REVIEW ON "TOPOLOGY AND SHAPE OPTIMIZATION: APPLICATION FOR CONTROL ARM"

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Abstract

Various optimization methods for structural size, shape and topology designs have been developed and widely employed in engineering applications. Among these, topology optimization has been recognized as one of the most effective tools for least-weight and performance design, especially in automobile engineering. Most existing research of topology optimization focuses on the design of automobile parts.The objective of the present review paper is to determine the different parameters which are useful to minimize the mass of the control arm considering topology optimization methods on the basis of previous research papers.

Keywords: *Topology Optimization; Upper control arm; stress, strain, total deformation.*

I Introduction

1.1 General

The vehicle suspension system is responsible for ride comfort and road holding as the suspension carries the vehicle body and transmits all forces between the body and the road. A classical car suspension consists of a spring (coil spring, air spring or leaf spring) and a damping element. The spring and damping coefficients are chosen according to comfort, road holding, and handling specifications. However, conventional suspensions can achieve a trade-off between ride comfort and road holding since their spring and damping coefficients cannot be adaptively tuned according to driving efforts and road conditions. They can achieve good ride comfort and road holding only under the designed conditions. Suspension System Components: As seen in Figure 1.1 and 1.2, a typical suspension system comprises four main parts:

Suspension mechanism: This is a system of linkages that controls the relative motions of the wheels and the vehicle chassis.

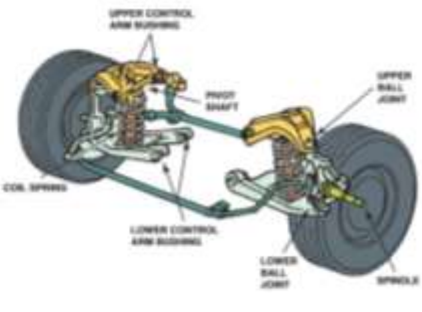

Figure 1.1 A typical independent front suspension used on a rear-wheel-drive vehicle

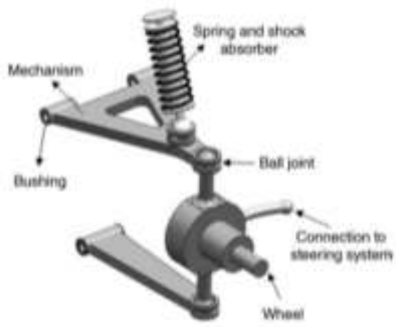

Figure 1.2 Main parts of a typical suspension system

Suspension spring: The suspension spring stores the road-induced kinetic energy of the wheel and isolates the vehicle body from road irregularities. There are usually two types of springs that are used in suspension systems. The main spring controls the vehicle body bounce (vertical) motion and the anti-roll bar helps to control the body roll (angular) motion. An automobile suspension system can use different types of mechanical, pneumatic, hydraulic, and electronically-controlled springs. Of these, the most popular option is mechanical springs, including coil and leaf springs, and torsion bars. Modern cars most frequently use coil springs.

Shock absorber: The shock absorber is a hydraulic device for damping the road-induced kinetic energy and controlling the wheel and body motions.

Bushing: Elastic parts are used in joints and mounting points of the suspension system.

1.2 Suspension Principles

Suspensions use various links, arms, and joints to allow the wheels to move freely up and down; front suspensions also have to allow the front wheels to turn. All suspensions must provide for the following supports:

1. Transverse (or side-to-side) wheel support.

As the wheels of the vehicle move up and down, the suspension must accommodate this movement and still keep the wheel from moving away from the vehicle or inward toward the center of the vehicle.

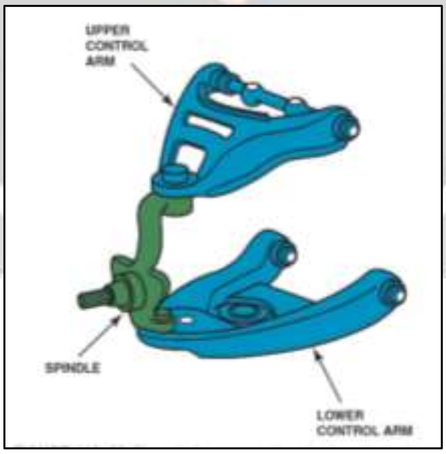

Figure 1.2 The spindle supports the wheels and attaches to the control arm with ball-and-socket joints called ball joints.

The control arm pivots on the vehicle frame. The wheels attach to a spindle that attaches to the ball joint at the end of the control arm. Transverse links are also called lateral links.

2. **Longitudinal (front-to-back) wheel support.**

As the wheels of the vehicle move up and down, the suspension must allow for this movement and still keep the wheels from moving backward whenever a bump is hit. Figure 1.2 show the separation of the pivot points, where the control arm meets the frame, provides support to prevent front-to-back wheel movement.

The design of the suspension and the location of the suspension mounting points on the frame or body are critical to proper vehicle handling. Two very important design factors are called anti-squat and anti-dive.

1. **Anti-squat.**

Anti-squat refers to the reaction of the body of a vehicle during acceleration. It is normal in most designs for the vehicle to squat down at the rear while accelerating. Most drivers feel comfortable feeling this reaction, even on front-wheel-drive vehicles. Anti-squat refers to the degree to which this normal force is neutralized. If 100% anti-squat were designed into the suspension system, the vehicle would remain level while accelerating.

2**. Anti-dive**.

Anti-dive refers to the force that causes the front of the vehicle to drop down while braking. Some front-nose dive feels normal to most drivers. If 100% anti-dive were designed into a vehicle, it would remain perfectly level while braking.

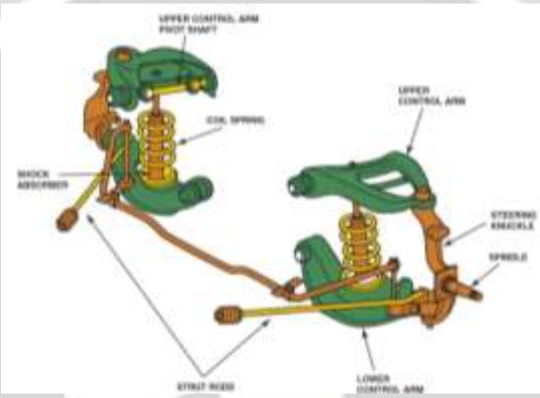

Figure 1.3 The strut rods provide longitudinal support to the suspension to prevent forward or rearward movement of the control arms

1.3 The front and rear suspension systems

The front suspension systems are extremely important to provide proper wheel position, steering control, ride quality, and tire life. The impact of the tires striking road irregularities must be absorbed by the suspension systems. The suspension systems must supply proper ride quality to maintain customer satisfaction and reduce driver fatigue, as well as provide proper wheel and tire position to maintain directional stability when driving. Proper wheel position also ensures normal tire tread life. The main front suspension components serve the following purposes:

1. Upper and lower control arms—control lateral (side-to-side) wheel movement.

2. Upper and lower control arm bushings—allow upward and downward control arm movement and absorb wheel impacts and vibrations.

3. Coil springs—allow proper suspension ride height and control suspension travel during driving maneuvers.

4. Ball joints—allow the knuckle and wheels to turn to the right or left.

5. Steering knuckles—provide mounting surfaces for the wheel bearings and hubs.

6. Shock absorbers—control spring action when driving on irregular road surfaces.

7. Strut rod—controls fore-and-aft wheel movement.

8. Stabilizer bar—reduces body sway when a front wheel strikes a road irregularity.

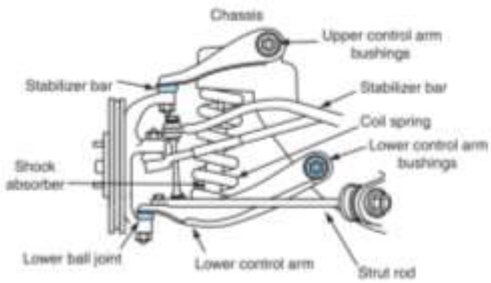

Figure 1.4 Typical short-and-long arm (SLA) front suspension system.

Control Arms

A control arm is a suspension link that connects a knuckle or wheel flange to the frame. One end of a control arm attaches to the knuckle or wheel flange, generally with either a ball joint or bushing. The opposite end of the arm, which attaches to a frame member, usually pivots on a bushing. The end attached to the frame must pivot to allow the axle or knuckle to travel vertically. (Figure 1.5)

The upper control arm is mounted high in the suspension system, and the upper end of the knuckle has a "goose neck" shape. The lower control arm is made from stamped steel to reduce weight. The rear lower control arm bushing is mounted vertically and carries only fore-and-aft loads. This mounting allows the use of a softer rear bushing in the lower control arm. The horizontal front lower control arm bushing and the lower shock absorber mounting are aligned with the wheel center. This provides a direct path for lateral cornering loads. This design allows the use of a hardfront lower control arm bushing.

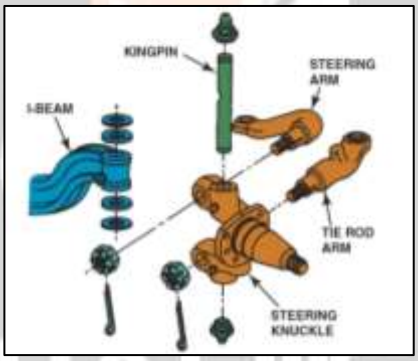

Figure 1.5 A kingpin is a steel shaft or pin that joins the steering knuckle to the suspension

The upper control arm is mounted higher so it is above the front tire. The higher upper control arm and the lateral and compression lower arms provide excellent suspension stability and steering control, especially during high-speed cornering or when driving on irregular road surfaces. A ball joint in the outer end of the upper control arm is attached to the top of the knuckle, and two shafts in the inner end of this arm are bolted into the strut tower. There are no provisions for camber or caster adjustments on this multilink front suspension.

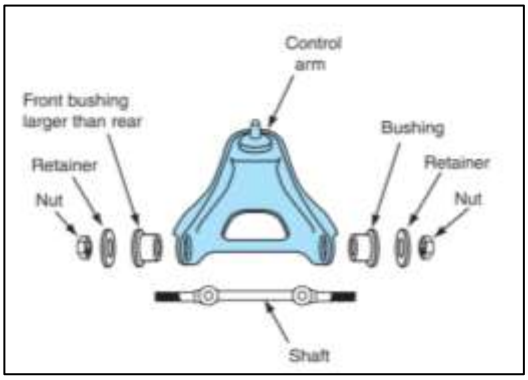

Figure 1.6 Upper Control Arm Component

1.4 Topology Optimization in Engineering Structure Design

In recent decades, structural optimization methods have gained great progress with the increasing performances of computers and computing algorithms. Solutions of practical and complicated optimization problems undergoing complex loading conditions are made possible to satisfy severe multidisciplinary design performances. Among others, topology optimization has become one of the most promising techniques.

Basic Engineering Optimization Methodologies

Structure optimization methods are basically classified into three categories: sizing optimization, shape optimization and topology optimization. Sizing optimization is a classical method and easy to conduct by choosing cross-sectional dimensions of trusses, beams and frames, or the thicknesses of membranes, plates and shells as design variables, as shown in

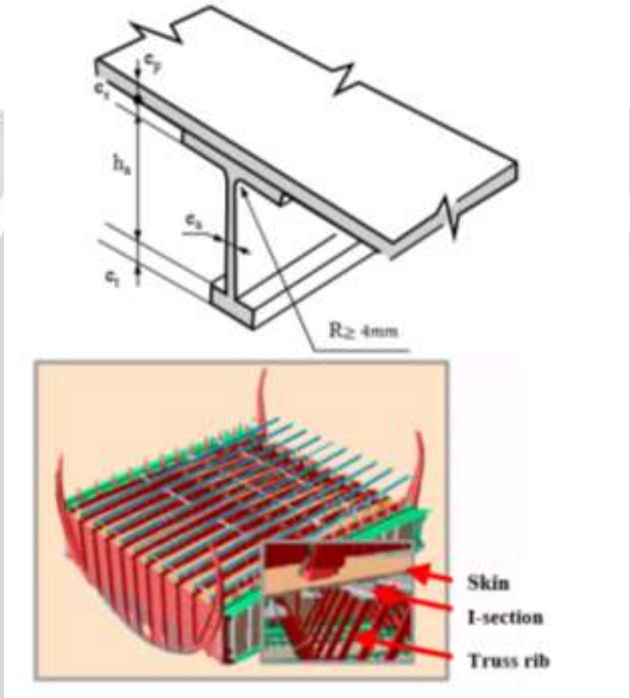

Figure 1.7 Sizing optimization for aircraft structure members

In size and shape optimization, the size and shape of the components of a structure can be manipulated. They can have any value between their limits, but they must always be present. But if the designer/engineer does not know what the shape or size of the structure should be, then topology optimization needs to be used. The two major distinctive features of topology optimization are that:

(1) the elastic property of the material, as a function of its density, can vary over the entire design domain; and

(2) material can be permanently removed from the design domain. There are several topology optimization methods which can be grouped into two categories:

(1) Optimality Criteria methods and

(2) Heuristic or Intuitive methods.

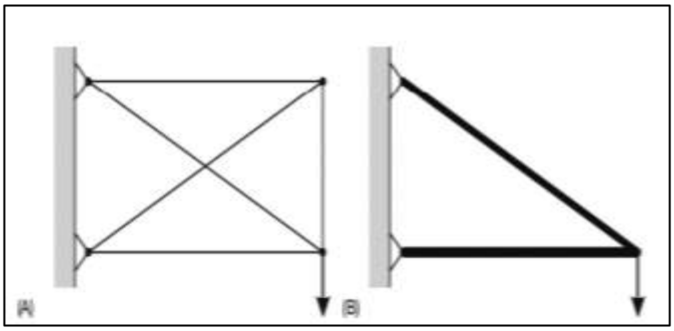

Figure 1.8 Topology optimization of a truss structure: (A) original topology; (B) final topology with some trusses removed.

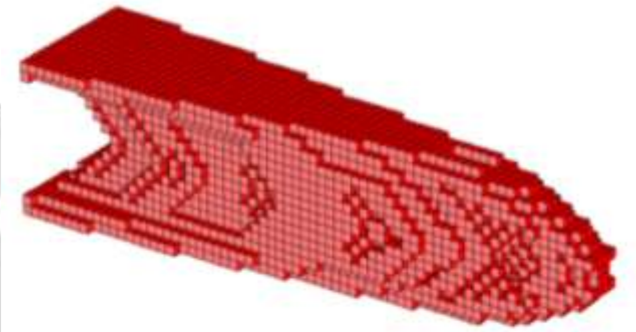

Figure 1.9 Final topology for a cantilever beam.

Optimality Criteria are indirect methods of optimization. They satisfy a set of criteria related to the behaviour of the structure. They are often based on the Kuhn-Tucker optimality condition, which means that they are more rigorous. They are suitable for problems with a large number of design variables and a few constraints. The Optimality Criteria topology methods are:

(a) Homogenization;

(b) Solid Isotropic Material with Penalization (SIMP);

(c) Level Set Method; and

(d) Growth Method for Truss Structures.

Heuristic methods are derived from intuition, observations of engineering processes, or from observation of biological systems. These methods cannot always guarantee optimality, but can provide viable efficient solutions. Some Heuristic topology optimization methods are:

(a) Fully Stressed Design

(b) Computer-Aided Optimization (CAO);

(c) Soft Kill Option;

(d) Evolutionary Structural Optimization (ESO);

(e) Bidirectional ESO (BESO),

(f) Sequential Element Rejection and Admission (SERA)

(g) Isolines/Iso-surfaces Topology Design (ITD)

1.6 The Component Development Process

II- Literature Review

This chapter contains the previous researches carried out by various researchers. The researchers are categorized in two different sections i.e. Literature Based on Suspension System and Literature Based on Topology Optimization for Different Objects.

2.2 Literature Based on Suspension System

Shaikh Ateekh Abdul Naeem & P. V. Jagtap; 2017 simulates a practical system such as a vehicle upper control arm (UCM). The work deals into various application aspects and manufacturing aspects to formulate an idea of the system. The vehicle suspension system is always responsible for driving safety and comfort. The suspension unit carries the whole vehicle body and transmits all forces between body and road. Mostly Structure optimization techniques in static load conditions have been used in automotive industry for light weight and for performance improvement of modern new cars. The paper shows the study of practical example for static analysis and optimization of upper control arm. CAD model was prepared using CATIA R20 software and finite element analysis was done using ANSYS 15.0. Static analysis done, and low stressed region identified and material removed from that region in various iterations. Further for validations of the study, experimental analysis of finally selected iteration was done, and the results found are very close to FEA results.

The main objective of the work carried out by ***S. Arun Kumar et.al. 2016*** is to model and to perform structural analysis of a lower control arm used in the front suspension system, which is a sheet metal component. Lower control arm allows the up and down motion of the wheel. It is usually a steel bracket that pivots on rubber bushings mounted to the chassis. The existing method in lower control arm.

E. Narvydaset et al. investigated circumferential stress concentration factors with shallow notches of the lifting arms of trapezoidal cross-section employing finite element analysis (FEA). The stress concentration factors were widely used in strength and durability evaluation of structures and machine elements. The FEA results were used and fitted with selected generic equation.

On the other hand, operational deflection shapes do show the effects of forces or loads, and may contain contributions due to several modes of vibration. ***Nikhil R. Dhivare and Dr. Kishor P. Kolhe; 2016*** deals with optimization and modal analysis of the upper arm suspension of double wishbone suspension. Upper arm has been modelled using CATIAV5, meshing will be done in HYPERMESH12.0, and ANSYS will be used for post processing.

2.3 Literature Based on Topology Optimization for Different Objects

In the work carried out by ***G Lakshmi Srinivas and Arshad Javed; 2019***, mass of an industrial manipulator-link is minimized using topology optimization method. Topology optimization is established substantial method for mass reduction of structural and machine components. A single link of manipulator is considered for optimization. For optimizing the design region, minimum compliance is chosen as objective function.

Junwen Liang, Xianmin Zhang, Benliang Zhu; 2019 presents a piezo-driven microgripper which can realize parallel grasping in a large displacement range (more than μm 140). The proposed microgripper is derived by a two-step nonlinear topology optimization method. A conventional linear topology optimization problem with loose boundary condition is solved first, and its solution is used as the initial design domain of the following nonlinear topology optimization. The comparison of the convergence results shows that this method can find a better structure of microgripper and save computation time simultaneously. Both the finite element analysis and experiment are used to verify the performance of the proposed microgripper. The experimental results show that the parasitic movement of the jaw is only 0.299% of the grasping movement and the average inclination angle of the jaw is 0.055mrad/μm. A pair of strain gages is integrated as a displacement sensor, and its performance is presented and verified by experiments.

Reducing weight of components in a manipulator is the need of robotic industry, not only to save cost by reducing the material but also to optimize the power consumption. Hence, topology optimization of manipulator links has wider scope to research and deliver the best possible solutions to design a system. ***Aditya Kulkarni and Arshad Javed; 2014*** focused on investigating the performance of the link using topology optimization and dynamic modelling. In this work, topology optimization is utilized to generate optimum shape and size of link, finite element approach is adopted in finding the inertia of the given body, deflection with stress and followed by kinematic modelling.

To meet the requirements of higher structural stiffness, higher vibration frequency, lower weight for the industrial robots, a method based on multi-objective topology optimization is presented by ***Xu-yang Chu et al;***

2016. The method takes the deformation, vibration frequency, structure weight of the robot as the objective functions, and it optimizes the robot structure with topological method.

III-Conclusion

Recent study shows that the researchers are scrutinizing about the methods applied for the optimization of various objects with the objective of reducing mass without affecting the strength and other requirement of the objects or products. There is more study is required on the typical methods toextraordinary deal. Nowadays, authors are more focused on the study of topology optimization asgradient based study for different functions in the shape optimization. The Adjoint solver is usedaccording to the existing variables selected for the optimization of various parts and confer new one.

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