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DEVELOPMENT OF DOUBLE TRANSMISSION DOUBLE EXPANSION TECHNOLOGY FOR ENERGY SAVINGS OF COMPRESSED AIR SYSTEMS IN INDUSTRIAL SCALE

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ABSTRACT

The double transmission double expansion approach (DTDE) of Compressed Air System (CAS) is expanded in the work. The influence of such technology on the performance characteristics of a pneumatic machine is presented. Examples of recoverable air capacity are shown.

Keywords: industrial energy systems, advanced energy technologies, efficiency improvements, compressed air systems, air wastes, energy recovery.

NONMENCLATURE

Abbreviations	
CAS	Compressed Air System
DTDE	Double Transmission Double Expansion
Symbols	
P_{air}	Air power, W
P_T	Transmission part of air power, W
P_E	Expansion part of air power, W
p_0	Ambient pressure, Pa
p_A	Supply pressure, Pa
p_B	Backward pressure, Pa
$\dot{V}_A$	Volumetric flow, m^3/s

1. INTRODUCTION

Classical Compressed Air Systems (CAS) have found their application in power tools, machines and industrial processes in almost all industrial sectors. Low investment costs, durable construction, complex tasks related to operation and movement, long service life, high power density, etc speak for those systems in manufacturing plants [1]. However, CAS has a big disadvantage - low energy efficiency up to 10-20% of input energy – which is not in the current trends, striving to minimize consumption of energy [1]. Such high energy consumption by CAS, with a simultaneous low amount of useful energy in the final machines, in a significant way affects economics and the natural environment. Therefore, apart from the classic energy audits and simple maintenance activities, CAS composes with various types of topographies and systems designed to increase energy efficiency. The paper [2] presents a literature review after solutions improving the effect of CAS systems. Comparing compressor efficiency, one of the key losses in the CAS is the over-inflated energy consumption caused by oversizing the components. Due to the design process and discretization of pneumatic parameters by appropriate standards, a typical pneumatic machine is oversized from 30 to 50% [3]. There are several techniques and constructions which can save energy in such CAS [4]: bridge-type circuit [2,5], booster regulator [6], the dual-pressure system [2, 7, 8] and exhaust air energy recovery solutions [8, 9]. However, the exhaust air energy recovery solution has only a laboratory scale version, there are no full-scale industrial solution, except work done in [8].

In this paper, we present an development of exhaust air energy recovery technology introduced as Double Transmission Double Expansion (DTDE) approach. This technology involves the CAS with a two-stage operating pressure. The DTDE term is introduced in [8]. Here we want to show the impact of the second stage CAS on the characteristics of the pneumatic machine and assess the amount of energy recovered.

2. THEORETICAL BACKGROUND

Fig. 1a shows classical compressed air system CAS composed of air compressor, air tank and pneumatic machine as a set of several actuators with pneumatic mufflers [1]. Another CAS through the stages of compression, transmission and expansion has been done in [10]. In this approach, air is compressed and then utilized in a pneumatic machine. Otherwise, the CAS can be divided into three subsystems: compression, transmission and expansion, in which compressed air undergoes transformation, doing the work. As noted in [4, 10] the pneumatic machine only utilizes the transmission part of energy. Work related to the air expansion into the atmosphere is irretrievably lost.

used to supply the low-pressure system, converted into mechanical energy/electricity and then exhaust to atmosphere [8]. Thus, CAS is divided into two stages, with a classical CAS and an additional overlay reducing the oversizing of pneumatic machines. The demonstrated approach is patented [10,11].

For both cases, it cans be defined a formula for air power. For classical CAS [10] air power is divided into transmission and expansion powers as:

$$P_{air} = P_T + P_E = \\ = p_A \dot{V}_A \left(1 - \frac{p_0}{p_A}\right) + p_A \dot{V}_A \left(ln \frac{p_A}{p_0} + \frac{p_0}{p_A} - 1\right) \quad (1)$$

In case of DTDE approach, each component is divided into first and second stage [8].

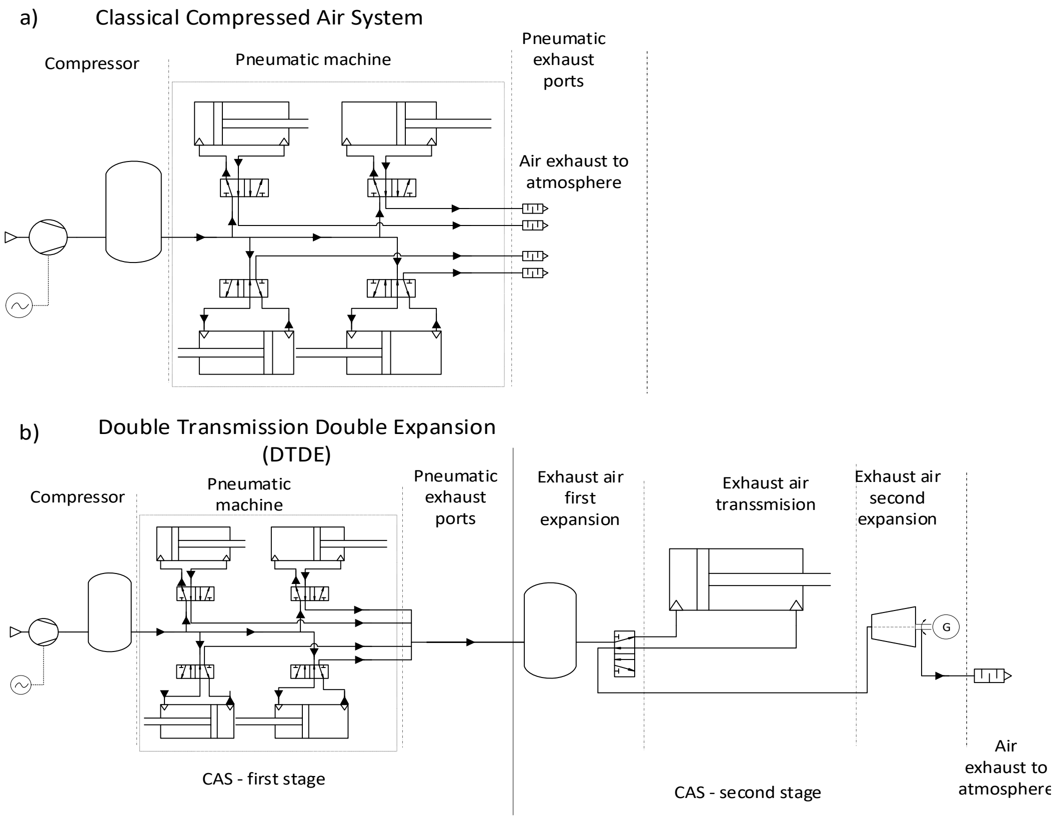

Fig 1 Topology of Compressed Air System: a) Classical; b) Double Transmission Double Expansion.

The method, shown in Fig. 1b, presents partial recovery of the exhaust air. All solutions propped up the energy recovery of the exhaust air are based on DTDE method [8]. The being of the DTDE method is the accumulation of exhaust air at a suitable pressure p_B depending on the operating pressure of the CAS installation p_A. The exhaust air from pneumatic mufflers is expanded to second stage pressure called backward pressure p_B. Then the air with lower pressure p_B can be

$$P_{air} = P_{T_A} + P_{E_{A-B}} + P_{T_B} + P_{E_{B-0}} = \\ = p_A \dot{V}_A \left(1 - \frac{p_B}{p_A}\right) + p_A \dot{V}_A \left(ln \frac{p_A}{p_B} + \frac{p_B}{p_A} - 1\right) + p_A \dot{V}_A \left(1 - \frac{p_0}{p_B}\right) + \\ p_A \dot{V}_A \left(ln \frac{p_B}{p_0} + \frac{p_0}{p_B} - 1\right) \quad (2)$$

3. RESULTS

As a part of experimental research of the DTDE method, technical tests of the device in the industrial plant were carried out. The appropriate DTDE system was fed through the pneumatic food packing machine of supply pressure p_A=7 bar and volumetric flow $\dot{V}_A$=4.6 m^3/h. The air power in the CAS second stage and electric power were recorded. In addition, the exhaust air, accumulated in the tank, was converted into electrical energy through an actuator, connected to the generator by set of a mechanical transmission.

a)

b)

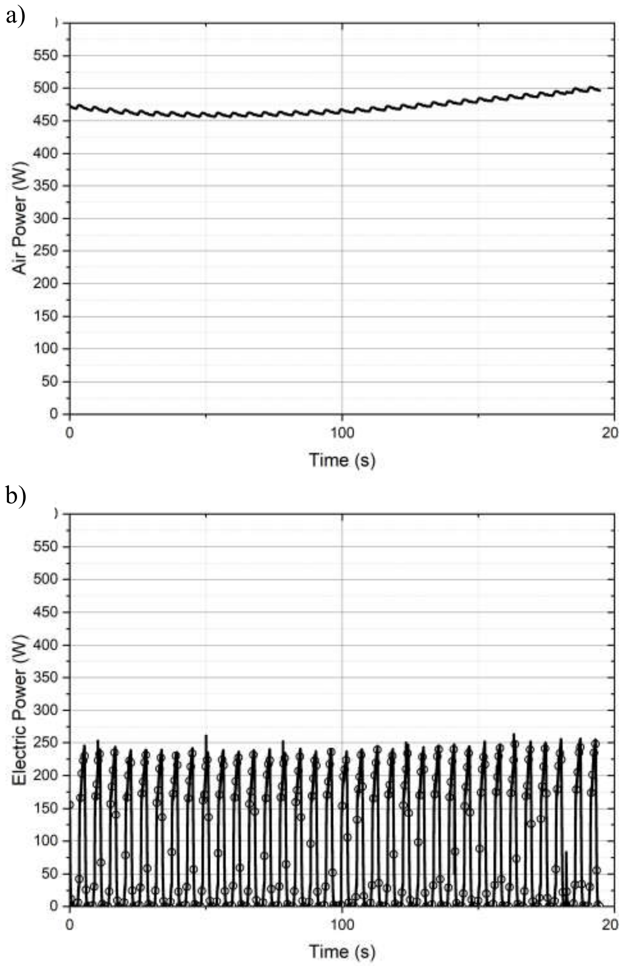

Fig 2 Expermental data: a) Air power; b) Generated electric power.

The results of the experiment are shown in Fig 2. The air power in the tank ranges between 450 - 500 W due to the pressure fluctuations in the tank (Fig 2a). The air power is converted into electricity (Fig 2b) with 50% efficiency, which can be used to power lighting or battery charging.

a)

b)

c)

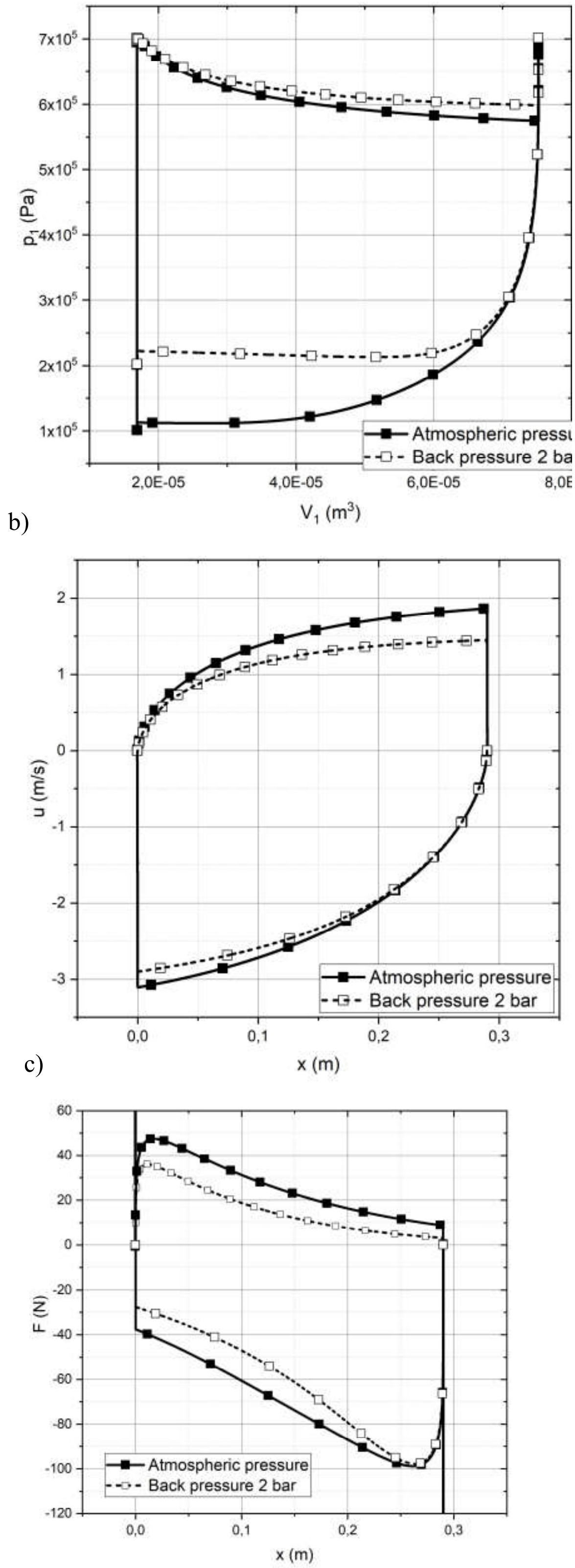

Fig 3 Computational results for pneumatic cylinder: a) Pressure-volume mapping; b) Velocity-displacement mapping; c) Force-displacement mapping.

In the construction of a mechanical transmission, a one-way clutch was used, which generated electricity generation only in extend move. In retract move of piston, the air power is wasted. The air power supplying the pneumatic machine, i.e. at the entrance to the first stage of the CAS, is about 1800 W, calculated using the formula (1). Using the DTDE system, you can recover about 28% of the input energy. Energy efficiency decreases by applying the conversion air power to electricity and amounts to 14%.

The second part of the tests is the evaluation of the impact of DTDE technology on the characteristics of the pneumatic machine. Computer simulations of the actuator’s parameters such us pressure, volume, force, velocity and displacement in the classical CAS and DTDE are carried out (Fig 3). Fig 3a shows the relationship between pressure and the volume of the actuator for both cases. Although the field of actuator’s cycle has been reduced by using DTDE, the pneumatic machine is still doing its task. Although less energy was supplied to the actuator, it still carries out its work. Fig 3b shows the piston velocity and displacement of actuators. Piston velocity is higher for the classical system. However, it translates into a slightly faster movement time of only few ms. The last chart, shown in Fig 3c, indicates the diagram of force and position of the piston. It is worth noting that the actuator performs the same task with higher efficiency for DTDE approach.

4. CONLUSION

By using a two-stage CAS system called DTDE energy gains are generated in the system. The backload of pneumatic ports does not affect the performance characteristics of the pneumatic machine. The amount of air power to be recovered in relation to the input power is 27%. Depending on its further use, the final efficiency of the modification is determined. In the case of conversion to electricity, an efficiency of 14% was obtained.

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