Keeping on Track with Sercos

eMotion-4000-8DOF from Bosch Rexroth is the basis for Europe's largest driving simulator. True-to-life vehicle movements enable realistic driving behavior.

Most simulation systems are very costly tools. Examples include numerical models calculated on high-performance computers for the predetermination of crash situations, flight simulators for the training of airplane staff, and the simulation of ocean waves for hydrodynamic research. They are not an end in themselves, but an economically optimized methodology, used instead of tests on real objects in real environments. It's similar in the research and optimization of driver/vehicle interaction in driving simulators. The more realistic the simulation, the better the results.

The largest driving simulator in Europe was commissioned in summer 2012 at the University of Stuttgart. The simulator was developed to improve the energy efficiency and safety of road vehicles. Bosch Rexroth was chosen to provide the advanced motion system, the heart of which is eMotion-4000-8DOF with its nerve cord, the Sercos ring.

The Bosch Rexroth Boxtel (NL) location has accumulated decades of experience in the development of vehicle simulation systems. The company has worked with airplane and automobile manufacturers since 1986 to simulate movements as realistically as possible. Since then, a large number of hydraulically and electrically operated systems have been built. These systems offer 2 to 8 degrees of freedom and handle loads of up to 14,000 kg (electrical eMotion systems).

Driving simulator for research

In 2009, the University of Stuttgart first approached Bosch Rexroth regarding the development and setup of the largest driving simulator in Europe. The intention was to employ this simulator for the automotive industry and other research institutes in order to conduct detailed research without having to carry out actual road tests. Examples include research on driving characteristics of new vehicle types, or the influence of 'assistant systems' on driving style. Such systems include brake controls and collision-prevention functions, which contribute to reduced fuel consumption and increased safety.

A key advantage of a driving simulator compared to actual road tests is the fact that test drivers always drive under identical conditions. For example, they are not exposed to different weather and traffic conditions. Thus, the necessary measurements are more precise and reliable and allow better comparison studies. Additionally, simulators allow situations to be simulated that would be too dangerous with real people and vehicles.

To draw accurate conclusions from the test results, it is important that the simulated world perceived by the test person be as realistic as possible. For vehicle tests, this requires the complex interplay of visualization (what the driver sees inside and outside the vehicle) and motion (what the driver feels during the execution of the driving actions).

Europe's largest driving simulator is housed at the University of Stuttgart and can handle a payload of 4,000 kg. This allows tests with a complete vehicle.

Structure

To implement both visualization and vehicle motion as realistically as possible, the simulator contains a passenger car that is placed in a dome. The car's engine compartment is filled with electronics. The internal equipment is identical to that of its real counterpart. LED projectors project a 360° panorama of the virtual environment onto the inside of the dome.

Motion system

An eMotion-4000-8DOF motion system from Bosch Rexroth is installed in the simulator to ensure that the driver convincingly feels acceleration, deceleration, and other forces as a result of his actions in the test vehicle. This is an 8-axis system, comprised of a powerful hexapod and an XY table combined with an advanced control system. The structure of the complete system begins with 3 parallel rails (X direction), anchored to the concrete floor. A gantry is then positioned that can move along these rails, driven by four synchronous AC motors and a rack and pinion drive. Two parallel rails (Y direction) are then mounted atop the gantry, creating an XY table. Linear rail guides are used for motion along the rails to optimize the movement of the XY table and ensure a low noise level. Synthetic bearing cages also contribute to the low noise level. Mechanical end stops are mounted to prevent the gantry from running off the rails, and to absorb simulator movement in an emergency situation.

The eMotion-4000 hexapod is mounted on the gantry system. It moves over the gantry system in the Y direction, driven by two AC servomotors (and likewise employs a rack and pinion principle). The hexapod includes six electric-powered actuators, on which the dome is mounted via six universal joints. Thus, the entire electrical system ultimately results in 8 degrees of freedom: two from the XY table, and the other six from the hexapod itself. The complete system can carry a maximum mass of 4,000 kg; including the dome, the vehicle, the projectors, and the test driver. Within a movement envelope of 10 m x 7 m, a maximum speed of 3 m/s and a maximum acceleration of 5 m/s2 can be achieved.

In the dome: The projectors can be seen above the vehicle.

AC servomotors move the hexapod over the gantry system in the Y direction

Realistic simulation

The combination of the XY system and hexapod makes it possible to simulate the accelerations and forces described. Because all degrees of freedom of the hexapod are supported by the six electric motors, the movements can be executed in a particularly powerful fashion. This results in strong, immediate accelerations that the driver experiences as forces with a magnitude and timing that closely resemble the forces experienced in a real-world driving situation.

An acceleration or deceleration (braking) process is simulated by combining two movements: forward/backward motion and tilting. This tilting makes use of gravity to press the driver into his seat when accelerating or to lift him out of his seat when braking. If the hexapod alone was used to create these two movements, a 'dip' would be created in the sense of acceleration, potentially disrupting the illusion. This is prevented by having the XY table take over the forward or backward movement from the hexapod before it reaches the end of its stroke. At the same time, it is important that the takeover of the movements be very carefully controlled, so that the test driver does not simultaneously experience being tilted.

System Control

The system can make every required movement needed to simulate a realistic environment. The trick is to translate all movements, speeds, and accelerations of the vehicle into movement and positioning of the motion system. Two control cabinets are used: one for the eMotion-4000 hexapod and one for the XY table. Both control cabinets facilitate signal exchange with customer-specific systems, and of course with the actuators of each system. The drive controllers in the cabinets are connected via Sercos® to the motion control, which runs special software developed by Bosch Rexroth. This software forms the heart of the system and ensures that the driver's actions immediately lead to the correct response from the motion system. Its response is defined by the application-specific S-parameter values (standardized Sercos parameters), which are sent to the drive controllers via the relevant service channel during configuration or system start. This response is arranged through the motion system settings, otherwise known as motion cuing. This motion cuing is based on models from NASA and TU Delft, but has been extended by Bosch Rexroth such that the movements are significantly more realistic. Establishing the correct settings for this motion cuing is a special task that can be carried out only on a joint basis with the customer. In addition to the motion cuing, the software incorporates various special effects, for example to convincingly simulate unevenness in the road surface.

Realism and comfort during the operation of the hexapod (eMotion-4000) and the XY table depends significantly on the synchronicity of the distributed drive controllers. The Sercos bus is the only automation bus that guarantees synchronicity well below 1 µs. This is achieved via hard, real-time scheduling of the Sercos telegrams. The bus was invented in the 1980s and still represents the most efficient method of highly synchronized data transmission, independent of the number of devices in the Sercos ring.

To further improve the motion quality, the Bosch Rexroth control software not only uses target positions during the motion production, but also uses additive moment target values in order to specifically compensate for the inharmoniousness for each part of the motion profile.

All data pertaining to a specific vehicle can be entered via the customer's host software (running on a separate computer), so that the motion system knows how to respond to the test driver's actions. This software is also responsible for projecting the correct images inside the dome.

Final result

The driving simulator is an advanced system that enables a variety of research to be carried out. The combination of true-to-life simulation of vehicle movement and the 360° panoramic view from the driver's position behind the steering wheel evoke realistic behavior on the part of the driver, so that serious research can be performed into specific aspects such as safety and energy-efficient driving. For the future, Bosch Rexroth is working on reaching even higher speeds and accelerations in order to make the system even more dynamic.

The reliability of the eMotion-4000 will be increased in the future through the ring redundancy function of the Sercos III network. The eMotion-4000 benefits from the expansion to include the Sercos automation bus. Due to the high usable bandwidth, all other peripheral devices, such as fast I/O for acceleration sensors or safety controls, can be operated via the Sercos ring. The whole system can be operated in a very energy-efficient manner using the native Sercos drive profile functions and the energy-saving and monitoring functions defined by Sercos Energy for all devices.

Future EMotion-4000 automation system structure based on Sercos III

Ethernet communication protocol

- Ethernet based
- 100 Hz communication

Hypcos (RT-linux based control system)

- Advanced Motion Control
- Motion cueing
- Test features
- Troubleshooting and error handling
- Interface between customer and motion

Sercos III

- Ethernet based
- 1 kHz communication

Control cabinet

- Indradrive HCS01
- Relays & I/O connections

- Design in accordance with EMC
- Designed for 4EE
- Safety onboard

Motors

- MSK motors
- Multiturn encoder
- Brake

From 1,000 kg to 4,000 kg

Bosch Rexroth has an interesting history when it comes to the development of affordable alternatives for XY/hexapod motion systems. Their first 1,000 kg system was installed at Renault in 2003, as part of the Ultimate simulator. A 2,500 kg system followed in 2005 at Leeds University, a 1,000 kg system at PSA (Peugeot Citroën), and a 2,500 kg system at VTI in Sweden. An additional system was installed at the University of Tongji, China. The system at the University of Stuttgart is the first 4,000 kg XY/hexapod system installed by Bosch Rexroth. A system with even higher performance and a 6,000 kg hexapod will be installed in Korea in 2018.