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## **BELT VIBRATIONS MEASUREMENT AND RELATIVE EFFICIENCY OF THE POWERTRAIN STUDY ON THE ENGINE TEST STAND FOR *SILESIA GREENPOWER* VEHICLE**

**Abstract:** The process of designing and building a professional test stand for measuring efficiency of the drive system in Silesian Greenpower vehicle was described in this paper. The fundamental aim of the study was to obtain an optimum belt tension at which the vehicle will be able to achieve the highest speed. The work depicts a description of the stand construction, research methodology, presentation of results, summary and conclusions. In particular, the article focuses on the measurement of belt vibrations and the study of the drive system efficiency on the constructed stand. One of the tasks was also to determine influence of proper belt tension on vehicle efficiency. The final effect of the research is a compilation of results for each belt tension and conclusions concerning practical correlations of studies with the trend in development of Silesian Greenpower vehicle design.

### **1. Introduction**

The ground on which this research was conducted stems from the need of reducing resistance and maximising efficiency in Silesian Greenpower vehicles – the electric racing cars participating in annual events held on prestigious motor circuits in Great Britain. The rules of the races determine the same motor and batteries for each competitor, so engineers have to seek for other factors which will lead them to the victory.

One of the most crucial elements of the vehicle is the powertrain. In order to increase its efficiency toothed belt transmission was chosen. However, the system will not work properly unless the optimum belt tension is maintained. The article describes the professional engine test stand designed especially for the research and tests which were conducted on the stand, including belt vibrations measurement and tests of relative efficiency of the powertrain.

## 2. Engine test stand construction

The base of the stand (Fig. 1.) is a modular construction, which provides two types of measurement. The first is the test directly on the vehicle, which is not the subject of the paper, and the second is the use of a separate drive system mounted on the stand. The greatest advantage of this way of research is the possibility of redesigning the powertrain without the necessity of altering the vehicle construction.

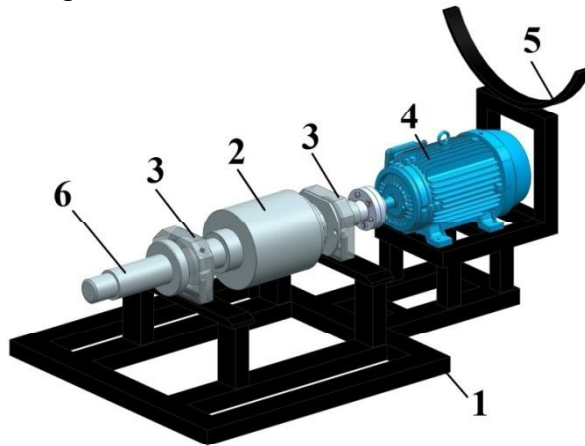


Fig. 1. CAD model of the base of the test stand

The base of the test stand consists of six main parts: 1- steel frame, 2- shaft with a track on which driven wheel drives, 3- self-aligning bearings fixing the shaft, 4- electric motor which can model braking forces of aerodynamics, 5- the support of the rear non-driven wheel, 6- place provided for the attachment of additional loads which simulate inertial deceleration by braking torque generated by the mass. During tests using the stand only, the force pushing the wheel to the shaft is maintained by 25 kilograms weight hung on a steel cable in rollers system. The whole stand construction was designed in CAD system – Siemens NX 8.5 and built by authors afterwards (Fig. 2.).

- 1– base of the test stand, 2– frame of the test stand,  
3– equipment board, 4– linear bearings,  
5– trapezoidal screw, 6– driven wheel

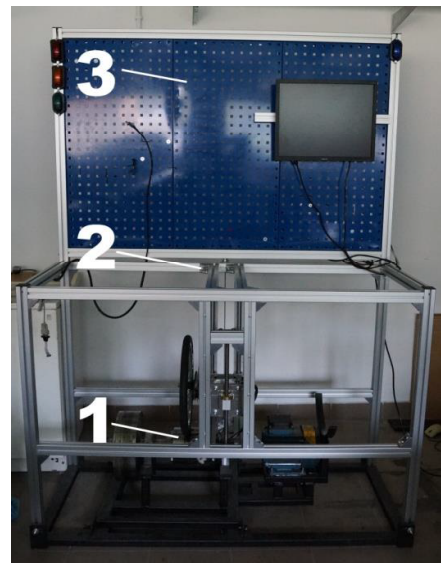


Fig. 2. The engine test stand

### 3. Belt vibrations measurement

The research conducted on the test stand was performed for six different tensions of the belt: named from A to F (tension A was too weak to transfer the rotation movement). The aim was to calculate frequency and assign maximum speed for each tension which then would lead to optimum solution. To measure acceleration of vibrations and then calculate frequency, the hammer was tapped on the belt near the place of attachment of the sensor with the same conditions for all tensions.

In order to determine the frequency of belt vibrations, acceleration-time graph (Fig. 4.) was plotted availing the measuring apparatus (Fig. 3.).

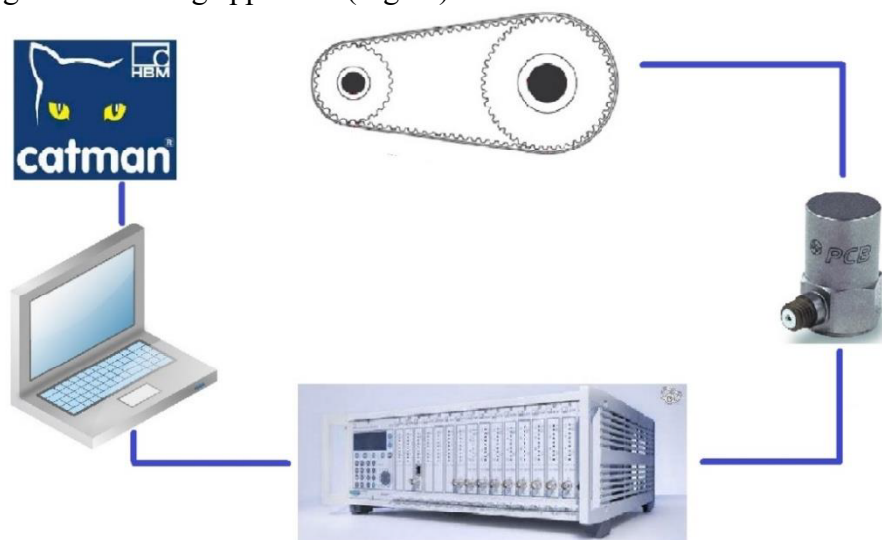


Fig. 3. Diagram of the measuring apparatus

The PCB Piezoelectronics sensor, called also piezoelectronic transducer, is attached to the belt with technical wax. The sensor avails piezoelectronic effect to convert the alterations in electrical voltage. The next element is the amplifier - MGCplus AB22AA HBM whose task is to enhance the signal from the sensor, its processing and enabling data archiving. The device has a modular design that allows measurement of many physical values by using proper expansion cards. For this study the AP 180 HBM card was used. The amplifier is connected via USB port to the computer with Catman Easy. The program has proper configuration parameters set and characteristics of a piezoelectronic sensor defined.

The results of the tests were presented as acceleration-time graphs. The first part of curve was neglected because of nearly the same amplitudes. The subject of analysis was the second part where intensive damping of vibrations occurred. To make all six graphs easily comparable, the scale of X axis was limited from 0 to 0,5 and Y axis form -100 to 100. The graphs differ significantly as for tension A period equals 0,03 s and for tension F – 0,007 s, which proofs that spectrum of tensions being tested was chosen properly.

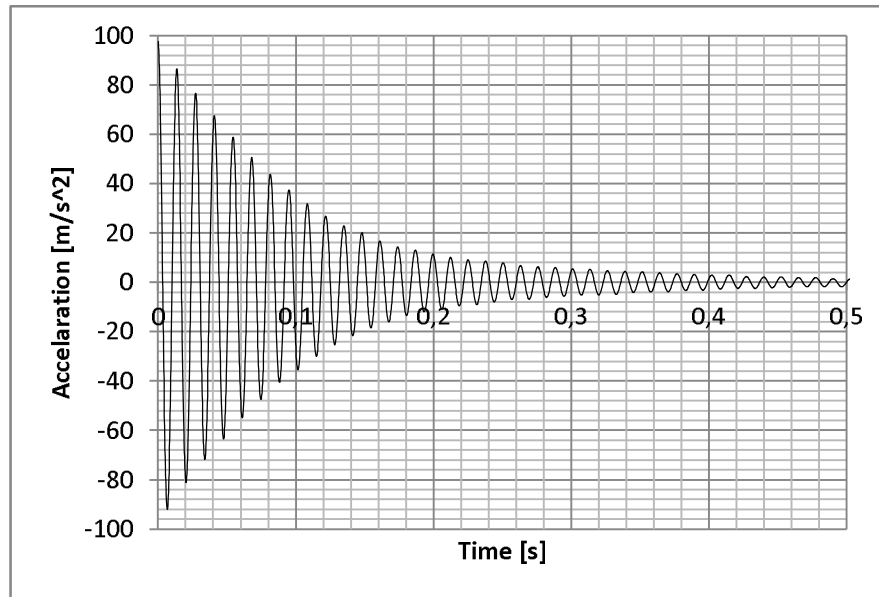


Fig. 4. Acceleration-time graph for tension C

The calculation of frequency values allowed the calculation of the force with which the belt is pulled. In this regard, equations on the belt span (1) and the force of tension (2), which are available in the controller of the mobile SKF belt tension meter [6], were used. Data used in this calculations are shown in (Tab.1 ).

$$S = \sqrt{CD^2 - \frac{(D-d)^2}{4}} \quad (1)$$

$$N = 4 \cdot m_p \cdot S^2 \cdot f^2 \quad (2)$$

$S$  – belt span,  $CD$  – distance between toothed wheels' axles,  $D$  – bigger toothed wheel diameter,  $d$ - smaller toothed wheel diameter,  $N$  – force of tension,  $m_p$  – weight of belt per linear meter,  $f$ – frequency.

Tab. 1. Data used in calculation of the force of tension

Parameter	Symbol	Unit	Value
Smaller toothed wheel diameter	$d$	m	0,055
Bigger toothed wheel diameter	$D$	m	0,110
Distance between toothed wheels' axles	$CD$	m	0,190
Weight of belt per linear meter	$m_p$	kg/m	0,036

#### 4. Relative efficiency of the powertrain

In order to create certain scheme of tests, the tension of the belt was set as usually and duty cycle of cars power was set to 100 per cent. This was followed by the tests of the more and

less tensioned belt. Thanks to the tests, the maximum speed with which the drive system mounted on a test bench can drive with a ratio of 2.25 was received. This also allowed the determination of time the car reaches the average speed, namely about 45 seconds.

After initial attempts to set a constant course, which will be accelerated with the car at each tension. Sample time was 60 seconds, the first 10 s was with 60% duty cycle, the next 30 seconds with 100%, another 10s - 60% and the last 10s without a drive. This course was designed to simulate the car turning, faster driving on the short straight and entering the next turn.

Research carried out on the test stand consisted of three tests for each tension, except for A which occurred to be too weak to transfer the rotation movement. The tension fixing was maintained by screwing the trapezoidal screw to which the motor was attached on two linear bearings (Fig. 2.) – the difference between two tensions (e. g. A and B) corresponds to one pitch of the screw.

The tests resulted in generating text files and graphs which can be easily pre-analysed thanks to an application created specially for Silesian Greenpower project by one of the members. Screenshot of application (Fig. 5.) shows graphs of speed, duty cycle, voltage, current (filtered and unfiltered). After comparing the graphs in the application, the data were exported to a spreadsheet in Microsoft Excel. Out of all the parameters, speed, duty cycle and current were selected and one graph was created. However, in order to improve the legibility of the function of the speed, it was approximated by a polynomial of the third degree. The speed values were averaged in order to find the representative value of all three tests for each tension. The maximum value of speed was read from the original tabular data. The numerical results are shown in Tab. 2.

*Tab. 2. Comparison of results for different belt tensions*

Parameter	Unit	Tension A	Tension B	Tension C	Tension D	Tension E	Tension F
Vibrations frequency	Hz	33,2	66,06	75	93	104,34	144
Belt tension force	N	5,5	22	33	41	52	105
Maximum speed	km/h	0	41,27	45,5	45	42,3	42

The results indicate the value of the transmission belt tension to be between 33 and 41 N to ensure optimal functioning of the drive system. In addition, these tensions were characterised by specific string sound which was absent in other tests. Overall analysis shows that managing the optimal belt tension is crucial to maintain the highest maximum speed of the car, otherwise, the value of maximum speed may decrease even by 10% (Tension B compared to Tension C). Neither too weak, nor too strong belt tension is acceptable.

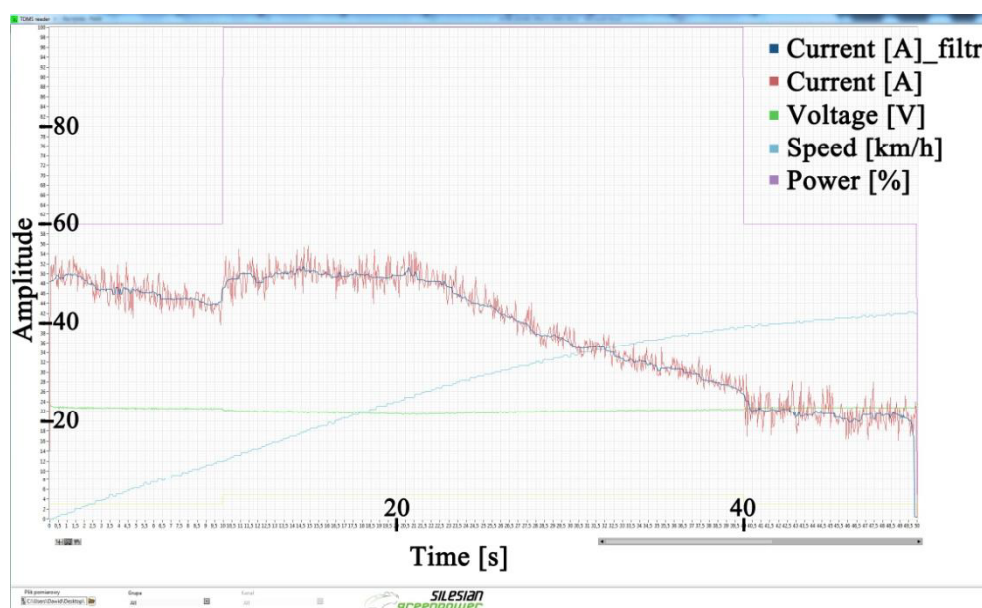


Fig. 5. The application used to read data from the stand

## 5. Conclusion

In this paper influence of belt tension on the relative efficiency of the powertrain was analysed. The study depicted a linear relation of belt tension on the efficiency of the powertrain. It was stated how to define the optimal belt tension and how to measure it in laboratory conditions. The final results have significant impact on further development of the Silesian Greenpower vehicle and its optimal performance on the motor circuits. The further research will cover measuring and maintaining optimal belt tension in real conditions during tests on the motor circuit and monitoring the variation of powertrain efficiency due to different belt tensions.

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