A PNEUMOBIL VERSENYEKHEZ KAPCSOLÓDÓ JÁRMŰMODELLEZÉSEK

VEHICLE MODELLING RELATED TO PNEUMOBILE COMPETITIONS

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ABSTRACT. In 2020 will the XIII. Emerson's International AVENTICS Pneumobile Competition be organized. Since 2010 most of car their system designs are based on any kind of modelling, and simulation. Parallel to that, the number of articles related to pneumatic vehicles is increased.

This article is summarizing the most relevant models and methods have been created during the decade.

1. INTRODUCTION

Since 2017 University of Óbuda is organizing the ACIPV conferences related to the Pneumobile competitions. Most of the articles are dealing with pneumatic components, system, or vehicle modelling. There are also research articles published outside the frame of ACIPV, and there are authors working on pneumatic vehicle drive not related to Pneumobile competition as well. There is an increasing number of researches relating to alternative vehicle protrution. In most of the cases alternative protrution means electric-, or hybrid electric drive, but there is an increasing attention paid on other alternatives, like compressed air vehicles (CAVs). The development of such vehicles also requires modelling and simulation. As the requirements are increasing, so do the expectations from the models created.

The list of the articles is far not complete! There are many other articles publicised in this area, and there are thesis works, student scientific conference papers too

The models used for pneumatically driven vehicles can be grouped in different groups:

The depth of modelling:

- concept,
- component,
- network of components,
- subsysems, and
- the entire vehicle.

The concept publications are not modelling the physical details of the vehicle, but they are laying the base of the pneumatic drive in respect of feasibility, economical, and environmental aspects down.[1], [12] In some cases, the optimisation of single components is required, as in case of optimisation of a directional control valve [3]. There is a need for modelling network of components, like cooperation between the valves, piston, puffer tank etc. There are many articles dealing with complete pneumatic systems from the tank till piston force, and motion [11]; [7], etc. The entire vehicle modelling describes the complete vehicle including pneumatic engine, protrution, control, and vehicle dynamics. [8]

Methods used by the design:

- Worksheets,
- analytical system description and modelling
- block modelling.

Worksheets are simple charts, usually created in Excel in order to support vehicle performance evaluation, and help construction decision making. The best example for that is the modell created by Sziki and his team [9] Analytical system description describes the equation of the complete system, usually in matrix equation, transfer functions, and state-space equations. Block modelling use the method of creating interchangeable individual function blocks, and creating the network of components in a block modelling environment, usually in Matlab/Simulink®

2. PUBLICATIONS RELATED TO PNEUMOBILE MODELLINGS

In this chapter the publications will be organized by their occurance.

2.1 ACIPV related articles

1st Agria Conference on Innovative Pneumatic Vehicles – ACIPV 2017

- Compressed Air, as an Alternative Fuel István Tibor TÓTH [12]

2nd Agria Conference on Innovative Pneumatic Vehicles ACIPV 2018

- Optimized Valve System for a Pneumatic Motor M. Madissoo, K. Türk [3]
- Adaptive control based air expansion range extension of pneumatic vehicles Zoltán Márton; Dénes Fodor [13]

– Analysis of the Rolling Resistance of Pneumobiles for Vehicle Dynamic Modelling Purpose Bence Márk Szeszák, György Juhász, GusztávÁron Sziki, Rita Nagy-Kondor, Tamás Sádor Sütő [9]
– Pneumatic modelling of a pneumobile Tamás Szakács [7]

3th Agria Conference on Innovative Pneumatic Vehicles – ACIPV 2019
– Adaptive Pneumatic Suspension Using Linear Quadratic Control Demeter László, FORGÓ Zoltán (Sapientia EMTE Erdélyi Magyar Tudományegyetem) 11-17
– Designing the Suspension of the Airrari Pneumobile Gábor Horváth, István Péter Szabó [14]
– Modelling and Validation of a Pneumobil Tamas Szakacs [8]
– Autonomous Possibilities of a Pneumatic Driven Vehicle Pintér Péter. Kurucz János [15]

2.2 Articles outer ACIPV
– Air Consumption Analysis in Compressed Air Powered Vehicles Uszynski, S., Ambroziak, L., Kondratiuk, M., Kulesza, Z. [11]
– Szíki, G. Á. – Juhász, Gy. – Nagyné Kondor, R. – Juhász, B. (2014). Computer program for the calculation of the performance parameters of pneumobiles, [9]
– The Pneumatic Hybrid Vehicle A New Concept for Fuel Consumption Reduction. Sasa Trajkovic [10],
– Compressed Air Vehicles Drive-Cycle Analysis of Vehicle Performance, Environmental Impacts, and Economic Costs, Andrew Papson, Felix Creutzig, and Lee Schipper, [1]
– Pneumatic Vehicle, Research and Design, Mihai Simon [5]

2.3 Evaluations of the Methods and Results
Trajkovic, in his doctoral thesis concludes ”The pneumatic hybrid vehicle (PHV) concept is a low-cost alternative to the more established electric hybrid. The PHV concept comprises no additional propulsion source and a pressure tank as an energy storage device. The main idea with the pneumatic hybrid is to use the ICE in order to compress atmospheric air and store it in a pressure tank when decelerating the vehicle. [10]

Compressed Air Vehicles Drive-Cycle Analysis of Vehicle Performance, Environmental Impacts, and Economic Costs by Andrew Papson, Felix Creutzig, and Lee Schipper [1]

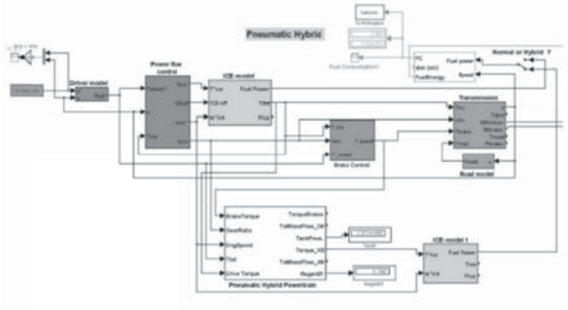

Fig. 1. A PHV Bus model [10]

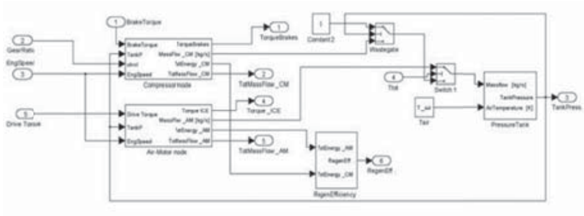

Fig. 2. The pneumatic hybrid specific subsystem [10]

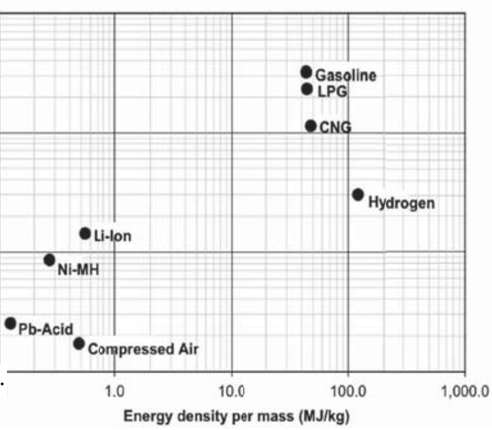

Fig. 3.

Fig. 3 specific energy density in the function of energy density per mass, and per volume [1]

Fig. 3 shows the specific energy density of different energy storages in the function of energy density per mass, and per volume. Their evaluation is: “Even at high pressures, compressed air carries much less energy than other transportation energy sources, including liquid and gaseous fuels as well as rechargeable batteries. Compressed air holds only 0.5% of the energy in gasoline and 1.5% of the energy of gaseous compressed natural gas (CNG). Similarly, the energy density of compressed air is poor compared with the types of rechargeable batteries available for vehicle use: lead acid (Pb–acid), nickel cadmium (NiCd), nickel metal hydride (NiMH), and lithium ion (Li-ion). Although batteries are significantly heavier than compressed air and hold less energy by mass, they still outperform in terms of volume, with compressed air holding 12% of the energy of Li-ion batteries.” [1]

The article assumes the compressed air is at 300bar pressure, and rates the specific energy density of compressed air to 0.35 MJ/kg.
According to other calculations the air itself at 300bar has 0.48 MJ/kg, in 10l industrial bottle (m_b=17 kg) is 0,08MJ/kg. Storing the gas in composite 10l bottle increases the value to 0.213 MJ/kg, and increasing the size from 10 liters to 80 liters increasing the energy density back to the range of Li-Ion batteries. [6]

	Compressed Air Vehicle	Urban Gasoline Vehicle	Urban Electric Vehicle
Fuel type	Compressed air	Gasoline	Electric battery
Fuel economy	38 mpg-e	32 mpg	163 mpg-e
Urban range	29 mi	408 mi	127 mi
Fuel cost ($/mi)	0.21	0.09	0.05

Fig. 4 Performance Characteristics of CAVs vs. Gasoline an EVs [1]

Taking the MDI CityFlowAIR [4] vehicle for basis, the authors published the following: “The drive-cycle simulation used here requires few parameters to calculate energy consumption. The CAV is modelled with the following parameters based on specifications from the vehicle manufacturer: a vehicle with mass of 1,200 kg, a compressed air tank with 300l volume and 300-bar maximum pressure, and a pneumatic motor power with 19 kW (25 hp) maximum power” [1], Fig. 4 shows the result of the calculations
Fig. 5 shows the result of the article. The state of the art in 2010 shows carbon intensity of CAVs, Gasoline vehicles, and EVs

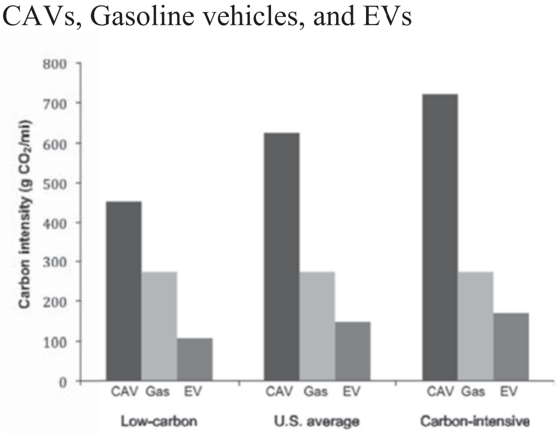

Fig. 5. Comparison of vehicle carbon intensity across electricity generation scenarios [1]

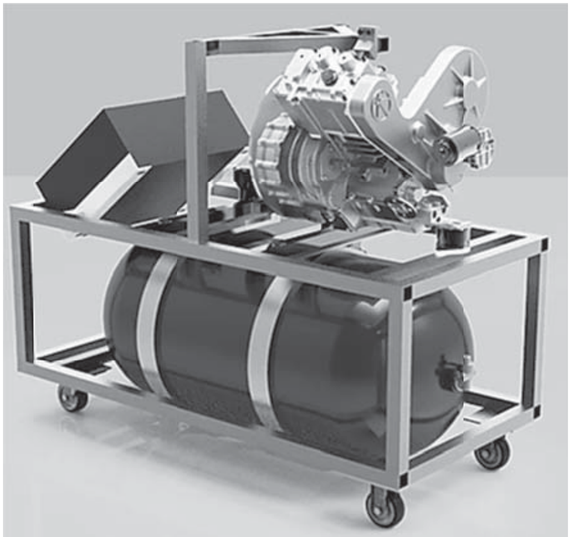

Fig. 6 MDI Air Power Unit [4]

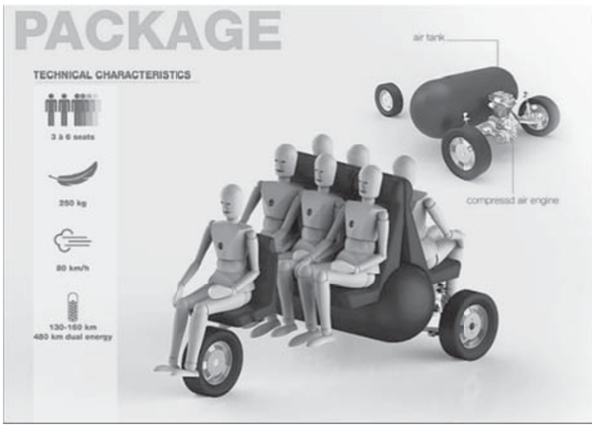

Fig. 7 MDI Air Tuktuk. [4]

The article has been edited in 2010. A decade later the manufacturer provides new different types of vehicles with extended range, and scale. [4]. Fig. 6 shows an air power unit from MDI, and Fig. 7 shows a personal car for 7 persons

An analytical model in Excel has been created by Áron Gusztáv [9]. “The presented computer program is capable of calculating the performance parameters of pneumobiles from the technical parameters of their machine parts.”

“The presented computer program is capable of the calculation of the performance parameters of pneumobiles from their other technical parameters.

One of them is done by Uszynski, S., Ambroziak, L., Kondratiuk, M., Kulesza, Z, and have published as “Air Consumption Analysis in Compressed Air Powered Vehicles” [11], the other is “Pneumatic modelling of a pneumobil”, and “Modelling and validation of a pneumobil” [7],[8]. The motivation for both is the Pneumobile competition. Both authors are based their concept on describing the pneumatic system of the vehicle based on gas chambers, and pressures building up caused by gas mass flows between chambers.

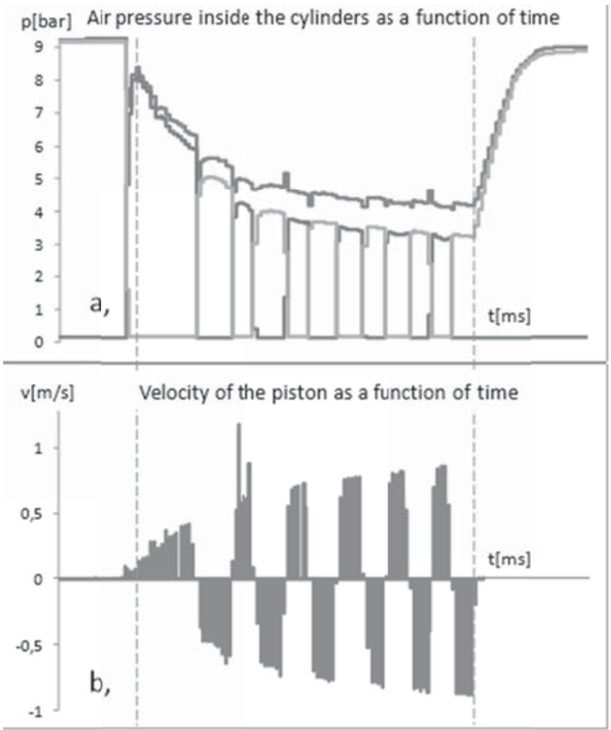

Fig. 8. Air pressure inside the cylinder and flowing out of the tank (a) velocity of the piston (b) as the function of the running time of the pneumobil [9].

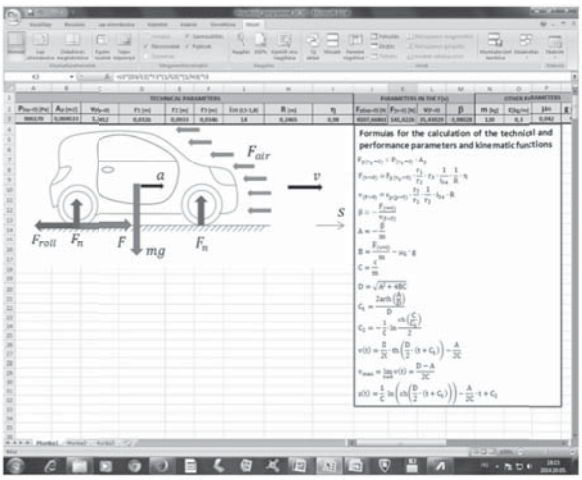

Fig. 9. The Excel program (columns A- M). [9].

Reached speed and covered distance within a given period of time and also the top speed of the vehicles can be calculated. Moreover, the optimal values of the technical parameters (such as the optimal gear ratio in the chain drive and in the internal gear hub) can be determined indirectly".

There is a couple of research publication building up the pneumatic system of a Pneumobile vehicle from function blocks. Two models have been developed in the same time, independent from each-other.

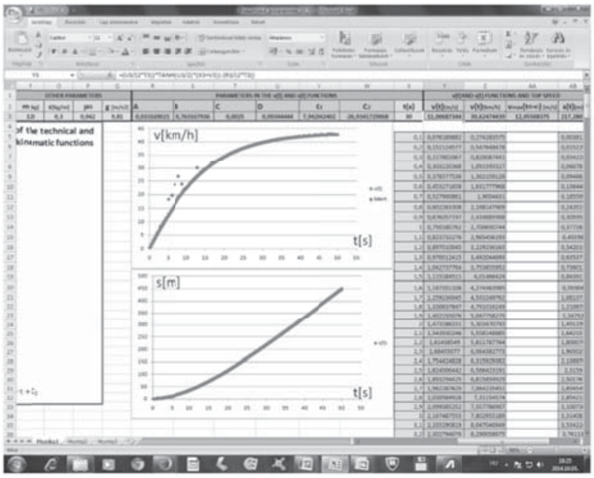

Fig. 10. The Excel program (columns N-AB). [9].

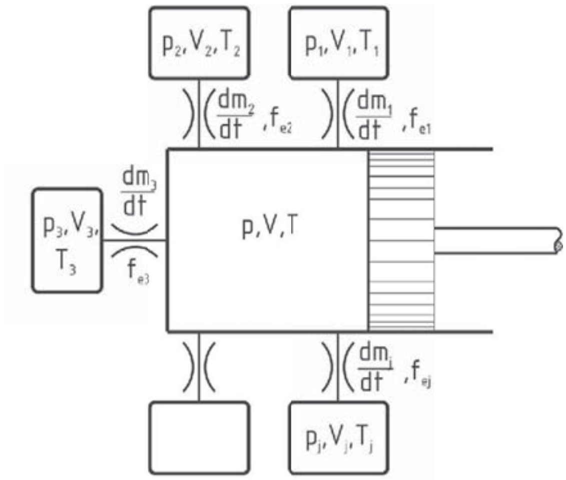

Fig. 11. Variable volume chamber in connection with other chambers [11]

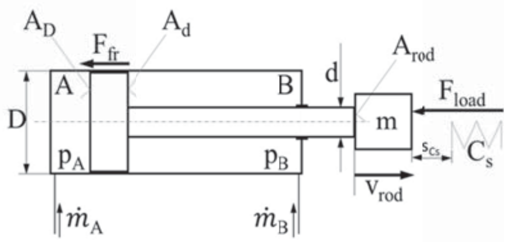

Fig. 12. The dual chamber piston by Szakács

$$F = p_1 \cdot A - p_2 \cdot A_2 - F_{fr} - p_0(A - A_2) - F_{load} \quad (1)$$

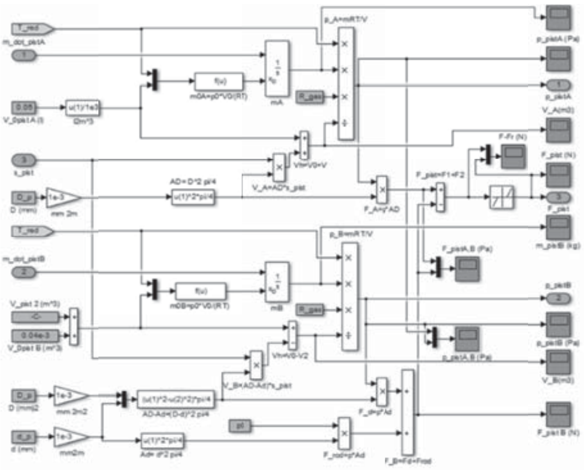

Fig. 13. The dual-chamber piston model in MatlabSimulink®[8]

Validation measurements carried out in order to gain information about piston chamber pressures. And piston speed during a straight run, on a measuring track.

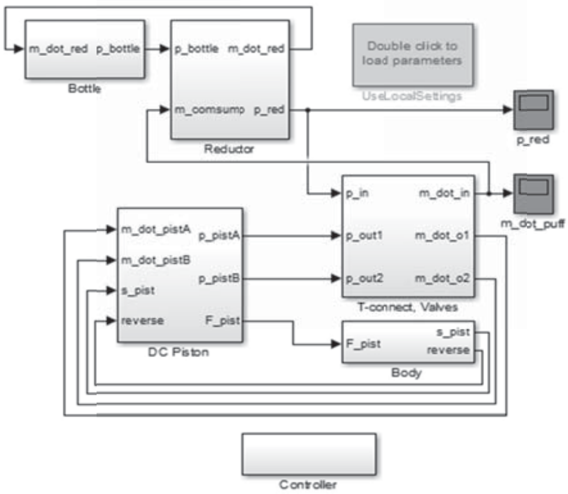

Fig. 14..The pneumatic system model [8]

A car setting of 8 bars system pressure, and 30% expansion mode has been selected [2]. The chamber pressures and piston position were recorded. The results are shown on Fig. 16

Having the same parameters set on the model, there was a simulation run. the simulation results of the two channel pressures are shown in Fig. 17

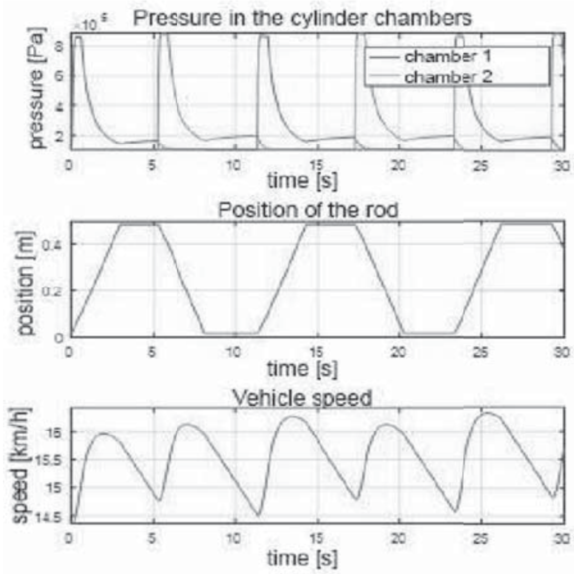

Fig. 15. Pressure in the piston chambers, change of position and vehicle speed in case 20 % of the actuator piston feed/pull-out [11]

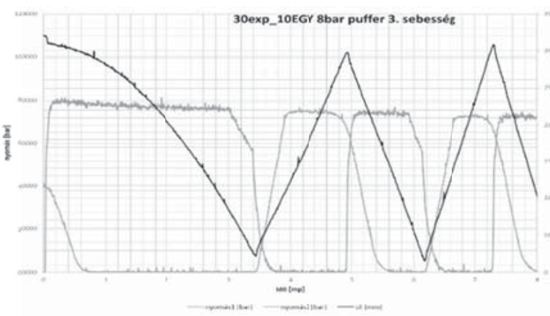

Fig. 16..Measuring results [2] [7]

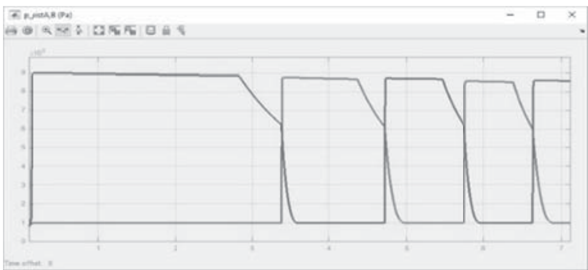

Fig. 17..Simulated piston chamber pressures [8]

3. CONCLUSIONS

The different research groups are developing their own models. Each groups are using their own modelling method, but sometimes these are very similar to each other. The ACIPV conferences are the most active events for researchers working in the area of pneumatically driven vehicle to share their results.

There are research groups working on the field of CAV modellings, and development outside the Pneumobile competition. There are such vehicles available in the market in Europe, India, and China.

4. OUTLOOK, RECOMMENDATIONS

The market potential of CAVs are currently low, but there is a potential in the area. The currently independently working research teams are already cooperating in the field of Pneumobile vehicle developments, but further increase of cooperation is expected. A formation of a consortium is recommended. A SWOT analysis of compressed air drive is still missing, and the published researches did not involve yet vehicle informatic system in the modelling, or it has not published yet. The stronger publicity of the research results are also recommended to connect the groups working within, and outside Pneumobile competition.

ACKNOWLEDGEMENT

The research presented in this paper was carried out as part of the EFOP-3.6.2-16-2017-00016 project in the framework of the New Széchenyi Plan. The completion of this project is funded by the European Union and co-financed by the European Social Fund.

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