

Recent Innovations in Vehicle Suspension Systems

Yucheng Liu*

Department of Mechanical Engineering, University of Louisville, Louisville, KY 40292, USA

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Abstract: Suspension system is one of the most important systems in a modern vehicle. It significantly contributes to the vehicle's availability and safety, keeps vehicle occupants comfortable and also protects the vehicle from damage and wear. Due to its importance in the vehicle structure, a massive amount of effort has been spent on enhancing the performances of suspension system, such as stability, controllability, and other capabilities. This paper briefly reviews recent innovations and some representative patents (since 2000) in this area and outlines the features and advantages of these inventions. The future trends of research in the suspension system design are also discussed.

Keyword: Suspension system, stability, controllability.

INTRODUCTION

Suspension system is an assembly of springs, shock absorbers and linkages that connects a vehicle to its wheels. In a running vehicle, it is the suspension system that keeps the occupants comfortable and isolated from road noise, bumps, and vibrations. Suspension system also provides the vehicle excellent handling capabilities, allowing the driver to maintain control of the vehicle over rough terrain or in case of sudden stops. Additionally, the suspension system prevents the vehicle from damage and wearing [1-4].

The basic components of the suspension system include springs, shock absorbers, kinetic parts, and auxiliary devices. The springs absorb impacts and provide cushioning when a wheel hits a bump in the road. The springs also resist the wheel's movement and rebounds, pushing the wheel back down. The type, number, and location of the springs differ based on different type of suspension systems, which will be demonstrated in the next section. The shock absorbers (dampers) restrain the spring motions and prevent the spring from continuing vibrating. In a suspension system, one shock absorber is located at each wheel. Kinetic and auxiliary devices of the suspension system are associated with particular type of suspension system, which will be introduced in the next section.

Due to the pivotal role the suspension system plays in the vehicle structure, many designers and researchers have spent a huge amount of time and effort in improving the capabilities of the suspension systems and tremendous progresses have been made on the suspension system design. These innovations apparently improve the suspension system's stability, controllability, and comfort ride comfort. This paper will briefly review some recent patents (since 2000) in designing advanced vehicle suspension system in section 3. Before that, an introduction of the suspension systems will be presented in section 2, which introduces the suspension types, properties, and important auxiliary components. Finally, the future trends of research in the suspension system design will be discussed in section 4.

DESCRIPTION OF BASIC SUSPENSION SYSTEMS

Overview

Different types of suspension systems are being used in modern vehicles. Generally, the suspension systems can be divided into two groups: dependent suspension system and independent suspension system. The dependent suspension system has one or more solid axles that hold opposite wheels together, therefore the wheels cannot move independently. The independent suspension system does not have such a wheel axle so that the wheels are allowed to rise and fall without affecting the opposite wheel. Based on the number of wheel axles, the dependent suspension system can be classified into single axle system and tandem axle system. A suspension system may have kinetic components and compliance components (springs and dampers) to locate it, both longitudinally and transversely. Popular kinetic components include trailing arm, control arm, and transverse linkage. The most common suspension springs are coil spring, air spring, leaf spring, and torsion bar. Figure (1) displays a suspension hierarchy that covers most popular suspension types.

Dependent Suspension Systems

Based on the number of wheel axles, the dependent suspension can be classified into single and tandem axle suspensions. Typical single axle suspensions include trailing arm suspension and leaf spring suspension [1, 2]. For the trailing arm suspension, the wheel axle is connected to the chassis by one or more trailing arms and the rear parts of the trailing arms are allowed to swing up and down. Coil springs are generally used in such suspension. In recent trailing arm suspensions, the conventional coil spring is replaced by air spring, which is powered by an engine driven or electric air pump or compressor [5]. This pump compresses the air and uses the pressurized air as a spring. Compare to the coil spring, the air spring provides a smooth ride quality but has less reliability. For the leaf spring suspension, the wheel axle is clamped to the leaf springs and the shock absorbers normally bolt directly to the axle. The ends of the leaf springs are directly attached to the chassis. The structure of this type of suspension is extremely simple therefore can be built at a low cost. However, in the leaf spring suspension

*Address correspondence to this author at the Department of Mechanical Engineering, University of Louisville, Louisville, KY 40292, USA; Tel: 001-502-852-6334; E-mail: y0liu002@louisville.edu

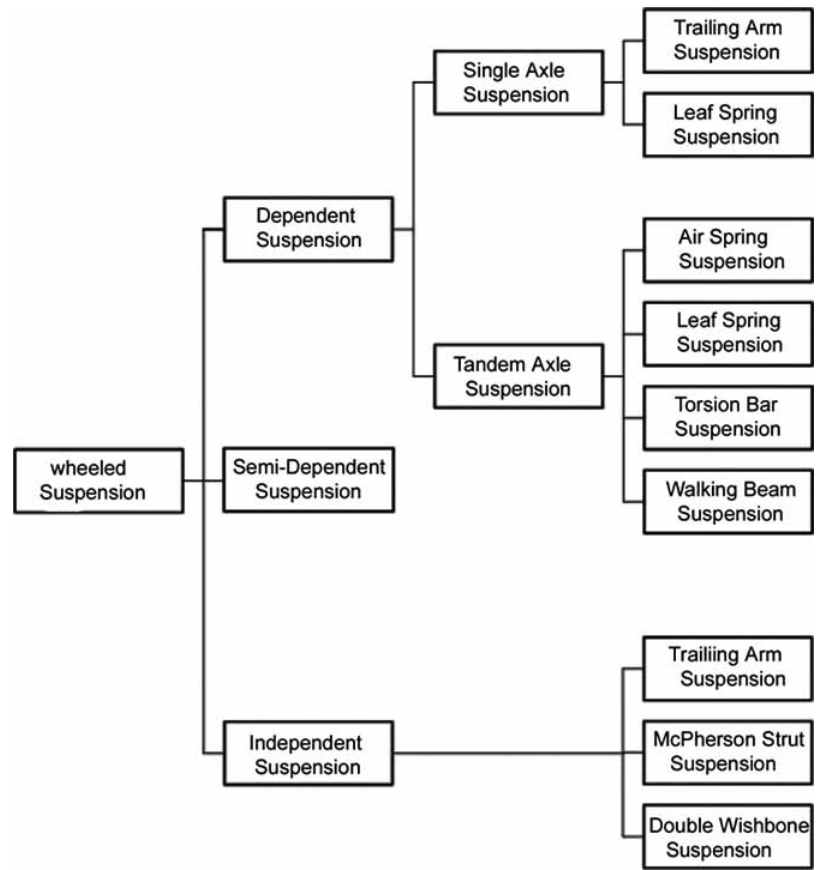


Fig. (1). Hierarchy of popular suspension types.

system, the lateral location of the wheel axle is almost prohibited.

A tandem axle is a group of two or more axles situated close together, which can provide a greater weight capacity than a single axle. Because of this merit, tandem axle suspension systems are commonly employed in heavy duty trucks and trailers having one or more trailing axles [3, 4]. According to different springs attached on, the tandem axle suspensions can be classified as air spring suspension, leaf spring suspension, torsion bar suspension, and walking beam suspension. The working principles of the springs in tandem axle suspension systems are similar to what in the single axle suspension systems. Traditional tandem axle suspension systems have a symmetric structure. However, asymmetric tandem axle suspension systems were also invented and have been used for vehicles [6].

Independent Suspension Systems

Just as its name implies, the independent suspension systems means the suspension system in which each wheel on the same axle can move up and down independently and without affecting the wheel on the other side. This trait gives the independent suspension systems better ride comfort and handling characteristics. Modern independent suspension systems include trailing arm suspension, double wishbone suspension, and McPherson strut suspension [1, 2].

Independent trailing arm suspension, also known as semi-trailing arm suspension, has a similar structure to the dependent trailing arm suspension. The only difference is

that in the independent trailing arm suspension, each wheel hub is located only by a trailing arm and there is no solid wheel axle to connect opposite wheels together. Double wishbone suspension, also called as upper and lower A-arm suspension employs two wishbone-shaped arms (A-arm) to locate the wheel on each side. In this system, a shock absorber is enclosed inside a coil spring and directly mounted to the lower A-arm. The upper and lower A-arms are the load-bearing members in this assembly. McPherson strut suspension system can be considered as a “simplified” double wishbone suspension by removing the upper A-arm. This suspension system is currently the most widely used front suspension system in passenger cars because it has a simple structure and therefore it is cheap to manufacture. Nevertheless, the double wishbone suspension has superior dynamic characteristics and load handling capability, therefore it is still used for higher performance vehicles.

Besides the dependent and independent suspension systems, there’s another suspension type called semi-dependent suspension. In this suspension system, the opposite wheels are connected by one or more twist beams instead of the solid axle so that one wheel can move relative to the other.

Auxiliary Devices

Different types of suspension systems have their advantages and drawbacks. In order to make up for these drawbacks, auxiliary devices such as sway bar, Panhard rod, and torque arm are usually applied on particular suspension

systems [2]. A sway bar is a torsional spring that connects opposite wheels together, whose main function is to increase the suspension's roll stiffness. Therefore, the sway bar is commonly used in independent or semi-dependent suspension systems as a stabilizer. A Panhard rod is a component to prevent the lateral motion of the wheel axle. It often appears in the rear dependent suspension systems that have solid wheel axles. In dependent suspension systems, especially the air spring tandem axle suspension, one or more pairs of torque arms are generally incorporated to locate and align the axles.

RECENT PATENTS IN SUSPENSION SYSTEM DESIGN

Because of the important role the suspension system plays in modern vehicles, a large number of innovations have been made on the suspension system design to optimize its performances. This section briefly outlines the advanced suspension system designs patented after year 2000.

The first patent [7] is about the design and application of roll stabilization mechanisms in vehicular suspension systems. The inventor designed a vehicular suspension system that includes at least front and rear suspension systems. Both suspension systems are independent suspensions which include a pair of upper and lower wishbones (A-arms) and coil springs. Each suspension system is interconnected to a force transmitting device, which transfers forces between the front and rear suspensions. The magnitude and direction of the transferred forces are progressively varied by the adjustment device, which is included in each force transmitting device, according to the relative positions of and the load applied to the pairs of the interconnected wishbones. The adjustment devices are functionally linked so that the vehicle attitude can be controlled and always maintained at a "stabilizing" position no matter what surface the vehicle is driving on. Consequently, the rolling motions of the vehicle are prevented.

Figure (2) shows a schematic diagram for the designed suspension system assembly. As shown in this figure, both front and rear suspensions are independent suspensions and each suspension is composed of a pair of lower wishbones 2a, 2b, and 2c, 2d, which are connected to the vehicle chassis assembly 1. Each wishbone is attached to a wheel assembly and provides a movable location means for the wheel. Four coil springs 4a, 4b, 4c, and 4d are mounted on the upper surfaces of wishbones 2a, 2b, 2c, and 2d respectively to support most of the weight of the vehicle. Two force transmitting devices 50 and 51 interconnect each pair of transversely adjacent wishbones 2a, 2b, and 2c, 2d. Each force transmitting device is essentially a torsion member that includes two transverse roll stabilizer bars 5a, 5b, and 5c, 5d. These are attached to the wishbones. The adjustment device 11 of one force transmitting device 50 is located between the transverse torsion bars 5a and 5b to control the function of the transverse torsion bars therefore stabilizing the vehicle. As mentioned before, the adjustment device 11 can be controlled simultaneously as a function of the vehicle motion and attitude.

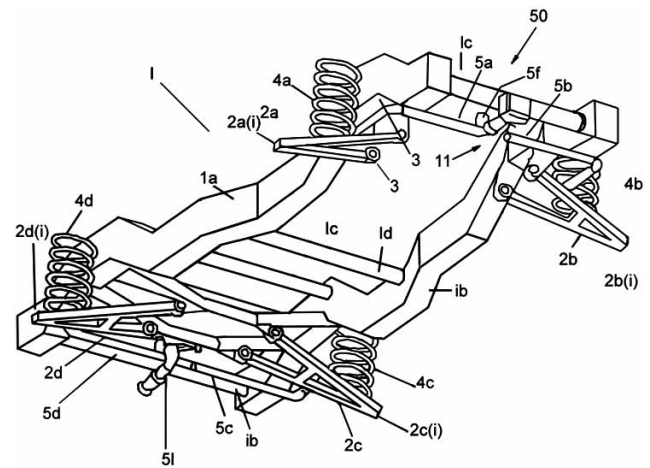


Fig. (2). Suspension systems with roll stabilization mechanisms [7].

The same inventor patented another roll stabilization assembly for the suspension system, whose principle is similar to the previous one [8]. In this patent, hydraulic actuators are used as the adjustment devices and the suspension systems are interconnected through fluid conduits which are controlled by a hydraulic fluid supplier and a fluid conduit valve.

Another anti-roll mechanism for the McPherson strut suspensions were invented and patented [9]. This anti-roll suspension system incorporates a roll compensating linkage, which is connected to the lever of each spring assembly, to translate the steering movement to a vertical movement on the suspensions while simultaneously lift the outside turn side of the vehicle and lower the inside turn side of the vehicle thereby restraining roll of the chassis when in a turn. As illustrated in Fig. (3), in this design, each McPherson strut is directly mounted at the lower end to axle 14 and connects at the upper end to an upper arm 24 of bell crank 26 through a link 22, where the arm 24 is pivotally connected to the vehicle chassis. Unit 30 is a lower control arm assembly which is connected to both wheel axle 14 and the chassis through pivot 32 and pin 34, respectively. Bell crank 26 is connected to the axle through its lower arm 36, a link 38, and an arm 40, which receives force and movement from steering of the vehicle. A steering link 46 is connected to an arm 48 on the axle assembly to receive steering input from the vehicle's steering system which is to turn the front wheels. This roll compensating linkage translates the steering input of the vehicle to rotary movement of the axles, which in turn transfers the rotary movement of the bell crank 26 to a vertical movement of lever 24, which either compresses (outside of a turn) or relaxes spring 18 (inside of a turn). The tendency of the vehicle chassis to roll when in a turn is therefore counteracted. In this suspension system, the bell crank 26 is the key component, which receives the steering movement of the wheels and converts it to the vertical movement of the springs. The same linkage can be observed on the opposite side.

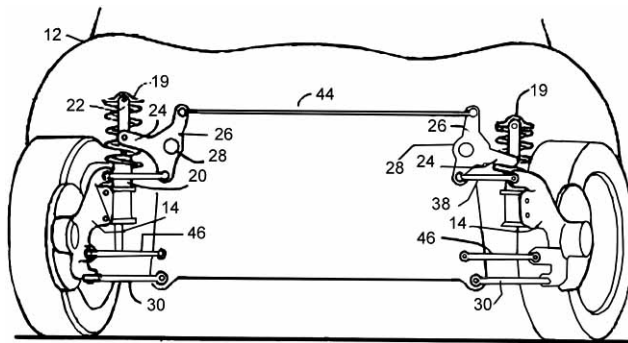


Fig. (3). Suspension system with an anti roll compensating linkage [9].

Next patent [5] is about an innovated air ride suspension system for light duty trailers. The application of the air springs eliminates the need for leaf springs and this patented suspension system evenly dissipates normal road vibrations and dramatically reduces the stress on trailers and their fixtures. In this suspension system, the frames have one (for single axle trailer) or two (for dual axle trailer) sets of brackets, including control arm brackets, axle stop brackets, air spring brackets, and shock absorber brackets. Control arms are inserted with resilient bushings and pivotally attached to the frames through the control arm brackets. Axles are mounted either above or below the control arms with standard U-bolt mechanisms. Air springs are mounted onto the control arm behind the axle and attached to the frames through the air spring brackets. Behind the air spring, a shock absorber is mounted to the end of the control arm and connected to the frames through the shock absorber bracket. This suspension system eliminates the need for leaf springs, evenly dissipates normal road vibrations, and dramatically reduces the stress on trailers and their fixtures. Figure (4) shows the air ride suspension system, where the control arm 22, air spring, and shock absorber 18 are connected to frame rail 10 through control arm bracket 12, air spring mounting bracket 14, and shock absorber bracket 54.

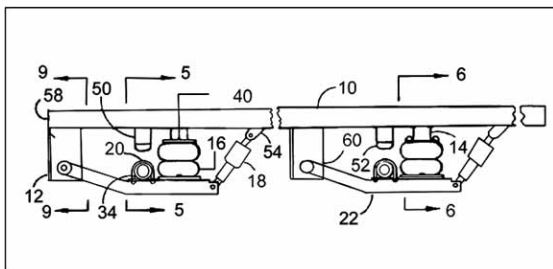


Fig. (4). Side elevational view of the air ride suspension system [5].

Another invented suspension system is described in [10], which belongs to the dependent suspension systems. One single axle suspension system is composed of a pair of beams 17 and 19, Fig. (5), that extending forward from a pair of levers (11) which are carried by the frame (3) on opposite sides, and pivotally connect to respective levers. The wheel axle is supported by the pair of beams and levers. This suspension system meets most objectives required by an

optimal suspension design. It provides a high degree of roll stability and provides a smooth ride performance even better than existing air spring suspension systems. Application of this suspension system can effectively protect wheel axle and other components because it reduces torque and stress on the axle. Besides its excellent performances, this design is equipped for easy axle alignment and can be used in either existing single or tandem axle suspension systems. Moreover, this suspension design is light in weight and can be fabricated at low cost.

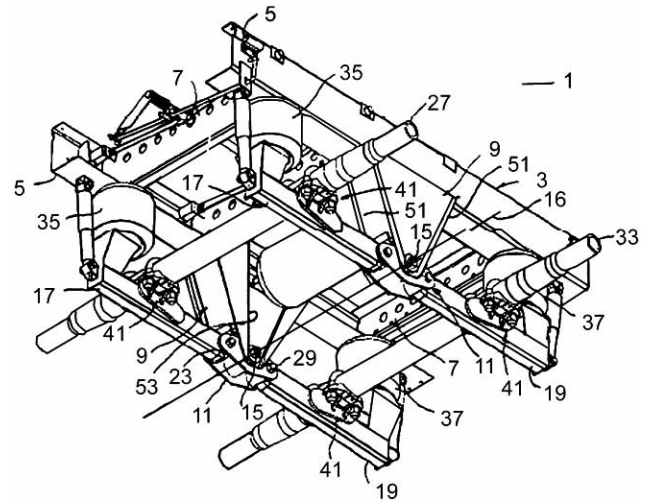


Fig. (5). Invented vehicle suspension system from [10].

The last patent [11] introduced in this paper is about a simple but ingenious design of an independent suspension system, which allows the wheels to remain relatively perpendicular to the road surface even during cornering, acceleration, deceleration and combinations thereof. This suspension system is a typical double wishbone independent suspension that the suspension connects to the chassis 1 and left and right wheels 4, 8 through left and right upper and lower arms 2, 3, 6, 7, Fig. (6). Different from the traditional one, the upper arm of the suspension on one side is cross-linked with the upper arm on the other side. Referring to Fig. (6), the left upper arm is connected to the right hand offset pivot shaft assembly 9 by a connecting rod 10. Similarly, the right upper arm 7 connects to left hand offset pivot shaft assembly 5 through another connecting rod 11. This cross-connection linkage is independent of the suspension's lower arms. This invention promises that the wheels can compensate for rolling of the chassis and only move vertically relative to the chassis structure. However, the chassis structure can either move vertically or roll relative to the wheels during cornering and other conditions. Therefore, an ideal contact and gripping force between the wheels and the road surface are acquired. The introduced invention can be applied as both front and rear suspension systems.

CURRENT & FUTURE DEVELOPMENTS

This paper reviews recent patents in suspension system design. In the introduced innovations, advanced mechanical mechanisms were designed and implemented into the

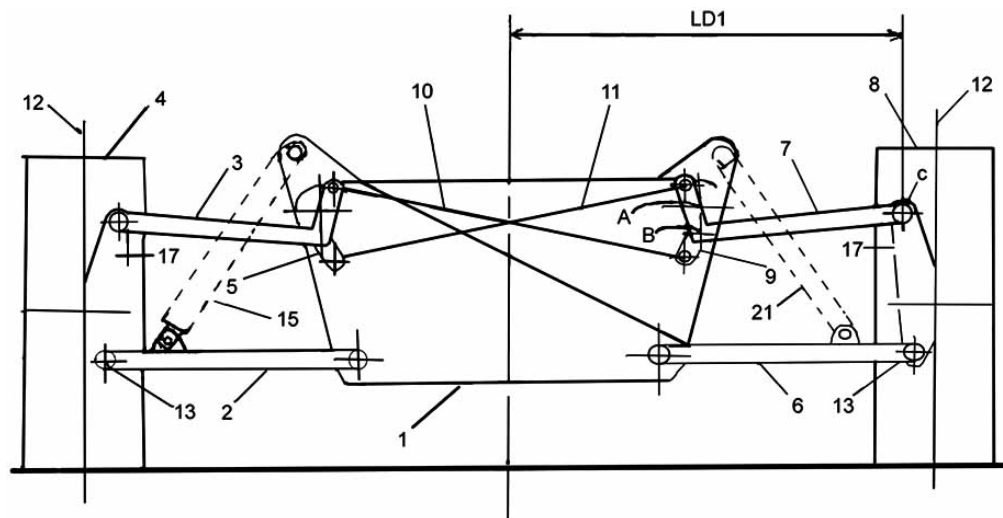


Fig. (6). Invented independent vehicle suspension system from [11].

suspension system to improve its controllability, stability, and ride comfort. However, the mechanical mechanisms are easily damaged therefore cannot perform properly. Besides the mechanical mechanisms, other apparatus such as hydraulic systems, electronic control systems, or hybrid systems can also be incorporated in the suspension systems to enhance their performances. Compare to the mechanical linkages, in addition to providing better reliability, the hydraulic and electronic control systems can react to road conditions or short term vehicle acceleration instantly and perform appropriate adjustments automatically. In sum, the incorporation of hydraulic and electronic systems in the suspension systems can be a future trend of research in this area.

Meanwhile, in modern vehicle suspension system, shock absorber is one crucial component in the vehicle suspension system which reduces the effect of traveling over rough ground thus achieving good ride quality. Recently, new types of the shock absorber that utilize magnetorheological (MR) or electrorheological (ER) fluid are being developed and

start to be applied to real vehicles. The application of MR and ER fluids allows the shock absorber to be continuously controlled therefore apparently enhancing its performance. With its advantages, the MR or ER shock absorber should be extensively applied in future vehicle suspension systems.

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