IOP Conference Series: Earth and Environmental Science

Innovative Solutions Shockproof Protection In Occupations Associated With An Increased Risk Of Injury

IOP Conf. Series: Earth and Environmental Science **50** (2017) 012044 doi:10.1088/1755-1315/50/1/012044

Innovative Solutions Shockproof Protection In Occupations Associated With An Increased Risk Of Injury

O V Denisov [1, a], Y I Buligin[1, b], A E Ponomarev[1, c], I A. Ponomareva[2, d], V V Lebedeva [3, e]

[1] Don State Technical University, Rostov-on-Don, Russia
[2] Southern Federal University, Rostov-on-Don, Russia
[3] Far Eastern Federal University, Vladivostok, Russia

Email: [a]OVD63@mail.ru, [b]bulyur_rostov@mail.ru, [c]ae_ponomarev@mail.ru, [d]iaponomareva@sfedu.ru, [e]vikuuuuulya@yandex.ru

Abstract. An important direction in the development of the shockproof devices for occupations associated with an increased risk of injury is reducing their overall size with the preservation the ability of energy absorption. The fixture protection of large joints, with the brace in the coils of an elastic-plastic material with shape memory effect, can effectively protect people from injury and can be used in the domain of occupational safety to reduce injuries by shocks or jolts. In innovative anti-shock device as elastic-plastic material applied equiatomic Titanium-Nickel alloy which has acceptable temperature phase transitions that is necessary to restore shape. As an experienced model first approximation was adopted shockproof device, having in its composition a bandage in coils of elastic-plastic material with shape memory effect and with electric contacts at the ends. This solution allows the punches to plastically deform with the absorption of the impact energy, and then recover the original shape, including at the expense of electric heating.

Relevance and statement of a problem

In the Strategy of a homeland security of the Russian Federation till 2020 as one of the main strategic threats of a homeland security is specified the progressing lack of work. Concerns express that further decrease in the total number of the population of a share of able-bodied population is expected [1]. Currently, Russia is the implementation of the national state standard specification (GOST) R 54934-2012 "System of management of occupational safety and health protection", however, it is impossible to speak about decrease in professional incidence. In particular it is specified that one of basic reasons of growth of professional pathology are non-optimal working conditions of personnel, availability of workplaces with harmful and dangerous working conditions [2, 3]. Quite important place in professional pathology is taken by diseases and injuries of large joints. For example, about 15% among stationary patients of ortopedo-traumatologic departments patients with pathology of a knee joint and it constitute persons of working-age [4]. For the professions which are characterized by the increased risk of an injury rate there is a probability of obtaining on a workplace of an injury of a large joint. It is described that in case of jumps and falls at the time of a landing the organism is affected by forces exceeding its weight almost five times. The wrong landing, especially in total with twisting, as a rule, brings in a knee joint to micro and to macroinjuries of a joint that causes further development of pathology, including with decline in quality of life and working capacity [5].

There are a large amount of various protective devices, but the most convenient are kneecaps [6], which are applied to prevention of injuries. Currently using of such protection devices isn't widespread for wide use (except for athletes), besides, there are practically no devices for protection of large joints in professions which are characterized by the increased risk of an injury rate. Innovative technical solutions and materials of the increased degree of protection and efficiency are seldom applied [7].

In the analysis of the modern technical solutions which are the cornerstone of domestic shockproof devices [8, 9] it was established that there is quite a large amount of such devices, most of the described elastic elements, which are currently used elastic bandages, laminated materials, soft shapes. All of them are executed in the form of an elastic deformable element on the basis of soft polyurethane and/or gel. However, all existing samples for a more optimal use may be modified from the point of view of increase of efficiency of depreciation shocks or blows, increasing the power consumption, for example, by the operation of the damping element of the applied material is not only elastic, but also in the plastic regions of deformation, the inclusion of safety devices on rational energy-absorbing elements, along with the task of reducing the dimensions of the models.

Discussion and results.

The important direction of researches in development of shockproof devices for the professions which are characterized by the increased risk of an injury rate determined decrease in overall dimensions of these devices when preserving their characteristics and the power absorbing capability. The projectable result can be received by means of application of innovative technical solutions. The development of the technology of the new century dictates the importance of examining the use of occupational materials that are capable of deformation in elastic and plastic regions with the subsequent recovery of the original shape. Those are alloys with the form memory effect (FME). It should be noted that among such materials the undisputed leader acknowledged alloys on the basis of a Nickel-Titanium (TiNi). Their fundamental difference, for example, from alloys on the basis of copper, is that TiNi is a stable compound. For such alloys with a thermoelastic martensitic transformation characteristic feature is premartensitic instability of their structure to shift. A natural consequence of the development of the instability for Ti-Ni alloy (50:50) is an implementation of the martensitic transition below 60'C. It is established that the martensitic transition temperature decreases with increasing Nickel concentration. Therefore, by changing the percentage composition of the compound may change the transition temperature and the time of the manifestation of FME within a wide range. Obviously, this changes the nature of the martensitic transformation and memory properties. The analysis and study of alloys based on TiNi we need to understand that this class of materials is characterized by not only the general regularities of the structural properties and transformations, as the ability to control their changes in a wide range. It makes use of alloys based on TiNi for a wide variety of technical tasks, as well as their use for the development of new composites with new properties. It is therefore quite logical to use as elastic-plastic material equiatomic TiNi alloy, with the temperature of phase transitions for shape recovery, developed an innovative shockproof device.

In the research as a pilot model, it was considered the proposed fixture shockproof protection comprised of a bandage in the form of spirals made of elastic-plastic material with FME having electrical contacts at the ends. The proposed technical solution allows to be deformed plastically in case of pushes and blows, absorbing an impact energy then to recover the initial form, with availability of a possibility of recovery including due to impact of electric current (heating). The spiral of a prototype of the protection device is integrated on all length an elastic rod element from the soft polyurethane capable to deformation. It provides an opportunity not only implementation of relative fixing of a spiral, preserving required distance between spiral turns, but also that is important, allows to participate in distribution of an impact energy [10] (fig. 1).

To restore the original shape of the shock devices used heating made of TiNi alloy with FME brace wires to the temperature required for recovery of plastically deformed coils. The heated wire device is due to the proposed portable electric heater connected to the power source. It is important that the proposed fixture restoration of the shape of the element can also occur due to the use of other heating devices, including appliances (e.g., hair dryers, heaters) that can facilitate its application and increase efficiency of work performed.

For thermoelastic damping TiNi alloy with FME the range of temperatures at which the shape recovery material (martensitic transformation), is in the experiment 320...340 K.

After the shape recovery is a passive cooling device to the initial temperature. Shockproof protective device with reduced turns of the wire becomes fit to work, especially to the damping of jolts and bumps.

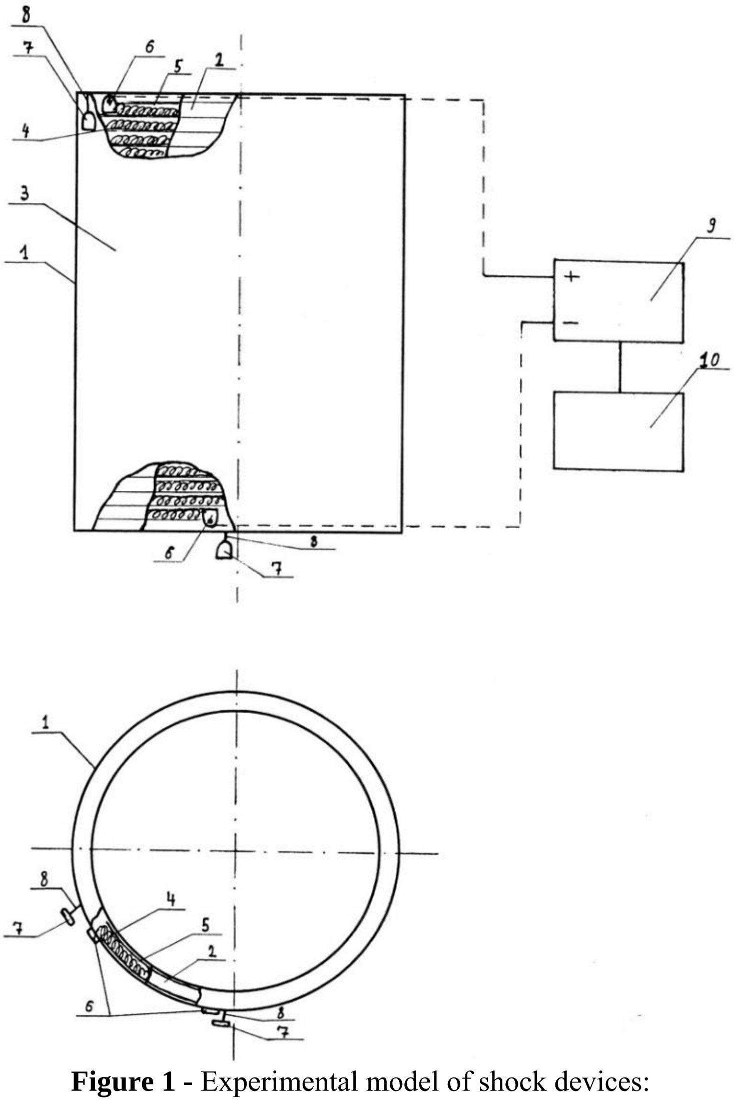

Figure 1 - Experimental model of shock devices:
1 – elastic bandage, 2 bandage of elastic plastic material, 3 – fabric,
4 – wire round with FME, 5 – elastic truss element, 6 – electrical connection, 7 – protective cap,
8 – threads, 9 – electric heater, 10 – power source

The pilot model of the device shockproof protection was carried out on the impact testing machine (GOST 10708-82), specially modified for this study under different temperature regimes accompanying the carrying out of works in different climatic and production conditions. In the course of the experiment at a given temperature was measured by a torque and the magnitude of shear deformation. The temperature of the spiral model was subjected to controlled changes by using the electric heater was measured using a digital thermometer (GOST R 8.625–2006). The signal transmission is carried out with the thermocouple junction by the conventional method were glued with glue BF-2 (GOST 12172-74) to the center of the spiral [12].

Features of methodology of the experiment: model shock devices, matched by size, was worn on the basis of imitating model of the human knee joint. Experimental device in this case is a tight fit protect "the joint" at the expense of the elastic properties of elastic bandage and brace.

As a model test device was made with the following dimensions: diameter d – 120.10-3 m (120 mm), length L – 210.10-3M (210 mm), the thickness of 5.10-3M (5 mm). The diameter DC of the spiral of TiNi alloy with FME amounted to 4.10-3M (4 mm) and wire diameter Dw – 1.10-3M (1 mm). The geometric characteristics of the model elements correspond to the normal linear dimensions (GOST 6639-69). The mass of experimental device was 0.5 kg.

The experiment plan was developed in accordance with the standard methodology of calculation of energy absorption for elastic-plastic elements [13, 14].

It is established that in case of blow to impact testing machine the working area U – 1.10-3M2 (1000 mm2) deformed by bending and twisting about 200 turns, which together absorbed approximately 150 J, and taking into account the deformation of the elastic shafts up to 200 J of impact energy.

For the purpose of determination of characteristics of power absorptivity at various temperatures one of investigation phases provided carrying out testing with measurement of dynamic characteristics in correlation with heating of deformable elements. Loading at each temperature level were carried out with the same speed, a certain angle of allotment of the impact testing machine.

Main results:

1. The power absorbing ability of these plastic elements with FME to a large extent correlates with a temperature (fig. 2).
2. The actual energy absorption is in the range of more than 100 J.
3. The nature of the curves is almost repeated at different shock loads up to critical (Fig. 3).

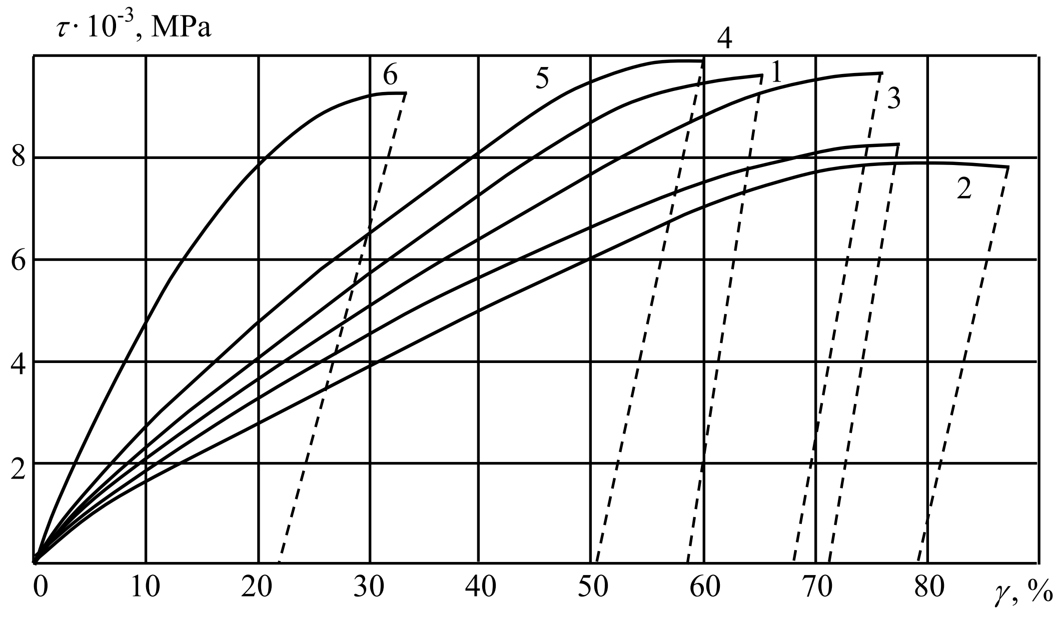

Figure 2 - Conditional charts of tension deformation
models based on the alloy TiNi-1 shear (torsion) and the increased temperatures:
1 – 298 K; 2 – 318 K; 3 – 323 K; 4 – 333 K; 5 – 353 K; 6 – 383 K (dotted line: elastic unloading)

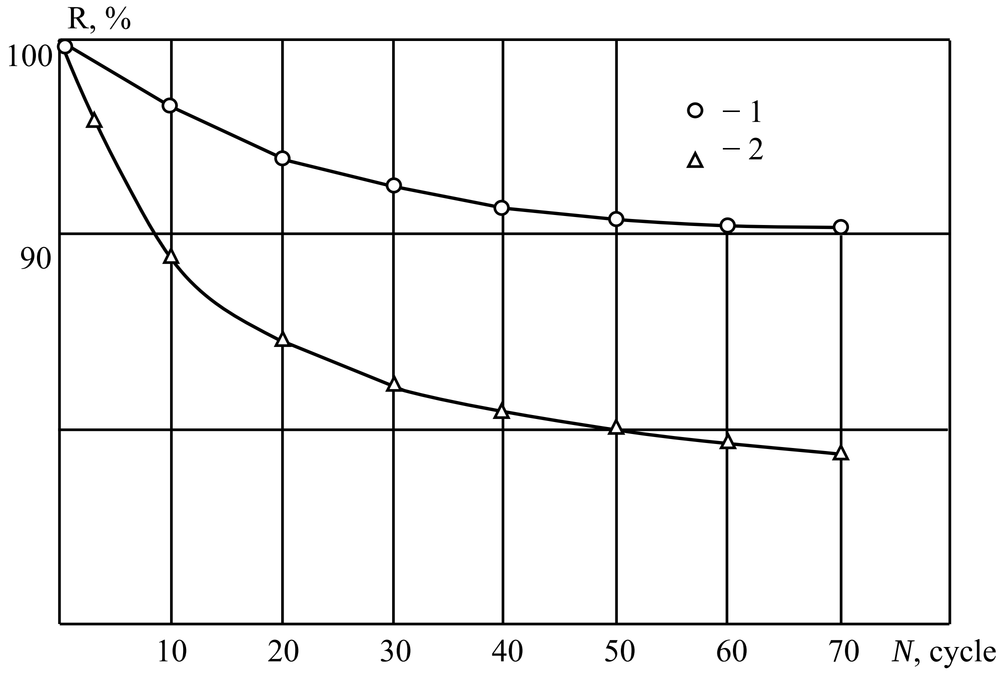

Figure 3 - The dependence of the degree of shape recovery of the number of cycles in the mode of FME (drums torsion at a temperature of 298 K and heated at 423 K) TiNi alloy:
1 − at constant strain of 10.3%; 2 − at constant strain of 15.4%.

In accordance with the regulations [15], the energy of over 100 J can be traumatic, consequently, for protective devices is sufficient absorption of energy of about 150-200 J.

According to the results of the experiment the features expected of the real device. In the event of a jolt or shock occur in the elastic deformation of the wire brace and elastic bandage, while the impact energy is absorbed and dissipated, thus preventing injury to the underlying tissues. When a significant impact that exceeds the level of capability of elastic deformation elements, the outer layer deforms an elastic bandage to limit state in the elastic zone, and rolled into a spiral wire brace initially deform in an elastic and then to plastic zones. It is established that the deformations of the spiral wire brace are made through twisting turns and plastic bending in the strike zone. During plastic torsion of a material is the highest energy absorption [16, 17].

When conducting experiments on the restoration of the shape of the experimental model showed a stable recovery rates spirals. It should be noted that the restoration of the deformed elements to a considerable extent depend on their degree of shear deformation. Thus, when shear strain to 10.3% observed degree of shape recovery in a first stroke reached 98-99 %, while at strains of 50 % (full collapse) the recovery was only about 80 %.

Figure 3 presents the simulated range of impacts in laboratory conditions, shows the evolution of the degree of shape recovery of a prototype. Shear strain in each cycle was carried out with a predetermined amplitude. The cycle consisted of the following stages:

− loading of the helical element at a temperature of 295...300 K;
− the removal of the load after reaching the desired deformation;
− subsequent heating to temperatures of shape recovery [18, 19].

Graphically, it is shown that with increasing number of cycles there is a gradual decrease of the degree of recovery of deformation until it reaches the stabilization value. With increasing amplitude of shear strain, the value of the degree of shape recovery decreases, and to achieve stabilization requires a greater number of cycles. In practice, most likely during the individual impact will be a sustainable recovery of the sample. Perhaps the explanation for this behavior TiNi elastic-plastic element redislocation mechanisms of deformation that correlates with the literature data and results of research on the effect of rote memory.

Conclusion
Thus, adaptation of shockproof protection of large joints is characterized not only reduction of dimensions in comparison with analogs (5 mm instead of 20-30 mm), but also allows to protect the employee from injuries very effectively. It can be recommended to application in the domain of occupational safety for decrease an injury in case of impact of blows or pushes.

References
[1] Babakov A N, Chernikova A G. Sostoyanie ohrany truda v Rossii [State of labor protection in Russia] // Bulletin of the IMSIT. 2013. No. 3-4. Pp. 21-23.
[2] Usikova O V, Sravnitel'nyj analiz organizacii sistem ohrany zdorov'ya i bezopasnosti truda (obzor zarubezhnogo opyta) [Comparative analysis of systems of health protection and labor safety (review of foreign experience)] // Sibbezopasnost’ [Sibsecurity]. 2013. No. 1. P. 249-253.
[3] Gubaev F A, Nikitina N V. Analiz sostoyaniya bezopasnosti truda pri provedenii dorozhnyh rabot i predlozheniya po sovershenstvovaniyu trebovanij ohrany truda [Analysis of the state work safety during road works and proposals for improvement of requirements of labour protection] // Ohrana i ehkonomika truda [Protection and labor Economics]. 2011. No. 3 (4). P.20-21.
[4] Decaylo V P, Boloboshko K B. Struktura travm i zabolevanij kolennogo sustava [The Structure of injuries and diseases of the knee joint] // Novosti hirurgii [Surgery News]. 2007. V. 15. No. 1. P. 26-31.
[5] Denisov O V, Ponomareva I A, Zimenko V A. Zashchitnaya povyazka dlya krupnyh sustavov pri zanyatiyah sportom [Protective armband for large joints in sports] // Novye standarty modernizacii pedagogicheskogo obrazovaniya v formirovanii zdorovogo obraza zhizni i bezopasnosti zhiznedeyatel'nosti [The New standards of modernization of pedagogical education in the formation of healthy lifestyle and safety]: proceedings of the Third regional scientific-practical conference. Krasnodar: Kuban state University. 2015. Pp. 90-92.
[6] Orlova E V, Karateev D E, Kochetkov A V. Kompleksnaya reabilitaciya bol'nyh rannim revmatoidnym artritom [Complex rehabilitation of patients with early rheumatoid arthritis] // Nauchno-prakticheskaya revmatologiya [Scientific-practical rheumatology]. 2013. No. 4 (51). Pp. 398-406.
[7] Davydenko V N, Ponomareva, I A Inginov A Y. K voprosu o bezopasnosti trenirovok i profilaktike travmatizma pri zanyatiyah volejbolom [To the issue of safety training and injury prevention in the volleyball] // Fizicheskaya kul'tura, sport, zdorov'e i dolgoletie [Physical culture, sport, health and longevity]: materials of the third all-Russian with international participation scientific and practical conference. Rostov on/D: SFedU. 2014. Pp. 36-42.
[8] Patent: Nakolennik [Knee pad]: RF patent for the invention 2425658, Appl. 13.01.2010, publ. 10.08.2011.
[9] Patent: Nakolennik dlya zashchity kolena cheloveka [Knee pad for protecting the knee of a person]: RF patent for the invention 2308373, Appl. 29.11.2002, publ. 03.07.2003.
[10] Patent: Protivoudarnoe prisposoblenie [Shock-proof fixture]: RF patent for the invention RUS 2578997 20.08.2014.
[11] Effekt pamyati formy v splavah [The shape memory effect in alloys]: transl. from English. L M Bernstein. Moscow: Metallurgy. 1979. 472 p.
[12] Splavy dlya termopar [Alloys for thermocouples]: Reference book / I A Rogelberg, V M Balim. Moscow: Metallurgy. 1983. 360 p.
[13] Prikladnaya mekhanika [Applied mechanics]: Proc. for high schools / by the editorship of G B Iosilevich. – Moscow: Higher school. 1989. 350 p.

[14] Tikhomirov A G , Denisov O B , Denisov I V, Nazarov A Yu. Osobennosti uprugoplasticheskogo krucheniya stal'nyh obrazcov s razlichnoj iskhodnoj teksturoj [Peculiarities of elastic-plastic torsion of steel samples having different initial structure] // Izvestiya vysshih uchebnyh zavedenij [News of higher educational institutions]. The North Caucasus region. Series: Natural Sciences. 2004. No. 3. P. 43-44.
[15] GOST 12.4.128 – 83 Kaski zashchitnye. Obshchie tekhnicheskie trebovaniya i metody ispytanij [Protective Helmets. General technical requirements and test methods]. EN 1621-1 Motorcycle impact protection. Part 1. Test methods and requirements for protection.
[16] Patent: Ustrojstvo dempfirovaniya kolebanij ob"ekta [Device for damping vibrations of the object]: 2073142 patent of the Russian Federation, IPC 6F 16F1/14; Appl. 10.12.1993; publ. 10.02.1997.
[17] Patent: Upravlyaemaya sistema amortizacii avtomobilya [Controlled damping of a vehicle]: patent 2256831 of the Russian Federation, 2003.
[18] Topilin I V, Ponomareva I A. Ob ispytaniyah opytnoj modeli ehlementa protivoudarnoj ehkipirovki voditelej avtomototransporta [About the testing of the experimental model of element shockproof gear drivers of motor vehicles] (Part 1) // Inzhenernyj vestnik Dona [Engineering journal of Don]. 2015. Vol. 36. No. 2-2. P. 123.
[19] Eremin I I, Denisov O V. Ob ispytaniyah opytnoj modeli ehlementa protivoudarnoj ehkipirovki voditelej avtomototransporta [About testing of the experimental model of element shockproof gear drivers of motor vehicles] (Part 2) // Inzhenernyj vestnik Dona [Engineering journal of Don]. 2015. Vol. 36. No. 2-2. P. 124.