ISSN 2457 – 5275 (Online, English)
ISSN 1842 – 4074 (Print, Online, Romanian)

THE PNEUMATIC PROPULSION SYSTEM OF A ROAD VEHICLE

Catalin CHIOREANU, Tudor MITRAN*, Sorin PATER, Marius PELE

University of Oradea, Str. Universitatii, Nr. 1, 410087 ORADEA, Romania

(Received 15 September 2019; Revised 05 October 2019; Accepted 02 November 2019)

Abstract: *The paper presents the functional scheme of a pneumatic propulsion system for road vehicles. This includes a high-pressure air tank, a low-pressure air tank and a pneumatic motor that converts the energy stored in the compressed air tank into mechanical work. The design of the pneumatic motor is an innovative one (the authors have no information about such system that has been designed or manufactured worldwide). It takes over the functions of the gear box: the adjustment of the torque and the change of the rotational sense. In order to estimate the autonomy of such a vehicle, one has developed an energy balance of the propulsion system. Based on the energy consumed for the generation of the high pressure compressed air it aims to estimate by calculus the distance that the vehicle can travel. This solution aims to offer a less polluting propulsion systems for the road vehicles. As known, the manufacturing and the recycling technologies for the electric batteries produce polluting materials and emissions.*

Key-Words: *Compressed air. Energy balance. Pneumatic motor. Pneumatic propulsion.*

NOMENCLATURE

α : the cam's rotational angle, rad
ict : the number of cylinders for one torque step, m^2
it : the number of torque steps,
Mcm : the mean torque developed by one cylinder, Nm
n_1 : the maximum rotational speed, rot/min
$\dot{m}_1$: the mass flow that passes from the high-pressure tank to the low-pressure tank, kg/s
$\dot{m}_2$: the mass flow that passes from the low-pressure tank to the pneumatic cylinders, kg/s
V_1 : the volume of the high pressure tank, m^3
R : the air constant, J/(kg.K)
T1 : the temperature of the compressed air inside the high-pressure tank, K
dp/dτ: the variation of the pressure inside the high-pressure tank due to the air consumption in the interval dτ, Pa/s
ρa : the air density, kg/m^3
V_m: the volumetric flow of the air consumed by the pneumatic motor, m^3/s
dr : the driving's wheel diameter, m
nr : the pneumatic motor's maximum rotational speed, rot/min
r0 : is the base circle radius, mm
s(α) : is the function of the piston's displacement, mm

1. INTRODUCTION

The idea of a pneumatic propulsion system is not a novelty. The pneumatic propulsion system for road vehicles should be an alternative to the electric propulsion. The main disadvantages for the electric propulsion are: the fact that the manufacturing and the recycling technologies are pollutant and, at least at this moment, the rechargeable batteries infrastructure involves a great amount of electric current that can lead to failures of the electric grid. Another advantage of this solution is the much shorter time necessary for the compressed air tank to be refilled in comparison to the one necessary for the electric batteries. Some theoretical studies aimed to reveal the strong and the weak points of the pneumatic propulsion systems for road vehicles [1].

* *Corresponding author e-mail:* tudor_mitran06@yahoo.com

ISSN 2457 – 5275 (Online, English)
ISSN 1842 – 4074 (Print, Online, Romanian)

These studies also offer information for the optimal conditions for the operation of such propulsion systems. Other studies in this field were focused on the environmental impact and on the costs of this solution [2]. These studies give information about the feasibility of implementing such propulsion systems and the conditions in this can happen.
The French company Motor Development International (MDI), established in Luxemburg [3] have realized a partnership with Tata Motors [4] in order to develop a large range of road vehicles with a pneumatic propulsion system. All these steps where not been finalized in serial product, although the main construction concepts of the vehicles were enounced.
The most proposed solutions are based on the Internal Combustion Engine cycle, that means that the general construction of the pneumatic motor is similar to the thermal engine. Another possibility is the use of pneumatic cylinders with single or with double action.
The objective of this paper is to present a new, innovative, concept for a pneumatic propulsion system for road vehicles. This is a continuation of the studies presented in a previous paper [5].
The authors have no information about such system that has been designed or manufactured worldwide. It takes over the functions of the gear box: the adjustment of the torque and the change of the rotational sense. The energetic balance should point the performances of the proposed system. Considering the energy conversion, one can estimate efficiencies with close values for both propulsion systems (pneumatic and electric), but the reliability (the safety in operation) and the endurance of the new pneumatic system will be net superior to the ones of the nowadays electric propulsion systems. Based on the theoretical study, one can think about the development of the system and it's practical application.

2. THE FUNCTIONING OF THE PNEUMATIC PROPULSION SYSTEM

In figure 1 is presented the operational scheme of the new proposed pneumatic propulsion system [6].

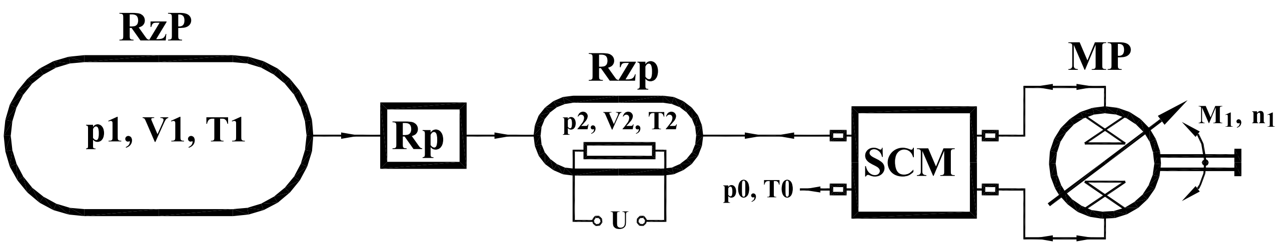

Figure 1. The functioning scheme of the pneumatic propulsion system

The system consists of the following main components: the high-pressure air tank RzP; the pressure regulator Rp; the low-pressure air tank Rzp; and the pneumatic motor with stepped torque adjustment MP. The pneumatic motor takes over and transforms the pneumatic energy from the low-pressure air tank in mechanical energy, generally under the form of a rotational movement, with the following parameters: the motor torque (M_1) and the rotational speed (n_1). These parameters can be adjusted by modifying the motor torque developed by the pneumatic motor. The adjustment of the rotational torque can be done in steps through the motor command system (SCM). Also, through the SCM system one can realize the braking of the vehicle with the recovery of the braking energy (by passing the motor into compressor mode) and, also, the inversion of the vehicle's moving sense.
The propulsion system operates as follow: the pneumatic motor (MP) takes over the pneumatic energy from the low-pressure tank (Rzp) and transforms it into mechanical energy at the parameters necessary for the actuation of the vehicle's running system. The pressure p2 (0,8 – 1 MPa) and the temperature T2 of the air inside the tank Rzp are maintained constant, so that the pressure and the temperature of the exhaust air from the motor should be approximately equal to the environmental pressure and temperature (p0 and T0). The pressure p1 of the air inside the tank RzP varies due to the consumption, from the maximum value p1 = p1max = 20 – 30 MPa, to a minimum value p1 = p1min = p2.
The pneumatic motor with stepped variable torque is a reversible pneumatic machine with stepped adjustment of the rotational torque. It is composed of more identical adjustment steps successively connected to the pneumatic energy source [6].
The functional scheme of the variable stepped adjustment pneumatic motor is presented in figure 2.

ISSN 2457 – 5275 (Online, English)
ISSN 1842 – 4074 (Print, Online, Romanian)

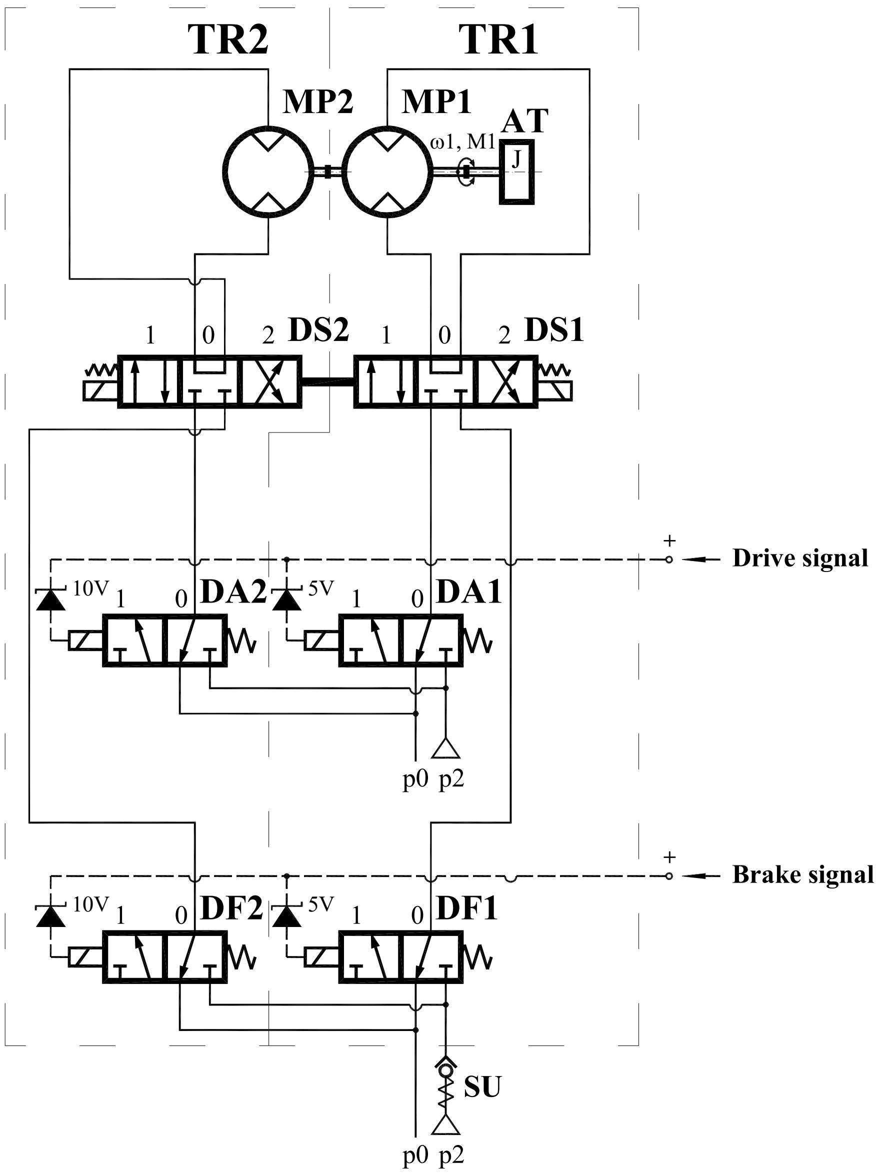

Figure 2. The functional scheme of the variable stepped adjustment pneumatic motor.

In the figure 2 it is presented the functional scheme of the pneumatic motor with two steps of the torque adjustment (TR1 and TR2). The TR1 torque adjustment consists of: the pneumatic motor (MP1) with constant capacity sense distributer DS1, for the change of the rotational sense: actuation distributer DA1, for the supply of the motor with compressed air; braking distributer DF1, for the braking with energy recovery of the braking energy.

The functioning of the pneumatic motor is the following:

1. The start and the acceleration of the rotational movement

Depending on the rotational sense, the sense distributers (DS1) and (DS2) are simultaneously switched on in the position 1 or 2 through an electromagnetic command. The supply of the pneumatic motors of the adjustment steps with compressed air is successively realized by switching the actuation distributers (DA1) and (DA2) in position1, by an electronic system with Zenner diodes. The shaft of the hydraulic motor is moving when the torque M1 developed by the motor is bigger than the resistant torque Mr. The rotational acceleration depends directly proportional on the difference between the rotational torques (M1-Mr) and inversely proportional to the reduced moment of inertia of the powered vehicle.

2. The rotational movement with constant angular speed

The rotational speed is constant when the motor torque is equal with the resistant one (M1=Mr). Depending on the resistant torque variation, the moment developed by the motor is varied in steps through the electronic system with Zenner diodes.

 ISSN 2457 – 5275 (Online, English)
ISSN 1842 – 4074 (Print, Online, Romanian)

3. The braking of the rotational movement with the recovery of the braking energy
The pneumatic motors of the adjustment steps turn into a compressor mode. The compressed air produced by the adjustment steps is discharged in the low-pressure tank (Rzp) if at least one of the braking distributers (DF1 or DF2) are in the position 1. For the braking, the actuation distributers are switched in the position 0, and the braking distributers are successively switched in the position 1 through the electronic system with Zenner diodes. The value of the braking torque (Mf) developed by the pneumatic motor depends on the number of the braking activated steps.

3. THE CONSTRUCTIVE SCHEME FOR ONE TORQUE STEP OF THE PNEUMATIC MOTOR

The main parts of the torque step with one pneumatic cylinder are (figure 3): the pneumatic cylinder (CP) with double action and bilateral rod and the cams (Cm1 and Cm2). Under the action of the air pressure, the piston inside the pneumatic cylinder has an alternative rectilinear movement that is transformed, through the cams, into rotational movement. The transmission of the movement from the piston to the cams is done through the sleepers (T1) and (T2). The cams (Cm1) and (Cm2) are fixed on the shafts (A1) and (A2) that are rotating with the same rotational speed, in opposite senses, through a gear transmission or by another way to transmit the rotational movement.

Due to this mode of the cam mechanisms construction, the resultant of the forces F_{21}^{0} (the action force of the element 2 – the tappet, on the element 1 – the cam) that actions on the cams is coaxially to the axis of the piston rods and, in this way, there are no radial forces that should produce friction forces.

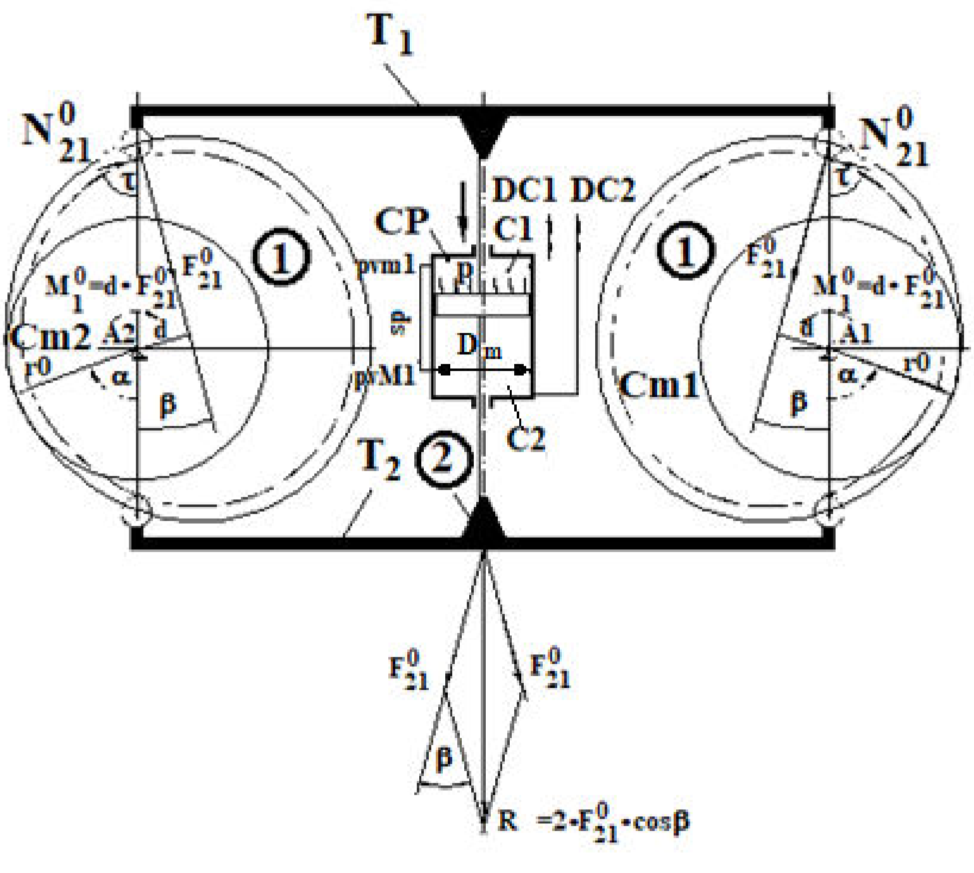

Figure 3. The constructive scheme of the torque step of the pneumatic motor.

The air pressure inside the variable volume chambers C1 and C2 (figure 4) formed inside the pneumatic cylinder is controlled by the distributors (DC1) and (DC2), that alternatively, put in connection the chambers with the low-pressure tank (Rzp). DC1 and DC2 are distributors 3/3 with three connections and three positions. They are switched by the cams CD fixed on a shaft and offset to the Cm1 and Cm2 cams axes with an angle π/2 (fixed on the shaft A2 from the figure 4).

ISSN 2457 – 5275 (Online, English)
ISSN 1842 – 4074 (Print, Online, Romanian)

In the position 0 of the distributor, the chamber inside the pneumatic cylinder is connected to the atmosphere, the exhaust process of the air from the chamber to the atmosphere takes place; in position 1 of the distributor, the chamber inside the pneumatic cylinder is closed and the expansion of the air inside the chamber takes place; in the position 2 of the distributor, the chamber inside the pneumatic cylinder is connected to the low pressure tank Rzp and the chamber is supplied with air under pressure.
When the piston moves from the point pvm1 (the point of minimum volume of the chamber C1) to the point pvM1 (the point of maximum volume of the chamber C1) the motor stroke takes place, and when the piston moves from the point pvM1 to pvm1 the exhaust stroke takes place. When in the chamber C1 takes place the piston's motor stroke, in the chamber C2 takes place the exhaust stroke, and vice versa (figure 4).

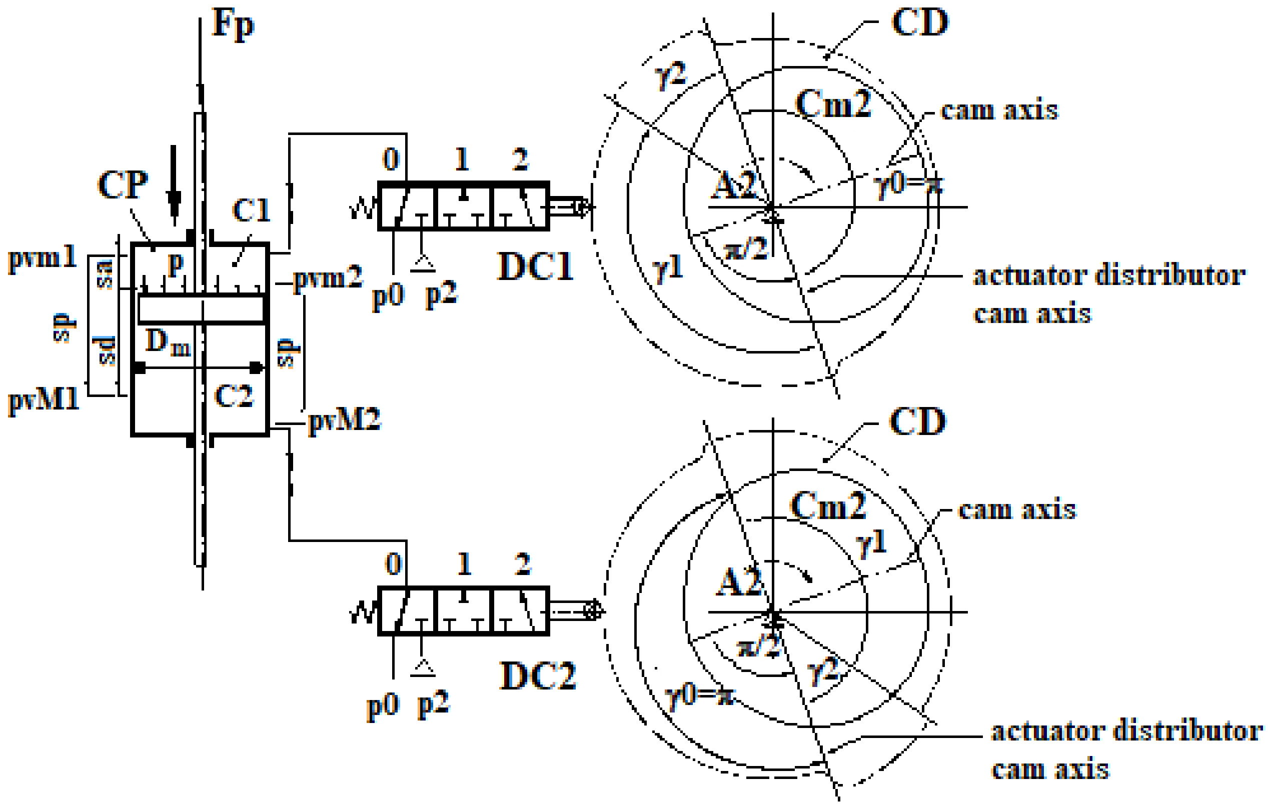

Figure 4. The actuation scheme of the distributers DC1 and DC2.

The piston's motor stroke includes the admission stroke (sa) and the expansion stroke (sd). At the admission stroke, the cam CD switches the distributor in the position 2. During this stroke, the cam CD rotates with the angle γ2. The air parameters inside the cylinder are constant: the pressure pa=p2=ct. and the temperature T2=ct (inside the low-pressure tank). This temperature is maintained constant at the value of the environmental temperature (T0) or the temperature inside the cabin, if the exhaust air is used for air conditioning. This can be done by using a heating system.
At the expansion stroke, the cam CD switches the distributor in the position 1.
During this stroke, the cam CD is rotating with the angle γ1. The air parameters inside the cylinder's chamber are variable: the pressure p=[pa, pd], the temperature T=[Ta, Td]; pa is approximately the pressure inside the low pressure tank; pd is the pressure of the air inside the chamber at the end of the expansion stroke; pd=po+Δpd; p0 is the environmental pressure and Δpd=0,1-0,2 bar is the pressure loss during the exhaust of the air in the atmosphere; by expanding the air near the environmental pressure, one can obtain a maximum efficiency of the pneumatic motor; Ta=T2 where: Ta is the temperature at the beginning of the expansion process.
At the exhaust stroke the cam CD switches the distributor in the position 0. During this stroke, the cam CD is rotating with an angle γ0=π.
The air parameters inside the cylinder's chamber are considered to be constant: the pressure pe=pd and the temperature Te=Td.

ISSN 2457 – 5275 (Online, English)
ISSN 1842 – 4074 (Print, Online, Romanian)

The following notation is used: kp=pa/pd. During the intake process, the volume V of the chamber varies between [0, Va] and in the expansion process the volume varies between [Va, Vt], where: $Va=\pi/4 \cdot Dm^2 \cdot sa$; $Vt=\pi/4 \cdot Dm^2 \cdot sp$; Dm is the diameter of the pneumatic cylinder; sa is the intake piston's stroke; sp is the piston's stroke.
One considers that the air expansion is a polytropic process of an exponent n:

$$pa \cdot V_a^n = pd \cdot V_t^n \Rightarrow sa = \frac{1}{k_p^{1/n}} \cdot sp; Ta = k_p^{\frac{n-1}{n}} \cdot Td \tag{1}$$

If the pneumatic motor has the cams Cm1 and Cm2 with a sinusoidal profile, the function of the piston's displacement is:

$$s(\alpha) = \begin{cases} \frac{sp}{\pi} \cdot \left[\alpha - \frac{1}{2} \cdot \sin(2 \cdot \alpha)\right] & \text{if} \quad \alpha < \pi \\ -\frac{sp}{\pi} \cdot \left(\alpha - \frac{1}{2} \cdot \sin(2 \cdot \alpha) - 2 \cdot \pi\right) & \text{if } \alpha \geq \pi \end{cases} \tag{2}$$

The rotational angle γ2 of the cam CD that switches at the intake stroke, results from the following equation:

$$sa = \frac{sp}{\pi} \cdot \left[\gamma 2 - \frac{1}{2} \times \sin(2 \cdot \gamma 2)\right] \Rightarrow \frac{sp}{\pi} \cdot \left[\gamma 2 - \frac{1}{2} \cdot \sin(2 \cdot \gamma 2)\right] - sa = 0 \tag{3}$$

The function for the variation of the air pressure inside the chamber C1 of the cylinder is:

$$pC1(\alpha) = \begin{cases} pa & \text{if} \quad \alpha \leq \gamma 2 \\ pa \cdot \left(\frac{sa}{s(\alpha)}\right)^n & \text{if} \quad \gamma 2 < \alpha < \pi \\ pd & \text{if} \quad \alpha > \pi \end{cases} \tag{4}$$

The function for the variation of the air pressure inside the chamber C2 of the cylinder is:

$$pC2(\alpha) = \begin{cases} pd & \text{if} \quad \alpha \leq \pi \\ pa & \text{if} \quad \pi < \alpha < \pi + \gamma 2 \\ pa\left(\frac{sa}{sp - s(\alpha)}\right)^n & \text{if} \quad \alpha > \pi + \gamma 2 \end{cases} \tag{5}$$

The function for the variation of the pressure angle is:

$$\beta(\alpha) = \operatorname{atan}\left(\frac{1}{r0 + s(\alpha)} \cdot \frac{d}{d\alpha} s(\alpha)\right) \tag{6}$$

The function of the torque developed by the cylinder's chamber C1 is:

$$MC1(\alpha) = \frac{\pi}{4} \cdot Dm^2 \cdot [r0 + s(\alpha)] \cdot \sin\beta(\alpha) \cdot pC1(\alpha) \tag{7}$$

ISSN 2457 – 5275 (Online, English)
ISSN 1842 – 4074 (Print, Online, Romanian)

The function of the torque developed in the chamber C2 of the cylinder is:

$$MC2(\alpha) = \frac{\pi}{4} \cdot Dm^2 \cdot \left[r0 + s(\alpha)\right] \cdot \sin(-\beta(\alpha)) \cdot pC2(\alpha) \tag{8}$$

The function of the total torque developed by one pneumatic cylinder is:

$$M1(\alpha) = MC1(\alpha) + MC2(\alpha) \tag{9}$$

The mean torque developed by one pneumatic cylinder is:

$$MCm = \frac{\int_0^{2\pi} M(\alpha) \cdot d\alpha}{2\pi} \tag{10}$$

In order to reduce the movement's irregularity degree, the engine's torque step can be provided with more cylinders. The cams of one cylinder are fixed on the shafts with an offset regarding the cams from the other cylinders so that the torque irregularity degree should be reduced.
The total torque developed by the pneumatic motor is:

$$M1 = ict \cdot it \cdot MCm \tag{11}$$

The power developed by the engine at the maximum rotational speed is:

$$P = \frac{\pi}{30} \cdot n1 \cdot M1\left[W\right] \tag{12}$$

In stationary regime, the mass flows are equal:

$$\dot{m}1 = \dot{m}2 \tag{13}$$

$$\frac{dp}{d\tau} \cdot V1 = \frac{dm}{d\tau} \cdot R \cdot T1 \quad \Rightarrow \quad \dot{m}1 = \frac{V1}{R \cdot T1} \cdot \frac{dp}{d\tau} \quad \left[kg/s\right] \tag{14}$$

$$\dot{m}2 = \rho a \cdot \dot{V}m \quad \Rightarrow \quad \dot{m}2 = \frac{p2}{R \cdot T2} \cdot \dot{V}m \quad \left[kg/s\right] \tag{15}$$

The emptying time of the high-pressure tank:

$$\tau g = \frac{V1}{\dot{V}m} \cdot \frac{T2}{T1} \cdot \left(\frac{p1max}{p2} - 1\right) \tag{16}$$

If all the motor's cylinders have equal dimensions, the air volumetric flow is:

$$\dot{V}m = \frac{\pi}{120} \cdot ict \cdot it \cdot Dm^2 \cdot sa \cdot n1 \tag{17}$$

The maximum distance that the vehicle can travel is:

$$Ad = \frac{\pi}{60} \cdot dr \cdot nr \cdot \frac{V1}{\dot{V}m} \cdot \frac{T2}{T1} \cdot \left(\frac{p1max}{p2} - 1\right) \tag{18}$$

ISSN 2457 – 5275 (Online, English)
ISSN 1842 – 4074 (Print, Online, Romanian)

If one imposes a certain value of the vehicle's autonomy (the mileage between two refuels), the capacity necessary for the high-pressure tank results from (17).

$$V1=\frac{60}{\pi}\cdot\frac{Ad}{dr}\cdot\frac{\dot{V}m}{nr}\cdot\frac{T1}{T2}\cdot\frac{p2}{p1max-p2} \qquad (19)$$

4. NUMERICAL APPLICATION

Based on this algorithm, a numeric application was developed.
The initial data for the calculus is:
- the torque step: the piston's stroke sp=50 mm; the cams rotational speed n1=3000 rot/min; the intake pressure pa=0,8 MPa; the pressure at the end of the expansion pd=0.12 bar; the temperature at the end of the expansion Td=293 K; the exponent of the expansion process n=1.38; the inner diameter of the cylinder Dm=50 mm; the number of the cylinders for one torque step ict=4.
- the pressure inside the low-pressure tank p2=0.8 MPa;
- the maximum pressure inside the high-pressure tank p1max=20 MPa;
- the number of the torque steps i=5;
- the diameter of the driving wheel dr=560 mm;
- the rotational speed of the driving wheel at the maximum rotational speed of the motor nr=1000/min;
- the imposed mileage between two refuels Ad=100 km;

The calculus was developed by using the Mathcad program and it was aimed to determine the capacity of the high-pressure tank needed for a mileage of 100 km between refuels at full load.
The results of this calculus are the following:
- the pressures ratio is: kp=pa/pd=6.67;
- the piston's intake stoke is:

$$sa=\frac{1}{k_p^{1/n}}\cdot sp$$

$sa = 1/6.679^{(1/1.38)}\cdot 50 = 12.6$ mm;
- the temperature at the beginning of the expansion is:

$$Ta=k_p^{\frac{n-1}{n}}\cdot Td$$

$Ta=6.679^{[(1.38-1)/1.38]}\cdot 293 = 494$ K;
- the variation of the pressure inside the chambers of the pneumatic cylinders (Cm1 and Cm2) are presented in the figure 5.

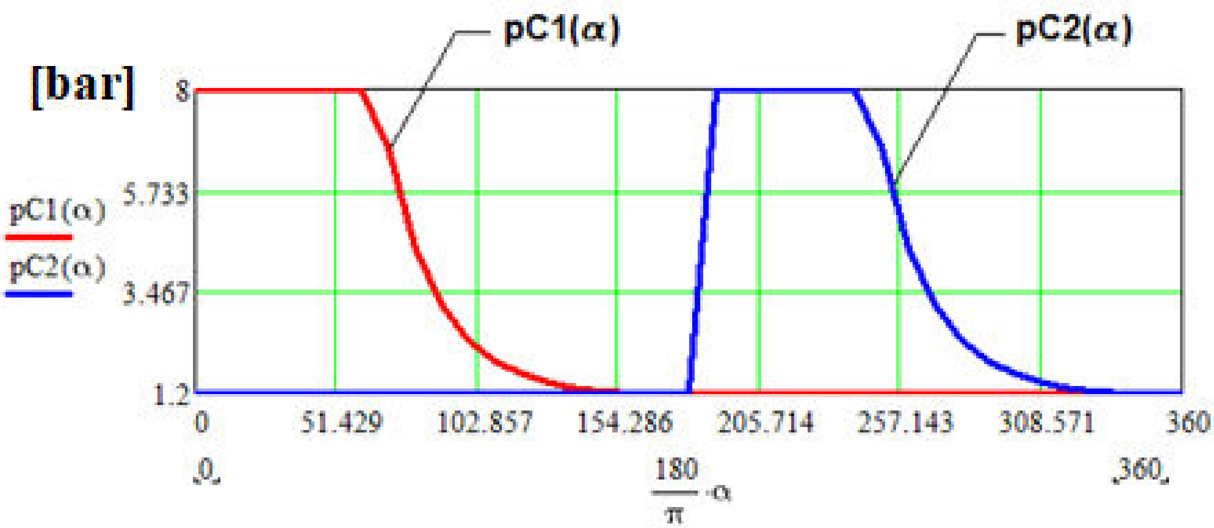

Figure 5. The variation of the pressure inside the cylinder's chambers C1 (pC1) and C2 (pC2)

ISSN 2457 – 5275 (Online, English)
ISSN 1842 – 4074 (Print, Online, Romanian)

- the torques developed in the chambers and the total torque of the pneumatic cylinder are presented in figure 6.
- the mean torque developed by the work of one cylinder is:

$$MCm = \frac{\int_0^{2\pi} M(\alpha)d\alpha}{2\pi} = 9 \ [N \cdot m]$$

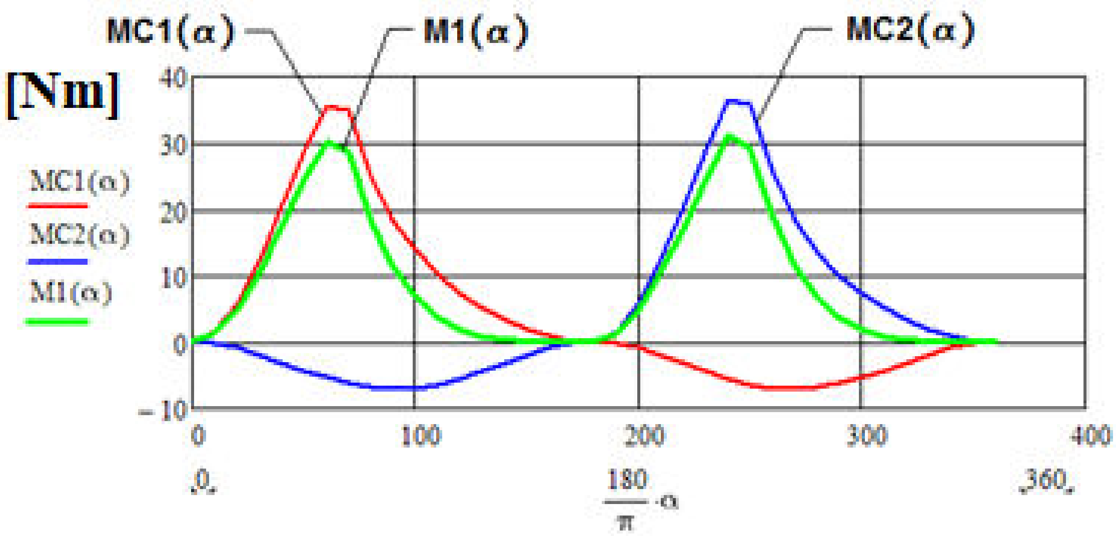

Figure 6. The variation of the torques developed by the of the cylinders C1 (MC1) and C2 (MC2) and of total torque of one step (M1)

- the irregularity degree of one torque step is: δ1=3.449;
- the total torque developed by the pneumatic motor is:

$M1 = ict \cdot it \cdot MCm$ = 4·5·9 = 180.2 N·m
- the power developed by the motor at the maximum rotational speed:

P=π·n1·M1/30=π·3000·180.2/30=56.6 kW;
- the volumetric flow of the air consumed by the motor at the maximum rotational speed is:

$$\dot{V}m = 10^{-9} \cdot \frac{\pi}{120} \cdot ict \cdot it \cdot Dm^2 \cdot sa \cdot n1 = 10^{-9} \cdot \frac{\pi}{120} \cdot 4 \cdot 5 \cdot 50^2 \cdot 12.6 \cdot 3000 = 0.050 \quad m^3/s$$

- the volume of the high-pressure tank for an autonomy of 100 km at full load is:

$$V1 = 10^3 \cdot \frac{60}{\pi} \cdot \frac{Ad}{dr} \cdot \frac{\dot{V}m}{nr} \cdot \frac{T1}{T2} \cdot \frac{p2}{p1max - p2} = 10^3 \cdot \frac{60}{\pi} \cdot \frac{100}{0.7} \cdot \frac{0.05}{1000} \cdot \frac{293}{494} \cdot \frac{8}{200-8} = 3.35 \quad m^3$$

The numerical application is based on deducted relations, that don't take in consideration the losses. The role of the application was to ride the graphics, and the initial values (such as the wheels diameter) have no relevance, because any value is possible in a practical application.
This numerical application is not a designing calculation, it's role is to demonstrate that the obtained values can practically be achieved.
For example, a minibus with the pneumatic motor's power of 56.5 kW, for an autonomy of 100 km., needs a high-pressure tank with a capacity of 3.35 m^3, loaded at maximum pressure of 20 MPa.

5. CONCLUSION

From the previous presented calculation, it results that the pneumatic propulsion is an alternative to the electric propulsion.
The main advantages of the pneumatic propulsion system equipped with the new motor with stepped torque adjustment presented in this paper are the following:
- it realizes all the propulsion functions, with the recovery of the braking energy;
- the dynamics of this propulsion system is superior because the torque developed by one torque step is constant and it does not depend of the rotational speed;

ISSN 2457 – 5275 (Online, English)
ISSN 1842 – 4074 (Print, Online, Romanian)

- one can estimate an efficiency at least equal to the one of the electric propulsion systems. The production of the pneumatic energy for the road vehicle supply is made with high performance electric actioned compressors with an efficiency of 70-80% at values closed to the efficiency of the electric battery recharge. The efficiency of the pneumatic motor is superior to the alternative current motor used for the propulsion of the electric vehicles because those systems need an inverter to convert the DC into an alternative current with variable frequency and voltage.
- the dynamic parameters of the pneumatic propulsion system are not depending on the load degree (the pressure) of the high-pressure tank. They are constant regardless the pressure inside this tank, with the condition that $p1 \geq p2$.

As one can see, the results of the calculus are for an operation at full load.

The range of autonomy in real conditions is higher. Theoretically a road vehicle is functioning at full load for maximum 10% of it's operation.

The results of this study can be extended to different operating regimes, so more accurate results can be taken into consideration for comparing this propulsion system with the electric one.

Also, one must observe that, for the calculus, the pressure of the air inside the high-pressure tank was considered to be p=20 MPa.

The numerical application is based on deducted relations, that don't take in consideration the losses. The role of the application was to ride the graphics, and the initial values (such as the wheels diameter) have no relevance, because any value is possible in a practical application.

This numerical application is not a designing calculation, it's role is to demonstrate that the obtained values can practically be achieved.

For example, a minibus with the pneumatic motor's power of 56.5 kW, for an autonomy of 100 km., needs a high-pressure tank with a capacity of 3.35 m^3, loaded at maximum pressure of 20 MPa.

Recent research [6] show that it is possible to manufacture high pressure air tanks made of carbon fiber. They have a honeycomb structure and can support pressures up to 30 MPa. A great advantage is that, in the case of a crash, the material is brittle and creates no shrapnel.

The tank can be placed on the floor of the vehicle. Also, parts of the car's body can be supplementary high-pressure air tanks.

So, theoretically, an autonomy of 100 km (at full load). can be reached by such a minibus.

This solution is applicable in urban transport for small size vehicles or minibuses.

From an environmental point of view, this solution permits the realization

There are current applications that permit the storage of the compressed air at 40-50 MPa in perfect safety conditions, including the consequences of the car crash [6].

REFERENCES

[1] Bossel, U., *Thermodynamic Analysis of Compressed Air Vehicle Propulsion.* Journal of KONES International Combustion Engines Vol 12, pg. 3-4, 2005

[2] Papson, A., Creutzig, F., Schipper, L., *Compressed Air Vehicles Drive-Cycle Analysis of Vehicle Performance, Environmental Impacts, and Economic Costs.* Journal of the Transportation Research Board, Washington, D.C. No. 2191, pg. 67-7, 2010

[3] *** , MDI Motor Development International, http://www.mdi.lu/produits.php,

[4] Sengupta, D., *Tata Motors to Roll Out Cars That Runs on Compressed Air Instead of Fuels.* The Economic Times March 22, 2008

[5] Mitran, T. Chioreanu, C., Dragomir, G., Fagadar, D., *A propulsion system for urban cars*, AMMA 2018 International Congress of Automotive and Transport Engineering, pp 659-666, Cluj-Napoca, ISBN 978-3-319-94408-1 ISBN 978-3-319-94409-8 (eBook)

[6] ^^^ - Seven Network's Beyond Tomorrow