# Model of Electromechanical Valve in the Anti-lock Braking System

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***Abstract.*** *The current trends in vehicle diagnostics tend to decrease production costs, whereas the same or even higher user safety and comfort level has to be assured. One option is using the centralized diagnostics, which doesn´t increase the production costs and still gives precision to the detection of an actual fault. The centralized diagnostics is an alternative to the today online diagnostic solutions. It is based on diagnostic models of every single part of the vehicle in which a properly as well as a faulty behaviour can be simulated. In this paper, the electromechanical valve of anti-lock braking system is described and modelled in detail. In order to proceed with the centralized diagnose of the anti-lock braking system of the vehicle, good understanding of the anti-lock braking system valve is necessary. A physical analysis, mathematical description and a general model of the valve was carried out. In the Conclusions, the signal measured on a real valve was compared with a signal created in the simulated environment on the model of the same valve. The output of the model exactly follows the real performance of the electromechanical valve.*

*Keywords: Anti-lock Braking System, Electromechanical Valve, Simulink Model in Matlab*

## 1. Introduction

The safety and reliability in the automobile industry has been discussed since the very first car was produced. The reliability of the braking systems is also discussed in [1]. Current vehicle diagnostics is based on the decentralized concept, which detects consequences of a fault. For modern methods of decentralized vehicle diagnostics, see [2] and **Chyba! Nenašiel sa žiaden zdroj odkazov.**.

The concept of centralized online diagnostics, developed at our university, is based on measuring of signals at central point of the power supply network in the vehicle. In order to recognize the signals while trying to detect a fault, a deep knowledge of all the performance relevant parts of the vehicle (parts working properly as well as the faulty ones) is required. Diagnostic models of the performance relevant parts are used for this purpose. Thus the method can be applied on the braking system and primarily on the anti-lock braking system. The terms “centralized diagnostics” and “decentralized diagnostics” are explained in [4].

Hence, the suggested method of centralized concept is based on advanced mathematical algorithms. The application of these algorithms can reveal faults even before they really occur. Some of the algorithms used in the automotive industry are described in [5]. The method of centralized diagnostics utilizes measuring of supply currents on the given wiring in the vehicle, so that the additional costs of installation during the final implementation of the system in the vehicle are noticeably decreased. (The purchase costs are the crucial element for implementing this method. The trend of minimizing the production costs is apparent in [6].) Nevertheless, to identify faults in the whole vehicle from one central point, it is necessary to have a deep understanding of all its parts.

The anti-lock braking system consists of a few performance relevant parts. This paper deals with one of such parts: the electromechanical valve within the anti-lock braking system control unit. Considering that the method uses the power supply of the vehicle for the diagnostics, it is essential to understand supply current pulses during switching the single parts in the control unit of the anti-lock braking system. This topic is also discussed in [7] and [8]. Thus the electromechanical valve model focuses on the accurate simulation of current consumption in the correct as well as the fault states.

## 2. Subject and Methods

The general model of the electromechanical valve consists of two parts: the electrical and the mechanical one.

*The electrical part of the valve*

The electrical part of the valve can be described as a serial circuit consisting of a coil with variable inductance and a resistor. For the schematic of this circuit, refer to Fig. 1. It can also be expressed by the equation No 1. The inductance value depends on the position of the movable plunger. The resistance value models the sum of the loss in windings, the metal part of the magnetic circuit and the air part of the magnetic circuit, which also depends on the position of the plunger.

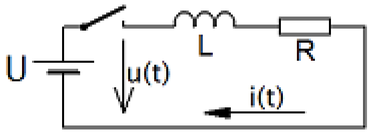

Fig. 1. Equivalent serial circuit coil.

$$\frac{di(t)}{dt} = \frac{1}{L(x)}u(t) - \frac{1}{L(x)}i(t)R(x) \tag{1}$$

where

| | |
|---|---|
| i(t) | current in the circuit |
| L(x) | inductance |
| R(x) | resistance |
| u(t) | voltage |

Every electrical circuit has also capacitance. In this case it was left out, because it is only usable at frequency levels closer to resonance. In this case, the resonant frequency is several orders higher than the maximal measured frequency (max. 1 kHz). The maximal measured frequency was defined by the step response of the valve.

*The mechanical part of the valve*

The mechanical part of the valve can be (simplified) understood as a mechanical oscillator, see Fig. 2. The oscillator is described by equation No. 2. In order to respect a real situation in an electrical valve, it is necessary to add range limits of some physical values in the resulting model (Fig. 3).

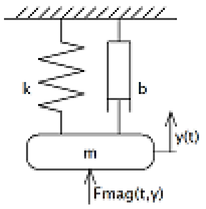

Fig. 2. Mechanical oscillator.

$$m\frac{d^2y(t)}{dt^2}+b\frac{dy(t)}{dt}+ky(t)+F_{mag}(t,y)=0 \tag{2}$$

where

| | |
|---|---|
| $y(t)$ | position of the movable part |
| $F_{mag}(..)$ | electromagnetic force |
| m | weight of the movable part |
| k | spring stiffness |
| b | damping coefficient |

Electromagnetic force is a product of the square of the coil current and of the magnetic constant (equation 3), which here depends on the position of the movable part. This dependence is the result of the change of magnetic resistance during the motion of the plunger, see equation 4.

$$F_{mag}(t,x)=i^2(t)*k_{mag}(x), \qquad k_{mag}(x)=\frac{N^2}{2\mu_0\,S\left(R_{m1}(x)+R_{m2}\right)^2} \qquad (3)\ (4)$$

where

| | |
|---|---|
| $i(t)$ | coil current |
| $k_{mag}(x)$ | magnetic constant |
| N | number of turns |
| $\mu_0$ | permeability of vacuum |
| S | cross-section |
| $R_{m1}(x)$ | magnetic resistance of air |
| $R_{m2}$ | magnetic resistance of steel |

## 3. Results

By connecting the models of the electrical and mechanical parts, including limits of the real system, we get the final model of the valve, see Fig. 3. The model was calibrated using constants measured on the electromechanical valve of the anti-lock braking system control unit VW 6Q0 614 117/Bosch 0 256 222 006.

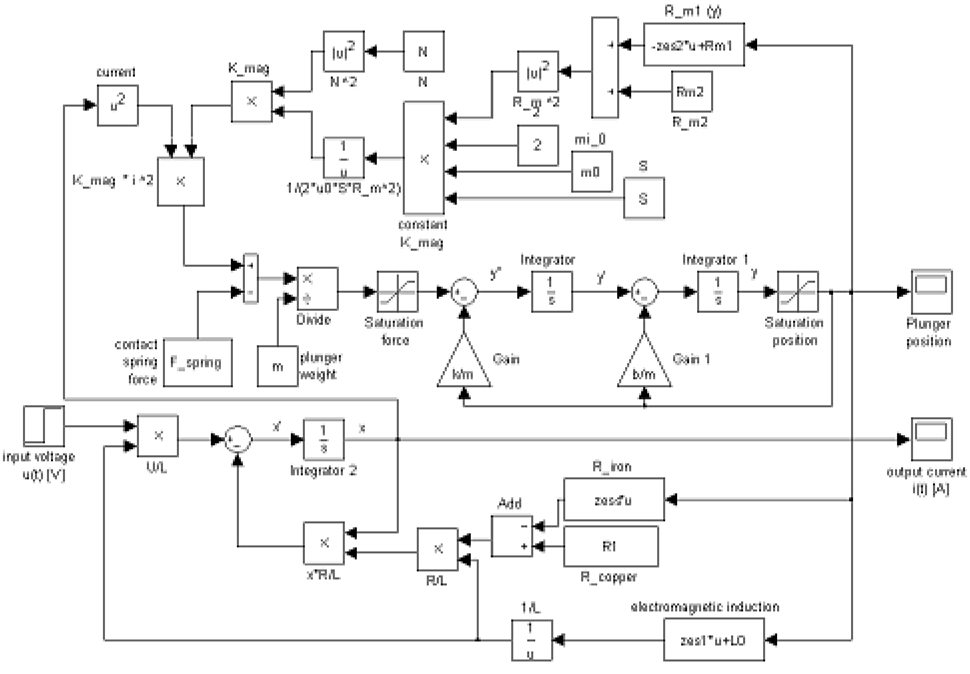

Fig. 3. Final model of the valve

*Results comparison*

For comparison of current consumption of the real valve and the model, see Fig. 4.

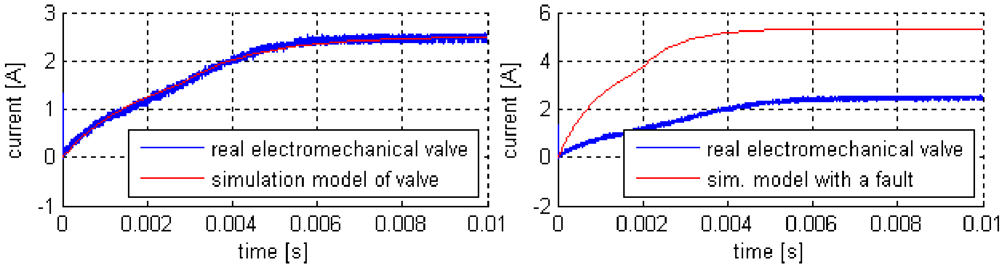

Fig. 4. Real valve compared with the model (left - a properly working valve, right –model with a half of the turns short-circuited)

## 4. Conclusions

Based on the results stated above it is obvious that the model well approximates the real valve. The deviations of the model from the real system were caused by measuring inaccuracy of some constants and especially by unknown dependence between the position of the plunger and the real inductance of the coil and the position of the plunger towards the losses in the magnetic circuit. Linear characteristics was used which intercuts the measured lateral points.

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