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STRESS CONDITIONS ON WALLS OF STEEL AND COMPOSITE (SCBA) BOTTLES DURING OF FILING FROM „AIR BANK“

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Abstract: Bottles/cylinders of breathing apparatus can be filled with compressors and directly connected to the „air bank". During the filling of the bottle/cylinder of breathing apparatus with high pressure compressors, or with the „banks of the air", pressure increases over time and the amount of compressed medical air (later on in the text CMA) in the bottle/cylinder. The consequence is an increase in the tension in the bottle/cylinder material that is in direct coupling with the specified parameters. The tension intensity and the effect of the increase in pressure in time on the tension of the steel bottle/cylinder using tensometric tapes can be identified. Dilatation measurements on steel and composite bottles/cylinders of breathing apparatus (SCBA) in real conditions were performed using tensometric measuring tapes. Tensometric measuring tapes, dilatation measurements were made on the steel and composite bottle/cylinder of insulating apparatus (SCBA) apparatus in real conditions during filling in the „air bank".
Keywords: „air bank", filling of the bottle/cylinder, compressed medical air (CMA), specified parameters, dilatation measurements

1. INTRODUCTION

When performing experimental research in which thermal dilatations, temperature, pressure, as well as identification of the mechanical characteristics of the steel and composite bottles of the SCBA apparatus were examined, several devices are used:

- Quantum MKS440A – a device for converting and processing signals (information about longitudinal, tangential or resulting deformations), and data acquisition,
- Measuring tapes KSI31–6/120 with two measuring fibers for the biaxial state of the known direction of longitudinal, tangential or resulting deformations, with which the experimental analysis was performed,
- Device HBM 1–P3IC/3000 bar – pressure transmitter and transmitter, intended for pressures ranging from 10 to 30 bar [1].
- Thermal imaging camera FLIR K65, for measuring the temperature of the environment, bottles and compressor during normal and sudden expansions of compressed medical air.

2. MEASURING EQUIPMENT

Quantum X data acquisition system

Device for signal conversion and data acquisition, produced by Hottinger Baldwin Messtechnik (HBM), Quantum MX440A, was used during the experimental tests of expansions on steel and composite SCBA bottles (Figure 1).

The device is characterized by: high–resolution measurement acquisition (24 bit) with the possibility of adjusting the sampling rate (up to 192 kHz), low–pass signal filters that eliminate the high–frequency signal of the basic signal or the noise signal that occurs as a regular occurrence during high–frequency measurements, reliable operation in a wide temperature range of the environment (from –20° C to +65° C), high test quality and reliable measurement results [1], [10].

Figure 1. Device QuantumMX440A [6].

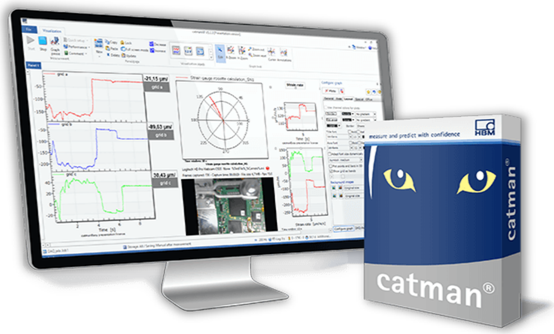

Figure 2. Catman Easy software inte–rface for acquisition and analysis [7].

Using of the Catman Easy software (Figure 2), the filter parameters were adjusted according to the nature of their basic signal and noise content, as well as the synchronous recording of sensor data in real time, while the communication between the acquisition and measuring sensors was realized through a standard PC connection and ethernet connections [1], [10].

Measuring tapes

The technology of making and applying measuring tapes (Figure 3) has been continuously improved for more than 60 years, and for the experimental analysis, measuring tapes manufactured by HBM with two measuring fibers for a biaxial voltage state of a known direction and a resistance of 120 Ω were used. These measuring tapes provide great safety and reliability when used and are used when measuring local deformations on real structures or models.

Their main disadvantage is that measurements are made on a very small surface and only at one measuring point. Also, due to the impossibility of gluing them on the measuring surface, problems may arise that affect the reliability of the test results and the impossibility of obtaining the maximum deformation values [1], [9], [11].

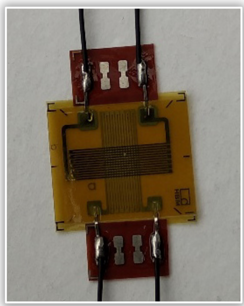

Figure 3. Double measuring tape XYxx.

Figure 4. Pressure sensor and transmitter HBM 1–P3IC/3000 bar with adapter.

Pressure sensor and transmitter HBM 1–P3IC/3000 bar.

For pressure measurement in many branches of industry, a pressure sensor and transmitter manufactu–red by HBM (Figure 4) is used, and for the purposes of this experimental research, a special adapter was made. The steel monolithic housing and robust design offer reliability in use, exceptional load resistance even in very bad environments in which it is used. This device is made of corrosion–resistant material and features IP67 protection. During testing, their use is reliable even when exposed to impact pressure, vibrations or variable pressure. They provide very reliable results in combination with HBM measuring tapes and during exceptional dynamic loads with a large number of cycles [1], [10].

The thermal imaging camera FLIR K 65

The thermal imaging camera FLIR K (Figure 5) is intended for use in firefighting units, whether it is searching for fire hotspots, searching for people (in smoky rooms or on the ground with low visibility) or identifying hazardous materials.

Figure 5. The thermal imaging camera FLIR K65 [8]

Due to its robust appearance, the camera is easy to use even with gloves, it is resistant to falls (on concrete from a height of 2 m), water penetration IP67 and high temperatures. The thermal imaging is enhanced by digital image processing, which shows more details, on a 4˝ display with a resolution of 320×240 pixels. It has an internal memory that can store 200 thermo–vision images or 200 thermo–

vision videos (up to 5 minutes of each record). Using a USB connector and cable, data from the camera can be transferred to a PC.

The thermal imaging camera meets the NFPA 1801–2013 standard, and is intended for operation in the temperature range from –20° C to +150° C. The Li ion battery provides four hours of operation [2], [4].

3. TESTING OF SCBA BOTTLES DURING FILLING ON THE "AIR BANK"

Experimental installation and test procedure

The experimental part of the research on the steel and composite bottle of the SCBA apparatus on the „air bank" was carried out in the compressor station of the Banja Luka Fire Brigade. During this experimental test, the same bottles were used as for the pressure water test, except that in this case the bottles were placed on the console of the „air bank" (Figures 12 and 13).

The fast filling of bottles of isolation apparatus is done for the reason of shortening the time of absence of firefighters from the zone of extinguishing a fire or a chemical accident. During the rapid filling of bottles, the firefighter exposes himself to danger due to a possible accident – bottle explosion [4].

To carry out experimental research, which consisted of testing the bottles of the SCBA apparatus (steel and composite bottles) with water under pressure and in real conditions during filling on the „air bank", certain preparations were previously made (Figures 6 and 7):

- Weighing the filled bottles of the SCBA apparatus (steel and composite bottles; item 1), and then re–weighing the empty bottles after releasing the CMA from them.
- Measurement of the noise level on the valves during the release of CMA;
- Weighing empty SCBA apparatus bottles (steel and composite bottles; item 1) without valves.
- Carefully removing the layer of protective paint with sandpaper to the material of the bottle (steel or composite material).
- Degreasing the surfaces of the bottles on which the measuring tapes are stuck.
- Gluing measuring tapes with two–component glue.
- Soldering measuring tapes and checking resistance.
- Numbering of the measuring points, that is, the position of the measuring tapes (measuring point 1 – the bottom of the bottle, measuring point 2 – the middle of the bottle and measuring point 3 – the top of the bottle).

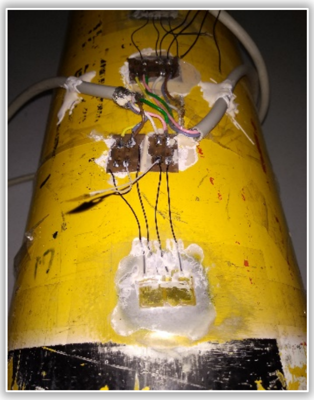

Figure 6. Steel bottle with ta–ped measuring tapes.

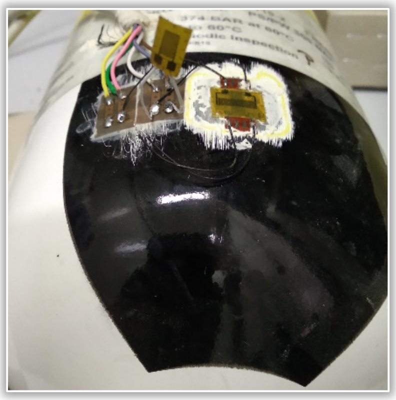

Figure 7. Composite bottle with glued measuring tapes.

Table 1. Technical data for steel and composite bottles (measured values): [1], [4]

Manufacturer, bottle type, serial number, year of manufacture	Internal number of bottles	P (bar)	Mass of filled pressure bottle (factory weight) (kg)	Mass of empty bottle with valve (kg)	Mass of empty bottle without valve (and without rubber linings) (kg)	Noise level when discharging CMA (dB)
MSA, Luxfer, composite, FCVK 07860, 12/2018	67	290	6,4 (3,9)	4,5	4,0	
Interspiro, SCI, composite, 8538, 07/2009*	XX	285	7,3 (4,9)	5,5	4,7 (4,3)[a]	93
MSA, Luxfer, steel, 185038, 04/2006	4	160	9,7 (8,37)	8,7	8,3	

[a] Measuring tapes are not glued to the Interspiro composite bottle, they have rubber linings in the upper and lower part to protect against mechanical damage, which was removed during weighing.

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The equipment for experimental analysis (Figures 1–5) consists of: measuring tapes XY31–6/120, transmitter and pressure transmitter HBM 1–P3IC/3000 bar, thermal imaging camera FLIR K65 and PC (laptop) [1], [4].

Experimental tests on both types of SCBA bottles were carried out for the case of loading with internal pressure, flow of compressed medical air in real conditions from the so–called bottles „air banks" and recorded with Catman Easy software. During the experimental test, longitudinal, tangential and resulting deformations were identified at pressures from 0 bar to 180 and 255 bar [1].

Pressure vessels

In operation, pressure vessels, from the safety aspect, represent specific energy equipment. They can be stable and mobile.

Containers that are under the pressure of liquid, compressed and dissolved gases, air or superheated liquids that do not change place from filling to emptying are called stable pressure containers [3].

Mobile pressure vessels are vessels under pressure of liquid, compressed and dissolved gases or air that change place from filling to emptying and are called bottles, if their diameter is less than 420 mm and their length is less than 2000 mm.

We classify „air banks" as stable pressure vessels, while SCBA apparatus bottles are classified as mobile pressure vessels.

Figure 8. Explosion of a steel SCBA cylinder during filling on a compressor [5].

Figure 9. The consequence of the explo–sion of a steel SCBA bottle [5].

Pressure vessels can be found in all branches of industry, and they have a certain accumulated energy, which is represented by the parameters of the energy medium with which they are filled. In the event of failure of the pressure vessel or explosion, devastating effects (Figures 8 and 9), damage to the building and the installation occur, along with a risk to the lives and health of people in the immediate proximity [4].

„AIR BANKS"

Reservoirs of compressed medical air „air banks", in some literature, are also called „air accumulato–rs" and basically represent a system of vessels under pressure, intended for the storage and distribution of compressed medical air.

Figure 10. „Air bank" with two ba–tteries of three bottles fixed to the wall [4].

Figure 11. „Air bank" with two batteries and two bottles each, fixed to the floor [4].

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The „air bank" consists of: tanks (50 l/300 bar steel cylinders) connected to the batteries by connecting pipes on the valves, a distribution board, sampling and relief valves, and pipelines for filling and leading to the pouring console. It consists of at least two batteries (Figures 10 and 11), while each battery consists of at least two (more often several) tanks, functionally connected to each other.

In practice, „air banks" with three batteries have proven to be the best, so that while one is being used, the second is being charged, and the third is in reserve. Its capacity is projected depending on the purpose and needs.

Nowadays, there is a tendency to design „air banks" of larger capacity, which are fed with one or more high–pressure compressors, due to practicality and economy, because the degree of utilization of the compressor is higher [4].

4. RESULTS OF EXPERIMENTAL RESEARCH ON THE „AIR BANK"

- Steel and composite bottle – longitudinal deformations at internal pressure from 0 bar to 240 and 250 bar

Explanation of abbreviations in the right part of the diagram:

- MP 1 – measuring point 1 (lower cylindrical part of the bottle),
- MP 2 – measuring point 2 (cylindrical part in the middle of the bottle),
- MP 3 – measuring point 3 (upper cylindrical part of the bottle).

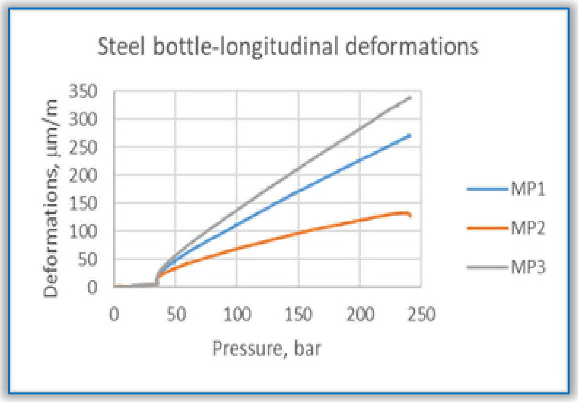

Diagram 1. Steel bottle – longitudinal defo–rmations, testing on the„ air bank" from 0 bar to 240 bar.

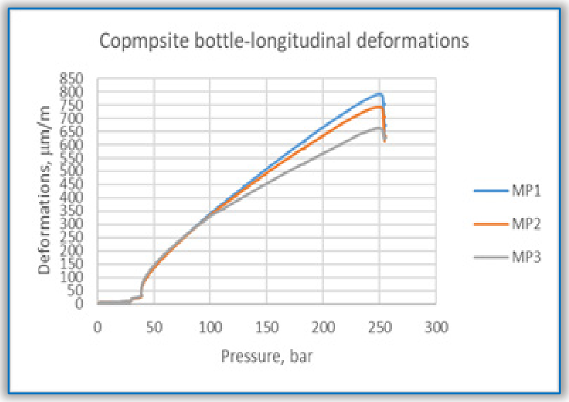

Diagram 2. Composite bottle – longitudinal deformations, testing on the „air bank" from 0 bar to 250 bar.

- Steel and composite bottle – tangential deformations at internal pressure from 0 bar to 200 and 210 bar

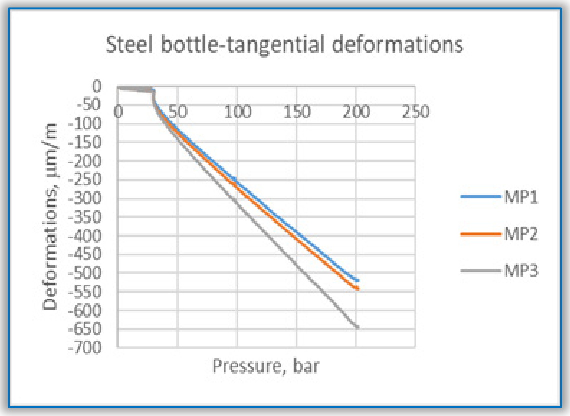

Diagram 3. Steel bottle – tangential deforma–tions, testing on the „air bank" from 0 bar to 200 bar.

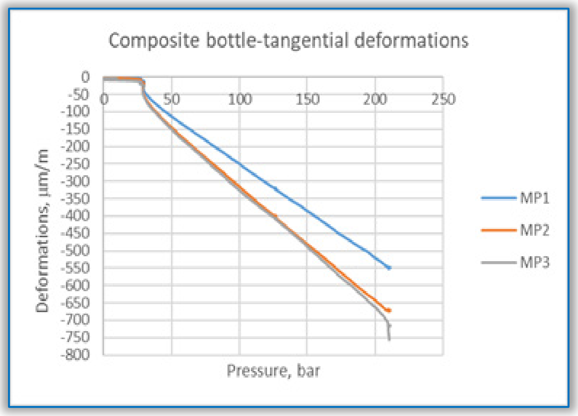

Diagram 4. Composite bottle – tangential defo–rmations, testing on the „air bank" from 0 bar to 210 bar.

Steel and composite bottle – resulting deformations at internal pressure from 0 bar to 240 and 255 bar

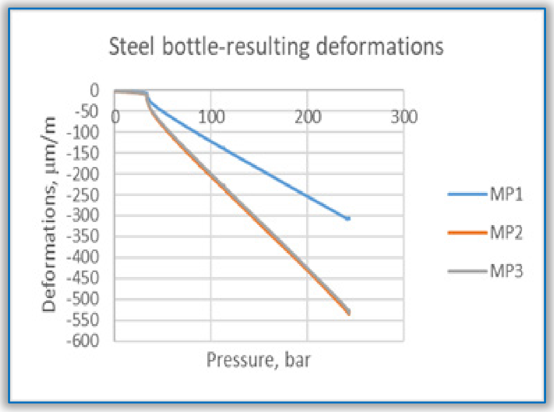

Diagram 5. Steel bottle – resulting deforma–tions, testing on the „air bank" from 0 bar to 240 bar.

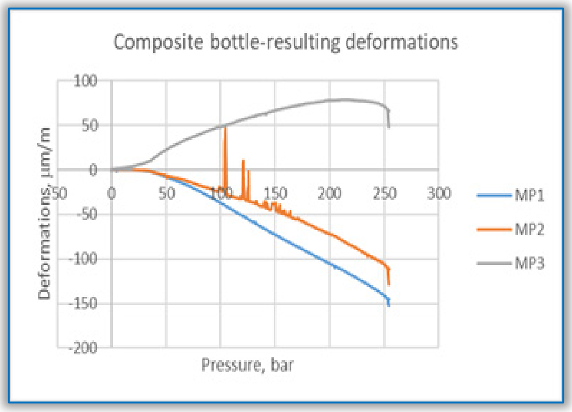

Diagram 6. Composite bottle – resulting de–formations, „air bank" test from 0 bar to 255 bar.

5. CONCLUSIONS

In order to define the parameters that significantly affect the safety of users in accident situations, which affect the increase of user safety and to arrive at significant parameters, especially when choosing equipment, these experimental studies were carried out. It can be reliably concluded that a very small number of authors have decided to research in the field of protection of respiratory organs, which can easily be proven by the lack of appropriate databases and knowledge bases, which could be applied in real conditions, both in the current and in the future researches. The degree of probability for determining factors that can threaten the safety of the user is determined by risk assessment, defining preventive measures to solve problems in which there is a possibility of causing an unwanted situation, but also the probability of their occurrence [1].

When it comes to technical systems like this, hazard identification is carried out in the design phase, which further enables the safe functioning of the installation and components with high reliability during use [4].

Considering that the experimental part of the test on the „air bank" is performed in real conditions, there is a drop in pressure in the „air bank" after each filling of the bottles. The processing of the obtained data was carried out using methods of statistical analysis for each measuring point. Namely, although the „air bank" in the Fire Brigade of Banja Luka consists of three bottles with a volume of 50 l, filled with compressed medical air under a pressure of 300 bar, in bottles of isolation devices that are filled directly on it, the highest pressure after filling is from 290 to 295 bar, depending on the volume of the bottle. With each subsequent filling, the pressure in the filled bottle was lower by 10 to 15 bar compared to the previously filled bottle.

Analyzing the intensity of deformations on the steel and composite bottle in the pressure range from 200 to 255 bar, it can be stated that they grow linearly, as in the test with water under pressure.

The highest values of deformations during the experimental tests of longitudinal deformations on the steel bottle (diagram 1) were read at measuring point 3 (MP 3 – upper part of the bottle), while the deformations at measuring point 1 (MP 1 – lower part of the bottle) have higher values than the deformations at measuring point 2 (MP 2 – in the middle of the bottle).

During the detection of tangential deformations on the steel bottle (diagram 3), the highest defo–rmation values were read at measuring point 3 (MP 3 – the upper part of the bottle), then at measuring point 2 (MP 2 – in the middle of the bottle), while the deformations at the measuring point place 1 (MP 1 – lower part of the bottle) significantly less compared to the deformations at the previous two measuring places. The deformation values at all three measurement locations have a negative sign.

Analyzing the results of the resulting deformations on the steel bottle (diagram 5), the highest deformation values are observed at the measuring points (MP 2 – in the middle of the bottle) and (MP 1 – the lower part of the bottle), while the deformation values at (MP 3 – the upper part of the bottle)

significantly smaller compared to the deformations at the previous two measurement locations. The deformation values at all three measurement locations have a negative sign.
The highest values of deformations during the detection of longitudinal deformations on the composite bottle (diagram 2) were read at measuring point 1 (MP 1 – the lower part of the bottle), while the deformations at measuring point 2 (MP 2 – in the middle of the bottle) have higher values than the deformations at the measuring point place 3 (MP 3 – upper part of the bottle).
During the detection of tangential deformations on the composite bottle (diagram 4), the highest deformation values were read at measuring point 3 (MP 3 – the upper part of the bottle), then at measuring point 2 (MP 2 – in the middle of the bottle), while the deformations at measuring point 1 (MP 1 – lower part of the bottle) slightly less compared to the deformations at the previous two measuring points. The deformation values at all three–measurement locations have a negative sign.
Analyzing the results of the resulting deformations (diagram 6), the highest deformation values are observed at the measuring points (MP 1 – lower bottle) and (MP 2 – in the middle of the bottle) and they are negative, while the deformations at (MP 3 – upper part bottles) positive and slightly less compared to the deformations at the previous two measuring points. Oscillations of intensity at (MP 2) are also noticeable.
All deformations during testing of both types of bottles (steel and composite) are in the area of elasticity.
When conducting experimental research on the „air bank", during sudden expansions of compressed medical air, an increase in temperature was observed at all three measuring points on the steel and composite bottle (Figures 12 and 13). The temperatures of bottles (steel and composite) at the measuring points before and after sudden expansions of compressed medical air vary in the temperature interval from 18°C to 28°C, depending on the measuring point.
The first temperature measurements, be it temperature measurements before or after filling the bottles, have slightly higher values, while the temperatures measured after emptying the bottles – by releasing compressed medical air into the environment have slightly lower values, due to the cooling of the valves and bottles during expansion. Analyzing the temperatures at the measuring points of both bottles, after discharging and refilling with compressed medical air, it can be stated that these temperature intervals, range from 18°C to 28°C.

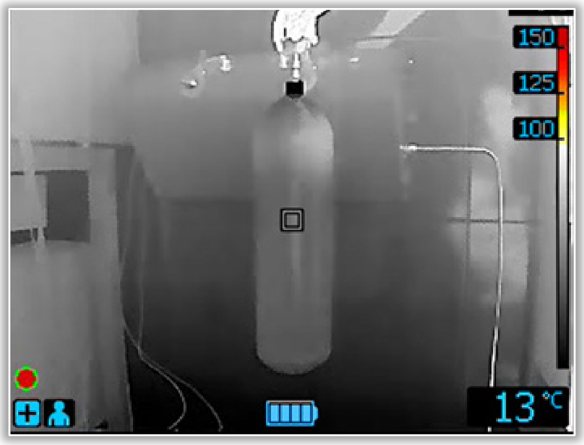

Figure 12. Thermovision image – measuri–ng the temperature of the steel bottle on the console of the „air bank" (at the beginning of filling) [4].

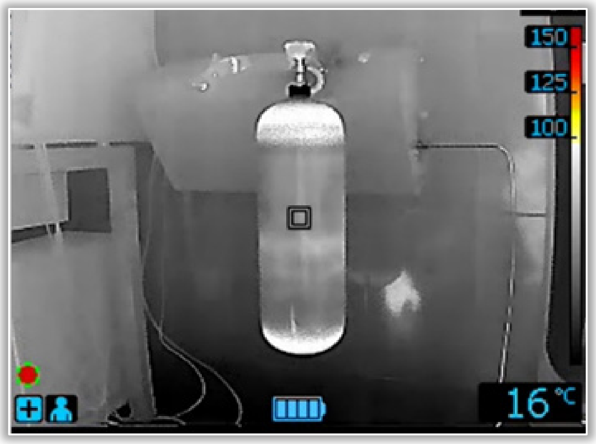

Figure 13. Thermovision image – measuring the temperature of the composite bottle on the console of the „air bank" (at the beginni–ng of filling) [4].

By comparing the results of the deformations (testing with water under pressure and on the „air bank") on the steel bottle for pressures of 200 and 300 bar, it can rightly be stated that the intensity of deformations during the test with water under pressure is higher compared to the intensity of deformations for the test on the „air bank".
On the diagrams showing the dependence of deformations on the change of internal pressure of water and compressed medical air for longitudinal, tangential or resulting deformations, a difference in the increase of deformations at the beginning of the pressure increase can be observed. Namely, in the case of deformations due to increasing water pressure in the steel and composite bottle, a linear

increase in deformations can be observed for all three measuring points from the very beginning due to the incompressibility of the test fluid (water). Bearing in mind the gaseous state of compressed medical air, the increase in deformations for water pressure testing of a steel or composite bottle is so to speak constant for all three measuring points up to approx. 30 bar, after which it increases linearly differently for each measuring point.

By performing several consecutive measurements on the „air bank", controlled by the gradient of the flow of compressed medical air, the filling time of the steel and composite bottle was from 45 to 70 seconds.

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