Functional Optimization of An Air-Car by Modeling and Simulation

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***Abstract*—In many technical sectors, pneumatic actuation systems are used due to their robustness, high reliability, constructive simplicity, and low manufacturing/use price. The paper highlights the components and characteristics of a pneumatic system that drives a kinematic chain. This chain sets a tricycle in motion with compressed air as power source. Modeling and simulation by mean of Automation Studio software are used for the functional optimization. Thus, the characteristics of the tricycle (speed, distance, etc.) are improved by determining the components in the pneumatic diagram and simulating its behavior. The aim is to reach a maximum distance with a certain amount of compressed air.**

***Keywords*—thermodynamic parameters, air-car, air tank, pressure regulator, air injection, control unit, energy**

I. Introduction

Pneumatic actuation systems have many applications, but the common requirement for compressed air to be used as efficiently as possible is its reliable capacitation in tanks and its treatment. These air capacitors must first of all store/supply it continuously, at the required quality and at a competitive price related to the price of other sources of energy. This actuation complex must be considered from the perspective of the production costs, of the component elements and, finally, of the role it plays in the application where it is intended to serve. The components meant to be used in an application must consider at least the air supply source, the tanks, the treatment components, the pipe network, the control means, the tightness of the connections and the existence of adequate ventilation as well [1].

This article highlights an application of the pneumatic system that is used to propel a tricycle. The existing components of the tricycle are used in the application. The intention is to improve the characteristics/functionality and the performance of the pneumatic system by simulating its operation with the help of the Automation Studio software module [2].

II. Diagram and Components of the System Pneumatic Circuit

The diagram of the analyzed/researched pneumatic system is shown in Figs. 1 and 2. This pneumatic complex uses a 10l tank/cylinder that has a pressure of 200 bar, a safety circuit, solenoid valves, pressure regulator, shown in Fig. 1 and pneumatic cylinders, and magnetic sensors, shown in Fig. 2.

Two pneumatic cylinders and four magnetic sensors were used in the assembly presented in Fig. 2 as follows:

1) P1, of Ø32 with a travel of 300 mm.
2) P2, of Ø63 with a travel of 300 mm.

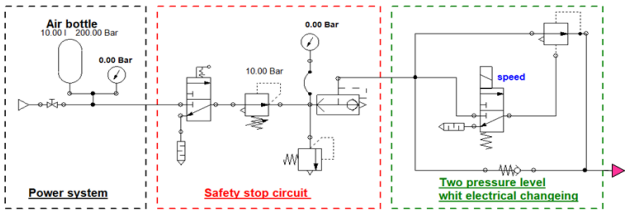

Fig. 1. Diagram of the primary pneumatic circuit used in the initial version.

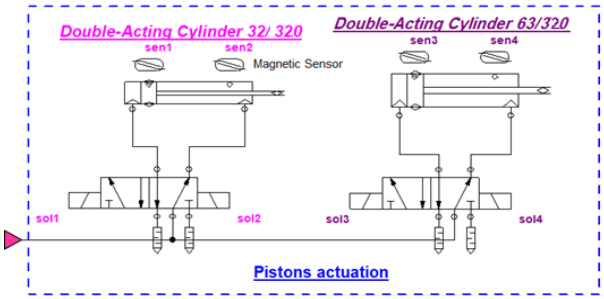

Fig. 2. Diagram of the secondary pneumatic circuit used in the initial version.

The kinematic drive chain of the system (tricycle) is shown in Fig. 3, the structure and Fig. 4, the kinematic diagram.

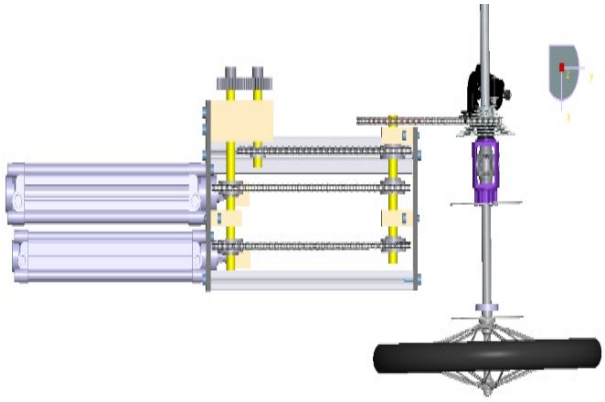

Fig. 3. Drive system, the mechanism structure.

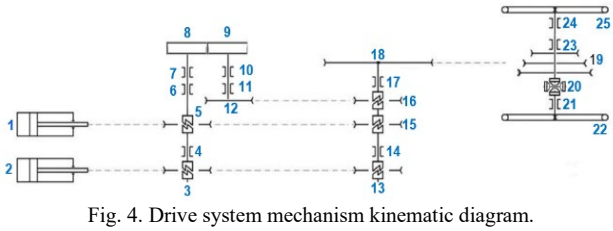

Fig. 4. Drive system mechanism kinematic diagram.

Pistons P1 and P2 are directly connected to the chain drive, with gears and ratchet. The rotational motion is transmitted through ratchets 13 and 15 when the exhaust stroke of the pistons is performed. Through the ratchets 3 and 5, the movement of the wheel is transmitted when the intake stroke of the pistons is performed; the pistons change their direction through gears 8 and 9. The rotational motion is further transmitted from pinion 12 to 16 [3].

The cumulative movement is transmitted from pinion 18 to gear box 19, which is located on the housing of the differential driving gear 20, to which the rear wheel of the vehicle is connected.

The push/pull force (F) includes the following elements: pressure (P), surface area (S), load coefficient (τ)—Fig. 5, push and Fig. 6, pull.

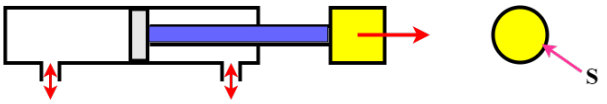

Fig. 5. Movements of the cylinder rod—Push.

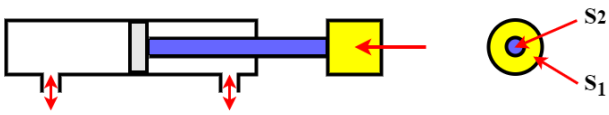

Fig. 6. Movements of the cylinder rod—Pull.

S = cylinder surface area, S1 = piston surface area, S2 = rod surface area.

The force required for actuation has the following parameters:

$$F = P \times S \times \tau \quad (1)$$

Its size is influenced by the surface area of the piston, cylinder, and rod [3].

To calculate the speed of the drive wheel over the entire kinematic chain, the average duration of the piston stroke was set at 1 s.

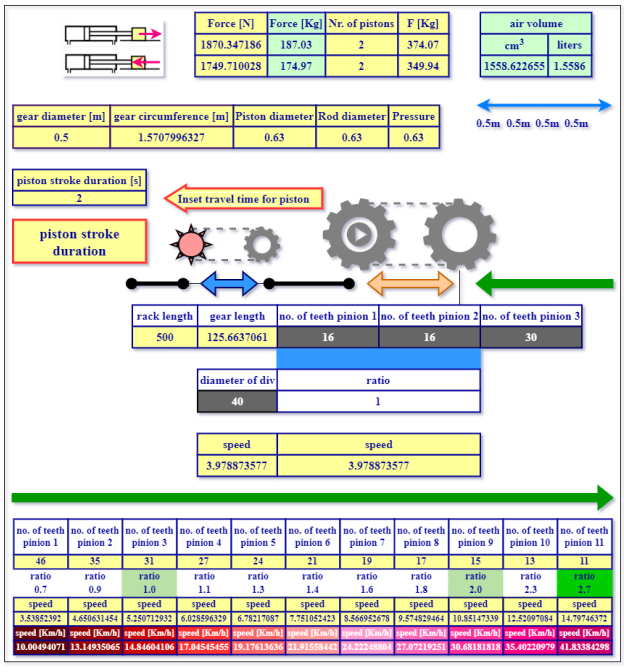

Fig. 7. Calculation of the tricycle speed depending on the system parameters.

As a result of the calculations performed in Fig. 7, using the Microsoft Excel application, the minimum speed was measured at the value of 8.6 km/h and the maximum speed at the value of 32.9 km/h.

For the simulation with Automation Studio, it was necessary to configure the pneumatic components according to the software library, as follows:

- parameters of the cylinder: maximum pressure—MPs (bar), total volume—VT (l).
- parameters of the pressure regulator: regulation pressure—SP (bar).
- parameters of the cylinder: extension (%), inclination—α (°), piston diameter—D (mm), rod diameter—d (mm), stroke—L (mm), load—M (kg).

The analyzed exhaust parameters: flow rate—Q (l/min), working pressure—Pw (bar), acceleration—$\ddot{x}$ (m/s^2), piston travel—dL (mm), linear movement $\dot{x}$ (m/sec), no. of strokes (dc) [4].

III. Modeling of the Pneumatic System

The research was based on the pneumatic diagrams shown in Figs. 1 and 2. The operation of the system was simulated by means of Automation Studio software, the primary pneumatic circuit in Fig. 8 and the secondary pneumatic circuit in Fig. 9, introducing the known parameters; thus, the direction of the fluid flow is represented by arrows and distinct colors for different pressures (blue, red), Fig. 10.

The energy losses of the compressed air represent a main technical barrier because of the high flow velocity. To improve the quality of the power transmission, this one is distributed to a sprocket / gear box coupling, which amplifies the torque/ transmission ratios in different speeds, Fig. 8.

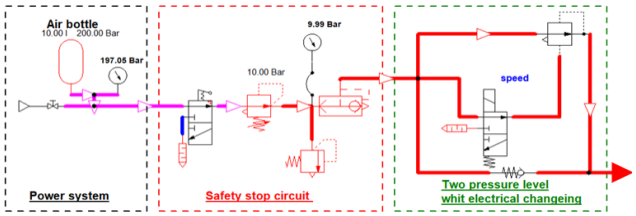

Fig. 8. Simulation of the primary pneumatic system operation.

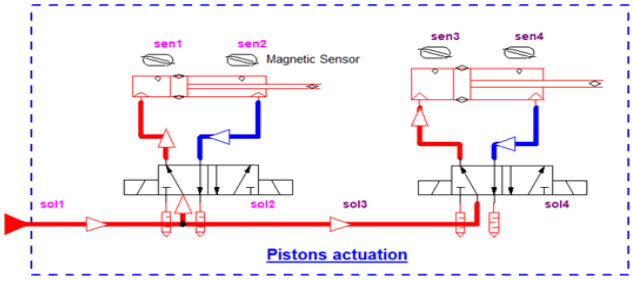

Fig. 9. Simulation of the secondary pneumatic system operation.

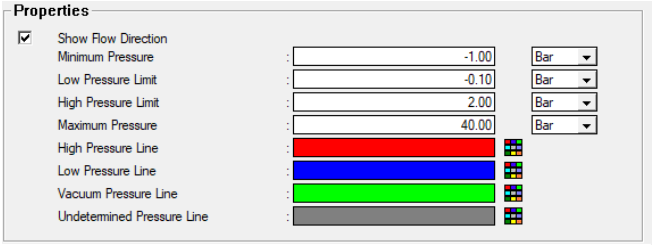

Fig. 10. Representation of the significance of colors in the program.

Both the pressure and the temperature inside each pneumatic piston were analyzed and evaluated, as well as the problems that occur at the air intake and exhaust (a low temperature is maintained in the system). The power of the system remains constant, but the pressure of the air decreases, having a minimum value at the exhaust. The maximum pressure exists only in the tank. The torque and power transmitted to the system by the pneumatic cylinders were evaluated after 300 cycles, in the laboratory, for different air pressures in the unit, depending on the strokes of the pneumatic pistons [5].

The flow directions and the pressure on these areas, depending on the composition and the constructive characteristics of the components, are highlighted through the simulation. They are represented by different colors according to their values, Fig. 10 [6].

The highest transmission torque in the system was achieved at the highest air pressure, which provides the highest force applied to the piston. An increase in the exhaust air pressure is predictable at bigger system pressures. As the pressure decreases, the torque transmission efficiency decreases too. An increase in the efficiency of this system can be obtained if the residual pressure of the removed air is used in another additional cylinder(s) that will produce a supplementary power. The cycle divided in this way improves the use of air energy in the system, increasing the distance covered by the vehicle. The air/pressure consumption is shown in Fig. 11. In order to meet different basic conditions of the pneumatic cylinders, the pressure is considered optimal at a value of 10bar. The losses of energy in the compressed air constitute the principal technical barrier as a result of the high flow velocity [7].

The following data are resulted from the simulation of the pneumatic system by means of the AS software: the tricycle can run 180 m, for 227 s, Tcycle ≈ 1.25 s/cycle, using a maximum pressure of 10 bar, maximum flow rate: 2500 L/min, Fig. 11 [8].

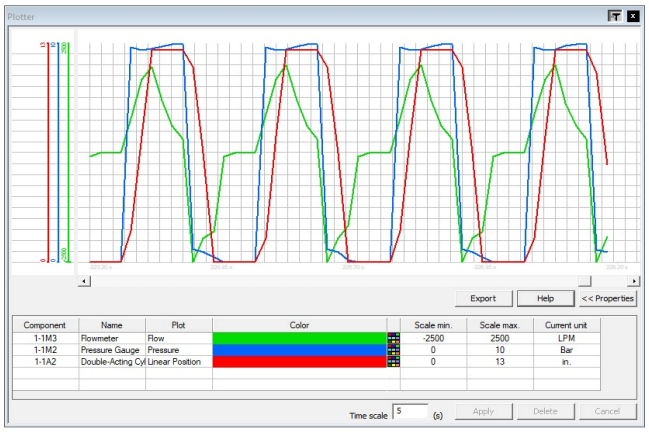

Fig. 11. Values obtained by simulation.

The data obtained through simulation were entered into the excel data base and the following values were obtained, Figs. 12 and 13:

- minimum distance covered: 861.7 m—with the speed-change gear on the big pinion;
- maximum distance covered: 3290.1 m—with the speed-change gear on the small pinion;
- minimum speed: 6.8 km/h—with the speed-change gear on the big pinion;
- maximum speed: 26.1 km/h—with the speed-change gear on the small pinion.

Following the analysis of the simulated values and of those achieved in the field with a tricycle, certain values can be amplified, for example: distance covered while keeping the air pressure constant, using a flow recuperator (directional control valve—collector) that returns a part of the dissipated energy, with the role of energy pneumatic "steering wheel".

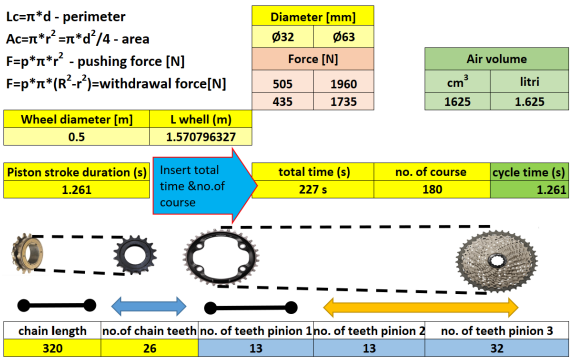

Fig. 12. Results obtained force, time.

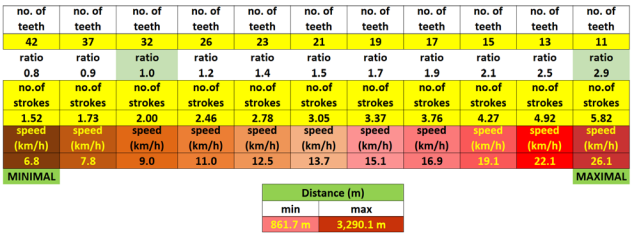

Fig. 13. Results obtained (distance, speed, consumption).

At the same time, from a thermodynamic point of view, the pneumatic circuit is an open system that exchanges both energy and mass with the external environment (in the case of flow losses due to the lack of tightness). It can be thermally insulated, leading to energy saving [5].

One can notice from the simulations that the energy efficiency of the system is reduced, but by interconnecting some viable components (solenoid valves, automatically controlled throttles) it is possible to make circuit air consumption data logs to flatten the load curve.

To increase the efficiency of the pneumatic system, a remote management and monitoring system can be integrated, which will allow the realization of effective strategies for the use of compressed air energy. Thus, the energy consumption associated with the entire system will be reduced, under the conditions of maintaining the optimal operational parameters [9].

This tele management complex will analyze in real time: the consumption and distribution parameters, the distribution quality (energy efficiency), the highlighting of areas with potential defects (loss of energy), the analysis of possible failures through continuous monitoring of the optimal pressure both for operation and for early detection of losses, resulting in low costs per technical process unit [10, 11].

IV. Conclusion

After modeling and simulating the pneumatic diagram by means of the Automation Studio software, the air

consumption was determined. This fact helps to select the solenoid valves with an appropriate flow rate, thus increasing the distance covered. It was found out that the maximum speed of the vehicle established by simulation was close to the speed in real conditions. The air consumption resulting from the simulation is approximately equal to the real one; the vehicle travels with a compressed air tank along 2,800 m.

Future research studies may make it possible to achieve significant energy savings of 5 to 50 %. It results that an improvement (even a small one) of the pneumatic circuit could lead to important financial and energy economies.

The propulsion system powered by compressed air has a unique advantage due to its benefits for the environment, because its emissions are non-toxic. However, improvements are needed to maximize the use of compressed air to be converted into mechanical work.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Mihai Agud conducted the research, simulation, and design; Stefan Velicu coordinated the entire research; Florin Enache performed the calculations and simulated the calculations; Mihai Stelian Hagiescu analyzed and centralized the data; Cristian Ionel Paunescu edited the paper; All authors have approved the final version of the paper.

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