The test bench for testing torsional stiffness of active anti-roll bar made of extended profiles with rectangular cross-section

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**Abstract:** The article describes the test bench constructed to determine the characteristics of torsional stiffness of extended rod elements, which can be used, for example, in cars as anti-roll bars. The bench has been designed so as to allow an examination of the samples with variable length and variable cross-sectional dimensions. It is possible to perform tests for different materials. The article contains a detailed description of the mentioned test bench and presentation of the results obtained from preliminary tests.

1. Introduction

Anti-roll bars improve driving comfort, steerability and safety. They limit the tilting of the body during driving around a curve. Tilting is a consequence of the centrifugal force. Little body roll is beneficial for accurate and safe driving. Too much of it can cause loss of steerability and, thus, might lead to a side slip and often a roll-over of a vehicle [1].

Classic (rod) anti-roll bar is an appropriately formed torsion bar characterized by constant stiffness, selected by the vehicle manufacturer[2]. Its value is described by the following formula:

\[
K_x = \frac{M_s}{\alpha}\]  

where:

- \(M_s\) [Nm] – torsion torque
- \(\alpha\) [deg] – torsion angle

In an anti-roll bar called active, stiffness can vary in certain range, fluently or gradually. The devices changing stiffness are generally costly constructions, with a complex structure. They require additional actuators, for instance: hydraulic, pneumatic, mechanical or mixed. An example of the mentioned device is BMW mechanism, shown in Figure 1.

Listed drawbacks of described equipment influenced the creation of the concept of fluent adjustment of torsional stiffness. For the object in question, which normally acts on the torsion, additional bending stresses are introduced. They change a resultant stress state and, as a consequence, also expected torsional stiffness. The developed concept assumes that the middle part of the anti-roll bar consists of a packet (two or four elements) of extended profiles with rectangular cross section each. Hence, bending-torsional stiffness is considered.

The described test bench has been built in order to determine the characteristics of torsional stiffness of extended rod elements. The results will be used to define a range of variation of this stiffness, nature of the change and an impact of individual factors (samples dimensions, mechanical properties of the material type) on this change.
2. Test bench for testing torsion stiffness of extended rectangular cross-section profiles intended for the middle part of anti-roll bar

The test stand for determining stiffness characteristics of twisted elements should provide reproducible, easy to write and edit, research results. A multitude of samples in different sizes, packetized in a variety of configurations shall enable a quick disassembly and reassembly of the unit in which tests are conducted. In the laboratory of the Department of Vehicles and Fundamentals of Mechanical Engineering in the Lodz University of Technology was built the bench that meets these requirements. Its block diagram is shown in Figure 2.

![Figure 1. The mechanism of an active stabilization installed in a BMW vehicle.](image1)

![Figure 2. Block diagram of the stand for testing torsional stiffness.](image2)
The test bench was equipped with two sensors: torque and incline. Obtained from these analog signals are directed to the measuring card National Instrument NI 9215 BNC type, which forwards them in a digital form to the recording unit (PC in Figure 2). Special software allows to record measurement results on PC and their subsequent processing for the purpose of presentation.

Figure 3 shows the test bench. Number (1) indicates a computer set for signal recording and data processing. The hydraulic drive unit (2), equipped with a manual hydraulic pump, is used to twist the profiles. The hydraulic actuator causes the rotation of particular elements of the bench. They are connected with each other in a series and they are respectively: torque meter MI50 (3), bi-articulated shaft and a set of testing profiles (minimum of two) which are mounted in a special test unit (5). Number (4) indicates an inclination sensor (which is part of the test unit).

The test unit is shown in Figure 4. It has two supports: fixed (3) and movable (2). The fixed support is placed in an extreme position of a bench and aims to permanently immobilize the studied profiles (1). The movable support acts as a base on which is mounted an inclinometer (7) Posital Fraba type ACS0802SV20HE2PM (tilt sensor). Apart from its basic function of profiles rolling, the support also allows their axial shortening and lengthening depending on a degree of the distance between the profiles and their twist. Extending mechanism (4) consists of two halves. Each of them is mounted on a corresponding profile in a way which prevents movement. Test elements are extended in the middle of their active length, by distancing both halves from each other. The distance is adjusted by wrenching two screws M12x1 (5) into the upper part of mechanism. These screws press against two pins (6) which are fixedly mounted in the lower part of mechanism. In this way, both halves move away from each other by an equal distance in relation to the longitudinal axis of the examined profile.

Figure 3. Test bench for testing torsion stiffness. 1 – recording unit. 2 – hydraulic drive unit. 3 – torque meter. 4 – inclinometer. 5 – test unit.
Figure 4. Test unit in position of work. 1 – a packet of profiles. 2 – movable support. 3 – fixed support. 4 – extending mechanism. 5 – two screws M12x1. 6 – two guide pins. 7 – inclinometer.

It is expected to carry out a series of studies of profiles with variable amounts in various length, width and height. Figure 5 shows an example of 4 profiles with beveled edges (they were prepared for construction reasons to allow an installation of an extending mechanism) with dimensions 5x22.5x650mm. They were made of spring steel 50HF and then hardened throughout and tempered.

Figure 5. Research profiles before hardening process.

3. The course of research and description of preliminary results
Profiles presented in Figure 5 were installed on the bench and there were conducted 7 series of tests. In each series there were recorded torsion angle and torque generated for the 9 following angle positions: 0°, 3°, 6°, 9°, 12°, 15°, 18°, 20° and a maximum angle for which allowed a stroke of hydraulic actuator (in this case 21,22°). In each series, the distance between both halves of extending mechanism increased
from 0mm up to 30mm with the 5mm stroke. Figure 6 shows the profiles in three characteristic positions: ready for testing, after extending both parts of the mechanism by 30mm (without twisting) and after extending both parts of the mechanism by 30mm and twisting by 21.22°. An effective length of the test pieces was 528mm. These values resulted from the initial assumptions which had been made beforehand.
Figure 6. Research profiles in characteristic positions. a) ready for testing (the first measurement was without extending). b) after extending both parts of the mechanism by 30mm (without twisting). c) after extending both parts of the mechanism by 30mm and twisting by 21.22°.

Obtained results were subject to an electronic processing and after this phase changing stiffness graphs were prepared (they included a generated torque [Nm] in a function of rotation angle [deg]). Received curves were similar in shape to straight lines, so the linear trend line was used. The graph referring to the profiles from Figure 5 was placed below (in Figure 7). It includes test results from the 1st and 7th series. The variable stiffness area is placed between both curves. For each series (between loading and unloading) we observe hysteresis. It is the effect of the friction appearing between profiles and in particular parts of the test bench.
Figure 7. The graph showing changing stiffness in a set of 4 twisted profiles with following dimensions 5x22.5x650mm (active length equal 528mm for each sample).

On the basis of known functions of trend curves from series 1 and 7 there were determined the maximum and minimum torque acting for twisting 20°. Then, using the formula (2), strengthening of profiles (increase of stiffness) was calculated and it amounted to 17.3%.

\[ K_{20} = \left( \frac{M_{\text{max}}}{M_{\text{min}}} \right) \times 100 - 100 \]  \hspace{1cm} (2)

where:

- \( K_{20} \) [%] = increase stiffness in the profile twisted by 20°
- \( M_{\text{max}}, M_{\text{min}} \) [Nm] = maximum torque, minimum torque

In the next step there was conducted research of the same elements. Their active length was shortened consequently by 50mm to 478mm and 428mm. Figure 8 shows them in the position “before initiating the test”.

Table 1. Summary of stiffness increase for 4 profiles with following dimensions 5x22.5x650mm while shortening their active length.

| Pos | No of profiles | Profile height [mm] | Profile width [mm] | Profile active length [mm] | Stiffness increase in profile [%] | Stiffness increase resulting from profile shortening [%] | Maximum torque read at 7th test series [Nm] |
|-----|----------------|---------------------|--------------------|---------------------------|----------------------------------|-----------------------------------------------|------------------------------------------|
| 1   | 4              | 5                   | 22.5               | 528                       | 17.3                             | ------                                        | 213                                      |
| 2   | 4              | 5                   | 22.5               | 478                       | 20.4                             | 18.0                                          | 255                                      |
| 3   | 4              | 5                   | 22.5               | 428                       | 30.8                             | 77.9                                          | 328                                      |
A change of profiles strengthening for $20^\circ$ torsion angle was recognized in a tabular form and presented in Table 1. An analysis of the data it contains indicates an upward trend in the strengthening of the samples by shortening their active length (strengthening from 17.3% at the length of 528mm to 30.8% at the length of 428mm). During the studies, an increase in the generated torque while extending profiles was observed (data for not extended profiles have not been included in the table). The mentioned increase is explained by theory of strength of materials [3], where in the rod-like elements, a torsional angle varies linearly according to the change of their length. So, to twist the same sample with a shorter length it must be ordered to a greater torque. This theory results from a well-known formula for torsion bars with a rectangular cross-section:

$$\varphi = \frac{M_s l}{\eta ab^3 G}$$  \hspace{1cm} (3)

where:
- $\varphi$ [°] – torsional angle of the rod with rectangular cross section
- $M_s$ [Nm] – torque acting on profile
- $l$ [m] – profile length
- $\eta$ – calculation factor
- $a$ [m] – longer edge of rectangle
- $b$ [m] – shorter edge of rectangle
- $G$ [Pa] – Kirchhoff modulus

The above considerations do not allow to clarify the increase in stiffness during extending profiles taking into account the change in their active length. Further studies and analysis will have to clarify what factors are responsible for and how they affect the stiffness on extended and twisted profiles.
4. Conclusions
The aim of the conducted research is to explain a phenomenon of increasing stiffness in twisted profiles which are extended in the middle of their active length. An assessment of the design parameters and a degree of their impact on the stiffening profiles constitute the result of the study. Preliminary studies lead to the following conclusions:

1. It is possible to increase the torsional stiffness of the elements with rectangular cross-section by extending them in the middle of their active length. It was verified by investigation of twisted and extended profiles (each time up to 30mm) with following lengths 528, 478 and 428mm. The following strengthening (showed in mentioned sequence) was obtained: 17.3%, 20.4%, 30.8%.

2. The increase of torsional stiffness (in profiles made of spring steel) depends on their length and cross-sectional dimensions.

Further work will include the investigation of more experimental profiles so that the obtained results enable the development of an empirical relationship describing the change of torsional stiffness of extended elements. Simultaneously, an attempt on an analysis of examined cases will be made. It is also planned to create a digital model and test it by using finite element method in the ANSYS 16.2 program. Properly constructed model will allow the analysis of more samples in various combinations with selected dimensions. It will reduce the cost of its preformation, implementation and reduce the duration of the study.

References
[1] Werner J 1966 Budowa samochodów. Konstruowanie podwozi, Warszawa: WKiL, p 477
[2] Wittek M 2010 Stabilizer Bars: Part 1. Calculations and Constructions. Transport Problems 5
[3] Jakubowicz A and Orłoś Z 1972 Wytrzymałość materiałów Warszawa: WNT