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## INTELLIGENT WHEEL WITH A PUGA® POLYURETHANE TREAD FOR HEAVILY LOADED SUSPENSION MINING RAILWAYS

**Abstract:** The increasing performance requirements of machinery and equipment (more robust, more resilient, overall better) as well as the market competition (less expensive) force most manufacturers to use high quality materials (materials science) and modern control systems (intelligent systems). They are the foundation of every emerging detail design, component parts as well as whole machines. Competitive products can be created only if the strict requirements for modern constructions work together with the most state-of-the-art measuring technology and its integrated control system. This is how they provide energy efficiency - the force behind technological development and innovation. The basis for almost all of designs is the intelligent wheel capable of responding to the changes of internal and external environment, and thus maximizing functionality and safety while lowering operating costs.

### 1. Introduction

More and more can be heard about the so-called smart or intelligent machines, devices, machine parts, etc. Intuitively the word “intelligent” brings to mind a connotation with sensors, detectors, measure and building management systems installed in them in order run full control. They are most often defined as technically advanced. The ability to react to the changes of the interior and exterior environment results in a great increase (according to the established electrical or financial criteria) of functionality, work comfort, safety, etc.

Just as the invention of the wheel was once a colossal milestone for technology as well as social and economic growth, today the development and technical implementation of the smart wheel could potentially create a ground-breaking discoveries in the very static, standard world of mechanical engineering technology.

### 2. The genesis - an attempt at defining the problem

A good example of the tremendous potential for innovation of the smart wheel is the suspension railway used in the mining of hard coal, see image number 1.



*Fig.1. Suspension railway with tread wheels working in the state of extreme load*

The analysis of the operational reliability of the suspension railway in mining was researched at the Mining Mechanization Institute of the Silesian University of Technology by doctor Tadeusz Giza [1]. According to tests he ran on the railway motors (main drive, motor drive mechanism, capstan, and electrical) most often it was the drive mechanism that was damaged. The drive mechanism failure constituted around 47% of all failures, where the breakdown of wheels happened in 17,86% cases and the time spent fixing them constituted 24,32% of all repairs. This shows the scale and significance of the matter.

This is why, in the light of this challenge, Gasket began research and production of new friction material made of PUGA® polyurethane [2]. Wanting to rise to the growing market competition the company is continuously running the basic and introductory scientific works, perfecting this technology. The company is currently looking for:

- new materials for coating the wheel's hub characterized by a greater resistance and friction factor between the wheel and the rail,
- improved wheel construction that would deliver better heat distribution and protection of the polyurethane layer of the wheel against structural degradation.

The end result of their work is the growing quality of drive wheels, which limits their import to Poland while expanding the export of increasingly better suspension railways equipped with friction drive.

### **3. The physical model of the “wheel–rail” system for the suspension railway**

To generalize the problem one can say that the suspension railways work in extreme conditions, in which the element under most stress is the “drive wheel - rail” system. The diagram of the two friction parts along with the corresponding force distribution in the x, y, z coordinates is shown in the Fig.2.

This example purposely contains almost all of the design challenges – optimisation of the material working in extreme conditions with the maximum friction factor – and construction and production of such a gauge-steering system which allows for the best working time and resistance of the transport system – the maximum function capacity expressed as:

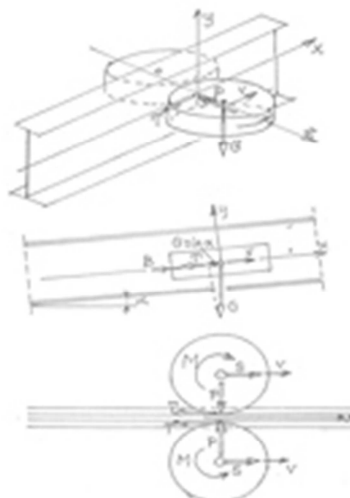
$$Y_c = \text{time of work} \times \text{the value of the load in tons.} \quad (1)$$

Under such assumption the tractive force of the two drive wheels equals:

$$F = 2 (T \pm G \sin \alpha \pm B). \quad (2)$$



Fig.2. Friction duo “drive wheel – rail” with the corresponding force distribution in the ortogonal setup of coordinates  $x, y, z$



Dys.1. Schemat układu napędowego oraz siły działające na bieżnię. Na foto działają siły przesuwnie oraz ściągania pionowe i siła bezwładności

The friction in engineering contains a fundamental contradiction. On one hand we strive to limit it, as friction lowers the effectiveness of any process. On the other hand there is not a single process possible to occur without friction. Friction is responsible for the rise in temperature and the exploitation of the rubbing elements. Lowering the energy consumption of the processes, so eagerly researched, is achieved by lowering the friction factor. And the increase in the friction factor makes lowering the pressure of the wheel against the rail possible and thus improves the conditions of the friction in the drive wheel / steel rail setup.

#### 4. The analysis of the conditions of exploitation and the pattern of abrasion of the drive wheels

The implementation of the integrated management system by Gasket, achieved through meticulous collection of production data (data base of the ERP-Rekord system), on the operational time of the wheels as well as detailed record keeping and analysis of the refund claims allows us to monitor and evaluate the quality of production. The conditions and the life span of operational usability are also under scrutiny through conducted classification of the wheel usage which is based on a close examination of the used wheels.

##### 4.1. Drive wheels properly made and properly used

The main group are wheels that were properly produced and properly utilized. The Fig. 3 shows the correctly made and used drive wheels.3.



Fig.3. Images of the correctly produced and used drive wheels

The characteristics of the properly produced and used treads are:

- relatively even friction wear of the rim and symmetrical concavities of the tread. For the outer diameter of the wheel it is between 340 and 355 [mm]. There are between 20 and 29 concavities in the rim, out of which 24 are of a 340 [mm] diameter,
- geometrical dimensions of each indentation don't differ between one other and the given examples of indentation in Fig. 3 are presented in table 1,
- the dimensions of indentation are significantly different and between 4.5 and 2.5 [mm],
- the side surfaces of the the wheels are cracked and their edges seems skewed,
- the utilization time of the wheels ranges between 500 to 1000 [mh] (motohours of work). The record time of the drive wheel is 2345 [mh].

Table 1. Drive wheel type: small Scharf in the nominal dimension of FI 340x100 with the firmness of 95° Sh A, the dimension of the used wheel - FI 335x74

Number of indentations	Length of indentation [mm]	Width of indentation [mm]	Depth of indentation [mm]
1	45	21	2,4
2	45	15	2,1
3	45	25	2,3
4	47	31	2,4
5	35	22	2,0
6	41	25	2,3
7	42	20	2,3
8	41	20	2,2
9	45	25	2,4
10	45	30	2,1
11	41	32	2,2
12	41	22	2,3
13	45	25	2,3
14	45	28	2,1
15	43	41	2,2
16	45	22	2,3
17	41	26	2,3
18	45	11	2,4
19	35	32	2,3
20	40	31	2,4
21	32	32	2,2
22	41	26	2,3
23	42	20	2,2
24	40	20	2,3

#### 4.2. Drive wheels under the claim for refund

The second group constitutes of wheels which are most often the subject of customer refund claims. The suspension railway user, our Client, often thinks that the wheels were improperly made – not in accordance with the wheel production technology - and that was the reason why the wheels didn't stand the conditions of usage.

Whereas the producer of wheels, while conducting an analysis of the customer claims and controlling the production processes and the used coating materials, will most often qualify the claims as a result of improper use.

Pictures of the wheels under refund claims shown in Fig. 4.



*Fig.4. Wheels under refund claims*

The characteristics of the treads of the wheels under refund claims:

- the irregular friction use in the rim of the wheel with a well-defined spot abrasion – the result of the sliding of the wheel on rail brought on by the blocking of the wheel for instance during braking,
- fractures in the outer layer of the drive wheels tread and accompanying clots of polyurethane that leaked out of the fracture,
- cross section of the treads are of two structures: outer – more compact described as the “tire” and the inner, less compact described as the “inner tube” - through the analogy to the construction of the car tires which seep polyurethane when broken due to high temperatures,
- in some cases the partial fraction of the polyurethane layer occurs (lack of adhesion to the metal hub of the wheel),
- the side surfaces of the treads are cracked and their edges seems skewed,
- the utilization time of the wheels ranges between 50 and 250 mh (motohours).

#### 4.3. Drive wheels “maltreated” during use

The third group are wheels which have undergone degradation and destruction during use. Examples of the destroyed wheels shown in Fig. 5.





*Fig.5. Drive wheel damaged during use*

The first far left photo shows ripped out parts of the elastomeric layer, with slots grooved by the time of exploitation, which, in theory, should be working against a flat surface of the rail.

The middle photos shows a wheel which came out of its axis and it was lifted in such a way that instead of being carried in the rail track, it was actually running on its top edge, which in result completely ripped off the polyurethane layer in 1/3 of its height. Even the top edge of the metal hub was crushed – the obliquity at an 10-15/45° angle.

The third, far right photo shows a wheel which had been working under an extensive amount of pressure, visible in the radial fractures of its layer.

#### 4.4. Factors which invalidate the customer refund claims

Gasket took under consideration the above mentioned cases and established the criteria which invalidate the customer refund claims. The following cases apply:

1. mechanical damage to the layer - abrasion of the layer as a result of braking, hanging sling, obstacles in form of hook en route, poor conditions of the route,
2. uneven use of the layer of the wheel caused by an incorrect assembly of the wheel on the engine's hub, the use of unsuitable screws,
3. damage to the metal part of the wheel (i.e. punched out holes, rubbed metal surface, etc.).
4. radial fracture of the layer on entire perimeter evident to the exceeded pressure applied to the wheel during use,
5. lack of traces of liquid polyurethane dripping from the wheel.

Simultaneously, based on the above-mentioned physical model of the wheel-rail circuit for suspension railways, simulation calculation were run which estimated the amount of generated heat in the polyurethane layer for any wheel working in stable conditions (e.g. running friction) as well as in the conditions of abrupt braking – blocking the drive wheels and the sliding friction between the wheel and the rail. For these conditions, experimentally, the values of the adequate friction factors were assessed. In a working wheel the first case generated heat equivalent to the power of 50 W. The latter generated around 1000 [W].

## 5. Working thesis

All the gained experience together with the carried out simulations allow for the following thesis to be formed: the decisive factor which influences the work of a wheel is the amount of

heat generated in the polyurethane layer. Therefore the increase in the life span of or the length of the operational activity of the wheel is directly dependent on the temperature of the polyurethane inside the layer.

Which means that apart from the research and work done on the improving of the layer material of the wheel (such as developing a dedicated composite as a polyurethane blend), more control can be gained over the working condition of the railway, monitoring the layer's temperature and thus navigating the work of the railway, and preventing:

- blocking of the drive wheel during braking (an ABS-like system),
- the loss of traction between the drive wheel and the rail during the start and acceleration of the railway.

Working in an interdisciplinary team we strive to achieve a modified DRIVE WHEEL, and then a NEW GENERATION DRIVE WHEEL equipped with the elements of the smart wheel and capable of:

- the mobility of more powerful drives while maintaining the current durability,
- bigger durability in the transferring of the current power.

Another advantage would be the lowering of costs of railway use and maintenance, and making the suspension railways more energy efficient.

## 6. The idea of an intelligent wheel

The very first step which needs to be taken in the construction of an intelligent wheel is giving it a certain amount of sensitivity, achieved through built-in sensors which register and send signals to the electric microcircuit designed to optimize the work conditions of the wheel-rail system. This is done according to the function shown in the 2.3. This circuit also allows monitoring of the technical state of the railway and dynamically changing working conditions, at the same time improving the reliability and lowering the costs of use of the suspension railway.

An ideal solution would be melting, into the serial produced wheels (lining) special sensors and a dedicated, programmable electronic microcircuit which enables the measuring/registration of the following parameters:

1. Time measurement – clock function
2. Temp measurement in the tread section
3. Measurement – number of rotations
4. Measurement of the force of the layer against the rail
5. Measurement of the driving speed

Data registered in such a way can be:

1. stored in the memory of the microprocessor and after the wheel reaches the end of its use, before it can be restored, data is read and kept in a dedicated database. This database identifies the information on the parameters of the wheel production and all that information on production and exploitation can be retrieved from it.
2. consistently sent to the control desktop of the railway. This way the operator can run a optimal operation use of the device. This solution will enable automated warning system against exceeding weight, speed, temperature thus delivering the optimal device handling and not “killing the machine” – typical for the work load in the mining conditions). This

as well as an automated diagnostics and planning/management of the system of the traffic is now made possible.

3. the base of intelligent support of the management of the railway according to the exclusively developed software which optimizes the work of the whole transportation system.

The above-mentioned prospects give the possibility of building a complete system for monitoring the basic parameters of production, especially the exploitation of wheels. This data will enable more cost effective service and maintenance, increase reliability and operational safety.

Knowledge database obtained in this way, along with the possibility of operating the railway and monitoring its condition and controlling the intensity of work will be the basis of a significant competitive advantage of the company in the market of drive wheels.

## 7. Comments and suggestions

This briefly presented idea of a smart or intelligent wheel which would meet all of the aforementioned requirements, remains in the field of theoretical contemplation, but tomorrow may already be a reality.

It comes as a result of a brainstorming of experts and specialists developing a research/implementation project under the title “Research and development of new technologies”, which is co-financed by the European Regional Development Fund as part of the POIG.01.04.00-24-034/11 project. The goal of the project is to accomplish a product innovation - a new generation drive wheel which will feature a compound material based on the PUGA® polyurethane.

The analysis of the problem indicated that the first step should be designing and building a module for temperature measurement on the surface / cross-section of the drive wheels and testing it in an industrial environment.

Its implementation requires the cooperation of an interdisciplinary group of experts and must be supported by research, development and construction of prototypes as well as production and tests under operating condition. Therefore Gasket put forward a proposal, which includes elements of the aforementioned intelligent systems and is awaiting the results of this contest. At the same time the company is conducting series of analytical tasks.

Gasket is also currently scouting the future specialists among students and science workers of such areas as: mechatronics and modeling of mechatronic systems, material engineering, construction and operation of machines, hoping for a possible collaboration prospects.

## References

1. Białas K.: Giza T.: “The analysis of the operational reliability of suspension railway in mining.” The report was presented at the 6th International Conference: “Safety of transport devices in mining”, 5-7.11.2008.
2. PUGA – the trademark of Gasket materials