STRESS CALCULATION DURING THE MOTION OF A PROTOTYPE CAR: NUMERICAL VS EXPERIMENTAL RESULTS

J. Cuadrado, R. Gutiérrez, M.A. Naya and M. González
Departamento de Ingeniería Industrial II - Escuela Politécnica Superior
Mendizábal s/n, Campus de Esteiro, 15403 Ferrol, SPAIN
E-mail: javicuad@cdf.udc.es

Conference topic: C

Numerical methods for the dynamics of flexible multibody systems have been developed by the related scientific and technical community during the last two or three decades. However, most examples which can be found in the bibliography are academic and very simple. The solution of realistic and complex problems along with their corresponding experimental validation, will be useful to evaluate the different formulations available, and will make them more valuable for the industrial world.

On the other hand, stress calculation is essential for the mechanical design of machines and mechanisms. An adequate way to numerically solve this problem consists of modeling the flexibility of those links whose stresses are of interest for the designer. In the experimental field, the well-established technique of extensometry enables the measurement of the stresses suffered by the actual components.

Therefore, the dynamic simulation of realistic and complex multibody systems giving as output the stresses undergone by components during the motion, and the comparison with the corresponding experimental results, should be addressed in order to credit the validity of a certain numerical method.

In this work, the abovementioned objective has been addressed. A prototype car has been taken as an example of complex and realistic multibody system. The actual vehicle has been built and its virtual counterpart has been implemented on a computer. In what follows, details of both the experimental and virtual systems are given.

The prototype car has been manufactured in steel tubing and parts from old cars have been cannibalized and conveniently adapted (i.e. engine, suspension and steering systems, etc.).

To obtain the motion of the car, four triaxial accelerometers have been attached to the chassis at the four corners of its base. Obviously, the twelve components are related through six constraint equations, given by the rigid body conditions. Accelerations provided by the sensors should be integrated twice in order to obtain the position of the chassis at all times. Moreover, signals of the accelerometers cannot be directly integrated as long as they are expressed in a local moving reference frame.

Therefore, to overcome this problem and, simultaneously, clean the accelerations provided by the sensors and assure that they satisfy the abovementioned constraints, a penalty formulation has been developed. In such formulation, the constraints and their first and second derivatives are introduced, amplified by a penalty factor, in the equation that transforms sensor accelerations to the inertial frame. In this way, accelerations expressed in the global frame are obtained and integrated by means of a numerical integration scheme.

On the other hand, in order to measure bending and torsional stresses, four Wheatstone bridges have been installed at four points of the chassis. Two of them are half-bridges, with an upper and a lower band each, to measure the normal bending stresses on the steel tubes surfaces. The other two are full-bridges, with two upper and two lower gauges at 45º to the tube axis, to measure the corresponding shear torsional stresses.

The sixteen captured signals –twelve accelerations and four strains– are recorded by a laptop personal computer after passing through a data-adquisition board, and local accelerations provided by the accelerometers are integrated in real-time and also stored in the PC.

The corresponding virtual system has been modeled in natural coordinates. The chassis in steel tubing has been considered as flexible, using the moving frame approach with static and dynamic deformation modes. All the other bodies of the car have been considered as rigid. The dynamic equations of motion have been set through an index-3 augmented Lagrangian formulation. For integration purposes, the unconditionally-stable single-step implicit trapezoidal rule has been applied.

To improve the convergence ratio, the integrator and the dynamic equations are merged in the following way: velocities and accelerations are expressed as functions of positions using the relationships provided by the integrator; then, all the kinematic variables are substituted into the dynamic equations, leading to a non-linear system of equations where positions are the unknowns; such system is solved through an iterative Newton-Raphson procedure, with an approximate tangent matrix.

Once convergence is attained, the new positions properly fulfill the constraints. However, velocities and accelerations, worked out through the integrator equations, do not satisfy the first and second derivatives of the constraints. Therefore, in order to clean the new velocites and accelerations, and force them to satisfy the constraints, mass-damping-stiffness-orthogonal projections are carried out. The leading matrix for both the projections in velocities and accelerations is the same, and is also coincident with the leading matrix of the Newton-Raphson iteration.

In order to reproduce at the virtual analysis the manoeuvre performed with the real car, rigid body positions of the chassis are recovered from the experimental test, and used to kinematically guide the forward motion of the chassis local reference frame.

Two manoeuvres have been carried out. In the first one, the car travels direct at an approximate speed of 5 m/s, and drops down a kerb of 12 cm height. In this way, the bending modes of the chassis are excited. In the second manoeuvre, the car also travels direct and drops down the same kerb, which this time only affects the right-hand-side tires. Thus, the torsional modes of the chassis are activated.

Finally, results of stresses obtained for both the experimental and virtual procedures are compared and correlation is established based on such results.