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## PASSIVE BALANCING SOLUTION FOR A HUMAN WALKING AND SITTING ASSISTIVE EXOSKELETON

*The design results and comparative analysis of statically balanced wearable assistive exoskeleton for human walking and sitting are outlined: their advantages, disadvantages and development prospects are indicated.A new constructive scheme of the controlled exoskeleton for passive balance during walking and sitting is described.The portability and compactness of the device are achieved by reducing the quantity ofbalancing elements. The application of new constructive solutionsallows both to use the same elementsfor implementing various functions and to switch the device into the required mode of operation easier.*

*The designed device can be used for the human musculoskeletal system assisting and for its physiotherapy. Moreover, the proposed approach to the balancing devices design is universal and can be applied not only for assistive devices designing, but also for manipulating devices with leverageswinging links, in general.*

***Keywords:*** *rehabilitation device, static balancing, exoskeleton, leverage mechanism, spring.*

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## АССИСТИРУЮЩИЙ ЭКЗОСКЕЛЕТОН ДЛЯ ПАССИВНОГО УРАВНОВЕШИВАНИЯ ПРИ ПРИСЕДАНИИ И ХОДЬБЕ ЧЕЛОВЕКА

*Изложены результаты проектирования и сравнительный анализстатически уравновешенных одеваемых ассистирующих устройств для ходьбы и приседания человека, указаны их преимущества, недостатки и перспективы усовершенствования. Описана новая конструктивная схема регулируемого экзоскелетона для пассивного уравновешения при ходьбе и приседании. Портативность и компактность устройства достигнуты путем сокращения числа уравновешивающих элементов, а применение новых конструктивных решений обеспечивает как использование одних и тех же элементов для реализации различных функций, так и легкость переключения устройства в нужный режим работы.*

*Спроектированное устройство может быть применено как для ассистирования опорно-двигательной системе человека, так и его физиотерапии. Более того, предложенный подход к проектированию уравновешивающих устройств универсален и может быть применен при проектировании не только ассистирующих, но и вообще для манипуляционных устройств с рычажными качающимися звеньями.*

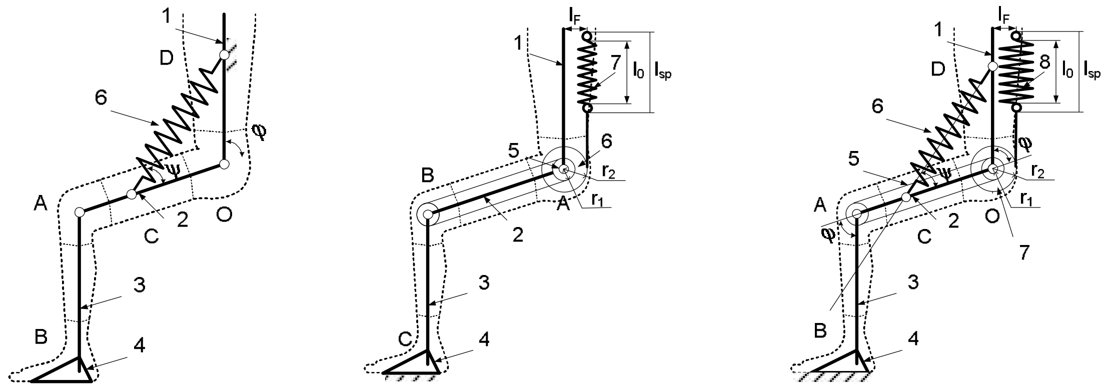
***Ключевые слова:*** *реабилитационное устройство, статическое уравновешивание, экзоскелетон, эластичный элемент, пружина,*

### 1. Introduction.

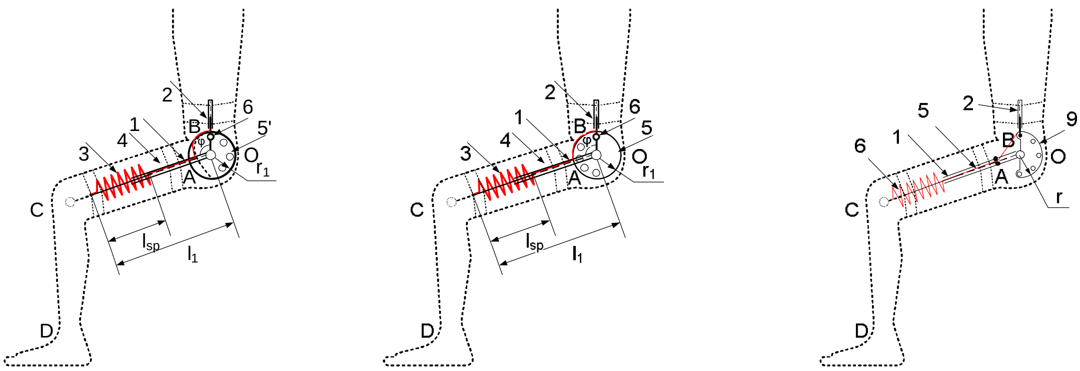
The assistive devices such as passive exoskeletons and orthoses, designed to rehabilitate and support the human musculoskeletal system functions, are basically performed by the leverage mechanisms [1-9].Their use forms a biomechanical system of device and human body. The gravitational forces and their moments act on the system links. The gravitybalancing of these links plays a significant role in these systems design and application process.

The authors have proposed a gamma of assistive balancing devices for human walking [2] and sitting [3,6], as well as universal devices-assistants for walking and sitting [4, 5-9] (Fig. 1), in which the cylindrical springs where used.Moreover, in the view of spring's contra directional action during walking and sitting, the authors have suggested two ways for designing the constructions for the last group of assistant devices. The first construction includes individual springs for each mode of operation [4], andthese springs are connecting and disconnecting to the biomechanical system alternately. The second scheme uses single spring and an element, e.g. cam [7], roller [7,8] or semi-roller [9], regulating spring orientation. Analysis of the proposed devices revealed their advantages and disadvantages, particularly, despite the schemes simplicity and the possibility to achieve the human legs exact static balancing during walking, they provide only human body partial balance during sitting. Based on the human walking and sitting assistive devices design experience and human body biomechanics empirical correlations, it can be statedthat the ratio between leg segment's total gravity moment relative to the hip joint and the body total gravity moment relative to the knee joint is approximatelyone to three in average statistics.It is obvious that the balancing spring's moments and forces must comply with this ratio.

Thus, human body exact balancing at sitting is possible in principle, but we must have three times more cumbersome spring than for walking, which is an obvious disadvantage of the presented schemes.



a) [2,4] b) [3,6] c) [4,5]



d) [7] e)[7,8] f)[9]

Figure 1. Assistive devices:
a - for walking; b - for sitting; c - for walking and sitting with two cylindrical springs;
d, e, f- for walking and sitting with one cylindrical spring and a regulating mechanism:
d - with a cam, e - with a roller, f - with a semi-roller.

Another disadvantage of proposed devices is that significant effort is required from this device user when switching balancing modes, since during switching the initial tension of the balancing spring was reduced to zero.

*__The aim of this work__* is to design a new portable passive balancing exoskeleton for human walking and sitting, which uses a spring with the possibly lowest stiffness coefficient and dimensions, and also ensures the device switching into each of its operation modeseasier.

**2. Human balancing by means of the adjustable portable exoskeleton.**

Let's consider the structural scheme of the device-assistant of human walking and sitting.It is a three-links flat leveragemechanism with rotational kinematic pairs, superimposed on the human body from each of its sides, and with balancing cylindrical tension springs.

The similar leveragesystems were repeatedly presented by authors in their previously published papers [2-9]. Here, the system is equipped with the regulating slider mechanism 6 to convert the directions of springs'actions and forces. Due to its mirror symmetry, the device is described only on the one side (Fig. 2).

With each mode of operation, the system can be simplified and considered as a 1-DOF swinging link with reduced mass at its free end, i.e., where the thigh link 2 swings relative to the hip joint O on an angle $\varphi$ , the shin together with the foot are represented by a concentrated mass, or the thigh link 2 swings relative to the knee joint D, and the mass of one arm and half mass of the torso and head are given by massof the link 1.

In the second mode of operation (sitting), in order to device becomes a single-motion mechanism, it is necessary to add a telescopic link 7 to connect links 1 and 3, the length of which should be fixed by fixator 8 only during sitting.

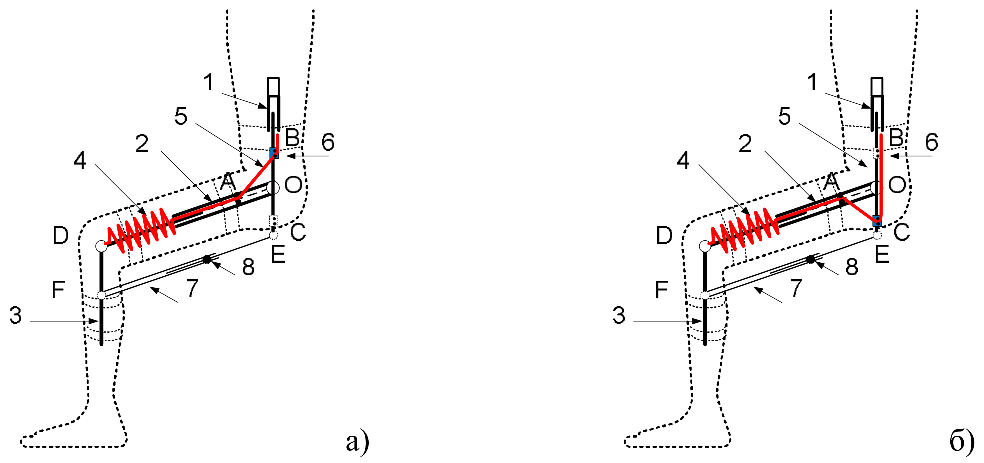



Figure 2. Walking and sitting assistive devices with a regulating slider:
a - in walking mode; b - in sitting mode.

1, 2, 3 — device links, 4 — spring, 5 — cable, 6 — adjusting slider,
7 — additional telescopic link used for sitting.

To balance the system, we use a linear cylindrical tension spring of non-zero free length, the stiffness coefficient of which is chosen from the condition of leg segments' exact balancing in walking mode.The spring is fixed along the thigh link from the knee side and to its free end the cable 5 is connected, which by passing through point A is retracted to the regulating slide (point B) and fixed behind it (see Fig. 2).Here, the stiffness coefficient value is regulated by the ratio of the OAB triangle sides OA and OB, and if they are not equal, then the cable must be pulled out of the slider and fixed at the distance of their difference (OA-OB).Herewith, for this balancing system we obtain the power characteristics close to the version where zero free length springs were used [1, 2].

With such a structure, the leg is indifferently balanced throughout the swinging angle variation in entire range of angle $\varphi$ . In walking mode the maximum force developed by the spring reaches in the human standing position. Exactly and only in the standing position the slider easily moves to point Cputting the device into a sitting mode and further forcing the system to change its balancing direction and partially balance the human body during sitting. By the distance of slider fixation point the system inevitable partial imbalance desired limits are regulated. The spring maximum tension of the walking mode becomes the initial tension for the sitting mode, this effect is used for approximate balancing of the effective gravitational moments during sitting.

If we don't provide such a tension (for cable and spring), the exact static balance during sitting still can be done, but it will be necessary to increase the distance OC three times, which is not so acceptable when designing a small-sized assistive device.

**3. Conclusion**.

We consider a number of constrictive schemes of portable assistive devices for human walking and sitting which arestatically balanced by cylindrical tension springs. Advantages, disadvantages and development prospects of these devices are shown.

The new improved constrictive scheme of the controlled exoskeleton is proposed.It passively balances the user's body during sitting and walking, and has slider controllers which ensuring ease switching of operation modes.

The telescopic link is added to the design to ensure the comfort and smoothness positioning for human during sitting. The cylindrical tension spring use in the construction suggests the possibility to realize the leg's exact static balance during walking and bodypartial balance during sitting.Relative to the previous ones, such a scheme does not require a high rigidity spring for system balancing, however, it requires a rather large stretch range. In the future, constructive solutions with a spring arrangement allowing to eliminate this disadvantage will be presented.

Designed device can be used both for assisting the human musculoskeletal system and its physiotherapy. Moreover, the proposed design approach is quite universal and can be used in designing not only assistive, but also other manipulation devices with swinging arms (links).

The main achieved advantages of the device are its versatility, compactness, adjustability and comfort in comparison with the known analogues, also ensuring the loads and angular displacements ranges dosing, i.e., the high efficiency during human physiotherapy.

The constructive design (figuration), prototype model preparation, experimental research and testing of the proposed device are assumed at the next stages of the ongoing project.

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