# ADAMS SIMULATION FOR ROPEWAY TECHNOLOGY

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INTRODUCTION

Ropeways, also called cableways, rank among the oldest transportation systems. On old Chinese ink drawings (around 300 BC) people are transported over rivers and canyons by means of hemp ropes and straw baskets. Even nowadays, ropeways are often the only means of transportation in impassable terrain. Ropeways are used for transportation of goods, as well as for carrying people. Meanwhile passenger-ropeways are not only build in mountain regions and ski-resorts, but also for public transport and as sightseeing-installations in amusement parks (e. g. EXPO-Ropeway 2000 in Hannover).
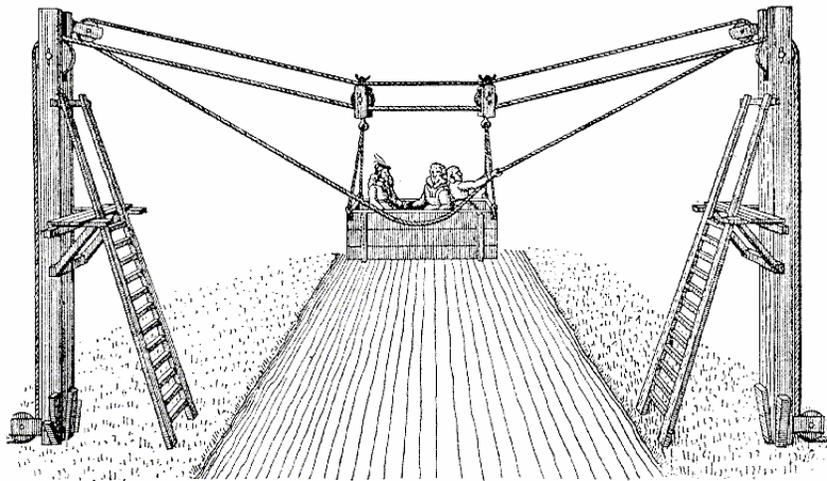
Fig. 1: Historical example -
ropeway of Faustus Verantius (16th century)
to cross a river

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This contribution deals exclusively with aerial ropeways. At these constructions the vehicles are carried *and* propelled by wire ropes. Another major ropeway group are the funicular railways where the vehicles are propelled by ropes, but run on fixed rails.
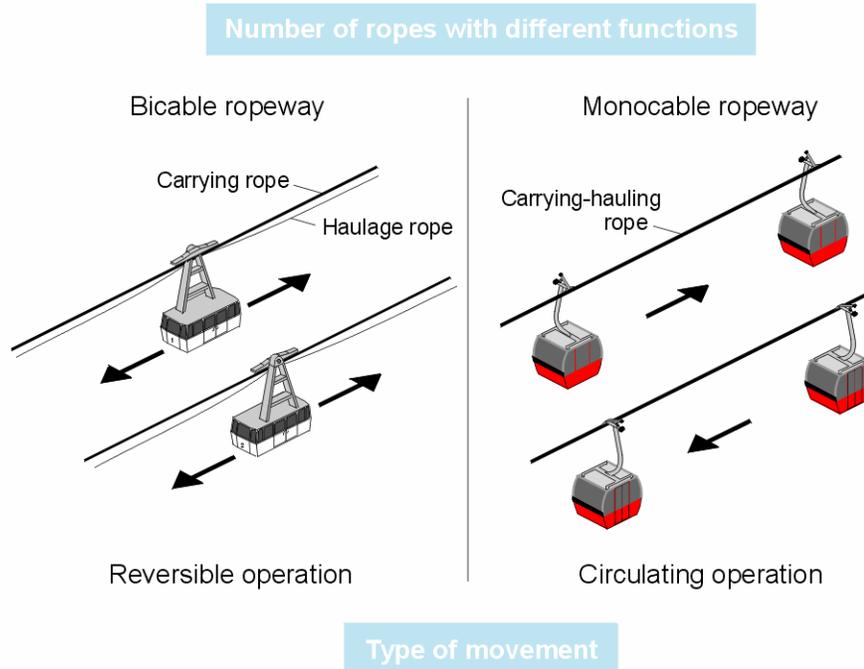

Fig. 2: Classification of ropeways

Aerial ropeways can be grouped by two main criteria (Fig. 2). The *number of ropes with different functions* and the *type of movement.*

At *bicable ropeways* you find one (ore more) carrying ropes along which the vehicle rolls by means of its carriage, and one (ore more) haulage ropes which propel the vehicles. At *monocable ropeways* the function of carrying and propelling the vehicles is taken over by just one rope, the carrying-hauling rope. A special construction of monocable ropeways are the double-loop-monocables (DLM) where the vehicles are transported with two parallel situated carrying-hauling ropes.

In the case of ropeways with *reversible operation,* the vehicles oscillate back and forth between the stations on the same track by inverting the hauling ropes direction of motion. At *circulating operation* ropeways the vehicles are propelled by constant or intermittent running ropes. Up- and downhill transportation takes place in different tracks. Circulating ropeways can be further subdivided into *detachable* and *fixed* installations. Whereas the carriers are permanently attached to the haulage or carrying-hauling rope at fixed ropeways, they are detached and re-attached in the stations at detachable systems.

In addition to that, ropeway constructions exist in various combinations of above-mentioned criteria (e. g. reversible monocable ropeway, circulating bicable ropeway).

Fig. 3: Different types of aerial ropeways

This article focuses on the problems of detachable circulating monocable ropeways (DCMR). This type of ropeway is selected for most new or reconstructed installations as a result of its high riding comfort and transport capacity.

PROBLEM DEFINITION

Vehicles of detachable circulating monocable ropeways (DCMR) are exposed to high dynamic loads during normal operation, in particular the rope grip and the hanger. Maximum loads are acting while crossing the towers, and much more at stations entry. In the interest of increased economy and ride comfort, the trend on modern DCMRs goes to:

- even larger carriers (up to 15 persons per carrier),
- raised operating speeds (up to 6 m/s),
- smaller and more compact terminal buildings.

All those facts are increasing the dynamic stresses on the components in a considerable way. Compared with this, ropeway manufacturers operate with no longer up to date dimensioning methods when considering modern ways of calculations.

Loads and stresses at stations entry

With DCMRs, the vehicles are able to pass from one terminal to the other at higher speeds than with comparable fixed gripped installations. In addition to that, a slower terminal conveying transit speed ensures comfortable passenger-loading and -unloading inside the terminals. To make uncoupling safe the vehicles, which may undergo a horizontal pendulum motion due to lateral winds or eccentric load arrangement inside the carrier, have to be adjusted to a horizontal position at the beginning of the stations entry.

Fig. 4: Catching device at the top-station of a 6-seater chairlift

For this reason, the stations are equipped with special „catching devices". At modern installations they are executed in form of entry centerings (see fig. 4) – also called entry

trumpet. The entry trumpet traps the rope grip at its guide roller and adjusts it to a horizontal position due to its funnel-shaped geometry. It is mounted via a swivel joint flush with the guide rail of the terminal. Outside the terminal the trumpet is elastically suspended by means of a spring/damper system, so it can perform a rotary movement about the bearing point when hit by the guide roller of the grip (see fig. 5).

The vehicles moment of inertia, in addition with the lever action between grip and carrier, causes considerable loads on the grip and the hanger during the necessary adjustment of the vehicle.
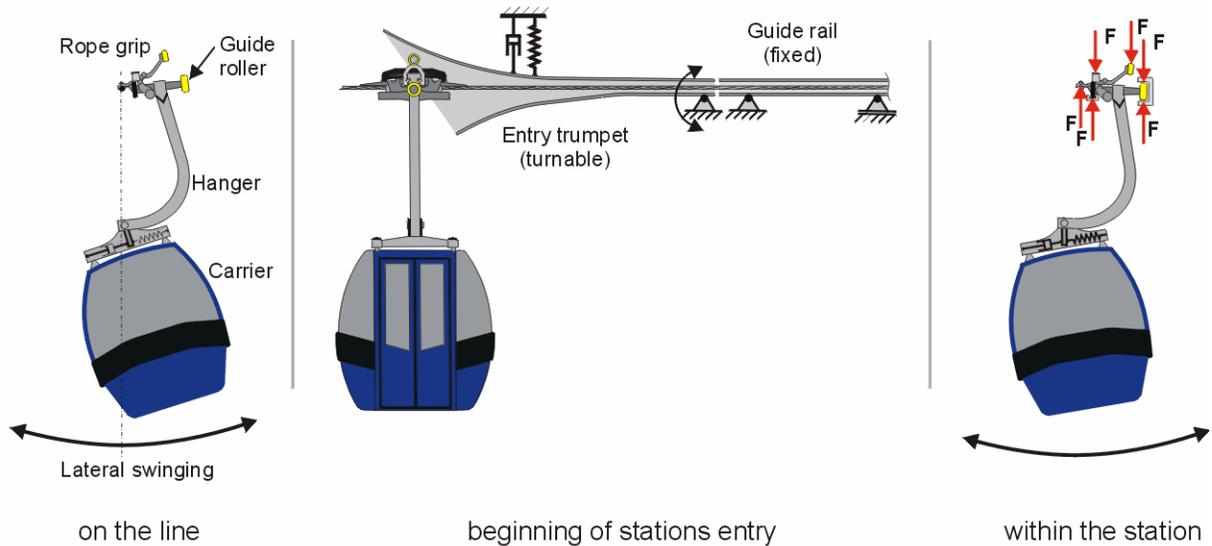

Fig.5: Terminal entry of detachable circulating monocable ropeways

Due to the tapered shape and turnable bearing of the entry trumpet the grip can undergo a pendulum angle while riding through. However, while running through the coupling rail and the deceleration area the grip must have a fixed horizontal position. This fixed grip guidance is necessary for a safe uncoupling operation and the transfer of the friction forces from the deceleration tires to the grips friction plate. But, because of the fixed grip guidance, the greatest loads and stresses on the components occur in this sections of the terminal.

Dimensioning of Parts and Equipment

For dimensioning the components, as well as for design modifications, it's essential to know exactly the forces acting on the system. Calculating stresses due to live and dead loads is not a problem. Against it, the calculation of the dynamic forces acting during the terminal entry is much more complicated, as the stations entry generates a several times overdetermined force system (fig. 5-right). For this reason the ropeway manufac-

turers are checking these stresses with measurements on real installations. But, on the one hand this method causes a great amount of time and money and, on the other hand the measurement method does not ensure detecting the worst loads occurring at stations entry.

Additionally, when considering the modern calculation methods (finite elements method, multi-body system dynamics, computer-aided simulation) detecting component loads with experimental measuring is no longer up-to-date. Furthermore, with respect to the increasing performance requirements from the customers and the general pressure of costs this strategy is surely no longer viable for the ropeway manufactures.

Objective

The above discussed problem represents a classical field of application for a multi-body system analysis. For this reason the Institute for Material Handling, Material Flow, Logistics (**fml**) at the Technical University of Munich started a research project with the following objective:

 "Simulation of stations entry of detachable circulating monocable ropeways"

The main goal of the simulation is to give the ropeway design engineer assistance with:

- Dimensioning of ropeway components.

- Optimization of stations entry with regard to decrease loads and stresses on components (e. g. optimal geometry and suspension of entry trumpet, optimal damping characteristics for mutual motion between carrier suspension and carrier).

- Detection of critical terminal entry situations.

The objective is achieved by developing a suitable mechanical model and its computation with ADAMS-View. The mechanical model is executed in a general way, so it is practical for gondolas as well as for chairlifts.

SIMULATION MODEL OF TERMINAL ENTRY

The mechanical substitute model "terminal entry" consists of three main assemblies: vehicle, terminal and carrying-hauling rope. Preliminary examinations showed that a rigid-body system is sufficient for the modelling of the entire stations entry process.

The vehicle (see fig. 6) consists of following components: rope grip (detachable), hanger, carrier-suspension, carrier and the load. The carrier can be executed as enclosed gondola, open chair, chair with weather protection device (bubble) or a special constructed load carrying device at material ropeways.
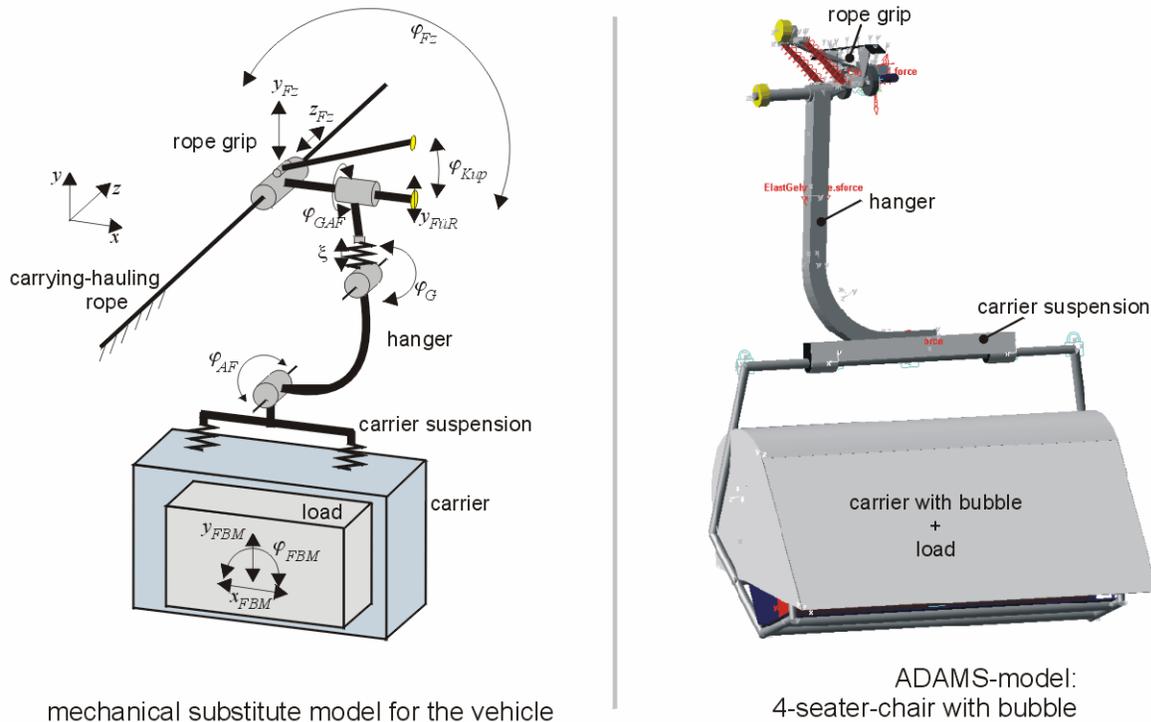

Fig. 6: Modelling of DCMR-vehicle

The rope grip is divided into two parts: grip actuating lever and main grip part. For modelling the elastic behaviour of the hanger it is split into two rigid bodies, the top and the bottom hanger, which have a turn- and displaceable connection to each other. Their mutual flexibility is restricted by means of a spring-damper-system. Therewith the vehicle has collectively up to 12^2 independent degrees of freedom (DOF).

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[2] Due to different executions of the carrier suspension the number of DOFs can decrease, for example if hanger and carrier suspension have a fixed connection.

The only moving part in the terminal is the entry trumpet. The rail system (guide rail, coupling rail and suspension rail) within the terminal is modelled with massless, non movable splines. The forces developing between the rail system and the grip are modelled with contact elements (*curve-to-curve contact*). The contact parameters are calculated by means of the equations of Hertz, which describe the forces acting between two each other touching rigid bodies.

At modern installations the deceleration device and terminal conveyor is executed as tire decelerator (-conveyor). The friction force between tire and grip is also modelled with a contact element. In this case, the contact parameters are calculated by means of a simple tire model (spring/damper).
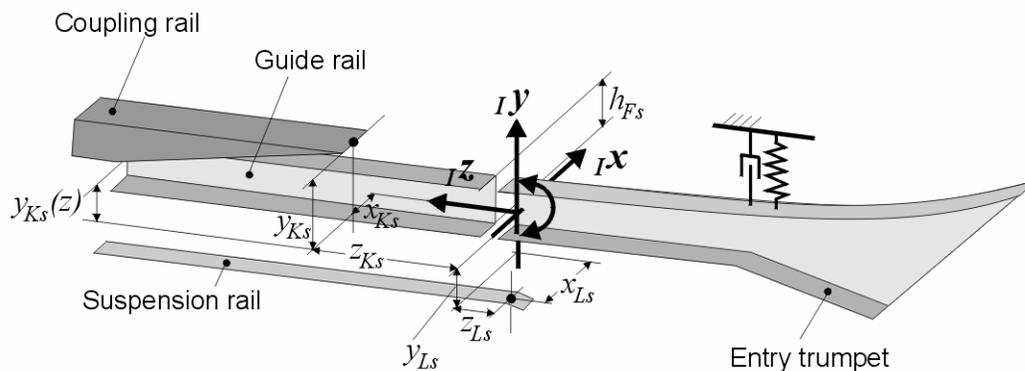

Fig. 7: Entry trumpet and rail-system of a DCMR-terminal

The rope grip is mounted via a swivel joint with the carrying hauling rope. The rope is modelled as a massless point, moving along the load travelling curve of the real rope.

The general mechanical model was adapted for a 4-seater-chairlift with bubbles and a 6-passender-gondola. The known ropeway manufactures GARAVENTA (CH) and DOPPELMAYR (A) supported the research project with extensive technical documentations. For this reason, a closed to reality performance for above mentioned installations was possible in ADAMS-View. The necessary parameters for the connection of the parts and components were found with empiric (e. g. characteristic of the damper between carrier suspension and chair) or theoretic (e. g. FEM-analysis for the elastic behaviour of the hanger) methods.

Fig. 8 shows the complete ADAMS-model for the terminal entry of a detachable 4-seater-chairlift with weather protection device.
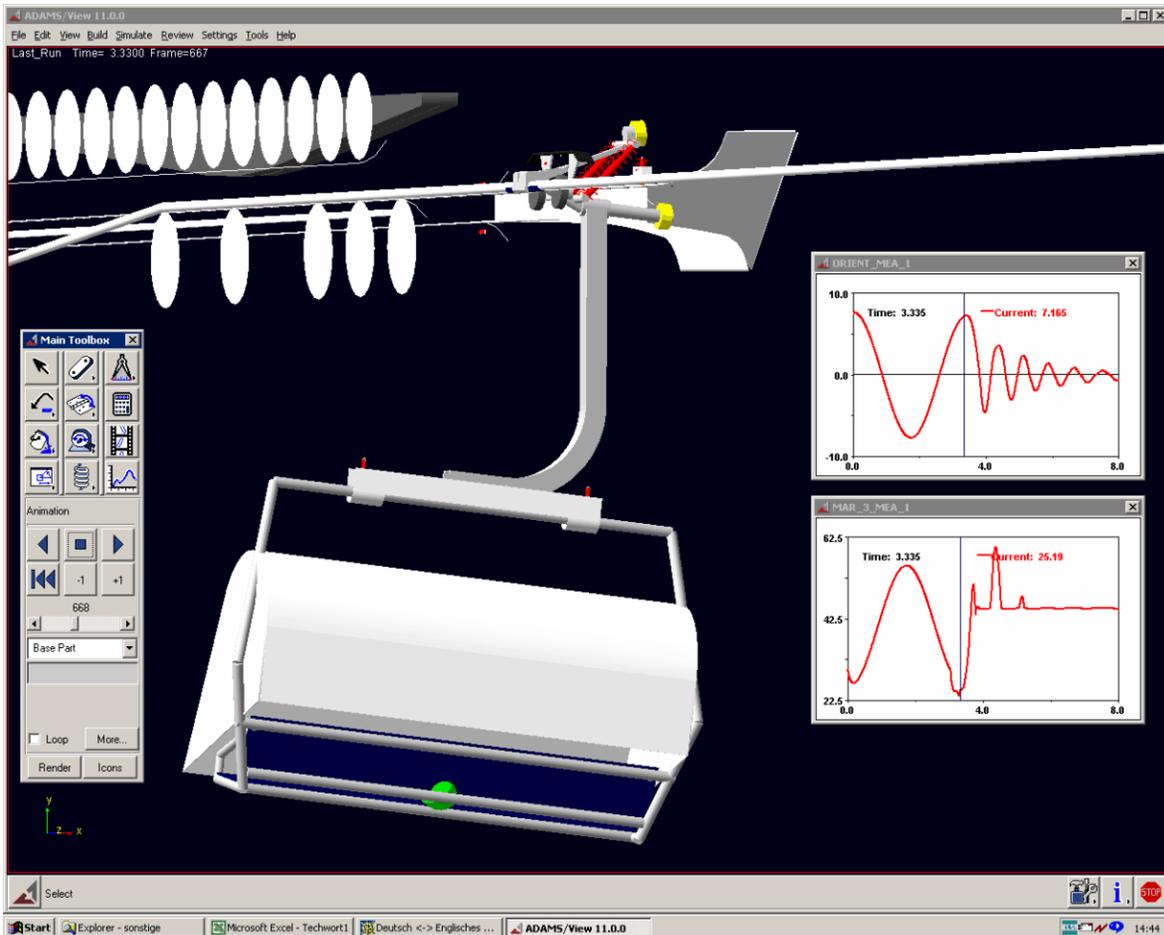
Fig. 8: Terminal entry for 4-seater-chair- DCMR

VALIDATION OF THE SIMULATION MODEL

The validation proves the usability and validity of a simulation model. As a role, a validation is done by comparison of measured and computed data. The German surveillance authorities for ropeways prescribes measurements of stations entry at new ropeway installations. Thanks to the good relationship to the authorities, the Institute fml could obtain these measured data for the validation.

Various terminal entry configurations with different loadings, pendulum angles and driving speeds were computed and compared with measured data. Most computations yield a quite satisfying result, so the simulation model can be stated as validated.

The following two figures show the comparison between measured and computed data. Fig. 9 shows the force acting on the guide roller, fig. 10 the vehicles absolute pendulum angle.
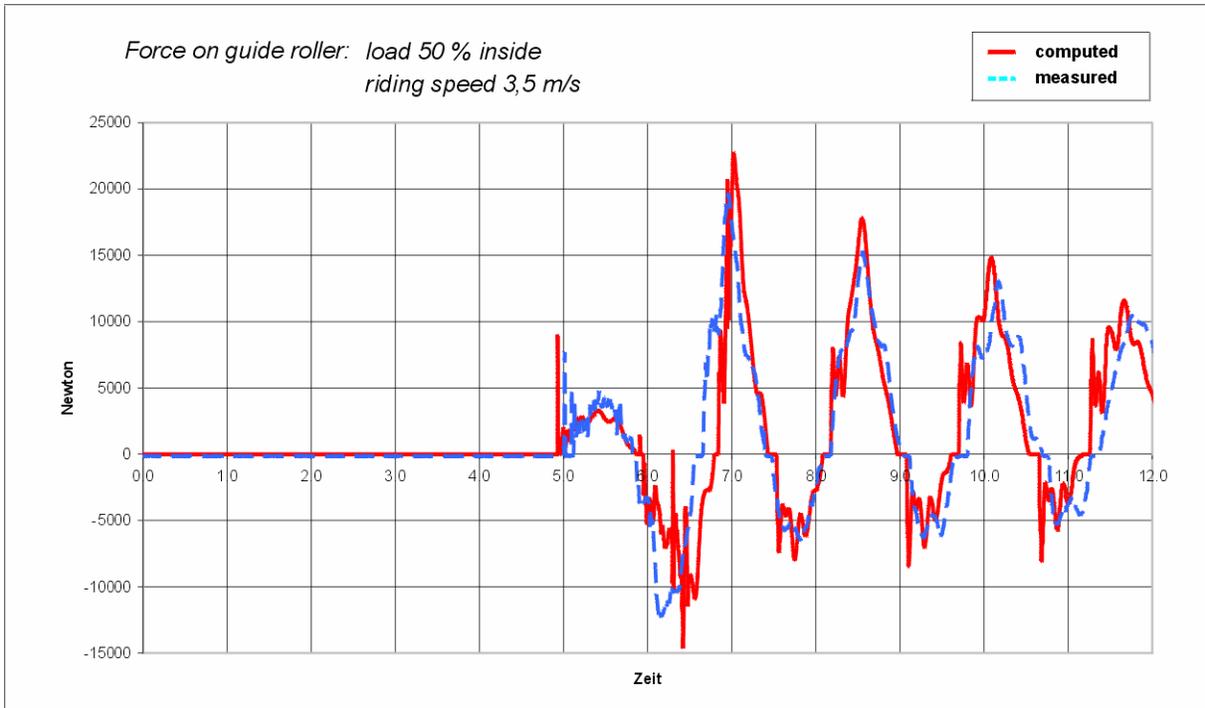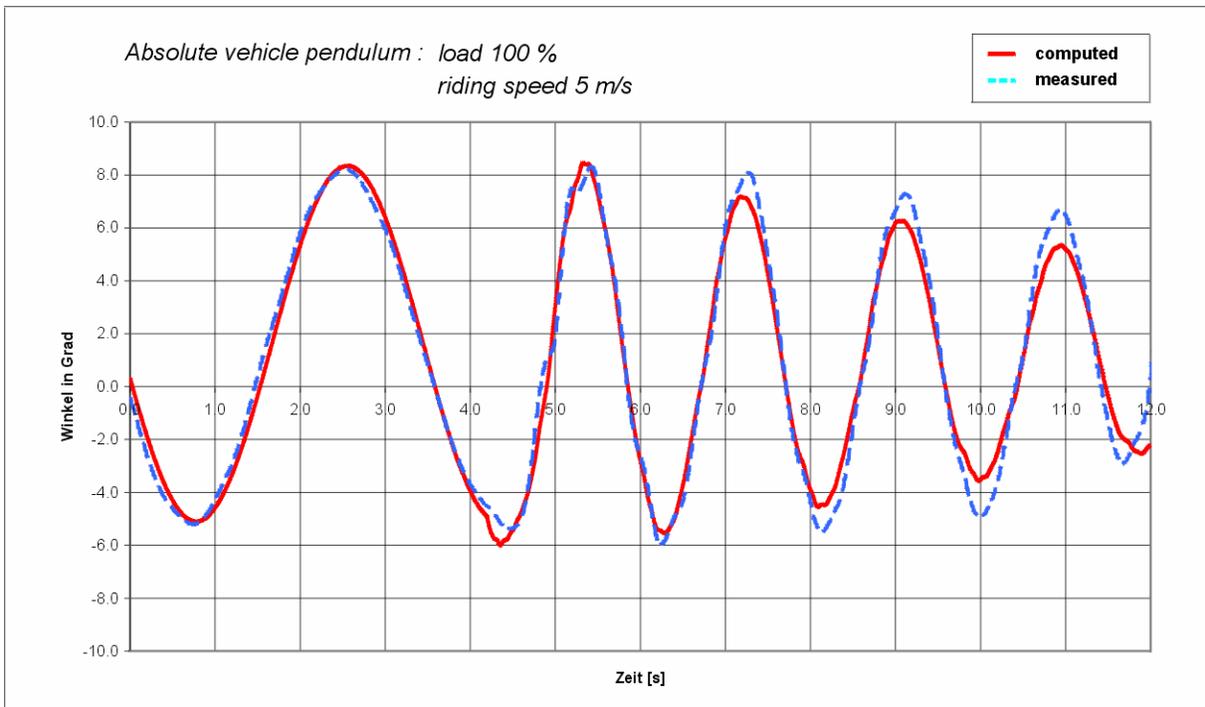
Fig. 9: Force on guide roller

Fig. 10: Absolute vehicle pendulum

SUMMARY

With regard to a sensible dimensioning of components, a multi-body system model is developed for the calculation of loads and stresses acting during the terminal entry of a detachable circulating monocable ropeway (DCMR).The comparison of computed and measured data shows quite satisfying results for calculated motions and forces.

The developed simulation model, in particular the model of the vehicle, could be used for computations of different problems at DCMRs, e. g. forces acting during the tower crossing of vehicles.

But, in addition to "just computing forces and motions", also various considerations with respect to a optimization of the ropeway construction (e. g. decreasing of loads and stresses, decreasing of vibrations, increasing of ride comfort) are fields of applications for a multi-body system simulation.

"Virtual Prototyping" provides, also the engineer in the special line ropeway technology, a very useful means for discussing and solving complex technical problems.

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