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Title

tECHNICAL cOMMUNICATION

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Abstract

# Executive Summary

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# 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.

Talk about how the rig’s use is used to analyze/improve. The parameters focused in these improvements will likely be reflected later on in the objectives/comparable sections.

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

Framework:

1. Simple explanation of vehicle dynamics to provide background for testing. Tires receive all road inputs and generate all tractive forces. There are two modes in which tires interact with the vehicle to produce traction – mechanically and aerodynamically. Mechanical grip is result of kinematic design of vehicle and setup of suspension components. Aerodynamic grip which is produced by wings and bodywork takes affect at higher speeds and is dependent on vehicle ride height and attitude.
2. What do dynamic tests yield for results? How are cars fine-tuned?

Shaker rigs work by suspending a car 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 linear actuators.

Explain how the ultimate motion of the actuator is affected by parameters that can be defined. Maybe frequency, response, force, etc.

* Track inputs
* Suspension components
  + Springs
  + Dampers
  + Anti-roll bars
  + Tires
  + Unsprung mass?
* Actuator data collection

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

Dynamic vehicle testing was first introduced to the laboratory environment in the 1950’s, with a focus on overall vehicle comfort and durability (Dodds & Plummer, 2001). Early testing apparatuses were designed using two-stage servo-valves and four linear actuators or posts, which were concurrently being developed by Moog (Dodds & Plummer, 2001). To operate the testing rig, a vehicle was suspended in the air in which each post supported one of the vehicle’s wheels. The posts were actuated vertically in accordance to a testing cycle which aimed to statistically replicate a vehicle’s wheel travel (Dodds & Plummer, 2001). While subjective results reported good comfort, users noted potential error from the test setup lacking lateral and for/aft forces as well as inertial forces associated with rolling tires. Furthermore, some unresolved dynamics issue with hydraulics systems used throughout the 1960’s muddied the results from “excitement simulations” (Dodds & Plummer, 2001).

The next breakthrough in dynamic vehicle testing was “Response Simulation”. GM Truck and Bus conceived that by using a vehicle as the transducer, road inputs at the tire contact patch could be determined while driving at the proving grounds. The measured wheel response could then be used to drive closed loop control of the servo-hydraulic system (Dodds & Plummer, 2001). Implementing this system improved relevance of test results and lead to the creation of multiple testing software.

In order to increase accuracy of simulations, contemporary testing rigs have been configured to allow forces and motion in multiple directions. Triaxial systems have the ability to generate vertical, lateral, and longitudinal forces, and yaw and pitch moments at each wheel (Dodds & Plummer, 2001). These more complex setups allows analysis of vehicle characteristics such as self-aligning torque and braking, which would be possible on previous four-post rigs. However, the setup for these tests are significantly more complex and require an extra actuator for every degree of motion (Dodds & Plummer, 2001).

An alternative method called “Body Restraint Testing” applies force and moment inputs through the chassis rather than wheels. The significance of this technique is that the inputs can be relatively small and output displacements in vertical, pitch, and roll can be large (Dodds & Plummer, 2001). Initial passive restraint setups were disadvantaged by changing the structural loading of the chassis, which skewed results. To eliminate this issue, later setups replaced fixed chassis restraints with actuators which could apply high frequency motions but respond to low frequency loads (Dodds & Plummer, 2001). These systems proved to have versatile control of the vehicle’s body and could introduce external forces such as aerodynamics in motorsports.

A common configuration found today is called the “7-Post Rig”, in which four of the posts support the wheels and three posts support the chassis. The unique characteristic of this setup is that the wheels are supported by flat plates which allows road inputs to be generated without impeding the natural motion of the wheels. The remaining three posts, often referred to as “aeroloaders” can be used to generate aerodynamic forces seen above roughly 100mph (“Seven-Post Rigs,” n.d.). Unfortunately, aeroloaders have a tendency to dampen the vehicle’s natural response to road inputs by the wheel plates. To mitigate this, a compliant linkage can be arranged between the aeroloaders and chassis to allow loading with a sufficient amount of compliance to let the vehicle move unimpeded (“Seven-Post Rigs,” n.d.). This solution has it’s own issue, being that the added compliance does not allow the large downforce loads to be generated in the simulation. By using “velocity feed-forward” algorithms to predict the motion of the chassis in addition to a compliant link, a workable result emerges for downforce to be simulated on a seven post shaker rig (“Seven-Post Rigs,” n.d.).

## 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 forces as they happen in real time, resulting data will not be relevant for 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 small form factors (Rydberg, 2008).

# 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 2 - Comparison of Candidate Solutions

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

# Project Recommendations

## Proposed solution

## Design and implementation challenges

## Anticipated project outcomes and impacts

# Glossary

# References

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