Higher, Faster, Further

Active damping control for turntable ladders

Turntable ladders nowadays are required to go higher, faster, further – and be safer. Lightweight construction is the key to achieving these goals. But there is a problem: The new lightweight ladders tend to suffer from bending oscillations. The Institute for System Dynamics at the Universität Stuttgart in Germany used dSPACE tools to develop an active damping control for the manufacturer IVECO MAGIRUS Brandschutztechnik.

Turntable ladders, the most distinctive item of equipment used in fire rescues and firefighting, can reach working heights of up to 55 m. Once a ladder's base is in position, the ladder itself has to reach rescue height in minimum time. Modern vehicles take far less time for this than the standard of 180 s that applies to the 30-meter ladders generally used in Germany. The extensible ladder is mounted on a hydraulic turntable and can be raised and tilted by two hydraulic cylinders. A 30-meter telescopic ladder can span more than 17 m horizontally – this is called outreach – and a load of up to 300 kg can be transported in the cage. With their requisite lightweight construction and considerable length, turntable ladders have limited flexural stiffness. So when they move, flexural vibrations are induced. External forces like the wind and load variations caused by the people in the rescue cage also cause vibrations. The usual way of countering this effect is to greatly reduce the speed of motion – which is far from ideal in an emergency rescue. Moreover, slow deflection movements impair the safety and comfort of the ladder.

Joint Research Project by the Institute for System Dynamics and IVECO MAGIRUS

Active damping of these flexural vibrations is therefore the main focus of a research project that has been running continuously since 1998, in close cooperation between the Institute for System Dynamics and IVECO MAGIRUS. Active damping control has been one of the standard features of the new CS ladder series (CS = computer-stabilized) since 2001. Combined with a memory function, it is one of the main reasons why the CS

IVECO MAGIRUS DLK 23-12 CS with rescue cage in action.

models have been so successful. Active damping control gives the CS ladders from IVECO MAGIRUS a unique selling point on the market. More than 700 vehicles with CS in their name are now in action worldwide. And the Institute for System Dynamics is continuing its cooperation with IVECO MAGIRUS, performing ongoing research and development to make the control even more effective. Now the third generation is just coming up to production level. It actively damps not only the fundamental frequency of the vibration, but also its harmonic frequencies.

> "The ControlDesk software provides numerous options for editing and managing various experiments, setups, and measurement signals simply via drag & drop."
>
> *Nico Zimmert, Institute for System Dynamics, Universität Stuttgart*

The Ladder's Movements

The operator controls the ladder's movements from the console on the vehicle or in the cage. The bending vibrations are captured by two different sensor systems. One of them consists of strain gauges on the ladder set not far from its mount. These detect the material strain caused by the ladder bending and output the elongation in its longitudinal and lateral directions. The other system consists of gyroscopes at the tip of the ladder. These measure the changes in its position, or more precisely, its rotational speed, in all three spatial directions. The vertical and horizontal deflection, and also the torsion of the ladder, are obtained from these two measurement systems by model-based analyses. Incremental encoders on each rotational axis are used to determine the angles of elevation and rotation. The ladder's current length is also ascertained by means of incremental encoders. The processor captures all the turntable ladder's states from the sensors immediately. It condenses and evaluates the incoming data, and converts it into suitable control signals for the hydraulic drives via model-based controller modules – all in a fraction of a second. The ladder's movements basically follow the operator's inputs. At the same time, its bending vibrations are actively suppressed by hydraulic drives, with a gentle counter-control that is hardly perceptible to the operator.

IVECO MAGIRUS DLK 55 CS with elevator and rescue cage ready for operation.

Advantages of Active Damping Control

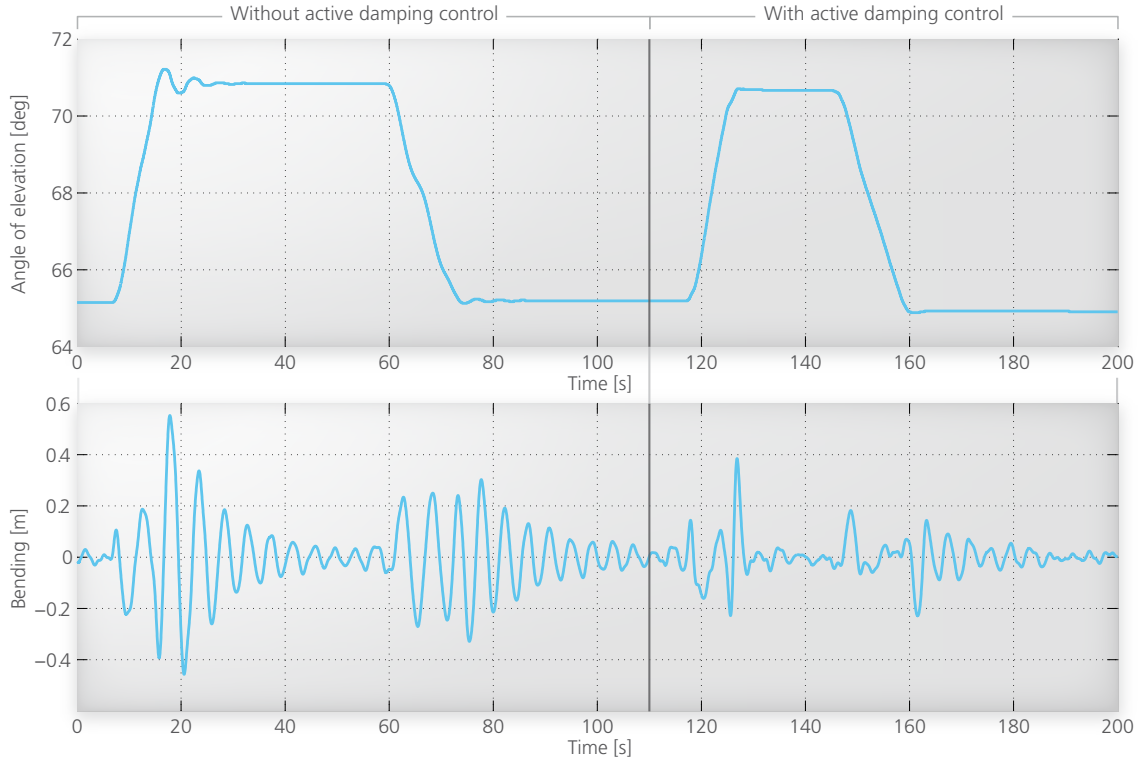
Using the active damping control software increases the stiffness of the overall system, making it possible to reach the rescue position much more quickly and safely. The speed of motion can be increased because reducing the bending and weight also reduces the dynamic forces. Moreover, because it is systematically designed to be lightweight, the vehicle has a low total weight. This means a longer outreach can be achieved from the same base. A rescue cage can hold only three to four people, so a memory function was developed for rescuing several people from the same rescue point. The operator specifies the trajectory between the rescue point and the ground during a teach-in operation. This trajectory can then be repeated within a preset tolerance and at maximum speed. The operator can specify at any time whether the trajectory should be repeated at maximum speed or more slowly. He or she can even stop the ladder at any point and reverse the direction of its trajectory. This provides great flexibility for work at the rescue location.

Model-Based Development

The active damping control was developed by model-based design, and all the control laws are available in analytical form. This means that the algorithm can always be adapted if parameters such as the ladder's length and payload are changed. The control has two degrees of freedom, that is, there is a feedforward control and a feedback control that can be designed separately. The feedforward control is designed so that only a minimum of bending or vibrations are induced in the ladder. The feedback control uses the sensor data to compensate the bending vibrations that occur despite the feedforward control, e.g. due to external disturbances. In the new

The Benefits of Active Damping Control:

- Greater safety for people and machine by reduced bending and other vibrations
- Faster ladder motion (especially with the memory function)
- More precise positioning
- Longer outreach and enhanced stability due to additional weight savings
- Greater comfort



Comparison of deflection at the ladder's tip and of the elevation angle of a DLK 55 CS while being raised at approx. 50 m ladder length, without and with active damping control.

IVECO MAGIRUS DLK 55 CS with elevator and rescue cage ready for operation.

generation of the active damping control, the higher eigenfrequencies of the ladder are also actively damped.

Test System Setup

During the design phase for the active damping control, we use a dSPACE prototyping system based on a DS1103 PPC Controller Board. The board communicates with the vehicle's ECU via the CAN bus and reads out all the necessary measurement data. The CAN communication can be set up quickly and simply with the dSPACE RTI CAN Blockset. During this phase, dSPACE's ControlDesk software provides numerous options for editing and managing various experiments, setups, and measurement signals via drag & drop. We use these to run experiments capturing static and dynamic variables so that we can identify parameters for model-based control design. Then we develop the control algorithms in the MATLAB®/Simulink®

dSPACE Products in Use:

- DS1103 PPC Controller Board as a controller module in the vehicle control during development
- Real-Time Interface to integrate the bus and additional measurement devices during identification
- RTI CAN Blockset for communication with the vehicle CAN
- ControlDesk to experiment with the active damping control
- TargetLink for autocoding to port the control algorithms to the microcontroller hardware
- Autoscaling tool to scale the fixed-point calculations automatically

> "With the dSPACE prototyping system, we can develop and test the active damping control quickly."
>
> *Nico Zimmert, Institute for System Dynamics, Universität Stuttgart*

environment and study their functionality and the initial design by means of simulations.
The next step is to test the algorithms on the actual vehicle, using the DS1103. The hand lever signals from the operating console are read, appropriately manipulated, and then transmitted to the ECU via CAN. This procedure lets us run intensive tests, fine-tune the control, and implement a new controller concept quickly and with very few hardware adaptations.

The TargetLink production code generator is used to implement the algorithms on the vehicle's ECU. The microcontroller in the ECU uses fixed-point arithmetic, so TargetLink automatically generates fixed-point source code in ANSI-C in the algorithms. The autoscaling tool, together with the ability to simulate algorithms in both floating-point arithmetic (by model-in-the-loop simulation) and fixed-point arithmetic (by software-in-the-loop simulation), make it possible to verify the algorithms

early in the design phase. And with the extensive simulation functions, it is easy to scale the complex mathematical calculations. dSPACE's integrated tool chain guarantees fast, consistent portation of the algorithms from the MATLAB/Simulink environment to the ECU.

Conclusion

The research project is an example of successful cooperation between a university institute and an industrial company. The Institute for System Dynamics not only plays a role in developing the technology, but also provides support throughout the project, from the prototype and the preproduction vehicle to the production vehicle. Product-related innovations can be designed efficiently, quickly, and successfully for both sides in this way.

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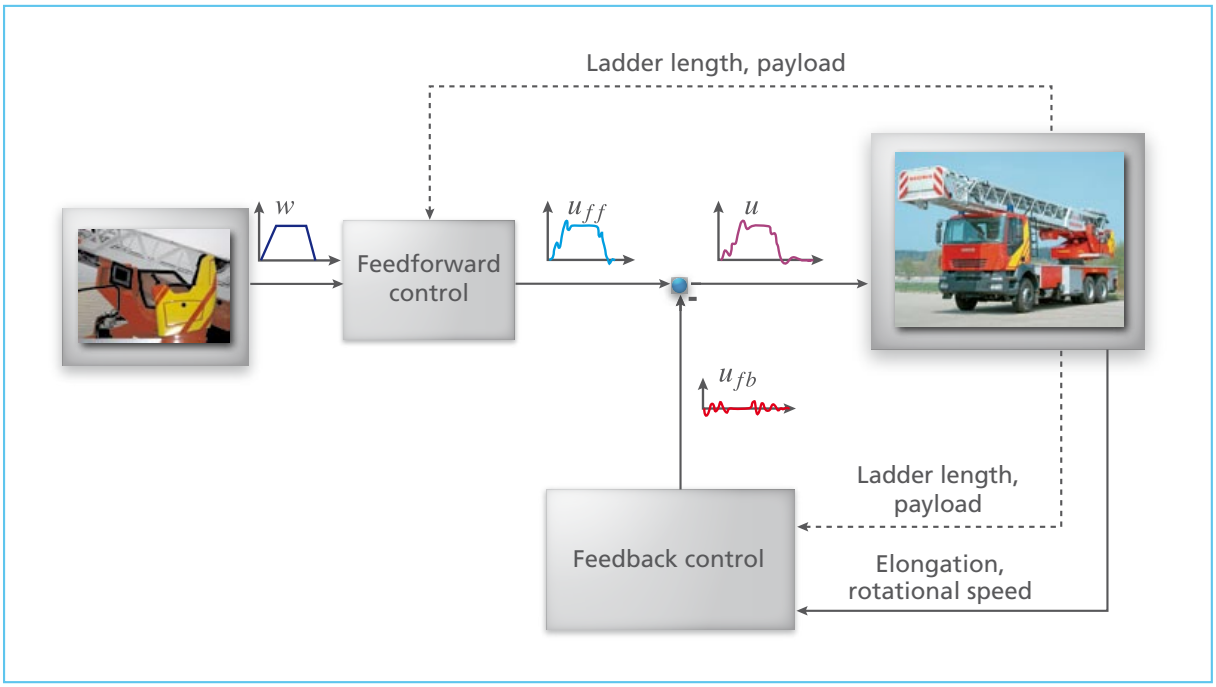
The Institute for System Dynamics

Research at this institute at Universität Stuttgart is mainly concerned with analyzing the dynamics of systems. The researchers use methods from system theory, modeling, simulation, control engineering and optimization, which they develop further. They study systems from widely differing fields, such as mechatronics, process engineering, traffic regulation, and biology. The result is an interdisplinary scenario that integrates all sorts of different sciences. It is characteristic of the institute that it not only performs basic research on developing methods, but also investigates how to implement the methods in automation engineering.

IVECO MAGIRUS Brandschutztechnik

At six locations throughout Europe, IVECO MAGIRUS produces a wide range of vehicles and equipment for fire protection and disaster control. With more than 1,300 vehicle units sold a year, IVECO MAGIRUS is one of the world's largest providers in this sector. The MAGIRUS brand is the global market leader for turntable ladders.



How the 2-DOF control works: The ladder length and the payload are parameters that vary over time and are used to adapt the control.