Article citation info:
Macikowski K, Kaszuba S, Pawelski Z. Vehicle stabilizer bars with variable stiffness characteristics. The Archives of Automotive Engineering - Archiwum Motoryzacji. 2016; 74(4); 83-94, http://dx.doi.org/10.14669/AM.VOL74.ART6

VEHICLE STABILIZER BARS WITH VARIABLE STIFFNESS CHARACTERISTICS

KRZYSZTOF MACIKOWSKI[1], STANISŁAW KASZUBA[2], ZBIGNIEW PAWELSKI[3]
Lodz University of Technology

Summary

The stabilizer is a device mounted to the vehicle body in a rocking manner. The ends of stabilizer bar arms are connected to the chassis elements. The central section is connected to the body by means of two radial bearings. The free ends (arms) are connected to suspension arms or suspension struts with short, bi-articulated bars. Stabilizer may be mounted either on the front or rear axle, or on both axles. Classic stabilizer is a U-shaped tube or rod of circular cross-section, made of spring steel and is characterized by a constant stiffness. In stabilizer bars referred to as active it is possible to change the rigidity. This allows to adapt the characteristics of the stabilizer bar to other components of the vehicle suspension, depending on the motion parameters it's possible to influence the vehicle's safety and handling, as well as the comfort of the driver and passengers. The article presents selected solutions of mechanisms and systems, whose role is to change the stiffness or tension of the bar. It also outlines the concept of stabilizer bar tension changes developed at the Department of Vehicles and Fundamentals of Machine Design at Lodz University of Technology.

Keywords: stabilizer bar, active stabilizer bar, variable stiffness

1. Introduction

The function of vehicle stabilizer bars is to improve the driving comfort, steerability and safety. They do not allow excessive tilting of the car body when driving at high speed on a curve. Tilting is a consequence of the centrifugal force acting on: the body of the vehicle, drive train system components, the passenger and the cargo. Insignificant tilt of vehicle

[1] Lodz University of Technology, Faculty of Mechanical Engineering, Department of Vehicles and Fundamentals of Machine Design, ul. Żeromskiego 116, 90-924 Łódź, Poland, e-mail: krzysztof.macikowski@p.lodz.pl

[2] Lodz University of Technology, Faculty of Mechanical Engineering, Department of Vehicles and Fundamentals of Machine Design, ul. Żeromskiego 116, 90-924 Łódź, Poland, e-mail: stanislaw.kaszuba.500@guest.p.lodz.pl

[3] Lodz University of Technology, Faculty of Mechanical Engineering, Department of Vehicles and Fundamentals of Machine Design, ul. Żeromskiego 116, 90-924 Łódź, Poland, e-mail: zbigniew.pawelski@p.lodz.pl

body is beneficial for accurate and safe driving. Excessive tilt can cause loss of steerability resulting from the reduction of the downforce pressing wheels to the ground, which in extreme cases can lead to loss of contact between the wheel and the road surface. The consequence of this situation is vehicle skid, or loss of lateral stability, which could result in the vehicle being overturned [1]. The device responsible for reducing the tilt, and thus improving the steerability is the stabilizer bar, which is a suitably shaped torsion bar of properly adjusted rigidity [1]. The rigidity is calculated by the following formula:

$$K_b = \frac{P * l}{\alpha} = \frac{M}{\alpha} \quad (1)$$

where:
Kb [Nm/rad] – bar rigidity
P [N] – torsional force of the bar
L [m] – bar arm length
α [rad] – bar torsion angle
M [Nm] – moment acting on the bar arm

In automotive engineering it is assumed, with a slight simplification, that the stabilizer bar stiffness is constant.

Among some widely known design solutions of vehicle stabilizer bars we may differentiate basic types are:

1. Solid rod stabilizer bars – made from rods of solid cross-section. They are characterized by being easy to manufacture. They are found in both passenger and heavy goods vehicles.
2. Hollow stabilizer bars – designed as a tube closed at its ends. They are characterized by up to 45% lower weight, while maintaining the same shape, equal maximum stabilizing force and equal maximum tension. Such beneficial effect is achieved by improving the tension distribution as compared to solid rod stabilizer bars [2]. They are used mostly for applications that require a reduction of the vehicle weight, usually in sports cars.
3. Divided stabilizer bars – the middle section is divided and bar tension mechanisms are installed in the place of the removed bar section. They are used to adjust the bar tension, depending on the vehicle run parameters. The solution is applied in high-end and off-road vehicles, for instance SUVs.

2. Conventional stabilizer bars (constant characteristic)

conventional stabilizer bar, of constant rigidity (Figure 1) is a U-shaped spring, usually made of spring steel [2]. The central portion of the bar is subject to torsion and the side arms are bent or and bent and subject to torsion [3].

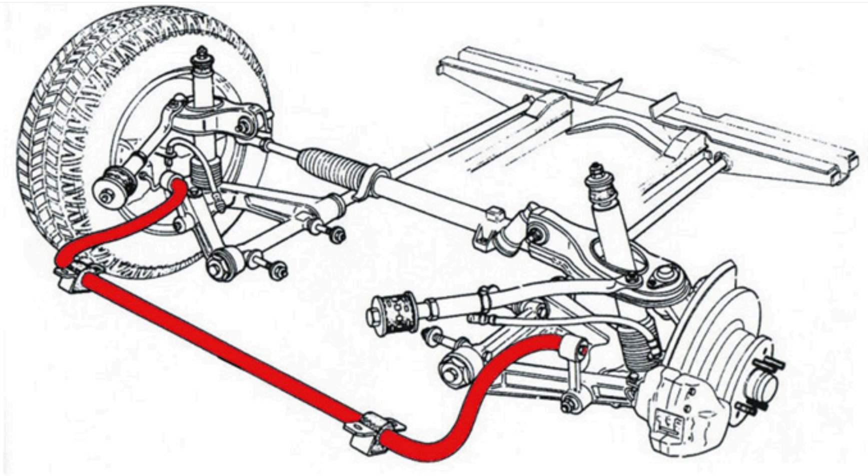

Fig. 1. Conventional stabilizer bar [10]

3. Active stabilizer bar (variable characteristic)

Stabilizer bars referred to as active are characterized by the fact that the rigidity parameter can be adjusted within certain limits, smoothly or in increments. This adjustment is carried out by means of hydraulic, electrical, mechanical, or mixed systems.

Stiffness characteristics obtained in the form curves (K_{b1}, K_{b2}, K_{b3}, K_{b4} exemplified in Figure 2), which, depending on the deflection of the beam arm, should be characterized by linearity and the possibility to increase or decrease the rigidity from the minimum value of K_{bmin} to the maximum of K_{bmax}.

The analysis of solutions applied in the construction of active stabilizers allows to anticipate some of the most common locations where the mechanisms for stiffness adjustment are installed by engineers:

- the central part of the bar (tensioning of the central part by means of mechanical levers or fitting the central part of the bar with tensioning mechanisms)
- bar arms (shortening or lengthening of the arms or altering the shape of the arm cross section)
- stabilizer bar arm ends (sliding the support points of the stabilizer bar connector interacting with the bar arm, replacing stabilizer bar connectors with hydraulic cylinders)

The remaining part of this article will describe some examples of mechanisms and systems, whose task is to alter the rigidity or the tension of the bar.

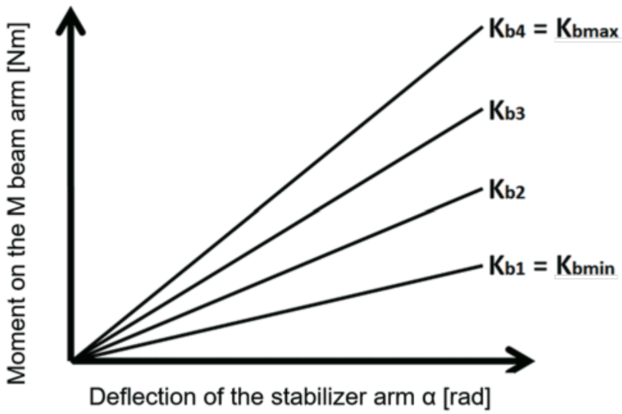

Fig. 2. The range of the active stabilizer rigidity alteration depending on its adjustment settings

4. Changing the stiffness in the central part of the bar

4.1. Tensioning the bar by means of mechanical levers

Figure 3 presents the concept of stabilizer bar tension change with the use of mechanical levers developed at the Department of Vehicles and Fundamentals of Machine Design at Lodz University of Technology. System 1 has a valve that controls hydraulic fluid delivered from a hydraulic pump (not shown) to two double-acting cylinders 2. Two levers 3 are articulated to the piston cylinder ends 2 on one side, and rigidly fixed to the central part 4 of the stabilizer bar on the other side. The central part 4 of the section between the levers 3 has a smaller diameter (lower rigidity) than the rest of the bar.

The principle of operation of the presented concept is based on the tensioning of the bar by extending and retracting the piston cylinders 3, depending on the parameters of the vehicle run. Independent control of each actuator allows to adjust the downward force pressing a selected wheel to the surface while not affecting the remaining wheel. This is possible thanks to the reduced diameter of the central section of the bar.

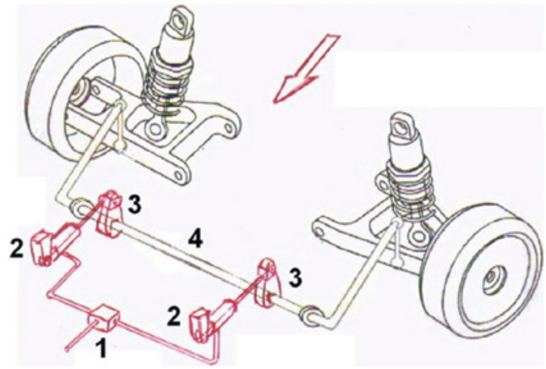

Fig. 3. The concept bar tensioning system by means of mechanical levers

4.2. Stabilizer bar with a Deplhi hydraulic-mechanical bar tensioning system

An example of the above described solution is the Delphi invention which is the subject of patent US6318737. The stabilizer torsion bar is split and in the place of removed material a bar tensioning mechanism is fitted. The solution operates according to the same principle and, as in the conventional solution, it does not operate when the vehicle is moving along a straight path. Wheel deflection is identical for the left and right. Its operation begins when the vehicle enters a curve or the wheel displacement becomes different for each axle. The reduction of the vehicle body roll is caused by hydraulic fluid pumped by hydraulic pump 82 to one of the two chambers of the mechanism – figure 4.

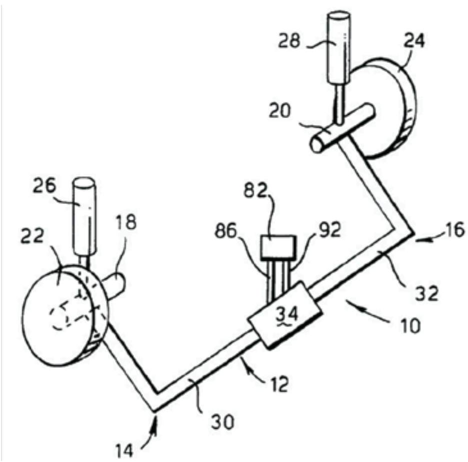

Fig. 4. Ground view of the vehicle suspension system, in which the stabilizer is equipped with a Delphi bar tensioning mechanism [4] indicated with number 34 on the drawing.

The principle of the mechanism involves the hydraulic fluid acting on the working surface 64 of the shaft 62 – figure 5. The shaft is equipped with a tripod joint 78 on each side, placed in helical grooves 70, 74 of the housings 38 and 42. The grooves are cut in opposite directions. The hydraulic fluid pressing against the working surface causes rotation in the groove of one of the tripod joints, and therefore axial displacement of the shaft in the direction corresponding to the direction of the pumped liquid. The tripod joint on the other side also rotates in the direction of the first joint, but faces resistance in the form of grooves cut in opposite direction, which causes the rotation of the stabilizer bar half. Thus, the bar becomes straightened. The creators of the patent suggest to condition the force applied by the pumped liquid in based on the given vehicle run parameters. In the presented mechanism, the housings are connected by means of a sleeve 40 which is rolled with element 42. Part 38 is prevented from slipping from the sleeve 40 by means of an expansion ring 54 and is sealed with a rubber ring 56. The authors of the patent indicate that the presented method of mechanism connection is not necessary, however is effective and recommended.

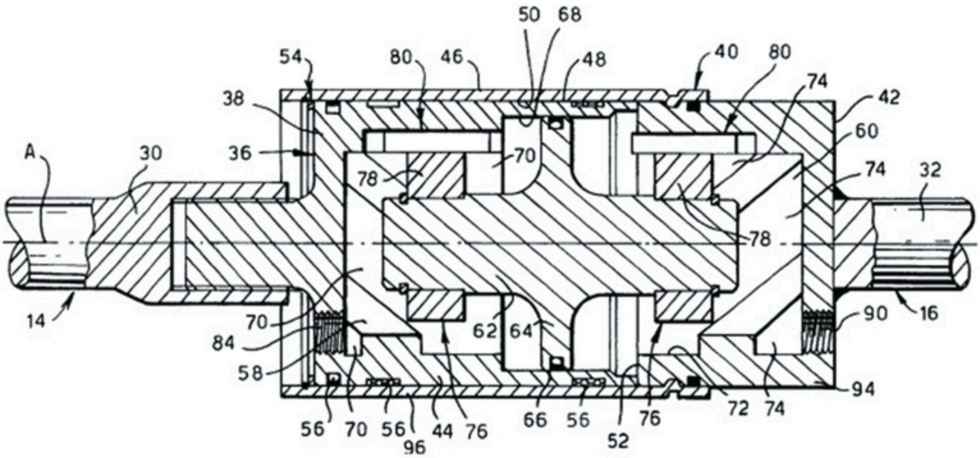

Fig. 5. Longitudinal section through a Delphi bar tensioning mechanism [4]

4.3. Stabilizer bar with tensioning mechanism fixed on a two-element central section, manufactured by Peterson & Erb

An interesting solution to change the stabilizer rigidity is the mechanical system presented by Peterson & Erb. This invention is registered under Patent No. US6832772. It consists of two main sections – Figure 6. The first section has an arm which is not modified. Arm 1 is connected to the central element 23 by perforated radial openings 7, 8, 9, 10, 11. The second part has arm 2, which also is not modified. Arm 2 is connected to the central section 5 by connector 24. The central section 5 is a tube with holes perforated correspondingly to openings 7, 8, 9, 10, 11 in element 23. The first half of the stabilizer bar described above is inserted into the second part and connected with the use of screw 6 (Figure 7), two appropriately profiled washers 6 and nuts 6 fitted on a selected opening 7, 8, 9, 10 or 11. It is important that the openings in each half of the bar align after the assembly and that the inner diameter of central section 5 and the outer diameter of central section 23 have the same nominal size, with clearance fit applied.

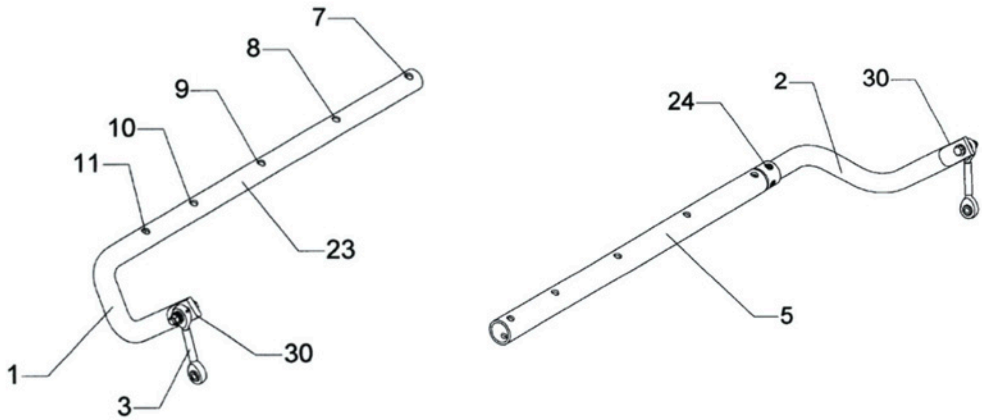

Fig. 6. Left: ground view of the smaller diameter stabilizer bar section. Left: ground view of the larger diameter stabilizer bar section. [5]

Figure 7 shows the vehicle stabilizer bar in two operating positions – of medium rigidity and the maximum rigidity. The maximum rigidity is achieved with connector 6 placed in opening 11. In such case the central section 5, characterized by a larger diameter is subjected to torsion. After placing the connector 6 in opening 7, the central section 23, characterized by a smaller diameter is subjected to torsion, resulting in the minimum rigidity of the stabilizer bar. Placing the connector in the remaining 6 holes corresponds to obtaining intermediate rigidity state.

The authors of the patent state that the central section 23 can be formed as a rod or tube. The stabilizer bar presented in Figure 7 was installed and tested in Honda S-2000 vehicle. The disadvantage of the solution is the need to adjust the rigidity of the stabilizer bar prior to the vehicle run in the selected conditions, which is time consuming and possible under workshop conditions only.

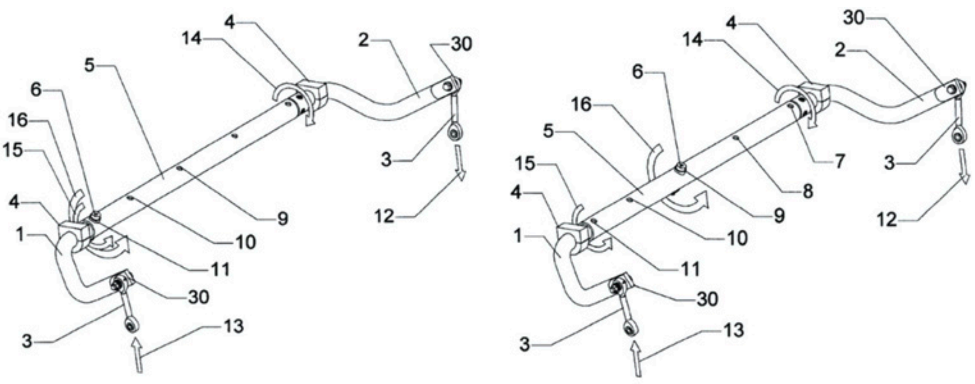

Fig. 7. Ground view on vehicle stabilizer bar in two operating positions [5] Left: stabilizer bar set to the highest rigidity value. Left: stabilizer bar set to a medium rigidity value

5. Changing the rigidity of the bar arms

5.1. Shortening or lengthening of the elephant racing stabilizer bar

The solution presented in Figure 8 whose operation principle is the subject of patent No. 5288101 is dedicated for Porsche 914 vehicles. The Elephant Racing stabilizer bar allows the change of the active stabilizer arm length within a specific range. This requires structural changes that involve the manufacturing of new, adaptive bar arms. The arms, available as a special design, are mounted on the two ends of the central bar section. The arms are provided with longitudinal grooves in which the position of the stabilizer bar connector rod can be adjusted, depending on the vehicle operator preferences. Setting the stabilizer bar connector rod in the position closest to the central section causes the maximum rigidity of the stabilizer bar, while increasing the distance from the central section reduces the stabilizer bar rigidity. The disadvantage of the solution is the inability to move the support point of the central section while driving the vehicle and the process requiring substantial amount of time, only possible to carry out after lifting the axle which is to be adjusted.

Fig. 8. Front axle stabilizer bar with adjustable arm [6]

In the discussed solution, the arms are made as separate elements of rectangular cross section. The material used for the arms is AA 6061-T6 high-strength aluminum alloy [7]. This contributes to reduced weight while maintaining its high strength characteristic.

5.2. Changing the shape of the cross-section of elephant racing stabilizer bar arms

This solution is available for sale as a universal spare part (without the automation), but also used in its electrically controlled factory version, in Porsche 911, 912 and 930 vehicles. It involves the use of a specially designed part – a stabilizer bar arm whose cross section is adjustable along its longitudinal axis, whose shape is similar to a rectangle – figure 9.

Fig. 9. Front stabilizer bar with adjustable arm [8]

The operation principle is similar to that shown in U.S. Patent No. FR2626819A1. The arm, on the side of the bar central section is provided with an electric motor rotating it in the range of 0 – 90˚. On the other side, the arm is connected to the connector rod of the stabilizer with a ball joint. Setting the arm in a position in which the cross section subject to bending has the highest cross section index, results in obtaining the maximum rigidity. The effect of setting a 90˚ turn position provides the minimum rigidity value (minimum cross section to torsion ratio). It is possible to set the arm in intermediate positions. In this situation, the change of the resultant force direction produced by the twisting moment of the arm produces a non-linear variable rigidity characteristic as a function of the rotation angle. An example of this characteristic is shown in Figure 10. It is derived from the computational analysis carried out at the Department of Vehicles and Fundamentals of Mechanical Engineering Technical University of Lodz for an element of a 40x8 mm cross section and a 274.4 mm arm length.

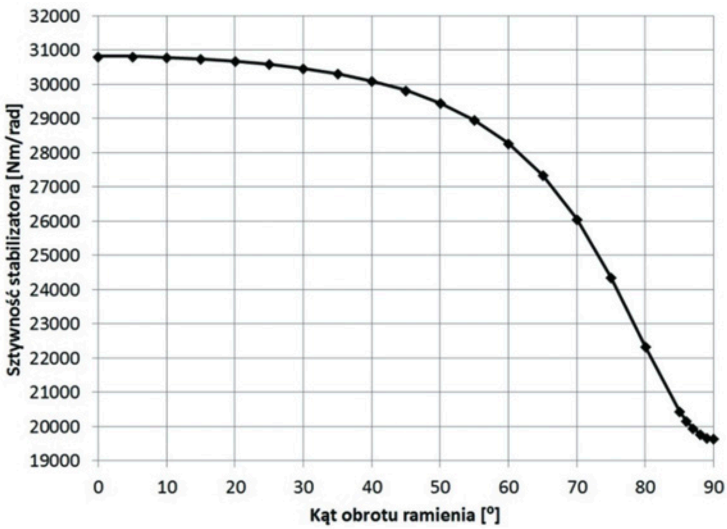

Fig. 10. Graph presenting the change of rigidity in a stabilizer of variable cross-section at the moment of being rotated to 90° from its vertical position to a horizontal position [own source]

6. Changing the rigidity as a result of variable forces acting on the bar arms ends

6.1. Moving the support points of the stabilizer bar connector interacting with a hyundai stabilizer bar arm

An example of such a solution is the Hyundai invention (Fig. 11), which is the subject of patent No. US8596647B2. The shift of the support points of the connector rods of the stabilizer bar takes place at their ends, at the point of attachment to the lower suspension arm. Thus the design of the stabilizer bar remains unchanged. The suspension arm is modified. Additional space is required for installing a sliding unit 5. Due to limited space, the system – including the drive train system unit 6 – is characterized by its compact design – Figure 11.

The operating principle of the invention consists in moving the support point of the stabilizer connector rod along the guides of the sliding unit on the suspension arm towards and from the vehicle wheel. The change of the support point of the connector on the wheel's suspension arm is regulated by the stabilizer bar tension that transfers the reaction onto the body of the vehicle running along a curve, ensuring its proper position. A double-acting linear actuator 19 is responsible for sliding. The actuator is connected to the housing of sliding sleeves 25 by means of suitable connectors (27 and 29). The sleeves 25 move longitudinally on two symmetrically arranged sliding shafts 23, which are rigidly mounted in the cavity of the sliding unit. The housing of the sliding sleeves is connected with a stabilizer bar by means of two ball joints. On the other side, the connector has a single ball joint. This solution can carry axial loads and moments produced at the stabilizer connector with low frictional resistance at the sliding shafts 23. The authors of the presented invention state that, thanks to the solution, it is possible to install cylinders of lower power and more compact dimensions. Flexible covers 26 protecting the sliding shafts provide appropriate protection against dirt ingression.

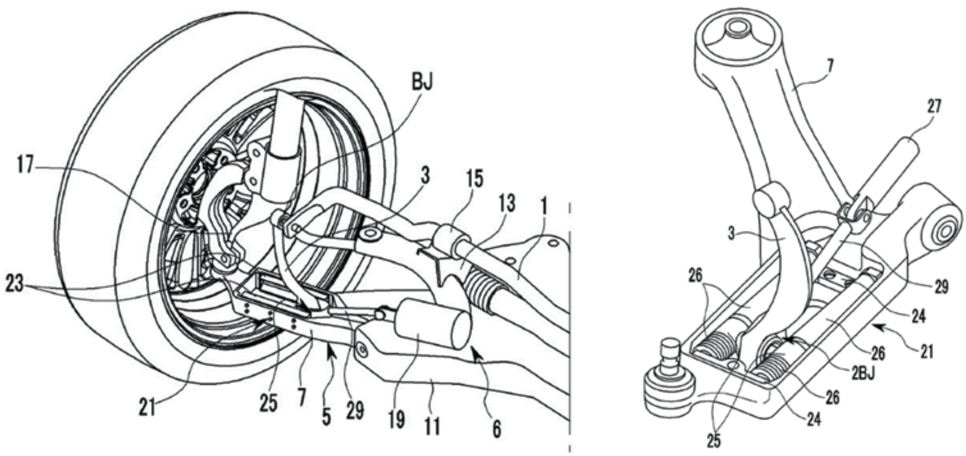

Fig. 11. Left: partial ground view on a vehicle suspension system with a rigidity shift mechanism installed. Right: ground view of the lower suspension arm with a modification to incorporate a sliding cavity [9]

7. Conclusion

The authors believe that among the designs presented in the article, the concept of tensioning the bar by means of mechanical levers, which was developed at the Department of Vehicles and Fundamentals of Mechanical Engineering at Technical University of Lodz, as described in section 4.1, is the only possibility that allows adjusting the downward force pressing the wheel to the surface, without affecting the other wheel simultaneously, as well as ensures the simplicity of the design.

The full text of the article is available in Polish online on the website
http://archiwummotoryzacji.pl.

Tekst artykułu w polskiej wersji językowej dostępny jest na stronie
http://archiwummotoryzacji.pl.

8. References

[1] Mitschke M. Dynamika samochodu. Warszawa: WKŁ; 1977. 266.

[2] Wittek A M, Richter H Ch. Stabilizer Bars: Part 1. Calculations and construction. Transport problems. 2010; 5 (4): 135-43.

[3] Werner J. Budowa samochodów. Konstruowanie podwozi. Warszawa: WKŁ; 1966. 477.

[4] Marechal M, Dazin G. Roll control actuator (Patent no US 6318737 B1). Boston: Delphi Technologies. Available from: http://www.google.ch/patents/US6318737. [cited 1999 Jun 4].

[5] Steven G, Conover. Vehicle center section adjustable anti-roll bar (Patent no US 6832772 B2). Peterson & Erb. Available from: https://www.google.ch/patents/US6832772. 2001 Okt 26 [cited 2016 Apr 9].

[6] Hollow Adjustable Sway Bars For Porshe 911/912/930. Santa Clara: Elephant Racing. Available from: http://www.elephantracing.com/suspension/swaybars/911swaybars-hollow-adjustable.htm. [cited 2016 Apr 19].

[7] Aluminum 6061-T6. Pompano Beach: ASM Aerospace Specification Metals. Available from: http://asm.matweb.com/search/SpecificMaterial.asp?bassnum=MA6061t6. [2016 Apr 19].

[8] QuickChange Blade Style Sway Bar For Porshe 914. Santa Clara: Elephant Racing. Available from : http://www.elephantracing.com/suspension/swaybars/914swaybars-blade-type.htm. [cited 2016 Apr 19].

[9] Lee U K, Jang S B, Yeong Py. Active roll control system (Patent no US 8596647 B2).Seoul: Hyundai Motor Company. Available from: http://www.google.ch/patents/US8596647. [cited 2011 Dec 9].

[10] Mason E. Alfetta front suspension antiroll. Available from: http://commons.wikimedia.org/w/index.php?curid=33148626 [cited 2014 Jun 2].