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# Thermographic bench tests of rubber-cord pneumatic spring

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**Abstract.** The article is dedicated to thermographic bench inspection of the rubber-cord pneumatic spring with or without air damper at different operating volumes. It also describes an experimental model, a procedure and results of thermographic bench tests of the rubber-cord pneumatic spring.

## 1. Introduction

One of the ways to increase the damping properties of pneumatic springs (PS) with rubber-cord casings (RCC) is air damping application [1...14]. However, it is known that constant casing bends and air throttling cause additional heating of the spring. In order to assess heating rates the Chair of “Automated units” of the Volgograd State Technical University performed bench tests of the pneumatic spring with and without air damper at a different operational volume. The purpose of these tests was to define the zones of maximum heating for different PS surfaces, as well as the peak temperature and the time for reaching a stabilized temperature mode.

## 2. Description of experimental model

Tests have been performed on a dynamic stand with servo-hydraulic actuator co-developed with *Biss ITW* (India) (figure 1) [15]. The test PS 1 is installed on a bench between the support plate 3 of hydropulsator 2 and adjusting channels 6 of the sprung mass 5. The test PS has a sleeve type rubber-cord casing (RCC) 1 VL 260-340, a bored piston 4 and an upper cover 7 with a filler connector 8. The bore of RCC 1 is connected with a bore 10 of piston 4 through the air damper with body 11 axially installed on the top end of piston 4 and fixed using a clamp 12 and bolts 13 with a sealing 14. Inside the body 11 there is a throttle 15 interconnecting bores 9 and 10, two rows of radial ports 16 and elastic non-return valve 17 shutting down these ports during the rebound and connecting bore 9 with bore 10 of the piston 4 only during the compression. The top end of piston 4 has an installed buffer of maximum compression 18 fixed with a clamp 12.

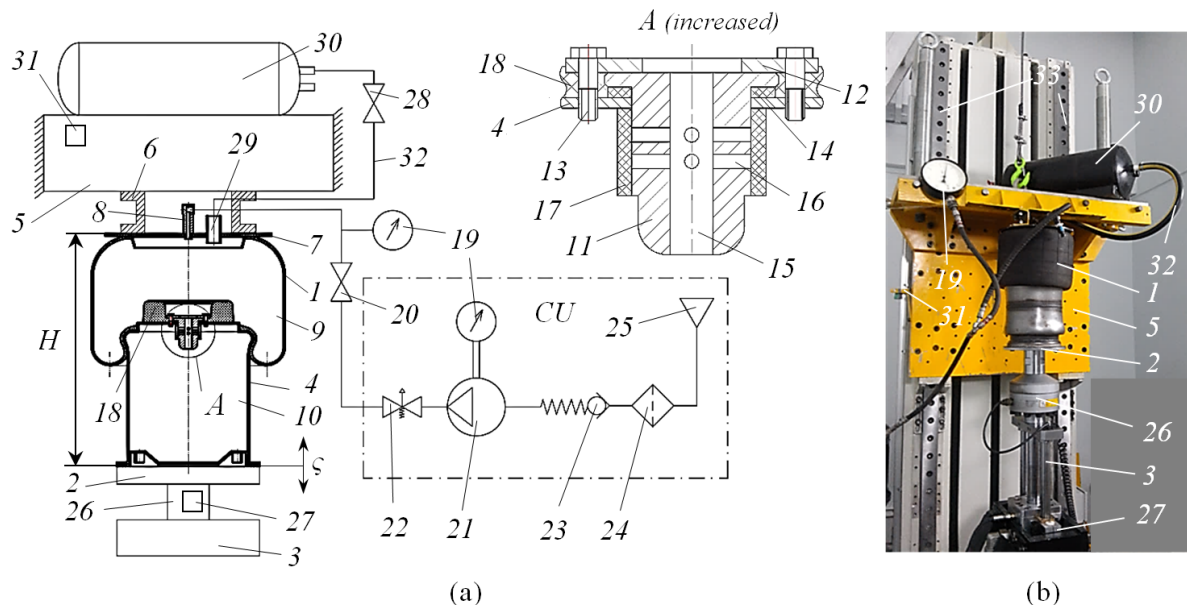
The PS volume above the piston in a static position  $V_{st} = 11$  L, as well as the volume of an extended bored piston  $V_b = 7.6$  L. The PS height in a static position (from the top RCC cover to the bottom RCC cover)  $H_{st} = 450$  mm. Static pressure in PS  $P_{st} = 0.2$  MPa. Throttle diameter  $d = 6$  mm. Hose length  $l_h = 1$  m, and its cross section  $d_h = 20$  mm. Receiver volume  $V_r = 20$  L.

## 3. Methodology for bench testing

The methodology for bench testing is as follows.



Before starting the test, the traverse and sprung mass are fixed against bench guides 33. To ensure the required operational volume in the PS piston its axial port either hermetically sealed or remained open. In order to increase an operational PS volume we connect receiver 30 to the bore 9 of RCC 1 through the inlet port 29 and hose 32. This receiver is installed on SM 5.



**Figure 1.** Tested pneumatic spring: (a) – scheme of experimental pneumatic spring; (b) – general view of experimental unit on the stand; 1 – sleeve type RCC; 2 – hydropulsator with support plate 3; 4 – bored piston; 5 – sprung mass (SM); 6 – adjusting channels; 7 – upper cover; 8 – filler connector; 9 – bore of RCC 1; 10 – bore of piston 4; 11 – body of air damper; 12 – clamp; 13 – bolts; 14 – sealing; 15 – throttle; 16 – radial ports; 17 – elastic non-return valve; 18 – buffer of maximum compression; 19 – manometers; 20, 28 – valves; 21 – compressor; 22 – bypass valve; 23 – check valve; 24 – filter; 25 – intake; 26 – force sensor; 27 – position sensor; 29 – connecting pipe with receiver 30; 31 – displacement and speed sensor; 32 – hose; 33 – guides;  $H$  – height of PS in static position;  $\varsigma$  – displacement of the hydropulsator plate;  $CU$  – compressor unit

While studying the process of PS heating with an air damping, damping node is installed in the piston. The pneumatic spring is put in a static position corresponding to its height of 450 mm by air supply from the external compressor to the filler connector and hydropulsator rod extension to the required height. The air pressure inside the PS is brought to the required value, while the operating pressure is controlled by pressure gauge 19.

Further, using control panel we set up an amplitude, rate and time period of hydropulsator rod extension. During tests we selected harmonic loading modes with a frequency of 1 Hz and amplitude of 50 mm which are close to resonant modes of sprung mass vibrations of the car.

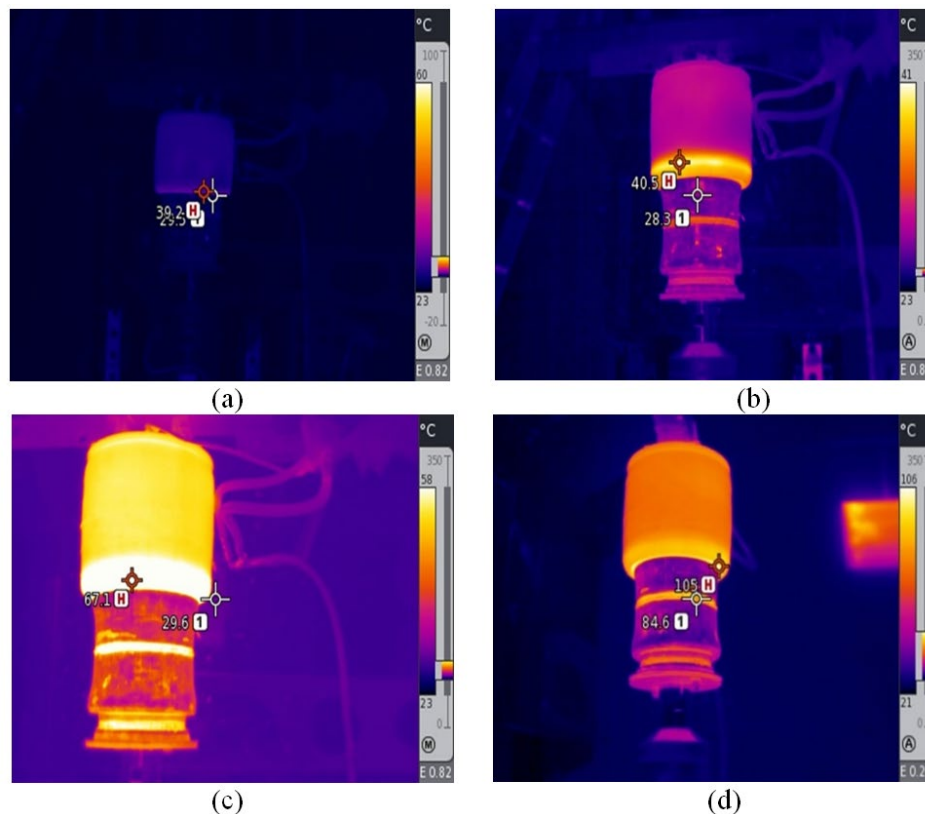
Using *Testo 890 VI* thermal imaging camera we measure the temperature in three zones of PS outer surface every two minutes: in the middle zone of RCC wall; on the RCC bend zone; in the zone of the bored piston. The tests have been performed in the laboratory at ambient temperature + 22 ... + 23 °C without forced air cooling of the PS.

In the process of testing the PS had the following operational volumes: 11, 18.6, 31 and 38.6 liters. With a volume of 11 and 31 L, the piston bore was covered by a plug. With a volume of 18.6 and 38.6 L, the bored piston, with a volume of 7.6 L, was either open, or was connected by a throttle or a throttle with a non-return valve opened during the compression. Also, with a volume of 31 and 38.6 liters, a 20 L receiver was connected to the top cover of the PS through a hose.

#### 4. Results of bench tests

Figure 2 shows examples of PS thermograms at different operational volumes with and without damping node. Brighter colors correspond to greater heating of PS surfaces.

Figures 3 ... 5 show the process graphs of heating the PS components (at different operational volumes, with and without air damper) depending on time.



**Figure 2.** Thermograms of pneumatic spring: (a) and (b) – with operational volume of 11 and 18.6 liters (without damping node); (c) – with operational volume of 18.6 liters and throttle of 6 mm; (d) – with operational volume of 18.6 liters, throttle of 6 mm and non-return valve

Figure 3(a) shows that maximum heating temperature  $+40\text{ }^{\circ}\text{C}$  of RCC bend zone at operational volume of 11 liters is reached during 0...20 min with an increasing average rate of  $1\text{ }^{\circ}\text{C}\cdot\text{min}^{-1}$ , and between 20...40 min PS temperature remains unchanged (curve 1).

An operational volume increase to 18.6 liters does not affect the maximum heating temperature of the bend zone, however, the time taken to reach the mode increases from 20 to 40 minutes. Whereas, between 0 ... 15 min, the rate of temperature increase averages  $1.2\text{ }^{\circ}\text{C}\cdot\text{min}^{-1}$ , and then the rate slows down by a factor of 10 (curve 2).

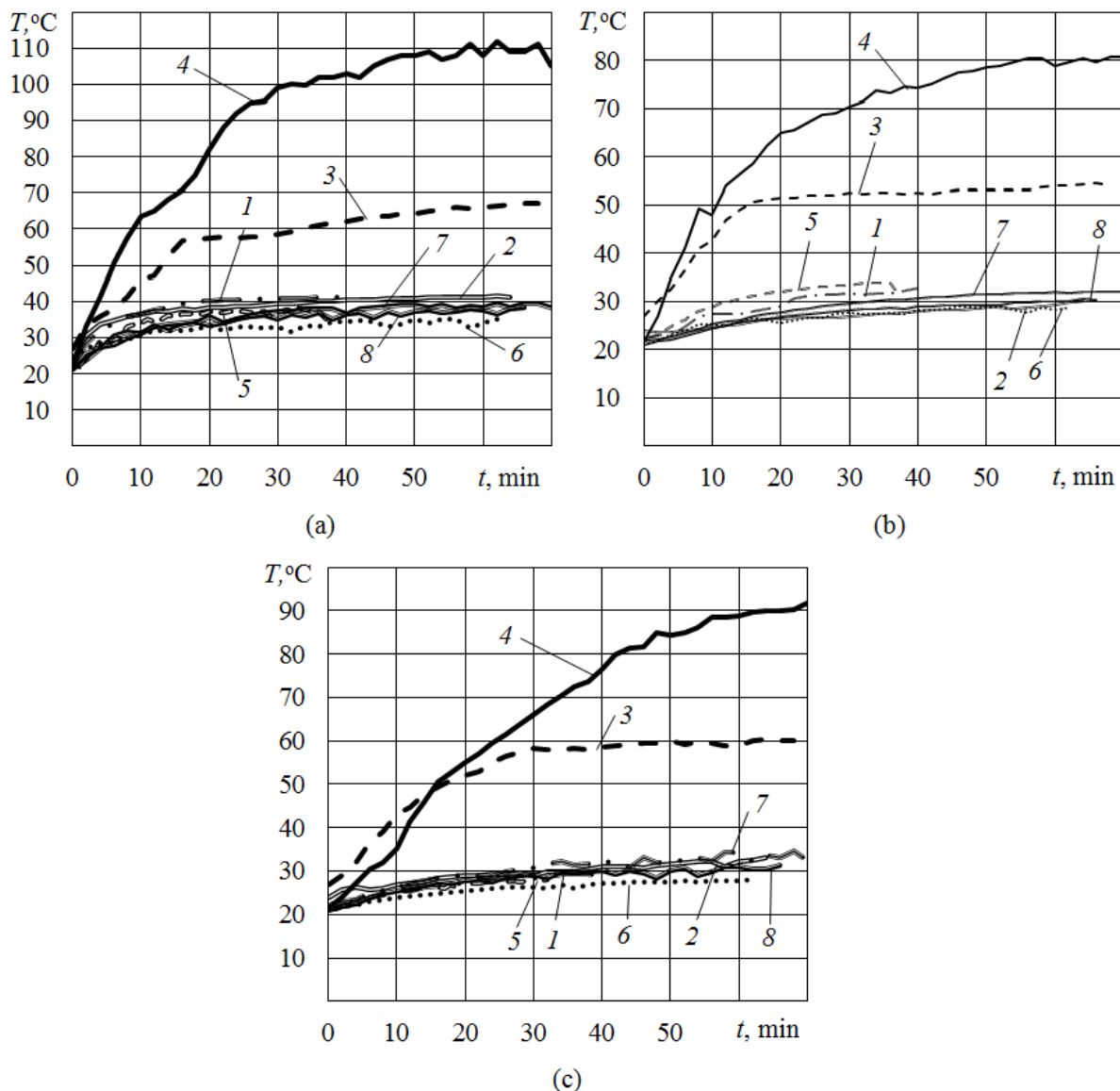
The throttle of 6 mm diameter installed in PS of 18.6 liters causes the increase of maximum heating temperature for RCC bend zone from  $+40$  up to  $+67\text{ }^{\circ}\text{C}$ , while the heating time to stabilize the temperature grows from 40 to 60 minutes. The maximum temperature increase from  $+22$  to  $+58\text{ }^{\circ}\text{C}$  at a rate of  $2.2\text{ }^{\circ}\text{C}\cdot\text{min}^{-1}$  is observed in the interval of 0 ... 16 minutes, at the interval of 16 ... 30 minutes the temperature remains practically unchanged, and in the interval of 30 ... 60 minutes the temperature rises to  $+67\text{ }^{\circ}\text{C}$  at a rate of about  $0.3\text{ }^{\circ}\text{C}\cdot\text{min}^{-1}$  (curve 3).

The throttle with a non-return valve installed in PS of 18.6 liters increases the maximum heating temperature of RCC bend zone from  $+67$  up to  $+110\text{ }^{\circ}\text{C}$  within 60 minutes. Whereas, the increase of maximum temperature from  $+22$  to  $+100\text{ }^{\circ}\text{C}$  at a rate of about  $2.6\text{ }^{\circ}\text{C}\cdot\text{min}^{-1}$  is observed in the interval

of 0 ... 30 minutes, in the interval of 30 ... 50 min the temperature increase slows down from 2.6 to 0.5  $^{\circ}\text{C}\cdot\text{min}^{-1}$ , and then the temperature slightly increases (curve 4).

The increase of PS operational volume from 11 and 18.6 liters to 31 and 38.6 liters has a slight effect on the decrease in the heating temperature in the RCC bend zone (curves 5 and 6).

The increase in operational volume of PS with the throttle, as well as with the throttle including non-return valve, from 18.6 to 38.6 liters leads to a decrease in the heating temperature of the RCC bend zone from +67 to +39.3  $^{\circ}\text{C}$  (curve 7) and from +110 to +38.6  $^{\circ}\text{C}$  (curve 8).



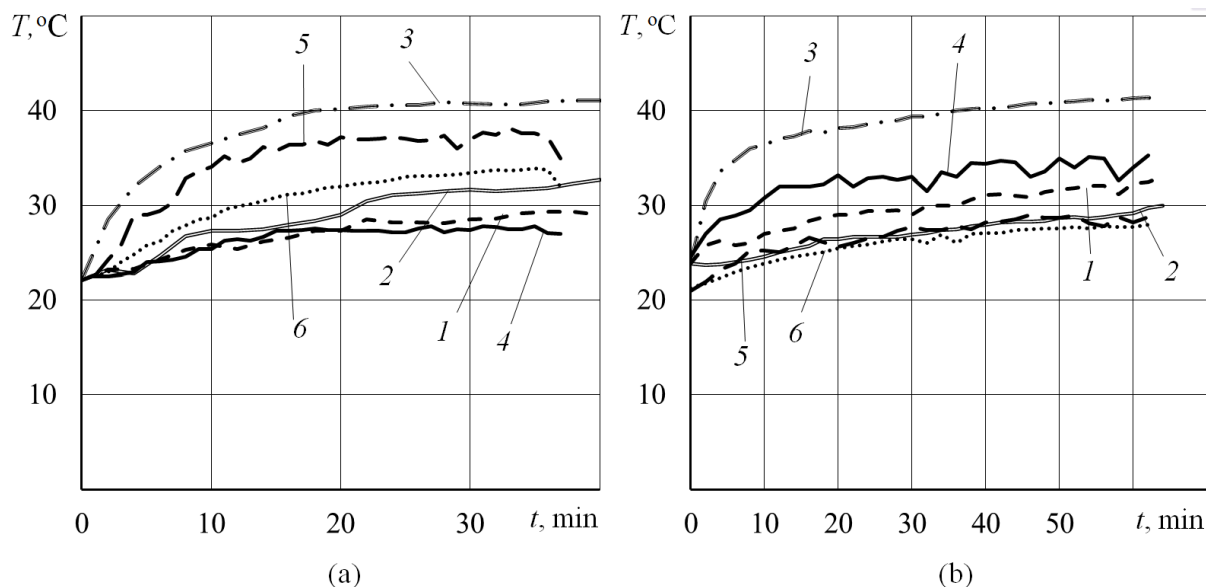
**Figure 3.** Process graphs of heating the PS components at different operational volumes, with and without damping node: (a) – RCC bend zone heating; (b) – RCC middle zone heating; (c) – PS piston wall heating; 1, 2, 5, 6 – PS with operational volume of 11, 18.6, 31 and 38.6 liters; 3, 4, 7, 8 – PS with operational volume 18.6 и 38.6 liters, throttle and throttle with non-return valve

Figure 3(b) indicates that the maximum temperature of +33  $^{\circ}\text{C}$  for heating the RCC middle zone with operating volume of 11 liters is reached within an interval of 0 ... 30 minutes with an average increase

rate of  $0.5\text{ }^{\circ}\text{C}\cdot\text{min}^{-1}$ , then the PS goes to the balanced state and the temperature of this zone remains almost unchanged (curve 1).

Operating volume increase to 18.6 liters reduces the heating temperature of RCC middle zone from +32 to +30.5  $^{\circ}\text{C}$ , however, the ramp-up time increases from 30 to 50 minutes, while the temperature increases extremely slowly at the average rate of  $0.1\text{ }^{\circ}\text{C}\cdot\text{min}^{-1}$  (curve 2).

Throttle installation in the PS with an operating volume of 18.6 liters causes an increase in the maximum heating temperature of the middle zone from +33 to +54  $^{\circ}\text{C}$ . Whereas, the heating time to reach the balanced temperature is 30 minutes. The maximum temperature increase from +22 to +52  $^{\circ}\text{C}$  at a rate of about  $1.5\text{ }^{\circ}\text{C}\cdot\text{min}^{-1}$  is observed in the interval of 0 ... 20 minutes, in the interval of 16 ... 30 minutes the temperature practically does not increase following by the decrease of temperature growth rate almost by 30 times (curve 3).



**Figure 4.** Process graphs of heating the PS components at different operational volumes, without damping node: (a) – PS with operational volume of 11 liters – curves 1...3 and 31 liters – curves 4...6; (b) – PS with operational volume of 18.6 liters – curves 1...3 and 38.6 liters – curves 4...6; 1, 4 – PS piston wall heating; 2, 5 – RCC middle zone heating; 3, 6 – RCC bend zone heating

The throttle with a non-return valve installed in PS of 18.6 liters increases the maximum heating temperature of RCC middle zone from 54 up to +80 $^{\circ}\text{C}$  within 60 minutes. Whereas, the increase of maximum temperature from +22 to +65  $^{\circ}\text{C}$  at a rate of about  $2\text{ }^{\circ}\text{C}\cdot\text{min}^{-1}$  is observed in the interval of 0 ... 20 minutes, in the interval of 20 ... 60 min the temperature increase slows down from 2 to  $0.4\text{ }^{\circ}\text{C}\cdot\text{min}^{-1}$ , and then the temperature slightly increases (curve 4).

The increase of PS operational volume from 11 and 18.6 liters to 31 and 38.6 liters has a slight effect on the heating temperature in the RCC middle zone (curves 5 and 6).

The increase in operational volume of PS with the throttle, as well as with the throttle including non-return valve, from 18.6 to 38.6 liters leads to a decrease in the heating temperature of the RCC middle zone from +54 up to +32  $^{\circ}\text{C}$  (curve 7) and from +80 up to +30.5  $^{\circ}\text{C}$  (curve 8).

Figure 3(c) indicates that the maximum temperature of +30 $^{\circ}\text{C}$  for heating the PS piston with operating volume of 11 liters is reached within 25 minutes with an average increase rate of  $0.25\text{ }^{\circ}\text{C}\cdot\text{min}^{-1}$ , then the PS remains almost unchanged (curve 1).



Operating volume increase to 18.6 liters practically does not affect the maximum heating temperature of PS piston, however, the ramp-up time increases from 25 to 50 minutes, while the temperature increases extremely slowly at the average rate of  $0.15\text{ }^{\circ}\text{C}\cdot\text{min}^{-1}$  (curve 2).

The throttle installed in PS of 18.6 liters causes the increase of maximum heating temperature of the bored piston from  $+30$  up to  $+60\text{ }^{\circ}\text{C}$ , while the heating time to stabilize the temperature is 50 minutes. The maximum temperature increase from  $+22$  to  $+58\text{ }^{\circ}\text{C}$  at a rate of  $1.3\text{ }^{\circ}\text{C}\cdot\text{min}^{-1}$  is observed in the interval of  $0 \dots 28$  minutes, in the interval of  $28 \dots 50$  minutes the temperature increase rate slows down up to  $0.1\text{ }^{\circ}\text{C}\cdot\text{min}^{-1}$ , and then the temperature remains practically unchanged (curve 3).

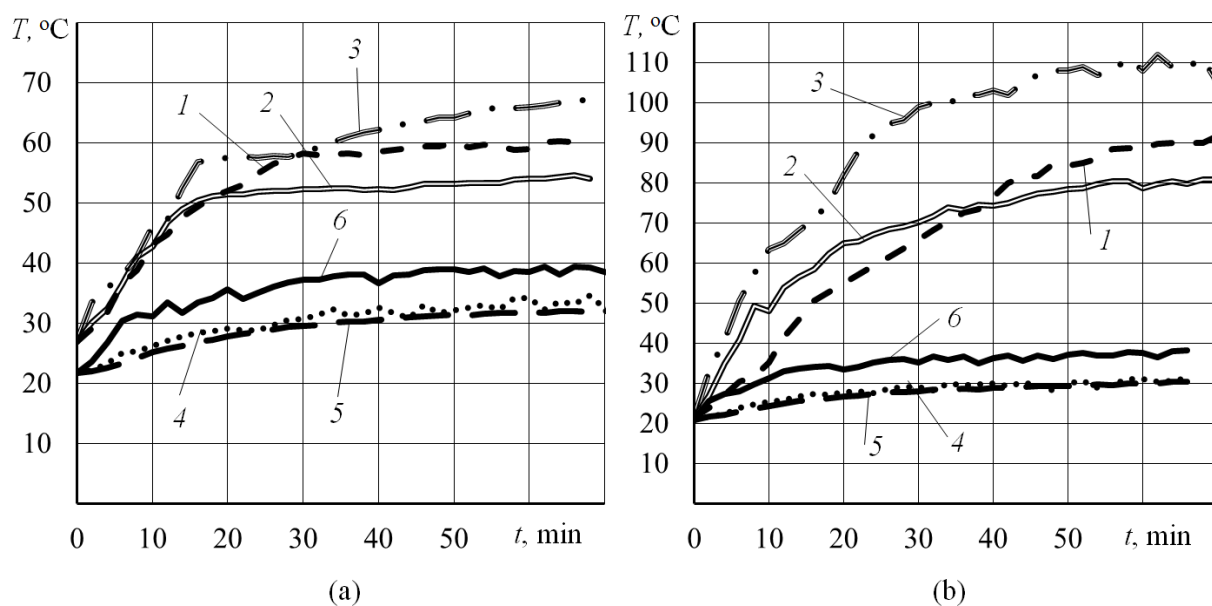
The throttle with a non-return valve installed in PS of 18.6 liters increases the maximum heating temperature of the bored piston from  $+60$  up to  $+90\text{ }^{\circ}\text{C}$  within 60 minutes. Whereas, the increase of maximum temperature from  $+22$  to  $+90\text{ }^{\circ}\text{C}$  at a rate of about  $1.1\text{ }^{\circ}\text{C}\cdot\text{min}^{-1}$  before reaching the balanced temperature is observed in a whole time interval of tests performed (curve 4).

The increase of PS operational volume from 11 and 18.6 liters to 31 and 38.6 liters has a slight effect on the heating temperature of the bored piston (curves 5 and 6).

The increase in operational volume of PS with the throttle, as well as with the throttle including non-return valve, from 18.6 to 38.6 liters leads to a decrease in the heating temperature of the bored piston from  $+60$  up to  $+33.2\text{ }^{\circ}\text{C}$  (curve 7) and from  $+90$  up to  $+30.6\text{ }^{\circ}\text{C}$  (curve 8).

The interval for reaching the balanced temperature of RCC bend zone, RCC middle zone and bored piston during PS tests with a receiver (figure 3, (a)...(c); curves 5-8) is 30 minutes.

Figure 4 shows that with an operating volume of 11 and 18.6 liters and the lack of air damper, the maximum temperature of  $+41\text{ }^{\circ}\text{C}$  for heating the RCC bend zone is reached within 30 minutes (curve 3). However, the maximum temperature of the piston wall (curve 1) and RCC (curve 2) is significantly lower, which is caused by the low rate of air heating in the operating volume and the high thermal metal conductivity of the piston. It should be noted that with an increase in operating volume from 11 liters (figure 4(a)) to 18.6 liters (figure 4(b)), the walls of the piston heat up slightly more than RCC walls. With an increase in the operating volume from 11 and 18.6 liters to 31 and 38.6 liters, the heating temperature for the piston wall, RCC middle zone and the bend zone decreases by an average of  $10\text{ }^{\circ}\text{C}$ .



**Figure 5.** Process graphs of heating the PS components at different operational volumes, with damping node: (a) – PS with throttle; (b) – PS with throttle and non-return valve; 1...3 – PS with operational volume of 18.6 liters; 4...6 – PS with operational volume of 38.6 liters; 1, 4 – PS piston wall heating; 2, 5 – RCC middle zone heating; 3, 6 – RCC bend zone heating

If we compare the graphs in figure 5, (a) and (b), we will see that the highest maximum heating temperature of the PS is achieved when installing a throttle including non-return valve. The maximum heating temperature of the piston wall is higher (curves 1) than RCC (curves 2), due to the higher thermal conductivity of the metal. With an operating volume increase for PS with a throttle from 18.6 to 38.6 liters, the heating temperature of +60 °C for the piston wall, +54 °C for RCC middle zone and +67.2 °C for RCC bend zone decreases to +34.7, +33.2 and +39.3 °C, respectively (figure 5(a)), that is, almost twice. With operating volume increase for PS with a throttle including non-return valve from 18.6 to 38.6 liters, the heating temperature of +90 °C for the piston wall, +80 °C for RCC middle zone and +110 °C for RCC bend zone decreases to +30, +30 and +37.2 °C, respectively, that is, almost three-fold (figure 5(b)).

The experimental data provided above were obtained for the most severe resonant test mode without a forced air cooling of the PS. Therefore, when the receiver is connected to the PS in the suspension/sprung design and when it is blown with an opposing air flow and its random vibrations, the maximum heating temperatures of the PS with an air damper installed in its piston will be much lower. This allows recommending the use of air damping instead of hydraulic shock absorbers or combination of both to improve the smooth ride and speed of vehicles with a pneumatic spring system.

## 5. Conclusions

- In the absence of a throttle in the piston of the pneumatic spring with an operating volume of 11 L, the maximum temperature of +40 °C of the bend zone of the rubber-cord casing is reached within 20 minutes. PS operating volume increase from 11 to 18.6 L does not affect the maximum temperature, but it causes a double increase of the heating time from 20 to 40 minutes. In this case, the maximum heating temperature of the piston and RCC remains lower approximately by 25%, i.e. +30 °C.
- Installation of the throttle of 6mm in diameter in the PS piston of 18.6 L, leads to a maximum heating temperature increase in the piston up to +60°C within 50 minutes, and the installation of a throttle including non-return valve raises its maximum temperature up to +90 °C within 60 min.
- Maximum heating up to +110 °C is achieved in the RCC bend zone when testing the PS with a throttle including non-return valve. This temperature increases within 60 minutes due to the air flow through the throttle and non-return valve, internal intermolecular friction of RCC and its friction against the piston wall.
- An increase in the operating volume of the PS without air damper leads to a slight decrease in the heating temperature: the piston walls – by 1 ... 2 °C, the bend zone and the middle zone of the RCC wall – by 5°C.
- An increase in the operating volume of the PS with a throttle leads to a decrease in the heating temperature of the piston wall from +60 to +35 °C, the bend zone and the middle zone of the RCC wall from +67 to +33 °C and from +54 to +39 °C, respectively.
- An increase in the operating volume of the PS with a throttle including non-return leads to a decrease in the heating temperature of the piston wall from +90 to +30 °C, the bend zone and the middle zone of the RCC wall from +110 to +37 °C and from +80 to +30 °C, respectively.
- In order to increase the vibration-protective properties of the vehicle's spring when using pneumatic springs with high operating volumes, it is possible to recommend installation of an air damper in the pneumatic spring with no risk of strong heating of its elements.

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