The design and application of a pneumatic suspension test bench

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Abstract. The suspension is one of the most important parts of a motorcycle. The main function of a suspension is to connect the frame with the wheels. During its operation different forces and torques affect this unit. It is important to analyse the behaviour of the suspension during its use. The subject of the article is to present the design and application possibilities of a device suitable for testing the rear suspension of motorcycles. With this equipment it is possible to analyse the rear suspension of motorcycles. During its operation, the test bench moves an artificial obstacle under the wheel. As a result, the equipment simulates the motorcycle’s passing through uneven road surfaces. This way we can analyse a rear suspension of a motorcycle or a suspension fixed to a test frame.

1. Introduction
The suspension is one of the most important structural units of a motorcycle. The primary role of the rear suspension is to connect the chassis with the rear wheel while providing proper damping. During its operation, the suspension elements are subjected to forces and torques of different magnitudes and types; so it is important to examine the appropriate safety, load resistance and behaviour during operation.

The subject of the article is the design of a pneumatic suspension test bench and the presentation of the areas of application of the equipment. During its operation, the suspension test bench moves an artificial obstacle under the analysed wheel, simulating the passage of the motorcycle through various uneven road surfaces. In this way, the rear suspension of an actual motorcycle or a suspension attached to a test frame can be tested.

2. Concepts for the movement of the artificial obstacle
The first step was to choose how to move the obstacle. The comparison happened according to those aspects which mainly affect the analysis.

The considered solutions were manual movement, the use of pneumatic or hydraulic cylinders, and the application of an electric motor with a rack and pinion or a belt drive. The aspects are the realization of linear motion, controllability, availability and the accuracy of the measurement.

When manual force is applied, the realization of linear motion is direct, no motion transformation is required. However, it is not possible to properly control forces and velocities of different magnitudes. It is not possible to set a force or velocity value accurately, nor can a person maintain this value unchanged, during analysis. Due to its inadequate controllability, the measurement will not be accurate when manual force is applied. However, getting the push is the easiest in this case, as we already have everything we need. However, due to inaccuracies, this is not appropriate for the purpose.
In the case of pneumatic or hydraulic cylinders, the realization of the linear movement is also direct. The force can be easily controlled between the appropriate ranges. With the help of these types of cylinders, both pressure and the speed can be regulated. Generally, the price of pneumatic cylinders would be relatively high, but due to prior usage applications; cylinders of this type are readily available, thanks to Pneumobile competitions [4]. This means that if the properties of the existing cylinders are suitable for the analysis, they can be used for this purpose. Hydraulic cylinders would be significantly more expensive and they are not available for us. Due to the proper controllability of force and speed, the analysis would be sufficiently accurate using the pneumatic version.

When using an electric motor, it is not possible to directly realize linear motion. Instead, it can only be created indirectly with the help of some motion converter. This can be solved, for example, with a rack and pinion or a belt drive. In the case of an electric motor, the force and speed can be easily controlled within the appropriate ranges. However, the proper design of the motion converter elements, in particular the tolerances of open drives [5], may affect the accuracy of the tests.

Since the use of pneumatic cylinders was optimal from all the listed concepts, I chose this solution to move the obstacle.

3. The selection of the pneumatic cylinder
During the selection, the main aspects were the nominal diameter of the piston, the stroke length, the number of cylinders and the method of installation. The nominal diameter of the piston can be 63, 80 or 100 mm, because cylinders of this size are readily available at the Institute of Machine and Product Design, where the equipment will be built.

The stroke length of the cylinders can be 320 or 500 mm. The actual stroke length is also affected by the way the cylinders are installed. The cylinders can be placed side by side in a parallel connection, one behind the other in series connection, or just one cylinder alone. In the case of series installation, the actual stroke length is the sum of the stroke lengths of the installed cylinders; but in this case the stable fixture of the cylinders would require costly technical solutions. Based on past experience, the forces created, would not just move the obstacle, but would make some damage to the equipment. [1]

During the test, the cylinders will move the obstacle, and the wheel will initially stand. The correlation between the forces acting on the wheel:

\[ F_h = F_v - F_g \]  (1)

Where \( F_h \) is the resultant force of the horizontal forces acting on the wheel, \( F_v \) is the force exerted by the cylinders, \( F_g = 78,48 \text{N} \), the rolling resistance.

Assuming uniformly accelerating motion, the value of acceleration is:

\[ a = \frac{v_m}{t/2} \]  (2)

Where \( v_m \) is the maximum speed to be reached, \( t \) is the time during which the cylinder performs one stroke. Calculated with an obstacle of mass \( m_o = 5 \text{ kg} \) in advance, required value of the resultant force of the horizontal forces:

\[ F_h = m_a \cdot a \]  (3)

The required value of the force exerted by the cylinders:

\[ F_v = F_h + F_g \]  (4)

With \( v_m = 120 \text{ km/h} \), this value is \( F_v = 599,28 \text{ N} \) for a stroke length of 320 mm and \( F_v = 411,78 \text{ N} \) for a stroke length of 500 mm. Since the force for the stroke length of 500 mm is smaller, cylinders with a stroke length of 500 mm will be installed.

Out of the available sizes, a cylinder with a piston diameter of 63 mm is sufficient, so we will use one of them.

3.1. Determination of the force exerted by the cylinder on the basis of pressure
The pneumatic cylinder exerts different amount of force at different pressure values. This force can be calculated by the following formula, if \( p \) is the pressure and \( D \) is the piston diameter of the cylinder:

\[ F_h = p \cdot \frac{D^2}{4} \]
In addition, by rearranging the formula, the pressure value required for the theoretical force of $F_{v2}=411.78\, \text{N}$ can also be calculated:

$$p = \frac{4 \cdot F_{v2}}{\pi \cdot D^2} = \frac{4 \cdot 411.78\, \text{N}}{\pi \cdot (0.063\, \text{m})^2} = 1320974\, \text{Pa} = 1.320974\, \text{bar}$$

(6)

The forces associated with the different pressures are summarized in Table 1. The forces in the table were calculated using formula (5).

| Pressure (bar) | Force (N) |
|---------------|-----------|
| 0             | 0         |
| 1             | 311.72    |
| 1.320974      | 411.78    |
| 2             | 623.45    |
| 3             | 935.17    |
| 4             | 1246.898  |
| 5             | 1558.62   |
| 6             | 1870.35   |
| 6.3           | 1963.86   |
| 7             | 2182.07   |
| 8             | 2493.796  |
| 9             | 2805.52   |
| 10            | 3117.25   |

Table 1. Forces associated with pressure values

4. Structure of the equipment

4.1. The unit containing the cylinder

The suspension test bench is made out of several separate units. One of the most important parts of the equipment is the pneumatic cylinder, as its parameters are measured during the tests. As previously described, the suspension test bench uses a cylinder with a cylinder diameter of 63 mm and a stroke length of 500 mm.

The cylinder is mounted on two 10 mm thick steel plates, using M8 screws. These plates are also fastened with screws to a mounting frame made of 40x40 mm aluminium profiles. A part is attached to the end of the cylinder piston rod, using an M16x1.5 thread. This component connects the cylinder to the obstacle.

![Figure 1. Model of the unit containing the cylinder](image)

4.2. The unit containing the obstacle and its guidance

By moving the artificial obstacle under the test wheel, it is possible to simulate the passage of a motorcycle through uneven road surfaces. This unit consists of two parts. One part is the replaceable, actual road surface that comes in contact with the wheel during the test. Several designs were made to
simulate different road faults. The other element is the metal frame attached to it. The two components are connected to each other by screws and form the obstacle moved during the test.

The obstacle is guided by linear guides, which are connected to a steel plate. The plate is fixed to a mountable aluminium frame with screws.

![Figure 2](image2.png)

**Figure 2.** The model of the unit containing the obstacle

### 4.3. Motorcycle mounting units

In case of a test with a real motorcycle, the front wheel is fastened to the equipment by a specially designed element; the frame of the motorcycle can be affixed with two aluminium supports.

![Figure 3](image3.png)

**Figure 3.** Analysis of motorcycle suspension

### 4.4. Test frame

The suspension test bench can also be used to analyse a suspension attached to a test frame. Like the motorcycle mountings, this is a possible unit of the equipment, but it is not part of all tests.

An essential part of this unit is the test wheel, which in this case, is the rear wheel of a Honda CBR 125 R motorcycle. The wheel is suspended on a mountable aluminium frame. The suspension corresponds to the suspension of an actual motorcycle, so it consists of the same elements. Thus, the wheel is connected to the frame through a swingarm and a shock absorber. The frame provides an opportunity to examine different types of suspensions, so the design of the swingarm may vary.

The shock absorber is connected to the frame by a specially designed unit. This unit consists of two 12 mm thick steel plates and individual elements connected to the frame. When installing the shock absorber, several connections can be realized, for example it can even be placed obliquely, at different angles. The shock absorber can be adjusted in 5 ° increments.
Figure 4. Analysis with the test frame

5. Test procedure and possible uses

5.1. The test procedure
At the start of the analysis, the device extends the cylinder so that the two-part artificial obstacle is moved under the test wheel in the opposite direction to the natural direction of travel. The obstacle runs straight and in a plane, thanks to the linear guides; so the test is carried out accurately.

5.2. Determining the force required to pass through an uneven surface
As the obstacle passes under the wheel during the test, it simulates that a motorcycle is travelling on sections with road defects and is applying similar forces to the suspension of the wheel as would affect a motorcycle. While using the equipment, the various parameters of the pneumatic cylinder are measured. Based on the results of the measurements performed during the test, it is possible to perform further calculations and evaluations; which can be used to determine the effect of the load on the suspension, while passing through uneven road surfaces.

The measured parameters include the pressure in the cylinder during the test, the distance travelled and the speed. Based on these, it can be determined how much force is required for the wheel to pass through the uneven road.

5.3. The analysis of damping and suspension
When the motorcycle passes through an uneven road at high speed, the chassis initially remains at rest. Only the wheel moves up while accelerating vertically, at a high speed; simultaneously the spring being compressed. A small force corresponding to the spring path acts on the frame. Behind the unevenness or in a recess, the preloaded spring pushes the wheel downwards. As a result, the frame is subjected to a smaller spring force, remains virtually at rest, and the wheel is constantly on the ground. \[2\] \[3\]

This is only true, if the force on the wheel is less than the spring preload. If it is larger, the wheel will bounce off the road and the effect on the frame will be correspondingly greater. In this case, the wheel detaches from the road for a short time while; not being able to transmit force, because the spring preload is not high enough, to push the wheel back onto the road fast enough. \[2\] \[3\]

Figure 5. If the suspension is not adjusted correctly, the wheel will bounce \[3\]
From continuous measurements of pressure and speed, it can be deduced how the suspension behaves when passing through uneven surfaces. For example, if the speed suddenly increases at a constant pressure value, it may indicate that the connection between the wheel and the obstacle has been lost, which may mean that the wheel will bounce off the road at the given setting under the simulated conditions.

5.4. Analysis of speed bumps
As there are no accepted and applied standards for the size of speed bumps, their size may vary. Due to these varied designs, it is often possible, that the suspension may be damaged, when passing through these decelerating elements, at a specified speed. With the pneumatic suspension test bench, it is also possible to study the effect of speed bumps on the suspension, because; when passing through speed reduction bumps, similar processes take place as when the vehicle passes through an uneven road or an obstacle. By attaching elements of a design similar to a speed bump onto the mounting point of the replaceable segment of the artificial obstacle, the loads acting on the suspension can be determined. Based on these measurements, a recommendation can be made for the size and design of the decelerating elements, for a given reduction in speed, so that it does not damage the suspension and the vehicle with it.

**Summary**
The subject of the article was to present the design and application possibilities of a device suitable for testing the rear suspension of motorcycles. The first step in designing, was to determine how to move the obstacle. We used a pneumatic cylinder for this. After the selection of the cylinder and the correlations between pressure and force, I presented in detail the structural design of the pneumatic suspension test bench. Then I described three possible uses. The equipment will be built and used in the work of the MotoStudent team of the University of Miskolc.

**Literature**
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