"A Review Study- Design And Analysis Of Suspension System"

K.N.Patel[1] B.N.Gelot[2] A.H.Gupta[3]
[1]PG Student [2,3]Assistant Professor
[1,2,3]Department of Mechanical Engineering
[2,3]Government Engineering College, Dahod.

Abstract— This Review paper describes the implementation of a parametric model of an automotive damper. The goal of this research was to create a damper model to predict accurately damping forces to be used as a design tool for the damper design team. This study pertains to mono tube gas charged dampers appropriate to two wheeler automobile applications. The goal of this model was to create accurately force vs. velocity and force vs. displacement plots for examination. The dynamic model and analysis is used to correlate the model to real damper data for verification of accuracy.

I. Introduction

In any design endeavor with limited time for research and development, tools that increase productivity or decrease necessary testing are crucial for success. This gives rise to a need for development tools such as computer models of suspension, chassis, and engine systems. Because of schedule constraints, the suspension design of most automobile two wheeler is based primarily on steady state analysis.

There are many types of automotive suspension dampers, which are commonly referred to as shock absorbers. This is a misnomer because the damper does not actually absorb the shock. That is the function of the suspension springs. As is well known, a spring/mass system without energy dissipation exhibits perpetual harmonic motion with the spring and the mass exchanging potential and kinetic energy, respectively. For the purpose of this paper, the term damper will be used. The function of the damper is to remove the kinetic energy from the system and to convert it into thermal energy.

There are numerous configurations of dampers: twin tube, mono tube with or without reservoir, and even a rod through damper type. For the purpose of this thesis, a mono tube damper without a separate reservoir will be examined. Another major distinction in damper types is the feature of external adjustability, i.e. if the damping can be adjusted after the damper is assembled. Automotive applications generally use a nonadjustable damper. In contrast, many dampers for racing applications have some degree of adjustability. Since the main focus of this research is to aid in racecar suspension design, the mono tube damper chosen has adjustable damping.[1]

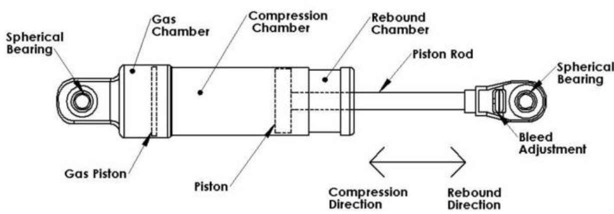

Fig. 1: Components of Mono tube Adjustable Damper

II. Literature Review

A literature review was conducted with two major goals. The first goal was to obtain a better understanding of how individual internal components and internal flows had been characterized in the past by studying the development of parametric models for damper characterization.

The second goal of the literature review was to gain an insight into the hysteretic behavior that occurs in characteristic FV plots. Understanding the causes of this phenomena and how it can be minimized are of crucial importance in damper design. Both of these concepts will be addressed in the cited literature.

In 1977, Lang published his Ph.D. dissertation studying the behavior of automotive dampers at high stroking frequencies. The work included creation of one of the first parametric models of a twin tube automotive damper with good agreement to experimental data. This paper is the milestone paper in understanding performance behavior of modern dampers.

The concepts behind Lang's model involved "the development of a mathematical model of shock absorber performance based upon dynamic pressure flow characteristics of the shock absorber fluid and the dynamic action of the valves" . Lang was one of the first to examine the internal physics of the fluid and the valves in an attempt to model their behavior. The model included the effective compressibility ', which also accounts for the compliance of the cylinder wall. This aided in correctly modeling one influence on hysteresis. Chamber pressures were also examined.[2]

The model used equations for standard steady orifice flow based on the pressure drop across the flow orifice. The dynamic discharge coefficients and the valve opening forces were found experimentally. A limitation to Lang's model was computing power; his work was completed on an analog computer. For this reason, dynamic discharge coefficients were assumed constant. Good agreement to experimental data was found using this assumption.

Lang then exercised his model to examine factors such as effective fluid compressibility, fluid vapor pressure, and frequency input. A nominal value of effective compressibility, $\beta' = 4.5\,E-6$ mm/kg, was found. FV plots were created using the nominal value, twice the nominal value, and half the nominal value. It was shown that as effective compressibility increases hysteresis increases, in both high and low speed regions.[2]

Examination of vapor pressure showed the same trend. As the vapor pressure of the damping fluid increases the hysteresis in the FV plot increases because this fluid in the rebound chamber vaporizes at higher pressures. Values from two to ten psi were tested. The hysteresis is caused by the cavitation of the fluid due to the increased vapor pressure values.

Lang's experimentation with input frequencies was particularly valuable. The range of 1-50 Hz was tested. It showed small differences in hysteresis in the 1-10 Hz region and increasing differences in hysteresis for 10-50 Hz range. The increase was most visible in the region affected by the effective compressibility. It was also determined that inertial effects of the valve parts were negligible compared to other forces due to their small mass.

In conclusion, Lang recommended separation of the gas and fluid in a twin tube chamber in order to control cavitation and frothing in the damper. He also theorized about a rod that travels through both compression and rebound chambers to eliminate the need for any internal gases. Both of these concepts have been applied to modern day high performance dampers.[2]

Reybrouck presented one of the first concise parametric models of a mono tube damper. Flow restriction forces were found using empirical relationships that included leak restriction, port restriction and spring stiffness correction factors. Once individual internal forces were found, another empirical relationship was used to calculate the total damping force. Pressure drops across the specific flow restrictions could also be found. These correction factors had some physical meaning, but their values were found through experimentation.[3]

This model showed excellent correlation with experimental data in the 0.5 to 30 Hz range, provided that hysteresis was minimal. Implementation of this model is difficult due to the numerous correction factors necessary for accuracy. There was no discussion about the causes of hysteresis aside from its dependence on frequency.

Reybrouck later extended his model to a twin tube damper and included a more physical representation of hysteresis. It was shown that hysteresis was caused not only by oil compressibility, but the compressibility of gas bubbles transferred from the reserve chamber. It was also shown that reserve chamber pressure greatly affects the solubility of nitrogen. As the pressure increases the entrapped bubbles are absorbed. This effect should not be neglected for accurate results.[4]

Kim also performed an analysis of a twin tube damper with focus on implementation into a vehicle suspension system. Kim's model included chamber compliance and fluid compressibility which yielded a differential equation for the chamber pressures that was solved using the Runga Kutta Method. Discharge coefficients were experimentally found and applied to the model. Incorporating damping data into a quarter car model, the frequency response of the sprung mass and tire deflection were calculated numerically. Good agreement with experimental data was found for single strokes of the damper, but no full cycle FV plots were included.[5]

Mollica and Youcef-Tuomi presented a mono tube damper model created using the bond graph method, based on Mollica's M.S. thesis work. This reference concluded five major sources for hysteresis in FV plots.

- Effective compliance of damper fluid,
- Compressibility of the nitrogen gas
- The resistive fluid damping through piston orifices
- The resistive friction acting on the floating piston
- Compliance due to the check valve preloads

A simplified model of a damper was created to examine the frequency effects on hysteresis. This simple model showed that for low frequencies the effort is in-phase with fluid flow and velocity. At higher frequencies, the force lags the flow and velocity by 90 degrees. This equates the hysteresis at high frequencies to a phase lag in a control system. This is similar to the hypothetical spring/damper discussion in the previous section.[6]

Reference also states "Air entrained as bubbles increases effective fluid compliance thereby increasing hysteresis due to additional phase loss occurring at the same input frequency." This shows the importance of eliminating any trapped gas in the damper oil in a mono tube damper to reduce hysteresis. This also aids in explaining the general trend of greater hysteresis in twin tube dampers that mix oil and gas in the reserve chamber.

The inertia of the gas piston was found to be negligible. Friction from the gas piston was found to be more important, causing an increase of hysteresis near the zero velocity regions.[7]

Talbott's M.S. thesis in 2002 presents a physical model for an Ohlins NASCAR type mono tube racing damper . One major goal of this model was to correlate the model to the real physics of the damper to avoid experimental correction factors used in earlier models. This approach increases ease of implementation to any type of mono tube damper with minimal experimentation necessary. Talbott and Starkey also published these findings in SAE paper 2002-01-3337.

Total flow is comprised of valve orifice flow, bleed orifice flow, and piston leakage flow. Flow resistance models were created for each separate flow based on the pressure drop across the orifice, path per Lang's work. Pressure in the gas chamber, Pg, was related to the pressure in the compression chamber, Pc using force balance on the gas piston. This relation of Pg and Pc was one of the important findings of this modeling method. Talbott assumed the oil and gas in the damper was incompressible.[8]

The other contribution of Talbott was the creation of a shim stack model that predicts the shim stiffness. The model was applicable to a minimum of three shims and a maximum ten. This was the first attempt at any modeling of this shim stack deflection in conjunction with a damper model.

Six non-linear coupled equations were created and solved simultaneously. With all unknowns, the damping force was found from the force balance on the piston assembly.

The model showed good agreement in both FV and FD plots. The low speed regions showed some difference in force due to the hysteresis present in the experimental data. [8]

III. SELECTION OF SUITABLE SUSPENSION SYSTEM

The selection of the suspension system which will best satisfy the requirements of an ATV was carried out. Out of the many available suspension systems in the market, the *Double Wishbone Suspension System* was selected for the ATV. This selection was done based on the following basic parameters:

(1) Load bearing capacity
(2) Flexibility
(3) Cost
(4) Technical aspects: Camber, Stiffness, Rolling
(5) Availability of parts and components

IV. CONCLUSION

From the above review it is concluded that parametric model for predicting damper performance was successfully created and shown to be applicable to numerous possible configurations of the damper. The model produce FV and FD plots with good agreement with respect to magnitude of the force and nonlinear trends of the forces.The design procedure for the chosen suspension system is divided into two stages

(1) Primary design
- Basic design and development of Suspension System components.
- Modified design parameters based on approximation of Dynamic Conditions
- Static testing and analysis

(2) Secondary design
- Mathematical modeling of finalized concept ATV
- Dynamic testing and analysis
- Modification of Design Parameters based on Dynamic Testing results

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