Strojnícky časopis – *Journal of* MECHANICAL ENGINEERING,
VOL 74 (2024), NO 1, 91 - 102

# METHODOLOGY FOR MEASURING FORCES IN MOTORCYCLE SUSPENSION USING A SYSTEM BASED ON ANALOGUE POTENTIOMETERS

**MÍŠA Jiří[1], TOBIÁŠ Martin[2], REPKA Martin[3], STRAKA Martin[4], GREGOR Lukáš[5]**

*[1-4] Institute of Automotive Engineering, Faculty of Mechanical Engineering, Brno University of Technology, Technická 2896, 616 69 Brno, Czech Republic, e-mail: 182705@vutbr.cz*
*[5] Institute of Manufacturing Technology, Faculty of Mechanical Engineering, Brno University of Technology, Technická 2896, 616 69 Brno, Czech Republic*

**Abstract:** This study explores the quest for a more cost-effective and practical method of measuring forces in motorcycle suspension systems by utilizing simple potentiometers as an alternative to sophisticated strain gauges. The research delves into the feasibility of potentiometers to provide accurate and reliable force measurements, offering potential advantages in terms of affordability, accessibility, and ease of implementation. Through empirical testing and verification, this investigation aims to establish potentiometers as a viable and economical solution for enhancing motorcycle suspension performance monitoring and tuning.

**KEYWORDS:** Analogue potentiometer, measurement, suspension forces, motorcycle

## 1 Introduction

With the gradually increasing computing power of modern computers, multi-body simulations have become an integral part of vehicle development. This type of simulation has been in common use since the 1980s and its applications continue to grow [1]. The reason for their increased use is mainly due to the possibility of optimizing and improving vehicle performance before the first prototype is built. This can reduce development costs and, most importantly, allow for a shorter time to market [2]. However, any simulation is only an approximation to the actual happening and not the reality [3]. Therefore, nowadays, emphasis is also put on the validation of such simulations or their coupling with actual measurement of quantities.

For this reason, a tool has been developed at the Institute of Automotive and Transport Engineering by a group of several researchers, whose aim is to calculate, using an inverse method, the quantities that act on a vehicle during driving, but with a limited number of sensors during driving. For such a tool to be successful, several measurements and checks are required to increase its accuracy and reliability for different types of vehicles [4].

As mentioned before, several control measurements are necessary to guarantee the reliability and correctness of the simulation results, which is where this project is included. The force effects in the vehicle suspension are an integral part of the input parameters [5]. Since the tyre has the greatest influence on the driving dynamics of the vehicle, it is necessary to know the forces in the suspension as they are a key element for the validation of the vehicle kinematic model and especially for the correct definition of the tyre characteristics [6].

Therefor the project aims to determine the force effects in the motorcycle suspension using the knowledge of the characteristics of the damping and elastic elements of the suspension, along with continuous measurements of the suspension travel during driving.

DOI: 10.2478/scjme-2024-0010, Print ISSN 0039-2472, On-line ISSN 2450-5471

Again, there is a strong emphasis on the ratio of usability and price associated with the cost of the research and this is one of the reasons why this research was undertaken, which aims to evaluate the way in which forces in the suspension are measured.

## 2 Experimental motorcycle

Our chosen motorcycle KTM RC 390 with a single-cylinder engine has been used at our university for academic purposes for several years and therefore its centre of gravity height, moments of inertia and other parameters used to describe the driving dynamics of single-cylinder vehicles are already well known. The measurement chain has been developed specifically for the purpose of measuring riding parameters in motorcycles. Thus, together with the easy possibility to connect to CAN communication, this motorcycle is also a suitable choice for this research.

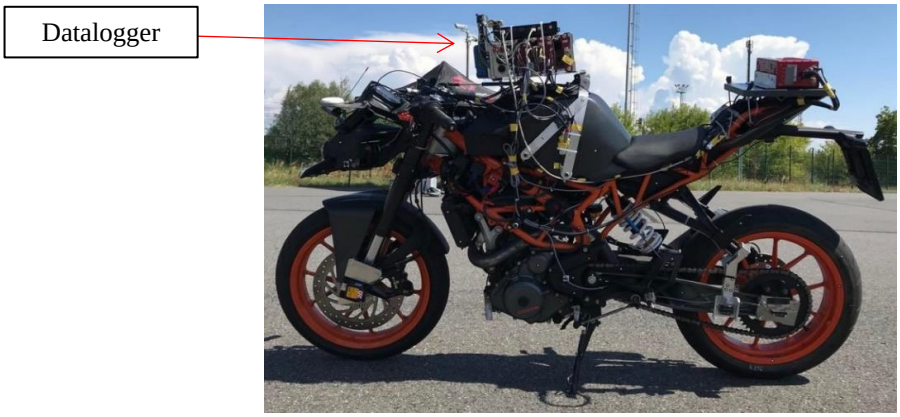



Fig. 1 Motorcycle KTM RC 390 equipped with measurement system

## 3 Measuring system

To measure the riding dynamics of a motorcycle, a measuring chain was designed, with applicability to both internal combustion engine and electric motorcycles. Due to the existing equipment at the university, a measuring chain was built based on the NI chassis cDAQ 9178 measuring station. Its undeniable advantage is the variability and the possibility of using several measuring cards. A significant disadvantage is the necessity to add the required accessories, which are usually standard in closed systems.

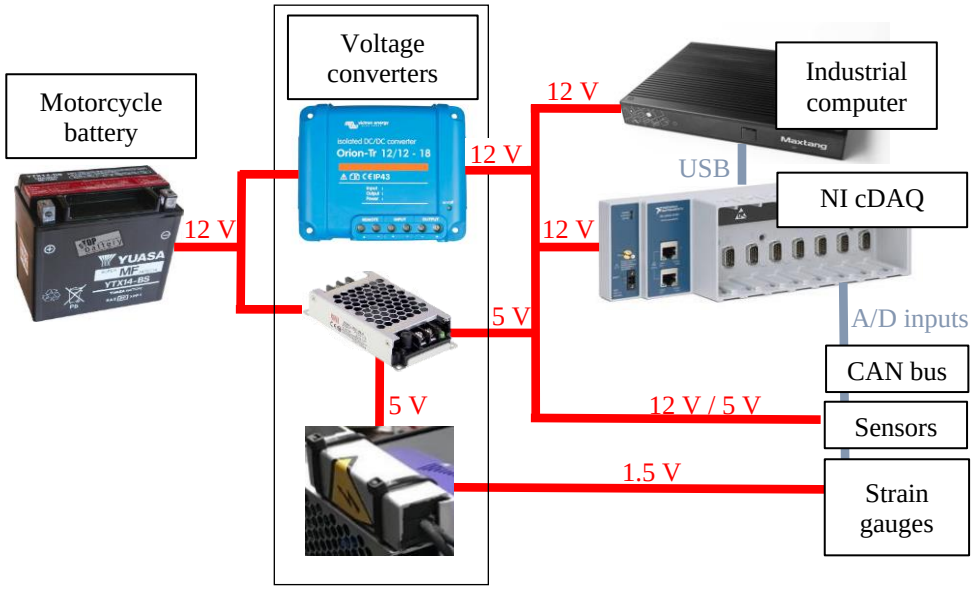



Fig. 2 Wiring diagram of the measuring system based on NI cDAQ

An example is the addition of voltage sources for different power supplies for individual sensors. The reason for this is the manufacturer's desire to adapt the measuring technology as much as possible to the user. Another necessity for the proper functioning of the system was the addition of an industrial computer using the Windows 10 operating system. The industrial computer can be used to control the cDAQ 9178 software environment. If remote control by another computer is required, it is possible to connect via a Wi-Fi module.

### 3.1 Strain gauges

The first strategy to determine the force in the motorcycle suspension is to use strain gauges. This method, which uses the conversion of strain gauge deflection into a change in voltage, has been used in practice for many years. In order to obtain the force from both the dampers and the springs, it was necessary to attach the strain gauges directly to the piston rod in the case of the forks and the bottom of the mount in the case of the rear damper (Figure 3). The use of a finished product in the form of a serial mounting of a strain gauge unit to piston rod is impossible due to the packaging.

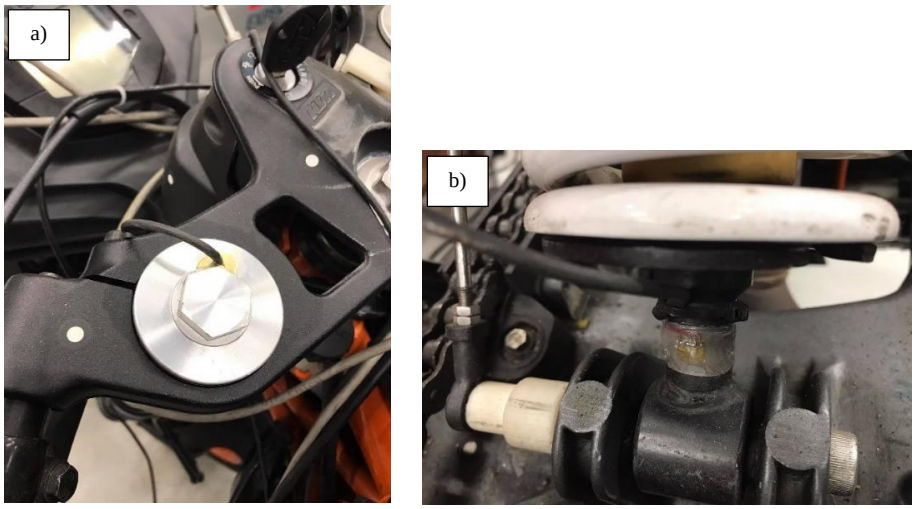



Fig. 3 Strain gauges used on motorcycle suspension: a – Left front fork; b – Rear damper rod.

In this case, there are high demands for tight clearances, as the piston rod diameters and fits are much smaller in motorcycles compared to cars. Thus, very small strain gauges were required to meet these requirements. It was necessary to completely disassemble the front forks, irreversibly create the exit holes for the wiring and intricately attach the strain gauges to the piston rods using a special adhesive. This task is only suitable for trained personnel as the glued and soldered joints are small in scale and the wiring must be properly insulated. If the wiring is not done professionally, oil leakage may occur when the forks are running. The forks use here have not been pressurized, but if a higher range of suspension is used where pressurization is present, the situation may be exacerbated [7].

Another difficulty in using small strain gauges is the very small deformation and change in output voltage. At the same time, there is a high requirement for the accuracy of the input voltage, which is limited to 1.5 V. Another difficulty in using such sensitive sensors is the necessity of using a linear voltage source instead of a conventional switching one. This is due to the significant sensitivity to noise. As such voltage sources are not readily available on the market, it was necessary to fabricate one (Figure 4). The resulting output voltage from the strain gauges must then be increased using a voltage amplifier. In this case, a NI 9237 card was used which, when connected to a linear voltage source, is capable of supplying the strain gauges themselves.

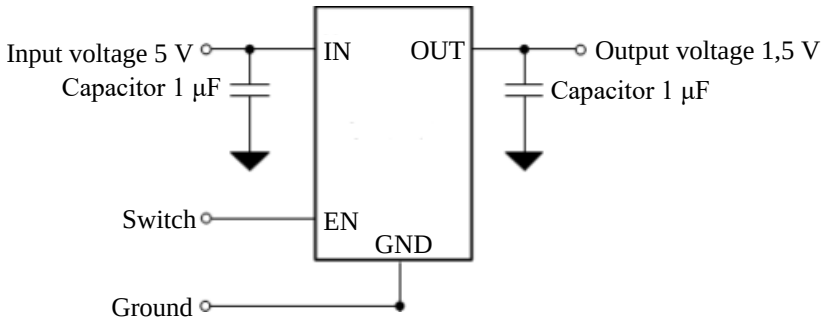



Fig. 4 Linear voltage converter for strain gauges

In order to obtain the force in the suspension it is necessary to know the dependence of the voltage change on the force. The best way to do this is to disassemble the front forks and rear damper from the bike and perform a calibration test in the lab. For this purpose, a hydraulically driven dynamometer was used, where an arbitrary course of measurements can be made. The entire damper or front fork was clamped into the dynamometer including the springs. A measurement test was performed using a continuous sinusoidal motion of the piston rod where the stroke, velocity, voltage changes and force were collected from the strain gauges and sensors of the dynamometer. After the measurements were taken, it was possible to obtain a calibration curve that gives us the desired voltage change versus force. The correctness of the calibration equation can be finally verified very simple when the motorcycle is assembled and placed on the scales, where the force in the suspension on a given axle should correspond to the load under a given scale. It is also necessary to take into account any spring preload, as the travel springs are very often preloaded after they have been assembled from the factory. Figure 5 then shows the complete workflow and measurements to obtain the required force in the motorcycle suspension during the test ride.

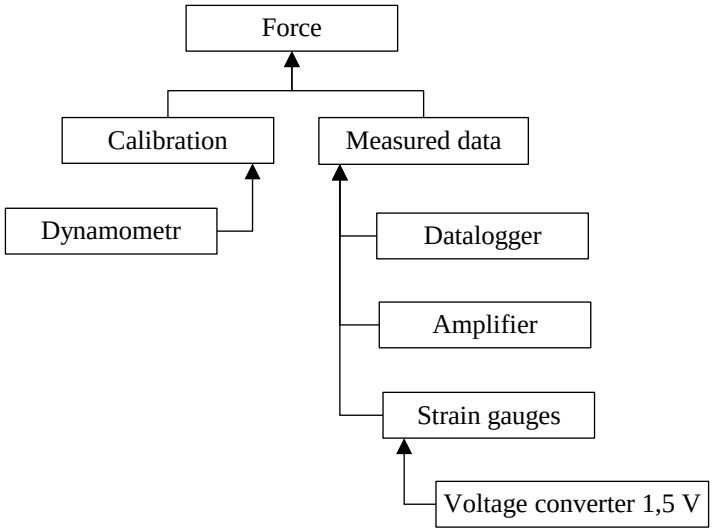



Fig. 5 Schematic workflow for obtaining force with strain gauges

### 3.2 Analogue potentiometers

The second way to determine the forces in the motorcycle's suspension during a ride is to calculate the required force due to spring compression and damper work using analogue potentiometers. This method is much more simplified, cheaper and less demanding on the professionalism of the user compared to the first alternative. In practice, analogue potentiometers are commonly used to measure suspension travel on automobiles as well as motorcycles. Their large presence is in the motorsport environment, where they are the most

important piece of measuring equipment for the appropriate adjustment of ride dampers, springs and controlling the movement of the suspension mass [8]. However, when they are used as an option for obtaining force in the suspension, negative comments on the accuracy of the measurement method are encountered, but unconfirmed and never publicly compared. And this is the main motivation for creating this article.

This method has a few major pitfalls that can significantly affect the results and their accuracy. The first is the lack of rigidity of the potentiometer itself and its mounting. If the potentiometer exhibits low stiffness it is very susceptible to the presence of vibrations due to engine unbalance and other disturbances caused by vehicle operation which can impose inaccuracies on the final results.

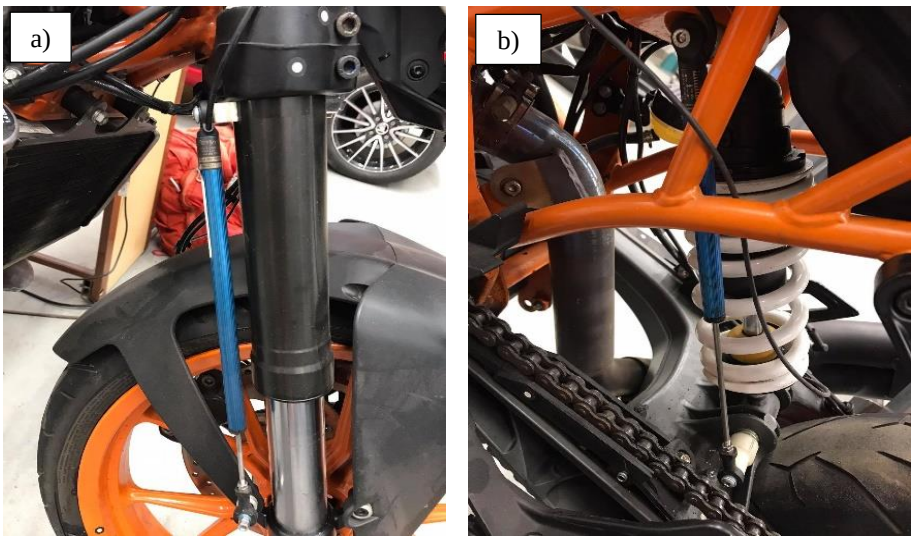



Fig. 6 Attached analogue potentiometers on motorcycle suspension: a - Frond right fork; b - Rear damper.

Another critical parameter is the knowledge of adequate stroke resolution and speed of the potentiometer. Since we will be sensing damper and spring compression stroke and velocity, it is imperative that the user takes the time to select the measurement technique. In order to have sufficient resolution, it is necessary to select the correct pair of a sufficiently accurate A/D converter and the maximum stroke length of the potentiometer. The simple equations below which describe the effect of A/D converter datalogger resolution and potentiometer stroke length [9].

Example for 12 bit A/D converter:

$$\Delta L = \frac{L_{damper}}{2^{12} - 1} = \frac{120}{2^{12} - 1} = 0{,}0293 \text{ [mm]} \tag{1}$$

$$\Delta V = \Delta L \cdot f = 0{,}0293 \cdot 200 = 5{,}86 \text{ [mm/s]} \tag{2}$$

Example for 16 bit A/D converter:

$$\Delta L = \frac{L_{damper}}{2^{12} - 1} = \frac{120}{2^{12} - 1} = 0{,}00183 \text{ [mm]} \tag{3}$$

$$\Delta V = \Delta L \cdot f = 0{,}00183 \cdot 200 = 0{,}37 \text{ [mm/s]} \tag{4}$$

Where $\Delta L$ is resolution of damper stroke [mm], $L_{damper}$ is maximum of damper stroke [mm], $\Delta V$ is resolution of damper's piston rod velocity [mm/s] and f is sampling rate [Hz].

The final limitation of this method of measuring suspension forces is the need to know the exact stiffness of the ride spring and the characteristics of the damper. From experience, it can be stated that no linear spring actually exhibits a completely linear stiffness characteristic and therefore it is advisable to first measure the stiffness of the spring over its entire range.

Furthermore, it is generally known that where damping is present, hysteresis is also presented [10]. Thus, if we measure the damper characteristic on a dynamometer and then want to use it to obtain the force from the damper, the application is limited by the possible inaccuracy due to the simplified characteristic. The use of potentiometers to obtain the force in the suspension is possible, but it is not appropriate to use it when the dampers reach high speeds of displacement and where the accuracy of the measurement is reduced by the presence of damping hysteresis. A more detailed description and results will be presented in the final chapter of this article.

As already mentioned, the force in the suspension consists of two force components. The first component is the force due to the spring and the second is the force due to the damper. Thanks to the potentiometer, we record the stroke of the damper or spring. Therefore, if we also know the stiffness of the spring, we obtain the first component of the force by multiplying the given parameters. The stiffness of the coil spring can be determined by using a spring load tester, where the dependence of the deformation and force can be obtained again by means of a potentiometer and a strain gauge, which are attached to the test stand [11], [12].

Subsequently, if we perform a numerical derivation of the potentiometer stroke recording, we obtain its velocity. If we measure the damping characteristic on the dynamometer, we are able to calculate the second force component. The result is two forces that add in the case of compression and subtract in the case of extension. The above description and the figure 7 below illustrate how this method of measuring forces in the suspension is simpler compared to measuring forces using strain gauges.

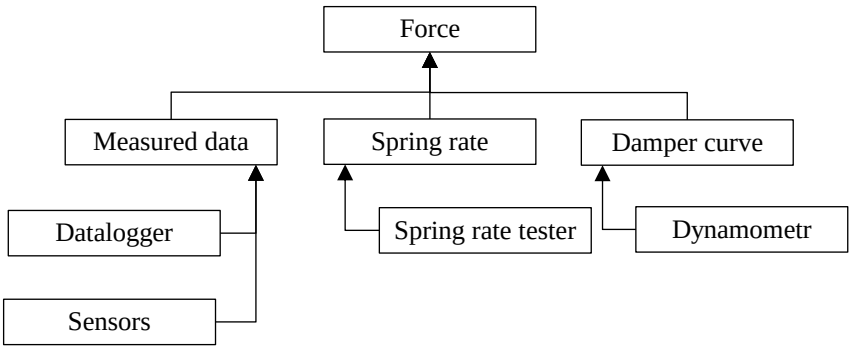



Fig. 7 Schematic workflow for obtaining force with analogue potentiometers

## 4 Measured test ride

A closed area, designed for vehicle testing, was used for the riding tests. The road surface was very smooth with an asphalt finish. A test track was marked out on the circuit, which occupied a flat area with a minimum length for the measuring section of 175 m in both directions, see. All driving tests included several repetitions in both directions in order to include a larger number of measurements necessary to obtain more accurate results. Another rationale for bi-directional driving is to eliminate the effect of weather conditions.



*Fig. 8 Photography of testing track with marked directions of riding*

A motorcycle braking test from a speed of 80 km/h was used to evaluate the measurements. With a total number of repeatability of 4 runs. The motorcycle accelerated smoothly to the desired speed and then began to decelerate to a complete stop. The sequence of the driving test is shown in Figure 9.

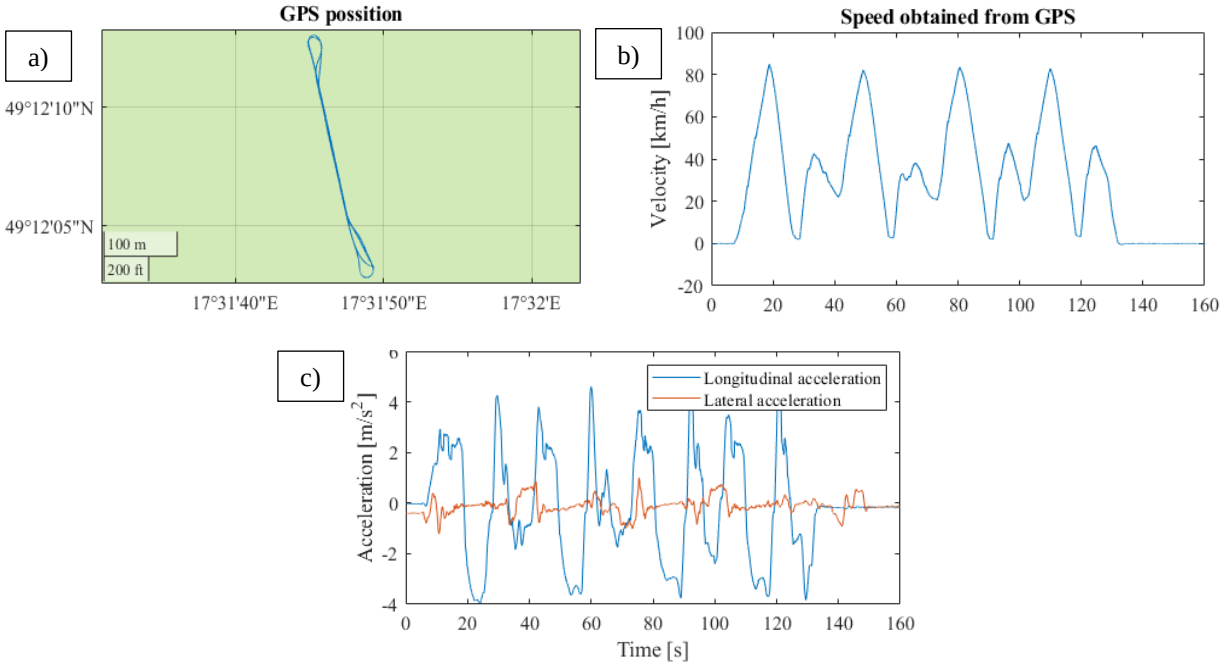



*Fig. 9 Recording of a ride test of a motorcycle decelerating from a speed of 80 km/h: a – GPS position; b – Speed from GPS; C – Acceleration.*

## 5 Results from measurement

This chapter focuses on a comparative analysis of two different methods of determining the forces in the suspension system of a selected motorcycle. The chapter is structured in two parts, each of which is devoted to one of these methods: one using strain gauges and the other using analogue potentiometers. The measurement data collected using these techniques were carefully processed and analyzed in Matlab R2019a software.

## 5.1 Force obtained by strain gauges

The waveform of the obtained forces in the motorcycle suspension by strain gauges is represented by the graph in Figure 10 above. The first is the force record from the strain gauge attached to the piston rod of the right fork, the second subsequently from the left fork, and the last from the rear damper. The graph clearly shows how the forces in the front forks show the same values and waveform. This indicates that the forks used are of symmetrical design. The slight offset between the forces for the forks is due to the slight difference in the stiffness of the springs and their preload, which is due to manufacturing inaccuracy. The significant offset in the case of the force waveform for the rear damper is mainly due to the difference in spring stiffness and spring preload, as well as the different motion ratio for the rear damper and spring. The difference in the force waveform for the front and rear of the suspension indicates how the motorcycle pitch during the ride test due to the effect of longitudinal acceleration. Another difference in the force waveform is the noticeable higher noise in the case of the rear damper force. This is due to the mounting of the rear damper unit directly to the main frame of the motorcycle, which also carries the single-cylinder engine, which exhibits non-negligible vibration during operation.

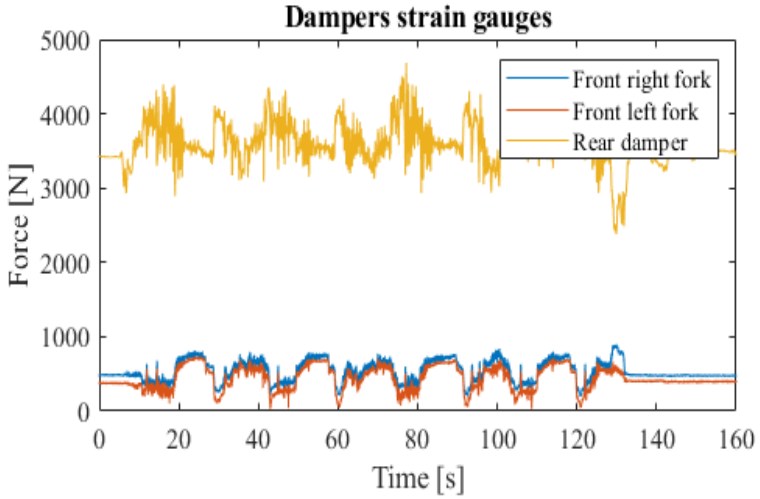



Fig. 10 Recording of force obtained from strain gauges

## 5.2 Force obtained by analogue potentiometer

Figure 11 shows the waveform of the motorcycle suspension travel as well as the waveform of the force in the rear damper unit due to spring compression and preload. The damper unit

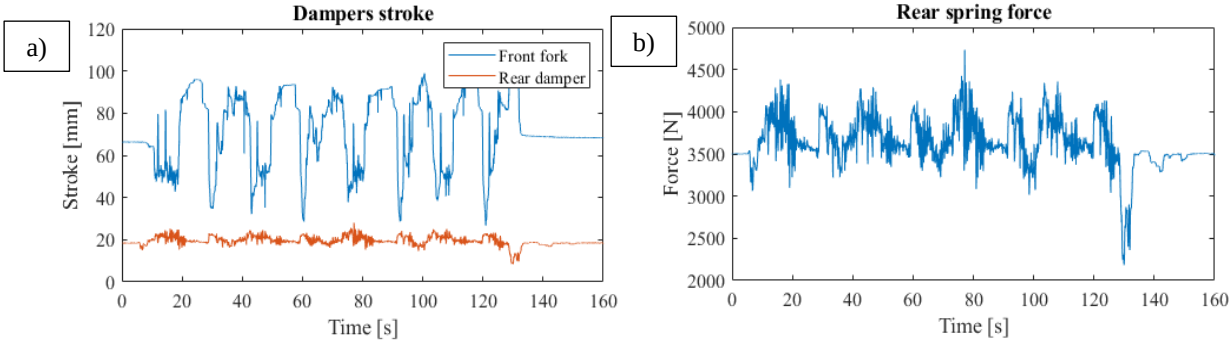



Fig. 11 Recording of suspension obtained from analogue potentiometer: a – Front forks and rear damper stroke; b – Rear spring force

travel was multiplied by the known spring stiffness and the spring preload was added to the result. Briefly, it can be seen how the spring force waveform exhibits less noise than when using a strain gauge. The values obtained on the right side of the graph are very close to those in Figure 10. The different waveform of the front and rear chassis motions is again due to the difference in axle stiffness and motion ratio.

The force component from the damper itself is not too high compared to the spring. This is mainly due to the very low travel speed of the damper. As these are transient states during driving, i.e. acceleration and deceleration, it is clear that the dampers operate at very low speeds. This is beneficial in this type of driving test, as it is the evaluation of the force from the damper that can accompany the largest bias in the results. The measured motorcycle damper showed a clearly linear and asymmetric damping curve for compression and rebound, and therefore the graphs in Figure 12 have a significant asymmetric waveform.

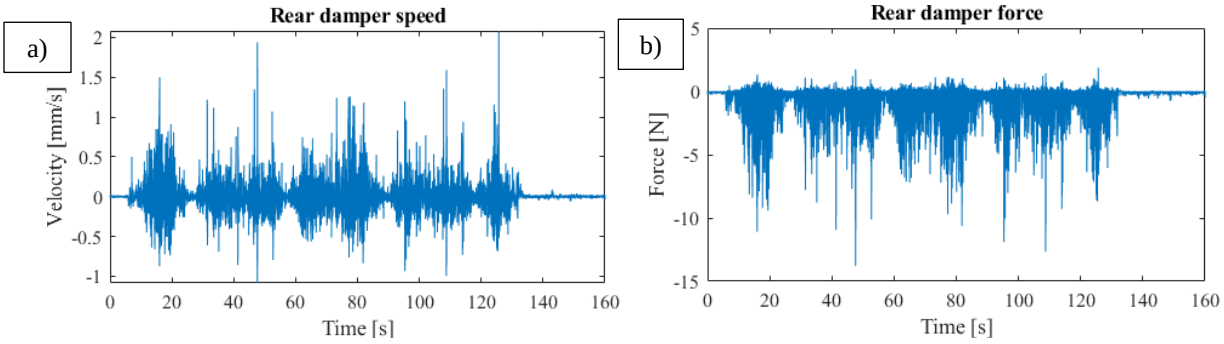



Fig 12 Recording of rear damper obtained from analogue potentiometer: a – Damper speed; b - Damper force

### 5.3 Comparison of two methods

Finally, Figure 13 shows a comparison of two methods of measuring forces in the suspension. The left graph overlays the force waveforms of the both methods. It can be seen that the forces reach very similar values in scale, so at the same time they follow the waveform over the whole measurement time. The right graph shows the difference in values of the two forces expressed as a percentage. It can be clearly seen that the difference between the measurement methods does not reach more than 4 % during the driving test. The more significant difference in the measurements is at the time of 120 to 140 seconds, where the motorcycle comes to a complete stop and the rear wheel is lifted. Even so, the difference is not more than 8 %.

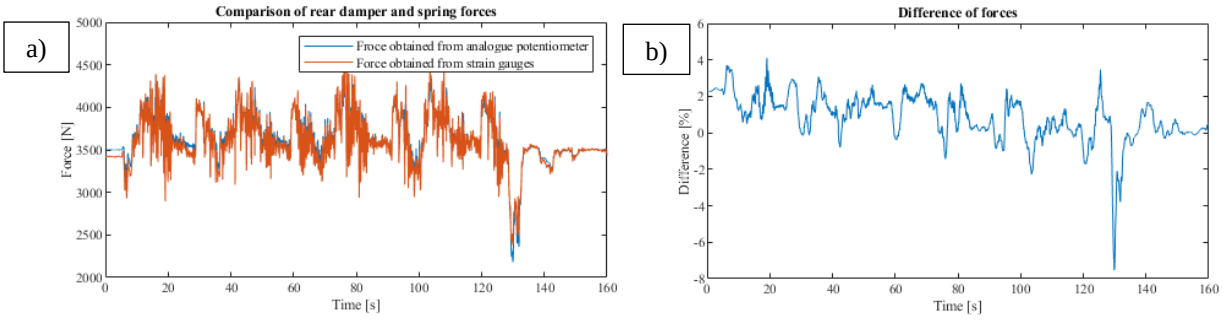



Fig. 13 Comparison of suspension forces recordings: a – Comparison of two forces; b – differences between two forces

On the basis of the results obtained from the measurement, it can be concluded that the measurement of the forces in the suspension of the vehicle is achievable by a method using analogue potentiometers. However, in order to guarantee sufficiently accurate results, it is

advisable to use the method when the suspended mass and dampers do not reach higher speeds. The method can be used both for academic purposes, where low acquisition costs are emphasized, and in motorsport environments.

Examples include the evaluation of the vehicle centre of pressure as a function of ride height, ride speed, or other methods of validating and measuring aerodynamic maps [13], [14]. Where vertical wheel loads can be obtained using strain gauges, but unlike analogue potentiometers, they are often prohibited by promoter rules [15], [16].

## CONCLUSION

In conclusion, the utilization of analogue potentiometers for measuring forces in motorcycle suspension systems presents a compelling alternative to the more expensive and complex strain gauge technology. Our research has shown that this approach offers a significant cost advantage and simplifies the measurement process. With the availability of standard, affordable analogue data loggers equipped with A/D converters of 12 bits or higher (depends on length of stroke and sampling rate), the transition to potentiometer-based measurements is not only feasible but highly practical.

The findings of this study indicate that the differences in force measurements between potentiometers and strain gauges are minimal, with variances of less than 8 %. This level of accuracy is more than sufficient for a wide range of ride measurements, making potentiometers a highly suitable choice for motorcycle or another vehicle suspension analysis.

A limitation of this measurement method may occur when detecting forces in the suspension during more dynamic driving over large bumps, when the damper velocity indicates higher values. As is well known hysteresis is mainly due to oil compressibility, gas entrapment, etc. and therefore larger deviations of the force component from the damper may occur [17]. However, this will need to be further refined in the future to find a given limit of applicability for faster piston rod movements.

In summary, the adoption of analogue potentiometers for force measurement in motorcycle suspension systems not only reduces costs but also streamlines data acquisition, making it an attractive option for researchers and engineers seeking to conduct various ride measurements without compromising measurement accuracy. This cost-effective and simplified approach opens up new possibilities for advance motorcycle suspension research, development or in a racing environment at private teams.

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## ACKNOWLEDGEMENT

The author gratefully acknowledge the group of people who specialize in vehicle dynamics at the Institute of Automotive Engineering BUT and MSR engines s.r.o. company with valuable advice and hardware resources.

## FUNDING

This work was supported by FME BUT program Fund of Science, project name Methodology for measuring forces in motorcycle suspension [Reg. No. FV 22-11].

## AUTHOR CONTRIBUTIONS

M. Tobiáš, M. Repka and T. Straka were helpful with measure equipment and preparing bike. M. Tobiáš has been assisted with track preparation and testing schedule. L. Gregor assisted with the theory of force acting on the motorcycle frame and suspension.