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# Design and Simulation of ANFIS Controller for Increasing the Accuracy of Leaf Spring Test Bench

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**Abstract**

Artificial Intelligence (AI) has been in use in several research fields and industries, including automotive. Intelligent control is a control technique that use different AI approaches like genetic algorithm, machine learning, neural networks and fuzzy logic. In this study, Adaptive Neuro-Fuzzy Inference System (ANFIS) is used for the correlation of the experiment and simulation results of a 5 degrees of freedom (DOF) servo-hydraulic leaf spring test bench. A multi-body simulation (MBS) software named Simpack is used to model the actual leaf spring test bench in the simulation environment. However, the results of the simulations do not fully correlate with the results of experiments for the same scenarios. Simpack is a dynamic analyses software and is not a control design tool, but it has an interface that exchanges data with Matlab simultaneously. Therefore, Matlab/Simulink, with its powerful controller design toolboxes has been used for co-simulation with Simpack. ANFIS toolbox has been used to improve the simulation model within the Simpack. In this study, the power of the libraries of both Simpack and Matlab/Simulink are combined to perform better simulations. First, MBS model of test bench is improved by using the experimental data. Second, Sugeno type ANFIS with grid partitioning is designed by training different experimental datasets. The objective of the training is to evaluate the piston forces that correspond to the actual displacement. Lastly, the trained ANFIS model is implemented to the MBS model and co-simulations are performed. The results showed that the simulation results were better suited to experimental data when ANFIS was used. Piston performances are improved by *88,5%, 74,3%, 73,7%* for piston 1, 2 and 3 respectively.


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## 1. Introduction

Advanced ride comfort and handling stability are two main expectations from the vehicle suspension systems which absorb the vibrations and impacts from the road surface. They protect the vehicle components from damage and provide a more comfortable ride for the drivers. Leaf springs are one of the most preferred components of the suspension systems. They are easy to maintain, cost effective and likely to be used to reduce vehicle weight [1-2]. Therefore, analyzing the characteristics of leaf springs with high precision is a necessity [3].

The desire for the high ride comfort of passengers has been increasing over the years. For this reason, automotive manufacturers are investing more in research and development projects for new suspension types [4-6]. Different intelligent control methods like neural network, fuzzy logic have been used for that purpose [7-8]. In this paper, an Adaptive Neuro-Fuzzy Inference System is used to improve the accuracy of the MBS model of leaf spring test bench which is a complex servo hydraulic system. This test bench has a complicated coupling relationship and nonlinear feature. It is used to find the forces acting on the leaf springs when certain inputs are applied and to investigate the effects of these forces on the durability of the leaf springs. Simpack as a powerful multi-body simulation software is used for modeling the test bench. Experiments are conducted on the actual leaf spring test bench and a large amount of dataset is gathered by using data acquisition system. However, the simulation results and actual system results differ for the same inputs. The aim of this study is to solve this correlation problem. There are different approaches that have been used in literature. Hao et al. [9] designed a leaf spring test bench to conduct different types of tests like permanent deformation, stiffness and fatigue. They used PID (Proportion Integration Differentiation) controller to increase the precision of these experiments. Tagawa et al. [10] correlated their test results analytically by formulating the force-deflection characteristics of leaf springs. Tank et al. [11] correlated CAE (Computer Aided Engineering) and Rig test results for stress and stiffness by using FEA (Finite Element Analysis) approach. Ghuku et al. [12] used image processing technique to obtain more precise results.

In this study, leaf springs are tested under different load conditions on the servo-hydraulic test bench. Virtual prototype of the leaf spring test bench created in the Simpack environment is improved with the data acquired from the experiments. Nevertheless, the results of the multi-body simulations did not fully correlate with the experiment results. This phenomenon has been investigated by the authors and an offline FLC is used to improve the results in the previous studies [3]. That solution was unique to the current situation and it required feedback signal. In this study, in addition to fuzzy logic, artificial neural networks have also become a part of the solution process to obtain a more generic result which is independent of both feedback and case.

The main contribution of this paper is, by using an intelligent control method, ANFIS, to find a generic solution for the correlation problem of this highly nonlinear test system. For this purpose, the power of Simpack in modelling and the power of Matlab in controls are combined. Co-simulations are performed to obtain more accurate results by using their superior sides. The remainder of the paper is organized as follows: ANFIS architecture is described in Section 2. Design and implementation of ANFIS is explained in Section 3. Related leaf spring test bench is identified in Section 4. Simulation results and discussions are presented in Section 5. Conclusions derived from this study are provided in Section 6.

## 2. Methodology

### *2.1. ANFIS Architecture*

ANFIS is a widely applied AI that combines the advantages of both Neural Networks (NN) and Fuzzy Logic (FL). It is generally used for complex and nonlinear systems in various fields. Denai et al. [13] used ANFIS approach to control neuromuscular system with large uncertainties and highly nonlinearity. Garcia et al. [14] designed an ANFIS based energy management system which consists of battery, renewable energy sources and hydrogen. Kurnaz et al. [15] controlled the autonomous behaviour of unmanned aerial vehicle by using ANFIS methodology.

ANFIS architecture was first proposed by Jang [16] in 1993 as shown in Figure 1 where circle represents a fixed node and square represents an adaptive node. It uses the NN learning algorithm to generate a Tagaki-Sugeno type Fuzzy Inference System that approaches a nonlinear system with a variety of linear systems. Fuzzy rules and