V360: High-Speed Laboratory
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Abstract

SNCF is able to keep increasing the commercial speed of its TGV – from 320 km/h today to 360 km/h tomorrow – thanks to the knowledge built up with the millions of kilometres travelled by its TGVs and the advanced research in power systems, braking, acoustics, rail dynamics, current collection, aerodynamics and other areas.

V360 was a vast test programme conducted in autumn 2006 on the high-speed line between Lyon and Marseille to confirm and refine earlier analyses of traction, braking noise, flying ballast, rail adherence, current collection and comfort.

The latest world speed record, at 574.8 km/h, pushed the limits of the wheel/rail contact 250 km/h beyond the latest commercial speed (320 km/h by the TGV Est). The tests at 360 km/h with 2 commercial trains showed the technical and economic feasibility of increasing commercial speed to that level.

1. Introduction

Why explore V360?

- Technological advances and the customers' needs drove the revenue-service speed of the TGVs from 260 km/h to 320 km/h on the newest French HSL, TGV-Est. The same “higher speed” trend is taking place on the European, Japanese and Korean high-speed networks which are all investigating commercial speed increases.
- The need to explore V360 is driven commercially by the journey time factor, a key factor in customer choices between air and rail. The pressure for modal shift to train is likely to increase with the growing policy focus on sustainable development (CO₂ emissions per passenger) and rising oil prices.
- The world speed record of 574.8 km/h (359.25 mph) in 2007 established, on the one hand, that the technical and safety limits had not yet been reached and on the other that technological advances in electric motors, power electronics, information technology and so on allowed to envisage speed increase without fear of blowing up maintenance costs.
- The commercial speed increase is the opportunity to prepare the new generation of high-speed rolling stock which, without denaturing the TGV’s proven fundamentals, shall have to propose to its customers new services, accessible to all, just as it faces new competition.

2. How to prepare the exploration of V360?

The decision to raise the commercial speed to V360 must be based upon both:

- the technical capability of the rolling stock/infrastructure pair to fulfil the service commercially under the same conditions of safety and comfort – and punctuality – as currently obtain at 300 km/h, as was done for the increase to 320 km/h
- a business model of the new service setting out the investment and maintenance costs against the expected benefits.

Besides the world record at 574.8 km/h, and the millions of kilometres travelled at 300 km/h by 500 TGV trainsets – and the mileage already accrued today at V320 – it was still necessary to validate the technical capability and to develop a business model, to examine all the functions of the guideway and vehicle system impacted by the speed increase.
The analysis of these functions was put into perspective with respect to:
- solutions already validated previously with TGVs or elsewhere
- existing solutions needing to be confirmed at V360 and validated by tests and/or feedback from the field
- some deeper research on a few technical and/or economical stumbling blocks, also finalised by tests and analyses.

The investigation obviously took into account the standards, particularly the Technical Specifications for Interoperability (TSIs) to be complied with, the prior research done for earlier projects such as, from 1990 to 1995, the new-generation “TGV-NG”, the MX100 project in 1996, the experience gained with V320, all the knowledge of the technical innovations – both for rolling stock and infrastructure – brought by the world records, and a sustained technology watch.

The technical framework was, for the infrastructure, the geometry of the lines laid out for V350 (the TGV Méditerranée and TGV Est) and, for the rolling stock, during the tests, the TGV-R trainsets (8800 kW).

Incidentally, although it is not the topic of this paper, a comparative analysis of ballasted track and slab track for commercial traffic at 300 and 350 km/h was made at the same time by the Swiss Federal Institute of Technology in Lausanne (EPFL) in relation with SNCF’s Research Department.

This paper will refrain itself to the technical analysis of the tests at V360 – the “high-speed laboratory” – and the outlook it offers.

3. Programme and results of the V360 test campaign

The elements of the system impacted by the speed increase were grouped into the following main, technically similar topics which we will delve into below:
- current collection
- traction
- braking
- aerodynamics
- dynamics
- comfort
- noise and the environment
- strength/behaviour of bogie- and body-mounted components
- infrastructure.

The signalling, whether it be TVM 430 or ERTMS, being flexible in relation to speed, was not examined.

Complementary tests to check the dynamic influence of the axleload on the infrastructure were also made.

3.1 Current collection

Current collection poses a technical problem essentially when trains run in multiple, because current collection by the second trainset is disturbed by the dynamic motion imparted to the catenary by the first one.
The solution tested included:

- a pantograph with a lightweight head to “better follow” the dynamics of the overhead line,
- a slight increase in the mechanical tension of the overhead line, from 25 kN to 28 kN. The tension could in fact be raised to 30 kN without a problem.

The results were deemed good enough for the same pantograph to be used record-breaking trainset V150. The pantograph, during the V360 tests, allowed a new speed record of V360 for trainsets running in multiple! The arcing was compliant with the TSI requirements.

The prime advantage of this pantograph is the reduced weight of the collector bow (mass of 4.1 kg instead of 7.5 kg for a classic head).

3.2. Traction

The motive power to be installed, \( P = F(v)\cdot V \), depends on the performance sought, that is the maximum speed, the acceleration available at each speed, the climbing ability, the stock’s resistance to forward motion and the available adhesion. \( F(v) \) takes the form

\[
F(v) = M\delta + Mgi + (A + BV + CV^2)
\]

Residual acceleration Gradient Rolling stock’s resistance to forward motion

The TSI requires a residual acceleration \( \delta \) on level track of 5 cm/s\(^2\) at maximum speed.

Given the gradient profiles of high-speed lines, in order not to squash the speed at the slightest rising gradient, SNCF aimed for greater residual accelerations (the POS TGVs at V320 have a \( \delta \) of 9 cm/s\(^2\)).

The TGV sets were adjusted to deliver during the test period a power of 10,400 kW (1300 kW x 8) which allowed to make runs of 50 km at V360 km/h while absorbing the various gradients of the Valence–Marseille line.

Greater power can be obtained by:
- a nominal increase in the power of each motor, which in turn requires or entails
  - a greater available adhesion,
  - a significant speed reduction when one bogie shuts down,
  - a heavier power car (traction motor + transformer + electrical equipment),
  - a less reliable kinematic (power) train that will have to transmit more force,
increasing the number of powered bogies at the cost of some passenger-carrying capacity. This means:

- a version of the single-deck TGV (TGV 1N) with 5 or 6 motor bogies (MBs) like the 1st generation TGV PSE
- a version of the double-deck, TGV 2N, with 5 or 6 MBs (by adding 1 or 2 MBs under the end trailers)
- a new type of HST (we might call it "Matériel à Grande Vitesse - MGV" for "HS Rolling Stock" to distinguish it from the TGV), with distributed motorisation and a capacity somewhere between that of the TGV 1N and the TGV 2N.

The latter three options avoid the problems usually associated with hiking the power rating of each motor. They also provide a greater starting effort.

3.3. Braking

The braking energy to be dissipated is proportional to $V^2$, in other words 25% more to go from 320 to 360 km/h, but for this analysis the following two types of braking are to be considered because they raise a different set of problems:

- emergency braking from V360 to 0 where the stopping distances under the conditions specified in the TSI (loss of a motor bogie or a trailer bogie, all with low adhesion) must all be complied with for a specified signalling system;
- service braking to comply with the permissible running speed on the particular profile.

The braking distances in emergency braking having been otherwise validated and considering the major technical modifications needed to simulate service braking from V360, the tests dealt only with improving adhesion. In particular, we tested the CERAJET system (projection of alumina at high-pressure) used on the Japanese rolling stock against the sanding systems used at SNCF.

Some gains in adhesion were achieved, and we noted surprising, still to be explained “memory effects” on wheel and/or rail.

Today, two types of “failsafe” or totally dependable brake are used:

- the disc brake with high energy limitations and maintenance costs
- the rheostatic electric brake with both energy limitations and inefficient utilisation of that “recoverable” (regenerated) energy.

The outlook now is:

- On the 25 kV system, the regenerative brake feeding back to the catenary, already used on the TGV Est for the POS trainsets, is more high-performing than and takes less energy than the rheostatic brake. It must still be made safe, for example by fitting better performing disc brakes for the event of “absence of catenary” (neutral sections).
- Enhance overall train adhesion by continuing the development work on the coefficient of adhesion and by managing the adhesion available at each wheel of the trainset, through computer control of the brake.
- High-powered disc brakes of 30 MJ (even 40 MJ available if necessary). Some braking in this energy range was done in the context of the world record.
- Technically, eddy current brakes (dependable by nature since they are independent of adhesion and wearless) do not seem strictly necessary. They can however be investigated from the standpoints of economy, considering the maintenance costs of brake discs, and of operations, since they could improve the throughput of a V360 line by boosting the deceleration between 360 and 200 km/h.
3.4. Aerodynamics

This topic is extremely important for it concerns a number of physical phenomena involved in the fulfilment, at V360, of a revenue service under the same conditions of safety and comfort as at V300 or V320. At issue are:

- the safety of persons from the slipstream effects when a train passes, and when trains cross,
- the “tympanic comfort” of passengers subjected to pressure waves in tunnels,
- the safety of track maintenance personnel and integrity of the rolling stock in the face of turbulent underbody flows likely to throw ballast,
- the comfort of passengers given the increase in aeroacoustical noise,
- the limitation of additional energy requirements for traction, by diminishing the resistance to forward motion and particularly the drag coefficient C

The separation of these phenomena is purely a heuristic tool. In fact, solving one is generally beneficial to one or more others, e.g. reducing turbulence affects resistance to motion, ballast flight and interior noise.

3.4.1 Slipstream effect and train crossings in free air

Air speed measurements made at the trackside confirmed that TGVs in single and multiple unit consist running at V360 both respect the TSI limit of 22 m/s.

Measurements made as trains crossed confirmed that the aerodynamic load on the rolling stock will be about 40% greater at V360 than at V300, on a line (LN5) with track spacing of 4.80 m; although this loading may seem high, it is merely of the same order of magnitude as the load on trains crossing at V300 on a track with a spacing of 4.20 m (LN1, LN2).

3.4.2 Running in tunnels

The TSI quotes the worst case – unsealed trainsets crossing in a tunnel having a given length with an adverse combination of their pressure waves. The tympanic safety criterion of 10,000 Pa measured in the worst case tunnel of the test line was respected.

3.4.3 Underbody turbulent flows and flying ballast

Comparative aerodynamic measurements on line of ICE3, V300/V360 – US/UM show the importance of reducing the turbulent zones occurring in trainsets between the power car and end trailer (this was achieved on trainset V150) and to research the front and rear shapes of the interface between two trainsets coupled in multiple to alleviate also this highly turbulent zone. It remains to validate the ballast’s behaviour at this level on a line or section of line having received the following modifications or upgrades:
- lowering of the ballast level between sleepers by 5 cm,
- efficient blowing or bushing off of ballast from the sleepers.
3.4.4 Aeroacoustics

The results presented here show the evolution of the noise inside the accompanying trainset (the one that “swept” and closed the line before and after the record run) – following laws of the form \( L = 10 \times K \log(V) \). The K coefficients of the straight lines in the intercar gangway and vestibule zones are of the order of 3, which shows that the rolling noise impacts in \( V^3 \). Conversely, for the whole set of measuring points in the passenger compartment, the higher coefficients of around 5 reveal the appearance of a noise of aeroacoustic origin (\( V^5 \) to \( V^8 \)).

3.5 Dynamic behaviour

The transverse Y and vertical Q measuring wheelsets of the leading bogie of the leading power car and of the trailer (non-powered) bogie between trailers (R) 2 and 3 served to verify the good dynamic behaviour of the TGV trainset at V360 and the dynamic influence of the axleload on the same trailer bogie, loaded first to 17t then 18t per axle.
The TSI criteria
\[
Y \leq 10 + \frac{2Q_f}{3} = 66.7 \\
Q \leq 90 + Q_0 = 175 \\
\frac{Y}{Q} \leq 0.8
\]
were broadly compliant, for example the results obtained for curves are:

\[Y = 35\]
\[\frac{Y}{Q} = 0.3\]

3.6. Comfort

3.6.1 Dynamic comfort

Acceleration measurements in the three directions were made on the floor of the passenger compartments and the vibration comfort indicator NMV was calculated

\[NMV_{\text{floor}} = \sqrt{\delta_{\text{weighted}}^2 + \delta_{\text{trans}}^2 + \delta_{\text{vert}}^2} \quad \delta_i^{\text{weighted}} \] represents the acceleration in direction i, weighted to take account of its effect on humans.

Recommended limit value for comfort in passenger saloon NMV < 2 (\(\oplus\) very comfortable, \(\ominus\) very uncomfortable)

The results of the measurements high-pass filtered at 1Hz (a frequency not uncomfortable for a seated passenger) and “averaged over several runs between the Up Line and the Down Line are as follows:

<table>
<thead>
<tr>
<th>Trailer R2</th>
<th>End</th>
<th>Middle</th>
</tr>
</thead>
<tbody>
<tr>
<td>V300</td>
<td>1.05</td>
<td>1.30</td>
</tr>
<tr>
<td>V330</td>
<td>1.45</td>
<td>1.60</td>
</tr>
<tr>
<td>V360</td>
<td>1.65</td>
<td>1.85</td>
</tr>
</tbody>
</table>

The increase in the vibration level in trailers should be able to be obviated thanks to filtering made possible by a suspended floor design, currently under test and in fact already used in other SNCF rolling stock.

3.6.2 Acoustic comfort

To the increased rolling noise (in V\(^3\)) comes to be added an aerodynamic part perceptible starting at 320 km/h (cf. § 3.4.4.)

Thanks to the measurements made in addition to the V360 tests on the accompanying trainset in the V150 campaign, the following results were obtained:

<table>
<thead>
<tr>
<th>Location</th>
<th>Initial Noise</th>
<th>Final Noise</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>In saloon</td>
<td>66.5 dBA</td>
<td>71 dBA</td>
<td>Law in V(^5) = rolling + aerodynamic noise</td>
</tr>
<tr>
<td>Vestibule</td>
<td>77 dBA</td>
<td>79.5 dBA</td>
<td>Law in V(^3) = rolling</td>
</tr>
<tr>
<td>Gangway</td>
<td>82.5 dBA</td>
<td>86 dBA</td>
<td>Law in V(^3) = rolling</td>
</tr>
</tbody>
</table>
The ongoing research is directed to:

- gaining more knowledge of the noise sources through an analysis of the transfer paths (first at standstill, later on line) along the bogie to body links and the body-to-adjacent-bodies links
- validating the contribution of a suspended floor on the basis of measurements at standstill of the current floor's and a suspended floor's acoustic and vibration “transparency”, and to carry over the attenuation to the measurements on line.

3.7 Noise and the environment

The environmental noise measurements come from the V360 trials on the Valence-Marseille HSL (LN5) and the levels measured at passby of the accompanying trainset during the record run on the new, TGV-Est line, at two different sites.

The levels measured are scattered, conditioned in the absolute by the topography of the measurement sites, the condition of the track and its alterations in line with the sites, plus the condition of the wheels and its evolution during the test campaign.

It is however safe to state that the step up from 300 to 360 would produce an increase of 4dBA between 300 (91.5 dBA) and 360 (95.5 dBA).

3.8 Strength/behaviour of bogie- and body-mounted components

We limited the tests to assessing the vibration behaviour of equipment fitted to the bogies, i.e. lifeguard, signal-brush holder and brake set, at speeds ranging from 300 to 360 km/h.

The results evidenced:
- a 30 to 40% increase of the vertical and transverse vibratory regimes
- that the vertical vibration level on the brake set, already vibration-prone, goes up 40%.

With future operation in mind, an analysis of all the body- or bogie-mounted equipment is underway, in order to specify stronger fasteners for the parts subject to heavy vibrations, that could fall off on line.

Other than that, the monitoring done of the temperatures of the axlebox and reduction gearbox components was not significantly different at V360.

3.9 Infrastructure

This is a major issue for V360 operation given the implications of the infrastructure on railway costs (both construction and maintenance), on safety, comfort and reliability.

The tests of V360 were conducted between Valence and Marseille on the line which has been in revenue service since 2001. The distances travelled at different speeds were as follows:
- 15 000 km V > 320
- 9 000 km V > 330
- 4 000 km V > 350
- 800 km V = 360

The measurements made during the runs, as follow-up to the V300 experience and the feedback from the more recent V320 experience, and in spite of the short time running at V360, have yielded some insights towards improving design and/or maintenance.

A more thorough analysis has been made together with EPFL Polytechnic, Lausanne to evaluate these evolutions with respect to the two basic track concepts: slab and ballasted.
This particular analysis bore upon the following items:

a) command of the track geometry, including
   o definition of indicators of good ride
   o maintenance techniques and associated costs
   o identification of the factors adversely affecting maintenance of good “top” and favouring sleeper pumping

b) the rail
   o risk of increasing “head-checking” type defects due to micro-slipping between wheel and rail

c) switches and crossings
   o especially the design and maintenance of adjustment switches

d) control of flying ballast (tied to good command of track geometry, to the under-body aerodynamics, the type of sleeper, the depth of ballast and other things).

The solutions tested on the infrastructure and the rolling stock proved during the record run to be very positive:
- the ballast (level, compaction, cleaning off,…)
- the V150 trainset (streamlining, …)

They give us confidence about the consequences of V360 operation on the infrastructure.

Conclusion

The results presented demonstrate that there is no technical obstacle to running commercial trains at V360.

Further research now underway to reduce noise and vibration levels in passenger spaces already points to avenues of improvement.

The tests before the world speed record run and the record run itself have shown that ballasted track has not reached its limits.

The most crucial problem perhaps is ballast blow-off. Both the tests and the record showed that solutions exist on both sides: rolling stock and infrastructure.

We have yet to work out a detailed balance sheet for infrastructure maintenance, based on, among other things, the analysis of experience on the TGV Est line.

Technological advances for the rolling stock allow us to assume the LCC will evolve reasonably.