Rotary MR Actuators with Current less Holding Torque for a Vehicle Door Assistant

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Abstract. Improvement of comfort functionalities is an important distinguishing mark for the competitiveness of automotive manufacturers. Therefore the utilization of rotary MR actuators offers several new possibilities like an entry assist functionality for example. Beside requirements like a good controllability and reproducibility of torque the actuator must offer a certain holding torque without electrical feeding, in order to rest (fix) the automotive door in any position for a long period of time. For the realization of an actuator with a current less torque two approaches are developed. The first one deals with permanent magnets and offers an almost linear control characteristic. The second approach uses magnetic hysteresis for current less torque generation, which results in a plurivalent control characteristic. The main advantage is an optimized design with respect to space and weight. The hysteresis behaviour can be compensated by an adequate control algorithm, resulting in an almost linear torque characteristic.

1. Introduction
Conventional mechanisms provide resting of automotive doors in only two or three positions. Therefore in certain parking situations the passenger is stressed by maintaining the desired position and avoiding a collision with obstacles without any assistance. Today in the luxury segment a full variable detent is implemented by using a special hydraulic damper [1]. Due to the fact that a non-controllable actuator is used, further comfort functionalities cannot be provided. By implementing a controllable semi-active actuator, additional features become possible [2]. To avoid a collision the door will be decelerated after detection of an obstacle. A virtual stop position will be faded in to prevent additional movement of the door in the same direction. Due to this functionality potential damage can be avoided. Getting out is facilitated by enhancement of the door’s resting torque. The user can support himself at the fixed door. The impact shock strains of door components can be widely reduced by decelerating the door to a minimal closing speed.

Since the door is hand-guided by the human a semi-active actuator is sufficient for such supporting functionalities. The specifications of an adequate actuator can be summarized to:

- Almost linear and reproducible generation of torque,
- short response time,
- good ratio between outer diameter and maximum torque,
- certain holding torque without electrical feeding (bias torque) and
- noiseless operation.
2. Actuators

Due to their characteristic rotary MR actuators are predestined for this kind of comfort applications. To lock the door over long periods of time, a current less holding torque is strictly required. Since no MR actuators with current less holding torque are established, novel concepts and rules for its design are needed.

For the realization of MR actuators with a current less holding torque two approaches are developed [3]. The first one deals with an arrangement of a permanent magnet and an electromagnet. As shown in figure 1 this approach uses an arrangement of a permanent magnet and an electromagnet to generate the current less holding torque. In the case of non-fed MR actuator a magnetic field is generated by the permanent magnet (PM), which results in a current less holding torque. The magnetic field in the working gaps can be amplified by feeding the electromagnet (EM) with current. The minimization of the magnetic field can be reached by reversing the current direction. The design procedure is described in [4] in detail.

An alternative approach shown in figure 2 utilizes hysteresis properties of magnetic materials. These materials replace the current less field generation of the PM used in the first approach. The range of semi-hard magnetic materials includes all alloys whose coercivity is between soft and hard magnetic materials. When an external magnetic field, provided in this case by an EM, is applied to the hysteresis material (HM), it becomes magnetized. The grade of magnetization can be controlled by the electric current based on the hysteresis properties of the HM. The current depending torque behavior of the hysteresis based actuator is shown in figure 3 for one closed loop of the hysteresis in addition with the initial magnetization curve (dashed line).

![Figure 1. Half-section of the PM based actuator [3].](image1)

![Figure 2. Half-section of the hysteresis based actuator [3].](image2)

![Figure 3. Control characteristics curve for the hysteresis based actuator [3].](image3)

3. Hysteresis compensation

Since an accurate control of force is essential when applying the hysteresis based actuator for applications like a vehicle door assistant, the compensation of the hysteresis phenomena is obligatory. In the following two approaches for compensating the hysteresis phenomena are proposed. A fundamental approach to hysteresis control is the inverse compensation as illustrated in figure 4. If an inverse model $\Gamma^{-1}$ can be constructed of the hysteresis operator $\Gamma$, the output $B_{wg}$ (i.e. the magnetic flux density in the working gaps of the hysteresis actuator) will be approximately equal to the reference trajectory $B_{des}$.

![Figure 4. Illustration of hysteresis compensation by an inverse model.](image4)
Two static approaches for hysteresis compensation, the Preisach approach and the modified Prandtl-Ishlinskii approach, are investigated.

A detailed description of the Preisach approach can be found in [5]. The basic element of the Preisach model is the hysteresis relay. It is characterized by the thresholds \( \alpha \) and \( \beta \). The output of the hysteresis model is computed as the weighted sum of relay outputs. A disadvantage of the Preisach approach is the high measuring expenditure for the parameter identification. The higher the required precision is the bigger is the measurement effort which is to be perform. Furthermore a comparatively longer computation time is required. An advantage of the Preisach approach is the high precision also in complex hysteresis modeling. The parameter identification can either be accomplished with a generic algorithm or also exclusive by measurements. Both, the major loop and the minor loops of hysteresis are considered for the parameter identification.

The Prandtl-Ishlinskii approach is defined as the concatenation of a Prandtl-Ishlinskii hysteresis operator \( H \) and a Prandtl-Ishlinskii superposition operator \( S \) [6].

A large advantage of the Prandtl-Ishlinskii approach is the comparatively low and state-independent computation time. The inner system states are only approximated. Hence the accuracy of modeling and compensation is lower compared to the Preisach approach.

Both compensation algorithms are tested in a simulation study. The results in Figure 5 show the effectiveness of the hysteresis compensation. By using an inverse hysteresis model the behavior of the plant becomes nearly linear. If the hysteresis characteristic is neglected, the error will increase significantly. The measured control characteristics curve shown in figure 6 confirmed the nearly linear characteristic of the hysteresis actuator in combination with the compensation algorithm.

![Figure 5. Effectiveness of hysteresis compensation by simulation.](image1)

![Figure 6. Effectiveness of hysteresis compensation by measurement.](image2)

4. Experimental results of the vehicle door assistant

Because of their almost linear control characteristics the PM-based approach as well as the hysteresis based approach in combination with a desired compensation algorithm seems to be applicable for the vehicle door assistant. To evaluate the door’s functionality the actuators are tested in a an application environment, which is designed according to dimensions of typical doors of vehicles and which provides the possibility of a reproducible user interaction with the door.

The highest challenge of the vehicle door assistant for the control of the actuator represents the deceleration algorithm. In order to prove the compensation approaches in combination with the hysteresis based actuator the door is accelerated to almost similar angular velocities \( \phi_t \) and swinging freely towards an obstacle assumed to be at the position \( \phi_{stop} = 60^\circ \) for example.

With both approaches, the Preisach and the Prandtl-Ishlinskii approach, the door is decelerated precisely towards the desired angle with only a minimum overshoot as shown in Figure 5. Additionally, the deceleration trajectory by use of the permanent magnet based actuator is shown. The results of a statistical evaluation of the measurements are given in Table 1.
5. Conclusion

For the generation of a current less holding torque, which is essential for applications like advanced door functionality, two MR actuators are developed. While the first is based on permanent magnets, the second utilizes hysteresis properties of magnetic semi-hard materials. Main advantage of the second approach is the minimized space demand, but the hysteresis behavior has to be compensated. In this paper approaches for hysteresis compensation are introduced. Two concepts the Preisach and the Prandtl-Ishlinskii approach are investigated. The Preisach approach provides better replication accuracy, while the main advantage of the Prandtl-Ishlinskii approach is the comparatively low and state-independent computation time. Since the behavior of the compensated hysteresis based actuator and the permanent magnet based actuator is comparable, both MR actuators are suitable for the vehicle door assistant.

References

[1] ATZ/MTZ, “Türhaltefunktion”. ATZ/MTZ extra 10/2005 – Die neue S-Klasse, Oldenbourg Verlag, Munich.
[2] Maas, J., Kern, S.: Mechatronic Vehicle Door Assistant. IEEE/ASME International Conference on Advanced Intelligent Mechatronics, Zurich (CH), Nr. 285, 4-7. September 2007.
[3] Wiehe, A., Güth, D., Maas, J.: Hysteresis based MR Actuator for current less torque generation. Proceedings of actuator2008 conference, Bremen (DE).
[4] Wiehe, A.; Kern, S.; Maas, J.: Rotatorischer MRF-Aktor für einen Türassistenten. at – Automatisierungstechnik 03/2008 special edition smart actuators, Oldenbourg-Verlag.
[5] Mayergoyz, I. D.: Mathematical models of hysteresis. IEEE Transactions on Magnetics 22 (1986) 603-608
[6] Kuhnen, K.: Inverse Steuerung piezoelektrischer Aktoren mit Hysterese-, Kriech- und Superpositionsoperatoren. Dissertation, Universität des Saarlandes, 2001

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