An application for a new type of pneumatic engine concept

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Keywords: pneumatic engine, tooth compressor, transport vehicles, unloading devices

1 Introduction

Heavy trucks are often equipped with loading and unloading systems like dock levellers with swing lip or telescopic lip. Most of these devices require hydro-electrical energy supply systems (eg. the pump that presses the working substance to the actuators must be propelled by electric engine.) The space taken by pump with electric engine can be reduced on condition that a new type of pneumatic drive will be considered. It is possible to supply pneumatic engine from air supply system that is existing on the board of transport vehicle which is a part of brake system. In addition, this solution allows for the use of compressed air energy stored earlier in the accumulation tank. Platform longitudinal movement that is provided by linear hydraulic cylinders also can be achieved with use of rotary pneumatic motor and simple linear gear units. For the other type of platforms engine rotational movement is converted to lip swing movement with usage of ropes or chains. The proposed concept assumes that the drive of the loading and unloading equipment is provided by a high-torque pneumatic engine which works in the reversed cycle of the tooth compressor and is propelled by compressed air directly from the truck's braking system. The reversal of the tooth compressor cycle is possible by attaching the discharge window of the compressor to the pressured tank with air. Such modification causes that suction window of the compressor becomes the outlet of the air and then tooth compressor is operated as a pneumatic engine.

2 Construction and working principle of pneumatic engine

Claw vacuum pumps (tooth compressors) are rotary positive displacement fluid machineries with built-in compression, which consist of two partly overlapping cylinders and two same-shaped conjugate meshing claw rotors; and each claw rotor contains a claw and a matching recess[1]. The two claw rotors rotate in opposite directions at a same rotational angular speed about their axes and are synchronized by a pair of gears. The outline of a single toothed rotor consists of the six curves shown in Figure 1:

- two epitrochoidal- arcs ab and ef
- epicycloidal arc - cd
- three arcs of circle -bc, de and fa

Mathematical equations describing those curves are presented in the paper [1]. The mathematical model assumes that the apex of the tooth (point b) is moving along the curve a2-b2 during tooth rotation.

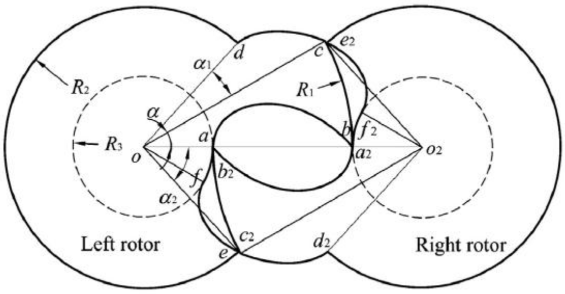

Figure 1: Geometry of the tooth rotors outlines

Complicated geometry allows for collision-free rotation of rotors. There are also some modifications of the rotor profiles that are improving efficiency of the tooth compressors eg. to reduce the harmful volume between teeth when rotors pass each other [2]. Currently the Atlas Copco company produces tooth compressors which are equipped in rotors with two teeth shown in Figure 2.Both rotors differs from each other. The left rotor profile is adapted to control the inlet window of the tooth compressor and is known as a female rotor. The profile of the right rotor is much thicker than the left one to reduce its weight (male rotor).

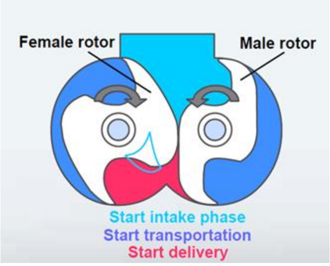

Figure 2: Female and male outlines of Atlas Copco tooth compressor

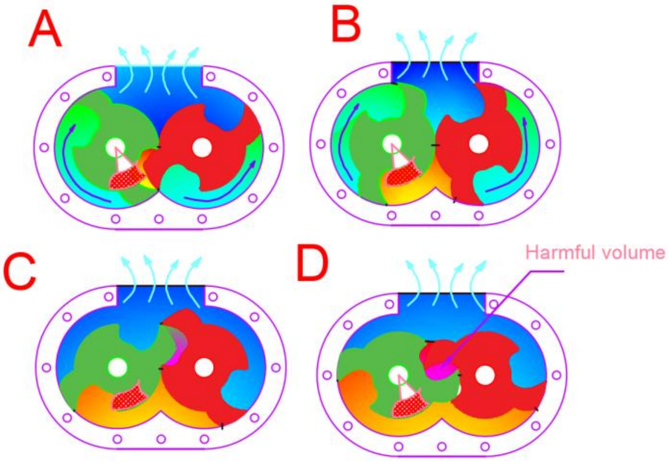

Figure 3: The reversed cycle of tooth compressor

3 The reversed cycle of the tooth compressor

The modification of the tooth compressor construction is also suitable not only for rotors with one tooth but also for rotors with two teeth. This paper describes the working cycle of pneumatic engine with two teeth profile rotors. Rotating rotors, depending on the occupied position, divide the engine working chamber into two or four sections. In every section a simultaneous execution of individual phases of the cycle takes place. The engine working cycle is as follows:

- The beginning of the compressed air flow through the intake port of Figure 3A. The phase begins at the moment of the inlet window exposure. The opening of the inlet start when the tooth of the left rotor passes inlet. The working chamber is divided into four sections In the lateral sections air which was decompressed earlier when was in lower section chamber is transported by rotors to outlet. In the upper section decompressed air is thrown out from working chamber to atmosphere.
- The core of the left rotor starts covering inlet window Figure 3B. The dose of compressed air which was accumulated in previous phase begins to expand in the lower section of the working chamber. The upper section at this moment decreases its volume.
- The upper rotating teeth of the rotor begin to interlock with each other Figure 3C. Side sections are starting to merge with the upper section. During this phase, the engine chamber is divided into two sections only. The air in upper section is removed to the atmosphere.
- Creation of the harmful volume inside pneumatic engine when teeth of both rotors are interlocking with each other Figure 3D. The outer edges of the teeth create separated from other sections volume which does not take part in decompression of the air in working chamber. The interlocking teeth after passing through this position divide lower section into the two side transport sections. When inlet window opens again a new cycle is started.

4 Computer simulation of pneumatic engine working cycle

Designing the presented concept of a pneumatic engine requires taking into account the conditions that occurs in the working chamber of the engine during its work. The first step that was taken to design the prototype of the engine was to perform a computer simulation in ANSYS. That simulation allowed for:

- Determining the pressures and temperatures that occur in the engine chamber for engine supplied by compressed air from the accumulation tank with air pressure 7bar
- Adopting the right size of the work chamber (to reduce air consumption and exclude the design of an engine with too much power to drive the transport platform
- Selection of clearance between rotors and housing
- Estimation of engine load, engine speed, and engine power.

An attempt to estimate the conditions that exist in the pneumatic engine working chamber has been made in [4]. However, to reduce the engine's air consumption, it was decided to simulate a smaller engine. The basic dimensions of the engine are:

- Working chamber volume - V_{ch} = 0.0005 m^3(without the volume of rotors)
- Outside diameter of the tooth - D_o = 120 mm
- Diameter of core rotor - D_{cor} = 85 mm
- Clearance between the housing and the rotor tooth C_o = 0.05 mm
- Clearance between cores of the rotors C_{cor} = 0.05 [mm]
- Width of rotors W_r = 30 mm

Input parameters entered:

- Inlet air temperature - T_{in} = 284 K
- Initial air temperature inside the chamber T_{ch} = 284 K
- Inlet air pressure - P_{in} = 0.5 MPa (air pressure in accumulation tank of brake truck system [5]
- Exhaust air pressure - P_{out} = 0.1 MPa
- Rotational speed of rotors - n = 1000 rpm
- Simulation time - t_{sym} = 0.06 s
- Time step - $t_{rot} = 2 \cdot 10e^{-5}$

As a result of the simulation the temperature field for fluid inside working chamber was obtained for each simulation time step. The temperature field is shown in Figure 4.

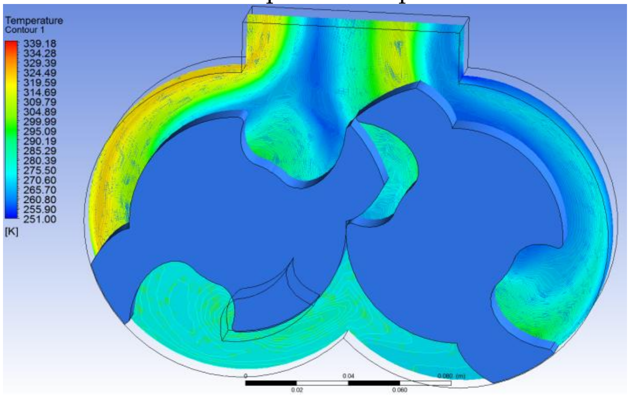

Figure 4: The example of fluid temperature field inside working chamber of pneumatic engine

The air stream at temperature 284 K is entering the working chamber until the inlet window closes completely. The air stream expands and the temperature of an air is rapidly cooled down to 265 K. Knowledge of the temperatures of fluid inside working chamber is important for selection of the clearance between the engine components. The main purpose of the simulation was to estimate the load that engine is able to transfer at the set of rotational speed and the set of air supply pressure. The average torque that can be transferred by rotors is:

- 5.30 [Nm] for the left rotor
- 5.41 [Nm] for right rotor]
- 10.71 [Nm] for both rotors

The detailed theoretical distribution of the moments that engine is able to transfer during one revolution is shown in Figure 5

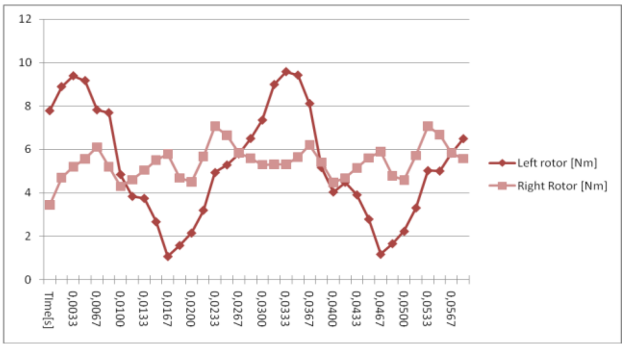

Figure 5: The distribution of load transferred by rotors obtained from simulation

5 Application of the engine and it's connection with braking system

Based on the simulation study, the pneumatic power rating P_{en} = 1 kW was calculated. The power of the electric motors that are driving the hydraulic pumps varies from 1 to 1.5 kW [6]. However the rotational speed of engine output shaft needs to be reduced and connection with gear unit seems necessary. A suitable output shaft speed for the platforms with swing lip is approximately 10 rpm. Figure 6 shows an example of a combination of a pneumatic engine with a two-circuit vehicle braking system. The smaller accumulation tank is connected to an air tank of the braking vehicle system. The pneumatic engine supply system should be equipped with a shut off valve coupled to the pressure gauge in the brake air supply tank to prevent from supplying the brake system with too low air pressure. Start an of an engine is initiated by a solenoid valve opened by the driver's cab. The valve closes automatically via limit switch.

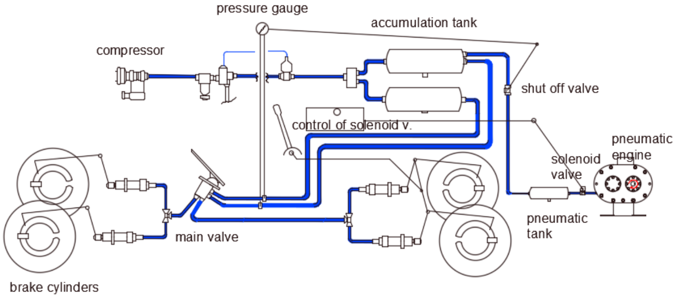

Figure 6: Combination of pneumatic engine with dual-circuit braking system of truck vehicle

6 Concept of a drive for dock leveller with a lip swing

The first proposed drive concept assumes the gravitational dropping of the u bridge and its lifting with a rope winding onto the output shaft of the pneumatic engine Figure 7. The end of lifting is accompanied by a strike of the edge of the platform by a limit switch causing the engine to shut off. The drive structure should be supplemented by a manual crank drive which operator could use in the event of a pneumatic engine failure.

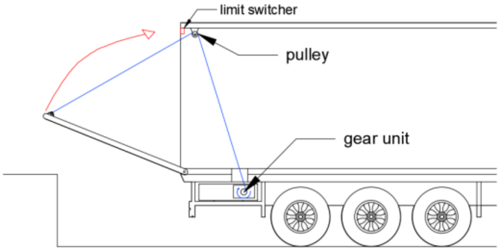

Figure 7: Scheme of a platform drive with swing edge

7 Concept of a drive for dock leveller with telescopic lip

The second concept assumes the drive of the retractable platform consisted of engine and linear gear unit. One of the ends of the platform is connected to the chassis of the truck with a spring. Such a drive design requires that the pneumatic engine additionally overcome the spring resistance. When the maximum swing is reached, the platform position is blocked by electromagnetic control pins. Releasing the lock causes the platform to return to the starting position, it can be performed at the request of the driver or, for example after fulfilling a specific condition such as: speeding up the vehicle. Such a solution can prevent the situation where after unloading the vehicle goes off with the platform extended. The schematic diagram of the presented drive system is shown in Figure 8.

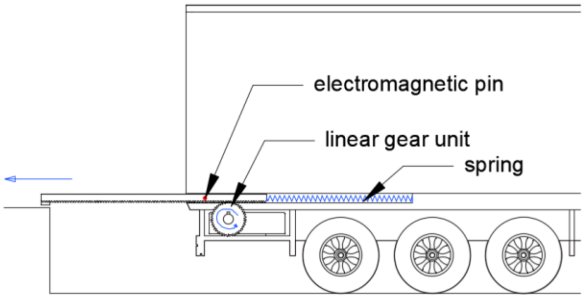

Figure 8: Scheme of a platform drive with retractable edge

8 Conclusions

The article presents the concepts of using a pneumatic engine working in reversed cycle to a tooth compressor cycle. Engine can be applied as a drive for loading and unloading systems on heavy vehicles. Simulation studies clearly show that the presented pneumatic engine powered by the air from the braking system has a similar power as other hydro electrical platform drives. The combination of an engine with gearbox is capable of providing sufficient torque and proper speed on the output shaft to drive the loading and unloading vehicle systems. Proper application of the presented concepts in practice will allow for the replacement of hydraulic platform drives. The next stage of research is to examine the prototype of a pneumatic engine and conducting experimental studies, eg. thermo graphic studies confirming the correctness of numerical calculations. Keep in mind that temperature tests will only be possible on the casing wall, so even after verification of the results of empirical testing, the simulation will remain the main tool for monitoring pressures and temperatures in the working chamber.

9 References

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