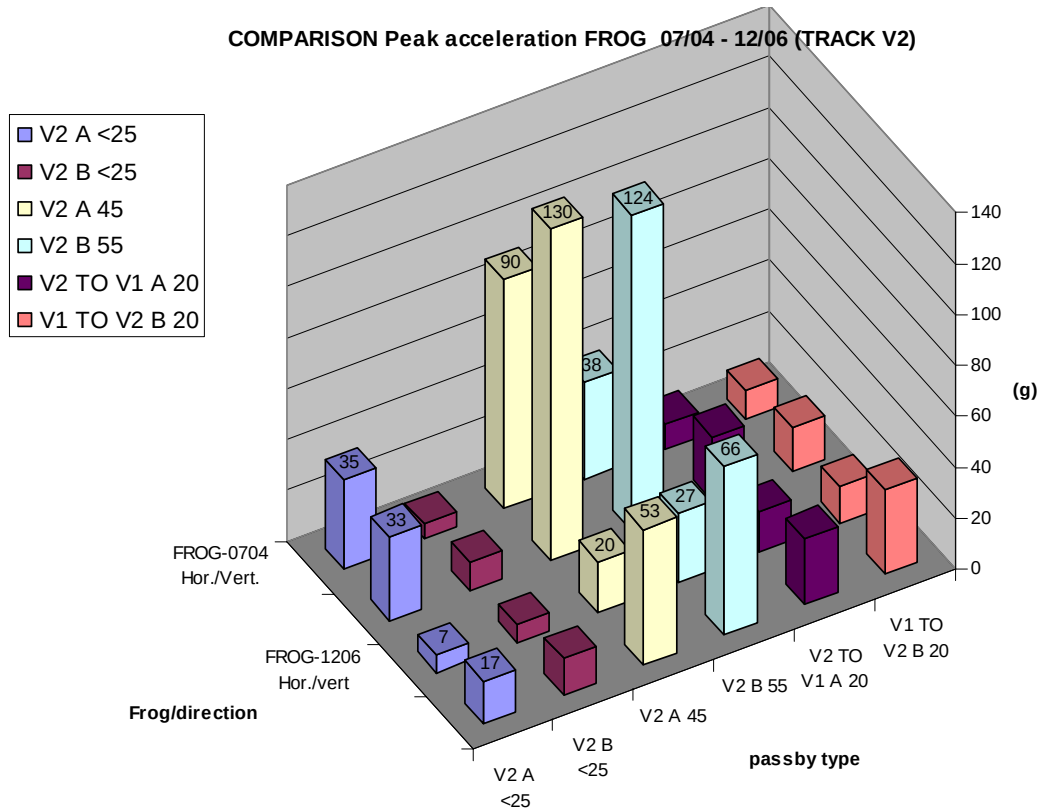


Figure 3.5.16

In the legend of this figure are given the track (V1 or V2), running direction(A or B) and speed (in km/h). These results show that:

- for runs in the A direction (normal traffic), the peak acceleration goes down with a factor 2 to 3.5 after modification; this difference is maximal in horizontal direction at high speeds;
- in the B direction (reversed traffic), the difference is only a factor 2 or less;
- changing of track leads to very similar vibration levels in the two cases.

- ✧ Comparison of passage over frog on track V1 (recharged) and over frog on track V2 (BFM frog) at 20 km/h (December 2006):

The results are summarised below:

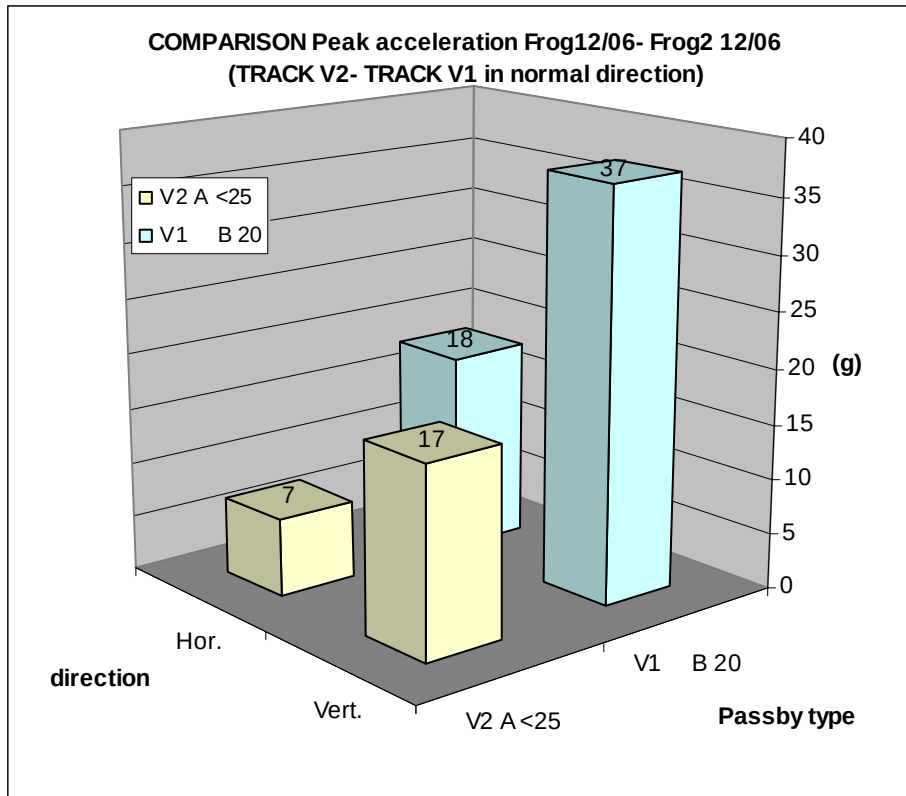


Figure 3.5.17

It is clear that the peak levels are a factor 2 lower when passing over the BFM frog (turnout 770) than when passing over the recharged frog on track V1 (turnout 773); here also, the gain in horizontal direction is slightly better.

The same analysis was done on the 1/3 octave maximum spectrum global value. This leads to very similar conclusions.

Time domain peak vibration velocity (up to 200 Hz):

The same analyses were carried out but now after integrating acceleration to velocity and limiting the frequency zone till 200 Hz, leading to the following results:

- Comparison of the FROG of turnout 770 on track V2 before and after the modification (BFM frog with railpads of 50 kN/mm)

Different cases for the “FROG” on track V2 before (07/'04) and after (12/'06) modification are compared below:

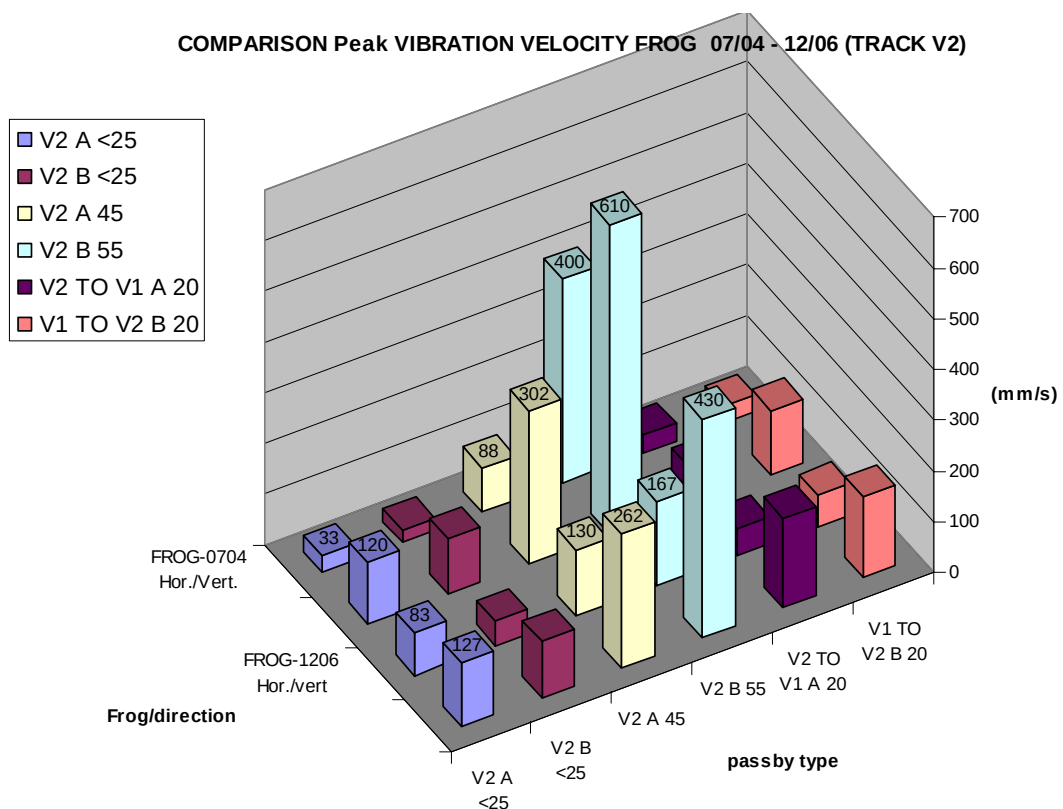


Figure 3.5.18

These results show that:

- there is no significant difference in vibration levels on the frog before and after modification;
- only in the B direction (reversed traffic) at high speed there is a small difference in vibration level on the frog;
- changing of track leads to very similar vibration levels in both cases.

- ✧ Comparison of passage over frog on track V1(recharged) and over frog on track V2 (BFM frog) at 20 km/h (December 2006):

The results are summarised below:

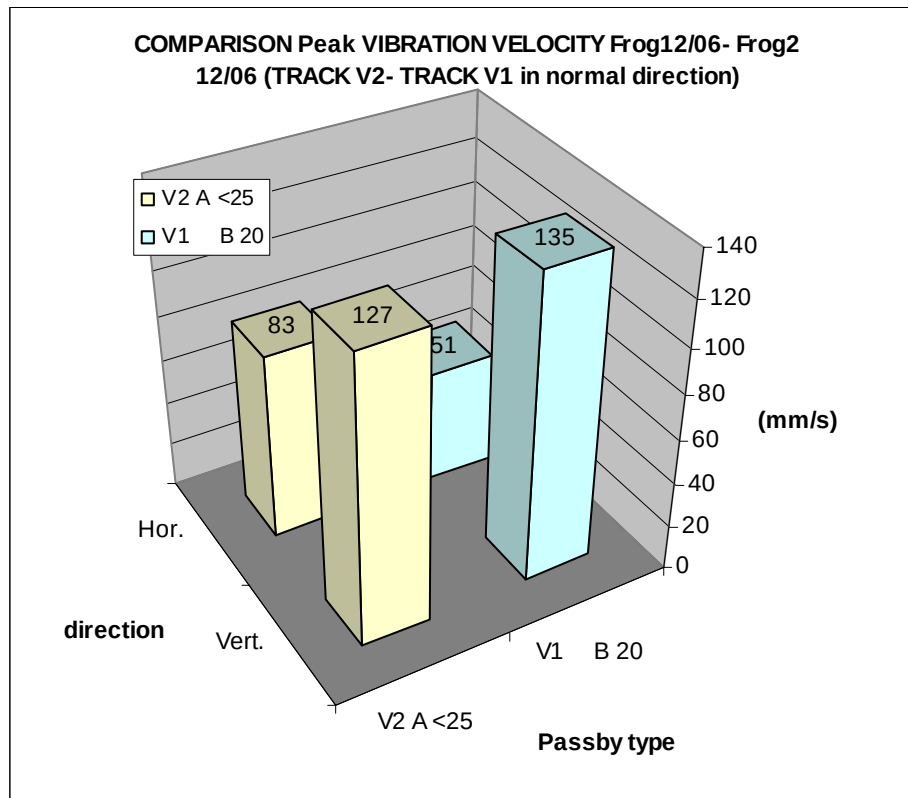


Figure 3.5.19

It can be seen that the peak levels in vertical direction are slightly lower when passing over the BFM frog (turnout 770) than when passing over the recharged frog on track V1 (turnout 773); in horizontal direction the opposite is true. No significant differences are found between both solutions.

Impedances

When comparing the measured impedances in vertical direction on the frog of turnout 770, no difference in first resonance frequency was found before and after modification. In July'04, a first resonance was found around 80 Hz. In December '06, this frequency was not significantly changed despite the introduction of 50 kN/mm pads (ballast elasticity seems to be dominant).

3.5.3.3. Embedded FDP turnout with discrete rail fixations, St-Bernardsesteenweg, Hoboken (Belgium)

Vibration levels were measured at 2.5 and 7 m from the outer rail, and noise level was measured at 7.5 m from track centre line. These measurements were carried out both in front of the turnout and, a few meters from there, in front of a tangent embedded track. Recordings were not only made for pass-byes on track V1 (with a passage over the frog and on a tangent section) but also for pass-byes on track V2 (with a passage over a crossing and on a tangent section). The speed of the trams during all tests was approximately 25 to 30 km/h and constant. During the passage over the frog, the tram keeps on running on the wheel thread. The measurement points are highlighted below:

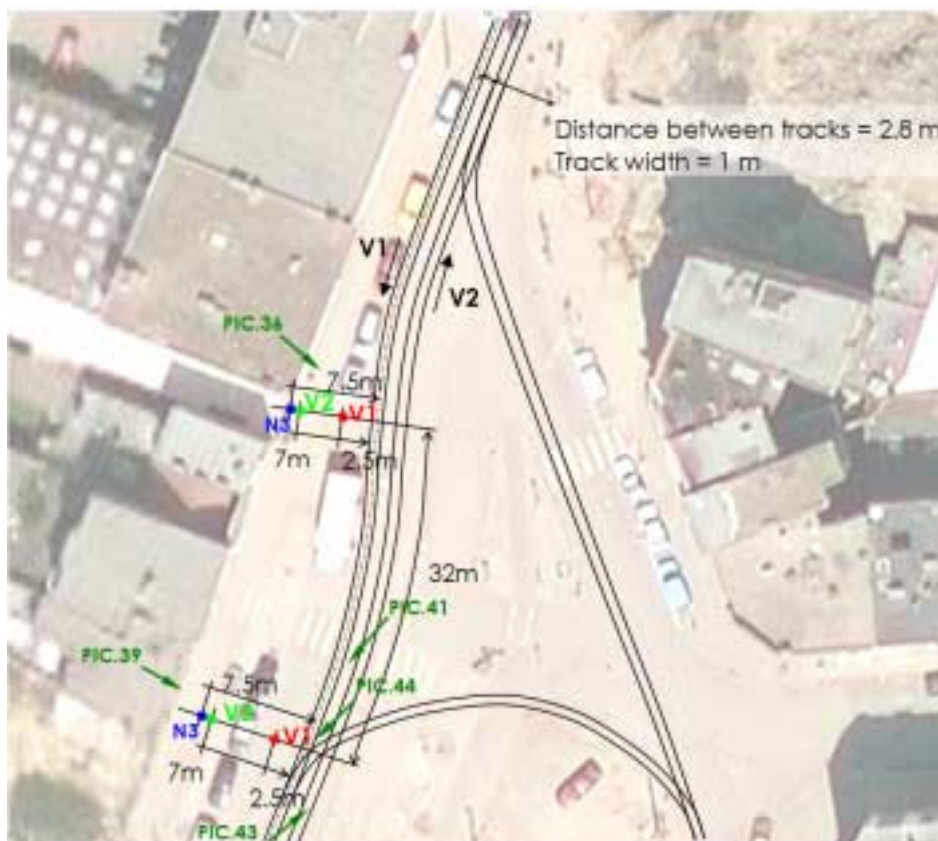


Figure 3.5.20

Comparison of the two sections in terms of noise and vibrations shows that, for the vibrations, the levels are on average the same when passing over the turnout frog (direct passage) as when passing on the tangent embedded track. For the noise, the maximum noise level at 7.5 m does not increase when passing over the turnout frog.

When comparing the pass-by on the tangent embedded track with the pass-by over the crossing, we notice an increase in vibration level of 6 to 7 dB. The maximum noise level increases with 4 dB(A) on average. This result is still good since the passage over a crossing is much more aggressive than a passage over a frog (in the crossing, the wheel runs on its flange).

3.5.3.4. Jez turnout with movable point frog, Linkeroever, Antwerp

The aim of the measurements on the frog in 'Linkeroever Blancefloerlaan' is the comparison of noise and vibration levels in the surroundings before and after installation of the new turnout with movable point frog. The considered turnout is equipped with an automated moving nose.

The situation of the test site is given below with indication of measurement points in the surroundings. Vibrations were measured in three points: V1 (vibrations at 5 m from outer rail), V2 (vibrations at 10 m from outer rail) and V3 (vibrations at 15 m from outer rail). Air borne noise was measured at 7.5 m from track centre line (point N4).

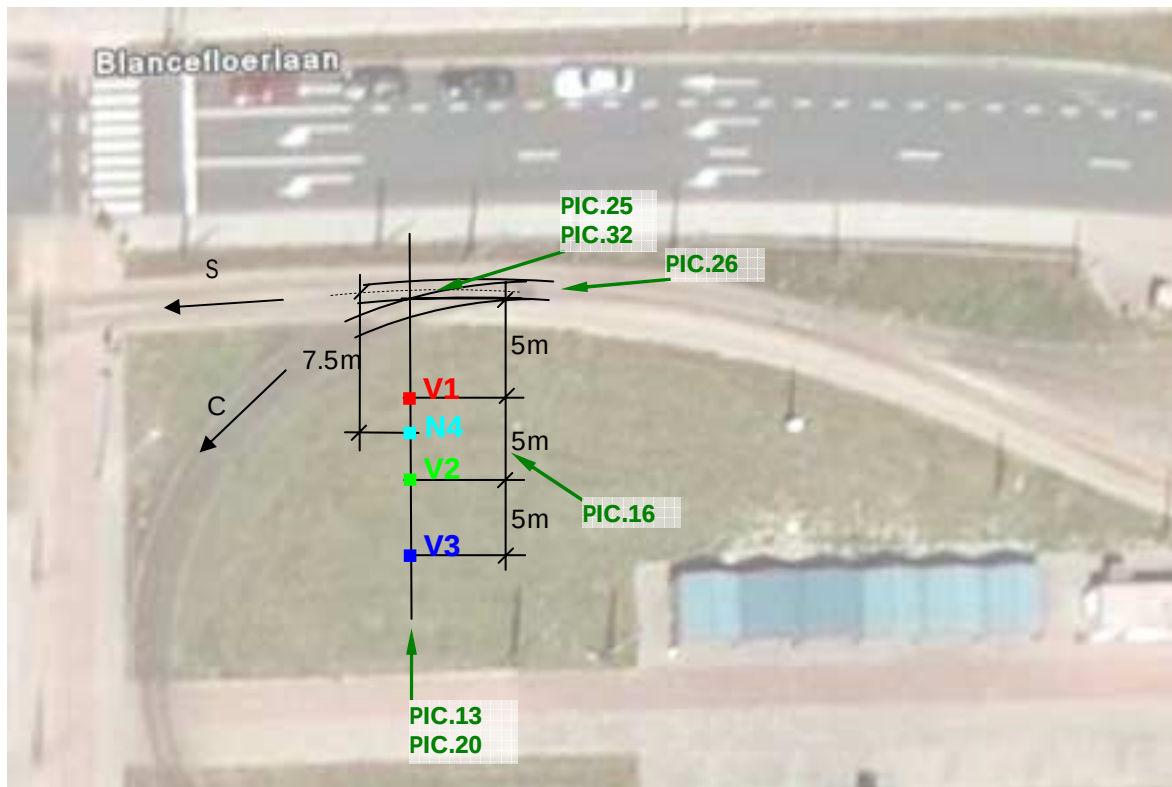


Figure 3.5.21

Two types of vehicles were registered, the 7200 or the Hermelijn tram, and the types 7000 and 7100, which are the older PCC trams. The speed of the trams during pass-by is very low (<10 km/h).

Comparison of the two measurement campaigns (before and after installation) in terms of vibrations, during frog passing, shows that, before installing the movable point frog, there is an attenuation of the vibration levels in function of distance with about 3 dB/5 m distance. This means that we have a single impact excitation (passage over frog). After installing the movable point frog, the vibration levels at 15 m are slightly higher than at 10 m. We do not have a single impact excitation any more but an excitation coming from the different wheels contributing to the overall vibration level. The contribution of the passage over the frog is not measurable any more in the vibration levels! This conclusion is valid for direct passage and for diverted passage.

The difference in vibration level in a point close to the track (5 m) is 5 dB when we compare the new turnout (movable point frog) with the original one.

In terms of noise, there is a reduction of about 6 dB(A) in L_{Amax} with the movable point frog. The measured max. noise levels (72.2 dB(A)) are coming from the normal rolling of the wheel over the rail (no significant impact noise from frog crossing).

3.5.3.5. Under sleeper pads + ballast mat (D2S solution), rue G.J. Martin, Brussels

A map of the turnout is given below with indication of measurement points at nearby buildings. Vibration levels were measured in two sections S2 and S3 at three locations: P2 (step), P3 (in front of building) and P4 (on foundation of building).

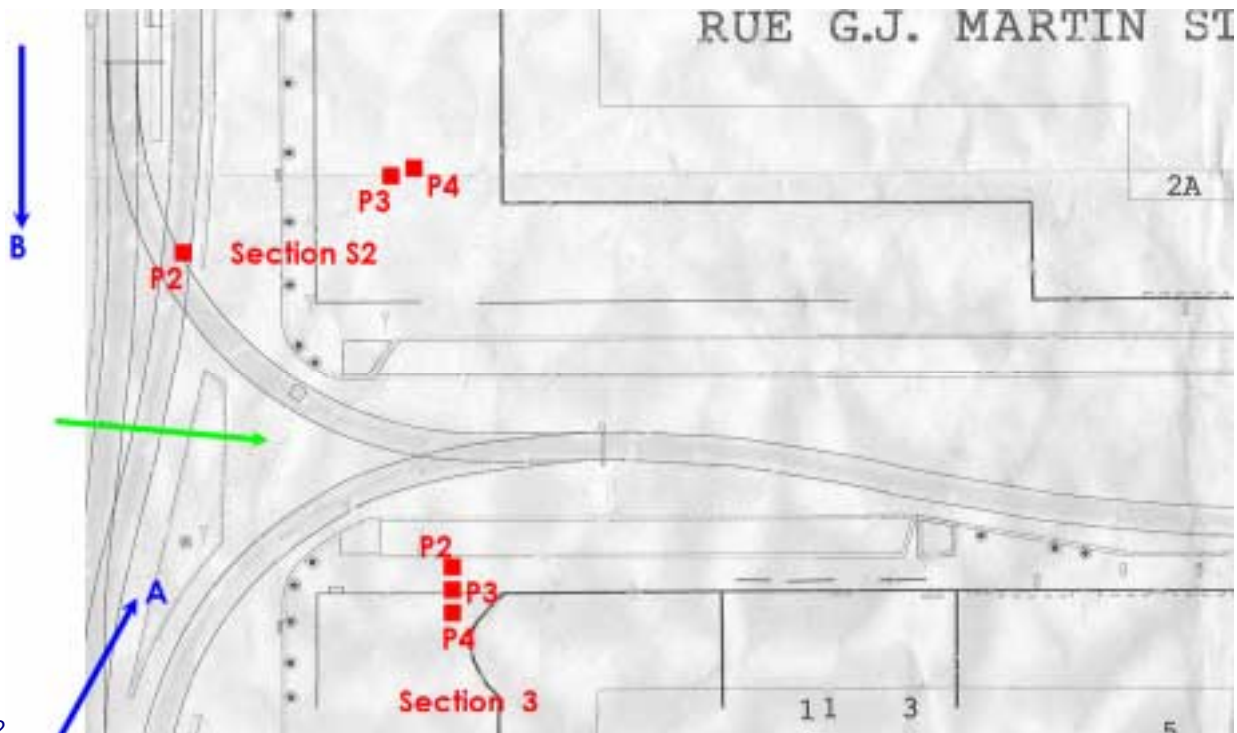


Figure 3.5.22

Measurements were carried out on the 11/11/04 (before installation, with existing turnout) and on the 13/02/06 (after installation of the new turnout), for different types of vehicles. The gain is calculated as the reduction of vibration level due to installation of the new turnout type.

Measurement results, together with calculated gains, are summarised below:



S2	Type	Direction	Leq			MAX		
			P2	P3	P4	P2	P3	P4
			dB(V) [re.1e-09 m/s]	dB(V) [re.1e-09 m/s]	dB(V) [re.1e-09 m/s]	dB(V) [re.1e-09 m/s]	dB(V) [re.1e-09 m/s]	dB(V) [re.1e-09 m/s]
11-Aug-04		A	102	95.4	95.1	110	104	104
		A	101	94.1	94.9	110	103	104
		A	99.6	89.5	92.9	108	98.2	103
	AVERAGE		100.9	93.0	94.3	109.3	101.7	103.7
13-Feb-06	7171	A	92.9	83.2	84	99	88.1	88.8
	7078	A	99.7	88.4	89.5	108	94.9	96
	7167	A	97.8	85.5	86.7	106	91.5	93.3
	7168	A	96	84.2	85	102	90.8	92.2
	7169	A	97.2	85.4	86.6	103	92.1	94.4
	7162	A	102	88.2	87.1	109	94.7	92.2
	AVERAGE		97.6	85.8	86.5	104.5	92.0	92.8
GAIN			3.3	7.2	7.8	4.8	9.7	10.9

Table 3.5.1 Results section S2

S3	Type	Direction	Leq			MAX		
			P2	P3	P4	P2	P3	P4
			dB(V) [re.1e-09 m/s]	dB(V) [re.1e-09 m/s]	dB(V) [re.1e-09 m/s]	dB(V) [re.1e-09 m/s]	dB(V) [re.1e-09 m/s]	dB(V) [re.1e-09 m/s]
11-Aug-04 13-Feb-06		A	108	102	99.2	113	107	104
		A	112	106	103	119	112	110
		A	109	104	100	115	111	107
	AVERAGE		109.7	104.0	100.7	115.7	110.0	107.0
	7038	A	105	99.1	92.4	111	105	99.1
	7006	A	106	101	92.7	112	109	99.4
	7170	A	105	100	91.3	111	106	97.3
	7020	A	105	101	92.4	112	107	98.4
	7035	A	103	99	90.7	113	109	100
	7171	A	103	98.6	90.9	111	106	101
	AVERAGE		104.5	99.8	91.7	111.7	107.0	99.2
GAIN		5.2	4.2	9.0	4.0	3.0	7.8	

Table 3.5.2 Results section S3

Reductions of the vibration levels up to 10 dB are found on the foundation of nearby buildings.

3.5.3.6. Embedded low profile turnout-wheel flange bearing turnout (COGI/D2S solution), place Arthur Van Gehuchten, Brussels

The new turnout is shown below with indication of measurement points at the nearby buildings.



Figure 3.5.23

Directions A, B, C and D show in which direction the vehicle was running during the tests. Noise and vibration levels were measured in one section (tram on turnout) at three locations: V1 (vibrations at 1 m from outer rail), V2 (vibrations at 5.5 m from outer rail) and N3 (noise at 7.5 m from track centre line). The vibrations were also measured on frog in horizontal and vertical directions. These tests were carried out on December 14, 2006, with PCC vehicles (type 7XXX).

The measurements in the surroundings are summarised below. The results are expressed in global values (0 – 2 kHz) for the different directions (A, B, C and D).



Measurements in surroundings: Vibrations

Speed	Direction	V ₁ (1 m)			V ₂ (5,5 m)		
		L _{veq} dB(V) [re.1e-09 m/s]	T _p sec	L _{max} dB(V) [re.1e-09 m/s]	L _{veq} dB(V) [re.1e-09 m/s]	T _p sec [re.1e-09 m/s]	L _{max} dB(V) [re.1e-09 m/s]
18km/h	A	118.9	4.6	123.2	99.32	7.5	103.9
20km/h	B	119.4	4.3	124	97.73	6.5	101.9
20km/h	A	114.6	4.8	118.8	95.32	6.8	99.7
19km/h	B	114.9	4.5	119.7	95.62	7.4	99.62
27km/h	A	116.5	3.6	120.2	96.3	6.8	101.2
26km/h	B	118.3	3.6	123	97.45	5.6	102
28km/h	A	119.6	3.4	124.1	99.39	4.3	104.4
27km/h	B	118	3.5	121.5	96.88	5.8	101.3
10km/h	C	107.8	8.1	113.5	94	11.0	99.54
10km/h	D	106.9	7.5	111.7	93.6	10.6	97.64

Table 3.5.3

Measurements in surroundings: Noise

Speed	Direction	N ₃ (7.5 m from track centerline)				
		L _{pAeq} dB(A) [re.2e-05 Pa]	T _p sec	L _{max} dB(A) [re.2e-05 Pa]	SEL dB(A) [re.2e-05 Pa]	TEL dB(A) [re.2e-05 Pa]
18km/h	A	79.13	8.6	83.59	88.55	82.34
20km/h	B	82.27	5.8	87.02	89.96	83.75
20km/h	A	78.27	8.4	83.47	87.56	81.35
19km/h	B	78.24	8.8	82.7	87.72	81.51
27km/h	A	81.73	6.5	87.28	89.95	83.73
26km/h	B	82.32	5.9	87.46	90.11	83.89
28km/h	A	84.48	5.3	89.85	91.78	85.57
27km/h	B	81.46	7.9	86.85	90.49	84.28
10km/h	C	71.96	13.4	77.09	83.26	77.05
10km/h	D	71.37	11.6	77.13	82.07	75.86

Table 3.5.4

The results of the measurements on the frog in horizontal and vertical directions are summarised below. The results are expressed in global values for the different directions (A, B, C and D).



Measurements on the frog: horizontal and vertical vibrations

Speed	Direction	Vibrations (0 – 2 kHz)			
		Leq		Max	
		H dB(V) [re.1e-09 m/s ²]	V dB(V) [re.1e-09 m/s ²]	H dB(V) [re.1e-09 m/s ²]	V dB(V) [re.1e-09 m/s ²]
18km/h	A	192	207	198	214
20km/h	B	193	210	199	216
20km/h	A	189	207	194	212
19km/h	B	190	207	195	212
27km/h	A	191	210	197	216
26km/h	B	192	211	200	217
28km/h	A	194	213	200	218
27km/h	B	192	211	198	218
10km/h	C	191	201	199	209
10km/h	D	192	199	202	205

Table 3.5.5

Pass-by in normal direction and reversed direction generate very similar noise and vibration levels (which increase in function of speed) in the environment.

The maximum noise levels are some 9 dB(A) higher (for similar speeds) when passing over this flange bearing embedded frog than when passing over the wheel tread bearing embedded frog at rue Baeck (see §3.5.3.7).

The vibration levels in the environment (at 5.5 m) are similar for straight passing over this flange bearing embedded frog and when passing over the wheel tread bearing embedded frog at rue Baeck. But soil conditions are different between both sites.

3.5.3.7. Embedded low profile turnout-running on wheel tread (COGI/D2S solution), rue Baeck, Brussels

The special trackwork in this test site consists of two turnouts:

- ✧ one with a low rail profile;
- ✧ one with a normal rail profile.

The new turnouts are schematized below with indication of measurement points at the nearby buildings. The arrows A, B, C and D show in which direction the vehicle was running during the tests. Noise and vibration levels were measured in one section (tram on turnout) at three locations: P1 (vibrations at 1 m from outer rail), P2 (vibrations at 5.5 m from outer rail) and N3 (noise at 7.5 m from track centre line). The vibrations on the frog were also measured in horizontal and vertical directions.

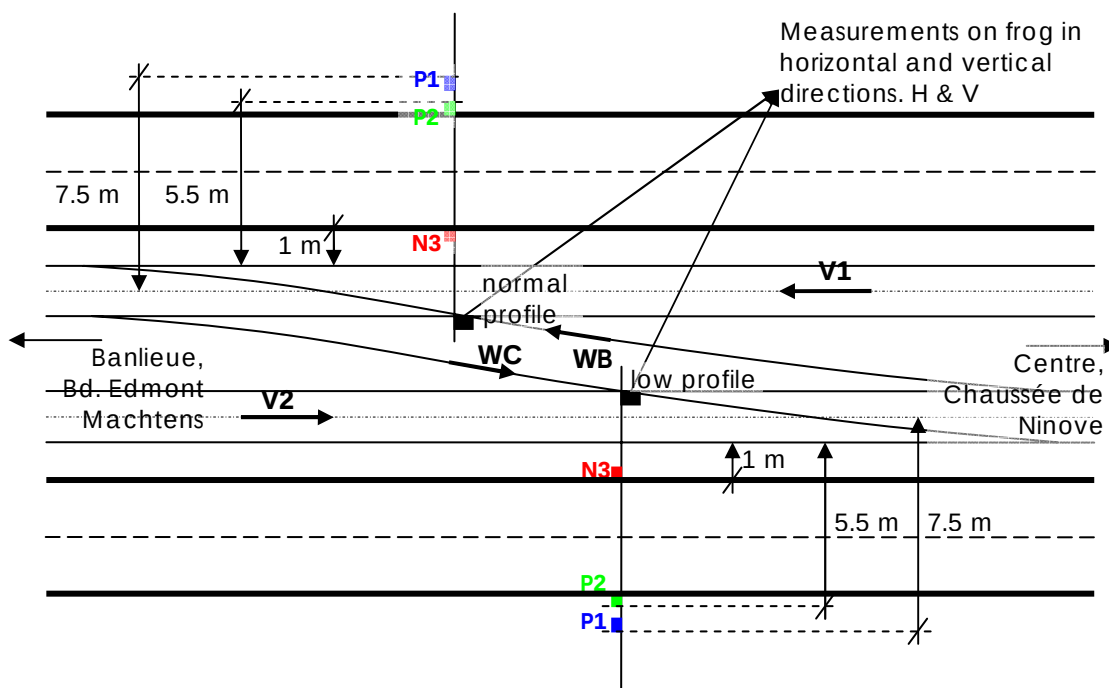


Figure 3.5.24

The results of two measurement campaigns, in the surroundings of the two frogs and on the frog itself, which were performed on the 23rd of February 2006 and the 14th of December 2006, are summarised below. These results are expressed in global pass by values calculated according the ISO 3095 norm: $L_p(A)_{eq,Tp}$, L_{MAX} , as well as TEL and SEL for noise. Tracks (V1, V2, WB and WC), speed and directions (B and C) are also given in the tables.

These codes are explained beneath:

- ✧ V1: Track number 1, pass by on high profile frog;
- ✧ V2: Track number 2, pass by on low profile frog;
- ✧ B: Pass by in direction of 'Banlieue', outskirts of the city;
- ✧ C: Pass by in direction of 'Centre', centre of the city;
- ✧ WB: Change of track in direction of 'Banlieue', outskirts of the city;
- ✧ WC: Change of track in direction of 'Centre', centre of the city.



Measurements in surroundings, vibrations at 5.5 m from the track

Track	Speed	Direction	P ₂ (vibrations) 23-02-06			P ₂ (vibrations) 14-12-06		
			L _{Ve}	T _p	L _{max}	L _{Ve}	T _p	L _{max}
			dB(V)	sec	dB(V)	dB(V)	sec	dB(V)
			[re.1e-09 m/s]	[re.1e-09 m/s]	[re.1e-09 m/s]	[re.1e-09 m/s]	[re.1e-09 m/s]	[re.1e-09 m/s]
V1	20km/h	B	98.5	4.3	103.8	97.6	5.5	102.4
V1	20km/h	C	96.3	6.9	102.2	97.0	7.3	103.0
V1	30km/h	B	100.6	3.8	106.2	102.0	3.8	106.9
V1	30km/h	C	99.0	5.0	103.4	100.8	4.6	105.5
WB	10km/h	B				95.6	14.3	100.5
WC	10km/h	C	94.2	13.9	99.3	94.6	15.1	100.6
WB	10km/h	B				95.9	13.1	101.8
V2	20km/h	C	99.7	5.0	105.5	99.5	6.3	104.1
V2	20km/h	B	98.3	6.1	102.5	100.5	5.4	106.0
V2	30km/h	C	103.0	3.8	109.5	102.1	4.4	107.3
V2	30km/h	B	102.7	4.1	108.2	104.6	3.8	110.8
V2	30km/h		102.2	4.3	107.6	102.2	4.5	106.6
WB	10km/h	B				102.3	12.3	109.1
WC	10km/h	C				101.0	14.1	106.1
WB	10km/h	B				103.2	11.1	109.8

Table 3.5.6

Measurements in surroundings, noise at 7.5 m from the track centre line

Voie	Vitesse	Direction	N ₃ (noise) 23-02-06					N ₃ (noise) 14-12-06				
			L _{pAeq}	T _p	L _{max}	SEL	TEL	L _{pAeq}	T _p	L _{max}	SEL	TEL
			dB(A)	sec	dB(A)	dB(A)	dB(A)	dB(A)	sec	dB(A)	dB(A)	dB(A)
			[re.2e-05 Pa]		[re.2e-05 Pa]	[re.2e-05 Pa]	[re.2e-05 Pa]	[re.2e-05 Pa]		[re.2e-05 Pa]	[re.2e-05 Pa]	[re.2e-05 Pa]
V1	20km/h	B	73.0	9.0	77.5	82.6	76.9	71.7	7.4	76.0	80.5	74.7
V1	20km/h	C	74.6	8.8	79.1	84.1	78.3	70.5	8.5	74.5	79.9	74.1
V1	30km/h	B	77.5	5.9	82.2	85.3	81.4	77.0	5.0	80.6	84.0	78.3
V1	30km/h	C	78.3	5.9	82.7	86.0	82.3	75.8	5.6	79.4	83.4	77.7
WB	10km/h	B						68.6	12.6	74.4	79.6	73.9
WC	10km/h	C	70.1	13.5	75.4	81.4	72.7	68.0	13.5	73.7	79.3	73.6
WB	10km/h	B						68.2	12.9	72.7	79.4	73.6
V2	20km/h	C	73.8	8.0	78.5	82.9	77.5	70.3	11.6	75.5	81.0	75.3
V2	20km/h	B	74.4	7.8	78.6	83.4	77.6	72.1	8.3	76.6	81.3	75.6
V2	30km/h	C	77.8	6.0	82.7	85.7	81.8	76.2	6.0	80.3	84.1	78.4
V2	30km/h	B	77.9	5.8	82.6	85.6	81.8	77.5	5.0	81.9	84.6	78.8
V2	30km/h		77.3	6.1	82.1	85.2	81.4	75.7	6.3	80.6	83.7	77.9
WB	10km/h	B						69.7	11.9	78.0	80.5	74.8
WC	10km/h	C						70.4	12.4	78.2	81.3	75.6
WB	10km/h	B						71.4	10.3	79.2	81.6	75.8

Table 3.5.7



Measurements on frog, vibrations in horizontal and vertical directions

Voie	Vitesse	Direction	Vibrations 23-02-06				Vibrations 14-12-06			
			Leq		Max		Leq		Max	
			H	V	H	V	H	V	H	V
			dB(V)	dB(V)	dB(V)	dB(V)	dB(V)	dB(V)	dB(V)	dB(V)
			[re.1e-09 m/s ²]	[re.1e-09 m/s ²]	[re.1e-09 m/s ²]	[re.1e-09 m/s ²]	[re.1e-09 m/s ²]	[re.1e-09 m/s ²]	[re.1e-09 m/s ²]	[re.1e-09 m/s ²]
V1	20km/h	B	189	200	196	207	188	203	193	209
V1	20km/h	C	191	200	200	206	189	201	196	207
V1	30km/h	B	192	203	197	208	193	208	198	213
V1	30km/h	C	194	202	202	208	195	208	203	214
WC	10km/h	C	189	201	197	210	185	198	195	208
WB	10km/h	B	187	195	195	203	185	195	194	202
WC	10km/h	C					185	198	193	206
V2	20km/h	C	189	196	195	202	189	197	194	202
V2	20km/h	B	189	196	195	203	191	199	195	204
V2	30km/h	C	192	200	197	205	194	202	198	205
V2	30km/h	B	193	201	200	206	194	203	198	208
WC	10km/h	C	187	193	192	199	184	191	190	197
WB	10km/h	B	186	193	194	201	184	191	191	198
WC	10km/h	C					186	193	193	199

Table 3.5.8

There is no significant difference between the vibration and noise levels measured on December 14, 2006 and the measurements carried out on February 23, 2006 (same turnouts). The conclusions of both measurement campaigns are:

For straight passage over the frog

- ✧ Surroundings:
 - for the soil vibrations, the levels are about 6 dB higher when passing over the turnout frog;
 - for the maximum airborne noise at 7.5 m, the noise increase is only about 3 dB(A) when passing over the turnout frog (in comparison with passage on tangent track).
- ✧ Frog:
 - no difference was found in vibration level between the two frogs (normal and reduced rail profile)
 - vertical vibration levels are 10 dB higher than horizontal levels.

For diverted passage over the frogs (at 10 km/h)

- ✧ The vibration levels generated in the environment (at 5 m from the frog) when passing over the frog with low rail profile are in average 6 dB higher than when passing over the frog with normal rail profile.
- ✧ For the airborne noise level, there is no significant difference in levels (normal frog ⇔ frog with low rail profile).

3.6 WP 6: FINAL ASSESSMENT

In most of the methods used for establishing noise maps according to directive EC/2002/49, special trackwork is taken into account with an increase of the TEL value (L_{Amax} value) by 10 dB(A) at trackwork locations.

Within the QCITY project, the noise increase during passage over turnouts has been measured in the network of De Lijn, leading to the following conclusion:

“The increase in noise levels due to turnout passing is difficult to assess. Considering the same vehicle and the same vehicle speed, the noise increase is not constant, even not for the same turnout. This is due to the fact that impact noise is generated, which has a transient character.

The average noise increase, which has been measured on twelve different turnouts (same vehicle, same speed) is 11 dB(A) (L_{Amax} value).

It is confirmed that noise from turnouts can be very disturbing. Mitigation measures have to be taken to avoid increase in noise levels when passing from tangent track to switch and frog areas. “

In this TURNOUTS project, the following findings have been achieved:

- ✧ Innovative numerical models have been developed, leading to calculated vibration levels and impact forces compliant with measured values within a 3 dB tolerance.
- ✧ The following results were obtained with the different tested innovative turnouts:
 - For the existing design BFM turnout with new crossing and elastic railpads (with a stiffness of 50 kN/mm) installed Porte de Vanves (Paris), RATP measured a gain of 6 dB immediately after the installation and of 4 dB after a longer period.
 - RATP could not measure any difference between before and after the longitudinal profile correction treatment of the second test turnout installed Porte de Vanves. The conclusion is that the geometry was not improved because the reprofiling was not correctly executed.
 - For the turnout installed in Rue G.J. Martin with under sleeper pads and ballast mat, the measurements showed a gain of 10 dB, which is in good agreement with the predictions from POLIMI. A similar installation in avenue de Tervuren also showed gains of 10 to 12 dB in comparison with the old installation.
 - A direct comparison could be made rue Baeck (Brussels) between a standard turnout, a low profile (deep groove) turnout and a tangent track. Normal running over the turnouts showed an increase in noise levels of 3 dB(A) compared to running on tangent track. There was no difference between the low profile and the standard profile turnouts. Vibration measurements for normal running over the frog showed a wide spread in increased vibration levels from 3 to 22 dB. Diversions caused an increase in vibration levels of 4 dB for the standard profile turnout and 10 dB for the low profile turnout, i.e. a difference of 6 dB.



- In place Van Gehuchten (Brussels, low profile turnout with flange bearing)), the noise levels were 9 dB higher than in Rue Baeck. The vibration levels however were very similar. This may be due to the softer soil at this location. The flange bearing frog showed no difference in impact between straight running and diversion.
- In Hoboken, where an embedded turnout is installed with discrete rail fixations, measurements were carried out for a PCC car running at 30 km/h. There was no difference in the noise and vibration levels for straight track and running over the turnout. However, when the vehicle crossed the second pair of tracks, increases in noise levels of 4 dB(A) and vibration levels of 6 dB were registered.
- In Linkeroever, Antwerp, where JEZ turnout with movable point frog is installed, measurements were carried out with the Hermelijn tram at a speed of 10 km/h going straight and taking the diversion. Measurements were carried out before and after the installation. Before the installation, the vibration levels decreased by 3 dB with each 5 m of distance. After the installation, the vibration levels were higher at 15 m than at 10 m. This means that the vibration levels do not come from the frog, but from the normal rolling of the vehicle. Therefore it was impossible to measure the influence of the frog at a distance of 10 m for a speed of 10 km/h. It is expected that the reduction in vibrations will be higher at higher speeds.



4 COMPARISON OF INITIALLY PLANNED ACTIVITIES AND WORK ACTUALLY ACCOMPLISHED

A comparison of the initially planned activities and work actually accomplished is given below, based on the major milestones of the project:

- ✧ Validated modelling procedures for existing types of turnouts - models considered as validated if they can predict the wheel/rail forces in the turnout with an accuracy of 3 dB: as described above, POLIMI and NTUA have developed innovative numerical modelling techniques capable to simulate the passage of a vehicle along the turnout, taking into account the variable geometry and stiffness of the turnout. These models have been validated on three different reference turnouts. Comparison with measured data has shown that the targeted accuracy of 3 dB has been reached.
- ✧ Availability of 7 new validated turnout designs, including drawings with geometry and material characteristics: the available 7 designs are:
 1. New BFM frog with railpads with a stiffness of 50 kN/mm
 2. Embedded FDP turnout with discrete rail fixations
 3. JEZ turnout with movable point frog
 4. D2S solution: turnout with under sleeper pads and ballast mat
 5. COGI embedded low profile turnout with wheel flange bearing
 6. COGI embedded low profile turnout, running on wheel tread
 7. Industrial turnout with casted manganese steel crossing
- ✧ Availability of 6 new turnouts (hardware) with quality verification: there were finally 7 new turnouts manufactured and tested, corresponding with the 7 designs listed above.
- ✧ Availability of seven turnouts on site (6 new turnouts and 1 modified turnout) with performance verification: there were finally 7 new turnouts and 1 modified, corresponding with the 7 designs listed above + one longitudinally reprofiled turnout. The performance is considered as valuable, i.e. it shows a reduction of the impact forces with 50 %, for most of them. In cases where the performance is not reached, an explanation could be found, based on numerical modelling or technical installation contingences.

In general, initially planned activities have well been accomplished and the results are fully compliant with the project's objectives.



5 IMPACT OF THE PROJECT ON ITS INDUSTRY OR RESEARCH SECTOR

The project has realised a major technical breakthrough in turnout designs for urban rail. Following validated findings are of utmost importance:

- ✧ low rail can be used in turnout systems without jeopardising the system
- ✧ completely embedded turnout systems (without discrete rail fixations) can be used without jeopardising the system
- ✧ noise and vibration impact during turnout passage can be reduced to minimal (less than 4 dB or 4 dB(A) increase vs. tangent track) when using:
 - embedded turnout systems (COGIFER);
 - hybrid turnout system (FDP);
 - turnouts with movable point frog (JEZ);
 - elastically supported frog (D2S).
- ✧ all validated turnout systems can be integrated in the street pavement (road traffic).

The major European industrial players for turnout systems (COGIFER, JEZ (VA) and BFM) have worked together in this project to come up with these solutions which are immediately applicable and available on the market.



6 PLAN FOR DISSEMINATION AND USE

6.1 EXPLOITABLE KNOWLEDGE AND ITS USE

The TURNOUTS consortium was comprised of representative organisations from industry, universities and operators. Although the product is the same for everyone, the exploitable knowledge may differ greatly depending on the organisation. Besides knowledge gained, several new products and ideas were developed during the duration of the TURNOUTS project.

6.1.1 JEZ – moving nose frog

JEZ Sistemas Ferroviarios has significant experience in the various applications for turnouts such as high speed, freight traffic, local trains and tramways. The use of swing nose crossings is well known in applications such as high speed and freight traffic. These types of crossings are not frequently found in urban transit system and very rarely seen in tramway networks.

During this project, JEZ has acquired the knowledge of how to adapt the design of such a product to the application for a tramway use. The main modification to the swing nose crossing is the adaptation of the rolling surfaces to the wheel profile(s) in use. Doing so required the study of the wheel profiles at De Lijn. Another important point learned during this project is the positive effectiveness of the use of swing nose crossings for tramway use in reducing impact and structural vibration. In addition, the turnout had to be adapted for the smaller radii at the diverging line as typically used in tramways and also to the use of girder rail.

The very positive results obtained during this project encourage JEZ Sistemas Ferroviarios to offer turnouts with swing nose crossing for tramway applications in those projects where low noise and vibrations are the main factors in the selection of the turnout. As the public becomes more and more sensitive to noise and structural vibrations caused by rail operations, urban transit systems will demand new systems that are environmentally friendly. This fact combined with its knowledge puts JEZ in an excellent position to exploit new markets that will increase the company's turnover. JEZ foresees an increase in the demand of turnouts with swing nose crossing. The knowledge acquired by JEZ in this project enables the company to offer a product that guarantees low noise and low maintenance.

To facilitate work in the design department, JEZ introduced the 3D CAD Unigraphics system to develop the prototype in virtual reality and avoid the lengthy process of prototyping and design changes. This technique, which was very successfully implemented in this project, will be applied to other projects in the various railway fields to shorten the design lead time.

As the swing nose crossing has two movable sections, know-how in motoring and integration of a swing nose crossing for tramway applications had to be acquired. This required close cooperation with the supplier of the tramway switch motors.



The following schedule is planned for commercial use:

- ✧ validation of the turnout at De Lijn end of 2006;
- ✧ commercialisation has started.

Patenting this new swing nose crossing is planned before July 2007.

The following economic benefits are expected:

- ✧ for this unique premium product, an increase in sales 20 % in the tramway market and in market share for tramway turnouts 15 %;
- ✧ stability in labour force: 5 more workers at JEZ foundry and machining workshop in total.

6.1.2 De Lijn – Moving nose frog and FDP foundation damping

First of all, as a transport authority De Lijn learned that systematic improvements to turnouts are possible and that the necessary modifications can be introduced at different levels:

- ✧ new design and geometry of the turnouts
- ✧ turnout constructed out of new materials
- ✧ use of new or modified control unit
- ✧ use of anti-vibratory damping system
- ✧ improved welding techniques.

Secondly, De Lijn has benefited from the international and multidisciplinary cooperation, due to the deliberate composition of the project team (research, industry, operators supported by technical experts). This has led to rapid and practical solutions.

In general, this type of project facilitates the transmission of knowledge gained in other disciplines to be exploited at a different level. For example, the benefits of the moving nose frog are well known on high speed track and heavy haul. Their advantages in terms of noise and vibrations can now be exploited on tramway tracks in the more sensitive urban environment. Admittedly at a higher initial cost, part of which is expected to be recovered through greater longevity.

De Lijn has decided to use the FDP foundation damping design as a standard and based on the initial positive experience with the moving nose frog expects them to be more frequently used in its network in those locations where they are beneficial.

De Lijn collaborated with the industrial partners JEZ en FDP in the development of 2 turnout prototypes:

- ✧ The first is a turnout with existing design, installed on a concrete slab with anti-vibratory damping system. This turnout which is installed in an embedded track is damped by using a poured polymer product. This technique is derived from that used for damping embedded track systems. The turnout was prefabricated and assembled in the factory to facilitate the installation and shorten the installation time.



- ✧ The second one uses a solution adapted from high speed applications. This so called swing nose crossing has on top of the 2 tongues also a movable nose. As a result we avoid the wheel of the vehicle falling into the crossing gap. This gap is now filled with the movable nose.

The additional second switch device which is necessary to control the movable nose mandated the manufacturing of a new control unit. The controlling, signalling, as well as the safety issues are very particular for this type of turnout. The turnout was also prefabricated to shorten the installation time.

The Lijn has planned the use of the FDP foundation damping concept for all its future rehabilitation projects. The moving nose frog needs to be further evaluated to see if the noise and vibration benefits remain in the long run and also to see if the maintenance costs and durability can compensate for the higher initial cost.

6.1.3 BFM – Welding process for manganese frogs

BFM has developed a new technique of welding the rail crops to the manganese crossings ; to do so, BFM reorganised itself to implement a more accurate method of collecting welding data , analyse the data and take an immediate action in order to guarantee a better quality of the welding which guarantees a better product for the final customer. The improved welding technique also reduces the impact forces of vehicle/rail interactions, which combined with better weld quality and manganese steel guarantees the increased longevity of the turnout. The reengineering of the welding process results in a more reliable process, a reduction in lead time, a better quality of its special products and increased customer satisfaction. BFM took advantage of this R&D research project to become more competitive and efficient.

The new welding process reduces the intermediate material to 3 – 5 mm: the effect is a reduction of the impact contact forces between wheel and rail. This is achieved by reducing hardness gradients between the rail, the intermediate material and the manganese crossing and the resulting hollow wear.

The result is a reduction of the noise levels when the vehicle passes over the turnout. The optimization of the welds leads to other benefits such as better fatigue resistance, reduced local deformation under load due to the use of improved material. The new welding technique will be covered by a new patent which will be presented to IPO in 2007.

Timetable for commercial uses

The new welding procedure must be thoroughly evaluated before it can be applied on a large scale in the production process. The first step consists of gaining feedback from the partners in the project and a final internal validation. BFM will propose the new solution to selected European Railways to obtain the necessary qualifications. After this approval process, the new solution can be proposed to other customers.



The economic benefit of the welding process is an estimated saving of about 20% in welding material plus a saving of about 30% from the reduction of working hours. The improvement in quality has led to a reduction in re-machining which was assessed at about 10% of total quality costs. To these costs savings must be added the possibility to increase the production output or use the saved working hours on other steps in the production or process improvements. The new technology eliminates a bottle neck in the production process and allows BFM to use its labour force more efficiently. The improved production process has reduced the lead time, which enables BFM to be more competitive in the market and to approach the light railways segment which normally does not use manganese crossings. As the advantages of the new technology can be applied to any profile, new markets can be opened. Additional market segments offer more labour stability. The investment in new projects and new products improves the company's image which is very important for its future.

6.1.4 D2S

D2S implemented its damping system with under sleeper pads with or without ballast mat. The system which was tested during a renewal project at STIB proved to be very effective against ground borne noise and vibrations. STIB has decided to use this system more extensively on renewal projects for track on ballast where its turnouts are causing annoyance.

By performing measurements on the various new turnouts, D2S has gained a first hand insight in the benefits of the various systems. As a noise and vibrations consultant, this is very important as it enables the company to assist its customers with the selection of the most up to date turnout systems.

D2S has patented the special design of the under sleeper pads.

The results of the various products developed within the TURNOUTS project will also be integrated into the QCITY project, thus guaranteeing a broad dissemination. In addition, they will also be used in the URBAN TRACK project.

6.1.5 FDP

FDP developed the system of foundation damping which was implemented at De Lijn (see above) and will become their standard construction method for turnouts in large track rehabilitation projects.

FDP also developed a new low cost industrial turnout to respond to the demand from large private operators for more reliable turnouts with lower maintenance costs. In the past, these operators often selected refurbished used turnouts for their switching yards. The new design was developed in cooperation with a large private operator who also installed the prototype in an area of heavy use. It is expected that, if that turnout meets the expectations, the operator may rebuild his entire switching yard with the new turnout.



6.1.6 COGI

Two new turnouts with low profile rails were developed: one deep groove and one flange bearing. The main advantage of these turnouts is that the installation depth is reduced by approximately 10 cm in comparison with the standard turnout for NP4aS rail. Both turnouts did not show any difference with standard turnouts with identical geometry installed in the same way. The reduced height has several advantages. When mounted on prefabricated slabs, the thickness of the slab can be reduced by 10 cm, what produces significant reduction in weight, which is beneficial for transportation and manipulation on site. The reduced height also means that the turnout can be easily installed on bridges or in parking garage type structures without the need for a costly thick concrete floor. For new track construction this also means that less earth has to be removed to enable track construction. The turnouts will be offered to all customers and may become popular due to the rise in the cost of steel which will make operators look at rails with less material such as the low profile rails.

The low profile switches are executed as monobloc switches and milled from a large bloc. The machining is done with NC machines, guaranteeing straight running surfaces and smooth curbs. The whole turnout is welded to reduce noise and maintenance costs. The components are assembled by means of gauge bars to ensure perfect track gauge.

The low profile turnout puts the company in a position to address the needs of new systems that opt for the modern low profile rails. In addition, it opens new possibilities for operators that are considering the use of low profile rails and turnouts.

The low profile is commercially available and was first presented at the 2006 INNOTRANS exposition in Berlin.

6.1.7 NTUA

NTUA developed a 3D finite element modelling methodology to study the dynamic response of metro and tram turnouts. Finite element modelling results were compared with the measured (by D2S) response of three reference turnouts and with the Flexible Multi-Body Model (FMBM) of POLIMI, revealing very good agreement. After validation of the developed analysis methodology, 3 new turnout systems were also modelled. The overall profit of NTUA from the TURNOUTS project can be summarised as follows:

The developed 3D modelling methodology has been successfully validated against field measurements. In fact, some of the comparisons can easily be classified as Class "A" predictions. The comparison with the model of POLIMI further validates the effectiveness of the developed approach. **The validation of the developed methodology will allow NTUA to become more competitive in the field of train-track interaction, also allowing for future research publications.**

The comparison of the dynamic response of different turnout systems provides deeper insights into the dynamics of the problem. The analysis of the three new concept turnouts further highlights the main factors influencing the dynamic response of train and tram turnouts. Valuable experience was gained, which will allow NTUA to proceed to further research in this



area. **With the experience that has been gained, NTUA can become a leader in this field, especially in Greece where such research efforts are limited.**

The 3D finite element modelling methodology developed by NTUA focused on the turnout structure. The central part of the turnout was discretised into 3D solid elements (plus beams and springs to introduce appropriate boundary conditions at the extremities of the modelled track section). The passing train and the mechanism of train-turnout interaction were modelled in a simplified way, assuming that a single rigid wheelset in series with a Hertzian spring impacts the turnout over the frog. Focusing on the dynamic response of a turnout system, the developed simplified modelling technique has been proven to be a reasonable simplification of complex train-track interaction phenomena.

The know-how that was gained by NTUA in the field of train-track interaction can be synthesised as follows:

- ✧ **Deeper understanding** of the dynamics of turnout systems and train-track interaction mechanisms.
- ✧ **Identification of the parameters with the greatest influence** on the dynamic response of turnouts.
- ✧ **Deeper knowledge of the effectiveness** of different dynamic response improvement techniques.

The developed technology can be used in future research projects, and in real-life applications. More specifically:

Future Research

The validated modelling methodology can be applied in the future to analyse the dynamic response of different turnout systems, such as commercial liners and/or high-speed trains. Future research may also focus on the developing stresses near the heart of a turnout and their effect on material fatigue. Alternatively, the developed know-how may be applied to study the dynamic response of various isolation concepts.

Real-life Applications

Such applications may involve the solution of problematic sections in train or tram networks. The problem may either be fatigue failure, or (most often) excessive noise and vibrations. The solution to such problems may be found using the developed technology.

The estimation of the economic benefit is not that straight forward for a University. However, it is envisioned that with the experience that has been gained NTUA may be possibly involved in similar research projects in the future. The economic benefit from one such project may be in the order of € 200,000. In addition, real-life applications may also have a similar or even greater benefit. Although train and metro networks in Greece are not as advanced as in the rest of Europe, it is believed that NTUA will get involved in more real applications in the future. A total of **€ 400,000** in the next 3-5 years can be held as a reasonable assumption.



6.1.8 POLIMI

POLIMI applied its FMBM to the reference turnouts for calibration against the measurements and the results from the NTUA 3D model. The various solutions were implemented in the model to perform sensitivity analysis, predict their outcome and decide on the best solution. The POLIMI FMBM has shown that if all parameters entered and the model are properly calibrated, it produces very reliable predictions.

This additional benchmarking of the FMBM will enable POLIMI to secure additional consulting work for its railway department.

6.1.9 RATP

RATP has appreciated the modelling of its turnout which gave a better understanding of the behaviour of the turnout during wheel passage and enabled a sensitivity analysis to determine the optimum way of installing its turnouts. RATP now has the knowledge to make an informed selection of turnouts that are better adapted for its operations. The turnout developed in partnership with BFM will benefit its operations as its design allows its installation on the same sleepers as the existing ones, so there is no need to renew the sleepers.

In addition, the shortened welds from the flash butt welding in combination with elastic pads has demonstrated that the turnout design achieves a significant reduction in noise and vibrations. The new turnout design will be installed on the network as of 2007. RATP expects a significant reduction in complaints, as 20% of complaints for the metro network and 17% of complaints for the tramway network are related with turnouts.



6.2 DISSEMINATION OF KNOWLEDGE

6.2.1 JEZ – Moving nose frog

JEZ has planned advertisements in the Spanish specialised press during 2007 and will present the product in at least two Spanish conference forums for railways and trams in 2007. The product has been presented in 2006 in a railway forum in Antwerp (Belgium). The product has been presented at INNOTRANS in Berlin 2006 and it will be presented at minimum two exhibitions in 2007 and 2008. An article will be published in the Spanish specialized press during 2007. The product will be included in the company's product brochure (CD format) and on its web site.

6.2.2 De Lijn

Past events: KVIV conference (Royal Flemish association of engineers), research, 50p.

Future events: Press release in several Flemish newspapers, general.

Publication in company brochure, general, 8000p.

6.2.3 BFM

The content of the present research will be object of an international paper which will be submitted in 2007 to the international specialized press.

The intention of BFM is to present the knowledge gained during the project in the Exhibitions, presentation of the company therefore Brochures; the audience will be essentially the Industry.

6.2.4 D2S

Past events: KVIV conference (Royal Flemish association of engineers), research, 50p.

6.2.5 FDP

Will promote its new design to other large private switch yard operators in the port of Antwerp.

6.2.6 COGI

The low profile is commercially available and was first presented at the 2006 INNOTRANS exposition in Berlin.

6.2.7 NTUA - 3D finite element modelling methodology

NTUA has planned a press release for publication in the magazine of the Technical Chamber of Greece (Audience : General, 100000), and plans to present its work at the 10th Int. Conf. on Application of Advanced Technologies in Transportation, May 27- 31, 2008, Athens, Greece, Audience : Research & Industry, 500. Other publications targeting the research public will be decided later.



6.2.8 POLIMI

POLIMI will present a paper at the Railway Engineering conference in London.

6.2.9 RATP

In 2006 the Research department presented a poster during the Innovation days at RATP, which is an event that is open to the general public.

The results of the project will be presented in the 2007 annual report of the research department. This brochure is distributed to RATP staff.