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# DESIGN OF MOTORCYLE ACTIVE CHASSIS GEOMETRY CHANGE SYSTEM

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*Summary: Modern motorcycles have a number of electronic systems supporting their driving stability. These are usually adopted solutions used in automobiles. However, the idea of trying to affect the driving stability with the use of up-to-now changeless parameters such as wheelbase or trail is quite new. Such an innovative solution of motorcycle suspension with variable geometry dependent on driving conditions was designed in thesis by Jakub Šmiraus and constructed at the Institute of Transport VŠB - Technical university of Ostrava under tutelage of MSc Michal Richtář.*

*Key words: Motorcycle dynamics, motorcycle suspension, variable suspension, variable trail, trail, active motorcycle geometry chassis.*

## INTRODUCTION

During development of the first motored bicycles, e.g. a steam powered Velociped Michaux-Perraux, emphasis was put on neither comfort nor driving stability. Only at beginning of 20th century, when internal combustion engine has been patented by Dr. Otto, his assistant G. Daimler commenced to inquire into issues of driving stability and handling of a single-track vehicle in particular. Since then, motorbike has been inexorably developed into more and more perfect machine with driving dynamics surpassing that of majority of contemporary cars, which resulted in occurrence of periods when engine power significantly outperformed capabilities of chassis. A significant breakthrough in motorcycle chassis design took place at the end of 90s, when new materials, e.g. aluminium alloy or various composites, were utilized. This brought about up-to-now unprecedented strength while sustaining or even decreasing weight of particular parts. It was then, when development of fast yet perfectly controllable and safe motorcycles was made possible. These days, new chassis design, damping and spring elements as well as brake systems with braking assistant solutions are perpetually modernized. The latest innovation in the field of motorcycles is an application of electronics to motorcycle chassis in the form of electronic stabilization of tilt and engine power regulation dependent on driving conditions.

## 1. MOTORCYCLE DIMENSIONS

Typical features of single-track vehicles have always been a good controllability, little road resistance and an easy handling. The above mentioned controllability and stability in a

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straight-ahead driving or pitch is determined especially by ratio of chassis dimensions, construction and an overall steering geometry.

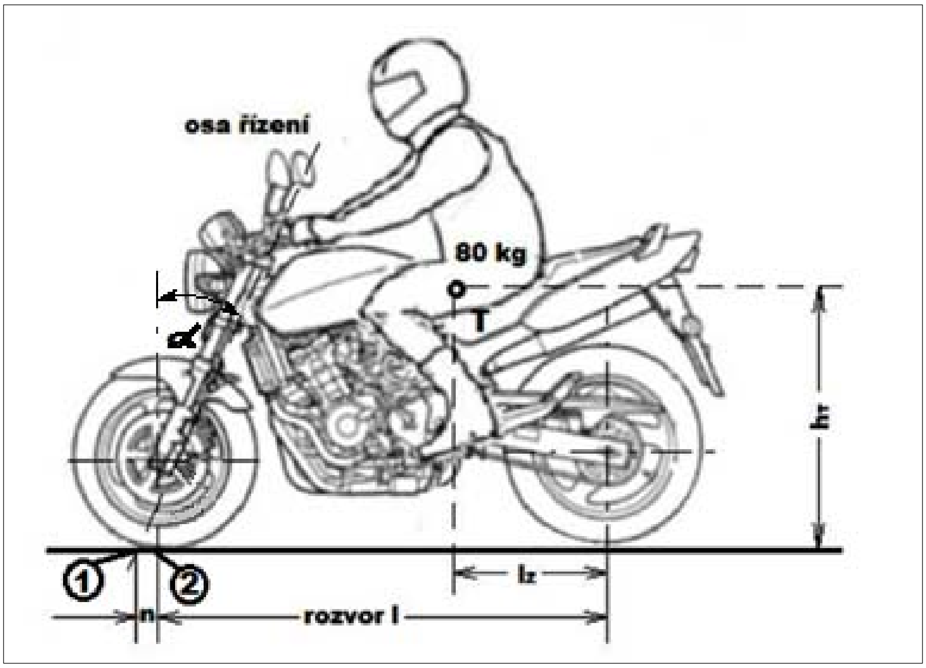

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Fig. 1 - Main parameters of motorcycle chassis geometry

- *Rake (α)*
- *Point of wheel contact (1)*
- *Steering axis and ground intersection (2)*
- *Trail(n)*
- *Wheel-base (l)*
- *Centre of gravity location ($h_T$ , $l_Z$)*

***Rake angle***

Rake angle of the front fork indicates the angle between the steering axis and the ground plane. A smaller rake angle of the front fork results in a greater stabilizing effect on the front fork. The rake angle (angle of steering axis) lies within about 24° to 30° to the ground.

***Steering axis and ground intersection***

Point of contact with the ground is indicated as wheel axis intersection perpendicular to the base of a stationary bike at a point of their intersection.

***Trail***

Trail is the distance between Steering axis and ground intersection and the Point of wheel contact. Trail has a significant impact on the stability and handling of a motorcycle.

***Wheel-base***

Wheelbase is the distance between the rotation axis of the wheels in a straight-line drive.

***Centre of gravity location***

Centre of gravity is determined by vertical and horizontal position. What is more important than examining its position on an unoccupied bike is observing the changes with an increasing load.

Source: (2)

The driving characteristics can be significantly affected by modification of the basic parameters. Therefore, if we want to customize the driving stability of an already constructed motorcycle, we have the following options. We can adjust the position of centre of gravity.

This can be achieved by change of a riding posture, which is, however, limited by placement of control and support elements of the motorcycle. Should a two-person crew drive the vehicle, the centre-of-gravity position shifts notably. Nevertheless, these changes are not always easy to control properly because it is impossible to encompass all the variety of passengers' weights. Further parameters of chassis are: wheel base, trail, rake or steering axis angle. These dimensions are set, but if they were adjusted according to the driving conditions the overall driving stability as well as the steering response to the initiative of the driver could be influenced. Lengthening of both wheelbase and trail would result in an increased straight-line stability, which would help to improve the comfort of long distance driving at higher speed. The opposite is assumed to be true as well. Shortening the latter mentioned parameters would lead to a decreased stability, yet at the same time a better handling, which is advantageous in the conditions of e.g. urban traffic. Such is the theory of these features impact on the motorcycle handling and driving characteristics.

## 2. SINGLE-TRACK VEHICLE DYNAMIC

### 2.1. The equation of motorcycle motion

The same rules and laws can be applied to the motion of all other vehicles. Motorcycle motion ca be defined by the same equation of motion as automobile or a train motion.

$$F_K = O_f + O_S + O_V + O_{ZR} + O_T \tag{1}$$

$$\frac{M_K}{r_d} = F_K = O_f + O_S + O_V + O_{ZR} = F_Z \frac{e}{r_d} + c_x \frac{\rho}{2} S_x v_r^2 \tag{2}$$

Under the conditions $O_S, O_T, O_{ZR} = 0$

$F_K$……. Driving force(Power) [N]

$O_f$…… Rolling resistance [N]

$O_S$……. Gradient resistance [N]

$O_V$…… Air resistance [N]

$O_{ZR}$….. Acceleration resistance [N]

$O_T$…… Draw resistance [N]

It is pointless to deal with particular resistances, stated in the above equation of motion (1), in this article. The text covers only the resistances which are expected to be affected by the intervention of an active change in steering geometry. The rolling resistance remains unchanged, but later it is going to be mentioned as one of the resistances ensuring the straight-line stability. Gradient resistance, greatly dependent on the track character – an external factor – will be considered as unchanged as well from the point of view of active change in steering geometry. Next in the equation (1), there is the air resistance, whose main component is a quadratic velocity $v_r$, an input factor of driving.

Another external factor is the density of air ρ, determined by the driving conditions. The following two ones, i.e. the coefficient of air resistance $c_x$ and the wind area $S_x$, are expected to alter after the geometry change. The benefit, although just a minor one, of such a change is the decrease of the product of these two variables when the speed increases. This also means a reduction of air resistance at higher speeds. Seemingly, an acceleration resistance is not affected by the chassis geometry change, which is only partly true. This resistance is not affected by the chassis geometry change unless we consider the maximum acceleration. This implies that by changing the wheelbase and thus changing also the distribution of load on each wheel it is possible to influence the value of the maximum acceleration or deceleration of motorcycle. When we lengthen the wheelbase we are able to shift the position of the centre of gravity. In case of a pursuit of a maximum positive acceleration the centre of gravity shall be moved from the rear wheel to the front one. Thus we can find the exact limit of the rear wheel slip by both the lack of a loading force on the front wheel and the motorcycle wheeling due to the shift of the centre of gravity to the back. At deceleration the effect will be exactly the opposite. At intensive braking the rear wheel is relieved, which leads to loss of stability or might even cause a vehicle roll. This situation is represented by the equation below.

## 2.2. Maximum positive or negative acceleration

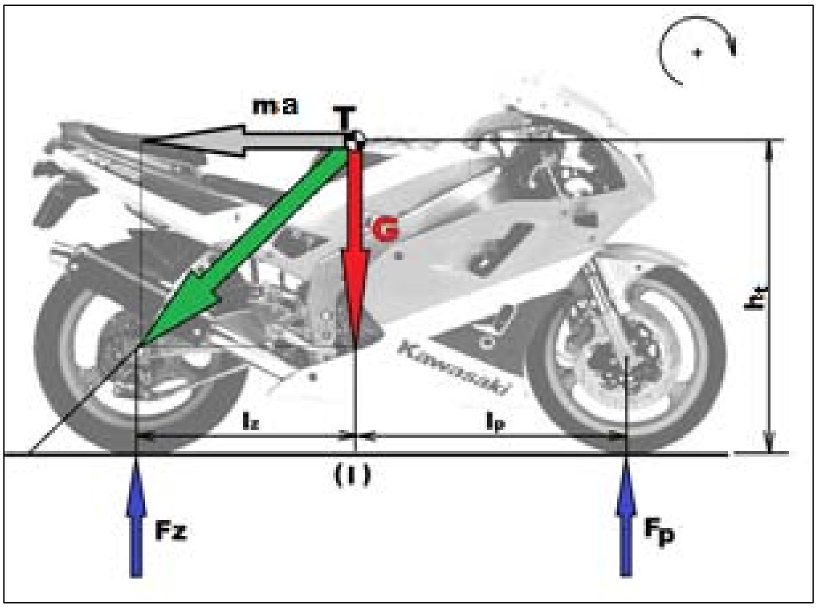

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Fig. 2 - Acceleration of the motorcycle

$$F_P.l - G.l_Z + F_S.h_t = 0 \qquad\qquad F_P = 0$$

$$G.l_Z = F_S.h_t$$

$$m.g.l_Z = m.a_{\max}.h_t$$

$$a_{\max} = \frac{g.l_Z}{h_t} \tag{2}$$

$$condition : \mu.F_Z \geq (f + \frac{a_{\max}.\vartheta}{g}).G \tag{3}$$

$F_p$, $F_z$…………..Dynamic wheel load [N]
$F_S$……………..… Inertia force [N]
G……………...Vehicle total weight [N]
$h_t$………………Center of gravity height [m]
l…………….…..Wheel-base [m]
$l_p$, $l_z$……………Center of gravity location [m]
$a_{max}$…………...Maximum acceleration [$m.s^{-2}$]
g……………..….Gravitational acceleration [$m.s^{-2}$]

The correlation shows that the acceleration value affects the ratio $l_Z/h_t$. When the centre of gravity moves towards the front, both the value of $l_Z$ and the theoretical maximum acceleration increase.

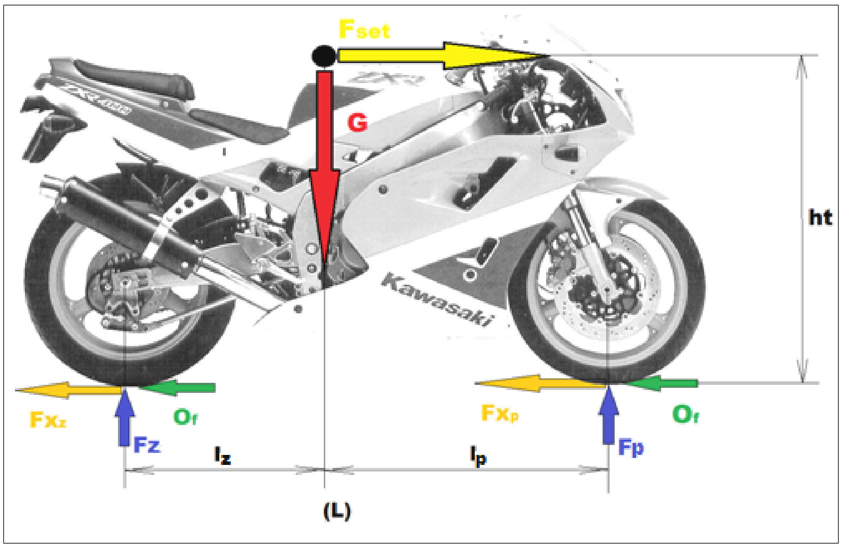

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Fig. 3 - Braking of the motorcycle

$$F_Z.l - G.l_P + F_S.h_t = 0 \qquad F_Z = 0$$
$$G.l_P = F_S.h_t$$
$$m.g.l_P = m.b_{\max}.h_t \tag{4}$$
$$b_{\max} = \frac{g.l_P}{h_t}$$

$$condition:$$
$$\mu.F_P + O_f = F_{X_P} + O_f \tag{5}$$
$$F_{X_P} + O_f \geq F_S$$

$F_{xp}$……………Adhesive force [N]

μ……………...Coefficient of adhesion

m…………...…Vehicle total mass [kg]

$b_{max}$…………...Maximum negative acceleration [m.s$^{-2}$]

## 2.3. Effect of a geometry change on the directional stability of the motorcycle

The stability of the motorcycle is secured by several moments and effects which result from the motion of the vehicle or its parts, one of them being a reversible handlebar torque. It displays as an anti-vibration handlebar stability and ensures a straight-ahead driving. Its components, namely moment arm ***a*** and force $\boldsymbol{F_{x1}}$, follow from the below stated calculation (6) and (7).

Return moment arm **a**

$$a = n.tg\delta \tag{6}$$

Steering return moment **M$_V$**

$$M_V = Fx_1 . a$$
$$M_V = O_f . a \tag{7}$$

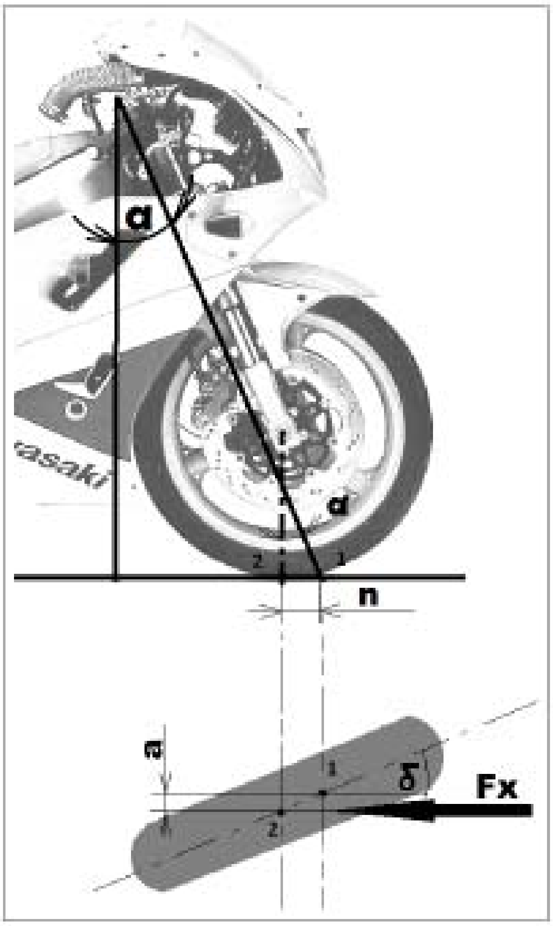

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Fig. 4 - Steering return moment

$Fx_1$ .........Braking force, roll resistance [N]
α ........... Steering axis angle [°]
n ........... Front trail [m]
a ........... Steering return moment [m]
δ ........... Angle of steering [°]
Mv ........ Steering return moment [N.m]
1. .......... Steering axis and ground intersection
2. .......... Tire contact area

It is obvious that the higher longitudal force $\mathbf{F_x}$ on moment arm **a** increase the steering return moment (fig.4). The correlation (6) clearly shows the impact of the trail size **n** on the return moment arm **a**.

Other aspects of driving stability are gyroscopic moment and rear wheel directional difference at deformation of the motorcycle frame. Fast-rotating wheel with its own very high stability becomes a gyroscope. It spontaneously maintains its position of rotary plane. As soon as the gyroscope is deflected from the rotary plane with external force a reaction to the deflective force, which is at 90° angle with the original pitching plane, is created. The forces increase with an increasing angle speed. The described reaction in such a flywheel to an axis lean is called precession. In other words, if we change the angle of the axis to the place, the pitching moment of the rotating gyroscope will have effect on the smaller moment arm.

## 3. DESIGN OF THE CHASSIS

During designing the wheel suspension, first of all the model and type of a motorcycle was defined. For practical aplication the touring motorcycles or supersports of the future are most useful for geometry changing system. As a platform for the design an old supersport Kawasaki ZXR 400 L was chosen. An aluminium frame was disassembled and transmitted as a 3D model into software Autodesk Inventor, where all the modifications in the wheel suspension equipped with a steering head were projected. The emphasis was put on maintaining strength and stiffness of the frame. Already during designing of the suspension of steering head, it was important to consider the future actuator for swinging motion of steering head. Several possible options of construction were designed, from which the most realistic ones are shown below on figure no. 5.

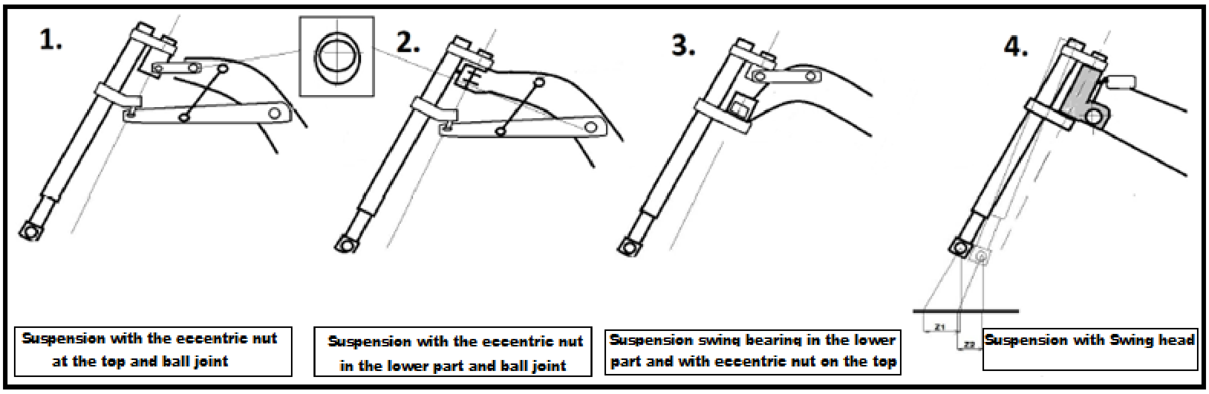

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Fig. 5 - Proposals to change the angle of the steering axis of a motorcycle

Based on the results of decompositions of loading forces and the assessment of safety as well as compactness of the whole design the solution no. 4 was selected out of the above displayed ones. An analysis of strength and stiffness of the frame has been also carried out. The results were compared with deformations in areas of high stress. The frame with optional front suspension geometry settings evinced lower torsion stiffness and the areas of high stress were concentrated rather in head stock than the points of interference in the original design. The areas of high stress concentration (fig.6) were additionally reinforced with fillet welds. It was necessary to carry out a calculation of chassis and to check the connection of the stressed parts, as regards cut or deformation caused by pressure. A numerical calculation of suspension shaft has been made. Consequently, it was designed with the generator of components in Autodesk Inventor and after that the results were compared to minimize the possibility of error in calculation of the suspension base.

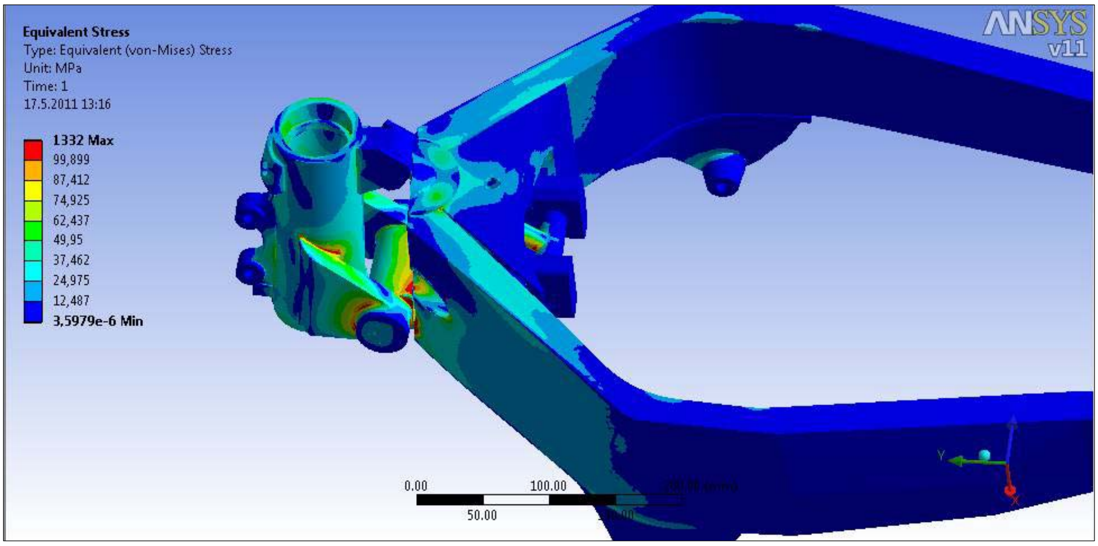

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Fig. 6 - Stress during torsion load of chassis (Ansys Workbench v11)

Prior to manufacturing of the part, also the actuator of motion had to be designed. To achieve a low weight gain of motorcycle and its propulsion as little space-demanding as possible it was decided upon an electromechanical system. It was made of a mechanical transmission gear and an electric motor, powered by board net. A speed reductor was utilised in the mechanical gear, which made it possible to use a high speed electric motor with small dimensions while maintaining the required output torque of gearbox. Another component of the transmission gear was a mechanical linear actuator, converting rotary motion into linear motion, which is necessary for setting the correct angle of the steering axis. The advantage of utilization of the mechanical linear actuator (fig.7) is the application of a self-locking property, because it is not necessary to use a brake, which helps to prevent from a change of the angle of the steering axis at enormous load of the suspension. The whole construction ensures absorption of forces generated during the driving of the vehicle in the base of suspension. Therefore, another reduction of the electric motor transmission gear size, was made possible. Electric motor transmission gear now loaded only with the electric motor torque.

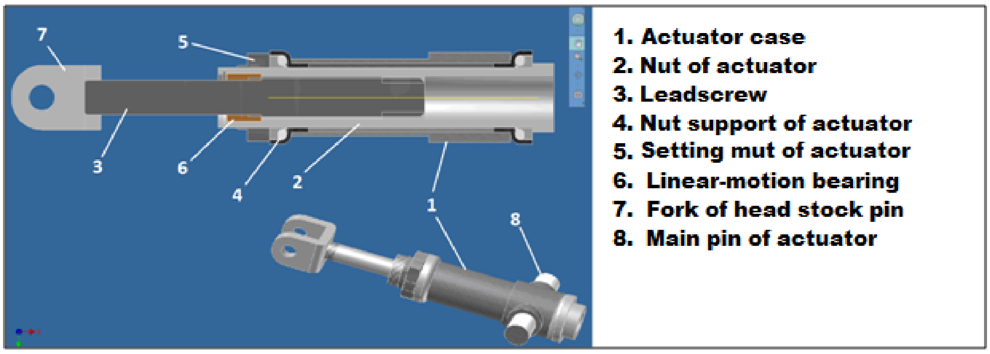

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Fig. 7 - Composition of Linear actuator

The final assembly in Autodesk Inventor proved that designed components are able to create a compact and functional suspension unit. Driving tests on motorcycle with designed suspension, called active chassis geometry change system, are now conducted.

## CONCLUSION

The designed system with steering geometry changes might be a pioneering idea in construction of the 21st century motorcycle chassis. The trail adjustment along with changes in wheelbase and ground clearance of the bike open up many options in the field of negative effects regulation resulting from the dynamic characteristics of motorcycle motion. With the introduction of composite materials and latest aluminium alloys, there come the possibilities of suspension construction with variable values of steering axis angle or wheelbase. The main idea in the construction of the designed suspension is to smoothly change the parameters of the chassis during the drive. This would be done manually by the driver in the first generation and automatically, depending on the optimal chassis setup, in the following one. In the future generations, the whole system could be fully automated, in which case it could collaborate without difficulty with the above mentioned already utilized stability and assistance systems. This connection would be similar to CAN-bus system of automobiles, where particular systems are connected to a common bus and managed by the central control unit (ECU).

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