STABILITY INVESTIGATIONS AND NARROW CURVING ANALYSIS OF A STREETCAR MODEL

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SUMMARY

The new serie of the streetcars designed, studied and produced by Fiat Ferroviaria for ATAC, the public transportation company of Rome, Italy, is presented in this paper.
Our objective for developing the new generation of streeetcars was to obtain not only an excellent curving performance and ride quality but also to reduce the noise level and to obtain a high passenger comfort. Its most important concepts design are a lowered floor, less wheel/rail wear and easily replaceable modular unit.
Thanks of dynamic projection application, with a continuos feedback between design process, theoretical studies and full scale stand and line tests we faced all technical problems and succesfully developed this new serial of streetcars.
The design concept of the vehicles, viewed on the sight of particularities and difficulties for simulation with MBS, is briefly described in the first part of the paper.
In the second part are shown some results obtain by theoretical analysis of vehicle with help of ADAMS/Rail - MEDYNA modeling and simulations. Particularly the running behaviour of streetcar on tangent track and on the tight curves has been pointed out.

1. INTRODUCTION

The environment conditions and specific type of service requested from the streeetcar imply the development of trucks which have excellent curving performance, high ride quality, good comfort and a low level of external noiseThe vehicle needs to satisfy both the above requests also being reliable, with lowered floor, a minimum axleload and as versatile as possible in concept (through the use of standardised modular components).
Based on these objectives but conscious of the difficulties (as many of this requests are contradictory from the point of view of design concept and dynamic perfomance), we have done a hard theoretical and experimental work to obtain a good compromise from the point of view of overall vehicle performance.
The design and construction process has gone on with a continues feedback between theoretical study and test results, till we arrived to todays design and performance solutions.
Particularly we have done a lot of work to optimise the primary and secondary suspensions, on defining the optimal flexibility of the wheels, on the solution of problems related with transmission between motor and wheelset and so on.

In the frame of this presentation isn't possible to insert all theoretical and test problems that we faced during the dynamic projection of streetcar vehicle.

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Beneath follow briefly only some noteworthy aspects witch show the difficulties we have been to surmount during theoretical simulations with ADAMS/Rail-MEDYNA, to assure a carefully and confident prediction of dynamic performance of the vehicle, but in the same time the potential capacity (and lack verified but overcomed or that are going to be resolve) with above-mentioned code.

Particularly we want to point out that the theoretical simulation has been to face and to resolve with satisfaction the numerical simulation problems related with the specific design and hard service conditions of the streetcars vehicles, as mentioned briefly subsequently:

- design : 3 main cars and two intercirculation bodies laying on 4 bogies, independent wheels, resilient wheels, jointed bogie frame, spherical joints between carbody and bogies, airsprings and so on.
- Service : running in sharp curves, possibility of multipoint contact wheel-rail due to grooved rails and sharp curves (additional contact of wheel flange on the internal face of grooved rail) , irregularity of the track, crash load of vehicles, high level of acceleration and deceleration and so on,

2. VEHICLE DESIGN

The streetcar here presented has been developed by Fiat Ferroviaria for ATAC, the public transportation company of Rome, Italy. It thrusts on the experience of the prototype of 1989, which later was produced in 54 units for ATM, the public transportation company of Turin, Italy.

The streetcar is characterized by lowered floor on 70% of the surface, where the access of the passengers is situated. The vehicle consists of three main cars and two intercirculation bodies, suspended on two traditional motor bogies and two trailer bogies with independent wheels.

- The front and rear car bodies are laying on one end on the carring beam of motor bogie through a bearing and on the other end on the intercirculation module via a single support-articulation point. This solution allows the vehicle to adapt optimally to the track geometry, both in horizontal and vertical direction.
- The central car is supported on the two intercirculation modules via a single support-articulation point.
- The intercirculation module, helded by the trailer bogie, rests on two groups of pneumatic suspensions, each one of them realized with two airsprings supported by the half frames of the bogie. The reaction of the car body to roll movements is obtained with an anti-roll bar mechanism.
- The motor bogies, placed in the front and at the end of the vehicle, are both equipped with asynchronous engines, each one of them acting on one of the axles. Their secondary suspension is make up of two air springs.
- Trailer bogies are constrained at the ends of the main car bodies by spherical joints. Their bogie frame is formed from two half parts, linked between them by a special joint This particular solution secure a high safety against derailment.

The particular connection of the conventional motor bogies to the car body through a bearing and the introduction of independent wheels in the trailer bogie guarantee a good curving behavior without the introduction of steering systems.

A view of the motor and trailer bogies is represented in figures 1a) and 1b).

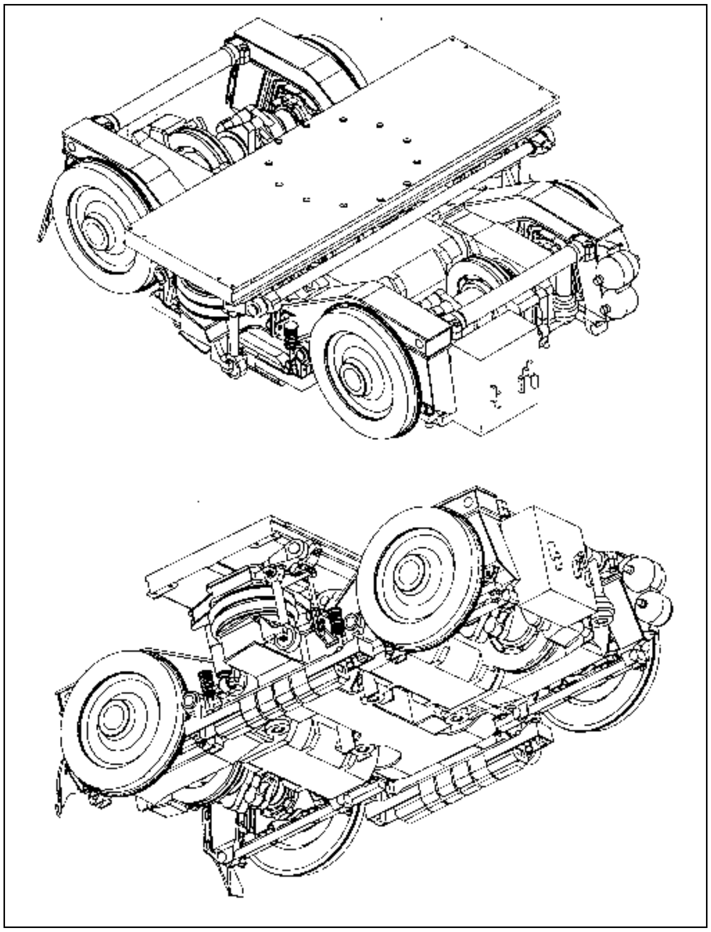

Figure 1a: motor bogie

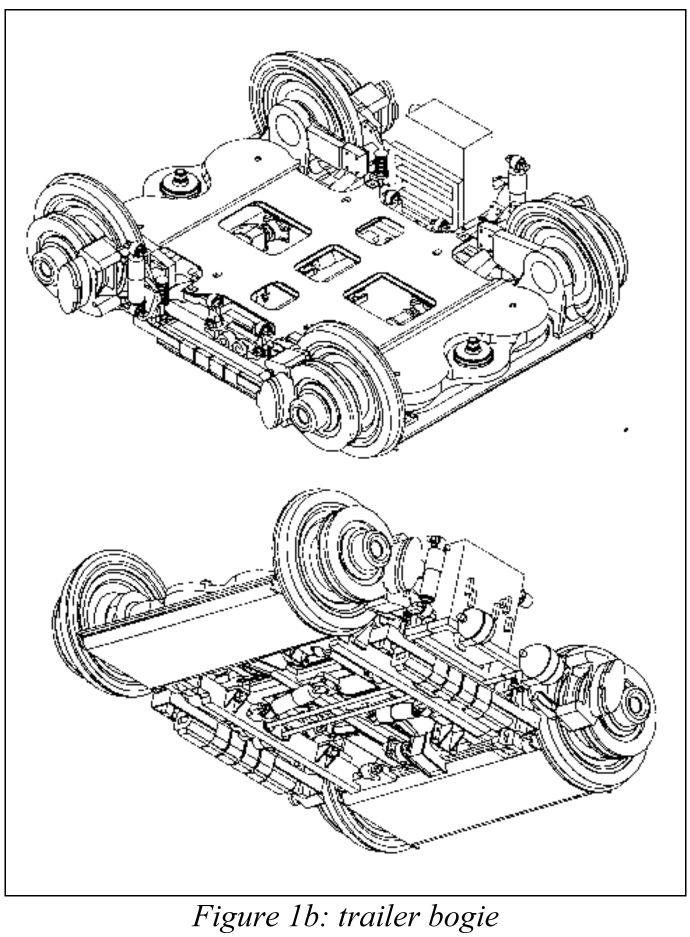

Figure 1b: trailer bogie

3. VEHICLE MODELING AND SIMULATION ANALYSIS

The purpose of the simulations with ADAMS/Rail has been the study of the static and dynamic behavior of the vehicle. The vehicle as described above has been modeled within the ADAMS/Rail graphical interface. Initially a suite of static analysis has been performed with the help of the ADAMS Solver, for example roll tests, in order to determine the displacement of the car bodies consequent to a lateral force, and twist tests, to detect the possibility of wheel unloading caused by vertical irregularities in the position of one rail in respect to the other. Consequently calculation of eigenmodes and dynamic analysis, like running stability and comfort evaluation, have been executed.
For the simulation of the quasistationary and dynamic curving behavior for very small curve radii (down to 15 m) the non linear wheel-rail element 21, available in the Medyna solver, has been used. This wheel-rail interconnection element, that during the simulation uses the real wheel and rail profiles and not a precomputed kinematic table, made it possible to model resilient wheels and to simulate typical phenomena characterizing the curving analysis of street cars, like simultaneous multi point contact and eventuality of derailment.

The eigenbehaviour of the model was analyzed with the linear wheel/rail element. The functions of equivalent conicity, gravitational parameter and roll angle parameter have been derived using proportionality formulas where the equivalent conicity is assumed as independent variable for the calculation of the other parameters. This assumption leads to the possibility of obtaining universally comparable results.

The root loci diagram represented in Fig. 2 and the frequency-damping-velocity plot in Fig. 3 correspond to an equivalent conicity value of 0.2 and factor 1 for the Kalker coefficients. In both diagrams the hunting modes due to the wheelsets and unstable modes due to the independent wheels can be recognized. The hunting mode coming from the wheelsets becomes unstable in this case for a speed of about 44 m/s and frequency close to 5 Hz. The single wheels are characterized by quasi statically unstable modes, with frequency zero and negative damping. This phenomenon can be observed in the results of time domain analysis that show that the single wheels at lower speeds run in a off-centered position.

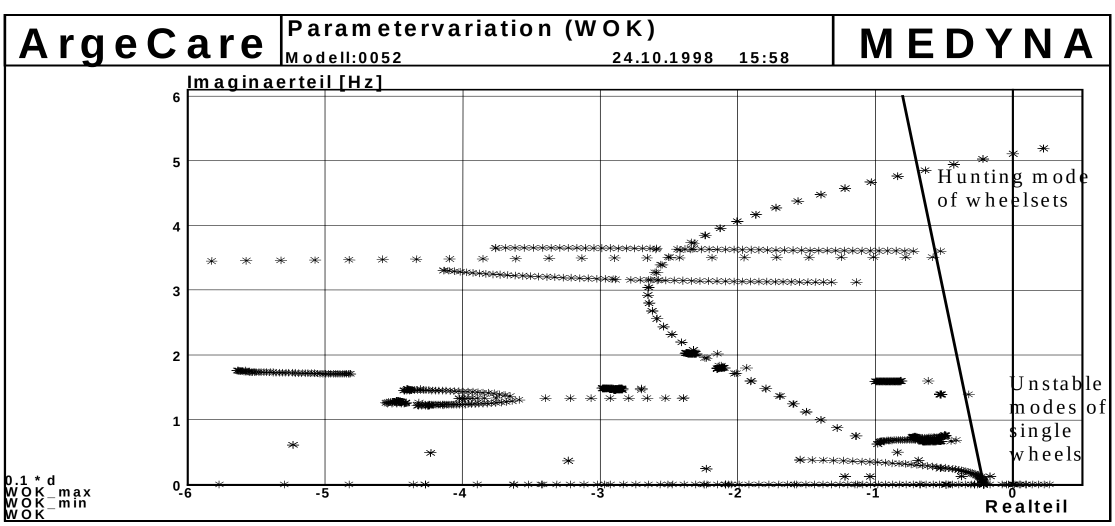

Fig 2: Root loci of the tram model for equivalent conicity 0.2

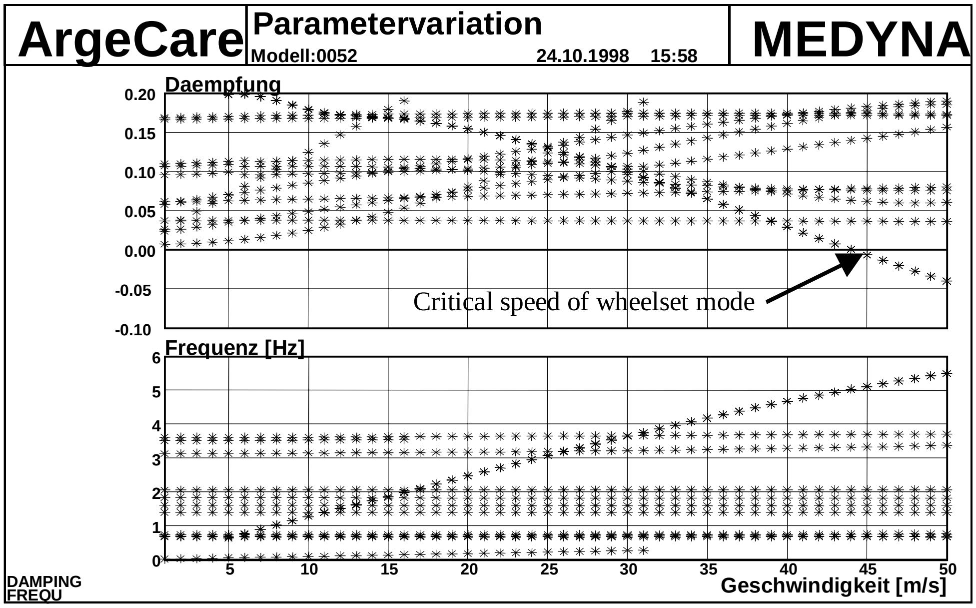

Fig 3: Frequency-damping function of the tram model for equivalent conicity 0.2

The same calculation was executed also for very low values of conicity. With this particular contact configuration, as shown in Fig. 4, the unstable mode corresponding to car body hunting appears.

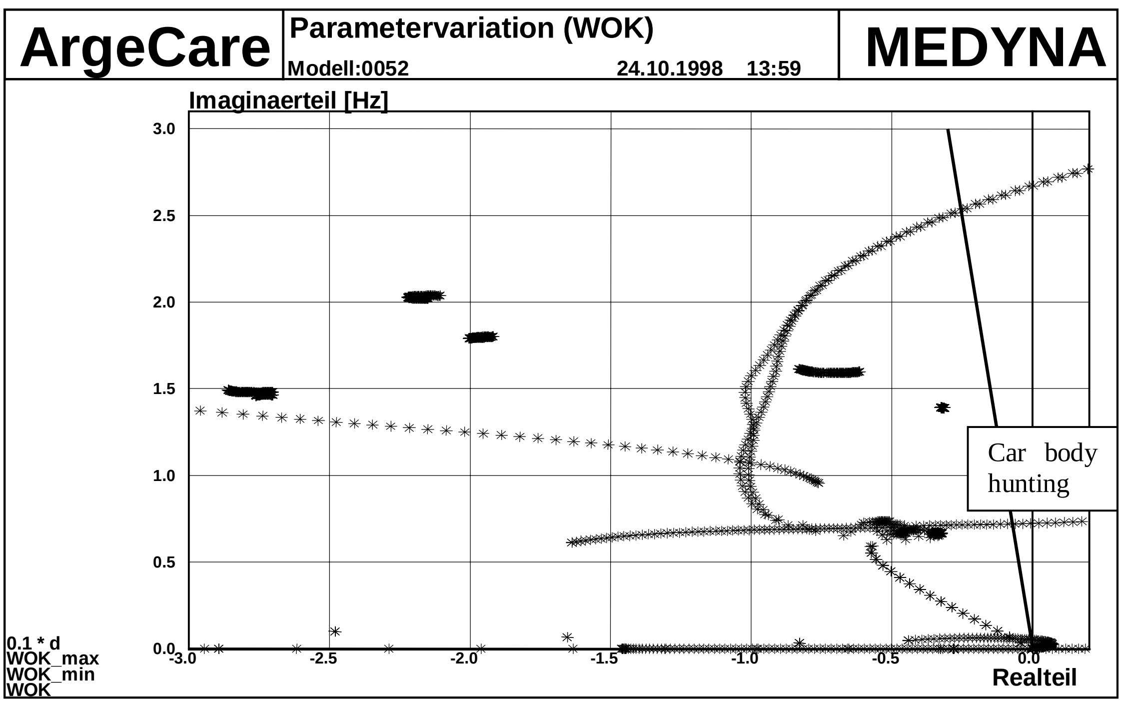

Fig 4: Root loci of the tram model for very low equivalent conicity (0.02)

The critical speed relative to the car body mode for the low conicity is 42 m/s, whereas the critical speed correspondent to the wheelset or bogie hunting modes goes up to 85 m/s for this case. Quasi static unstable modes due to the single wheels are still present.

With the simulation in time domain it is possible to reproduce the results of the linear stability analysis. Hunting modes are initiated in a simulation with 90 m/s starting from central position. This is shown in Fig. 4 for the lateral displacement of the leading wheelset. By reducing the velocity to 60 m/s, hunting dies out. Periodic movement with an amplitude below flanging corresponds to a conicity value which is in the range of 0.02. Wheelset or bogie hunting do not occur, whereas car body hunting is present.

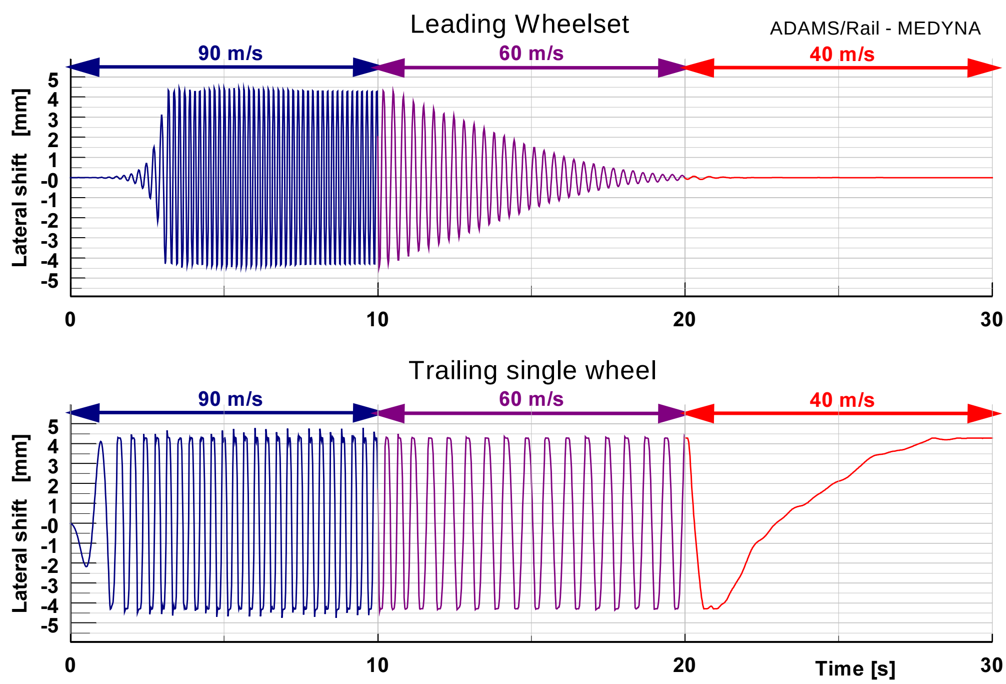

Fig. 5: Lateral displacement of the leading wheelset for velocity of 60 and 90 m/s

The eigenmode representation coming from the results of the linear stability analysis showed that the single wheels are involved in this hunting mode. In the lateral displacement time history of the trailing single wheels, shown in Fig. 5, for velocity 90 m/s the start of the hunting movement can be observed. For velocity 60 m/s the hunting movement is not damped out as in the case of the wheelsets, but remains unstable with a frequency value reduced to the range of the car body hunting mode shown in Fig. 4.
When the speed is reduced to 40 m/s it can be observed that the car body hunting mode also disappears. What is left is the quasi static unstable mode due to the single wheels which is responsible for the single wheels to run in an off-centered position.

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uy [mm]: 4.21

		1	1	2
Coord. rail	mm	15.69	-47.80	15.97
Penetration	mm	0.042	0.045	0.050
Load	kN	25.00	23.61	32.37
Max.press	MPc	778.76	1819.86	849.85
Cont. Stiff.	MN/m	888.97	792.42	969.02

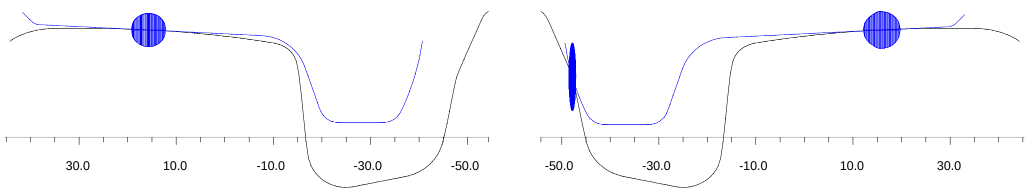

Fig 6: Flanging situation of wheels or wheelsets for hunting modes as represented in RSGEO

Vehicles not running on groove rails don't show the sudden stop when flanging in lateral wheel displacement evident in Fig. 5. This is due to the flanging on inner side of the wheels, shown in Fig. 6. The second contact point does not occur on the wheel approaching the rail with the inner flange face but on the other side. For this reason the physical behavior of such a vehicle can be simulated with satisfactory results only with the use of a detailed description of the wheel-rail contact mechanics.

The results coming from these calculations regarding wheel-rail contact forces will be used in the frame of a project whose aim is the optimization of the wear indexes and the experimentation of the use of newly developed wheel profiles in comparison with the standard adopted profiles.

REFERENCIES

1. Parena, D., KIK, W. : Stability and curving Analysis of streetcar "72550".
   ADAMS/Rail News & Views, December 1998