MECA0063: Vehicle Architecture Suspension technologies

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Outline

RIGID AXLES SUSPENSIONS

- General considerations
- Hotchkiss
- Four link
- De Dion
- SEMI RIGID SUSPENSIONS

Outline

INDEPENDENT SUSPENSION

- Trailing arm suspension
- Short Long Arms:
 - A arms
 - H arm
- Mc Pherson
- Five links
- Rear trailing arm suspension
- Semi trailing arm suspension
- Swing axle

Lesson 2: CONSTRUCTIVE TECHNOLOGY OF SUSPENSIONS



Solid axles



Solid axles

- On solid axles, the two wheels are mounted at the two ends of a rigid shaft
- The motion of one wheel is transmitted to the other one
- Both wheels experience common camber and steering motions
- The solid axles are used on live (motorized) axles:
 - On rear axles of many trucks and on some passenger cars (e.g. pick-up vehicles)
 - On front axles of four-wheel drive trucks
- Solid axles are also used
 - On front axles of trucks when large-load capacity is required







Solid axles

- Advantages of solid axles:
 - The camber of the wheels is not affected by the body roll, the unevenness of the road
 - No wheel camber angles in turn, except the higher compression of the outer tires due to lateral load transfer
 - The alignment and the wheel track are preserved minimizing wear
- Disadvantages of solid axles
 - Major drawback is the susceptibility to vibrations, tramp-shimmy of steering
 - Suspended mass is high, so higher transmissibility of vibrations from road to rolling body

Solid axles: Hotchkiss



Gillespie Fig7.1: Hotchkiss suspension





Toyota Tacoma rear solid axle

Solid axles: Hotchkiss

- The most common and the oldest type of solid axles
- The axle is centered and damped with semi-elliptic leaf springs
- Transmission of engine power through a longitudinal shaft with two universal joints (Hook-Cardan) (constant velocity lay-out)
- The leaf springs are mounted longitudinally and are connected to the body at the two ends (one fixed end and one free end not to constrain its extension)
- The leaf spring also ensures other functions like lateral guidance of the axles and also the transmission of longitudinal forces developed in the tire-ground contact patch.

Solid axles: Hotchkiss

 The roll of a Hotchkiss with leaf springs



Milliken Fig 17.44



Heisler Fig 7.7 Leaf spring micro bending due to acceleration/braking torques

Solid axles: Hotchkiss

ADVANTAGES

- (+) Low manufacturing cost
 DRAWBACKS
- (-) Important unsprung mass
- (-) Uncontrolled friction between the leaf springs
- (-) Suspension travel due to lateral forces
- (-) Loss of stability with softer (i.e. longer) springs for light cars.
- (-) Lateral deformation and torsion appears when passing high torque and high engine power. Thus reintroduction of traction arms and lateral guidance bars to sustain high braking / traction forces



Gillespie Fig 7.2: Four link suspension





Solid axles: 4 links

- Answer to the difficulties of leaf springs
- Good choice for large passenger cars with rear solid axle
- The lower control arms transfer the longitudinal forces and provide the longitudinal control
- The upper arms take the braking / traction torques and the lateral forces
- The set of upper arms can be replaced by a triangular arm, but with a similar functionality



Solid axles: 4 links

ADVANTAGES - DRAWBACKS

- (+) Enables to use coil springs or air springs to increase the comfort, reduce the uncontrolled friction, increase NVH comfort
- (-) More expensive
- (+) Better control of the roll center of the suspension mechanism
- (+) It makes possible to tailor anti-dive and anti squat geometries
- (+) Better properties for the roll stiffness and roll-steer properties



Gillespie Fig 7.3 : De Dion Suspension



Milliken Fig 17.43 : de Dion suspension

- Across between solid axles and independent suspensions, the De Dion axle (patented by the Count de Dion and Georges Bouton in 1894) consists of a cross tube between the two driving wheels and of two half shafts connected to the differential.
- The differential is mounted on the chassis to reduce the unsprung mass.
- The tube is curved to avoid geometrical interference with the differential

- The system is classic, but of little use in practice
- The tube maintains a perfect geometry of the wheels
- The tube is sometimes able to extend by sliding to have a better comfort
- The control of the lateral motion requires a sliding tube or a splined shafts, which add friction into the system
- The motion of the axle can be controlled by various spring and damping systems

ADVANTAGES - DRAWBACKS

- (+) Like solid axles, the system maintains the wheels in a proper geometry, while reducing the unsprung mass
- (+) The control of the de Dion Axles can be achieved either by leaf springs or by coil (air) springs
- (-) The sliding pivot introduces some friction in the system
- (+/-) One has to introduce a lateral guidance system (e.g. a Panhard bar)
- (+/-) Better comfort than solid axles (lower unsprung mass), but still remain below what can be offered by independent suspensions systems.



Examples: Smart Fortwo, Alfa GTV6, Mazda Cosmo...



De Dion axle of Alpha Romeo GTV6

Lateral restriction systems



Milliken Fig. 17.16 : System for restraining the lateral motion

Semi-rigid axles

Semi-rigid or twist axle rear suspensions





Semi rigid suspension of VW Golf

- Quite novel family of suspension systems
- Mostly used for the rear axle of small (A/B) passenger cars with front drive
- Origin of the name: a beam axle experiences some torsion to enable the roll motion of the unsprung mass
- The axle kinematic allows controlling all parameters except the anti squat because there is no applied traction torque
- Three major types (lay-out) of semi rigid axles depending on the position of the twisting beam
- The roll axis is modified by the position of the twist beam



Working principle of a semi rigid suspension

- This is the simplest type of axles. Using a very schematic analysis, it can be modeled as longitudinal arms hinged to the chassis, connected by a torsion spring, and completed by vertical coil springs, and shock absorbers
- In some cases, the coil springs can be substituted by torsion bars
- This type of suspension is very compact, easy to manufacture, simple to assemble
- The semi rigid axle lay out does not allow to transmit some engine torque so that it can only be implemented on the rear axle of front wheel driven cars



- <u>Type a:</u> twist beam is located at the level of the bearing with the chassis.
- Similar to an independent trailing arm suspension
- <u>Type b:</u> The twist beam is positioned at mid way between the bearings and of the wheels.
- In rebound, there is a rotation about the axis of the bearings
- In roll, it has the same properties as a semi-trailing arm independent suspensions
- <u>Type c:</u> The twist beam is located in the axis of the wheels
- Requires a Panhard bar to restrain the lateral motion

ADVANTAGES – DISADVANTAGES

- (+) The large distance between the supports (bearings) minimizes the structural stresses in the car body
- (+) Load transfer is favorable to longitudinal arms
- (+) Simple to manufacture
- (+) Attachment by two points only \rightarrow Simple to assemble
- (+) Extremely robust
- (-) Rather limited kinematic capabilities (limited geometric parameters)
Semi rigid suspension



 Semi rigid axles are used on many mid class passenger cars (segment C: VW- Golf, Fiat Punto...)

Independent suspension

Independent suspensions

- Contrary to solid axle suspensions, the independent suspension allows an independent motion of the two wheels of the axle.
- The vertical motion of one wheel does not affect the motion and the geometry of the other one
- Nearly all modern cars and light duty vehicles have independent suspension systems on the front wheels
- The major advantages of independent suspensions are:
 - They are very compact and allow for a larger space for the engine compartment
 - They improve the comfort
 - They improve the handling



Independent suspensions

ADVANTAGES

- They are very compact and allow for a larger space for the engine compartment, which enables a lateral engine mounting
- Provide a better resistance to shimmy and wobble vibrations by decoupling the wheels and interposing the mass of the engine
- Provide a higher roll stiffness with a given vertical spring rate
- Easy control of the roll center by controlling the position and the geometry of the suspension arms
- Capability of controlling i.e. minimizing the modification of the wheel geometry and so the pressure distribution in the contact patch in bounce and rebound
- Larger suspension travel than solid axles

Independent suspension with trailing arms

- Historical success of VW and Porsche cars during WWII
- Front parallel trailing arms with the same dimensions, connected on their front part to a torsion bar that provides the spring system
- The wheels remain parallel, but they take the same camber as the roll of the unsprung mass



Gillespie Fig. 7.4 Independent suspension with trailing arms

Independent suspension with trailing arms







Gillespie Fig 7.5 A arm suspension



- The most common lay out in many passenger cars after WWII
- Two triangular arms maintain the geometry of the wheels
- The upper and lower arms have generally different lengths so the name of short long arm suspension
- The arms are generally named A-arm or H-arm (USA), wishbones (GB), suspension triangles (en français)
- Variants or equivalent designs:
 - The upper arms is replaced by a simple unique link
 - The lower arms is substituted by a lateral arm and an angle strut

- The SLA suspensions are well adapted to
 - Vehicles with a longitudinal engine at the front and rear drive wheel
 - Vehicles with a chassis subframe separated for the benefit of the assembly and for shock absorption



(b) Horseshoe subframe





(a) Transverse equal-length wishbones

(b) Transverse unequal-length wishbones

Heisler Fig 7.34 : Effect of short long arms on the minimization of the wheel track change



Camber modification of A-arms on modification of camber change: (left) equal length vs (right) short-long arms a^{-1}



Camber modification of A-arms on modification of camber change : (left) parallel vs (right) non-parallel



- The design of the geometry calls for great care to reach high performances
- The geometry of the arms (hinge position) can improve the camber of the outer wheel by counteracting the wheel camber due to roll at the price of a higher camber on the inner wheel
- Taking unequal arms is attenuating the unfavorable conditions on the outer wheel, even though deteriorating the compensation on the inner wheel
- It is necessary to minimize the contact patch modifications during wheel travel



Double triangle suspensions mounted on a chassis subframe

Porsche 993 (rear rolling train)







Gillespie Fig. 7.6 Mc Pherson strut suspension

- Mc Pherson developed a suspension geometry similar to SLA suspension using a telescopic strut
- The strut is a prismatic joint combined with a shock absorber
- The wheel is rigidly attached on the lower end of the strut, so the prismatic joint maintains the wheel in a predefined camber geometry
- The lower part of the strut takes is subject to the lateral and longitudinal forces generated in the wheel contact patch because of the rigid connections with the wheel knuckle
- In its upper part, the strut is connected to the car body using a spherical joint



Examples: Fiat Croma, Lancia Thema, Saab 9000, Fiat Tipo, Tempra, Lancia Delta, Dedra...





- The Mc Pherson struct combines :
- A sliding tube,
- A damping element,
- A spring element.



Genuine Mc Pherson system

- System combining the damper, the spring element and the knuckle.
- The system includes also the wheel carrier.
- The stabilizing bar is used for guidance.
- The combined shock absorber is bounded in the lower part to the wheel carrier and the upper part directly to the car body.

Pseudo Mac Pherson suspension

SUSPENSION TRAIN AV - MOYEUX

 Berceau - 2. Triangle de suspension - 3. Barre etabiliestrice - 4. Biellette de renvoi - 5. Pivot - 6. Amortisseur - 7. Butoir - 8. Ressort
9. Coupelle supérieure - 10. Tampon élastique - 11. Bride de lixation - 12. Patier de barre stabilisetrice - 13. Moyeu - 14. Roulement à double rangée de billes - 15. Clip - 16. Déllecteur



- The hub (5) is bounded to the Mc Pherson combined strut and shock absorber
- The lower link (2) is a triangular arm able to take over the longitudinal forces
- With only the lower triangle, it is not possible to control the dynamic camber.
- However, the strong lower arm enables to pass large torque and power.
- It is generally used for mid size cars and very often on front wheels of front wheel driven vehicles.

ADVANTAGES - DRAWBACKS

- (+) The Mac Pherson system is extremely compact. It allows the lateral engine mountings in the front axles. It is usually used in front drive vehicle
- (+) Because of the large separation of the connection points in the car body, it is well adapted to semi monocoque car body structures, even though the higher connection of the strut is a highly stressed zone.
- (+) The strut has the advantage of introducing a small number of parts
- (-) The strut geometry requires a high vertical space under the car bonnet, which strongly limits the reduction of the height of the front car

Multi (five)-link suspension



Miliken Fig 7.33: Five link suspension of a Mercedes

Multi-link suspension





- Recently, the multi-link suspensions (five links) were developed (e.g. Mercedes, Corvette after 1984)
- The idea is simple: using 5 links in order to create the five kinematic constraints to define a suspension mechanism able to achieve a desired one dof wheel path
- The links are connected through spherical joints, which transmit no torque and moment
- The whole wheel carrier is rotating during the wheel steering
- Generally one can see multi-link approach as a separation of upper and lower A arms
- This approach provides a high flexibility to design the suspension characteristics



Miliken Fig 7.34: Five link suspension of the Corvette

- The position and the orientation of the links proceed from the same idea as for 3 links and 1 triangle (1 triangle = 2 links)
- Great flexibility of this kinematic approach: tailoring the instantaneous center of rotation in the different projection planes
- Aim: to achieve the desired kinematic performance in the frontal plane without any compromise with the kinematic in the lateral plane
- Other targets : to realize very short knuckle axes and very small scrubbing radius





W203 Suspension Steering And Braking Parts



Multi-link suspension system with crossed upper links (rear axle, 1997 Mercedes-Benz W220 S-class)



Milliken Fig 7.24 : Rear trailing suspension







Citroën 2CV's trailing arm suspensions

- Often used on luxury cars in which performance is expected: e.g. rear suspension of the Corvette before 1984
- The control arms absorb the longitudinal forces, and the braking/acceleration torques. They also control the squat and dive motions
- The trailing arm suspensions have the advantage to reduce the unsprung mass by mounting the differential on the chassis



Gillespie Fig 7.8 : Rear trailing arm suspension of the corvette before 1984

Rear suspensions with semi trailing arms



Gillespie Fig 7.9 : Rear semi trailing arm suspension

Rear suspensions with semi trailing arms



Milliken Fig 7.25 : Rear semi trailing arm suspension
Rear suspensions with semi trailing arms



Rear semi trailing arm suspension of BMW

Rear suspensions with semi trailing arms

- The independent suspension with semi trailing arms were very popular on BMW and Mercedes
- The rotation axis makes generally an angle of about 25° with respect to the transverse direction of the car
- It gives rise to a wheel camber intermediate between trailing arms (no camber change with respect to the chassis) and swing axle
- The semi trailing arm generates steer effects with vertical motion (jounce and rebound)
- The combined effect steer / camber on the outer wheel is acting in an opposite direction to the turn direction, which generates a roll steer of the rear axle.
- Compliance to the lateral force creates another steering effect that might become oversteering if uncontrolled

Rear suspensions with semi trailing arms





Milliken Fig 7.26 : Rear swing axle suspension



In the Corvette before 1984, a half shaft with a universal joint is used as the upper control arm while a strut is used as the lower lateral arm

Milliken Fig 7.27 : Swing axle rear suspension (Corvette before 1984)

- The simplest way to make a rear suspension is to use swing suspension arm.
- The wheel is attached to an arm connected to the differential by a Universal joint.
- Famous example: the VW beetle , Spitfire Triumph
- It can be seen as a limit case of semi trailing arm
- The camber behavior is entirely determined by the rotation of the arm about its joint
- Because of the short radius circular motion the camber changes can be very important. Thus it is difficult to have a good performance in turn with swing axles



Swing axle

VW Beetle



Spitfire Triumph



Why are the wheels crooked?

A split rear axie. The rear wheels are individually sus-pended, to adjust to the shape of the road, (Most European races have this, but few parsenger card) Take the opposite, the rigid rear axie, What if your car hits a rut hale? Clank.

Sessoned drivers well for firs themp. In a Volkworgen, in rever come. Volk for 3 years, 'no ever come. Volk for 3 years, 'no ever come.' Volkworgen zo en commer, 'no ever pension on all four whenis, (Not many possenger can how this, either).

79



Gillespie Fig 7.10 : Rear swing axle suspension: jacking



- The jacking problem, which is present in every independent suspension, is critical with swing axles
 - Occurs in turn when the wheels develop important lateral forces and when the outer wheel is the most loaded. The lateral forces pointing inward wrt the chassis tends to lift the vehicle
 - \rightarrow the body is lifted up and its resistance to roll over decreases
 - → Reduction of the cornering stiffness due to the high camber thrust in the opposite direction to side slip forces
 - → Can lead to roll over or jack knifing
 - Jacking can be attenuated by including an extra arm to limit the wheel motion



http://www.youtube.com/watch?v=LR9Bbc mbrVU

- Jacking phenomenon in which the rear axles is pushed upward by the lateral forces developed at the contact patch
- Swing arm was applied in many small cars after WWII, especially British car as the Triumph and the Spitfire ones
- <u>http://herald-tips-</u>
 <u>tricks.wikidot.com/rear-</u>
 <u>suspension:jacking-and-tuck-</u>
 <u>under_movie</u>

Rear swing axle suspensions

ADVANTAGES – DRAWBACKS

- (+) Low cost
- (-) Quite limited options to set-up the kinematics
- (-) Jacking of the rear axle lift by lateral forces in turn
- (-) Linking between vertical motion and generation a high positive camber