Programmable belt type device with optoelectronic command to improve the artificial ventilation during sleep

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In this article it is proposed a medical equipment type belt which has the role to assure the respiratory rhythm through abdominal respiratory stimulation during the exhalation stage. The main role of the equipment is to assure the rhythm of the exhalation in pathological cases such as apnea during the sleep or the chronic respiratory insufficiency with continuous necessity of oxygen therapy (minimum 8 hours a day), neuro-motor disorders, kyphoscoliosis, obesity, impairments following the post poliomyelitis tuberculosis or in the pulmonary rehabilitation in the final stage of the chronic obstructive broncho-pneumopathy (BPOC). The proposed equipment uses the effect of shape memory of the NiTi smart alloys under the form of wire through optoelectronic command.

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1. Introduction

Sometimes it is necessary to observe the sleep of children or adults in a sleep laboratory in order to better understand the problems that can cause the sleep disorders. In the diagnosis and classification of various problems during the sleep it is used a test called polysomnography (PSG) that measures different stages of sleep. During the sleep cycle special measurements of the respiration, brain activity, muscular and eyes movement and also the movements of the legs are performed. The study of sleep does not involve painful procedures. All the measurements supposed by polysomnography are made using electrodes/ accessories (small adhesive disks/clamps applied on the skin) and belts around the chest. Each measurement was designed taking into account the comfort of the diagnosed person [1, 2, 3].

The analysis and interpretation of the sleep alteration is a complex process. The type of recording influences the rapidity of the final result. For instance a polysomnography record contains almost 1.000 pages with details that the doctor has to interpret.

In pediatric patients, the incidence of Sleep Disorder breathing (SDB) is 2% for OSA(Obstructive sleep apnea) and 7-8% for snoring. Snoring, sleep apnea and the development of neurocognitive and behavioral disorders represent the main symptoms. In these cases, snoring is noisy and is present for the greater part of sleep. Accurate diagnosis and treatment protocol is critical for a child with OSA as it is associated to complications as: pulmonary hypertension, chronic pulmonary heart disease, low height-weight development, behavioral problems, reduced school performance, bedwetting and daytime sleepiness or irritability. For this reason, over the years different surgical techniques were developed to solve the clinical symptoms evident on the polysomnographic test. In this paper, the authors report the experience at the Department of Cranio-Maxillo-Facial Surgery, Policlinico Umberto I, "Sapienza" Universita di Roma, in the treatment of pediatric patients with OSAS and midface retrusion [4, 5].

Depending of the doctor's diagnosis there can be taken different intervention measures. One of these, in the urgent cases of intervention, implies using equipment of backing up the respiration during sleep. An innovative solution for these devices is represented by obtaining a device with intelligent elements of activation made of wires with form memory [6].

Nitinol shape memory alloys (NiTi-SMAs), with near equiatomic concentrations are known as the main choice among commercially available SMAs, due to their elevated physical, mechanical and functional properties as well as to their excellent corrosion resistance in different environments [7-14]. Shape memory effect, besides super-elasticity and damping capacity, of NiTi shape memory alloys with the transformation enthalpy of 28KJ/kg is characteristic for the reverse transformation of martensite (M) phase into parent/austenitic (A) phase during heating and participates to the development of work generating applications (actuation) under the form of thermal and electrical actuators [15-20].

In this article, a device with medical applications that uses active elements with shape memory under the form of wire is proposed. These elements are electrically activated with an optoelectronic system. The heating behavior of the elements was determined through differential calorimetry and the response to thermo-mechanical loading on an experimental stand.

2. Experimental details

Wires of 1 mm-diameter were purchased from Saes Getters, having the chemical composition 54.5 Ni-45.5 Ti (mass %) equivalent to Ni49.35Ti50.65. The wires were treated by means of a thermo-mechanical treatment comprising heating cycles and turn to an arch wire shape on a mechanical device. After thermo-mechanical tests, fragments of the wire were cut and analysed through differential scanning calorimetry performed on a NETZSCH DSC 200 F3 Maya, with sensitivity: <lW, temperature accuracy: 0.1 K and enthalpy accuracy—generally <1%, calibrated with Bi, In, Sn, and Zn standards.

The elements with shape memory are formed of helical arcs from shape memory alloy NiTi, which after the stage of inspiration of the air, are contracted, creating a pressure under the thorax of the patient, necessary to eliminate the air with CO_2 out of the body. Depending of the number of elements with shape memory (springs) and of their sizes (the diameter of the wire, the diameter of the spire), we can obtain practically the whole range of pressures till the highest with applications in the medical practice. Establishing the parameters in the program will be made according to the data registered in the polysomnography apparatus [21, 22].

3. Experimental results

The block diagram of the device is schematically given in Fig. 1. The computer programme is designed to allow the data entered by the doctor, data that are registered by the polysomnography apparatus.

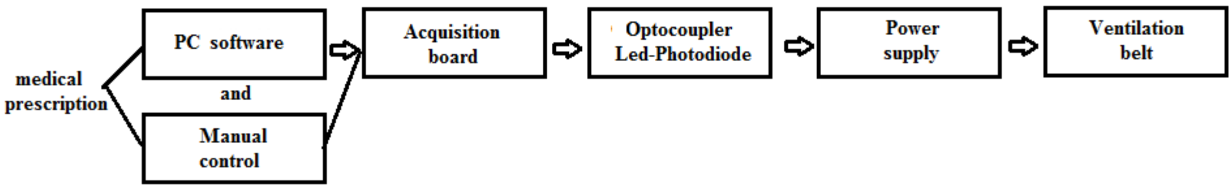
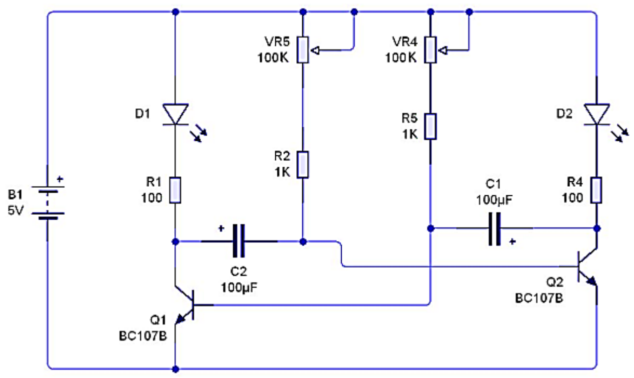


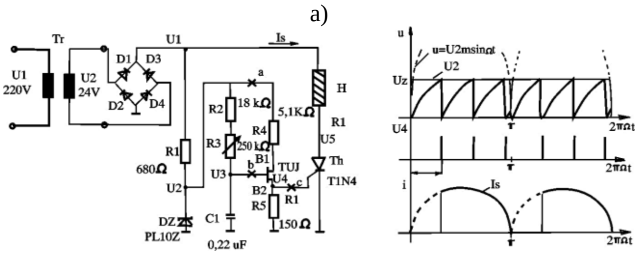
Fig. 1. The block diagram of the device

According to desired parameters, the acquisition plate commands the frequency parameters to the frequency of the led and the photo resistance will modify the value. These variations lead at their turn to the alteration of the alternative tension or continuous pulsatory from the power supply. This tension with well -established parameters of frequency will be used to command the ventilation belt. The chosen acquisition plate is of Arduino type, with licensed programs to use and has the role of bi-stabile element of programming for the led in the photo couple [23].

In order to change manually the parameters, it is provided also a bi-stabile assembly that can replace the computer and the acquisition plate and which through the rotation of two potentiometers VR4 and VR5 of 100 KΩ can act upon the parameters of the D1 and D2 led-s, the photo resistance and implicitly on the parameters of the ventilation (Fig. 2).



a)



b)

Fig. 2. a) Bi-stable assemblage for manual adjustment of the ventilation parameters and b) the force power supply

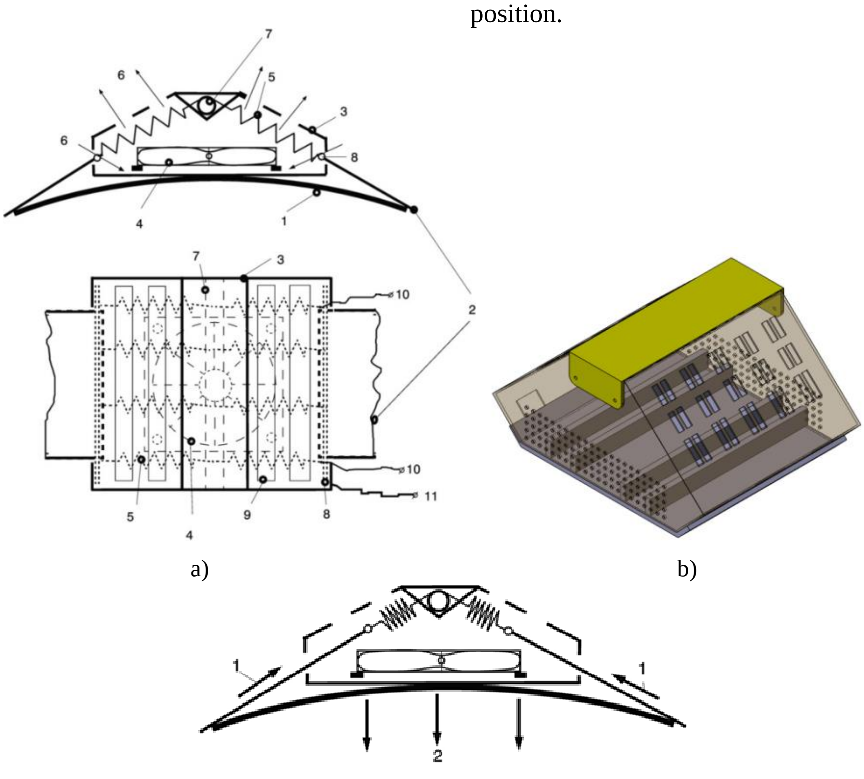
The optocoupler consists in a usual white led (D1 or D2 in Fig. 2) and a photo resistance of OPH1 type. The used power supply is double, one of low intensity (maximum 500 mA) and tension of 5V (cc) which powers the ventilator, the acquisition plate and the manual adjustment assembly or the power source (Fig. 2b). The power supply for the elements with shape memory consists in a dimmer, coupled serially on the shape memory elements from the secondary of the transformer. The secondary of the force transformer is designed for a current of maximum 2A and an alternative tension of 24V.

The element R2 is the photo resistance that commands finally the thyristor that regulates the parameters of the current heats through Joule-Lentz the element with shape memory, H.

The ventilation belt is formed from the fixing element (harnesses) and the active part of actuation. At its turn, this active part is formed from a plastic carcass; the active elements from helical springs of NiTi alloy which at heating produce the necessary machine work and a ventilator necessary to cool these elements (Fig. 3a, b).

In order to obtain the mechanical tension in harnesses of approximately 10 kgf (100 N), the springs were manufactured from NiTi wire with 1mm diameter and the specific resistance of 2Ω on one meter length. To bring a spring with the wire of 1 meter in a tight position in less than 2 seconds, it is necessary at the end of the spring a voltage of 5 V at a current of 2A.

Using six springs are sufficient to obtain the maximum mechanical tension and are necessary a voltage of 24V at a current of 2A. If we want to obtain higher mechanical tensions it is possible the supplementation of the number of springs. During the exhalation (Fig. 3b) the springs made of NiTi are powered with voltage, being in tight position, the mechanical tension formed working on the abdomen and harnesses. The spring is undone, and can be used in multiple applications. During the inspiration (Fig. 3a) the springs of NiTi are in a relaxed, elongated position.



c)

Fig. 3. a) The compounds of the ventilation belt.1-abdomen, 2-harnesses, 3-carcass, 4-ventilator, 5-NiTi spring, 6-flow of air to cool the springs, 7-insulated support to maintain the NiTi springs, 8-rod for connecting spring and harness, 9-slit for the cooling air, 10-power for ventilator, b)the 3D design of the plastic carcass of the apparatus proposed through 3D printing, the ventilation belt, c) the distribution of the mechanical tensions on the abdomen: 1: harnesses forces and 2 on the chest

The proposed equipment can work separate or in synchronization with the ventilation apparatus only for the exhalation stage to improve some physical parameters:

- the respiratory effort decreases,
- the snore is eliminated,
- the arterial saturation with oxygen increases,
- the rate of pulse is stabilized and also the blood pressure oscillations.

The medical system with intelligent elements can act only upon the exhalation stage, the pressure being exerted from the outside to the inside (and not from the inside to the outside as in absorption) through the compression of the thorax through the activity of the shape memory elements of Nitinol (NiTi). These elements with shape memory are electronically activated using a computer, an acquisition plate and a variable power source. Using the computer program, the time parameters will be optimized

(2 times- inspiration and exhalation) and the intensity of the abdominal pressure will be indicated by the specialist doctor.

The main physical characteristic of the NiTi alloy used is the temperature of phase transformation martensitic-austenitic temperature at which the springs modify their shape from elongated in tight and vice versa.

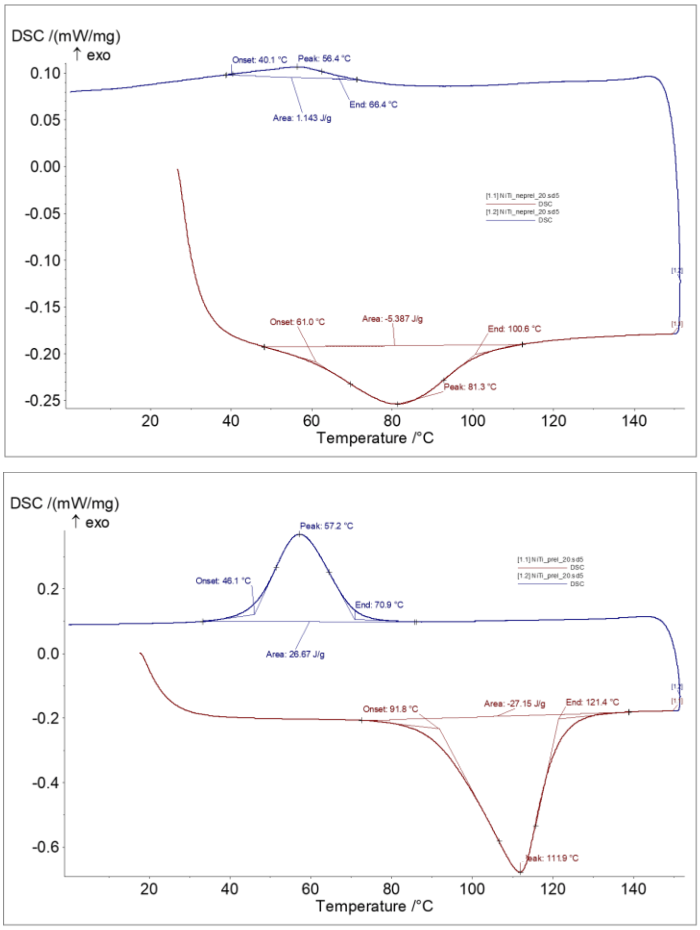
At the used alloy, the interval of temperature of phase transformation is of 70-80°C. The accidental heating over 120 °C of the springs will be avoided in order to balance the alteration of the shape memory property. To obtain the shape memory springs, the NiTi wire is convoluted under mechanical tension, spire after spire, on a pipe of fireproofed steel whose diameter is the inner diameter of the spring intended(in this experiment the diameter was of 10 mm).

The ends of the bobbin obtained are mechanically blocked against the loosening forces that will appear during the thermo-mechanical treatment. The obtained assembly is introduced in the pre-heated oven at 500°C where it is maintained for 15 minutes, after that being cooled brusquely through its insertion in a recipient with water and ice to finish the hardening treatment of inserting in the solution.

Using this thermo-mechanical treatment, it is imprinted to the wire of Nitinol the hot state (warm phase) (helical spring with spire of 10 mm).

In Fig. 4 there are presented the DSC diagrams of the shape memory alloy, initial state and after the thermal treatment, through which there are determined on the cycles of heating/cooling the domains of transformation temperatures characteristic to the martensitic alteration and its reversion. Through differential calorimetry we can establish the main temperatures of transforming the memory shape alloy: As, Af (the reversion of the transformation) at heating and Ms and Mf at cooling (direct transformation).

All the functioning parameters of the powering and control system of the experimental equipment are established according to the transformation temperatures. In Table 1 there are presented the characteristic parameters of the martensitic transformation and the reversion at cooling, respective heating the material. The application of an education treatment of the warm shape of the shape memory alloy leads to the alteration of the domains of transformation temperatures especially on the reversion of the martensite (M→A), with a difference of approximately 20°C between the values A50 in austenite although the direct transformation (A→M) takes place in approximately the same domain (differences lower than 1 ˚C between the values of temperature M_{50}).



a)

b)

Fig. 4. DSC charts of NiTi wire (d=1 mm) a) initial state and b)after thermal treatment evaluation of the DSC chart recorded at 20°C/min heating rate

Table 1. Calorimetric parameters determined from the DSC charts in Fig. 4

Parameters	Heating rate	A_s	A_{50}	A_f	$\Delta H_{M\to A}$	M_s	M_{50}	M_f	$\Delta H_{A\to M}$
	^{0}C/ min	^{0}C	^{0}C	^{0}C	KJ/ kg	^{0}C	^{0}C	^{0}C	KJ/ kg
Initial	20	61	81.3	100.6	-5.387	66.4	56.4	40.1	1.143
Heat treatment	20	90.7	110.5	118.8	-27.15	70.9	57.2	46.1	26.67

After the thermal treatment applied to the NiTi alloy both at heating and cooling, the domains of transformation were narrowed and in the same time they were emphasized as values (big differences between the initial and final values of the coefficients $\Delta H_{M\to A}$ and $\Delta H_{A\to M}$).

4. Conclusions

In the present work it was presented the concept of an equipment of regulating the respiration during the sleep of the patients with impairments as sleep apnee, equipment made of plastic with light elements designed to 3D imprint and intelligent active elements of NiTi (shape memory alloy). The proposed equipment can work singularly or in synchronization with the ventilation device only for the exhalation stage in order to improve some physical parameters: it decreases the respiratory effort, the snore is eliminated, and the arterial saturation of oxygen increases, the pulse rate and the blood pressure oscillations are stabilized.

Applying a treatment of educating the warm form of the alloy wires with shape memory leads to the modification of the domains of transformation temperatures especially on the reversion of the martensite (M→A), with a difference of approximately 20°C between the values A_{50} in austenite although the direct transformation (A→M) takes place in approximately the same domain (differences lower than 1°C between the values of temperature M_{50}).

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