

Compression bandages and gradient systems on the basis of TiNi shape memory alloys in the field of medicine

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ABSTRAKT

A device is being presented here that uses the shape memory properties of alloys. *TiNi* shape memory meanders as functional elements of the device are inwoven in an elastic material and heated by means of electric current. Wires with A_f - or M_s -temperature below 30°C can be used for the permanent compression dressing. In this case, a short-time heating above the A_f -temperature from the body or by electrical impulse leads to constant compression remaining. For gradient systems, wires with M_f -temperature above 30°C and a small hysteresis are used. Using a series connection of elements with shape memory effect, the individual elements can be heated separately by means of an electric current resulting in a compression gradient that can be used at the continual repeating to achieve a massage effect.

1. MEDICAL PROBLEMS

Compression treatment of the chronicle phlebitis and the lymph swellings has the aim to compensate for the vein insufficiency and to avoid its progress. This is reached by the compression dressing for not compensated vine insufficiency with the swelling and by the compression sock for maintain of the compensated state. A gadget compression is used as an additional measure [1].

Compression dressings and socks are made from elastic materials and must ensure the pressure on the swelling from 20 up to 60 mmHg depending on their compression class. Single- or multi-partition rubber cuffs (so called gradient system) will be used for the gadget compression therapy. The last one compresses and decompresses alternately the treated swelling by the air fooling its partitions. The use of these medical means is connected with a lots of problems:

1. The exerting force of the elastic compression dressing decreases linear during the decreasing of the swelling. This makes more difficult the use of permanent dressings.
2. The use of compression socks provides a considerable problem due to difficulties at their putting on and taking off, namely the greater must be the work pressure, the stiffer is the sock fabric and the more difficult are the sock putting on and taking off .
3. The rubber cuffs is fooled with air by a pump. Everyone partition of the multi-partition cuff is connected to the pump with a hose to produce the ongoing compression wave. The longitudinal of this compression wave can be correspondingly reduced only restrict. This technique is very massive and presupposes, therefor, a stationary treatment.

Compression bandages and gradient systems with functional elements from a shape memory alloy [2] developed and patented by our company allow principally to solve all these problems and, moreover, to reach all three functions in the one compression system.

2. PRODUCTION OF THE MEMORY COMPOSITION FABRIC

The compression bandage is made from a composition material which consists from two layers of light elastic synthetic material and superficial springs placed between these layers. The springs from memory alloy wires are wound on a bend device to meander shape (Fig. 1). They are heated for a short time up to 700°C by an electrical impulse to save their meander shape after winding. The impulse length is adjustable inside of limits from 1 to 10 s. After the taking off from the bend device, meanders are trained to the two-way effect by the thermal cycling under a load.

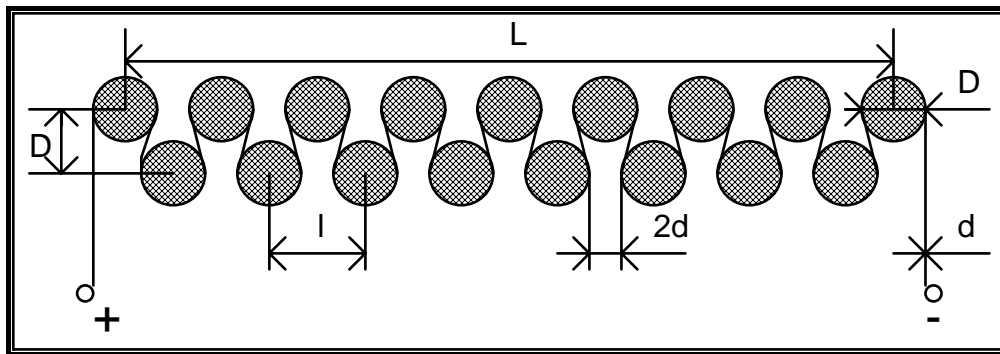


Fig.1. The bend device for production of meanders from memory wires

The imbedding of meanders between elastic synthetic layers occurs with a help of an ultrasonic welding machine produced by "Ultrasonics Steckmann GmbH" so that meanders are placed close side by side, but separated from each other through wedged seams. Either compression dressings with different width and length or compression bandages of different size are made from this composite. The dressing or bandage endings are provided with a zipper or a climbing lock to make possible their fastening on the body.

The finished bandage is stretched at the temperature $T < M_f$ at that the meanders are in the martensitic state (M_f is the temperature of the forward transformation finish). This stretching occurs at little stresses, because the inelastic yield of the martensite is very low. It makes possible easily to put the bandage on and to take it off. Three kinds of bandages distinguish depending on their functional manner and on the transformation temperatures of memory wires. These can be regarded as passive and active one. A passive bandage is activated by the heating from the body or by a single electrical impulse. An active one is activated by the heating by electric current and controlled by an electronic devise.

3. PASSIVE COMPRESSION BANDAGES

A compression bandage is activated just after its placing on the swelling if the whole transformation hysteresis loop of memory wires lays below the temperature $T_0 \cong 30^\circ\text{C}$ (Fig. 2a) that corresponds to the temperature within bandage placed on the body. The compression occurs during the bandage heating from the body. The bandage must be cooled below M_f by the spraying, for example, to be taken easy off. The bandage decompresses due to the two-way memory of trained meanders at their transformation to martensite during the cooling. It is useful to take memory wires with a small hysteresis loop for this kind of compression

bandages. In this case M_f -temperature doesn't lay so low that the cooling of bandage gets unpleasant or dangerous.

Transformation temperatures can be chosen so that T_0 -temperature lays between the start temperatures of the forward (M_s) and reverse transformations (A_s) (Fig. 2b). In this case, the heating above A_f -temperature after the placing on the body occurs by means of an electrical impulse. The bandage retains in the compress state after turning the current impulse off. The easy taking off is again possible by the cooling below M_f -temperature.

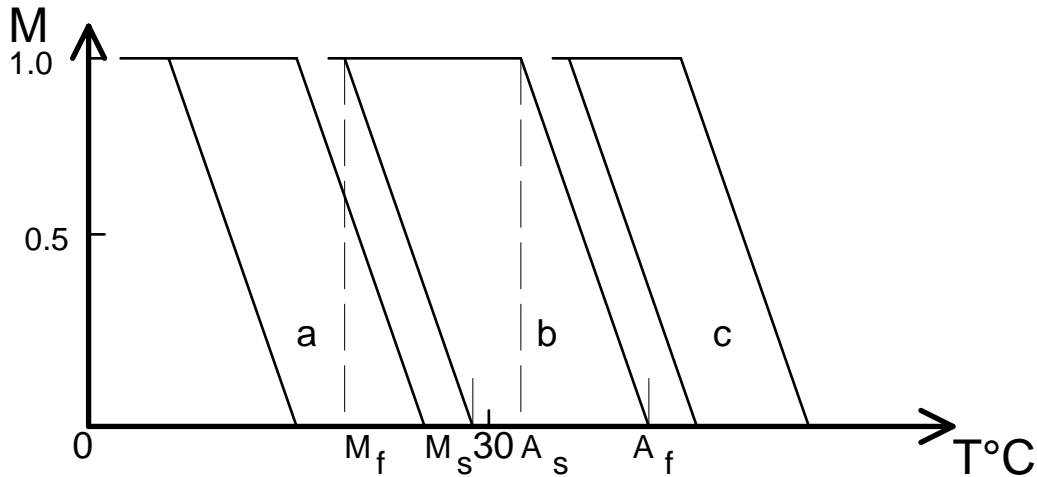


Fig. 2. Hysteresis loops of memory wires for three kinds of bandages

The meanders must be electric connected together at this method and provided with electrical contact.

The advantages of the last method are follows: a) the pressing force is adjustable depended on strength and length of the electrical impulse so that different heating temperatures T are reached inside of the interval $A_s < T \leq A_f$ and b) memory wires from *TiNi* two-components alloys with a normal transformation hysteresis width ($25 \div 30$) $^{\circ}\text{C}$ can be used, whereby the temperature of the taking off lays still about 15°C . The increasing in price due to the more complex production belongs to disadvantages of this bandage. From the functional side, these bandages doesn't principal distinguish, and the both can be used as the permanent bandages or dressings.

An essential and principal advantage of the bandage with memory elements for the compression treatment compared to the usual elastic dressing is that the exerting pressure on the swelling retains constant or even increases during the deswelling at the permanent treatment. The pressure of an elastic dressing with a starting compression force F_0 and an elasticity coefficient k exerting on an cylindrical swelling with a starting radius R_0 is calculated by Laplas' low:

$$D_0 = \frac{F_0}{R_0} = \frac{k(2\pi R_0 - l_0)}{R_0}. \quad (1)$$

The radius decreases during the deswelling so that $R_1 < R_0$. The compression force decreases linear, as known. As a result, the pressure difference is negative:

$$\Delta D = D_1 - D_0 \propto \left(\frac{1}{R_0} - \frac{1}{R_1} \right) < 0. \quad (2)$$

It is characteristic for memory meanders from *TiNi*-alloys that the exerting force during the decreasing of meanders length (ΔL) remains constant or increases linear with a very little coefficient (Fig. 3). The inelastic strain of the bandage can, thereby, result from 50 up to 250% depending on the meander shape. The shape is optimised according to necessary compression force and deformation (swelling size).

3. AKTIVE BANDAGES AS GRADIENT SYSTEMS

A third variant of compression bandages distinguishes principal from the first both according to their functional manner. The transformation temperatures lay above T_0 so that $T_0 \leq M_f$ (Fig. 2c). Memory meanders are electric connected with each other so, that they can be activated in a certain order by their heating by the electric current. An electronic control system

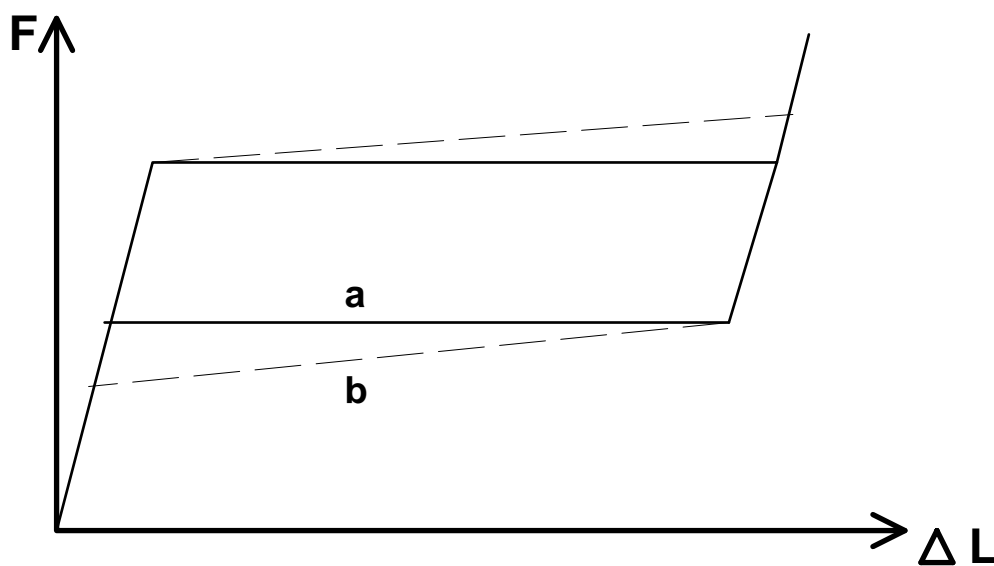


Fig. 3. Deformation diagram of *TiNi* memory meanders

allows to set up as requested the electric impulse length as soon as break-time between the impulses and the end pause. After the end pause, the whole process starts from the beginning. This bandage produces ongoing pressure waves and imitates in that way the massage effect. This kind of massage is very oft used in the lymph swelling therapy and occurs up to day by hand. The massage aims at displacement of fluid from the lymph swelling. It is useful, too, for this gradient system to take memory wires with a small hysteresis loop (Fig. 2c). In this case A_f -temperature doesn't lay so high that the heating of bandage gets unpleasant or dangerous for the skin.

The question about the cycling stability and degradation of memory properties is very impotent for this application. On the other hand, it was shown by us that the rehabilitation of these properties is possible by means of the short-time heating of meanders about 100°C above A_f . This heat treatment by a strong electric impulse restores the starting memory properties without to change other mechanical characteristics. The main degradation mechanism at the cycling without to overcome the true plastic yield is the reversibility loss of martensite boundaries due to the increasing of the defect concentration at these boundaries during the cycling. At the short-time overheating, the reverse transformation driving force

increases so significant that the boundaries come from their defects off. The martensite crystals eliminated on this way from the transformation restore their reversibility.

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