Optimization of a Rotary Transformer with Electrical Steel Core

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The Electrically excited synchronous machines provide a high efficiency within a wide range of speed. Moreover, the adjustable excitation of the rotor offers an additional degree of freedom, which can be used to optimize the overall efficiency. In order to transmit a DC current to the rotor a power transmission system is necessary. Commonly used slip rings with the major disadvantage of a limited lifetime and an increased susceptibility for external influences are used. Rotary transformers with a ferrite core are limited in size because of the poor tensile strength. Therefore placing them inside the machines housing is very complex. To avoid these disadvantages the institute for drive systems and power electronics developed a brushless transmitter with an electrical steel core. This novel rotary transformer design enables the arrangement of electrical steel along the circumference to axially direct the magnetic flux as shown in figure 1. The stator winding causes the main flux in the stator core which closes through the air gap and the rotor core leading to a AC current in the rotor winding.

All the steps during the Monte Carlo optimization lead to a guideline for further dimensioning of rotary transformers with a qualitative characteristic for each action of which the most important are summarized in table 1. An upturned arrow indicates an increase of the respective action. Additionally each action is rated in red and green colors.

This methodic approach allows it to dimension and to optimize rotating transformers. Further examinations illustrate that transformers can also be used for large machines, turbo-generators, hydroelectric power stations and windmill-powered plants. For every single previously mentioned applications rotating transformers can have major advantages referring to cost and needed space. All this points out the high potential in a global market.

The investigated actions lead to the new core design shown in Fig. 4 with an improved efficiency. Also the magnetizing current could be reduced to . In addition to the Monte Carlo optimization, an automatic optimizer using the Active Set method was implemented in the calculation program. This optimizer is capable of optimizing rotary transformers from any starting position within the parameters of Fig 3.
Problem Statement

For a research project in which the Virtual Vehicle Research Center is involved in, which examines the car to infrastructure communication, widely known as C2X (car-to-X) communication, a prototype to demonstrate this technology is needed. To be able to represent various use-cases with a vehicle, based on a trajectory which is dened by a potential user only with certain points (user-points) on a plane, is the essential task of this Master’s thesis. The chosen vehicle is actually a robot with an all-wheel electric drivetrain and omnidirectional steering. For this type of vehicle a co-simulation environment should be developed which is able to simulate the movement of this vehicle along a user-defined trajectory.

Problem Solution

Mobile robots are increasingly sharing their work envelope with humans. Compared to robots with locomotor systems, which are based on animals, the movement with standard wheels has an advantage and is currently the most used chassis type. Robots with wheel-based chassis can be dierentiated through the amount of available degrees of freedom, relating to the instantaneous center of rotation. In the course of the work the suspension kinematics of a mobile robot with four independent steerable and drivable wheels is looked upon.

The task of the robot is to follow a given trajectory and in addition reach a given orientation of the robots body in relation to it. Based on given points, which also include a desired robot velocity and orientation, a set of auxiliary points is automatically generated. With these additional points a continuous trajectory is re ned and is stored in the input matrix M, see figure 1.

Figure 1: The developed co-simulation concept

For the robot to be able to follow a given path, a velocity vector as connection between the robots center of gravity and a point of the path, ahead of the robot, is dened. The angle of that vector is proportional controlled as a function of the deviation between the robot and the path. To determine the deviation, the current position of the robot is measured and geometric considerations are applied (this is done in the block called deviation/position alongside given trajectory, see figure 1). The orientation of the robot is regulated using a rst-order sliding-mode controller, as acting the angular velocity of the robots body is used. The knowledge of the needed angular velocity of the robots body, as well as the velocity vector of the robot (both calculated in the velocity and angular velocity- vector calculation-block of the simulation), allows the use of inverse kinematics to determine the steering angles and the wheel speeds, these considerations are applied in the Motion-Controller-section of the simulation environment, which can be seen in figure 1. For the regulation of the steering angles a sliding-mode controller with super-twisting algorithm is used, the wheel speeds are regulated using a PI-controller with anti-windup. For both cases a luenberger-observer, using a simple model of a non-deformable wheel, was implemented to determine the relevant restoring torque. The measured variables, which are needed for the implemented controllers, are the current steering angles and wheel speeds of all wheels. The actuating values are the steering- and drive torques for the wheels. The multi-body model which should represent the vehicle is called Adams/Car.

The controller design was made using a co-simulation between MATLAB/ Simulink and ADAMS/Car. The used vehicle model in ADAMS/Car was developed with a series of driving maneuvers. From this preliminary investigation arise that no additional springs or dampers, with the exception of the tires, are needed. This was gained from the fact that driving on a rough road with the robots maximum velocity of 50 km/h did not lead to a total loss of vertical tire forces.

A various amount of different trajectories were tested, for example a double lane change or a s-curve trajectory which is shown in figure 2. In this figure the blue points represent the pre-dened user-points, which in this case amount to a s-curve. In between these blue user-points the already mentioned auxiliary points are generated. The red line shows the movement of the vehicle along the given trajectory. The vehicle itself is represented with an up-scaled rectangle, the front of the vehicle is illustrated with a green line. The robot starts on the lower left side of the trajectory with a velocity of zero and then accelerates till it reaches the pre-dened velocity of 35 km/h.

With this velocity a lateral acceleration of nearly 0.55 g is reached. At the end, which is in the upper right side of the trajectory, the robot is decelerated to standstill again. It can be seen that the vehicle drives along the trajectory with its body unden. A potential user is not only able to dene certain points for the robot and the velocity at these points, but also the orientation of the vehicle alongside this given trajectory. This can be explained best looking at figure 3. In this gure the robot drives along a trajectory which consists of blue dots. A potential user is able to dene the angle, which is the angle between the y-axis of the robots body and the connection line of two points along the trajectory. The angle also comes from the user, but indirect, as it is the angle between the mentioned connection line and the global x-axis. From these two angles the angle for the body of the robot, which is called , can be derived.

Although no dynamic model was implemented (rather a simple kinematic model was used), based on Descartes principle of rigid body motion and the tested s-curve trajectory raises a lot of lateral acceleration to the vehicles body (and thus also on the tires) a satisfying accuracy was reached, which can be seen in figure 4. In this gure the deviation of the robot in relation to the given trajectory is shown. Most importantly the deviation can be brought the zero again at the end of the trajectory.

Figure 2: Robot position along the given trajectory

With the co-simulation model which is presented in this Master’s thesis it is possible to not only evaluate the driving behaviour of the proposed vehicle in an early stage of the development process via multi-body simulation, but also to show that this vehicle is able to follow a trajectory, which is pre-dened only by given points on a plane and the desired velocity and robot-body orientation at these given points. This was among other things achieved using advanced control techniques such as sliding-mode controllers, which are usually very robust and effective.

In the given concept, one must already consider during planning of the desired robot trajectory, that the instantaneous center of rotation is far enough away from any wheel center. If that is not the case, high steering velocities are needed and if they cannot be achieved, a safe robot motion is not guaranteed.
Master Thesis

Reconstruction of Load States for Failure Probability Estimation of Automotive Vehicle Components

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Task Description:
An essential quality criterion for motor vehicles is their reliability. It is equivalent to the probability that a product works failure free during a predefined mileage and under given functional and environmental conditions. Furthermore, the knowledge about the current vehicle component health state and the user profile is an essential information. It can be used for right sized design in regard of real life load states, the development of new operating strategies and the introduction of predictive maintenance methods. Institute for Mechatronic Systems in Mechanical Engineering is doing research on innovative solutions for load states monitoring and lifetime prediction of automotive vehicle components [1]. A major feature of our approach is the abandonment of additional hardware. The aim is only to work with series production car sensors and standardized vehicle signals in preferably efficient algorithms.

In context of this master thesis, the objective is to explore methods of sensor fusion and implement them into a microcontroller. It should then be applied to the vehicle with a connection to the vehicle CAN (Control Area Network) bus. Additionally a schematic method for the estimation of the future failure probability should be introduced. It is based on reconstructed load states from sensor fusion.

Core Work:
Load states are generally used to estimate the lifetime of vehicle components in operational strength analysis. [2] However in series production cars they are often not directly available due to cost and packaging reasons. Therefore, it is preferable to reconstruct these states with sensor fusion methods. Additionally there is a further main requirement for such a system in automotive applications. For the deployment to the vehicle the selected methods need to be very efficient and with minimal computational requirements. In an experimental proof of concept, this work applies the presented algorithms to a microcontroller in the car. They are validated with additional sensors mounted to the test car.

Load states reconstruction in different modules is shown in Figure 1. Each module can be developed according to its individual requirements. Kalman filters [3] are used where plenty of correlated and sensed states are available. Then, against for the description of vertical dynamics it is more efficient to exclusively use the dynamic motion equations. Overall, the conjunction of different modules creates a sensor fusion network that enables the reconstruction of load states for steering, powertrain and chassis from vehicle CAN bus data. By means of fitting additional sensors in form of side shaft torque measurement shafts, linear potentiometers for the vertical chassis movement and steering rack force sensors, a basic validation can be accomplished. Thus, it is possible to calculate load states for single vehicle components like the steering rack force inside the steering gear box without additional sensors.

As basis for the estimation of failure probabilities, an extended procedure on Miner-Haibach operational strength analysis is developed [4]. It fulfills the major requirement to compute the current condition of a component regarding given past load states and in relation to the design basis. Thus a nominal damage of the component is given as a result. As shown in Figure 2 the reconstructed load states are used to create a current and future load collective and to predict a future failure probability. Additionally further outer influences on the lifetime of components are considered inside the method. The basic systematic of the developed procedure on Miner-Haibach is shown in Figure 3. After the transfer of time dependent information about load states and probability density functions into the estimation of a current nominal damage (left side), a computation of the failure robability is performed (right side). This requires the accountancy of further states. The probability for a failure at a certain nominal damage $D_{fail}$ has to be determined. Besides the information about the current damage, a future load collective has to be synthesized. In a first try, this is extrapolated from the load states history with an increasing uncertainty of the prediction with growing prediction horizon. From these three states, a statement about the failure probability of a component in dependence of a lifetime variable $T$ (e.g. km mileage) can be made. This information can be used in different ways. On the customers side new functions like mobile applications or individual operation strategies can be introduced. The OEM can define more accurate service intervals. Additionally the information about real life load states can be used for right sized design of automotive components in lean development cycles.

All in all this work introduces a sensor fusion network for the efficient reconstruction of load states. The application to a microcontroller shows its capabilities online and in real time. For future work, the complexity of the underlying models has to be reduced especially according to the number of free parameters. This enables the application to different vehicles without costly validation procedures. Regarding the failure probability estimation for automotive components, an experimental proof of concept has to be carried out. Furthermore the system needs to be extended to additional components.

Figure 1: Framework for the reconstruction of load states

Figure 2: Structure of the remaining lifetime estimating

Figure 3: Estimation of the failure probability in dependence of a lifetime variable

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