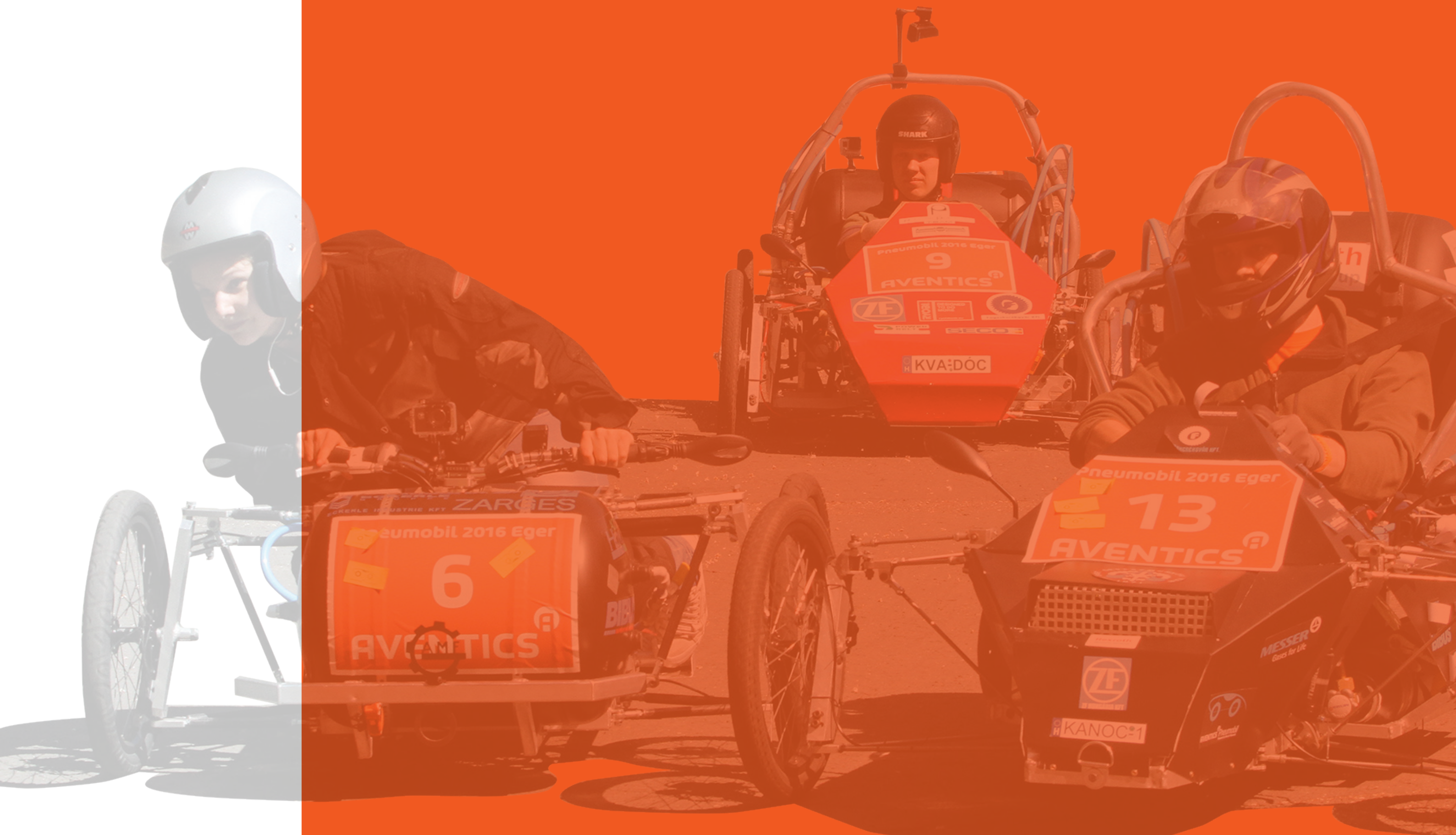
AVENTICS

Proceedings of 1st Agria Conference on Innovative Pneumatic Vehicles – ACIPV 2017

May 05, 2017 Eger, Hungary



AVENTICS Pneumobil

Proceedings

of the

1st Agria Conference on Innovative Pneumatic Vehicles – ACIPV 2017

May 05, 2017
Eger, Hungary

Edited by
Prof.Dr. László Pokorádi

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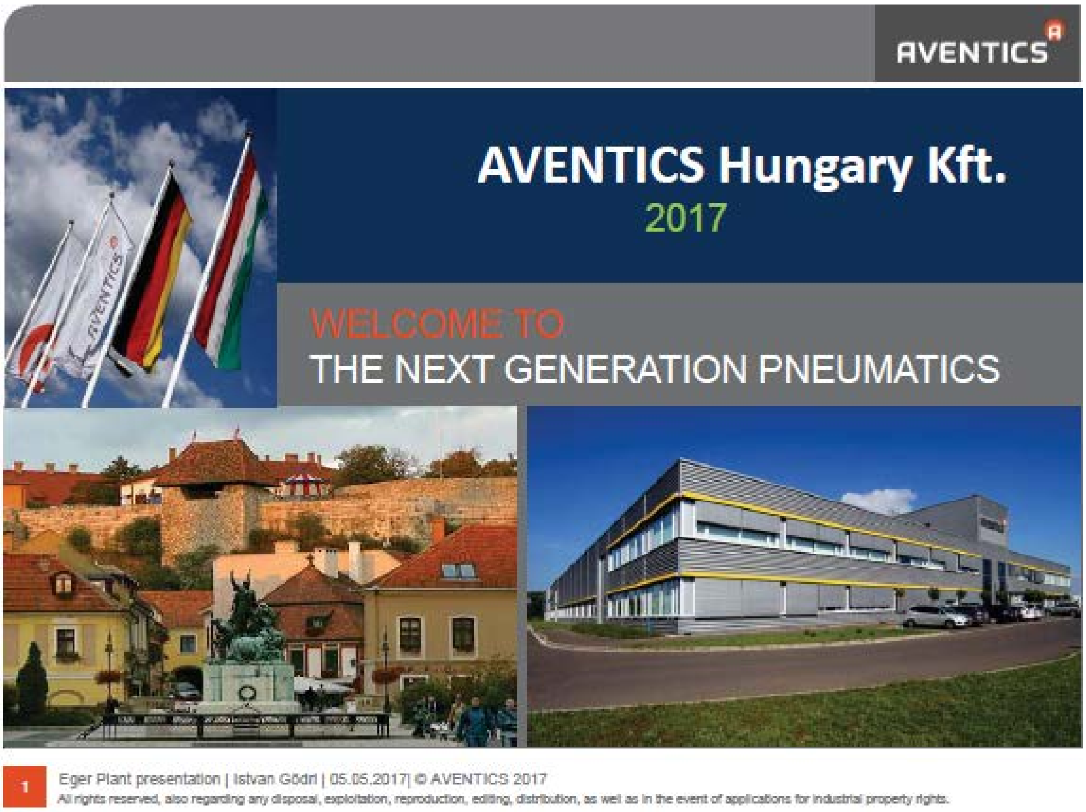
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2017
WELCOME TO
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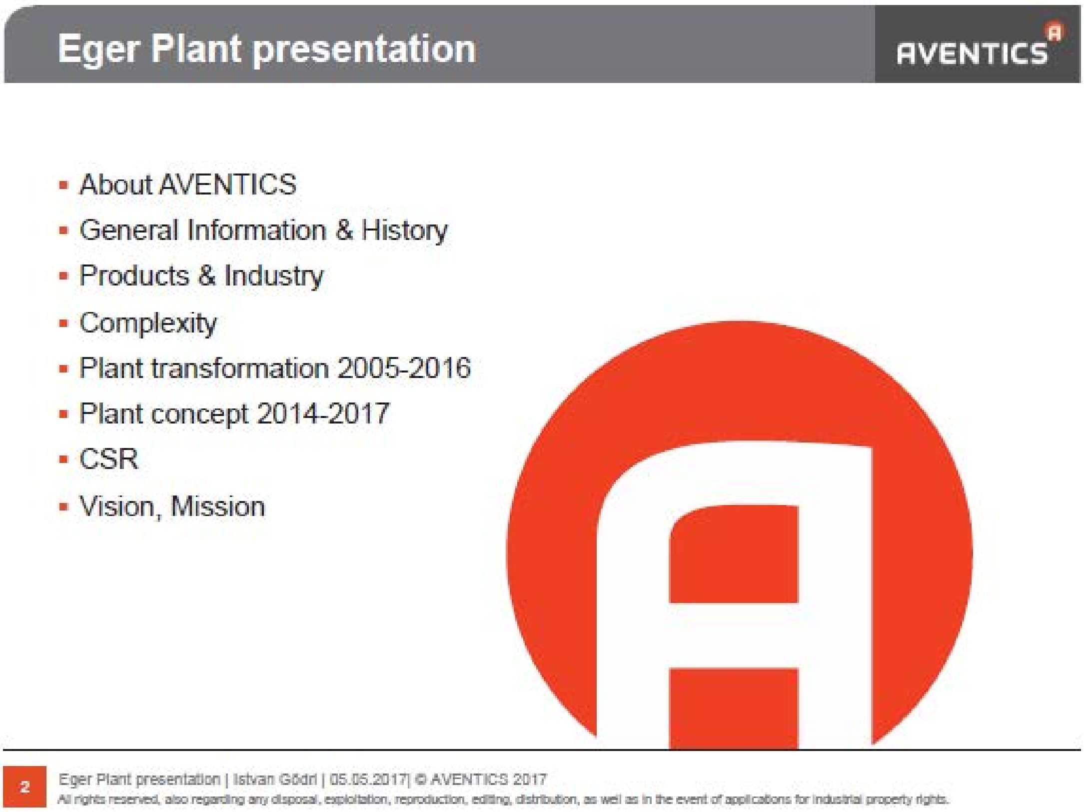
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About AVENTICS

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Our Strategy: Based on Megatrends

Urbanization

Increasing pace of urbanization leads to mega cities with high density, resulting in massive impact on the future of mobility, working life and societies' sectors.

Commodity Scarcity

Water, food, energy, and other commodities increasingly become scarce due to the higher population and development pace especially in emerging markets. This requires higher levels of engineering expertise.

Aging Population

Both in mature and in emerging countries life expectancy is constantly increasing. Global population growth will mainly increase in emerging countries. This requires new technologies for people in need.

Environmental Improvement

The reduction of fossil-fuel dependencies and greenhouse-gas emissions is interdependent with the increasing energy demand. Besides the focus on bio-based materials and re-use, efficiency remains important to create more sustainable value chains with lower energy use, less waste and pollution.

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About AVENTICS

AVENTICS

Sustainability

VALUES

- Future-oriented approach and result focus
- Cultural diversity
- Fairness and responsibility
- Initiative and determination
- Reliability, credibility, and legality
- Openness and trust

QUALITY

- Extensive application of quality methods
- Systematic use of methods to prevent errors in our product engineering process
- Certified in international standards such as ISO 9001 and TS 16949
- Trustworthy to different industry standards

EMPLOYEES

- Our greatest asset
- Agile, focused and passionate
- Global network
- Constant promotion and development of know-how

ENVIRONMENT

- Sustainable use of resources
- Waste prevention and recycling
- Economic and environmental strategy
- Fulfillment of social responsibility
- Certified in accordance with ISO 40001 and 50001

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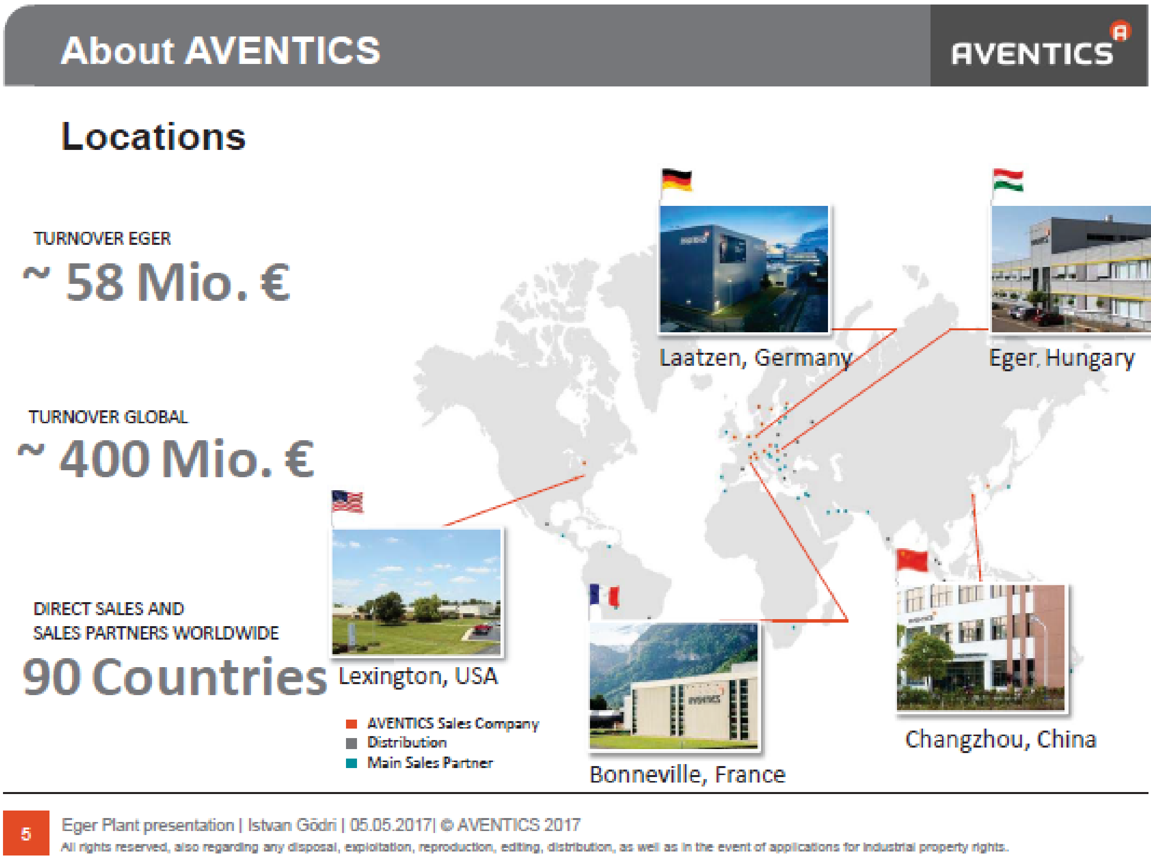
About AVENTICS
AVENTICS
Locations
TURNOVER EGER
~ 58 Mio. €
TURNOVER GLOBAL
~ 400 Mio. €
DIRECT SALES AND
SALES PARTNERS WORLDWIDE
90 Countries
Laatzen, Germany
Eger, Hungary
Lexington, USA
Bonneville, France
Changzhou, China
AVENTICS Sales Company
Distribution
Main Sales Partner
5
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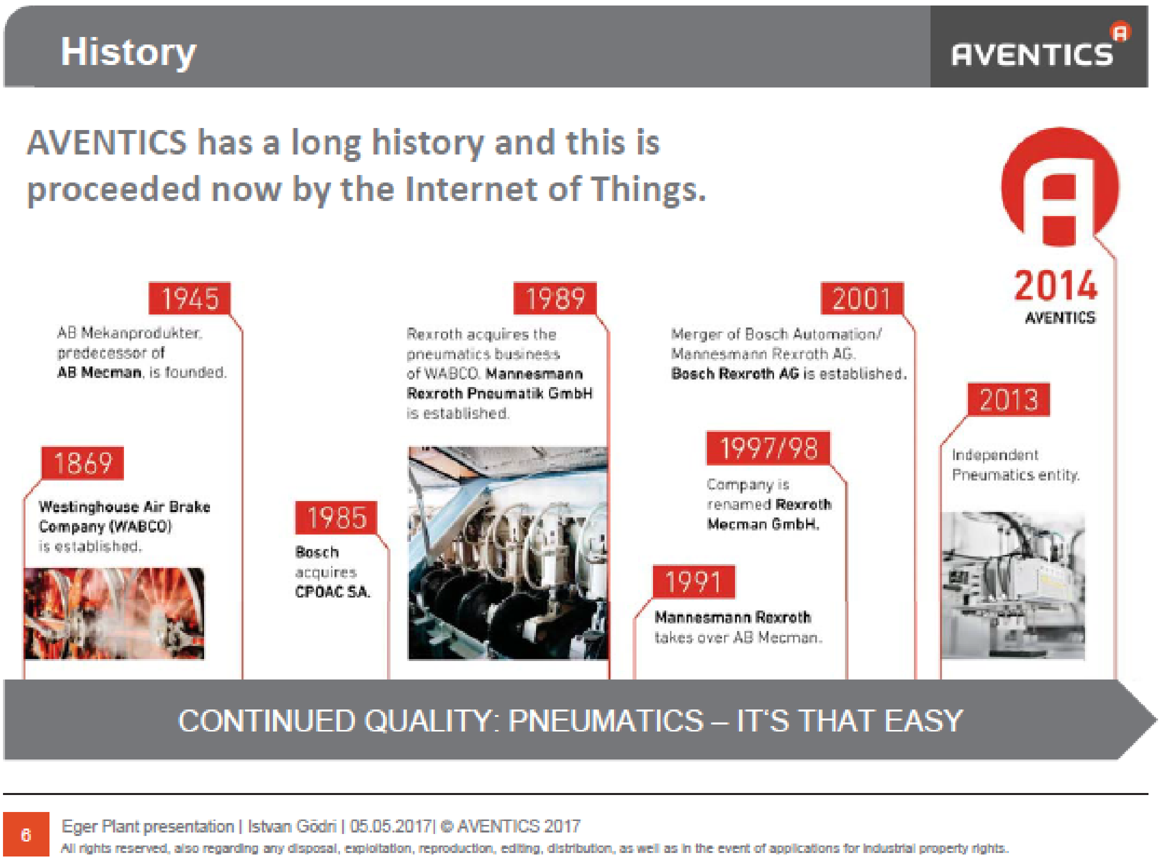
History
AVENTICS
AVENTICS has a long history and this is
proceeded now by the Internet of Things.
1869
Westinghouse Air Brake Company (WABCO) is established.
1945
AB Mekanprodukter, predecessor of AB Mecman, is founded.
1985
Bosch acquires CPOAC SA.
1989
Rexroth acquires the pneumatics business of WABCO. Mannesmann Rexroth Pneumatik GmbH is established.
1991
Mannesmann Rexroth takes over AB Mecman.
1997/98
Company is renamed Rexroth Mecman GmbH.
2001
Merger of Bosch Automation/ Mannesmann Rexroth AG. Bosch Rexroth AG is established.
2013
Independent Pneumatics entity.
2014
AVENTICS
CONTINUED QUALITY: PNEUMATICS – IT'S THAT EASY
6
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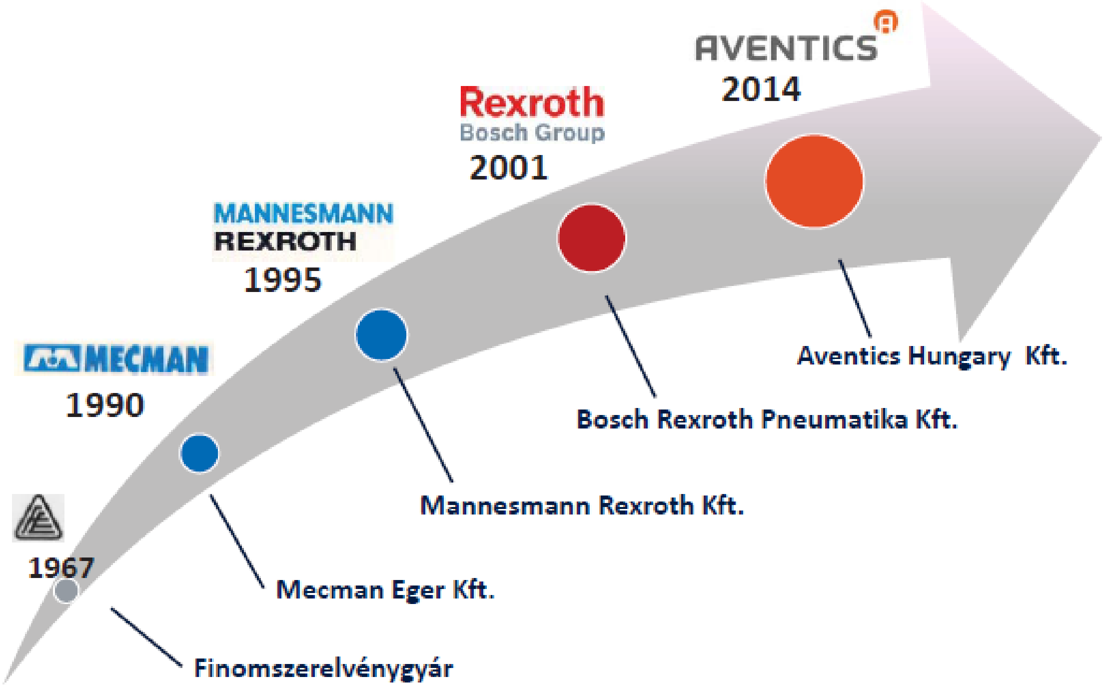
History – Eger Plant



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Core Sectors

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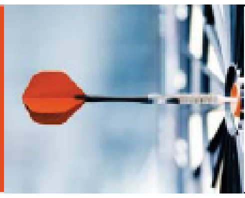
Our DNA

AVENTICS

Focused



We are the pneumatics experts and focus on our core competencies.
With the expertise of our employees, we are the leading technology specialist in many areas.

Passionate

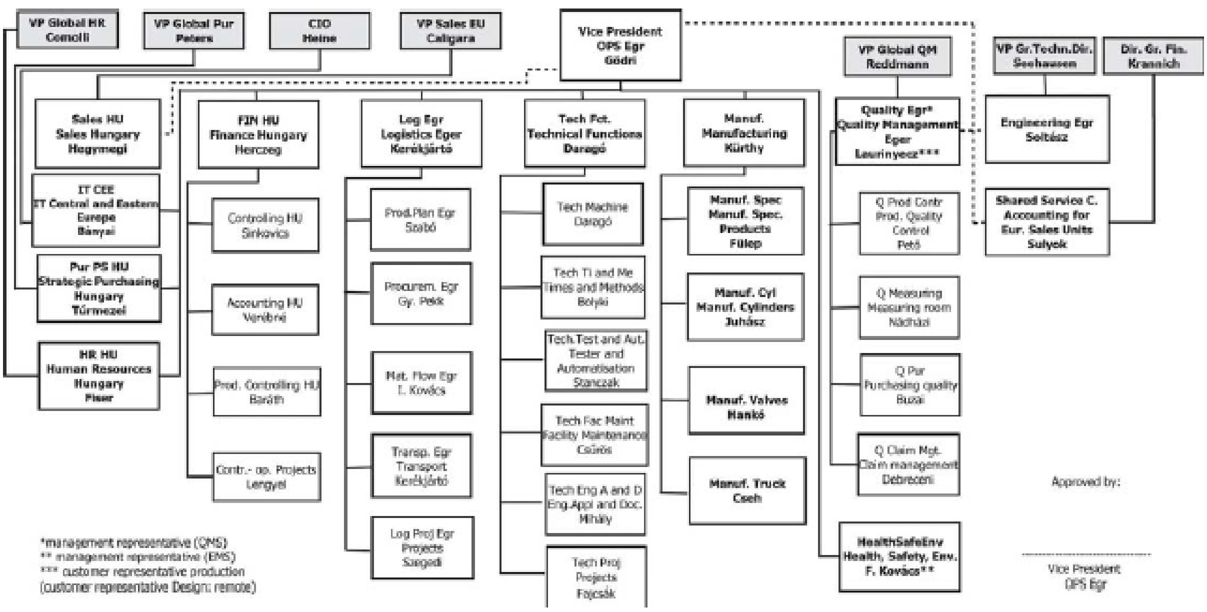
We maintain long term customer relationships.
Our technologies are our heart and soul.

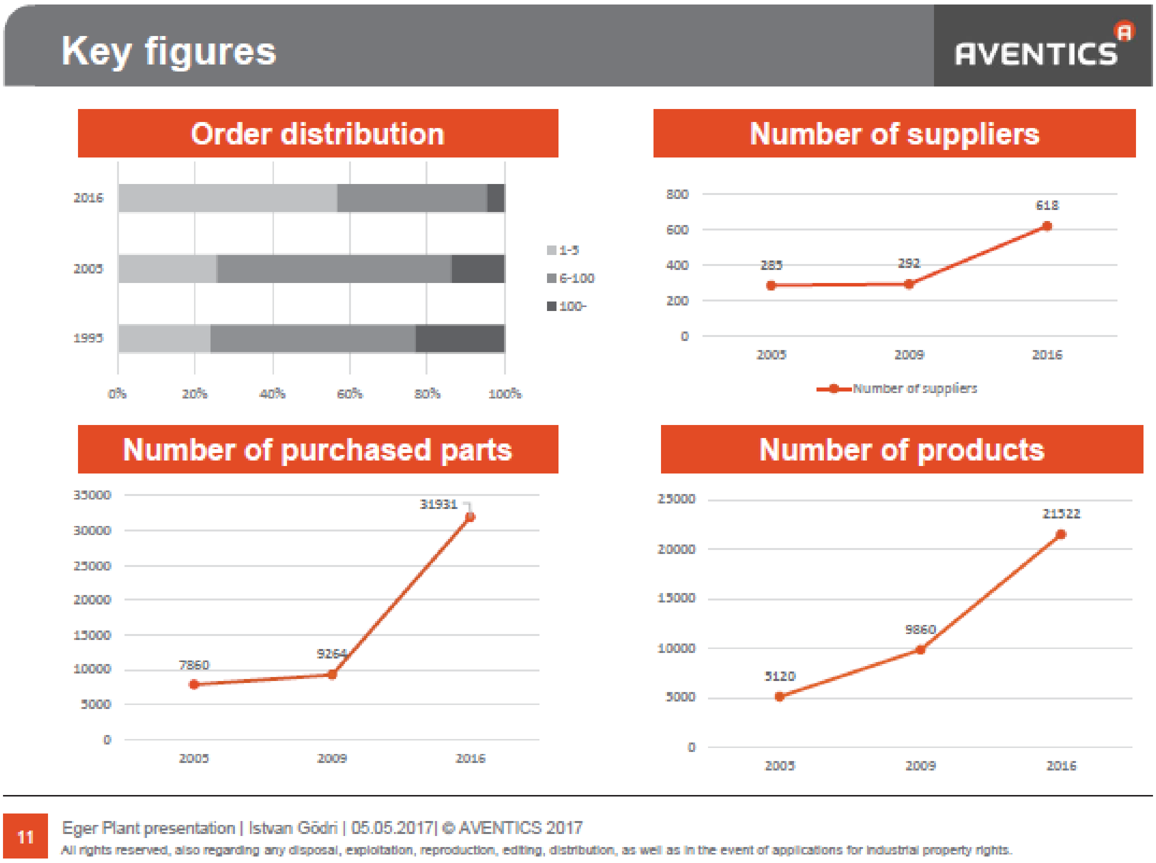
Agile

We respond quickly to customer queries.
With our products and by living up to our promises, we create measureable added value for our customers.

Eger Plant Organisational chart – 03.2017

AVENTICS




Key figures
AVENTICS
Order distribution
2016
2005
1995
0%
20%
40%
60%
80%
100%
1-5
6-100
100-
Number of suppliers
800
600
400
200
0
285
292
618
2005
2009
2016
Number of suppliers
Number of purchased parts
35000
30000
25000
20000
15000
10000
5000
0
7860
9264
31931
2005
2009
2016
Number of products
25000
20000
15000
10000
5000
0
5120
9860
21522
2005
2009
2016
11
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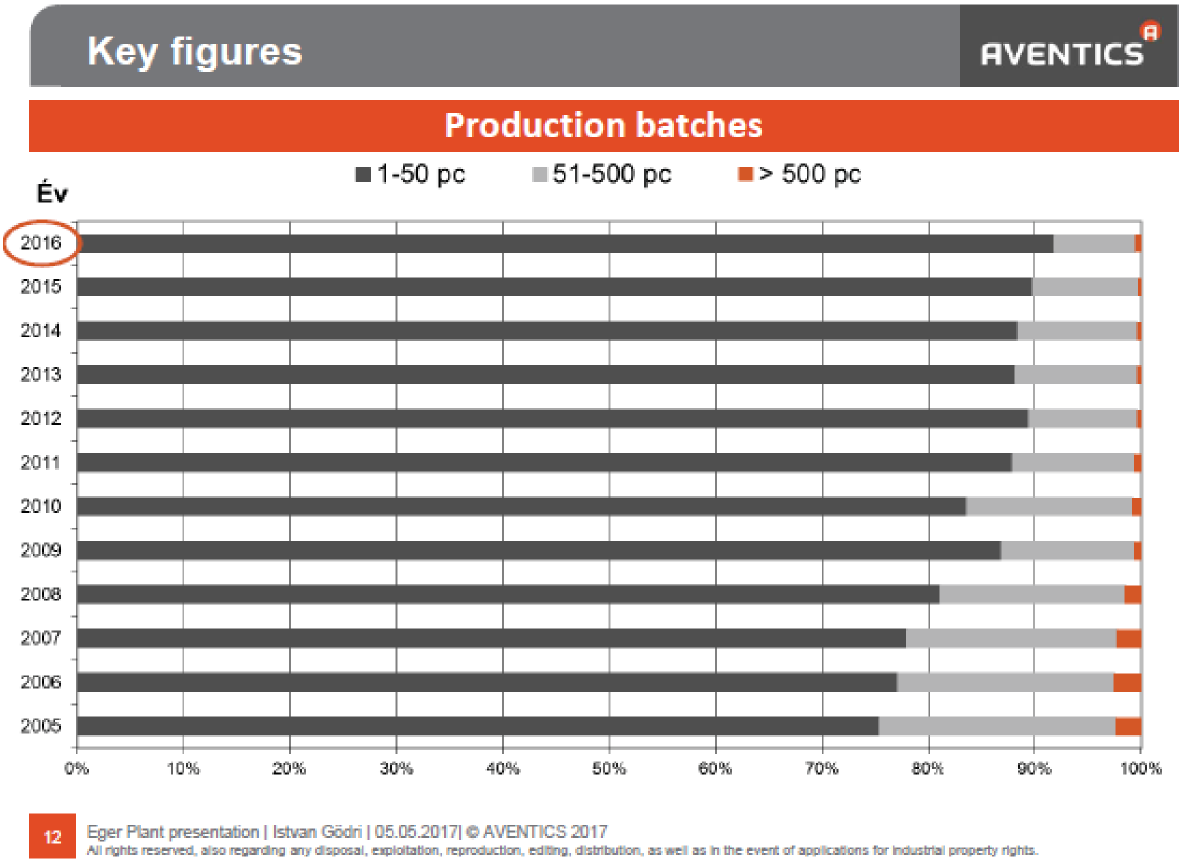
Key figures
AVENTICS
Production batches
Év
1-50 pc
51-500 pc
> 500 pc
2016
2015
2014
2013
2012
2011
2010
2009
2008
2007
2006
2005
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
12
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Products manufactured in Eger

AVENTICS

Machined products Marine parts	Cylinder machining and assembly	Valves machining and assembly	Automotive

Customers

AVENTICS

Strong and high quality customer base

Industrial pneumatics

DÜRR, KRONES, Sidel, MULTIVAC, Schlafhorst, salvagnini, Tetra Pak, HEIDELBERG, KBA, Renault, saurer, RIETER, TRÜTZSCHLER, HOMAG, dubal, kubal, GreCon, PSA, BOSCH, Motion Industries, VOITH, Womack

Truck

DAIMLER, SCANIA, MAN, VOITH, EATON, ZF, VOLVO, Mack, Renault Trucks, UD

Marine

HYUNDAI, ZF, stx, WÄRTSILÄ, GKN, MAN, DOOSAN, mtu, CATERPILLAR

Good and broad customer relations for decades – and growing!

Business field

AVENTICS

AVENTICS Pneumatics in Eger

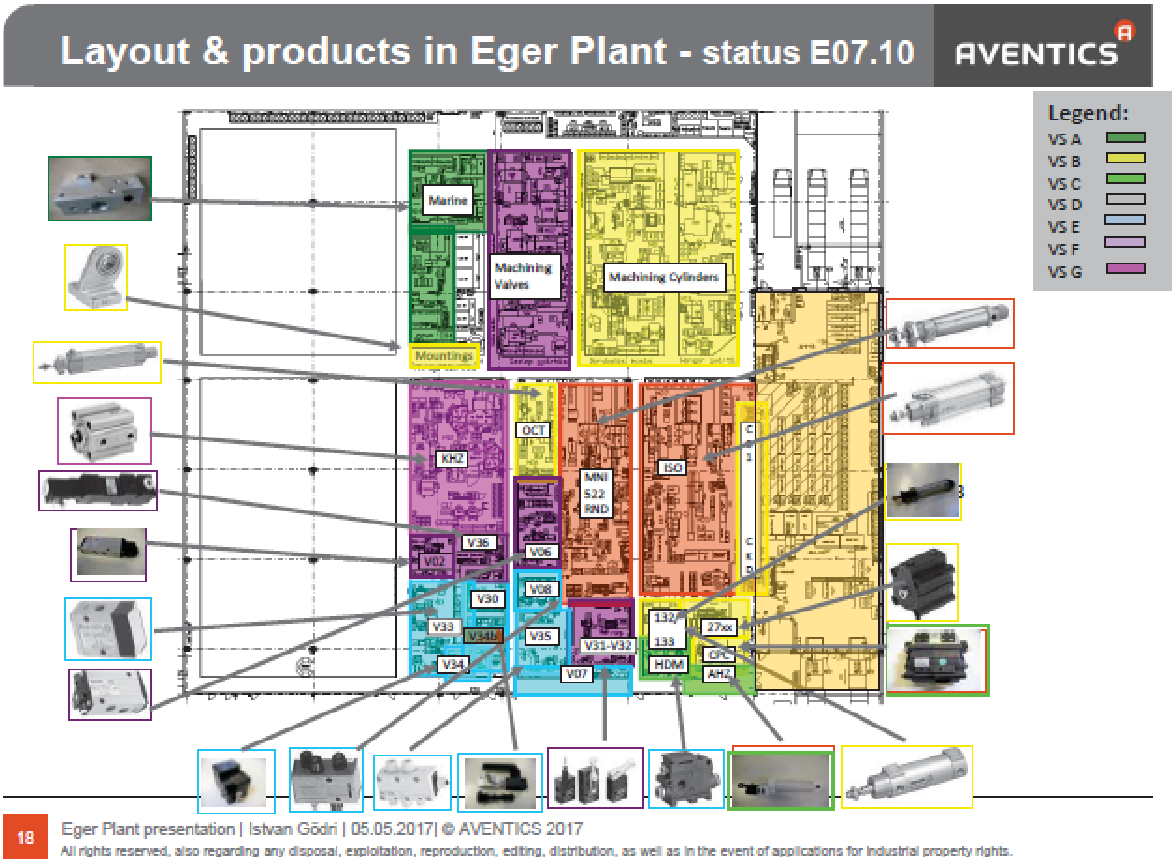
Our products are used in branches:

- General automation and engineering
- Print media industry
- Packaging industry
- Food industry
- Marine systems and controls
- Transport systems industry
- Metal production
- Textile Industry
- Automotive / truck industry

Plant transformation 2005-2016

AVENTICS

Business case: limited space and continuous need to increase the Value Add/m2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AVENTICS
Legend:
VS A
VS B
VS C
VS D
VS E
VS F
VS G
Marine
Machining Valves
Machining Cylinders
Mountings
OCT
KHZ
MNI
522
RND
ISO
V36
V02
V06
V30
V08
V33
V34b
V35
V34
V31-V32
V07
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HDM
CFC
AHZ
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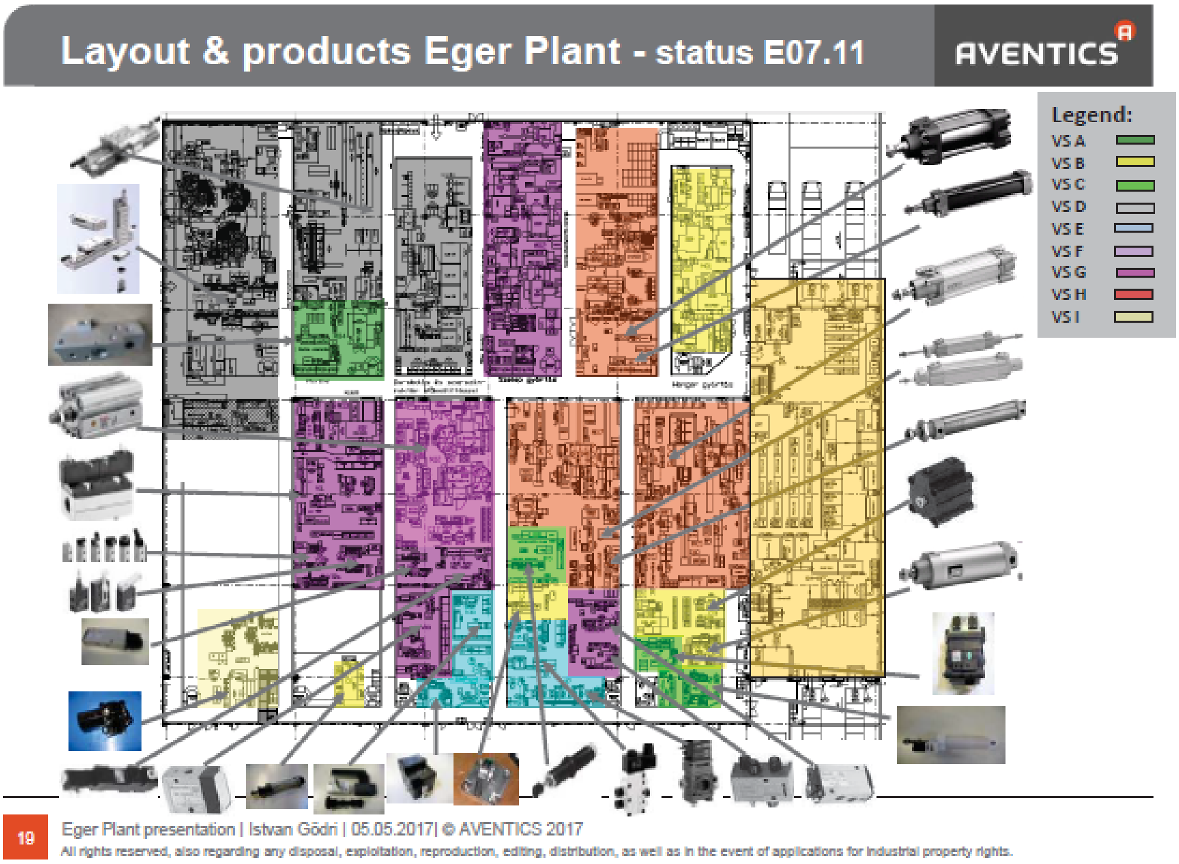
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AVENTICS
Legend:
VS A
VS B
VS C
VS D
VS E
VS F
VS G
VS H
VS I
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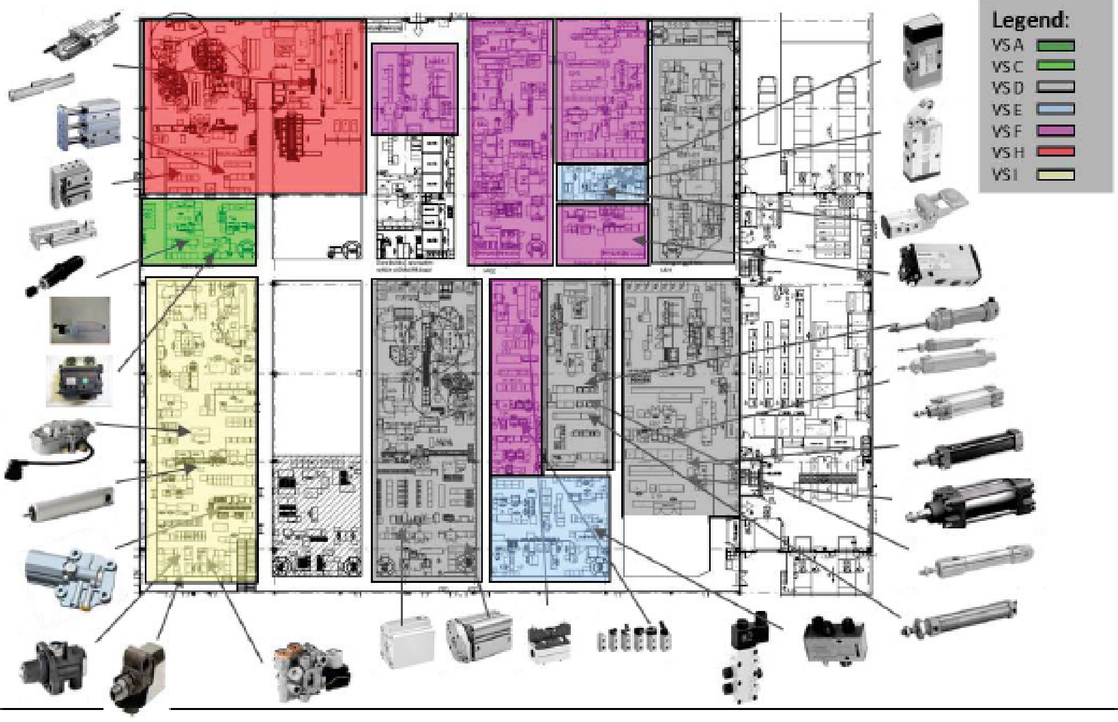

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Plant Concept – status 30.06.2017

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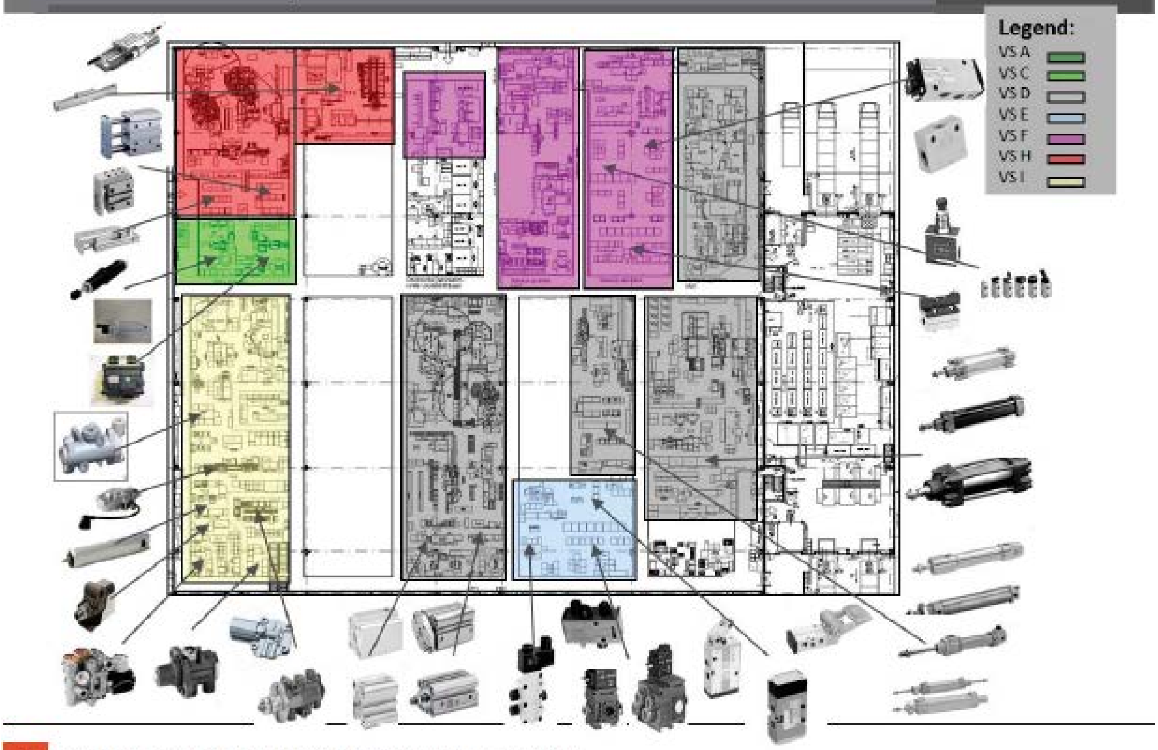

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CSR – Social projects
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Social projects:
▪ Local culture
▪ Simple assembly work for handycapped people, external job-shop for handycapped people
▪ Youth Sport: Kids International Football Cup
▪ Education: trainee opportunity, tool and equipment support, presentations, Pneumobil
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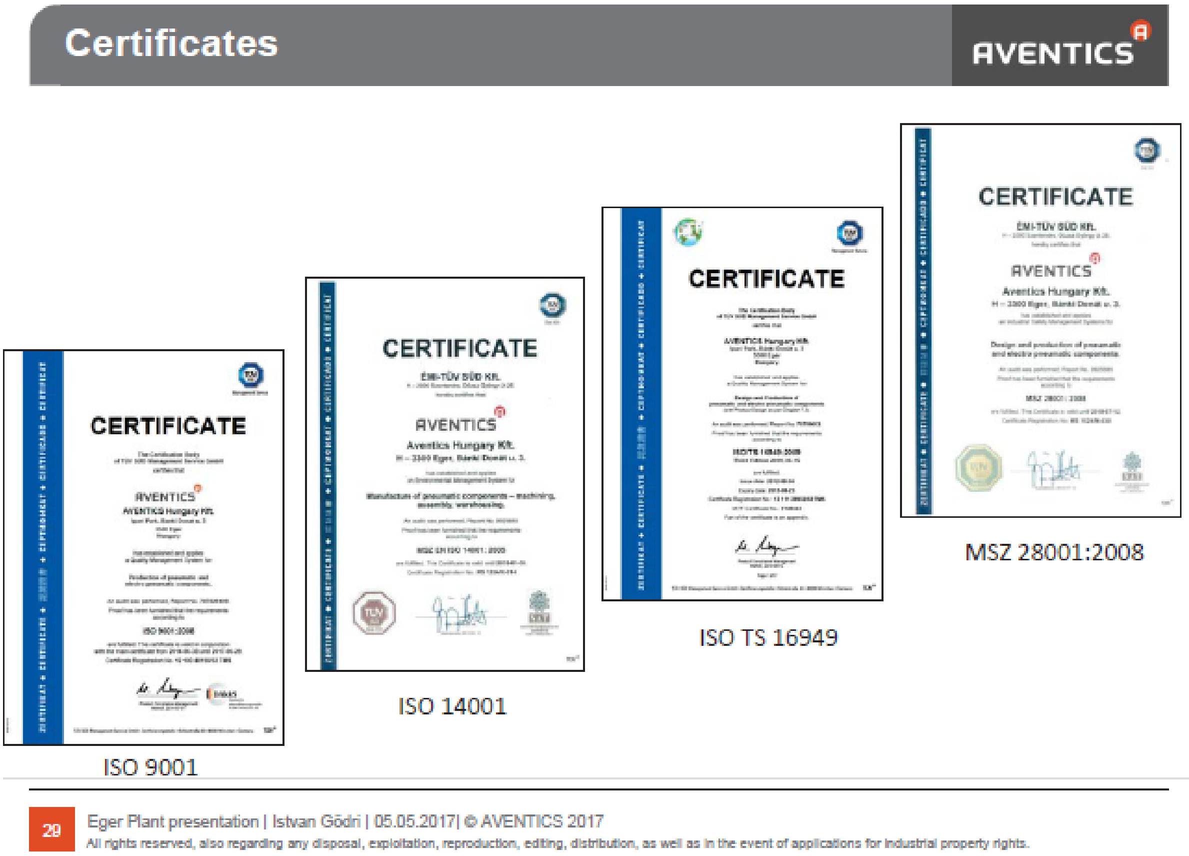
Eger Plant Vision
AVENTICS
Vision
▪ Leading benchmark manufacturing in pneumatics
▪ To be competitive and flexible to assure our growing opportunities
Mission
We want to assure long time competitiveness and market advantage to our customers, offering them products with small series on a large scale, at low cost but high quality
Cylinder
Valve
Marine
Truck
EGER PLANT – LEAD PLANT FOR CYLINDER MANUFACTURING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CERTIFICATE
ISO 9001
CERTIFICATE
ISO 14001
CERTIFICATE
ISO TS 16949
CERTIFICATE
MSZ 28001:2008
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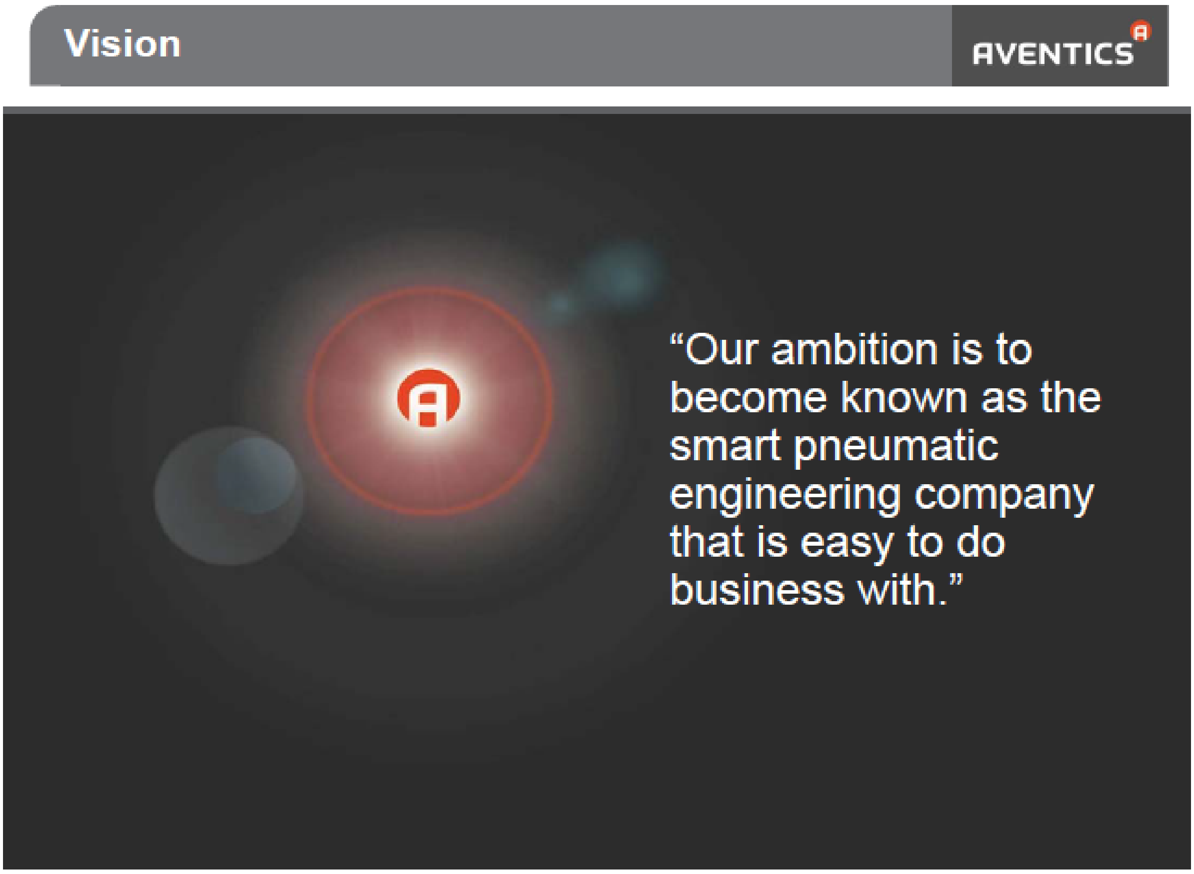
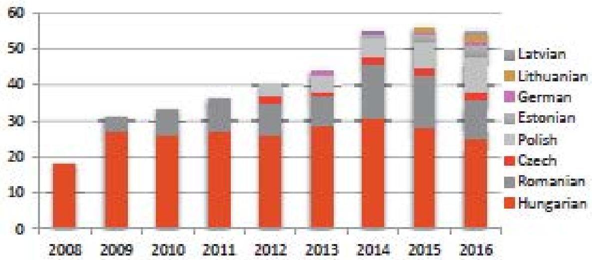

Vision
AVENTICS
"Our ambition is to become known as the smart pneumatic engineering company that is easy to do business with."

Pneumobile

Pneumobile history

Participant nations



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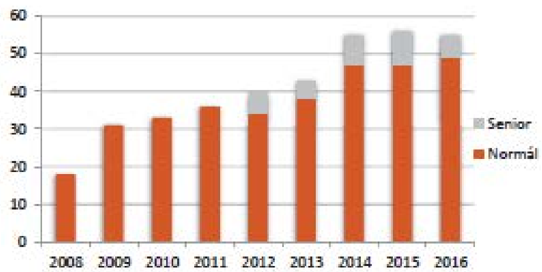
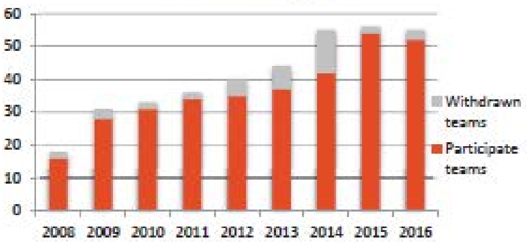


The number of participants and withdrawing teams



The number of participating universities (years)

Phisical results

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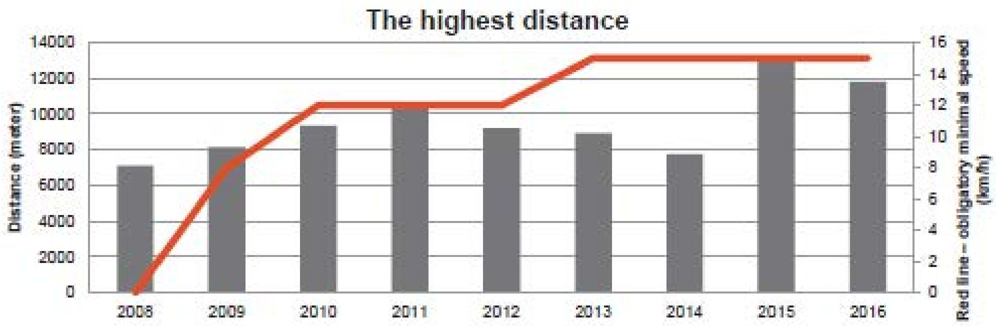

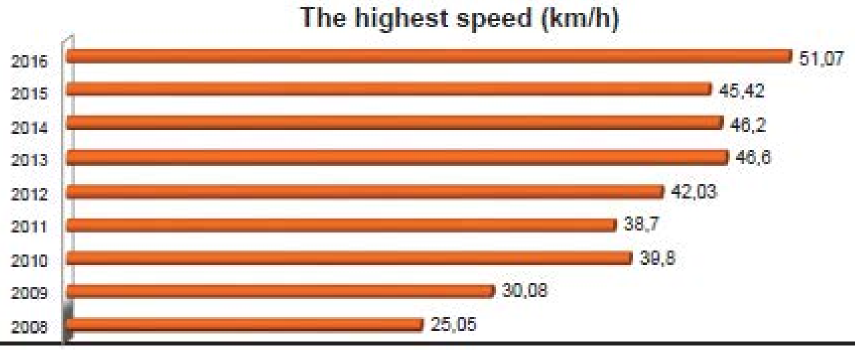

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Best pneumobiles

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Thank you for your attention!

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Compressed Air, as an Alternative Fuel

István Tibor TÓTH

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Abstract: The majority of people nowadays believe that the future belongs to electricity, in transport of course, to electric drive. Alternative drive even arises as CNG, LPG, biofuels or hydrogen. Only one car manufacturer engaged seriously with the idea of a hydro-pneumatic hybrid, but it is also suspended, because the calculated unit costs.

On the one hand, for now the e-cars can produce economic and not only economic losses, on the other hand, it has had in the history of technology when the internal combustion engine, the electric drive, the steam drive and the pneumatic drive were serious competitors.

In my article I try to give a taste of the history of pneumatic-powered vehicles since early 1800s to the 1930s and the 1970s to the present day. I would like to call your attention to some interesting parallels in the development of electric and pneumatic drive vehicles, also flashed some potential scenarios, their causes and possible outputs.

1. INTRODUCTION

Pretty trite statement, but the feeling is that history will repeat itself again today. The ongoing sales force more and newer products in the field of drive systems for vehicles as in any other field. Referring to the environment, not only looking for a more efficient system, but a so-called renewable energy sources, or green-energy drives can be developed as alternative to the classic internal combustion engine.

In the early days of the vehicle history it was a serious quest in the choice of fuels, rather, the choice of drive modes at all. Which system won in that competition, we know, the majority thinks he also know why won the internal combustion engine, but very few people know the history of the various drives. The diversity was surprisingly large for more than a century ago, and the air motor, or compressed-air engine, ergo the pneumatic drive system played a major role.

2. THE HISTORY OF VEHICLES WITH PNEUMATIC ENGINE, THE HEROIC PAST

First recognized as a solution can be mentioned the compressed-air vehicle was devised by Charles Carpenter Bompas, a patent for a locomotive in 1828 in England, but the first recorded compressed-air vehicle was built in 1838 in France. The car ran on test and worked well on the 9th July 1840, but the idea was dropped.

The Parsey compressed-air locomotive in 1847 had a reservoir A filled with compressed air, automatic reducing valve C, and a double-acting engine E (see Fig.1.) The locomotive was intended for coal-mine work.

Constructed by Baron von Rathen system in 1848 made at a speed of 16-19 km/h in about 8 km long route in London from Putney to Wandsworth. The American Railroad Journal said inter alia in 28. August 1847: “Of no other known power either can it be said with so much truth, that it is un limited in its souace, and free from everything like nuisance in its application.” [Railway Locomotives and Cars, 20. volume. Simmons-Boardman Publishing Corporation, 1846.]

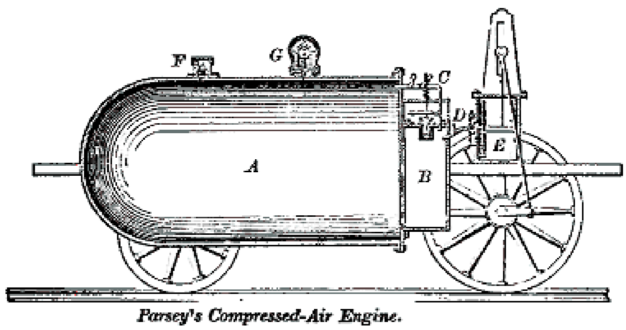

Fig. 1. The Parsey compressed-air locomotive of 1847 [http://www.aqpl43.dsl.pipex.com/MUSEUM/TRANSPORT/comprair/comprair.htm#fs

The idea of Andraud and Tessie of Motay from 1838 was revived by Louis Mékarski, who built a narrow gauge motor truck for testing and in result of the successful test built a standard gauge tramcar as “an ideal transport method, quiet, smooth, no smoke, fire or fumes”. This car was similar in design to the single deck horse cars with 3,45 m long body, for 20 passengers inside and 14 passengers outside as shown in Fig. 2.

The first produced in series air powered vehicles were actually trains. The Mékarski air engine, the Robert Hardie air engine and the Hoadley-Knight pneumatic system were used already in the end of 1800’s to power locomotives. [http://www.automostory.com/first-air-car.htm]

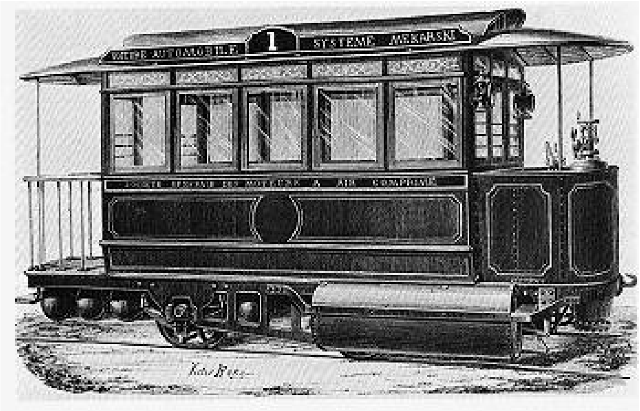

Fig.2. The Mékarski tram. From a sketch by Victor Rose (1875).

The Mekarski Compressed Air Locomotive produced the Mekarski air engines from 1886 to 1900. These engines used for street transit in many cities in several countries around the world. In France in Nantes 1897-1914, Aix-les-Bains 1897-1913, La Rochelle 1898-1929, St. Quentin 1898-1908, Vichy 1895-1927, Marseille 1891-1896, Lyon 1887, Paris 1887-1900-1914. In England in London 1880, 1882-1884. In Switzerland, Bern 1889-1901. In USA in Toledo only test in 1880.

In the Great Britain instead the Mékerski vehicles used real British improvements as Scott-Moncrieff Car, Wantage, Beaumont loco in London, Liverpool, Chester, Birmingham for longer or shorter periods between 1875-1920.

The US market was characterized by several manufacturers compete as the British. Of course, also appeared in the Mékarski, but larger role got the Popp-Conti, W. Scott-Moncrieff and the interior Hardie air-motor or street-car system, Hoadly-Knight cars, Compressed Air Power Company, J.G. Brill Company of Philadelphia, Standard Fireless Engine Company.
The enhanced Compressed Air Locomotive Hardie in New York City travelled between 1892-1900 already with regenerative braking system.

Fig. 3. Porter air motor No.27 at Homestake Gold Mine. Photographer: Mike Decker

Between 1896-1930 hundreds H.K. Pittsburgh Compound Porter Air Locomotive made for use in explosive mines (Fig. 3.).

Between 1923-1930 in Europe, the French, German and Belgian mines had had three-stage European Three-Stage Air Locomotive units were towing.

In 1930, the last developments in the German Diesel-Pneumatic Hybrid Locomotive said about a 1,200 horsepower diesel and compressed-air powered hybrid locomotive V3201 (Fig. 4.). The diesel engine driven compressor supplied the necessary air to the pneumatic drive system and the heat loss of the diesel engine was used to reach 26% efficiency improvement.

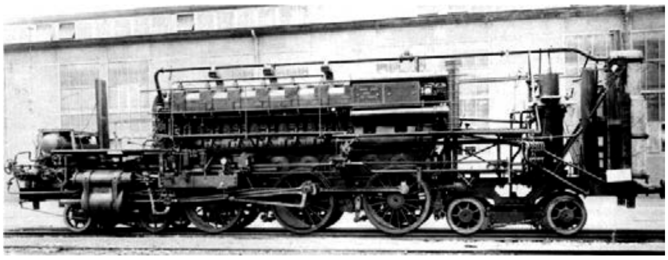

Fig. 4. The internals of the V3201 [http://www.aqpl43.dsl.pipex.com/MUSEUM/LOCOLOCO/diesair/diesair.htm]

Nearly half a century meant the air-powered locomotive possible serious direction in the transport sector. In everyday life it was commercially available the air motor, which used in the metropolitan transport and in the mines as well. Until the 1820s designed pneumatic railway lines where the air supply pipeline laid along the track have been secured through, the low oil price in the 1930s and the improved internal combustion engines they came into the background together with the electric drive.

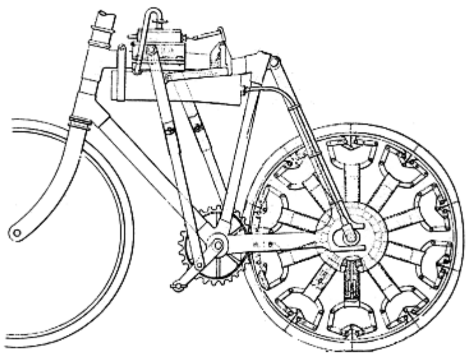

Fig. 5. Compressed-air energy-storage bicycle [http://www.aqpl43.dsl.pipex.com/MUSEUM/TRANSPORT/oddbike/oddbike.htm]

In addition to the primary direction were more interesting ideas. Like the compressed-air energy storage bicycle from 1902 (Fig. 5.), a kind of hybrid. The primer drive by pedal got help from a compressed-air motor. The ten-cylinder compressor built into the rear wheel pumped up the reservoir under the top tube.

In 1926 Lee Barton Williams from Pittsburg claimed a car started on gasoline and after 10 mph it switched to compressed air only.

In 1934 Bob Neal in Arkansas and the same time the Netherlands native Johannes Wardenier claimed to have invented the first air car.

If we believe in the contemporary newspaper article, it was really competitive in the air motor: "A side view of the compressed air car, showing the four fuel tanks which will drive the car 500 miles at a speed of 35 miles an hour. The engine requires no cooling system, no ignition system, no carburator, nor the hundreds of moving parts included in a standard gasoline motor." (Fig. 6.)

A side view of the compressed air car, showing the four fuel tanks which will drive the car 500 miles at a speed of 35 miles an hour. The engine requires no cooling system, no ignition system, no carburetor, nor the hundreds of moving parts included in a standard gasoline motor.

EITHER the era of "free air" is about to come to an end, or the cost of motoring is about to be reduced to practically nothing. In an amazing demonstration conducted recently in Los Angeles a standard automobile chassis, powered with a newly-developed compressed air motor, whizzed around the city streets at not one cent of cost to the driver for fuel.

Fig. 6. Compressed air car from Los Angeles [www.automostory.com]

2. IS THE PAST WILL BE REPEATED?

We could tell that there is nothing new under the sun, or history repeats itself. After 40-50 years again started the search, or the investigation for the best fuel, for the best drive system, and of course once again shows up the compressed-air engine both independently and like hybrid solution.

A modern version of the 1820 version appeared in Brazil. In 1980s invented by Oskar H.W. Coester, and developed by Aeromovel Global Corp. the continuously supplied air driving technology. The reinterpretation of the engine gave a new particular solution (Fig. 7.).

The Jakarta case has a 3135 m long simple loop line served by 3 vehicles, 288 passengers each. The maximum speed is 70 km/h and the average energy consumption is the today's most fuel efficient electric vehicles of a similar level, 2,93 kWh/vehicle-km according to the company's website. [www.aeromovel.com.br]

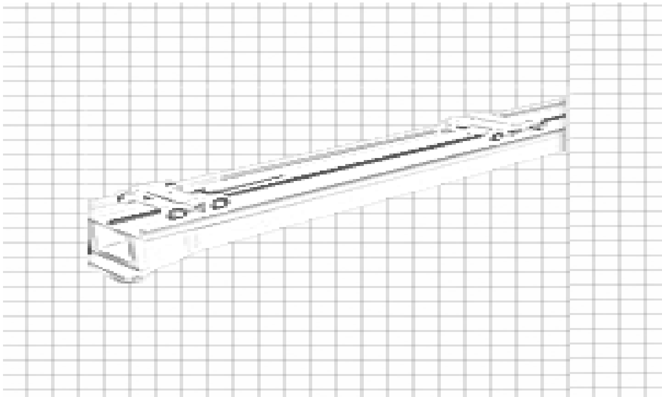

Fig. 7. The principle of "Aeromovel drive"

The father of the Modern Air Car Movement is Terry Miller. He planned to design a spring powered car and understood, that compressed air can be much better energy storage, without corrosion, break or wear out. His Air Car One he built for 1500 dollars and patented. (Fig. 8.) Terry Miller published the complete details on how to make his engine.

Fig. 8. Terry Miller's Air Car One. [pinterest.hu]

Many others have experimented, designed and created vehicles with pneumatic drive. For example Professor Armando Regusci Campomar also built Compressed air motorcycle shown in Fig. 9.

Fig. 9. Armando Regusci 1998. [www.regusciair.com]

These low-budget vehicles are very remind us on our Pneumobils, or maybe the Pneumobils in recent years looks more industrial and user-friendly.

Guy Negre, the French developer patented in several countries air-powered engine, a whole small fleet of vehicles based on what developed, Fig. 10.

Fig. 10. The fleet of Guy Negre [www.mdi.lu] 2009.

MDI had an AirPod tricycle approved in 2010 and then its work with the European authorities resulted in the fact that all new automotive standards will mention compressed air. MDI had ambitious plans to updated expand the fleet where appeared on the cars in addition pneumatic bicycles, boats and forklifts too.

Fig. 11. MDI products [www.mdi.lu] 2014.

C.J. Marquand has also developed a pneumatic engine, which he planned to build in a vehicle combined with recuperation.

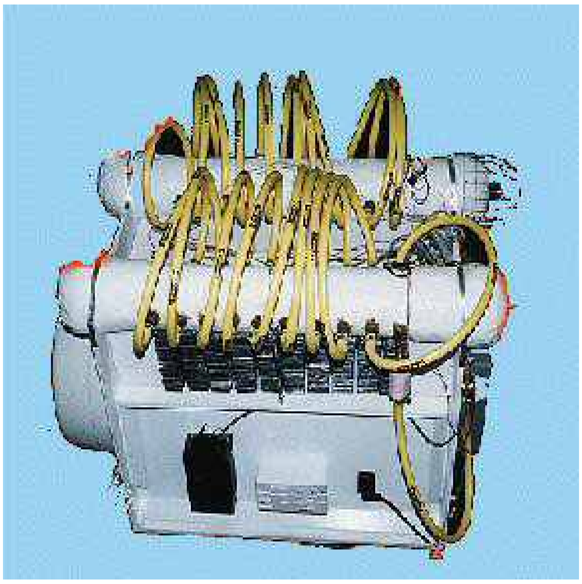

Fig. 12. C.J. Marquand air engine. [hu.pinterest.com]

Lino Guzella, Professor of Thermotronics, and his group developed a pneumatic hybrid drive. It has to be simpler and cheaper construction than the electric hybrid. Initial tests in the ETH Zurich Machinery Laboratory corresponds to a fuel saving of one third in 2009. Scheduled to be 25-50% more efficient, but only 20% more expensive than gasoline engine, and only half of the electric hybrid cost would be. The new engine concept was interesting for major motor companies. And entered the financial crisis together with the global recession.

The only company has made efforts, spend money on air hybrid concept, the French PSA.

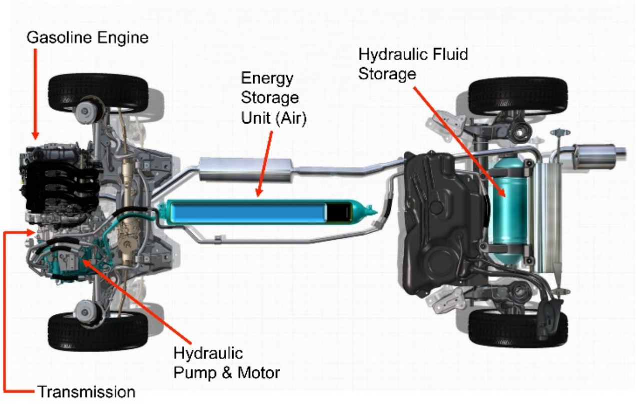

Fig. 13. The PSA Hybrid Air. 2013. [carknack.net/wordpress]

According to the PSA, the hydro-pneumatic-mechanical power transmission system is cost-effective, reliable and service-friendly, does not require special infrastructure to build, it can be used anywhere in the world, if only because – in contrast to batteries – is not sensitive to extreme temperature conditions. At the same time Gilles Le Borgne, Director of Development of PSA in an interview claimed that the production of Hybrid Air would only be economical if they could sell annually to 500 thousand cars because of a number parts – hydraulic motor, special transmission, 300 bar pressure gas tank – containing, what is lacking in other cars.

3. CONCLUSIONS

In the end of the 19th and beginning of the 20th centuries the electric, steam, air and combustion drive competitively developed. The very first car moved by steam, the city public transport changed horses first on compressed air drive, speed of 100 km/h crossed first electric car, series production gasoline car made for the first time.

Rightly we might think that the natural selection is completed, but not yet and probably never will be finished, which is the normal result of the development of technology and of the human factor.

After the 1930s practically disappeared in vehicles the steam and the air drive, the electric drive logically limited to some special user areas, such the public transport with catenary, as trams, trolleybuses, trains, and vehicles where battery weight was useful and the range was not a primary requirement, as forklifts and other power machines. The internal combustion engine (ICE) has become not only fashionable, but economical, liveable and sustainable. Through its dominant industrial and service sector, the ICE has become a basic element of the world economy. Developments, researches had always carried out, attempts have been made, but it did not seem serious chance to change until the end of the last century.

Maybe some new economic operator, a new business concept revived the demand of electric and other alternative drive systems. Now it seems to be winning electric drive with batteries, but more than incomprehensible to me, why spend companies billions on admittedly unprofitable production of e-cars, when the PSA did not started the seemingly competitor and ready to manufacture Hybrid Air cars.

I think the changes will be even more serious, just a matter of time. It is pity that while many solutions should be taken away, not necessarily because of technical or general economic reasons.

Go for it, continue the Pneumobil development!

REFERENCES

Railway Locomotives and Cars, 20. volume. Simmons-Boardman Publishing Corporation, 1846. https://books.google.hu/books?id=CFAjAQAAMAAJ&pg=PA552&lpg=PA552&dq=baron+von+rathen+system&source=bl&ots=QxIlYsLuGz&sig=R15olUZCZsw-bxLg2pNGmiZYRrk&hl=hu&sa=X&ved=0ahUKEwjosabOmdPSAhXCkSwKHWXlAzIQ6AEIGDAA#v=onepage&q=baron%20von%20rathen%20system&f=false (10.03.2017.)

http://www.aqpl43.dsl.pipex.com/MUSEUM/TRANSPORT/comprair/comprair.htm#fs (10.03.2017.)

http://www.automostory.com/first-air-car.htm (10.03.2017.)

RailroadPix.Com Railroad Photos - Homstk27.jpg http://www.railroadpix.com/rrphotos/detail/538.html (10.03.2017.)

http://www.aqpl43.dsl.pipex.com/MUSEUM/LOCOLOCO/diesair/diesair.htm (10.03.2017.)

http://www.aqpl43.dsl.pipex.com/MUSEUM/TRANSPORT/oddbike/oddbike.htm (10.03.2017.)

http://www.automostory.com/images/first-air-car.jpg (10.03.2017)

http://www.aeromovel.com.br/en/projeto/jakarta/ (10.03.2017.)

https://www.google.hu/search?q=terry+miller+air+car+plans&tbm=isch&tbo=u&source=univ&sa=X&ved=0ahUKEwjxntO2ndTSAhWCBSwKHWTPD8oQsAQIFw&biw=855&bih=669&dpr=0.8#imgrc=LRw8gHsbOXhS_M:

http://www.regusciair.com/photos (10.03.2017.)

Studying through the Pneumobile competition

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Abstract: Since the first Pneumobile competition a lot of Pneumobile vehicles have been built at the University of Miskolc. During the planning phase, every new team has had similar problems. They cannot estimate how much work is needed to design and build a new car. Usually they don't understand exactly some tasks of the rules of competition, they don't know where to start the work, and they always have time management problems. Besides, team members have to also concentrate on teir study and usually they have too little engineering knowledge. A conceptual design of the Pneumobile vehicle can be helpful to avoid these problems. A conceptual design contains every possible solution of subpart of the vehicle (e.g. suspension, steering drive unit etc.) and the methodical process of the planning. The solutions can come from literatures or from the blueprints of former teams.

1. INTRODUCTION

On Pneumobile competition every year at least one team take part from the University of Miskolc. From 2008 to 2010 I was one of the team members, since 2011 as supporting professor I am helping the preparation of the teams. This competition is a great opportunity for the students to learn and play in the same time. From the perspective of the university it is a perfect project-based learning opportunity, where the students have chance not only develop a “virtual project” but also build it.

In this year I started to work with a new Pneumobile team, which is include 4 students, how studying on the University just one year ago (they started the third semester in September). With that new team I realised the development of a Pneumobile can be very difficult for students. For reduce they job it need to simplify. In this paper I would like to collect most of the difficulties which need to solve by the team members, then I would like to collect the possible solutions of them. With a conceptual design of the Pneumobile vehicle could avoid most of the problems.

2. DIFFICULTIES OF THE TEAMS

In the following the possible difficulties are introduced, which appear by every teams.

2.1 Before start of the development

In the beginning of the preparation the students need to create a team, so need to find 4 students how would and can work on this project. Usually the most of the students don't want to do anything, they just want to “survive” the semesters. If at least 4 students have been founded it hard to know exactly how they able to work. Today the perfect grades not enough to will be a good engineer, they need to do something besides the study. The Pneumobile competition is a greate opportunity for that.

2.2 Design and documentation phase

In general the teams has many difficulties with the documentation. The new teams don't know exactly how to make a report or a documentation. In the table 1 shows the results of the documentation of the teams. The possible maximum point of the documentation is 100. If there is any insufficiency the point is decease.

Table 1. The results of the teams

Name of the team	First time participate	Second time participate
Puffogók	84	95
MEkkmestAIR	98	98
Dairp	68	90
Airmeks	45	85
RockAIR	51	-

As you can see, every team can reach higher point in the second year. It is understandable because they have some experiences in the reports. There are some KO criteria in the rules of the competiton. If the KO-s are not fulfilled, the team is not allowed to participate on the competition. In the first year just the team MEkkmestAIR made the documentation without KO criteria, every other team had some deficiencies. More important every team hadn't have any KO criteria from the second time of participating on the competition. The team RockAIR participate first time on the competition, therefore they made only one documentation.

This big difference between the first and second documentation came from different direction. Usually the new teams have difficulties to clearly understand all the rules of the competition. Mostly they understand the core of the rules, but don't know exactly the details.

The planning of the vehicle causes other difficulties. The new team usually don't know where start working on the project, and don't know how to divide the tasks among themselves.

Often they concentrate on a relatively little segment of the vehicle, and forget to work on the other segments (e.g. they concentrate the perfect cylinders of the driver engine, but forget to plan the frame the suspension and the steering).

Fig. 1. The first plan of the team Dairp (2012)

In general, the first year the teams can plan just a not completed Pneumobile, which is barely enough to introduce the vehicle to the jury. The Fig. 1 shows a plan of a vehicle from the first documentation of the Dairp team. On the Fig. 2 shown a one year later version of the same vehicle. As you can see one year experience is enough to design a very detailed vehicle. Usually after one year "suffering" with a rough design is enough to learn who easier to work with a complete plan than improvising with a semi-finished draft. Usually after one year the team members want to design detailly every part of the vehicle from the frame to the last screw even if it is not necessary for the jury.

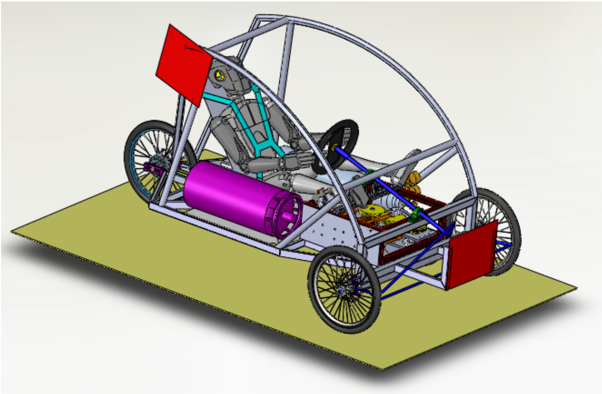

Fig. 2. The second plan of the team Dairp (2013)

2.3 The construction phase

In every year the teams must send the documentation to the jury until 31. December. Because January is the exam period at the Hungarian Universities the team members are focusing only on the studying. The construction of the Pneumobiles usually start around mid-February.

Though the pneumatic components are supported by the Aventics company, the teams need to find other sources for the other elements. The price of the other components is around 300.000 Hungarian Forint (~1000 Euro). The sources can be the University or companies, so the teams need to contact with the possible sponsors, but the new and young team members have many trouble with that. The students usually don't have any relationship with the industrial partners and they don't know the technical stores. Usually they don't have any information about the prices of the parts and raw materials.

If the team has not enough sponsors and money, they need to find some cheap solutions, so they are using what they find. One opportunity can be to recycling the elements from the older teams. In 2016 the team Airmeks gave an extreme example for the reusing when their biggest sponsor is retracted. About 80% for their vehicle build from the parts of the older Pneumobile teams.

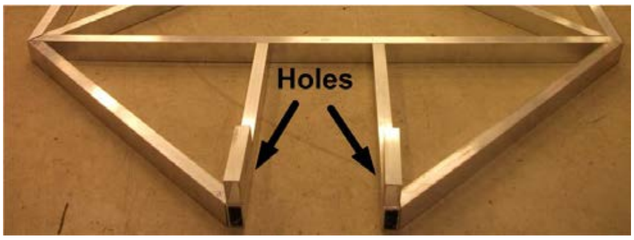

Fig. 3. Possible problems with holes

Every team in the construction phase find themselves in some unexpected situations, and the new teams usually have less experience to solve it. One of the common problem shown on the Fig 3. The building of the car is started with frame, which need to weld from profiles. After the frame is finished, the other part need to fix on that with screws. On the Fig 3. the arrows show the demanded positions of the holes for the screws, but from the frame don't have enough place for the drilling machine, so it need to cut out a little part of the frame.

The participants always must learn the time management. Often the work is started too late and the students cannot estimate the required time. They think it need just some days to construct the whole machine, but it costs 4-5 times more than they think. Due the previous reasons the new cars usually are finished in the last moment. Therefore they don't have time to test the vehicle.

2.4 The competition

Because the Pneumobile are not tested on the competition could be some troubles. These difficulties should solve immediately even if one of the function of the vehicle is damaging or disappear. A typical problem are shown in the fig. 4.

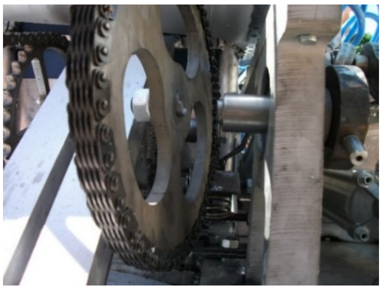

Fig 4. A broken shaft

3. THE POSSIBLE SOLUTIONS

As you can see in the previously chapter the most of the problems are coming from the planning phase. In every development project the designers use some kind of methodology. The intuitive design process (Fig. 5) is the mostly used by students. The intuition depends on personal experiences and knowledge which are limited for the students. Besides the right idea comes rarely in the right time, and the first idea of the designer has great influence to the task. These disadvantages are increasing if the deadline is approaching.

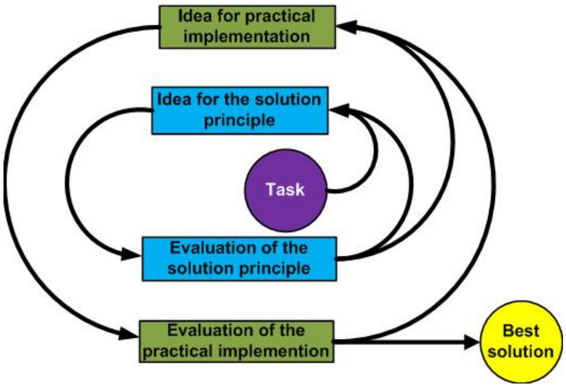

Fig 5. Intuitive design process

The intuition are presented in every development process but with conceptual design it could have limited influence. To help the further student projects need to develop a conceptual design, which is specified for the Pneumobile vehicles.

3.1 The conceptual design of Pneumobiles

For the conceptual design the guideline VDI 2222 could be a great starting point, but it need to purrify for the Pneumobile projects. The Task is clearly known from the competition rules, but the design specification need to determine. The specifications on the form of requirement list is shown the Table. 2. The list is based on the rules of X. Pneumobile Competition (2017). In the future, maybe some updating is needed if the rules are changing. The requirement list on the Table 2 is mostly just an extract of the rules, but it can be use like a reminder when the students develop their Pneumobile.

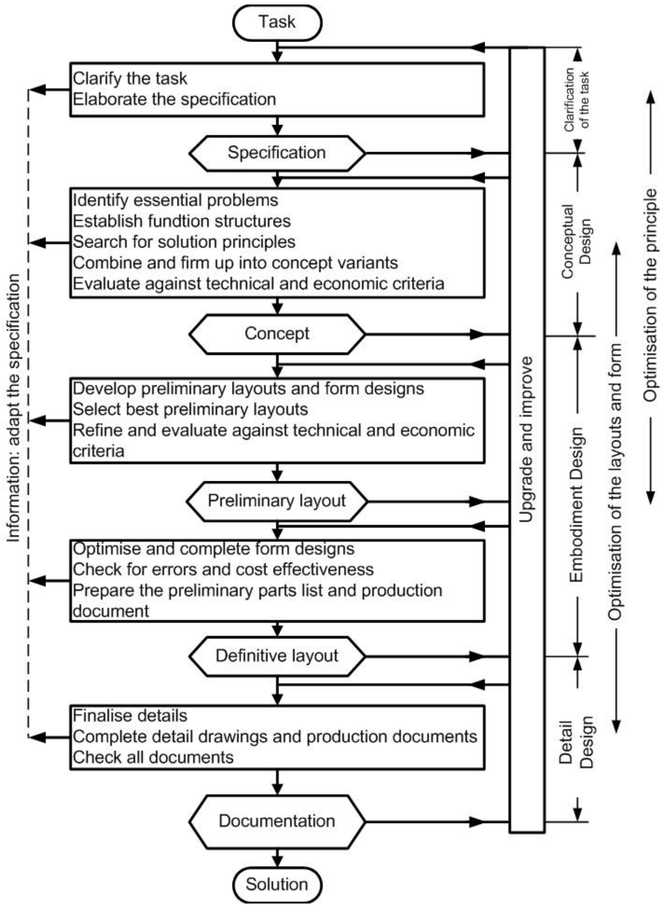

Fig. 6. Guideline VDI 2222

For finding all solution principles can be used the sources, which came from the blueprints of former teams and from other literature. Today the literature not limited on books and articles, on the social media (e.g. video sharing sites) also a great opportunity to find some solution which are useable for the Pneumobiles as well. On example shown on the fig. 7.

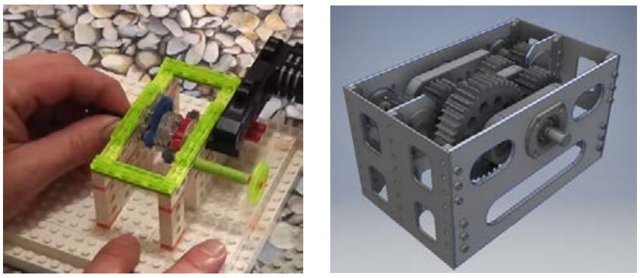

Fig. 7. The general idea of the driver unit from the social media

In order to the principles in the future will be usable every possible solution has to cataloguize for the further Pneumobile projects. The catalogues can be compiled based on works of Karlheinz Roth.

Table 2. Requirement list

Geometry	2500 mm length, 1700 mm width, the height is 90% of the width, min. 3 wheel; only „car type”
Clothing	Helmet, closed shoes, long sleeve cloth
Air supply	safety circuit is given air supply is given but optional Puffer: no plastic, max. 60 liter, qualified
Energy	10 litre, 200 bar bottle (Ø 140x900 or 1300 mm)
Materials	**frame**: only metal; **steering**: no plastic; **suspension**: no plastic
Engine	max. 4 cylinder, max. Ø 100 mm and standard stroke inside the vehicle
Protection	Roll cage (min. 6 point, Ø 35x 2 tube of aluminium, 5 cm higher than the helmet) min. 3 point fixed belt bottle fixing inside the frame
Control system	**Pneumatic** circuit with DC scheme editor **electric**: max. 48 V DC; self-designed microcontroller or PLC
Drive chain	direct or geared NO electric or hybrid contain free-wheel or clutch
Suspension	wheel: min. 16” (front max. 26” with 28 spokes and double-wall rim) NO plastic
Steering	NO plastic max. 10-degree play turn around on 8 m wide speedway
Breaks	every wheel should be equipped 2 independent cycles parking brake needed
Production	In our workshop: turning, milling, drilling and welding machine
Assembly	manual assembly at the university
Costs	Sponsors needed for: frame and shafts, bicycle parts, bolts, bearings
Deadlines	**Documentation**: 31.12.2016 **Exam**: 02.04.2017 **Prove of the operability**: 23.04.2017 **Competition**: 04-05.05.2017

3.2 Specialize for Pneumobiles

The Pneumobile projects had have unconventional demands. The task and the specification is well known at the start of the development.

Because the core of the main parts of the vehicle are well known, don’t need as many layout as the guideline VDI 2222 suggest. The simplified development process for Pneumoblie vehicle shown on the Fig. 8.

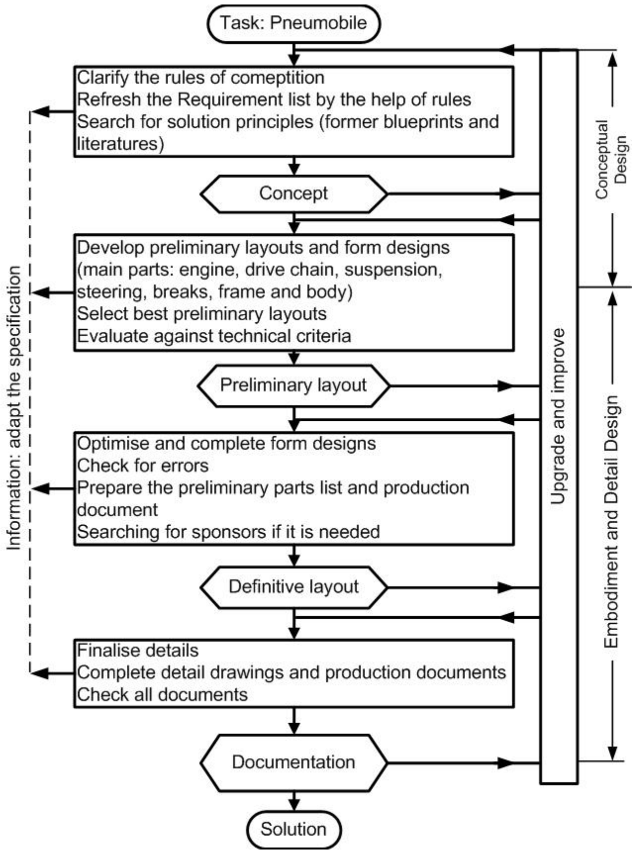

Fig. 8. Specialized process for Pneumobiles

4. CONCLUSION

Although the Pneumobile competition is a great opportunity to develop the knowledge of the students, it also contains many difficulties. These difficulties are increasing when the students are younger and if it is their first Pneumobile project. Though a conceptual design not always lead to a better solution, but it can be used like a guideline for development of the vehicle.

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REFERENCES

Bihari, J. (1012) Pneumobile competition and education. In: *Advenced Engineer*, (2), pp. 125-134

Roth, K. (2000). *Konstruieren mit Konstruktionskatalogen, 3. Auflage*, Springer, Berlin.

VDI-Richtlinie 2221. (1993). Methodik zum Entwickeln und Konstruieren technischer Systeme und Produkte. *VDI-Verlag*, Düsseldorf, 1993

www.pneumobil.hu

Evolution of the Pneumobiles from Szeged

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Abstract: The University of Szeged Faculty of Engineering takes part in the International Pneumobile Competition since 2009. Our race teams achieved a lot of nice success, year by year we made faster and faster racing cars, meanwhile, we collected a lot of experience. In this article, I briefly summarize the main steps of the evolution of our cars.

Last year one of the main fields of our development was the front running gear. Until 2015 we use rigid running gears but the increasing speed made necessary to design a sprung one. This was a new challenge for us. In 2016 the new front running gear worked well but we designed some changes. In this article, I present the 2017 version of the front running gear of the Airrari racing car.

1. 2009-2010: FRAME DEFORMATIONS AND SKIPPING CHAINS

The University of Szeged Faculty of Engineering joined to the pneumobile competition in 2009. This is not an automotive faculty, but we have researches in the related sites, for example (Farkas, Molnár, 2016). We achieved really good results during the years.

In 2009 we made two racing cars, with each car our primary goal was the good result in the long distance competition. The teams: P-Mobil: Péter Kószó, Tamás Szabó, Norbert Szebellédi, Adrián Szőnyi, supporting teacher: Dr. István Tibor Tóth. Szegedi O_2: István Juhász, Khaddam Souleiman, Zsolt Pocsai, Mária Talpai, supporting teacher: István Péter Szabó.

Fig. 1. Szegedi O_2, 2009

The two teams had a budget at about 400.000 HUF. One of the cars had 50 mm cylinder diameter and the other had 80 mm.

The main valves were CD07 5/2 with 12 mm diameter tubes. With the performance of these pneumatic systems we could use bicycle parts throughout the complete drive chain.

In 2010 we participated in the competition with the same cars. The teams: EMKÁ: Tibor Barát, Oszkár Bíró, Balázs Muladi, Norbert Temesvári, supporting teacher: Péter Szabó István. EMTIK: Sándor Csikós, András Csúcs, István Mayer, István Szeles, supporting teacher: Dr. István Tibor Tóth.

For the increasing of the performance we changed the cylinder diameter from 80 to 100 mm and increased the flow capacity of the pneumatic system, too. The increased performance caused frame deformations, resulting in the frequented pneumobile failure: the chain skipping. It needed to It was necessary to straightening and strengthening the frame.

Earlier we used the strongest BMX chain for the torque transmission. With the 100 mm diameter pneumatic cylinder there were chain break in several cases, so for the primary drive we use motorcycle chains.

In these early years the racing cars must be able to roll backwards. (In 2017 this rule is valid again.) In our cars this was achieved by the modification of the gear hub. One of the 7 gear was removed, so it became a neutral position.

In 2010 we had nice results: the EMTIK team placed second in the long distance competition.

We were also pleased with the team EMKÁ despite a failure. The car was better than the EMTIK in the arcade and the drag race. A pneumatic connection hose released the tube, so that was the end of our long distance competition. The pressure of the gas remained in the tank was 150 bar, the car was made only 2 kilometers. In the documentation every team has to estimate the expected result of the car in the long distance race. We still don't know how but in the haste before the deadline our documentation we made a mistake: we estimated our long distance results to 2 kilometers. As the failure happened exactly at the distance of 2 kilometers we received the Special Prize of the most accurately estimating team! In the arcade and the drag race we made 8^{th} and 7^{th} place, so in accordance with these good results we had a new conception for the next years.

2. 2011: PNEUMOBILES CHOPPED IN HALF, CYLINDERS CONNECTED IN LINE

A new rulebook came into force, which was made necessary by the growing performance of the cars. It contained new regulations about the running gear geometry.

We had a lot of work for the season 2011, because either of our cars did not suit the new requirements. We decided that the racing car of the team EMKÁ finish his career – in one piece. Its front running gear was united with the rear of the old EMTIK frame. The rack and pinion unit of the EMKÁ was adopted by a new team: the MKLaren.

Members of the team SZMNTIK: Sándor Csikós, László Mustafa, Dávid Korom, Ádám Kószó, supporting teacher: Dr. István Tibor Tóth.

Members of the team MKLaren: Péter Deák, Miklós Hörömpő, Balázs Muladi, Norbert Temesvári, supporting teacher: István Péter Szabó.

The name is a "misrepresentation" of the McLaren, showing the initials of "Mérnöki Kar" – Faculty of Engineering.

Fig. 2. MKLaren, 2011

Our rack and pinion power unit worked well, with the 100 mm diameter cylinder it gave 320 Nm of maximum torque. Based on the results of the last year we intended to plan a car which is outstanding primary in the drag and arcade races.

As above, when the car starts, in the cylinder the pressure is decreasing, so the force on the piston rod, too. This effect can be decreased with better gas supply – with the low pressure resistance and high flow capacity of the pneumatic circuit and engine. Two cylinders have two air supply connection in each stroke direction, so the size of the gas inlet cross-section is duplicated.

For the higher velocity we need to increase the power or the velocity of the engine. The power could be increased by parallel connected cylinders, and to increase the velocity we could connect the cylinders in line. We decided on the linear connection. This solution is our own development. The front cylinder moves the rear one, and this rear cylinder works, too, giving the movement to the rack and pinion unit.

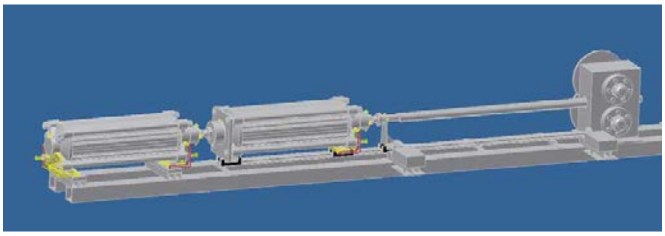

Fig. 3. The in-line connected cylinders and the rack and pinion unit of the MKLaren

The velocities of the two piston are added together. The force of the piston rod is not changed, so it do not need stronger and heavier frame. The disadvantage of the solution is the consumed energy for the acceleration and deceleration of the mass of the rear cylinder.

For the frame we made more conceptual plans, finally the team designed in full detail the 5^{th}, "E"-version.

For the maneuverability we used small front wheels which were slowed with disc brakes.

Another development was the aerodynamic case made of fiberglass.

The construction has proved effective: the vehicle was finished one day before the competition, and it reached 3^{rd} place in the drag race – without any tests.

This year brought a novelty. The MKLaren team did not manufacture the frame in the Faculty, but in industrial conditions: at the Tornado International, Ltd. It meant a new opportunity for our team member students to improve they practical experience.

In the middle of the preparation we had to reorganize our works. Arriving with the frame to the Faculty we had to recognize that two teams' work was too much for the place, so we had done the remaining steps of the MKLaren's manufacturing in my home, it often lasted until morning.

3. 2011: THE FIRST BUFFERS OF SZEGED – THE FIRST VICTORY OF SZEGED – IN KECSKEMÉT

With my team we spent a lot of time in the summer with the tests and development of MKLaren. The four branches of the activity were: A fejlesztés négy ága: the utilization of the expansion work, applying buffer tanks, determination of the optimal gear ratio in accordance with the increased performance and use a gearless transmission hub (http://www.fallbrooktech.com/cycling/n360) instead of the former seven-speed version. We also had to take into account that, in contrast to the 220 m drag race track of Eger, in the main square of Kecskemét we competed on a 70 m track.

In the field some teams used buffer tanks to increase the gas supply of the pneumatic circuit. Without these tanks the performance is limited by the troughput of the pressure reducer on the nitrogen tank. We built in three tanks, the total volume of these was 36 liters.

Fig. 3. First buffer tanks

We had done a lot of test, so we thought we were prepared for the race. As it turned out we should have been testing on a bumpy road, too. In the main square of Kecskemét the shaking of the vehicle and the too low control pressure led to the malfunction of the limit switches, so the motor sometimes stopped. The arcade competition was gone because of the too low control pressure: from the 3rd place of Q1 we fell back to 7th place in Q2, but we were successful in the drag race.

Fig. 4. MKLaren, the first victory

Our job became more difficult by the fact that the right tie-rod bent, so the right front wheel began to drizzle. We have quickly corrected the running gear by welding together two pipe wrench. Pulling it over the tie-rod the running gear was strong enough to go to drag race. We won it, it was the first victory of the University of Szeged.

The linear connection of the cylinders appeared in more cars from Szeged. The Pneugeot Team drove a chain drive unit with the two pneumatic cylinders. The Pneugeot Team has debuted in Kecskemét and took parts in more competitions. The team members: Sándor Bene, Csaba Rózsa, Richárd Szarka, Árpád Virág, supporting teacher: Dr. István Tibor Tóth.

4. MKLAREN: CHAMPION OF 2012, SENIOR CHAMPION OF 2013 AND 2014

In 2012, Eger the University of Szeged was represented by the Pneugeot and the MKLaren teams.

The MKLaren had further modifications before the competition. In the previous year the buffers and the gearless transmission hub helped us to win. We changed the rear wheel to a smaller, 20” one with the transmission hub. It has two great advantages: the gear ratio can be changed under load, during the drive, so it does not need to pause the throttle, and this gearless transmission hub can transfer higher torque than the concentional gear hubs. This torque can result greater force on the asphalt if the wheel has smaller diameter, so we changed it to 20”. Because of the extra loads we use double-wall aluminium rims, DT spokes and soft tires.

We increased the buffer capacity because the track of the drag race in Kecskemét was 70 m long, but in Eger it is 220 m. In Our large buffer capacity (84 l) was unique. It became a popular solution in the field. In the tests we achieved 45 km/h maximum velocity. The track in Eger upwards, so the race results are a slightly weaker.

Thanks to the improvements, we won the drag race. The new track record of Eger: 27.372 s.

The development of the MKLaren was finished. It entered for the race unchanged in 2013 in senior category. It reached 26.285 s in the drag race, 2nd place in the full field, best in senior category. It was the best senior in drag race and arcade race, so the MKLaren won the Senior Champion title. In 2014 the team repeated it.

The car is currently on display at the Faculty of Engineering University of Szeged, Building D as the most successful pneumobile of the Faculty.

5. 2013-2015: SLIPPING WHEELS

Since 2013 the Pepp-Air Team participates the competition. Member of the team: Sándor Bene, Dávid Csamangó, Péter Levente Dobos, László Módra, supporting teacher: Dr. István Tibor Tóth.

The other team was the Diff-Air: Tamás Asztalos, Jenő Fölföldi, Tamás Kéri, Norbert Varga, supporting teacher: István Péter Szabó.

The higher and higher cornering speed needs better running gears. On the inner side of a three wheeled vehicle the wheel could lifted up from the ground in a corner and the car drifted out. We decided to build a four-wheels car. The first version of the Diff-Air was the duplication of the MKLaren: in each side there were two cylinder in line. We increased the puffer capacity to 144 liters.

Due to our traditionally bad schedule we finished the vehicle in Eger. It resulted a bad place in the middle field, fighting a number of technical problems.

The rulebook of 2014 maximized the total buffer capacity to 100 liters. It would have been little to a four-cylinder engine, so we removed the cylinders and the the rack and pinion unit from the left side. It reduced the power but the weight, too.

Fig. 5. Diff-Air, 2015

To increase the torque on the rear wheel we removed the transmission hub from the wheel and fixed it to the frame.

Fig. 6. Drivechain of the Diff-Air with the hub transmission in front of the wheel

The rack and pinion unit drives anintermediate shaft, then through a chain drive the torque is decreased. The transmission hub is loaded by this low torque. Through another chain drive that drives the wheel we can increase the torque greatly: the torque of the hub trasmission is 95 Nm and the torque on the rear wheel is 200 Nm.

The four wheel add stability in the corners, the aluminium frame was much lighter than the steel frame of the MKLaren. In 2014 the Diff-Air was in 4th place of the drag race. In the drag race of the gala competition in Kecskemét the Diff-Air reaches 2nd place in 2014 and 2015, too. It is a well maneuverable car, which is capable of spectacular skidding.

With the Diff-Air we reached the limits of the Nuvinci transmission hub. The dynamic load from the pneumatic cylinders occurred the slip of the transmission hub more times, so we will not use this type of transmission. The second weak point of the Diff-Air was the high gas consumption. Our current development aims the lower weight and consumption.

For the further plans it was an important factor that the Entra-Sys, Ltd. has become our long-term permanent partner.

6. 2016: AIRRARI

Members of the team: Dávid Benedek, Gábor Horváth, Tamás Kéri, Dávid Kóczi, supporting teacher: Dr. István Péter Szabó.

Fig. 7. Pepp-Air Senior Team, Airrari, Pepp-Air Team, 2016

To reduce the consumption we built in one long stroke cylinder. We have returned to the three-wheel construction. Our plans worked, but there was a new problem occurred by the track: the rear of the vehicle popped up on the bumps of the road. During the tests on flat asphalt we reached 50 km/h, so actually this is the greatest measured speed of the pneumobiles from Szeged. In 2016 the Pepp-Air finished in 3rd position in the drag race, the Airrari was 4th.

The main problem of the Airrari is the popping rear wheel. For the reaching of the maximum speed on a bumpy road we have designed a new frame and rear running gear.

There is a novelty in Szeged that more students work on the car, not only the four team members.

7. FRONT RUNNING GEAR GEOMETRY

The cornering speed is very important. On a three-wheel car the wheel on the inner side could lift up from the ground, so the vehicle have to stay on the curve by the traction of only two wheel. We wanted to design a sprung front running gear, it is good for the stability and the higher cornering speed.

Fig. 8. The front running gear of the Airrari, 2016

Our requirements against the new front running gear and steering system:

- negative wheel camber angle as on the previous cars, to reduce the axial load of the front wheel on the outer side of the corner,
- spring stroke is 20 mm out and 40 mm in, the change of the track must be minimal in this range,
- the turning circle diameter must less than 6 meters,
- the actions of the springs are independent,
- during actions of the springs the toe-out of the wheels must be constant.

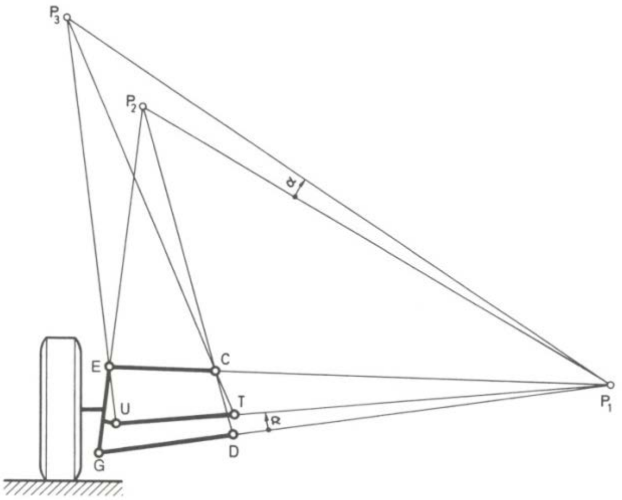

Fig. 9. Drafting the joining points of the front running gear. (Kádár, L., Dr. Varga, F., Kőfalusi, P., 2014)

We use a rack and pinion steering gear. The extension of the rack had to fit in the 26 mm gap between the frame and the pneumatic cylinder.

The joining point of rack extension and the tie-rod (T point in Fig. 9.) effects the work of the running gear: with the correct position with this joining point the toe-out of the wheels could be kept constant, otherwise the running gear may dangerous and unusable. The correct position of this T-point is represented in Fig. 9. U is the endpoint of the steering knuckle, C and D are the ball-and-socket joint on the frame (Fig. 9.).

The correct working check and final modifications were done with the Lotus Shark Suspension Analysis software:

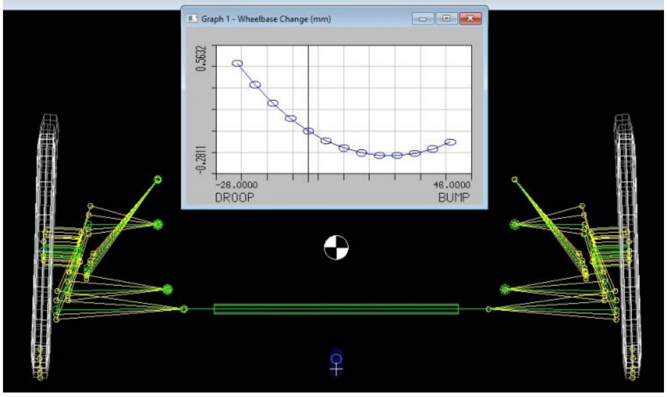

Fig. 10. Airrari front running gear, 2017 – Lotus Shark Suspension Analysis – wheelbase change in function of spring stroke position

In this year our rack and pinion steering gear was developed, too. The gear rack has adjustable guide bearing, so the the backlash of the 2016 version is greatly reduced:

Fig. 11. Airrari steering gear (without housing), 2017

9. CONCLUSIONS

The University of Szeged Faculty of Engineering has very good results in the International Aventics Pneumobile Competition. We hope this article provides not only a brief summary of the history of our teams, but useful informations to other teams, too.

REFERENCES

Farkas, F., Molnár, T. (2016). Some Recent Applications of the Renewable Energies. In: *Hungarian Agricultural Engineering* (HU ISSN 0864-7410 – Print) / HU ISSN 2415-9751 – Online) The Hungarian Academy of Sciences and Szent István University.

http://www.fallbrooktech.com/cycling/n360 (10.03.2017)

Kádár, L., Dr. Varga, F., Kőfalusi, P. (2014). Közúti járműrendszerek szerkezettana. *BME MOGI:* http://www.mogi.bme.hu/TAMOP/kozuti_jarmurendszerek_szerkezettana/index.html (10.03.2017)

Lotus Shark Suspension Analysis: http://www.lotuscars.com/engineering/engineering-software (10.03.2017)

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A bibliometric analysis on air powered vehicles technology

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Abstract: Based on several selected databases, this paper applies bibliometric method to analyse the scientific publication on air powered vehicles related technologies. Using frequency analysis keywords, basic information of the publications and most cited articles will be provided. The evolution of literature during the accounted period of selected database and suggested implications for further research is explored.

1. INTRODUCTION

This paper presents preliminary information concerning the state of the art in the field of road (wheeled) vehicles technology powered by air.

A distinction has to be made when referring to air powered vehicles, as the air is not a fuel but an energy carrier. According to ISO 13600 "an *energy carrier* is either a substance or a phenomenon that can be used to produce mechanical work or heat or to operate chemical or physical processes". The ISO 13600 series are designed as tools in order to define, describe, analyse and compare technical energy systems at different levels. From this point of view, pressurized air, can be acknowledge as a system or substance that contains energy for conversion and it can be used later or somewhere else as energy usually as mechanical energy.

The use of air as an energy carrier in order to perform mechanical work dates back to 1838 with the first built air powered vehicle. In the recent years, several result were announced by several companies as APUQ, MDI, Tata Motors, Engineair, Honda and PSA Peugeot/Citroën. A notably presence is also the Aventics Pneumobile, an international competition for designing and building pneumatic driven vehicles for university and college students.

Taking into consideration the definition of technology, as in the title of the present paper, according to Oxford Dictionary (www.oxforddictionaries.com), technology represents "the application of scientific knowledge for practical purposes, especially in industry". On a larger sense, the technology regarding the air powered vehicles can be seen as a collection of techniques, skills, methods and processes used in production of it or in the accomplishment of different objectives i.e. with the use of scientific investigation. All of this can be applied to the components of air powered vehicle technology as schematically presented in fig. 1.

Alongside the precised components others as piping systems, control valves etc. are present as well. Different concepts, configurations or structures can enlarge the field of present research. Due to a broad range of applications in the field of air powered vehicles, this paper focuses on the vehicle as a whole, an integrated system.

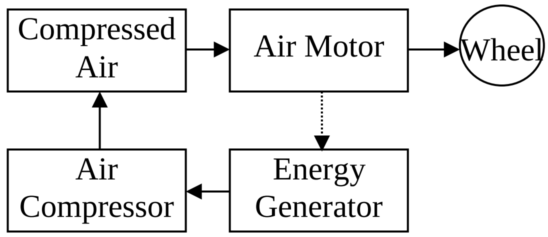

Fig. 1. Schematics of air powered vehicle technology components

In this regards, the aim of this study is to present an objective and rigorous references selection procedure for literature review (Teleky and Bălan, 2014) concerning the state of the art in the field of air powered road vehicles technology where the vehicle as a mean of transportation in the automotive field is considered.

Some preliminary information resulted from the references analysis will be provided as well. The paper will be completed with supplementary information in order to become a state of the art survey in the application of pressurized air as an energy carrier in vehicle designed to travel by roads.

2. METHOD OF REFERENCES SELECTION

The field of research, respectively the object of references selection, is represented here by air powered vehicles and its basic components as previously stated.

The methodology used for the selection of representative references of the above mentioned field of research is further presented during the following steps.

First step consists in selection of references by interrogation of scientific databases as indicated in Table 1.

Table 1. Databases used for references selection

Name	Short name	Web adress
Cambridge Journals	Cambridge	http://www.cambridge.org/
IEEE Explore	IEEE	http://ieeexplore.ieee.org/
ProQuest	ProQuest	http://www.proquest.com/
Science Direct	Science Direct	http://www.sciencedirect.com/
Scopus	Scopus	https://www.scopus.com/
Springer Link	Springer	http://link.springer.com/
Web of Knowledge – Thomson Reuters	ISI	https://apps.webofknowledge.com
Wiley – Online Library	Wiley	http://onlinelibrary.wiley.com/

The interrogation procedure consist in using database specific syntax (parentheses, commas, quotation marks, wildcards etc.) composed by logic operators (and, or, not) applied over desired main or secondary terms used as keywords. Also, within each database, including or excluding criteria as article type, source type, thematic, language, year of publication etc. can be applied on specific fields.

In Table 2 the fields of search for each interrogated databases are presented.

Table 2. Databases field of search used

Database	Field of search
Cambridge	All fields
IEEE	Article title, abstract, keyword
ProQuest	Full text
Science Direct	Article title, abstract, keyword
Scopus	Article title, abstract
Springer	Article title, abstract
ISI	Article title
Wiley	All fields

Within the specific query some databases allow selection of subject, i.e. Science Direct and Springer, other allows thematic selection, as Scopus, while IEEE allows selection of both thematic and subjects.

Regarding the date of publication as a criteria, in order to get consistent results and due to the fact that several databases are limited in time, the time frame was choose to cover 15 years.

Taking into consideration the above stated related to databases query, the following table presents a synthesis of reference selection criteria.

Table 3. References selecting criteria

Field	Including criteria	Excluding criteria
Document type	Article, Review	Book Review, Books, Business Article, Conference paper, Conference review, Databases, Discussion, Editorial, Erratum, Letter, Note, Report, Short communication, Short Survey, Undefined etc.
Source type	Journal	Book Series, Conference Proceedings, Images, Laboratory Protocols, Reference Works, Trade Publications etc.
Language	English	Chinese, German, France, Italian, Japanese etc.

Regarding the topic of the search *air* powered vehicle in order to get appropriate results the keywords used were combined in the following syntaxes: ("air powered" AND vehicle; “compressed air" AND vehicle; pneumatic AND vehicle. As can be seen, the use of quotation marks will impose to the database search engine, if implemented this function, to search the whole expression rather the individual terms or combinations of them. The selection process is similar to the principle applied in Venn diagrams. The next table presents the number of results obtained using additional keywords as stated before.

3. RESULTS

For the second step, an analysis of titles of the selected references was performed and the including and/or excluding criteria were applied. Through this, the number of references was reduced by excluding the ones inappropriate for the desired topic as can be seen in the last row from table 4.

More than that, for all the databases selected except Cambridge and Springer, the automatically selected references were manual refined to correspond to the desired topic. Due to the fact that some scientific papers can have in the references, papers that are not indexed by the selected databases due to publication year, language, not being available in electronically format etc., they can be added to the reference list along with other references published in other languages.

A following step in refining the references can be selection of the references based on content, a step that was not applied in this paper.

After all the refining the total number of references taken into account was 42 scientific papers.

Table 4. References results in selected databases

Search syntax	Database							
	Cambridge*	IEEE	ProQuest	Science Direct	Scopus	Springer	ISI	Wiley
"air powered" AND vehicle	7.982	3	72	610	47	37	18	279
"compressed air" AND vehicle	5.787	32	1.010	2.437	96	393	111	952
pneumatic AND vehicle	237	279	3.141	4.192	1.014	914	639	1.863
("air powered" OR "compressed air" OR pneumatic) AND vehicle) + database specific criteria + manual selection	N/A**	6	13	16	13	1.224**	7	17

* only logic operators search; ** lack of refine tools

4. DISCUSSIONS AND CONCLUSIONS

A preliminary analysis of references resulted in the followings.

A first element discussed correspond to the number of references found for the discussed topic. As can be seen in fig. 2, the graphically represented trend is inconsistent. Taking into consideration a general increase of the amount of worldwide scientific production, a small number of scientific papers related to air powered vehicles can only be explained by the low interest on the field. This situation can be correlated with the low potential of the air as a energy carrier as expressed by Papson A., Creutzig F., and Schipper L, in 2010 [Papson *et al*., 2010]: per volume, the air contains only 12% of the energy in Li-Ion batteries and 1% in that of gasoline.

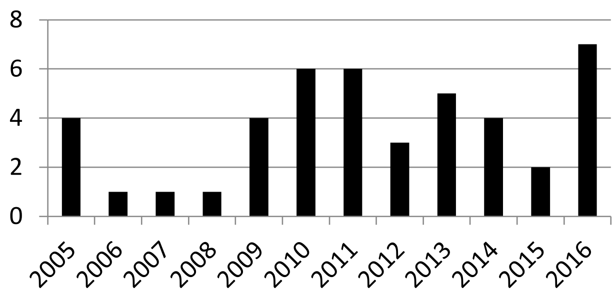

Fig. 2. Annual variation of identified references

From the 42 references found, as precised before, the first and latest (table 5) and most cited (table 6) four papers were selected. Even the first compressed air vehicle was built between 1838 and 1840 by Andraud and Tessié du Motay in Paris, France and it's supposed to previously have scientific papers regarding air powered vehicles, only in the recent times scientific production have been electronically indexed by online databases.

Table 5. Oldest and newest identified references since 2005

No.	Oldest references	Newest references
1	Huang and Tzeng, 2005	Hung *et al.*, 2016
2	Huang *et al.*, 2005	Wang et al., 2016
3	Huang *et al.*, 2005	Yan *et al.*, 2016
4	Chen *et al.*, 2005	Békési *et al.*, 2016

As can be seen from table 6, no citations were acknowledged by Science Direct database regarding the most cited papers indexed by Scopus. In this regard, in order to have a compre¬hensive state of the art, the authors must interrogate several databases as some of them do not share their content. In order to compare with potentially the most common search engine - Google, Google Scholar was also used to indicate for selected papers their frequency occurrence. The results revealed a larger number of citations due to an extended type of publica¬tions indexed in an automatic process. Also, an open database, Research Gate, was interrogated for the same reason. In this type of database the entries are manually inserted by users and the result indicates that only part of the authors are willing to insert their papers in this type of database.

Table 6. Most cited identified references

No.	References	Citations, according to			
		Scopus	Science Direct	Google	Research Gate
1	Papson *et al.*, 2010	8	N/A	17	5
2	Dönitz *et al.*, 2011	7	N/A	10	4
3	Liu *et al.*, 2006	7	N/A	7	N/A
4	Chen *et al.*, 2005	7	N/A	13	N/A

Another result involved text analysis (table 7) respectively based on an online solution (http://www.wordcounter.com/) the most frequently used words were ranked in order to identify the main themes and subthemes. As Ryan and Bernard (2003) precised, themes come from data as an inductive approach and also investigator's prior theoretical understanding of the phenomenon under study in an a priori approach. This way, a priori themes can occur from: text analysis, which can indicate the main characteristics of the field studied; from knowledge already recognized in literature reviews; from commonsense, researchers values and its personal experiences.

Table 7. Wordcount and most frequently used words within identified references

From titles		From keywords		From abstracts	
word	frequency	word	frequency	word	frequency
air	18	air	28	air	178
vehicle	15	power	20	system	150
engine	15	system	19	energy	112
system	14	vehicle	19	engine	107
hybrid	14	hybrid	17	power	106
pneumatic	13	compresse	16	compresse	77
power	9	energy	14	vehicle	66
compresse	8	pneumatic	14	pressure	64
analysis	7	efficiency	12	efficiency	64
energy	7	engine	12	hybrid	59
air-power	6	start	6	pneumatic	59
study	6	air-power	6	fuel	58
design	5	simulation	6	result	56
performance	5	model	5	model	53
efficient	4	design	5	design	49
characteristic	4	engin	5	use	44
base	4	vehicl	5	vehicl	42
storage	4	dynamic	4	paper	36
engin	4	analysis	4	control	34
vehicl	4	optimization	4	performance	32
dynamic	3	hydraulic	4	exhaust	30
gas	3	engineer	4	simulation	29
powertrain	3	automobile	4	present	29
simulation	3	emission	4	study	28
pneumatic-power	3	techn	3	develop	28

Taking into account the above stated, and using other two online applications (http://sporkforge.com, www.online-utility.org) the following terms appear: as characteristics, energy, power, pressure; as processes, storage, exhaust, expansion; as concepts, system, hybrid, model, simulation; as components, valve, cylinder, powertrain, tank. Combining them as a whole, the following two sentences: **hybrid pneumatic engine for efficient vehicle powertrain; pneumatic engine for efficient vehicle powertrain hybridization**; can construct the present directions and future trends that are followed by researchers.

REFERENCES

Gery W. RyanH. Russell Bernard (2003), *Techniques to Identify Themes*, In: Field Methods, **Vol 15, Issue 1**, pp. 85 – 109.

Papson, A., Creutzig, F., Schipper, L. (2010). *Compressed Air Vehicles Drive-Cycle Analysis of Vehicle Performance*, *Environmental Impacts, and Economic Costs*. In: Transportation Research Record, **Issue: 2191**, Pages: 67-74.

Teleki B.E., Bălan M.C. (2014). Hidrogen Production by Anaerobic Digestion of Biomass with High

Lighocellulose Content – References Selection Procedure. Applied Mechanics and Materials, **Vol. 659**, pp. 475-480.
*** http://en.pneumobil.hu/
*** http://sporkforge.com/text/word_count.php
*** http://www.apuq.com/
*** http://www.engineair.com.au/
*** http://www.tatamotors.com/
*** http://www.topspeed.com/cars/honda/2010-honda-air-concept-ar100356.html
*** http://www.wordcounter.com/
*** https://en.oxforddictionaries.com/definition/engineering
*** https://www.groupe-psa.com/en/newsroom/automotive-innovation/hybrid-air/
*** https://www.mdi.lu/
*** https://www.online-utility.org/text/analyzer.jsp

APPENDIX

List of identified references

No.	Title	Authors	Year
1.	Development of a hybrid pneumatic-power vehicle	K.David Huang, Sheng-Chung Tzeng,	2005
2.	Energy-saving hybrid vehicle using a pneumatic-power system	K. David Huang, Sheng-Chung Tzeng, Wei-Chuan Chang,	2005
3.	Hybrid pneumatic-power system which recycles exhaust gas of an internal-combustion engine	K. David Huang, Sheng-Chung Tzeng, Wei-Ping Ma, Wei-Chuan Chang,	2005
4.	Simulation on the port timing of an air-powered engine	Chen, Y; Liu, H; Tao, GL	2005
5.	Exergy analysis on power system of air-powered vehicle	Liu H., Tao G.-L., Chen Y., Ding W.-H.	2006
6.	Study on air charging process of quick recharge station for air powered vehicle	Liu H., Tao G.	2007
7.	Development of a vaned-type novel air turbine	Singh, B R , Singh, O	2008
8.	Rapid Start of Hybrid Pneumatic Engines	Iulian Vasile, Christian Dönitz, Christoph Voser, Jan Vetterli, Christopher Onder, Lino Guzzella,	2009
9.	A method for reducing exhaust pressure of vehicle compressed air powered engine	Zhenggang Xu; Xiaopeng Xie	2009
10.	Computer Aided Design and Analysis of Air Engine Piston	C. K. Tembhurkar; P. D. Kamble	2009
11.	Modelling and optimizing two- and four-stroke hybrid pneumatic engines	Dönitz, C, Vasile, I , Onder, C H, Guzzella, L	2009
12.	Aspect of Dynamic Simulation and Experimental Research Studies on Hybrid Pneumatic Power System	Huang, K David, Hoai-Nam Nguyen	2010
13.	Compressed Air Vehicles Drive-Cycle Analysis of Vehicle Performance, Environmental Impacts, and Economic Costs	Papson, Andrew; Creutzig, Felix; Schipper, Lee	2010
14.	Performance study on three-stage power system of compressed air vehicle based on single-screw expander	He Wei; Wu YuTing; Ma ChongFang; Ma GuoYuan	2010
15.	Preliminary design of a series Hybrid Pneumatic powertrain for a city car	R. Hayeri; A. Taghavi; M. Durali	2010
16.	Prospects of development of autonomous pneumatic vehicles	Bozrov V.M., Ivlev V.I.	2010
17.	Air fuelled zero emission road transportation: A comparative study	Haisheng Chen, Yulong Ding, Yongliang Li, Xinjing Zhang, Chunqing Tan,	2011
18.	Energy efficiency analysis for air-powered vehicle system based on single-screw engine	He W., Wu Y., Ma C., Zhuang H.	2011
19.	Energy efficient use of compressed air in pneumatic drive systems for motion tasks	M. Doll; R. Neumann; O. Sawodny	2011
20.	Performance Study on Multilevel Hybrid Power System of Pneumatic-fuel Vehicle	W. Guo-ye; Z. Juan-li; C. Xiao-gang; W. Jun; Z. Chang-song	2011
21.	Planning for a 100% independent energy system based on smart energy storage for integration of renewables and CO2 emissions reduction	Goran Krajačić, Neven Duić, Zlatko Zmijarević, Brian Vad Mathiesen, Aleksandra Anić Vučinić, Maria da Graça Carvalho,	2011
22.	Research on expansion ratio of air power engine system	Q. Yu; M. Cai	2011
23.	Validation of the fuel saving potential of downsized and supercharged hybrid pneumatic engines using vehicle emulation experiments	Dönitz C., Voser C., Vasile I., Onder C., Guzzella L.	2011
24.	A Study of Performance Output of a Multivane Air Engine Applying Optimal Injection and Vane Angles	Singh, Bharat Raj, Singh, Onkar	2012
25.	Design Methodology of Camshaft Driven Charge Valves for Pneumatic Engine Starts	Michael Moser, Christoph Voser, Christopher Onder, Lino Guzzella,	2012

26.	A simple and efficient mild air hybrid engine concept and its performance analysis	Lee, Cho-Yu, Zhao, Hua, Ma, Tom	2013
27.	Dynamic modeling of compressed gas energy storage to complement renewable wind power intermittency,	Jean-Paul Maton, Li Zhao, Jacob Brouwer,	2013
28.	Hydro-pneumatic accumulators for vehicles kinetic energy storage: Influence of gas compressibility and thermal losses on storage capability,	Pierpaolo Puddu, Maurizio Paderi,	2013
29.	The Dynamics Simulation Analysis of Automotive Air Suspension and Control System Based on Adams and Matlab	Meng, Cai, Liang, Gu	2013
30.	A real-time model of an automotive air propulsion system	Yi-Hsuan Hung, Yu-Ming Tung, Hong-Wei Li,	2014
31.	System Identification and Embedded Controller Design for Pneumatic Actuator with Stiffness Characteristic	Khairuddin Osman, Ahmad 'Athif Mohd Faudzi , Rahmat, M F, Suzumori, Koichi	2014
32.	The Applications of Piston Type Compressed Air Engines on Motor Vehicles	Yuan-Wei Wang, Jhih-Jie You, Cheng-Kuo Sung, Chih-Yung Huang,	2014
33.	Working Characteristics of Variable Intake Valve in Compressed Air Engine	Yu, Qihui, Shi, Yan, Cai, Maolin	2014
34.	Gasoline hybrid pneumatic engine for efficient vehicle powertrain hybridization	Dimitrova, Zlatina; Marechal, Francois	2015
35.	Gasoline hybrid pneumatic engine for efficient vehicle powertrain hybridization	Zlatina Dimitrova, François Maréchal,	2015
36.	Energy conversion characteristics of a hydropneumatic transformer in a sustainable-energy vehicle	Yan Shi, Tiecheng Wu, Maolin Cai, Yixuan Wang, Weiqing Xu	2016
37.	Exergy Analysis of the Revolving Vane Compressed Air Engine	Subiantoro, Alison, Wong, Kin Keong, Kim Tiow Ooi , Subiantoro, Alison, Wong, Kin Keong, Kim Tiow Ooi	2016
38.	Fuzzy logic speed control for the engine of an air-powered vehicle	Yu, Qihui; Shi, Yan; Cai, Maolin; Xu, Weiqing	2016
39.	Pneumatic Hybrid Drive Concepts	Békési, Zs, Jánosi, L, Fledrich, G	2016
40.	Power characteristics of a new kind of air-powered vehicle	Shi, Yan; Wang, Yixuan; Liang, Hanwen; Cai, Maolin	2016
41.	Research on a pneumatic hybrid engine with regenerative braking and compressed-air-assisted cranking	Wang, Lei, Li, Dao-fei, Xu, Huan-xiang, Fan, Zhi-peng, Dou, Wen-bo, Yu, Xiao-li	2016
42.	System design and mechatronics of an air supply station for air-powered scooters	Yi-Hsuan Hung, Jian-Hao Chen, Chien-Hsun Wu, Syuan-Yi Chen	2016

Upbair's vehicle – a model of simplicity and robustness

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Abstract: The vehicle of our team, **Upbair –** which represents the University POLITEHNICA of Bucharest, is an experimental vehicle with compressed air, designed to participate in the race "PNEUMOBIL 2017", organized by company Aventics. The vehicle was designed by Upbair team: Mr. AGUD Mihai – team leader, Mrs. NICA Loredana-Ioana, Mr. UNGUREANU Liviu, Mr. STANCIU Robert-Daniel – team members, coordinated by Mr. Ghinea Mihai, associate professor at University POLITEHNICA of Bucharest. The car is a vehicle that imitates simple operating principle of a three wheels bicycle. The motor is also composed of two simple pneumatic pistons (32 mm and 63 mm and the stroke is 320 mm), which are controlled by mechanical valves. The vehicle can operate in two modes: the "way of saving precious energy" and "speed mode". Its structure is made of aluminium tubes of 35 mm diameter, with 3 mm thickness walls, and the boards of 10-20 mm thick aluminium. It is, therefore, designed to support the head of the other parties. In order to improve innovation, we use a high-performance gearbox made by *Pinion* (Germany). Under the driver's floor, there is a 3mm thick aluminum sheet (or made by a special plexiglass). Moving glass elements and gas are also protected by a 3 mm thickness aluminum sheet, to avoid possible injury of the driver. The gas bottle will be isolated from the driver by surrounding it with a 3 mm thickness aluminium sheet. The engine is equipped with a professional shifter that is quite a challenge. The wheels have 20 inch as diameter, with double-stitched rim and 32 spokes that have 1.8mm thickness. The direction system used is identical to the one of a bicycle. It has a handlebar, fork and wheel bearings to turn easily. The braking system consists of 2 disk brakes which operate independently, one system for the rear wheels and the other on the front wheel. The parking brake is on the front wheel. We use self-locking lever and a V-Brake. An important aim of the project was the driver protection from all the moving elements of the engine. Thus, the vehicle is designed to protect the driver in case of accidents. The helmet, safety belt, and the whole structure (assuring safety for almost 80% of the drivers' body), and the thick bar above the helmet, contributes to the drivers' protection, as well. The safe and comfortable driver's position in vehicle allows the easy steering of the vehicle. All the equipment needed for the vehicle control, especially the safety equipment, is easily accessible to the driver. He sits in a seat equipped with four fixing position belts. Even if they wear seat belt and protection helmet since the starting point, when required the drivers could leave the car in less than 15 seconds.

1. SIMPLE CAN MEAN PERFORMANCE

"Upbair no. 48" is an experimental vehicle with compressed air, designed to participate in the race "PNEUMOBIL 2017", organized by company Aventics (Agud *et al*., 2016).

The idea behind the vehicle came from a simple design of trike called delta (fig. 1). In order to avoid the tilting on the left or right side, it must calculate correctly the center of gravity (CoG), in fact, the position of the driver (fig.2).

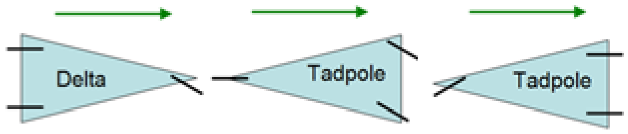


Fig.1. Types of tribike

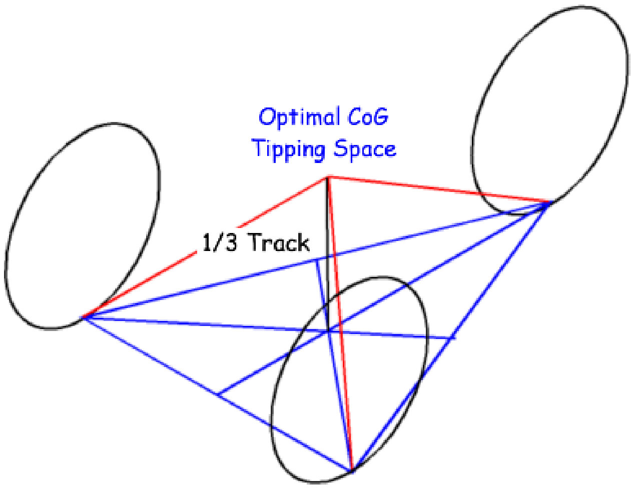


Fig. 2. Spatial position of Centre of Gravity

Calculating the optimal CoG - Looking down from above (fig.3), if it is drawn a triangle (blue line) between the three contact points and at the mid point of each line it is drawn another line to the opposite corner (red line), then the intersection of these three lines is the optimal point where the driver CoG should sits (Jetrike, 2017).

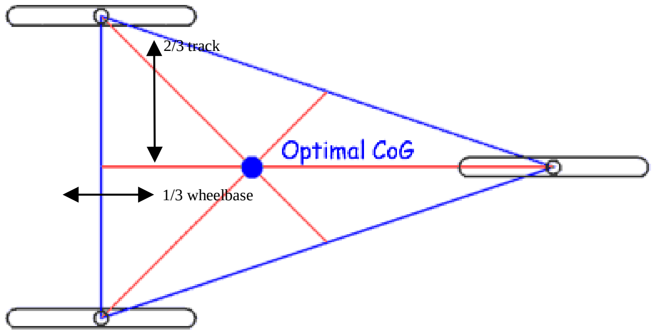


Fig.3. Planar (XOY) position of CoG

Calculating the lateral position of CoG - Looking from the front (fig. 4), if it is taken the track measurement B and it is divided in halfs it gets A. We use A to construct an isosceles triangle between the contact patches. This triangle represents the tipping point of the trike, and if the CoG is inside the triangle, then the trike skids when it looses traction while cornering, otherwise the trike tips.

Calculating the longitudinal position of the CoG – A similar triangle can be drawn on a side view of the trike using the wheelbase measurement from B to derive A. It can then use this side-on triangle to calculate where to place the CoG in order to prevent the tipping forward when breaking.

Based on these calculations, it can be established the correct position of the driver for our upbair trike. The car lenght is 2015mm with the width of 1175mm. The engine and the back whells are protected by metal plates and the car frame. The driver's head and back are protected by a 395mm hight aluminium tube. The ground clearence is 102mm wich is more than enough to protect the bottom of the automobil from obstacles that may appear on the race track.

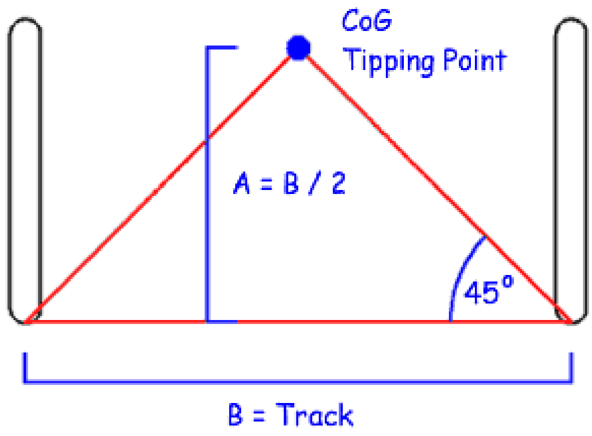


Fig.4. Planar (YOZ) position of CoG

The center of mass is closer to the back of the car at 400mm from the back wheel and at 328 mm height, which gives us a good stability as shown in Fig 5 (Jetrike, 2017).

In the figures, the dimensions of the vehicle are shown to be in compliance with regulations, and the center of gravity (G) is determined by the CAD program.

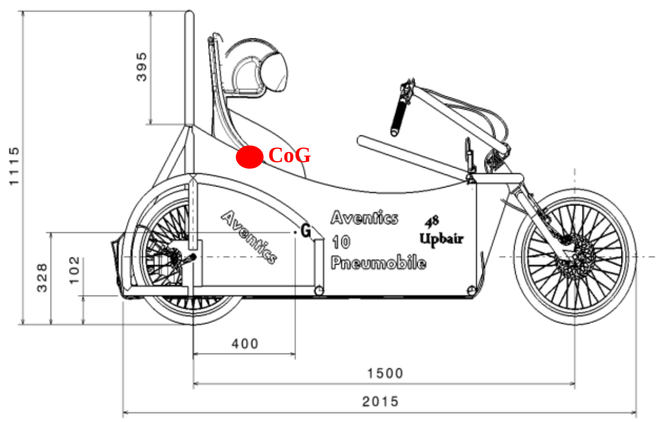


Fig.5. The dimensions are given in mm.

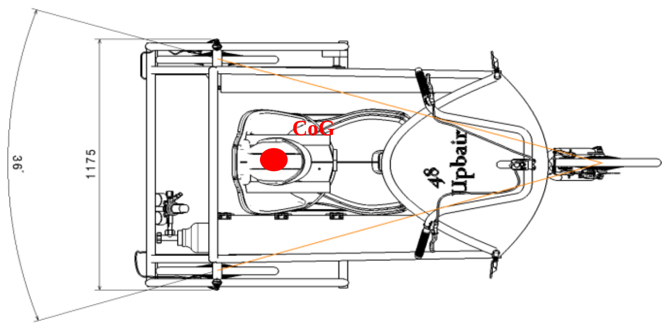


Fig.6. The dimensions are given in mm

2. FRAME AND STRUCTURE

The vehicle is made of aluminum tubes of 35 mm in diameter and the wall thickness of 3 mm, and the boards 10-20 mm thick aluminum, it is designed to support the head of the other parties. At the bottom is provided a platform composed of five sleepers to face the driver's weight, engine and compressed air bottle. The vehicle is designed to protect the driver in case of accidents (Agud *et al*., 2016).

The frame will be welded by an authorized company for welding aluminum vehicle and assembled with removable mechanical assembly (screw and nut).

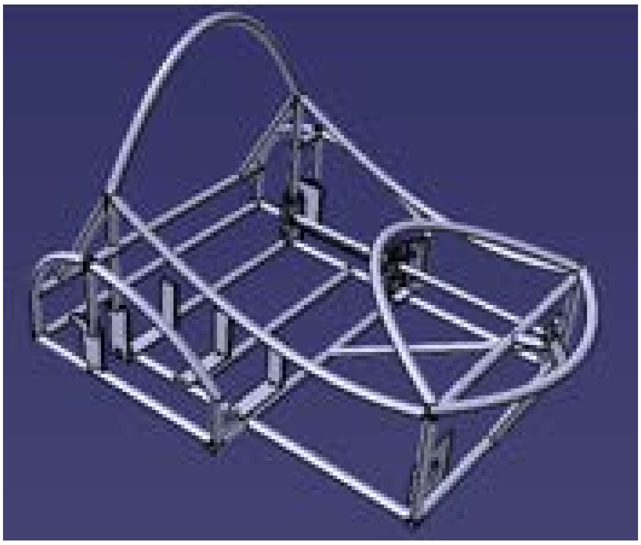
Aluminium has a density around one third of the steel's or copper's, making it one of the lightest commercially available metals. The resultant high strength to weight ratio makes it an important structural material allowing increased payloads or fuel savings for transport industries in particular.

Aluminium is the world's most abundant metal and it is the third most common element comprising 8% of the earth's crust. The versatility of aluminium makes it the most widely used metal after steel.

The body frame is all made by 35mm aluminium tube (fig.7), which gives the vehicle a good resistance while keeping the weight as low as possible. The frame covers the car like a 6 point cage offering protection to all the inside parts and also the driver. The floor of the car is reinforced with 3 transversal aluminium tubes that reinforce the structure. As seen in the picture below, we also have a bended tube on the back of the car to protect the back of the driver. In front, we designed a windshield from two bended tubes that protects the driver from debris.

All the interior components are tight on the frame using special designed adaptors. This way we maintain rigidity and reduce vibrations that could affect the mechanical components.

As it is shown in figure 7, the structure has a strong rigidity, with a modern contexture (fig. 8) which offers a good safety for the entire car (Agud *et al*., 2016).



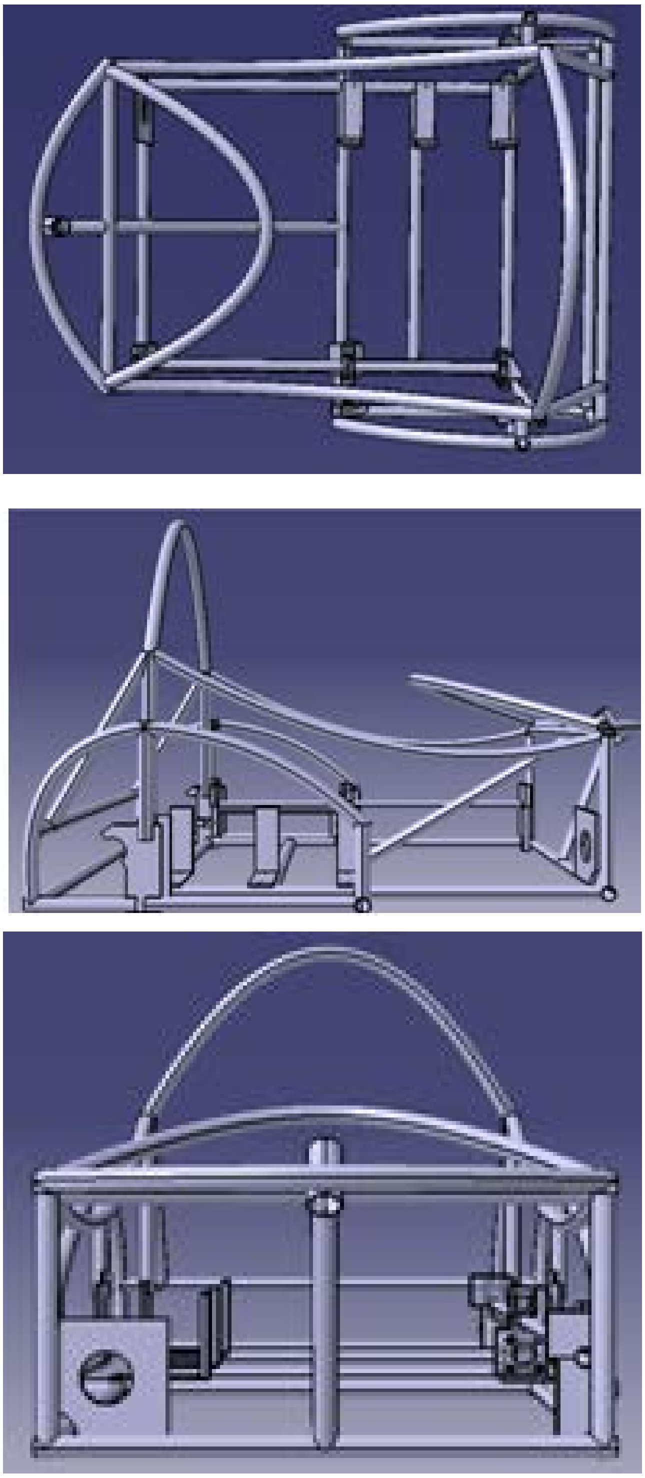


Fig.7. Isometric views of the frame

All welds will be realized by a specialized company, by using the latest technology. The utilized types of aluminium are: 5754, H1111 (for sheets), 6060, T6 (for pipes) and 5083, H111 (for plates).

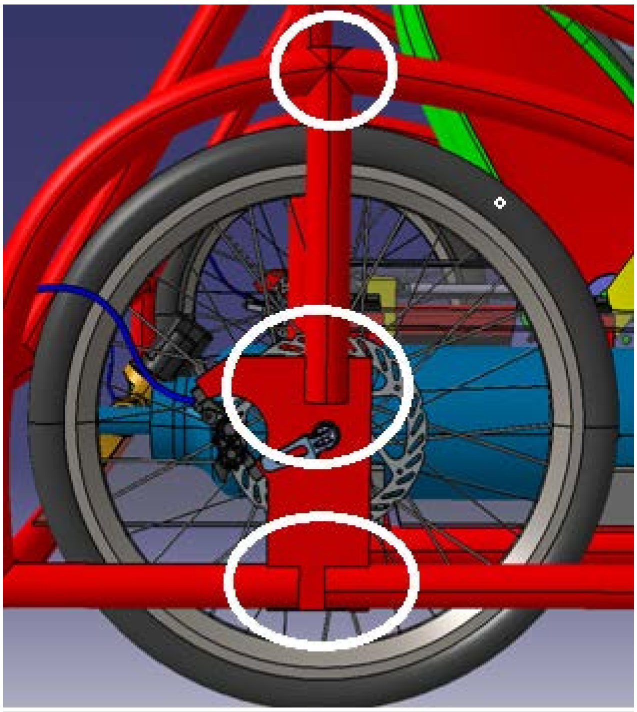


Fig.8. Details with strong linkage of components

The engine is designed to operate in two modes, energy saving mode and speed mode. Economic engine piston works with 32 small and large piston is disabled pneumatic and mechanic.

The small piston is controlled by distributor 11 and 22, when the tap 1 (ball valves with level) is closed and valve 2 (with ball valve level) is opened. In the speed mode, the engine works with both pistons.

The big piston actuates the transmission; at the output it commands the distributor 11, tap 1 opens and valve 2 closes and at the input the small piston withdraws the whole system with the big piston having the command from distributor 2.

Fixing the engine frame is made in three points, two side straps and in the middle it will lock screw see these images**.**

Transmitting motion from the engine to the wheel, axle is driven via a chain and sprockets. The engine is designed to be a single structural unit (Agud *et al.*, 2016).

The 2 pistons are connected to the car frame (fig.10). The pistons tubes are then connected to a special element (shown in yellow), that makes the connection between them and the chain. When the piston is pushing the yellow element, this is dragging the chain along a linear guide. We used the linear guide to help with the linear movement of the pistons. The mechanical parts are fixed with screws, this way we have easy access to all the elements in case we need to do any calibrations or repairs. We also have 2 End limit position sensors that tell the pistons what move to do (Agud *et al.*, 2016, Aventics, 2017).

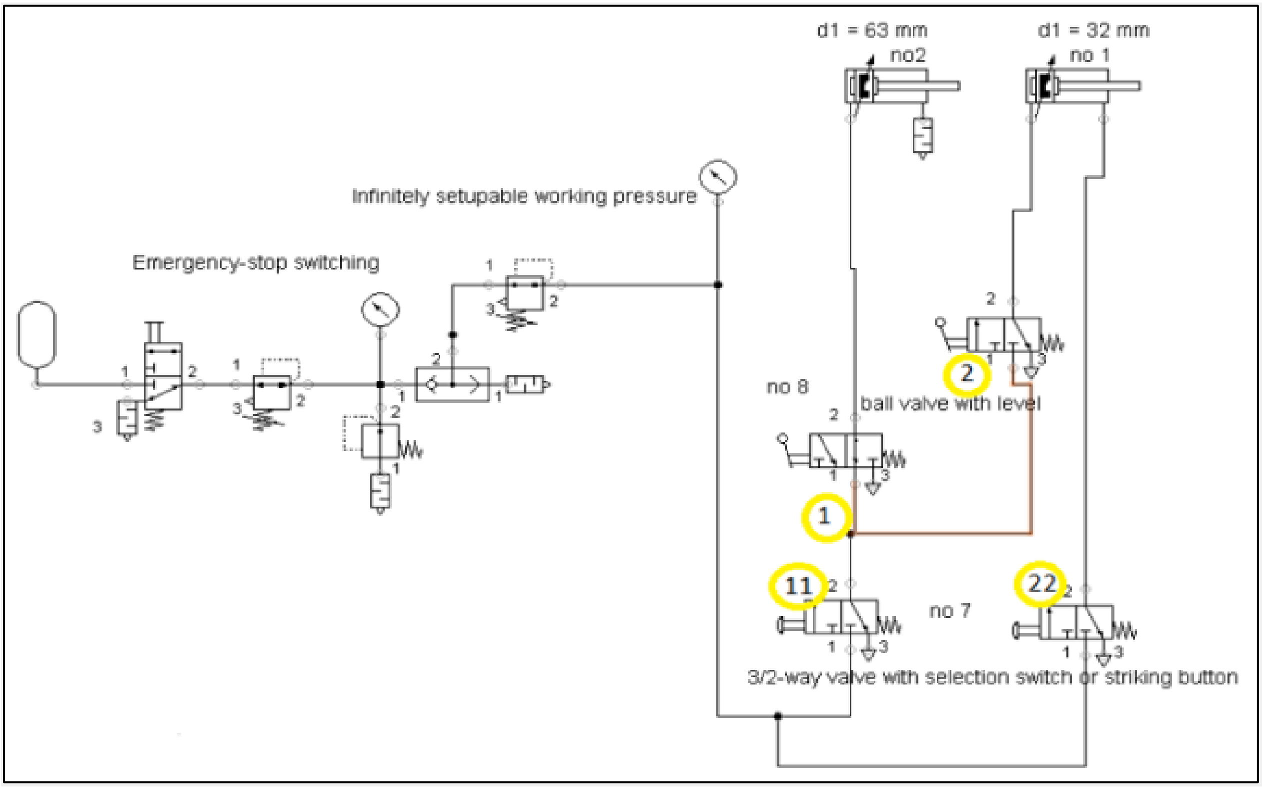


Fig.9. Pneumatic scheme

3. PNEUMATIC SCHEME & ENGINE

The motor of the vehicle consists in two Aventics cylinders, one piston Ø 63x320 and one Ø32x320 operated by the distributors that are operated at the end of the race (fig.9) (Agud *et al.*, 2016, Aventics, 2017).

All the mechanical parts are machined with special tools to have good precision and tolerance. The 16 tooth pinion is fixed on a shaft that is hold in place by two bearings which give it better rotation with less friction.

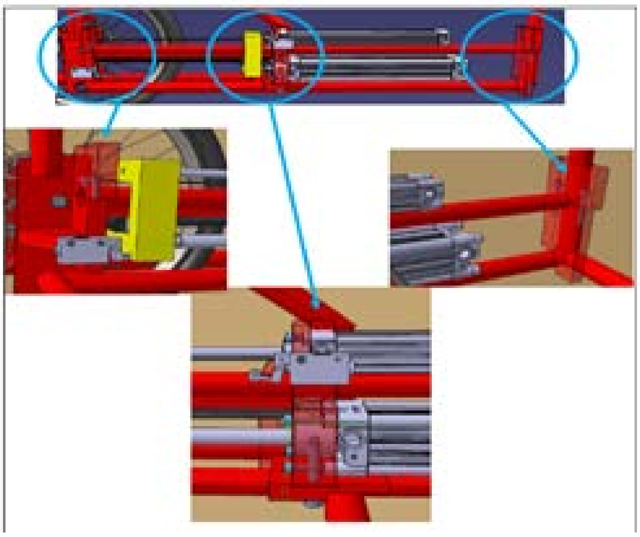


Fig.10 Engine mounting system

To have a smooth and vibration-free movement was used a linear track from Aventics seen in the following figure.

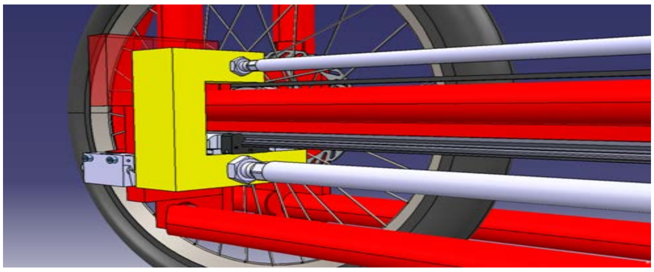


Fig.11 The linear guide Aventics

The idea behind the transmission is very simple, the piston pushes the yellow element which is connected to the linear guide and the chain on the bottom Fig 11, the chain then rotates the cogwheel from the speed hub which then rotates the wheel. The speed on the wheel is given by the number of spins on the cogwheel multiplied by the gear transmission. This way we get better performance than just going without the speed hub. With the inferior gear we get a better start and by going into higher gears we increase the maximum speed.

5. SECURITY

The braking system consists of 2 disk brakes operating independently: a system for the rear wheels and one for the front wheel. On the front wheel, we have a second brake, the parking one, which is a V-Brake controlled by a self-locking lever. We can see the braking cable in blue.

The Disk-Brake and V-Brake from the front-wheel are shown in figure 14, a, b (Agud *et al*., 2016, Gulati, *et all*, 2012).

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Calculation of braking distance is described in details in our project. We therefore considered more important to present in this paper another aspect of our theoretic work. Below it is described a small optimization study regarding the traffic dynamic necessary to anticipate the possible accidents.

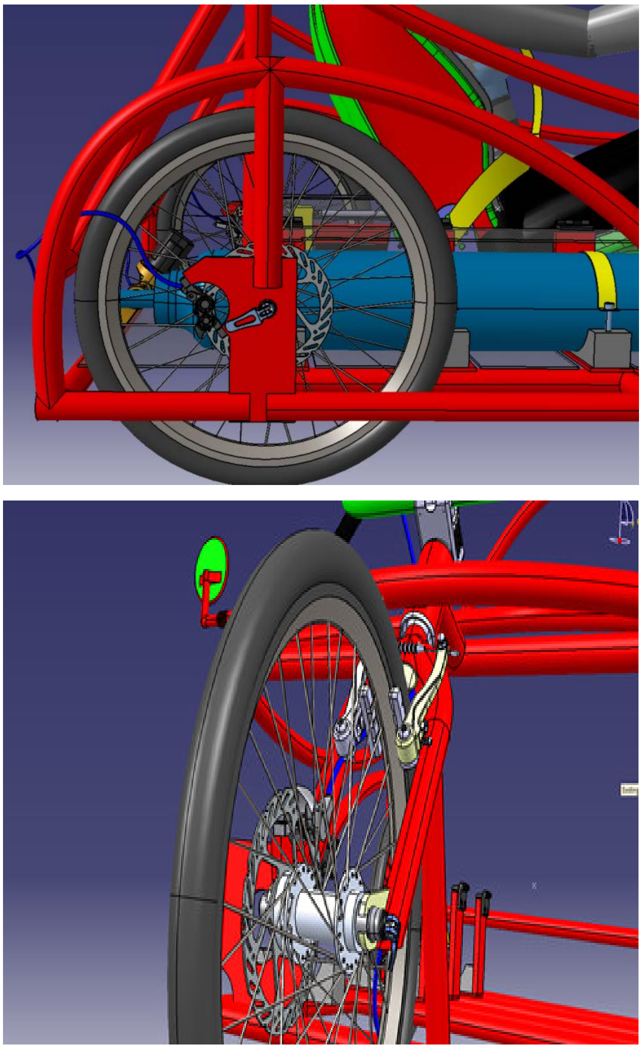

Fig.12. a, b Braking systems

5.1. The traffic optimization problem

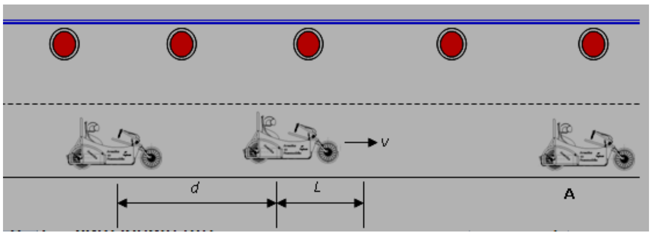

Fig.13 The idealization of the problem

In figure 13 is the idealization of the traffic when more than two pneumatic cars are on the route. The problem taken into consideration is the restriction of the cars speed such as the traffic remains optimal and safe (Ghinea, 2012, Olson, 2013).

Input data are:

1. The supposition that all cars have length *L*, a constant speed *v*, and the distance between cars is *d* (fig.13).
2. The distance *d* must remain constant, considering a safe distance. The more cars speed increase the

distance d increase too, thus the minimal safe distance is calculate with:

$$d = \frac{v^2}{2\mu g} + t_r v \tag{1}$$

where:

- μ – friction coefficient between road surface and wheel,
- g – gravitational acceleration,
- t_r – driver's reaction time.

3. When the cars are in danger of collision, the cars' flow must decrease, thus the number of cars passing through point A in a certain time represents the best safety measure of the traffic flow.

Thus, the number of cars N, which passing through point A in time t is described by the relation (Ghinea, 2012):

$$\frac{N}{t} = \frac{v}{L+d} = \frac{v}{L + \left(\frac{v^2}{2\mu g} + t_r v\right)} \tag{2}$$

It is easy to find the necessary time for a car to reach the point A. If we assume that a car just pass through point A, the next car must travel the distance $d + L$ in order to reach this point, too. At speed v, this distance must be covered by time t_1.

$$t_1 = \frac{d+L}{v} \tag{3}$$

The number of cars which passing through point A in time period t is the following:

$$N = \frac{t}{t_1} \tag{4}$$

thus:

$$\frac{N}{t} = \frac{v}{L+d} = \frac{v}{L + \left(\frac{v^2}{2\mu g} + t_r v\right)} \tag{5}$$

Next, a few calculus and substitutions must be realized in order to obtain the **objective function.**

$$\frac{N}{t} = \frac{v}{L+d} = \frac{v}{L + \left(\frac{v^2}{2\mu g} + t_r v\right)} = \frac{v}{L\left(1 + \frac{v^2}{2\mu g L} + \frac{t_r v}{L}\right)} \tag{6}$$

We can make the substitution:

$$\frac{v^2}{2\mu g L} = x^2 \Rightarrow x = \frac{v}{\sqrt{2\mu g L}} \tag{7}$$

it is obtained :

$$\frac{N}{t} = \frac{v}{L+d} = \frac{v}{L + \left(\frac{v^2}{2\mu g} + t_r v\right)} = \frac{v}{L\left(1 + \frac{v^2}{2\mu g L} + \frac{t_r v}{L}\right)} \Rightarrow$$

$$\frac{N}{t} L = \frac{v}{\left(1 + x^2 + \frac{t_r v}{L}\right)} \tag{8}$$

The numerator v of the final fraction and the denominator multiply and divide with $\sqrt{2\mu g L}$ and the result is:

$$\frac{N}{t}\sqrt{\frac{L}{2\mu g}} = \frac{x}{\left(1 + x^2 + x \cdot t_r \sqrt{\frac{2\mu g}{L}}\right)} \tag{9}$$

The next substitution is

$$\frac{N}{t}\sqrt{\frac{L}{2\mu g}} = y, \quad t_r \sqrt{\frac{2\mu g}{L}} = \beta \tag{10}$$

and it results the objective function (Ghinea, 2012):

$$y = \frac{x}{1 + \beta\, x + x^2} \tag{11}$$

In order to solve this equation, a usual computer program like Excel or Matlab can be used. The y function is an exponential one, where x and β must have small values, thus $x \in [0,2]$ and values of β will be 0,01; 0,1 and 0,2 (Fig. 14).

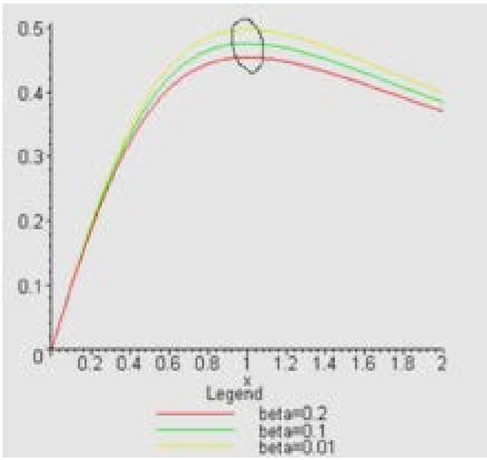

Fig.14 The curves of objective function

It is necessary to find an equation for speed *v*, which must minimize the traffic flow by biggest speed. Observing that the biggest values for *y* appear for any value of β around *x* = 1.
Taking in account that relation:

$$\frac{N}{t}\sqrt{\frac{L}{2\mu g}} = y \tag{12}$$

a maximum value for y_{max} involves an increasing $N\sqrt{L}$ value for and a decreasing value for *t*. Thus, it results the optimal value of *v* ($\sqrt{2\mu g} = v_{optim}$). Forwards, the maximisation of value *y* can be easily made by minimization of the value of the 1/*y*, that:

$$\frac{1}{y} = \frac{1}{x} + \beta + x \Rightarrow \tag{13}$$

by derivation

$$\frac{d\left(\frac{1}{y}\right)}{dx} = -\frac{1}{x^2} + 1 \Rightarrow \tag{14}$$

for a minimal value of 1/*y*. This means:

$$\frac{d\left(\frac{1}{y}\right)}{x} = 0 \Rightarrow -\frac{1}{x^2} + 1 = 0 \tag{15}$$

with values for x= ±1. Could it be possible to use the value for x= -1? No, of course…The optimal speed can be obtained by using x=1.

$$\frac{v}{\sqrt{2\mu g L}} = 1 \Rightarrow v = \sqrt{2\mu g L} \tag{16}$$

Introducing these relations in Excel, we obtain a more or less realistic situation of the safe distance between cars, given certain situations and cars speeds.

$$v = \sqrt{2\mu\, gL} \tag{17}$$

For several values of the *L*, μ, *g*, t_r, we obtain a proper value for *v* function by the used variables. For example, for the same values of *L*, μ, *g* and *v*, but with different value *tr* (0,1sec and 0,001 sec), the safety distance is almost the same (194,6 m and 192,7 m). But if μ varies from 1 to 0,01, the value of *d* increases dramatically (from 21,21 m to 194,6 m).

E16

	A	B	C
1			
2	Parametrii		
3	*L* - cars length (m)	2	
4	miu - friction coef.	1	
5	*g* - gravitational acc.(m/s^2)	9,81	
6	tr - driver reaction time(s)	0,1	
7			
8	*v* - cars speed	70	19,4439
9		km/h	m/sec
10			
11	N/t - number of cars / time	0,8376	
12			
13			
14	*d* - safety distance (m)	21,2138	

	A	B	C
1			
2	Parametrii		
3	*L* - cars length (m)	2	
4	miu - friction coef.	1	
5	*g* - gravitational acc.(m/s^2)	9,81	
6	tr - driver reaction time(s)	0,001	instantaneusly
7			
8	*v* - cars speed	70	19,4439
9		km/h	m/sec
10			
11	N/t - number of cars / time	0,91334	
12			
13			
14	*d* - safety distance (m)	19,2888	

E19

	A	B	C
1			
2	Parametrii		
3	*L* - cars length (m)	2	
4	miu - friction coef.	0,1	
5	*g* - gravitational acc.(m/s^2)	9,81	
6	tr - driver reaction time(s)	0,1	
7			
8	*v* - cars speed	70	19,4439
9		km/h	m/sec
10			
11	N/t - number of cars / time	0,09888	
12			
13			
14	*d* - safety distance (m)	194,638	!!!

	A	B	C
1			
2	Parametrii		
3	*L* - cars length (m)	2	
4	miu - friction coef.	0,1	ice!
5	*g* - gravitational acc.(m/s^2)	9,81	
6	tr - driver reaction time(s)	0,001	instantaneusly
7			
8	*v* - cars speed	70	19,4439
9		km/h	m/sec
10			
11	N/t - number of cars / time	0,09986	
12			
13			
14	*d* - safety distance (m)	192,713	!!!

Fig. 14 A few examples of the safety distance calculation in Excel (see relation 17)

6. CONCLUSIONS

As we know, pneumatic motors have existed in many forms over the past two centuries, ranging in size from hand-held motors to engines of up to several hundred horsepower. Some types rely on pistons and cylinders; others on slotted rotors with vanes (vane motors) and others use turbines. Many compressed air engines improve their performance by heating the incoming air or the engine itself. Pneumatic motors have found widespread success in the hand-held tool industry, but are also used stationary in a wide range of industrial applications. Continual attempts are being made to expand their use to the transportation industry. However, pneumatic motors must overcome inefficiencies before being seen as a viable option in the transportation industry.

As long as vehicles exist, engineers will try to find out the best solution to propel them. The internal combustion engines are commonly mounted in cars, but there are many restrictions that they have to overcome, due to ecology standards and noise limits. Limited sources of fossil fuels cause an increase in prices of petroleum and diesel, so reduction of their consumptions will be beneficial for economic reason.

Alternative sources of energy could solve problems. And because of that, we believe that pneumatic engine is the answer.

REFERENCES

Agud, M., Nica, L.I., Stanciu, R.D., Ungureanu, L. (2016) *Tehnical_document_upbair_no.48_v2.0*, The 10th edition of the PNEUMOBIL competition.

Ghinea, M. (2012) *Objectif function development in optimization's problems for engineering*, Course notes, University POLITEHNICA of Bucharest.

Gulati, V., Mehta, S., Kashyap, A., Pawar, K. (2012) *Design and FEA of a Recumbent Trike*, International Journal of Applied Engineering Research, ISSN 0973-4562 Vol.7 No.11, Research India Publication, http://www.ripublication.com/ijaer.htm.

Olson, G. (2013) *Brake performance and stability for bicycles*, SAFER & SVEA seminar „Vehicle Dynamics Challenges", May 15th, Goteborg, Sweden.

www.aventics.com

www.jetrike.com

Pneumatic Motor With Planetary Piston

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Abstract: In our project, which was supported by the Institute for Scientific Research of the Sapientia Foundation, we have developed a Wankel-engine-like planetary-piston pneumatic motor. The essence of the innovation is that the "fuel" of the engine is compressed air and it has more simultaneously active chambers. The number of these chambers can be increased, leading to a curved polygonal contour of the piston moving inside a stator with complex geometry. This machine is a volumetric one (i.e. not a turbine) and its efficiency can be increased by letting the compressed air to expand in the active chamber.

1. INTRODUCTION

Our project supported by the Institute of Research Programs of the Sapientia University was focused on the development of a Wankel-engine-like pneumatic motor with planetary piston. In fact the main idea behind these developments was the modification of the Wankel-engine (Fig. 1) by changing the number of its "cylinders" (chambers). The adaptation of this idea to build a pneumatic version was argued by the relative simplicity of this versus the combustion engine: the pneumatic version ought to be a working model of the modified Wankel-engine.

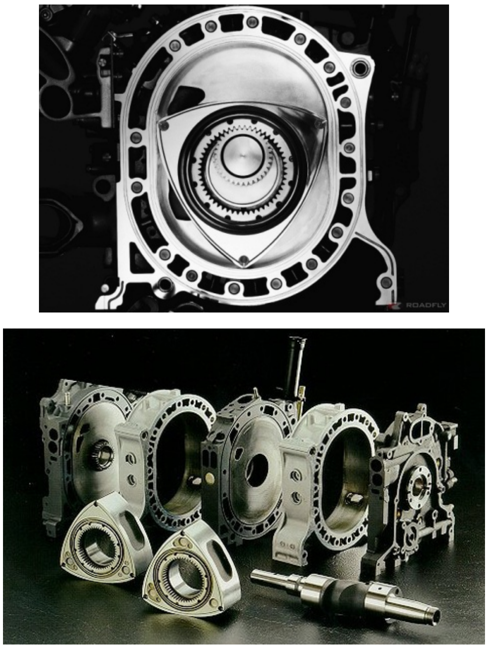

Fig. 1. Parts of the Wankel-engine (Internet)

2. THE GEOMETRY OF THE MOTOR

As mentioned in some references, the internal contour of the stator is described mathematically by the epitrochoid curve (Fig. 2). By definition this "is a roulette traced by a point attached to a circle of radius *r* rolling around the outside of a fixed circle of radius *R*, where the point is at a distance *d* from the center of the exterior circle" (Wikipedia) and on this web-page you will find a nice animation showing how this curve is plotted by the mentioned point.

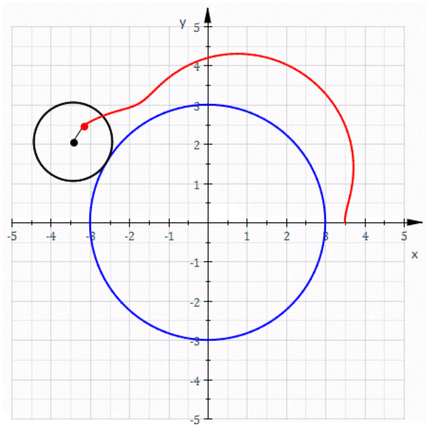

Fig. 2. The epitrochoid curve (Wikipedia)

In the case of the Wankel-engine the fixed circle is inside of the moving one but the result is the same. Moreover: because the Wankel-engine has three chambers, there are three, symmetrically positioned points on the rolling circle (the edges of the planetary piston). The epitrochoids must be closed and not-self-intersecting curves and they must be congruent (the three points move along the same curve), otherwise the chambers of the engine cannot be created. The influence of the position of the moving point (expressed using the *r*/*d* ratio) is shown in the Fig. 3: the curves were obtained as plots of the

$$x(\theta) = (R+r)\cdot\cos(\theta) - d\cdot\cos\left(\theta\cdot\frac{R+r}{r}\right),$$
$$y(\theta) = (R+r)\cdot\sin(\theta) - d\cdot\sin\left(\theta\cdot\frac{R+r}{r}\right) \tag{1}$$

parametric equations of the epitrochoid.

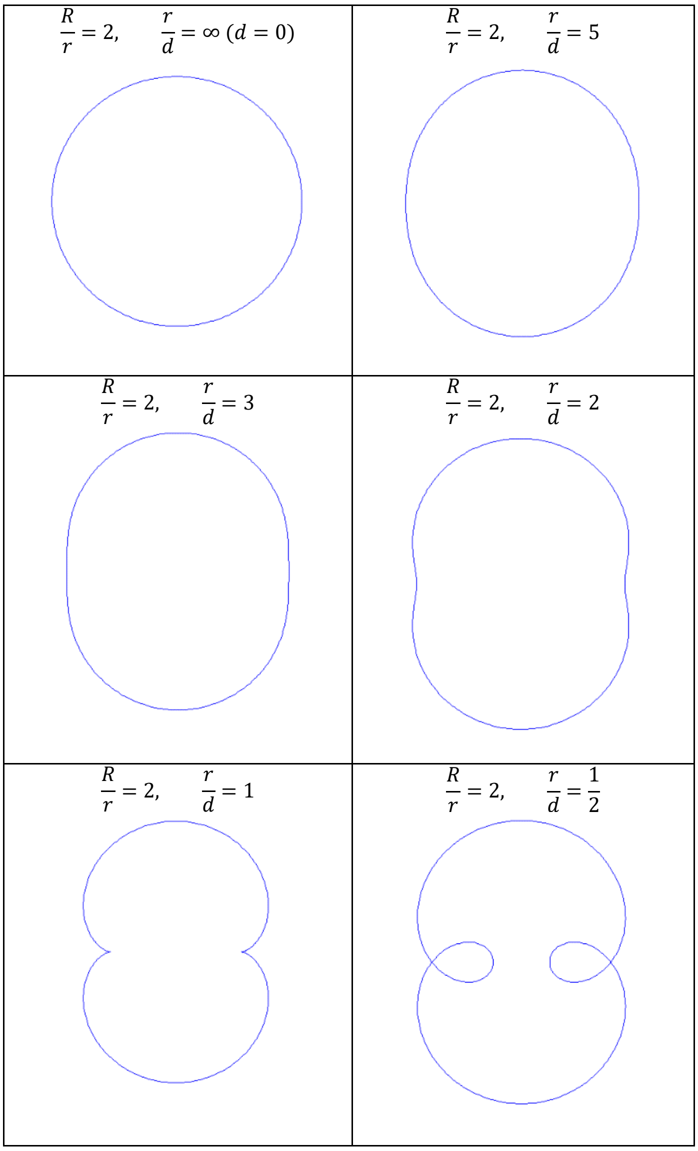

Fig. 3. The influence of the *r*/*d* ratio

From these plots we can observe that for a very large *r*/*d* ratio this curve is close to a circle (the point is close to the center of the moving circle). Decreasing this ratio we obtain some smooth convex curves. Under the *r*/*d* = 3 ratio the curve become concave, then for smaller values it will lose its smoothness, and finally, it becomes a self-intersecting curve.

The classic Wankel-engine is built with a concave but smooth internal contour.

It can be observed that because the Wankel-engine is a four-stroked one, the positioning of the intake and of the exhaust orifices without valves requires an odd number of the chambers (3, 5, ..., three in case of the classic version).

The external contour of the piston is not so generously documented, in some references we can find that is somehow close to the Reuleaux-polygon but in our study we have discovered the fact that this polygon does not fit the internal contour in all cases. Instead of developing the analytical formula of the ideal contour (that fits exactly the stator) we have computed the coordinates of its points with the precision asked by the CNC milling of the prototype.

To accelerate the development and to have a visual control on the obtained result we have written a little program. This calculates the contour of the rotor with Boolean operations, starting form a circle drawn with the radius of the rotor.

We have studied the influence of the parameters using our program and we have observed, that with the increasing *r*/*d* the minima of the internal volume of the chamber decreases. The ratio of the maxima and the minima of this volume in case of the internal combustion cannot be arbitrary because of the optimal compression ratio. E.g. if it is fueled with gasoline, this ratio cannot be much over of 10 because of overheating and auto-ignition during the compression, and it also cannot be much under of 10 because of the decreasing efficiency. But in the case of pneumatic engines the minima of the volume means the clearance (or dead) volume, so its smaller values are the better. Visually this can be observed in Fig. 4, where the *n*' parameter is the ratio of the radius of the piston (that is the *d* distance of above) and of the *r* radius of the rolling circle (that is the radius of the rolling circle of the gear).

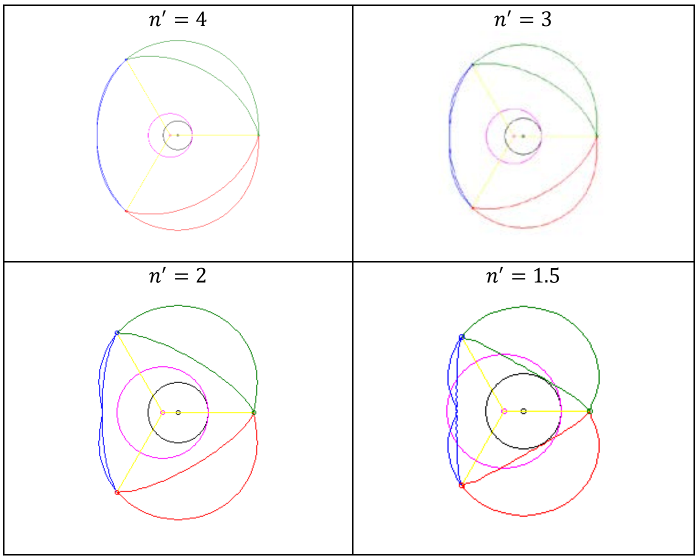

Fig. 4. Increasing death volume

Based on these observations we have chosen a geometry with *n*' = 3 that leads to a smooth and convex curve and a reduced dead volume.

We also have studied different variants with more or less chambers (edges of the piston; Fig. 5, *n* is the number of the chambers). In the case of the two-stroke pneumatic engine the number of the vertices is not restricted to odd numbers, it can be any number starting from 2. It can be easily observed, that by increasing the number of the chambers, their internal volume reported to the size of the motor decreases. Larger number of chambers leads to smaller specific power of the engine.

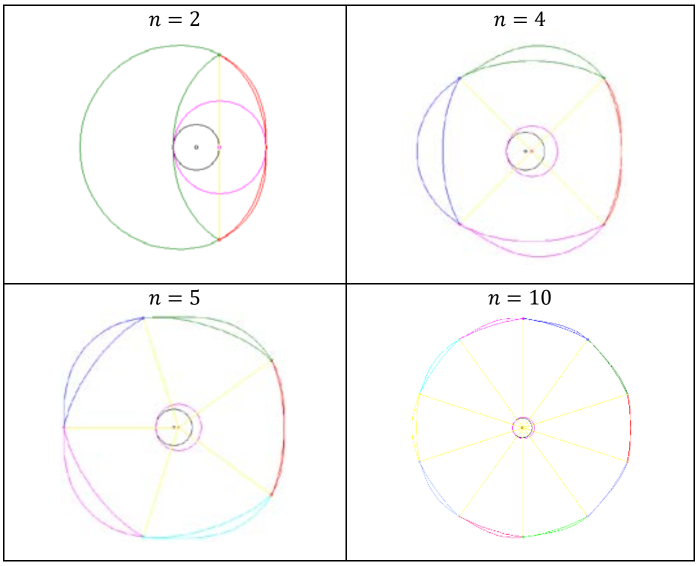

Fig. 5. Decreasing swept volume

3. THE COMPUTED CHARACTERISTICS OF THE MOTOR

The engine can be used with or without expansion. In the first case there is an active phase (stroke) when a chamber is filled with compressed air that rotates the piston. In the second phase the compressed air is exhausted near at the same pressure with it has had during the intake. This version can be built without valves.

A more economic way of using the energy is the implementation of the expansion: this version must be equipped with valves. The chamber is filled only partially with compressed air that expands after closing the intake valve, so the air is exhausted at a smaller pressure.

Our program is able to simulate the thermodynamics and to compute the idealized mechanical characteristics of the engine using the

$$p \cdot V^k = const. \qquad (2)$$

formula, where *k* takes values between the limiting values of 1 (isothermal expansion) and 1.44 (the adiabatic case). The volume *V* is computed from the geometry, the pressure is obtained from this formula, so the force exercised on the piston and its moment can be computed in a relative simple manner. Fig. 6 shows some quantities computed for a version with four chambers.

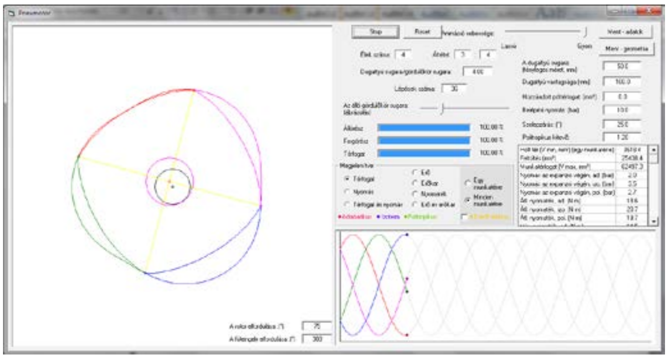

Fig. 6. Simulation of a motor with four chambers

4. THE PROTOTYPE

After all simulations we have concluded that from the point of view of the energy efficiency and of the specific power of the engine it ought be one with only two chambers and using expansion, but this engine must be built with two pistons those work with a half stroke delay. This is explained by the null or very small force and moment at the end of the expansion in one chamber while the other chamber is still in the exhausting phase.

The simplest version with a single piston is that with three chambers: because of the overlapping phases we get a rotating moment at any time.

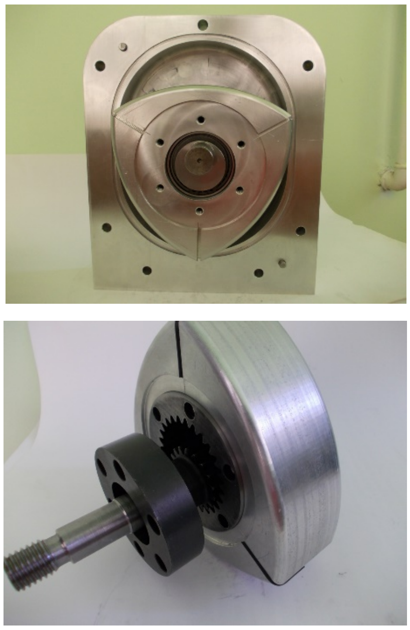

Fig. 6. The main parts of the prototype

The prototype was built with the *r*/*d* ratio equal to 3. The radius of the piston was taken to 81 mm, its thickness to 50 mm. The edges of the piston were provided with rubber strips to reduce the leaking of the compressed air, so it must be lubricated with grease or oil.

It was tested only in a simplified manner because we have no stand built for these tests. It has a reduced internal friction and leaking, rather constant torque and RPM. We have observed some deficiencies of the chosen solutions but we will able to correct them developing the second version.

REFERENCES

[1] Kenneth C. Weston: ENERGY CONVERSION (7th chapter: The Wankel Rotary Engine), Pws Pub Co 1992, ISBN-13: 978-0534938611, or in electronic form http://www.personal.utulsa.edu/~kenneth-weston/

[2] Jan Norbye: THE WANKEL ENGINE: design, development, applications, (2nd chapter): 978-0801955914, or in electronic form: https://netfiles.uiuc.edu/ro/www/SocietyforExperimentalMechanics/wankelfiles/wankelgeometry.pdf?uniq=juflkq

Fuzzy Control of Antagonistic Pneumatic Artificial Muscle

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Abstract: Due to high nonlinearity of pneumatic systems pneumatic artificial muscles (PAMs) also known as pneumatic muscle actuators (PMAs) are difficult to control, therefore a robust control is necessary to achieve the desired motion or position. Several control methods have been applied to control different systems driven by PMAs. The early control methods were based on classical linear controllers and then some modern control strategies have been developed (e. g. adaptive, fuzzy, neural network, sliding mode and others). In this paper the possibility of using a fuzzy control system on a variation of the classical ball and beam setup is presented. On the basis of experimental results, especially the achieved overshot the following is concluded: -the fuzzy control is a promising method for controlling pneumatic servo-systems actuated by PMAs.

1. INTRODUCTION

This paper examines the possibility of using fuzzy logic to control the position of pneumatic artificial muscles. The accurate positioning of any actuator is an important cause in any application especially concerning the field of robotics. Due to the compressibility of air it is the inherent nature of pneumatic actuators to be nonlinear. Pneumatic artificial muscles (PAM) also known as pneumatic muscle actuators (PMA) are no exception. These are actuators that turn pneumatic pressure into linear motion. Contrary to pneumatic cylinders where the applied pressure expands in the chamber and drives the piston along the shaft with a force proportional to the square of the diameter and the pressure, in PMA-s the applied pressure expands the muscle radially. Since the muscle membrane consists of a flexible material such as rubber and a wire mesh with high tensile strength laying on one another or galvanized together, the applied pressure causes the flexible material to expand forcing the mesh to take up its shape. Since the strands of the mesh are more resistant to stretching than the flexible material the radial expansion is accompanied by axial contraction. In PMA-s the force is proportional to the diameter of the muscle and pressure.

This simple construction of a flexible material and wire mesh reduces weight and allows for easy assembly far simpler than traditional pneumatic cylinders. These actuators also require no maintenance or oil since there are no moving parts, this makes them an ideal candidate for industrial and mobile robotics where the high power to weight ratio makes PMA-s more advantageous than pneumatic cylinders in certain applications, however PMA-s have 3 distinct drawbacks. They have a short range of motion compared to traditional cylinders, their nonlinearity is coupled with hysteresis (Sárosi J. 2015A), and they can only exert force in one direction because of this they require eider an antagonistic setup or a spring over muscle setup (Sárosi J. et.al. 2011).

In the last decade there has been a lot of research regarding the positioning of PMA-s (Sárosi J. et. al. 2014) with results showing that a precision of 0.01 mm can be achieved over an extensive operating temperature using both antagonistic and spring over muscle setups.

Several robotics applications have been developed using PMA-s (E. C. Lovasz, et. al 2017, Hosovsky, et. al. 2016, Sárosi J. et. al 2015C) where the aforementioned setups were used to achieve motion. Various control systems have been used for the positioning of these systems sliding mode control (Sárosi J. et. al. 2014) and adaptive fuzzy control (B Ranjbar-Sahrei et. al. 2012) with no clear indicator of which one is superior.

In this paper we attempt to prove that a classical fuzzy logic controller can be used to achieve precision comparable to the aforementioned works.

2. MATERIALS AND METHODS

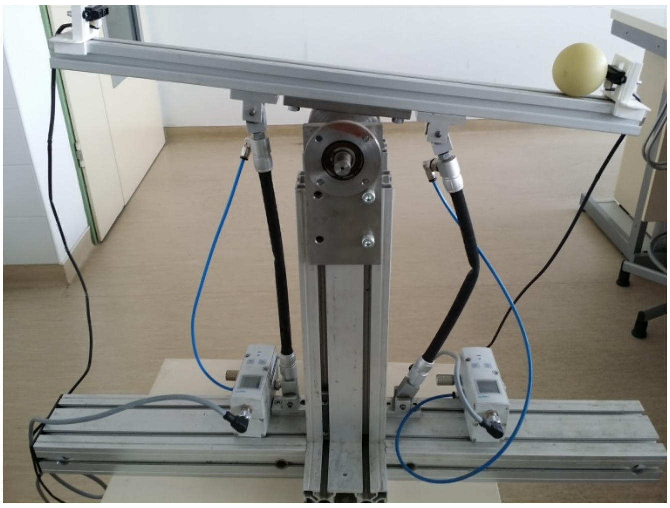

Fig. 1. The ball and beam system

Fig. 1 shows the ball and beam system which consists of 2 FESTO DSMP 10-250N PMA-s which have a 10 mm diameter and 250 mm of contracting length connecting to the beam. The ball that we position runs in a groove along the beam the beam has a length of 1 m. On both ends of the beam there are 2 SHARP GP2Y0A21YK infrared proximity sensors to measure the distance of the ball from each edge, Fig. 2 shows the nonlinear characteristic of these sensors. To regulate the pressure the PMA-s are connected to their own VPPM-6L-L-1-G18-0L6H-V1N-S1C1 pressure regulators, these regulators have an analog input range of 0-10 V and a pressure regulation range of 0-600 kPa. Processing of the sensor data is done on an NI-cRIO-9074 to collect the analog values from the proximity sensors an analog input card is required similarly to control the pressure regulators an analog output card is required. For this purpose we have selected an NI 9201 which is a 12 bit analog input module with 500 kS/s on all 8 channels and a NI 9263 which is a 16 bit analog output module with 100 kS/s on al 4 channels. Both of these have a voltage range of 0-10 V.

After the system components have been selected, the next step was to find an equation for the response of the infrared sensors, since their nonlinear response was too difficult to handle. First we chose a distance range on which we would use the sensor, based on the response the sensor gives shown in Fig. 2 we selected a large range of 100-800 mm. We conducted sample measurements along this region Fig. 3 and have concluded that while the SHARP GP2Y0A21YK infrared proximity sensor is capable of detecting position at a distance of 800 mm the output voltage differential is minute, finding a suitable equation along this range yields equation (1)

$$y = 259.672701 \cdot x^{-1.040961} \qquad (1)$$

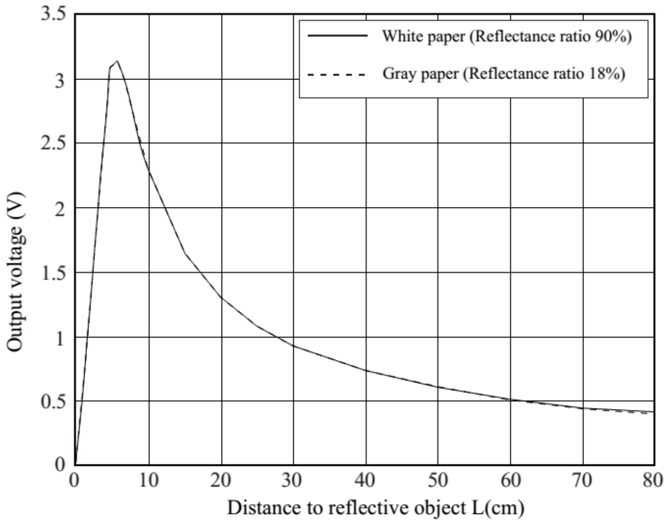

Fig. 2. Relation between distance and output voltage for SHARP GP2Y0A21YK infrared proximity sensors

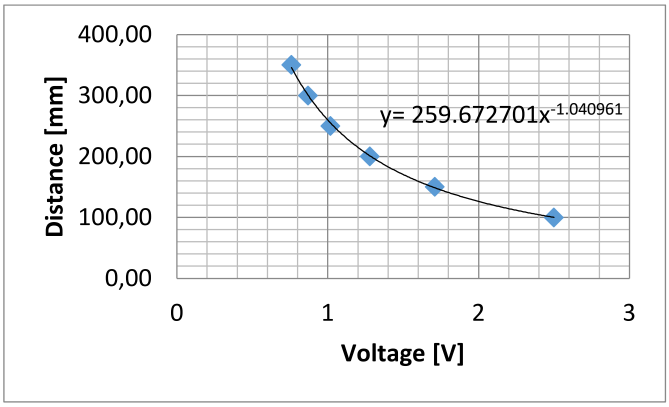

Fig. 3. Equation based on measured points

Analysing equation (1) we can see that for distances longer than 350 mm the change in voltage is minute and is discarded for the purpose of higher accuracy. To compensate for the loss in range we used 2 infrared proximity sensors and read the result of the one that gives the higher output voltage.

Now that we have a way to relate distance to voltage, we have an input for our system which is position from center, by deriving this input we have a measurement of speed as well. Using these two as the input of our fuzzy system and voltage differential as our output we have created the following fuzzy membership functions Fig. 4, Fig. 5, Fig. 6.

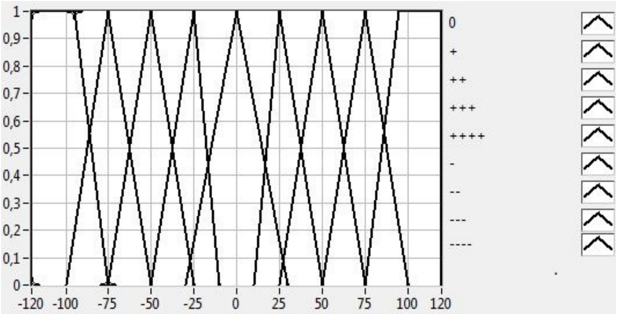

Fig. 4. Fuzzy membership function for position from centre

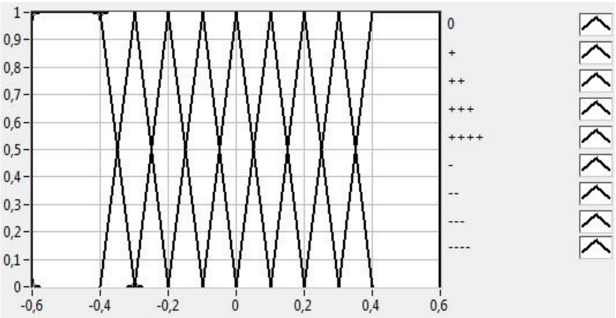

Fig. 5. Fuzzy membership function for velocity

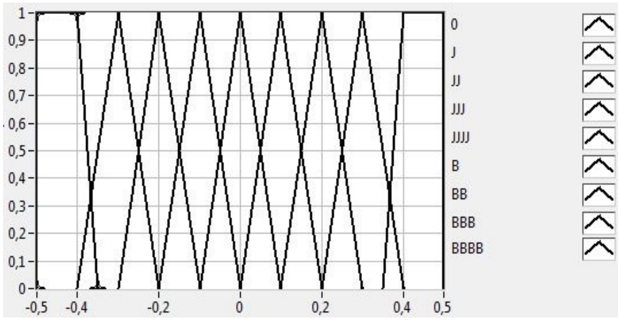

Fig. 6 Fuzzy membership function for output voltage differential

We used triangular membership functions for the system with trapezoidal membership functions at the ends of the ranges. We used 9 membership functions to classify distance and 9 membership functions to classify velocity these rang e from ---- to ++++ each symbol noting a greater degree of position and velocity Using the established membership functions we created the following rules for the system shown in Table 1. Using the rules in Table 1 we have calculated the control surface shown in Fig 7. We can see that the control surface has a smooth transition and has saturation in the ends.

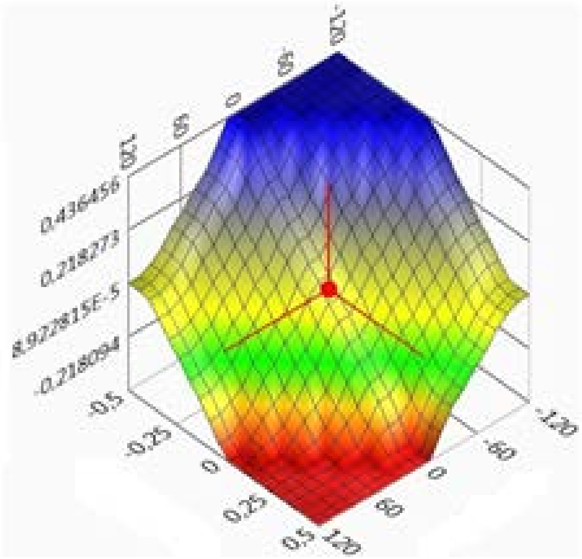

Fig. 7. Fuzzy system control surface

Table 1. Fuzzy system rules

Distance [mm] / Velocity [m/s]	- - - -	- - -	- -	-	0	+	+ +	+ + +	+ + + +
- - - -	JJJJ	JJJJ	JJJJ	JJJJ	JJJJ	JJJ	JJ	J	0
- - -	JJJJ	JJJJ	JJJJ	JJJJ	JJJ	JJ	J	0	B
- -	JJJJ	JJJJ	JJJJ	JJJ	JJ	J	0	B	BB
-	JJJJ	JJJJ	JJJ	JJ	J	0	B	BB	BBB
0	JJJJ	JJJ	JJ	J	0	B	BB	BBB	BBBB
+	JJJ	JJ	J	0	B	BB	BBB	BBBB	BBBB
+ +	JJ	J	0	B	BB	BBB	BBBB	BBBB	BBBB
+ + +	J	0	B	BB	BBB	BBBB	BBBB	BBBB	BBBB
+ + + +	0	B	BB	BBB	BBBB	BBBB	BBBB	BBBB	BBBB

3. RESULTS

Fig. 8 shows the response of the system to minor disturbances. We placed the ball away from the centre 3 times and waited for the system to respond and settle.

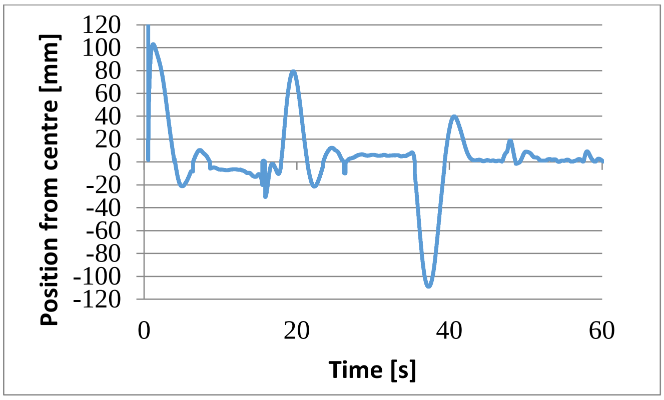

Fig. 8 System response to disturbance

The system has minimal overshoot and settles within an acceptable time of about 10 s, since the settling speed is dependent on the incline of the beam and we worked with the maximum incline we could not develop a faster response in this system.

4. CONCLUSION

We have concluded that next to sliding mode control fuzzy control is a viable alternative for positioning of PMA-s with certain drawbacks. There is no known systematic approach to design fuzzy controllers it is a very time consuming activity based on trial and error, however this setup is excellent as a demonstration device for fuzzy systems.

REFERENCES

B. Ranjbar-Sahraei, F. Shabaninia, A. Nemati and Sergiu-Dan Stan, (2012) "A Novel Robust Decentralized Adaptive Fuzzy Control for Swarm Formation of Multiagent Systems," in IEEE Transactions on Industrial Electronics, vol. 59, no. 8, pp. 3124-3134

E.-C. Lovasz, D. Mărgineanu, V. Ciupe, I. Maniu, C. Gruescu, E. Zăbavă, Sergiu-Dan Stan, (2017) Design and control solutions for haptic elbow exoskeleton module used in space telerobotics, Journal of Mechanism and Machine Theory, Vol. 107, pp 384-398, ISSN 0094-114X

Hosovsky A., Pitel J., Zidek K., Tothova M., Sárosi J., Cveticanin L, (2016) Dynamic Characterization and Simulation of Two-link Soft Robot Arm with Pneumatic Muscles Mechanism and Machine Theory, Vol. 103, ISSN 0094-114X, pp. 98-116

Sárosi J., Csikós S., Asztalos I., Gyeviki J., Véha A. (2011) Accurate Positioning of Spring Returned Pneumatic Artificial Muscle Using Sliding-mode Control 1st Regional Conference - Mechatronics in Practice and Education (MECH-CONF 2011), Subotica, Serbia, 8-10 December, ISBN 978-86-85409-67-7, pp. 350-356

Sárosi J. (2014) Accurate Positioning of Pneumatic Artificial Muscle at Different Temperatures Using LabVIEW Based Sliding Mode Controller 9th IEEE International Symposium on Applied Computational Intelligence and Informat-ics (SACI 2014), Timisoara, Romania, 15-17 May, ISBN 978-1-4799-4693-8, ISBN 978-1-4799-4694-5, Pendrive, pp. 85-89

Sárosi J. (2015) Elimination of the Hysteresis Effect of PAM Actuator: Modelling and Experi-mental Studies Technical Gazette, Vol. 22, No. 6, Print ISSN 1330-3651, Online ISSN 1848-6339, pp. 1489-1494

Sárosi J., Bíró I., Németh J. Cveticanin L. (2015) Dynamic Modelling of a Pneumatic Muscle Actuator with Two-direction Motion Mechanism and Machine Theory, Vol. 85, ISSN 0094-114X, pp. 25-34

Sárosi J., Gergely A., Tölgyi F. (2015) Student Project on Pneumatically Driven Muscle-like Actuators 3rd International Conference and Workshop Mechatronics in Practice and Education - MECHEDU 2015, Subotica, Serbia, 14-15 May, ISBN 978-86-918815-0-4, pp. 153-157

Simon János, Goran Martinović, (2013) "Navigation of Mobile Robots Using WSN's RSSI Parameter and Potential Field Method", Acta Polytechnica Hungarica, Journal of Applied Sciences Vol.10, No.4, pp. 107-118.

Determination and Solution of the Motion of Equation of a Pneumatic Drive Vehicle

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Abstract: As a part of a several-year long development process, applying our computerized measuring system, we determined the basic characteristics of the engine of a pneumatic driven mobile. Utilizing the above characteristics and also the Maple 13.0 software we established and solved the equation of motion of the vehicle and determined its velocity- and covered distance-time functions. The dependence of the above kinematic functions on the technical parameters was analyzed by the GeoGebra 4.4 software. The dynamic simulation of the motion of the vehicle was also performed with the MATLAB/Simulink 7.8 software. Applying this software the optimal parameters of the drive can be determined indirectly.

1. INTRODUCTION

In 2008 the Bosch Rexroth Hungary Company announced a special competition for the institutions of higher education. The aim of the competition was to design and create a vehicle powered by compressed air. It immediately became a huge success among the professors and students in higher education. Throughout the years it became a prestigious and professional competition. Our team has been taking part in the competition since the beginning, and it gave a lot of fun and achievements to our faculty, to the students participating in the competition and to the professors as well.

2. MATHERIALS AND METHODS

From race to race the vehicles evolved. Figure 1 shows the parts of the pneumatic engine of a model in 2013 (Szíki *et al.*, 2014). (Fig. 1)

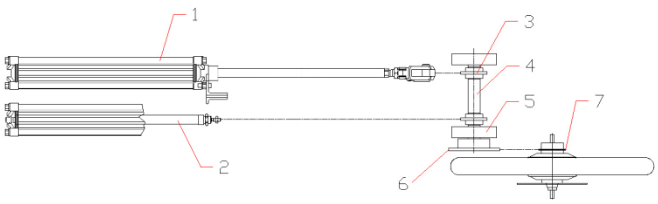

Fig. 1. Parts of the engine of a pneumobil model in 2013

In this model the two ∅80 cylinders (1) are arranged parallel next to each other. The cylinders work independently only in pulling mode. These are connected to two ∅25 cylinders (2) with a chain, they are responsible for pulling back the bigger cylinders. The force of the cylinders drive the crankshaft (4) through two sprockets (3) integrated on two freewheels. The crankshaft is attached to the frame of the vehicle with two Y-bearings (5). The drive sprocket (6) is fixed at the end of the crankshaft, which transfers the torque to the wheel through the driven sprocket (7). We use an internal gear hub which makes us possible to change gears while driving.

In order to be successful in the competition we had to introduce measurement technologies and scientific evaluation of the measurement results. After that, we used the results to develop our vehicle. This work is a part of a several-year long development process. In this article we introduce the scientific work that led us to the determination and solution of the equation of motion of the vehicle. The main aim of the measurements was to determine the performance diagrams of the pneumatic engine. This data cannot be found in today's literature. With the help of this knowledge we are able to optimize the drive of the vehicle theoretically. This article does not contain the optimization process in details. With the help of the measurement result we were able to determine and solve the equation of motion of the pneumobil, which we are going to explain in details.

In 2013 the Bosch Rexroth Company introduced a new race category. The aim of this category was to create a measuring system, which observes the technical parameters of the pneumobil. We decided to take part also in this category thus we created a computerized measuring system, where the data acquisition device is a NI CompactRIO. The data are transmitted to the computer through a Cisco Wi-fi router. The task of the measuring system is to acquire the signals of the sensors attached to the pneumobil and transmit them to the computer in real-time mode. Before, the measuring system could measure the physical signals, the sensors have to transform the physical quantities into electrical signal, like voltage or electric current. Since the computer is not able to receive the signals of the sensors, the data acquisition device has to digitalize them first. The software controls the whole system. It gathers the measured data, analyzes them, then displays the results. On Figure 2 we can see the flow chart of the controlling and measuring systems of the pneumobil. (Fig. 2)

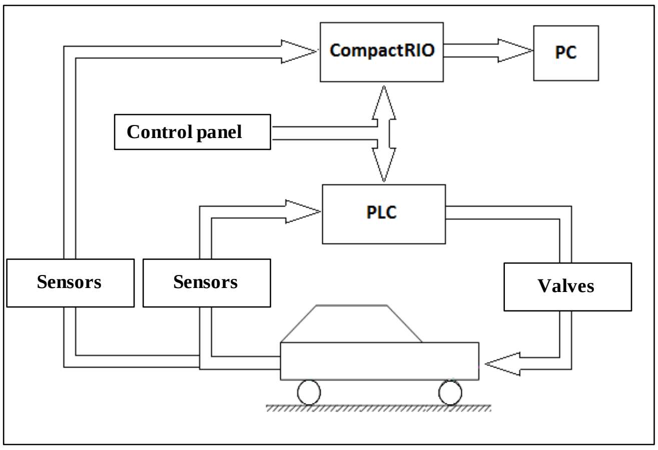

Fig. 2. Flow chart of the controlling and measuring system

Measured quantities:

- Air pressure inside the cylinders
- Air pressure coming out of the tank
- Position of the piston
- Velocity of the pneumobil
- The air consumption of the pneumatic engine
- Running time of the pneumobil (time)

Derived quantities:

- The force exerted by the compressed air on the piston (piston force)
- Velocity of the piston
- Acceleration of the piston
- Power of piston force

Derived to be displayed functions (only the most important ones):

- Air pressure inside the cylinder as a function of time
- Piston force as a function of time
- Velocity of the piston as a function of time
- Power of piston force as a function of time
- Piston force as a function of piston velocity magnitude

The last function is one of the most important characteristics of the pneumatic engine. (Fig. 3)

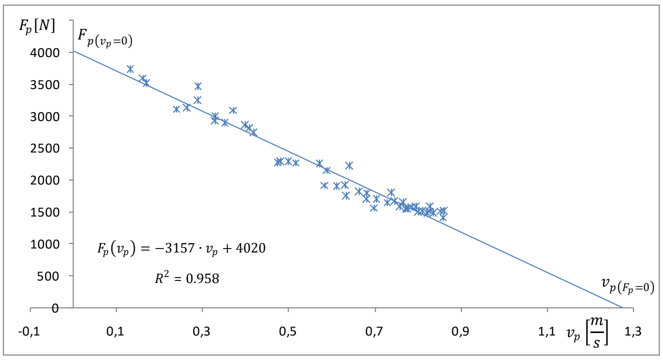

Fig. 3. Piston force as a function of piston velocity magnitude

The small crosses in the figure denote experimental values. It can be seen that these data points fit well a line. The intersections of the fitted line with the F_p and v_p axes are denoted with $F_{p(v_p=0)}$ and $v_{p(F_p=0)}$ respectively. The equation of the $F_p(v_p)$ function can be expressed with the above parameters:

$$F_p(v_p) = -\frac{F_{p(v_p=0)}}{v_{p(F_p=0)}} \cdot v_p + F_{p(v_p=0)} \qquad (1)$$

From this function – regarding Figure 1 – the driving force on the periphery of wheels of the pneumobil can be determined as a function of pneumobil velocity:

$$F(v) = \beta \cdot v + F_{(v=0)}, \quad \beta = \frac{F_{(v=0)}}{v_{(F=0)}} \qquad (2)$$

We can see that the above function is also linear. The $F_{(v=0)}$ and $v_{(F=0)}$ intersections can be calculated as:

$$F_{(v=0)} = F_{p(v_p=0)} \cdot \frac{r_1}{r_2} \cdot r_3 \cdot \frac{1}{i_{34}} \cdot \frac{1}{R} \cdot \eta,$$

$$v_{(F=0)} = v_{p(F_p=0)} \cdot \frac{r_2}{r_1} \cdot \frac{1}{r_3} \cdot i_{34} \cdot R \qquad (3)$$

The r_1, r_2, r_3 parameters represent the radiuses of sprockets 3, 6 and 7, i_{34} is the gear ratio in the internal gear hub, R is the radius of the driven wheels and η is the efficiency of driving.

3. RESULTS AND DISCUSSION

For the determination of the $v(t)$ and $s(t)$ functions we solved the differential equation of the motion of the pneumobil. Before solving the equation we had examined whether the tyres will slip on the surface of the road – at the given input parameter values – when the vehicle starts from rest. The tyres will roll without slipping if the inequality bellow is true:

$$F_{(v=0)} \leq \mu_0 \cdot m_h \cdot g \qquad (4)$$

In the above equation μ_0 is the coefficient of static friction and m_h is the portion of the mass of the pneumobil on the driven wheels. Provided that the road has a dry asphalt surface ($\mu_0 = 0.9$) we got that the tyres won't slip. Figure 4 shows the forces which act on the vehicle. (Fig. 4)

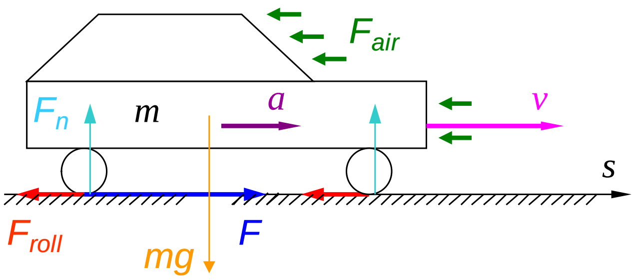

Fig. 4. Forces act on the pneumobil

The formulas of driving force, air and rolling resistance are the following (Budó, 1994):

$$F = F_{(v=0)} + \beta \cdot v, \quad F_{air} = c \cdot v^2 = c \cdot \dot{s}^2,$$

$$F_{roll} = \mu_R \cdot F_n = \mu_R \cdot m \cdot g \qquad (5)$$

Newton's second law of motion for the pneumobil is as follows:

$$F - F_{air} - F_{roll} = m \cdot a = m \cdot \dot{v} \qquad (6)$$

Thus the differential equation of the motion is the following:

$$F_{(v=0)} + \beta \cdot v - c \cdot v^2 - \mu_R \cdot m \cdot g = m \cdot \dot{v} \qquad (7)$$

$$-\frac{c}{m} \cdot v^2 + \frac{\beta}{m} \cdot v + \frac{F_{(v=0)}}{m} - \mu_R \cdot g = \dot{v} \qquad (8)$$

Introducing the following constants:

$$A = -\frac{\beta}{m}, \quad B = \frac{F_{(v=0)}}{m} - \mu_R \cdot g, \quad C = \frac{c}{m},$$

$$D = \sqrt{A^2 + 4BC} \qquad (9)$$

$$-\frac{c}{m} \cdot v^2 + \frac{\beta}{m} \cdot v + \frac{F_{(v=0)}}{m} - \mu_R \cdot g = \dot{v} \qquad (10)$$

$$-C \cdot v^2 - A \cdot v + B = \dot{v} \qquad (11)$$

Providing that the mobile starts from rest we get the following initial value problem:

$$-C \cdot v^2(t) - A \cdot v(t) + B = \dot{v}(t), \quad v(0) = 0 \qquad (12)$$

The solution of the above problem with the Maple 13.0 mathematics software (Maple) is as follows:

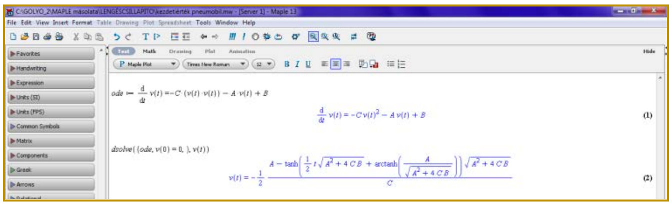

Fig. 5. Solution of the initial value problem of the pneumobil

Thus the $v(t)$ function is the following:

$$v(t) = \frac{D}{2C} \cdot \mathrm{th}\left(\frac{D}{2} \cdot (t + C_1)\right) - \frac{A}{2C} \qquad (13)$$

The $s(t)$ function comes from the $v(t)$ function by integration:

$$s(t) = \frac{1}{C} \cdot \ln\left(\mathrm{ch}\left(\frac{D}{2} \cdot (t + C_1)\right)\right) - \frac{A}{2C} \cdot t + C_2 \qquad (14)$$

The C_1 and C_2 constants are determined using the $s(0) = 0$ and $v(0) = 0$ initial values:

$$C_1 = \frac{2\mathrm{arth}\left(\frac{A}{D}\right)}{D}, \quad C_2 = -\frac{1}{C} \cdot \ln\left(\mathrm{ch}\frac{DC_1}{2}\right) \qquad (15)$$

For the visualization of the dependence of the $v(t)$ and $s(t)$ functions on the input technical parameters $(\beta, m, F_{(v=0)}, \mu_R, c)$ we applied the GeoGebra 4.4 software (GeoGebra). (Fig. 6)

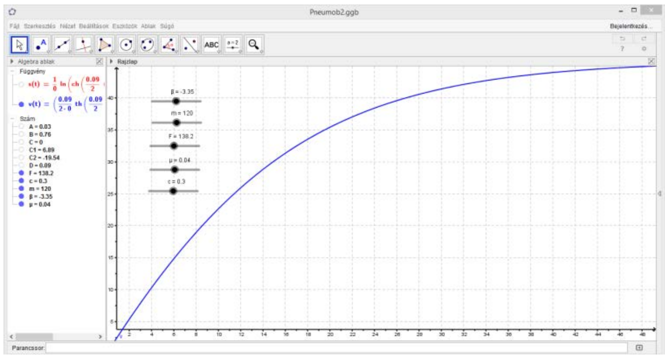

Fig. 6. Dependence of the v(t) function on the input technical parameters

In the above software, the parameter values can be varied with dragging sliders. After we drag a slider the graph of the function immediately changes.

The dynamic simulation of the motion of the mobile has been performed with the MATLAB/Simulink7.8 software (Simulink). The block diagram of the simulation is presented in Figure 7. (Fig. 7)

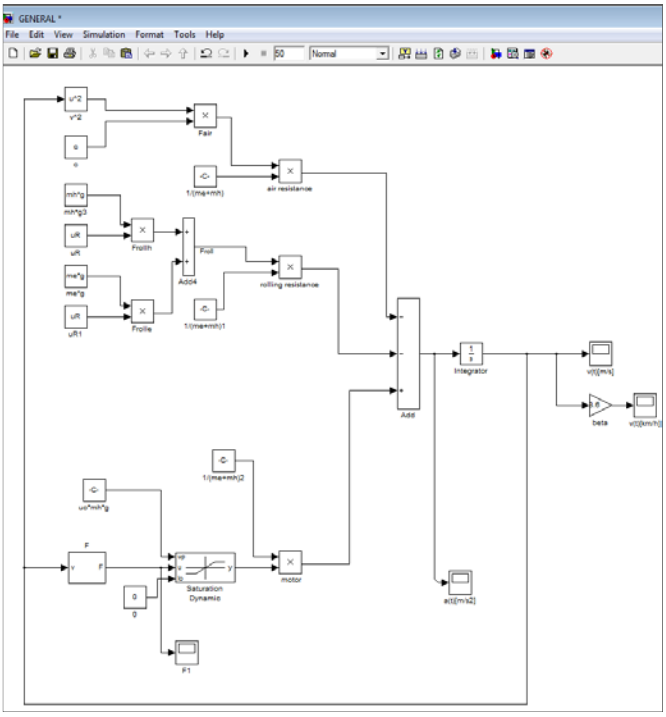

Fig. 7. The block diagram of the dynamic simulation of the motion of the mobile

The calculated velocity-time function by the Simulink software is presented in Figure 8. (Fig. 8)

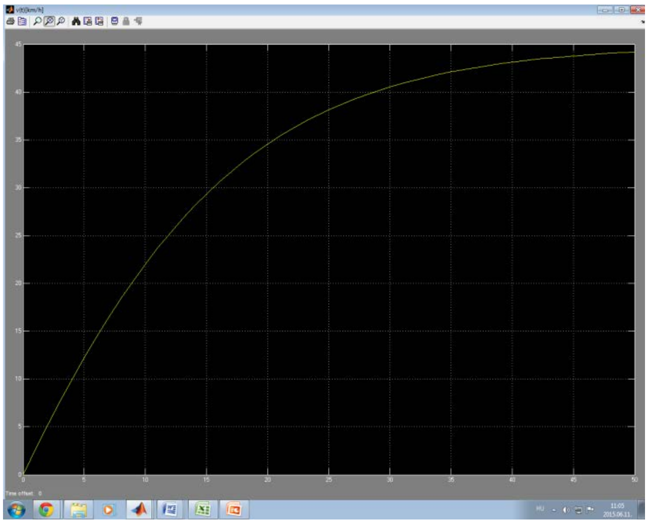

Fig. 8. Velocity-time function calculated by the Simulink software

Figure 7 and Figure 8 well represent that the velocity-time functions obtained by the two different procedure are the same.

5. CONCLUSIONS

Applying our computerized measuring system we determined the basic characteristics of the pneumatic engine of an own developed pneumobil. Utilizing the above characteristics and also the Maple 13.0 mathematics software we established and solved the equation of motion of the vehicle. As a result we have got the velocity – and covered distance-time functions providing that the vehicle starts from rest. The dependence of the above kinematic functions on the input technical parameters was analyzed with the GeoGebra 4.4 software. The dynamic simulation of the motion of the vehicle was also performed with the Simulink 7.8 software. With this software the optimal technical parameters of the drive (such as the optimal gear ratio in the internal gear hub) can be determined indirectly. In the near future our aim is to develop a two dimensional model for the more complete and accurate dynamic characterization of the motion of the pneumobil. In this model the vertical load and longitudinal force on the tires would be calculated as a function of running time, in the case of the longitudinal force, applying the Pacejka "Magic Formula" (Pacejka, 2006). We also intend to measure all the necessary constants in the applied formulas for rolling and air resistance and also in the Pacejka formula (Pacejka, 2006).

REFERENCES

G. Á. Szíki, Gy. Juhász, R. Nagyné Kondor, B. Juhász (2014). Computer program for the calculation of the performance parameters of pneumobiles. ISCAME, 159-166.

Á. Budó (1994). Mechanika [Mechanics]. Nemzeti Tankönyvkiadó, Budapest (H); ISBN 9631859703.

Maple 13.0. Copyright © Maplesoft, a division of Waterloo Maple Inc. 1981-2009.

http://www.geogebra.org

http://www.mathworks.com/products/simulink/

H. B. Pacejka (2006). Tyre and vehicle dynamics. SAE International pp. back cover, ISBN 978-0-7680-1702-1.

Vehicle frame optimization using Finite Element Method

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Abstract: A research has been made to find and avoid a serious design flaw in the metal frame of the FlexAir Pneumobil race car. During take-off, the load provided by the driving piston causes distortion of the vehicle frame, which results insufficient load on the chain drive, causes chain break, and fall off. In order to correct the mistake, the frame had to be investigated, and modifications had to be taken. In this paper an investigation using FEM of the rolling cage of Pneumobil race car built by University of Óbuda FlexAir team will be presented. The FEM provides us possibility to simulate stress allocation, deformations caused by the extreme load, helps us to optimize the frame, and having the necessary modifications done the improvements can be validated again by the simulation. Having different solutions tested, the one, which provides the best result will be realized by the students. At the end of the paper further methods are recommended to avoid unexpected failures during the design phase.

1. INTRODUCTION

During the last century the factories, and research institutes are collected significant knowledge about car, and engine design. However pneumatic engines are different from conventional engines. They are producing an extremely large driving torque, with low speed. In an average pneumobil race car cylinder forces are in the range of 2-4kilonewtons, main axle torque are 2-300Nm These extreme conditions are causing surprises even for experienced constructors.

2. DESCRIPTIONS

The following two chapters are describing the vehicle, and the problem. Because pneumobils are not conventional vehicles, a short introduction about the linear force conversion to rotational motion is described at first. After the work principle description the problem caused by the extreme load, and the failure mode is described.

2.1. The vehicle

Pneumobil is a compressed gas powered vehicle. As fuel 200bar compressed nitrogen is used, and according to the technical specification linear pneumatic cylinders must be used to provide driving force.

In order to utilize both stroke of the linear piston a double chain drive is used. The fork shaped head at the end of the piston rods pulling one chain on the upper, the other on the bottom side (Fig. 1).

The endless chain is guided on both sides by chainwheels, on one side with a bushing, on the other with a free-wheel. The free wheel side drives the main axle. To provide a unidirectional drive torque on the main axle of the vehicle, two oppositely mounted especially for this powertrain designed freewheels are used. (Fig 2, and 3)

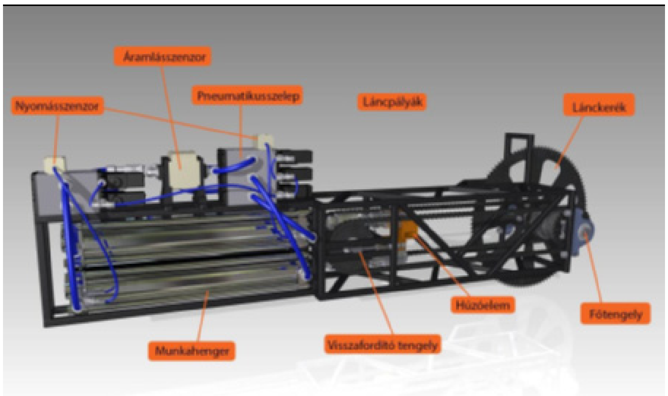

Fig. 1.The pneumatic engine and its frame.

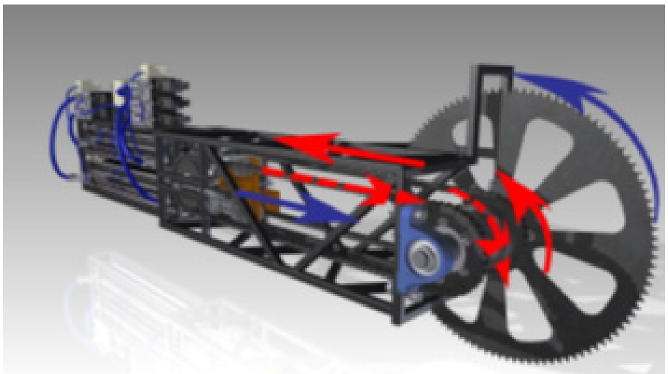

Fig. 2. Pneumatic engine operation in positive stroke of the cylinder

During positive (outward) stroke of the pistons, the left freewheel drives the main axle, the other rolls free. In opposite stroke, the counterpart freewheel drives

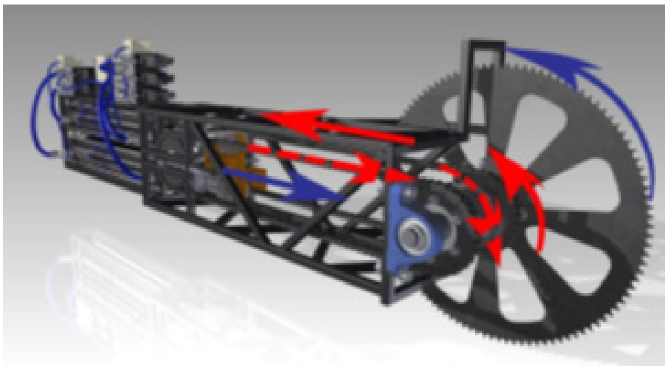

Fig. 3. Pneumatic engine operation in negative stroke of the cylinder

2.2. The problem

The above mentioned problem occurs during start. The greatest load on the chains occur while the vehicle stands still, and is being accelerated. The total mass of vehicle and driver is to be accelerated is about 160 kg. Cylinder forces are in the range of 2-4kN

Fig. 4. Direction of load on the engine frame

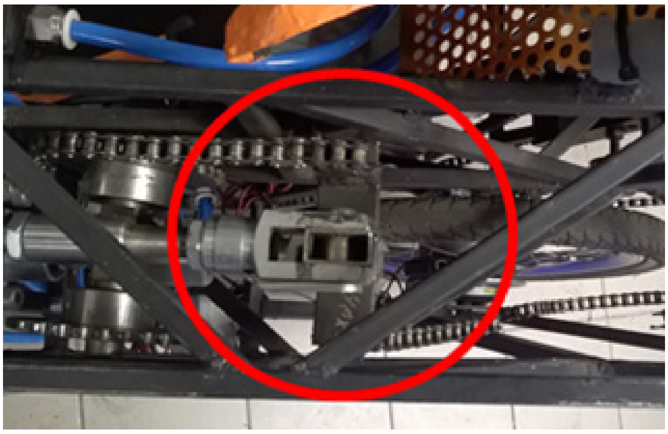

Fig.5. Chain break as a result of chassis distortion

It can be seen that, because of chains used for force transmitting, during operation, always pulling force occurs on the engine frame. (Fig 4)

Figure 5 shows the chassis distortion resulted damages on the pneumatic engine.

3. MODELLING

In this paper a significant malfunction of the University of Óbuda FlexAir Pneumobil team's car is investigated, and solved.

The problem occurs during start the: The driving pneumatic pistons are providing so large stress on the vehicle frame that causes distortion on the frame which twists the transmission geometry. As a result chain drop off, or chain break occurs.

In order to avoid the problem a complete investigation of the chassis and the drive train had to be performed.

In order to analyse the problem, finite element method (FEM) was used. (Kiss, 2016)

The FEM is usually applied during the design phase, and one of the static material proof is done after the production. In this example the FEM is used for failure analysis.

There was a series of simulation runs using different loads performed. During model-creation some problem needed to be solved. First an appropriate CAD model needed with exact geometry, and material properties. (Fig.6) The frame is made of 15 by15 mm hollow section carbon-steel with 1.5mm wall thickness.

This frame (fig. 6) is bearing all the static, and dynamic loads.

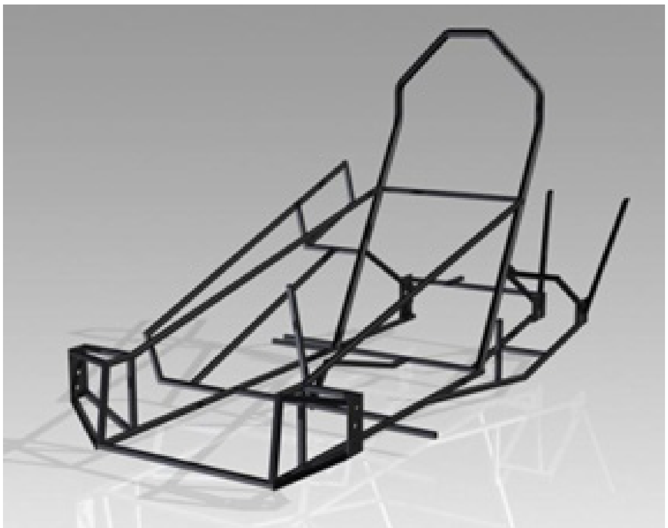

Fig. 6. Chassis model of *FLUX-Gate pneumobil*

The main advantage of this material is that it is easy to weld, and easy to form in any desired shape. The disadvantage is that the density is greater than any of the preferred light metal alternatives. A weight optimization is therefore necessary, especially in race purposes.

Before the optimization the initial conditions must be set. All materials are set to S235JR steel. The frame model constrains are set to "weld". The blind (no load bearing) part has been removed for simplicity, and minimizing modelling mistakes.

Further possible modelling mistake can be taken by incorrect parts coupling. During simulation modification of the construction had to be done, and stopped simulation had to be restarted several times.

Fig.7 Noded frame.

The noded frame can be seen on fig. 7. The software used 214496 tetrahedral nodes. The mass of the frame: m=19.312 kg. When a modification is applied on the part, de nodding must be always repeated. Having the nodding successfully done, the initial conditions must be set, like material properties, loads, constrain surfaces and reference coordinate systems

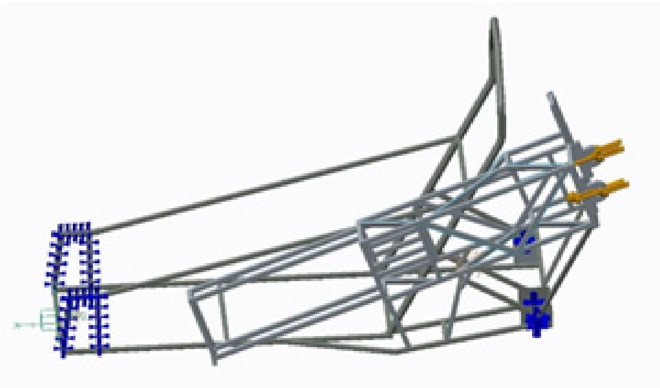

Fig.8. Applied force, and support surface

Having the parameters, and conditions set, the FEM analysis can now be run

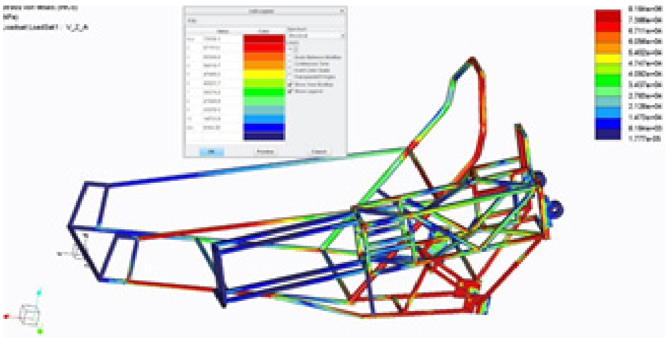

Fig.9. Stress distribution on the frame

The time required for the analysis is proportional to the model complexity. For simpler models the software provides result within minutes, the rather complex model simulation takes up to days. The simulated parameters in our case were stress σ=[kPa] and displacement l=[mm]. The simulation mode is static analysis, which provides results without dynamic properties. No damping, or inertia is considered in the simulation.

A special caution must be paid during the set of the conditions, because the accuracy of the simulation depends on the accuracy of the conditions. (Pokorádi, 2009) Taken it in mind has the load vector, and the fixation of the frames set. (Fig 8)

The FEM software runs the simulation within the elastic deformation range of the steel material. Plastic deformations can not be modelled, but so great mechanical stress are not allowed either on the real vehicle operation.

The failure caused by the roll torsion described in the introduction can obviously be seen on the figure. The load on the frame, on the side, where the engine is located is significant, which is the origin of the distortion. The engine frame itself does not have significant stress. (Fig 9)

It can be seen on the picture, that where the engine's frame is connected to the chassis the stress is σ_{max}= 814 MPa while on the opposite side the maximum is $\sigma \approx 51$ MPa This stress difference can be the reason of the chassis twist.

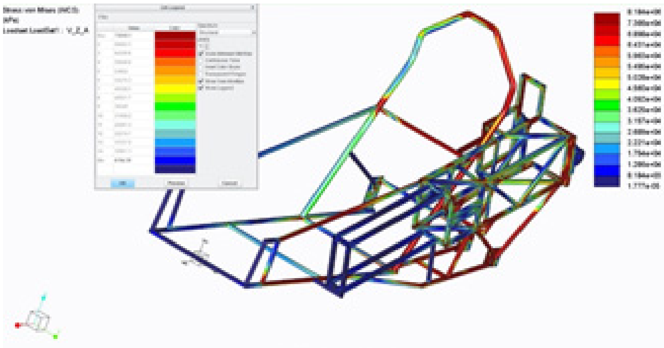

Fig.10 Stress distribution on the frame

Having the stress analysis completed, we started the displacement analysis.

A reference coordinate system needed to be set, which serves as a base for displacement calculation.

As a result for mechanical stress, elastic distortion occurs in the construction, which will be calculated, and displayed by the FEM analysis program. The resulting distortion is shown by a vector, originated from the reference coordinate system, and pointing to the examined point of the construction. The greatest distortion measured during the simulation, as it is shown on Fig 11, l_{max}=95.078 mm.

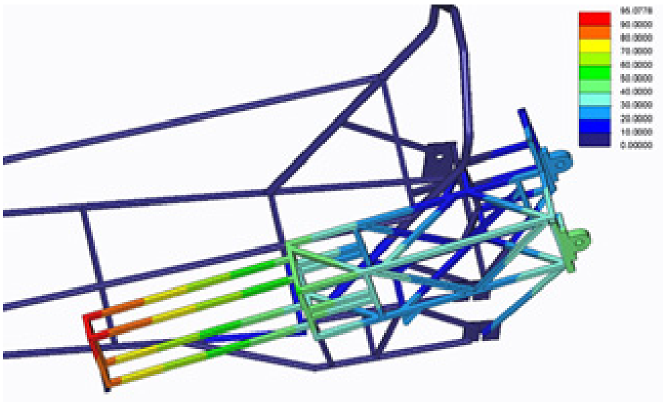

Fig. 11. Displacement of the frame

If we compare the stress and the displacement analysis one can see that the two examined phenomena are inverse-proportional with each others. Where the biggest stress occurred, there was minimum of the displacement, and vice versa.

In the fixed nodes of the frame there is less, on the free parts there is larger displacement. Such free rods with greater distortion can be found at the end of the engine chassis.

4. RESULTS

The asymmetric design of the engine frame, and the resulting uneven load causes distortion of the frame, which is proven by the FEM analysis.

The goal is to balance the chassis for load stress, which in turn avoids chassis twist, and keeps the distortion in acceptable range. Part of the load must be lead to the less stressed side of the frame in order to reach even distribution of symmetric load. Because of the chassis is already manufactured, to reach even load was done by strengthen those rods, where the highest stress occurred.

The strengthening for practical reasons was done, by doubling of the rods simply by welding the same type of component to the overloaded parts.

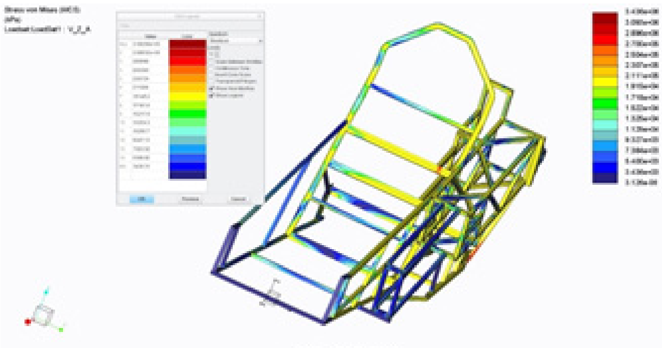

Fig.12. Stress distribution on the optimized frame

It can be seen on figure 12 that having the engine frame rods strengthened provides satisfactory results. The extra rods have distributed the stress, and lessened the displacement.

Besides the engine frame, the engine supporting rods were also strengthened. As the result, the load distribution became even. It can also be seen that such rods are bearing now load, which were not significantly loaded previously.

Looking at the change in the displacement swown on figure 13, significant improvement can also be seen. The l_{max}=95.078 mm-displacement has been reduced to l_{max}=14.11 mm. Displacement reduction can be seen also in the engine supporting rods.

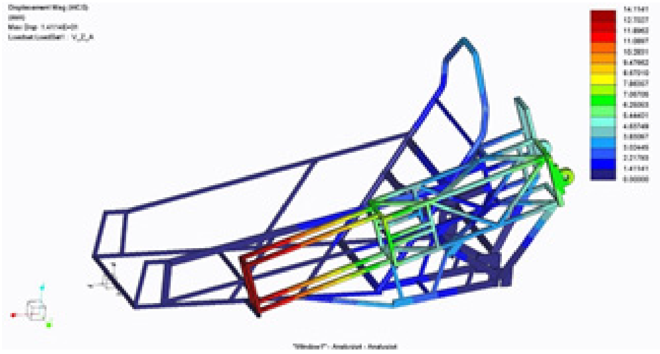

Fig.13. Displacements of the optimised frame

This amount of displacement is satisfactory. Considering that the load is evenly distributed, it will not cause twist of the frame, the drive chain will not be dropped, and no chain break will be resulted.

5. CONCLUSIONS, RECOMMENDATIONS

FEM analysis is usually performed during the design phase-This paper shows an example where the FEM used for problem solving applied successfully. The extreme load caused twist and distortion was eliminated, and minimised, and therefore chain break is eliminated.

As further investigation vibration test is recommended, as Szabó J. describes (Szabó, 2012) This investigation will eliminate the disadvantage if the static FEM analysis.

Further recommendation is that, the FEM, and vibration analysis together with vehicle dynamic analysis would be performed in the design state.

An other possible method would be an FMEA analysis, combined with risk estimation (Hanka, 2012)

REFERENCES

Hanka L: Kockázat becslése numerikus módszerekel a MATLAB alkalmazásával, folytonos eloszlások diszkretizálása. (Risk estimation by numeric methods using MATLAB discretization of continuous distribution) MŰSZAKI KATONAI KÖZLÖNY XXII.:(3.) pp. 55-69. (2012)

Kiss, Gy: Megadott vázgeometria tervezésének ellenőrzése véges-elemes módszerrel. (optimisation of given vehicle frame by FEM) BsC thesis at University of Obuda 2016 .

Pokorádi L Uncertainties of Mathematical Modeling In: Doru Paunescu (editor.) Proceedings of the 12th Symposium of Mathematics and its Applications. Konferencia helye, ideje: Temesvár, Románia, 2009.11.05-2009.11.07. Politehnica University of Timisoara, pp. 471-476.

Szabó J. Z. Vibration Diagnostic Test for effect of Unbalance INES 2012 16th IEEE International Conference on Intelligent Engineering Systems 2012 Lisbon, Portugal June 13-15, 2012. ISBN 978-1-4673-2692-6 (printed proceedings)