LIGHTENING THE TILT

VEHICLES FITTED WITH TILTING SYSTEMS HAVE PROVEN ADVANTAGES. THE SPEED INCREASE IN CURVE NEGOTIATION ALLOWS FOR A REDUCTION IN JOURNEY TIMES, BUT THE PRICE TO PAY FOR SUCH A FEATURE CAN BE HIGH. TILTING SYSTEMS ARE MADE UP OF COMPLEX PIECES OF ELECTRONIC EQUIPMENT FOR DETECTING CURVES, COUPLED TO HYDRAULIC OR ELECTROMECHANICAL DRIVE SYSTEMS, WHICH REQUIRE COSTLY MAINTENANCE THROUGHOUT THE LIFE CYCLE OF THE VEHICLE. HENCE TILTING TRAINS MUST RUN ON WINDING ROUTES WITH HIGH NUMBERS OF CURVES, WHERE THEY CAN DELIVER OPTIMUM PERFORMANCES AND COMPENSATE FOR THEIR HIGH LIFE CYCLE COST.

Towards the end of the 90s, Spanish manufacturer CAF (Construcciones Y Auxiliar de Ferrocarriles) developed a proprietary tilting system called SIBI (All-Round Intelligent Tilt System). Its key feature – prior knowledge of the track profile – coupled with precise determination of the position and speed of the train, allows the system to be tailored to each curve and operate without delays. Inverse dynamics techniques are applied to achieve maximum comfort levels. The SIBI is currently installed on the 594 and 598 series DMUs run by Spanish operator Renfe and will shortly be implemented in the new DMUs for the Italian island of Sardinia.

However as part of its innovation plan for 2008, CAF explored the possibility of developing a new generation, light and compact tilting system compatible with any new or existing bogie design.

THE CONCEPT

Rather than replacing the SIBI, the idea was to offer a lower performing system that is simpler and cheaper to implement, i.e. to develop a complementary system that works perfectly well for routes where the high performance of SIBI (up to 8°) is unnecessary.
The requirements, therefore, were to allow the train to tilt up to 2° without using electronics or actuators. The tilting effect produced by the inflation and deflation of the air springs was considered as one solution (see Fig. 1), since it has already been successfully tested in Japan. The new feature, however, lies in the detection of curves by the system.

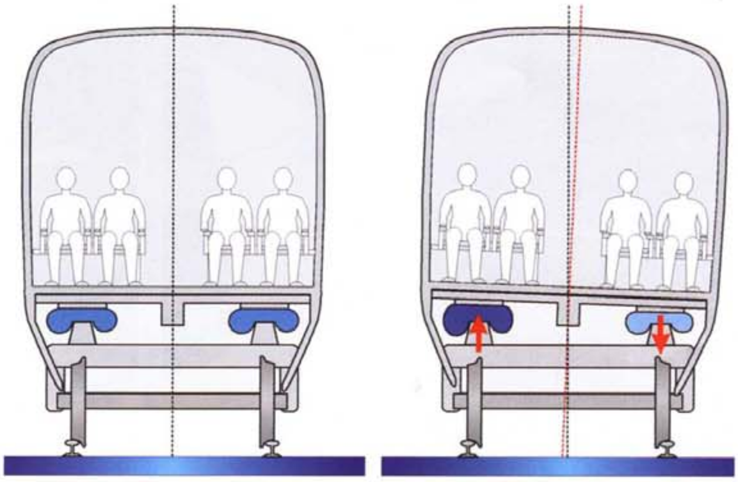


Fig. 1. Tilting concept using air springs

As mentioned above, the main requirements were simplicity and, as a direct consequence, a high level of reliability. This is why the solution adopted is based on the exclusive use of mechanical means to detect curves. Three possible mechanisms were studied for detecting acceleration in the car body, in the bogie and the relative lateral displacement between the car body and bogie. This innovative study resulted in a patent covering the three devices.

The mechanisms are designed to translate the impacts of the curve (acceleration or displacement) into direct action on the levelling rods, causing the outside air spring to inflate and the inner to deflate.

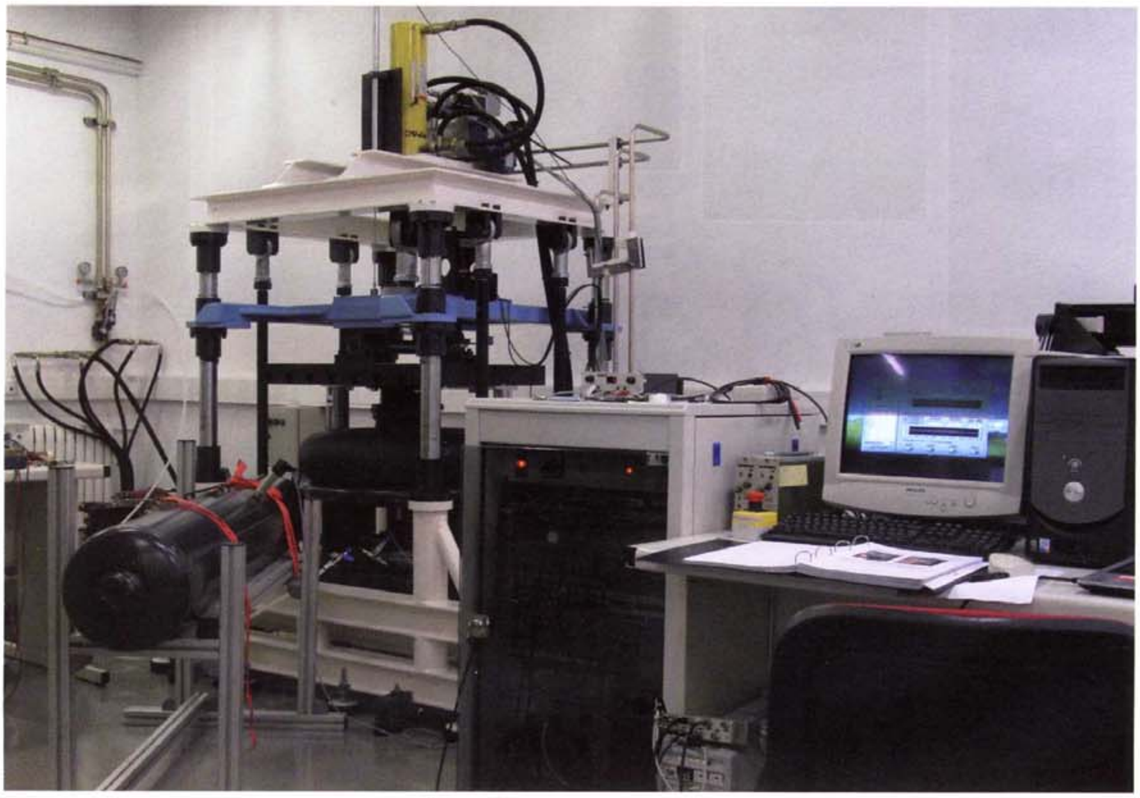


Fig. 2. Test bench used to analyse pneumatic behaviour

Fig. 7. Modified bogie & sensors

Phase 2 in February 2010 consisted of track tests. The conventional track route between Lleida and Madrid was chosen because it combines straight stretches and curves with different radii and speeds. Runs were made at different speeds and, as a result, at different uncompensated lateral accelerations.

The objective of the tests was to evaluate the system in a real operating environment, comparing the behaviour of the modified car with its unmodified equivalent. The tilt angle and reduction in uncompensated lateral acceleration were assessed, together with the system stability and air consumption.

To this end, accelerometers, air flow meters, pressure and displacement sensors, gyroscopes and inclinometers were installed in the car body and bogie (see Fig. 7).

RESULTS & CONCLUSIONS

Findings from both the static and track tests looked promising, despite the fact the solution implemented was not the best of the three patented.

It was checked that the system tilted correctly, and an inclination of 1.35° was obtained for uncompensated acceleration levels of $1.0 m/s^2$ (compared to the conventional coach), and 1.65° for $1.4 m/s^2$. These values are good, despite the fact that the vehicle

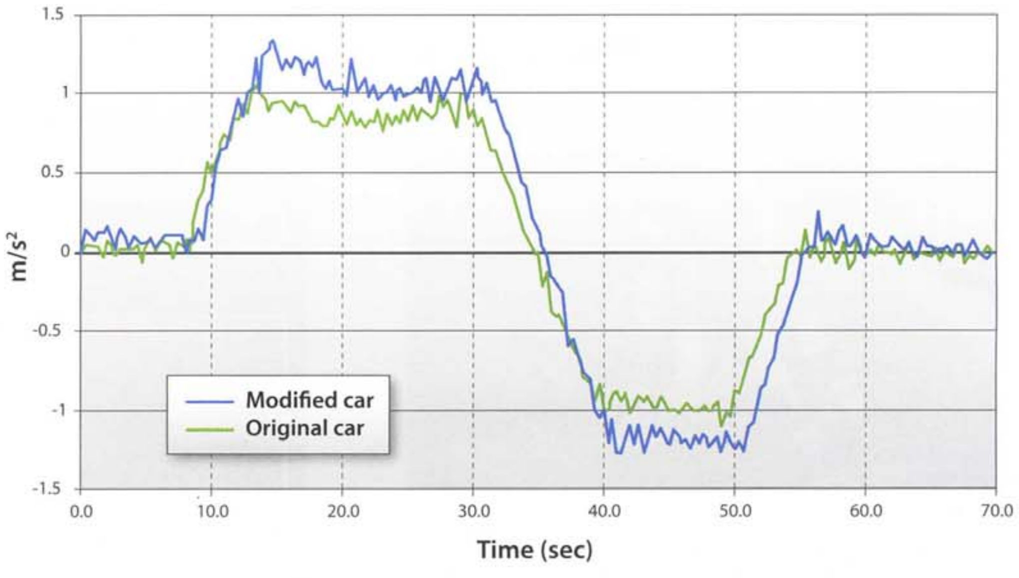


Fig. 8. Comparison of lateral acceleration at passenger level

illustrated in Figure 5. The data collected provided valuable input on the dynamics of the system and helped adjust the mechanism to optimise its performance.

A rotating platform was then used to simulate yaw turning, check the mechanism was unaffected and ensure the integrity of the components remained intact, even when entering curves with a reduced radius. Figure 6 shows how the isolating mechanism functions.

Fig. 6. Yaw isolation was checked using rotating platforms

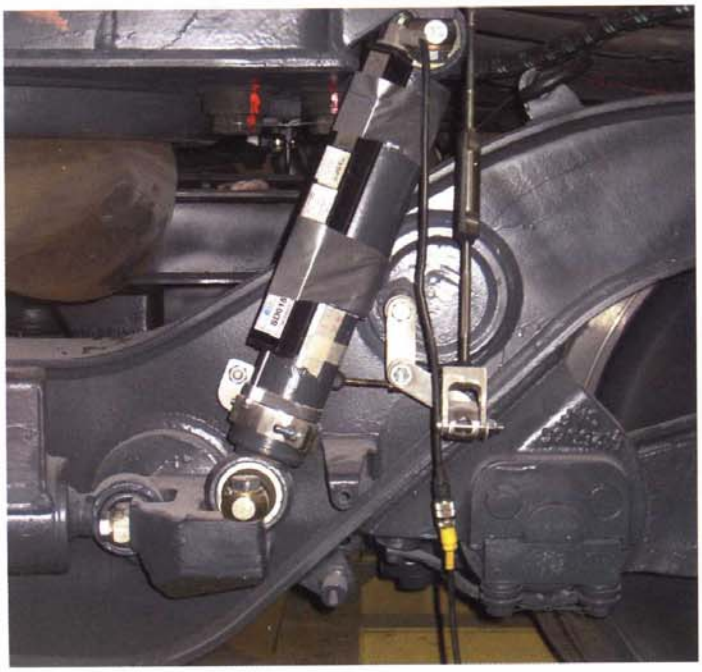


Fig. 3. Renfe's 594 series unit

STUDIES & SIMULATIONS

The three solutions were modelled using Simulink to study dynamic behaviour and, in particular, to determine the influence of the different design parameters.
The stability of the system was one of the key aspects taken into account and every effort focused on this area. Achieving a high level of stability decreases dynamics and increases the response time. Conversely, highly sensitive detection mechanisms are unstable and may cause discomfort. The first steps of the process sought a compromise.
The influence of the pneumatic circuit (air spring, piping, reservoir, etc) was also explored through empirical studies in the laboratory, with suitable dimensions determined for the different components, to achieve the desired response (see Fig. 2, p. 92).

Finally, all the models were integrated into the SIDIVE dynamic simulation tool to assess the behaviour of different vehicles when equipped with this innovative tilting system.

PROTOTYPE

One of the solutions was installed on an existing train to assess the system – one of Renfe's 594 series units, shown in Figure 3, being retrofitted at the end of 2009. Since the vehicle was not equipped with an anti-roll bar, it was easier to install the system since the new concept involves suppressing the function of this bar.

Considering the tests were temporary and the train had to be returned to its original condition, the simplest detection mechanism requiring the least number of modifications was chosen: the relative lateral displacement detector between the car body and bogie. According to simulations this was not the best solution, but it would nevertheless deliver an acceptable performance (around 1.5°) at an extremely low cost.
The refitting work involved replacing the pneumatic pipe with a more appropriate alternative, based on simulations, increasing the capacity of the levelling valves and installing a series of mechanical elements to convert displacement into valve action. Conventional valves were used for this test.
The weakness of this solution is that it is vulnerable to yawing, especially on curves with small radii. To overcome this problem, a system that isolated lateral displacement from the rotation between the car body and the bogie was designed, manufactured and installed. The complete mechanism is shown in Figure 4. In order to obtain comparative data, only one of the two cars of the 594 unit was modified.

Fig. 4. Curve detection mechanism

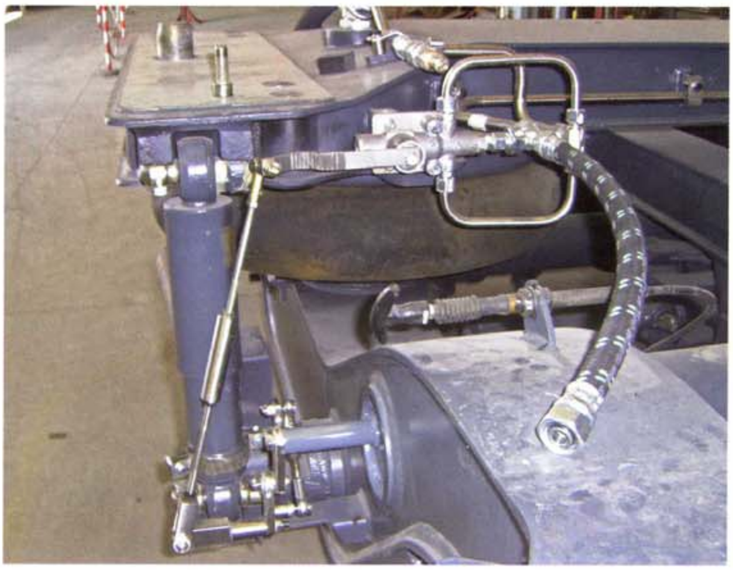
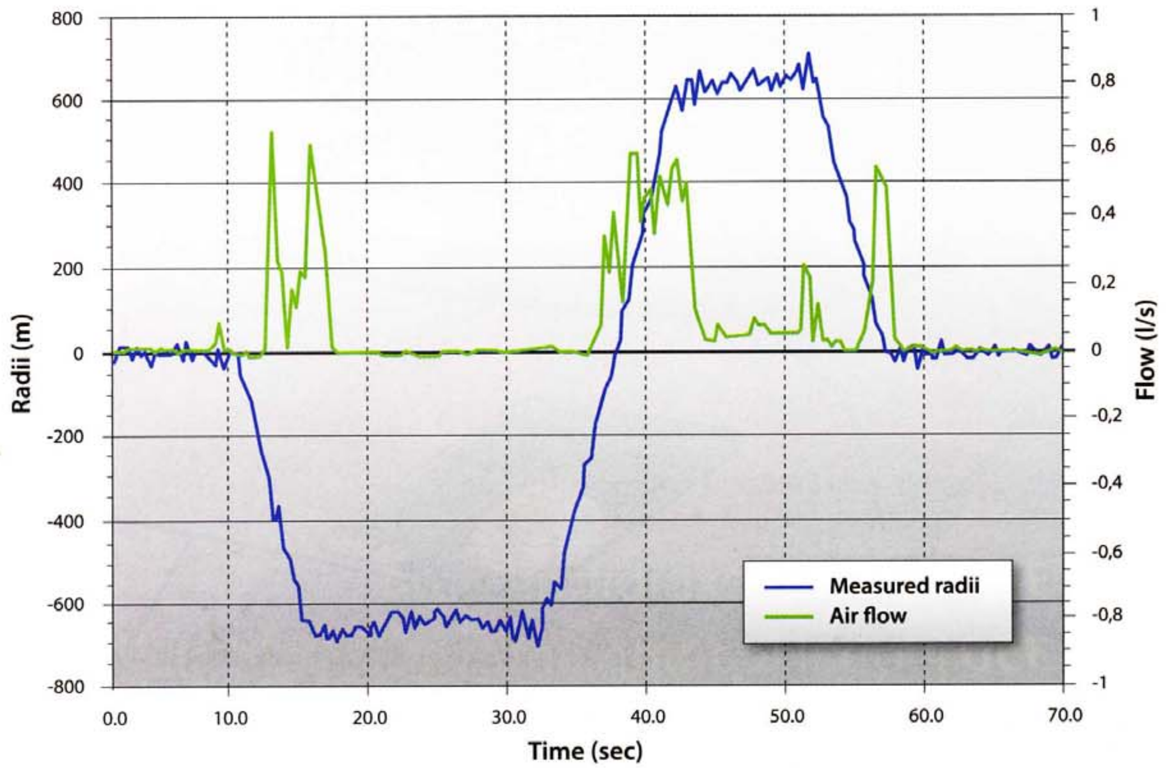


Fig. 5. Testing car on tilting platforms

TWO-PHASE TESTING

Once the train had been modified, the tests were performed into two phases. Phase 1 in January 2010 assessed the system in the factory using platforms. Firstly, entry into the curve was simulated by tipping the car using tilting platforms, as

Fig. 9.
Air consumption



was in tare condition and so the detection system less sensitive. The performance achieved would allow the train to run through curves at a speed 5% higher than normal. Figure 8, p.96, details the performance of the system in terms of lateral acceleration, comparing both cars.

Another check performed was whether the system responded fast enough to ensure the train operated correctly on all of the curve radii and transition periods studied. The time required to reach the maximum tilting angle was 4.1 seconds, with 3.6 seconds needed for the system to return to resting position. In general these values are valid for the majority of the curves. Replacing commercial valves used with others specific to this application would further improve these times.

Air consumption was judged reasonable, with approximately 50 litres consumed on the majority of curves, with a maximum of 70 litres on one in particular. Based on this data, an estimated 1.7kW of additional power will be used by the compressor in each car, assuming a curve density of about one curve per kilometre. An example of the air consumption is illustrated in Figure 9, using the same curve sample as for Figure 8. Finally the comfort test described by standard ENV 12299 was performed, with similar values obtained for both cars. This confirms that the system does not reduce the ride quality of the vehicle.

INTO THE FUTURE...

The system is so simple it can be easily applied to any vehicle. So the next step is installing it on all the cars of a train – the idea is not to test the system on a single car but to mount it on a complete train to certify it under normal service conditions, for qualification approval prior to entry into commercial service.

Several operators who have recently procured vehicles from CAF are currently considering whether to fit the final units in their series with this latest-generation tilting solution. They will either opt for the tried and tested solution or one of the other mechanisms, depending on their application ■

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