The Hunting Stability of the German High Speed Steam Locomotive 05

Long before MBS software programs had been used for dynamic analysis, the German Railway placed an order for the development of a new type of high speed steam locomotive for the track between Berlin and Hamburg. In 1936, this locomotive performed a world record with a running speed of 200.4 km/h. A working group from the Technical University Stuttgart set up a SIMPACK simulation model of the record machine and performed a stability analysis of the running behaviour. It could be shown that the record run was not endangered by hunting instability.

HISTORY

In the 1930’s, several European countries made preparations for high speed railway traffic: among them Poland, England, France and Germany. In 1931, the head office of the Deutsche Reichsbahn published a request for proposals for a high speed steam locomotive needed for the intended high speed traffic and for tests of a new generation of high speed passenger railway vehicles. Being anxious about losing their market share to the new self-propelled railcars like the “Fliegender Hamburger”, nearly all famous German locomotive factories like Borsig, Henschel, Krauss-Maffei and Schwartzkopff submitted design proposals. Finally, Borsig received the contract to design and manufacture three prototypes of a new generation type 05 steam locomotive.

On May 11, 1936 the locomotive 05 002 (tracking four passenger wagons and one measurement car) reached the speed of 200.4 km/h on its mainline track from Hamburg to Berlin, (between Friesack and Vietztnitz), setting a world record speed for steam locomotives and all operational railway vehicles used for public transportation (Fig. 2 and 3).

During this epoch, the theoretical investigations of the running behaviour had only been based on static methods (Heumann Theory). Nowadays, we know that the track guidance of railway vehicles includes a stability problem due to the contact of wheel and rail. The corresponding linear theory was already stated by the French scientists M. Julien and Y. Rochard in 1935. Due to the non-existence of computers, this knowledge fell into oblivion. The office of research and experiment (ORE) of the International Union of Railways (UIC) sponsored a competition in finding a theoretical description of the running stability of railway vehicles. The Japanese researcher Matsudaira re-investigated the linear theory and presented his prize winning paper in 1957.

With steam locomotives, neither elastomeric suspension elements nor hydraulic dampers can be found. All mechanical damping, which is needed for a sufficient running stability, is provided with Coulombic friction in the plates between the bogie and wagon frame and in the leaf springs. Leaf springs are often connected in series with flexcoil springs to get the desired non-linear suspension characteristic with damping behaviour depending on the amplitude.
Instead of the linear stability analysis, MBS time domain simulations using the non-linear simulation model have to be used for the stability analysis.

**WORKING GROUP OF STUDENTS AT THE UNIVERSITY OF STUTTGART**

J. Eckstein, A. Heer and Ch. Wiese (students at the University of Stuttgart), set up a SIMPACK simulation model of the DR 05 steam locomotive. All their efforts were devoted to the investigation of the historical technology of the German type 05 high speed steam locomotive.

Copies of the original manufacturing drawing of the locomotive were provided by the company MÄRKLIN in Göppingen. Thanks to MÄRKLIN possessing and retaining a great stock of historical drawings, the students were able to perform their work.

With this support, the student group could model the main parts of the DR 05 in a CAD-System (Fig. 4) which delivered extremely accurate data for the mass properties (i.e. mass, inertias, c.g.).

All these parts were exported to SIMPACK to set up the simulation model and the graphical representation (Fig. 5 and 6).

**THE DRIVING WHEELS**

As is the rule with all multi-axle steam locomotives, the axle load balancing device uses a series of leaf springs, balancing levers, flexcoil springs and connecting tensioning bolts. The vertical force is distributed evenly over the three driving wheels on each side. Thus, the three driving wheelsets with a diameter of 2.3 m do not provide any pitch stiffness to the locomotive frame. The vertical support of the front and the rear trailer bogie stabilize the locomotive pitch motion. The wheel flanges of the middle wheelset have thinner wheel rims than the other wheels in order to improve the curving behaviour.

**THE FRONT TRAILER BOGIE**

The front trailer bogie is designed in the classical steam locomotive design with the axle bearings guided with sliding shoes. The respective load of the locomotive is connected to each side of the bogie using a horizontal friction slide element. Each element lies on the top of a leaf spring package which is serially connected with flexcoil springs at both ends. The flexcoil springs are supported by two levers that fit into the axle bearing boxes. The horizontal guidance of the bogie frame is provided with a pivot pin, which can move laterally on a sled, ±75 mm. Two pre-stressed leaf springs provide the centring force for the pivot pin.

**THE REAR TRAILER BOGIE**

The rear trailer bogie is designed with outside mounted axle bearings. The respective vertical load of the locomotive is suspended directly on the bogie frame with intermediate friction slide elements. In the vertical direction, the bogie frame is suspended with leaf spring packages and flexcoil springs connected in series with the axle boxes. The pivot pin on the bogie frame can also move laterally.

**THE TENDER**

The tender which carries the supply of coal and water with a weight of up to 47 tons is equipped with a leading two-axle bogie and three trailing axles, which are directly guided into the ten-
Enhanced Flexible Body Simulation in SIMPACK 8.902

SIMPACK 8.902 contains several enhancements of flexible bodies. The handling of markers has been improved to handle different versions of a flexible body with ease. To enable full EHD (Elasto Hydro Dynamic) capabilities and a detailed graphical representation of deformation, internal nodes of reduced finite element models may be recovered from the deformation states. Additionally, some numerical problems due to an inaccurate representation of inertia forces have been solved.

NEW MARKER HANDLING ON FLEXIBLE BODIES

In order to make the handling of design versions of flexible bodies easier, in SIMPACK version 8.902, the handling of markers on flexible bodies has been completely redesigned. Version 8.902 now makes a stringent distinction between markers and nodes. Markers are generated in SIMPACK to connect the flexible body with the multi-body system by joints, force elements or constraints, whereas nodes are always entities of the finite element model. Thus, markers and nodes can be connected by the user in any desired arrangement. Backward compatibility is guaranteed by retaining the well-known automatic interpolation of markers on flexible bodies, which is now called "classic connection". In this case, up to four nodes that are input to the interpolation of the marker are automatically determined by their shortest distance to the marker.

To avoid an increasing number of markers in the case of new design versions, markers are no longer automatically generated when reading an SID file. The generation of markers is now done by the user in the new "options" tab of the body definition dialogue (see Fig. 1).

When loading a new version of a flexible body, its markers no longer have to be congruent with the new node positions (see e.g. Fig 4). Therefore, three new types of connections between markers and nodes have been added. The user-defined connection allows the user to manually select up to four nodes that are used as input for the in-

Fig. 6: SIMPACK model of the tender

Fig 7: Unstable hunting of the locomotive at 260 km/h

Reference Article:
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