Jakob Werle

Temple University | Fall 2023

Linear Actuators for Motorsports Shaker Rig

tECHNICAL cOMMUNICATION

**DRAFT**

**2023-11-28**

Abstract

# Executive Summary

Table of Contents

[Executive Summary 1](#_Toc152202411)

[Problem Analysis 3](#_Toc152202412)

[Overview of problem and its significance 3](#_Toc152202413)

[STEM fundamentals of problem 3](#_Toc152202414)

[Lessons from prior responses to the problem 3](#_Toc152202415)

[Project objectives and constraints 4](#_Toc152202416)

[Candidate Solutions 4](#_Toc152202417)

[Scope of solutions considered 5](#_Toc152202418)

[Explanation of candidate solutions 5](#_Toc152202419)

[Electro-hydraulic system 5](#_Toc152202420)

[Electro-mechanical system 5](#_Toc152202421)

[Electro-pneumatic system 5](#_Toc152202422)

[Comparative assessment of candidate solutions 5](#_Toc152202423)

[Project Recommendations 7](#_Toc152202424)

[Proposed solution 7](#_Toc152202425)

[Design and implementation challenges 7](#_Toc152202426)

[Anticipated project outcomes and impacts 7](#_Toc152202427)

[Glossary 8](#_Toc152202428)

[References 9](#_Toc152202429)

List of Figures

[Figure 1. Ayrton Senna racing for McLaren 6](#_Toc94295766)

List of Tables

[Table 1 - Comparison of Candidate Solutions 5](#_Toc152202499)

# Problem Analysis

## Overview of problem and its significance

In motorsports, having an effective setup package is critical to being competitive. Suspension setup, in particular, is hypersensitive to specific drivers and tracks. With limited track testing time, racing teams must start optimizing setup packages earlier than competitors outside of the racetrack. One method of analyzing suspension parameters is using a shaker rig, which is a testing apparatus comprised of mechanical actuators that oscillate the vehicle’s wheels and chassis to simulate driving conditions.

According to some articles focused on miscellaneous use shaker rigs, having the rigs vibrate as precise and accurately as desired can pose a challenge. There are various types of components available to use as source of oscillations, but each has a potential problem.

## STEM fundamentals of problem

Shaker rigs work by suspending by its tires and chassis and moving them in specified directions to simulate the forces and motions encountered on a racetrack. Shaker rigs interact with the actual vehicle that is being tested which means the functionality of each component must be understood. To characterize the forces and motions outputted by the rig, sensors are fitted to a car and driven around a track (Boggs, 2009). The data collected while driving is then processed into a “drive file”, which is how the computer tells the shaker rig how to move (Boggs, 2009). The shaker rig controls the motion of each part of the vehicle with a linear actuator.

The linear actuator works by…

How do I explain fundamentals about different types of actuators that might not be used right now?

Should I explain vehicle components?

## Lessons from prior responses to the problem

The earliest shaker rigs used 4 vertical posts. [What type of actuators]. According to Dodds and Plummer in their paper titled, ” Laboratory Road Simulation for Full Vehicle Testing” (Dodds & Plummer, 2001), a limiting factor in the early days of shaker rig technology was a lack of understanding of the loading conditions and the inaccessibility of adequate testing hardware. They continue to explain that the introduction of servo-valves combined hydraulics systems’ high power with the control of electronics which opened up functionality in frequency ranges needed to operate accurate vehicle testing.

What made electro-hydraulics adequate?

As shaker rigs developed, progress was made in both the configuration of actuators and the methods used to derive a simulation model.

(Rydberg, 2008) discusses the use of hydraulic servo systems being introduced to more industries. His paper explains that the widespread use of hydraulic servo systems is thanks to their high precision, fast operation, and easy adjustability. It is suggested by (Hahn et al., 1994) that servo-hydraulic actuators have a downside, being the non-linear behavior of fluid dynamics. They were able to successfully create a servo-hydraulic control system that compensates for the non-linear behavior.

## Project objectives and constraints

The goal of this project is to improve the shaker rig simulations used in motorsports by evaluating the configuration and type of actuators used. To improve the quality of useable information extracted from simulations, shaker rig posts will be compared. The data collected by a shaker rig is based off the motions imparted on the vehicle during the simulation. If the apparatus is unable to replicate the real life forces, resulting data will not be relevant to analyzing vehicle performance.

Shaker rig posts operate by moving platforms or attachment points along a linear axis at high frequencies and with great force. Typical shaker rigs use servo-valve hydraulic linear actuators. Other applications have shown that pneumatic or electrical actuators could provide similar results with different cost/benefits.

The overarching goal is to improve the ability to optimize a racecar. The target audience would be racing teams and/or motorsports testing facilities. By developing more effective shaker rig testing apparatus, teams can extract more precise and reliable data and subsequently use that data to generate more competitive suspension setups. The responsibility of a shaker rig is to replicate the forces imparted on a vehicle by driving conditions. Each component used in a shaker rig contributes a certain amount of error in replicating these motions and forces. Post actuators and control mechanisms will be analyzed to find improvements in the accuracy in which they help replicate driving conditions.

Ultimately, the level of precision and accuracy the shaker rig can replicate driving conditions is based on the simulation model generated to run the rig. The primary method for generating simulation parameters is by collecting data using sensors placed on an actual vehicle driving around the subject racing circuit (Boggs, 2009). This places a contingency on the quality of data pulled from driving and the ability to process the data into a functional testing “drive file” (Boggs, 2009).

A high performance actuation system is one that has wide bandwidth frequency response, low resolution and high stiffness. Additionally, systems may call for intense duty cycles and light and small form factor (Rydberg, 2008).

A 7-post shaker rig applies forces to the chassis with aeroloaders at three points in order to simulate aerodynamic and inertial loads that effect the chassis. Using only three aeroloaders, the chassis’ pitch, heave and roll motions can be controlled since the chassis is assumed to be rigid (Southward & Boggs, 2008).

Frequency response is explained as the rate at which a dynamic system can operate and/or return information (*The Importance of Frequency Response*, 1996). For testing suspension, the response time would be an important factor in generating usable data. Sources show that shaker rig tests operated in the range of 0-30 Hz for road cars (Jonson & Enders, 2016), and potentially higher for racing cars. The actuators used in shaker rigs would not only need to respond at these frequencies but also provide reliable forces and motions.

# Candidate Solutions

## Scope of solutions considered

The use of linear actuators in shaker rigs is vital to simulating the forces and motions endured by driving and for collecting data to analyze suspension parameters. Contemporary shaker rigs typically utilize hydraulic servo systems.

To improve the results of shaker rig testing, different actuators are compared…

## Explanation of candidate solutions

### Electro-hydraulic system

A system that utilizes electronically controlled servo valves to control hydraulic linear actuators.

### Electro-mechanical system

### Electro-pneumatic system

A race car on a track

Description automatically generated

Figure 1. Ayrton Senna racing for McLaren

## Comparative assessment of candidate solutions

A high performance actuation system is one that has wide bandwidth frequency response, low resolution and high stiffness. Additionally, systems may call for intense duty cycles and light and small form factor (Rydberg, 2008).

Table - Comparison of Candidate Solutions

|  |  |  |  |
| --- | --- | --- | --- |
| Property | Electro-hydraulic | Electro-mechanical | Electro-pneumatic |
| Max actuation power (1-100 Hz) [kW] | 100+ | ~40 | ~2 |
| Bandwidth frequency response |  |  |  |
| Resolution |  |  |  |
| Stiffness |  |  |  |
| Duty cycle |  |  |  |
| Form factor |  |  |  |
| Costs |  |  |  |
|  |  |  |  |

# Project Recommendations

## Proposed solution

## Design and implementation challenges

## Anticipated project outcomes and impacts

# Glossary

# References

Boggs, C. M. (2009). *The Use of Simulation to Expedite Experimental Investigations of the Effect of High-Performance Shock Absorbers*. https://vtechworks.lib.vt.edu/handle/10919/26108

Dodds, C. J., & Plummer, A. R. (2001). *Laboratory Road Simulation for Full Vehicle Testing: A Review*. 2001-26–0047. https://doi.org/10.4271/2001-26-0047

Hahn, Piepenbrink, & Leimbach. (1994). Input/output linearization control of an electro servo-hydraulic actuator. *1994 Proceedings of IEEE International Conference on Control and Applications*, 995–1000 vol.2. https://doi.org/10.1109/CCA.1994.381197

Jonson, O., & Enders, E. (2016). *Correlation Work on Shaker Rig Tests and Simulations—An investigation of damper, bushing, friction and tire modeling with respect to vertical vibration insulation*. https://hdl.handle.net/20.500.12380/239095

Rydberg, K.-E. (2008). Hydraulic Servo Systems. *Hydraulic Servo Systems*.

Southward, S. C., & Boggs, C. M. (2008). Comparison of the Performance of 7-Post and 8-Post Dynamic Shaker Rigs for Vehicle Dynamics Studies. *SAE International Journal of Passenger Cars - Mechanical Systems*, *1*(1), Article 2008-01–2966. https://doi.org/10.4271/2008-01-2966

*The importance of frequency response*. (1996, August 1). Power & Motion. https://www.powermotiontech.com/hydraulics/hydraulic-valves/article/21885043/the-importance-of-frequency-response