

THE ARCHITECTURE OF INTELLIGENT MECHATRONIC SYSTEM USED FOR INCREASING THE NEUROMUSCULAR CONTROL

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Abstract: *The paper presents intelligent and complex mechatronic system which can perform predefined sequential motion cycles used for increasing neuromuscular control of athlete performance. The equipment comprises two parts: an automation panel and a pneumatic assembly. The Master Control Unit of the automation panel is programmed to run a specific software application that ensures the proper fulfilment of the motion cycles. The MCU is connected to a Radio Frequency transceiver and could be easily connected to IoT and/or LAN using a wired net controller. The input data has the following sources: the remote RF sensors' data, the position of the proximity sensors (placed on the pneumatic cylinders), the numerical codes transmitted by the IR remote control and/or by IoT connection and the current motion cycle's settings. The output data consists of digital output signals (send both to the solenoid valves through relays and to the status lamps) and text messages written onto a LCD display.*

Keywords: *Mechatronic system, neuromuscular control, Biomechanics.*

1. Introduction

In the training of athlete, due to the competitive specificity, in addition to the development of motor skills (speed, strength and endurance), a very important aspect is the development of motor skills balance and coordination. The development of these two elements in fact involves the execution of physical exercises aimed at increasing the neuromuscular control of the athlete performance. To perform specific exercises, such as counter-procedures used against the design techniques of the opponent on the ground, there is currently no dedicated equipment, which is why they are performed with the help of a partner. In the development activity of the athlete, the first stage is the formation of conditioned reflexes stimulated by performing repetitive movements of low intensity, ie by performing at low speed some movement cyclograms. In order to develop coordination, it is necessary to dynamically change the parameters of the movement, namely: speed and direction of movement. It is very important that, with the development of neuromuscular control, the endurance of the athlete in question can be developed, thus eliminating the obstacle created by the appearance of fatigue.

This endurance development is achieved by increasing the execution time of the cyclogram, by adding additional movements within it. Also, the development of the speed of execution and / or reaction of the athlete can be achieved by imposing an increasingly fast pace in the execution of the exercise cycle or by dynamically changing the direction of travel imposed on the athlete in question. Another very important aspect in the development of balance in the case of athlete is the mobility of their coxo-femoral joints, as an important part of the opponent's ground design procedures is based on manipulating one of the opponent's legs, over the mobility of the coxo-femoral joints. his femurs. The main problem with using a human partner in these exercises is that he cannot perform the required cyclograms correctly due to lack of experience, fatigue and last but not least due to the subjectivism in making the necessary decisions. Therefore, there is a need for well-trained human partners, or for the use of systems that allow the correct implementation of the necessary

cyclograms. As these well-trained partners are generally athlete or coach, it is often inefficient to use them, as they are short of their own training time and / or not enough to cover as many people as possible. trainers simultaneously.

2. The requirements that the intelligent mechatronic system must meet

Starting from the aspects mentioned above, it was necessary to design an intelligent mechatronic system, which would allow the implementation of such movement cyclograms, necessary for the development of the neuromuscular system of strength and endurance of the lower limbs and mobility of coxo-femoral joints of athlete. The proposed mechatronic system will replace a human partner in the execution of the movements required to train the athlete against the ground design procedures of the opponent and not only. This will be called the handling system (abbreviated - SM). The main requirements that such a system must meet are:

- enable the movement and posture to be performed with a high degree of precision and repeatability, which facilitates symmetrical development in terms of neuromuscular control / dynamic and static balance, strength and endurance in the lower limbs, and from the point of view of the mobility of the coxo-femoral joints, of the athlete;
 - to allow the level of intensity of the physical stress to be adjusted according to the specific needs of each athlete;
 - allow for easy and risk-free operation;
- be able to be used, under certain conditions, by athletes who are injured or in the recovery phase after exercise, whether it is training or competitive;
- to allow all these goals to be achieved without the help of a third party;
- be able to be placed in a regular training room.

3. Description of the manipulation system (MS), designed to be used in the training of athletes, for the development of neuromuscular control

The purpose of any training session is for the athlete to overcome his limits, consciously and voluntarily, by adapting the neuromuscular to the demands to which he is subjected. The level and types of demands are determined by the coach through the training plan, based on the latter's experience, as well as on the information gained during the relationship established between the latter and the athlete, which allows the coach to estimate in objectively the level of training of the athlete and to know his anatomo-physiological specificities.

The designed handling system replaces the actions that usually need to be performed by a partner / coach to help train an athlete (referred to in this case as the user). This system allows the user to perform certain exercises whose purpose is to develop neuromuscular control / dynamic and static balance, strength and endurance of the lower limbs of athlete, as well as to maintain and / or develop the mobility of their coxo-femoral joints. Specifically, the manipulation system will allow the user to perform in the best conditions training for the development of neuromuscular control / dynamic and static balance, strength and endurance of his lower limbs, allowing him to perform exercises such as those that form the basis of counter-procedures. used against the design techniques of the opponent on the ground. to correct the biomechanics of movements and reduce the risk of injury during training.

Also, the manipulation system will allow the user to perform in the best conditions training to maintain and / or develop the mobility of his coxo-femoral joints. During these trainings, the manipulation system will supplement the actions of the athlete's human partner.

One of the most complete exercises, which allows the development of neuromuscular control / dynamic and static balance, strength and endurance of the lower limbs of the athlete, is to move in one leg of the latter, in the direction and speed imposed by a human partner. [1,6,7,8]. The athlete's moving leg is called the support leg, and the other leg is called the manipulated leg, as the human partner dictates to him the direction and speed of movement by manipulating the latter limb. The role of the human partner is to keep the athlete in a constant state of imbalance, constantly changing the

direction of travel, and the role of the athlete is to adapt to the demands imposed, trying to move and even intuit the direction of movement. to be able to maintain balance. As an example in this sense, if the human partner finds that the athlete has the center of gravity [2] backwards, then he will push him backwards, by means of the manipulated leg. The correct reaction from the athlete will be for him to move (hopping in one leg) in the required direction (backwards), simultaneously with the movement of the center of gravity towards the face (i.e. bending his torso towards the face). The disadvantage in this case is that the full control over the determination of the position of the athlete's center of gravity and also the speed of change of direction of travel is left to the discretion of the human partner. Therefore, any mistake of his can have a negative impact on the health of the athlete. This type of exercise is the foundation of the counter-procedures used against the design techniques of the opponent on the ground, allowing the simultaneous development of both motor skills and motor skills, as well as reducing the risk of injury in the training of athletes.

Regarding the exercises that allow the maintenance and / or development of the mobility of the coxo-femoral joints, of the athletes, they are performed in two ways:

- using specially built devices [3] [4]. Their major disadvantage is related to the fact that the training of the mobility of the coxo-femoral joints is done with both feet on the ground, or on the device in question, thus eliminating the balance component of the exercise;
- with the help of a human partner. This exercise is performed by supporting one of the legs on the partner, who has the role of opening the angle between the two limbs as much as possible. In this situation, the disadvantage is that the human partner must be very well prepared to be able to respond quickly and correctly to the requests of the athlete in question, otherwise the risk of injury is imminent. The advantage in this case is given by the presence of the balance component during the exercise, the athlete having only one foot on the ground and having to maintain a correct posture [5].

The role of the designed handling system is to supplement the presence of the human partner in performing the exercises described above, eliminating the disadvantages mentioned in each situation, to correct the biomechanics of movements and reduce the risk of injury during training.

3.1 The architecture of the manipulation system designed for its use in athletes' training, for the development of neuromuscular control

Starting from the requirements that are to be fulfilled by the designed handling system, the main elements / subassemblies that are part of it, are (see fig.1):

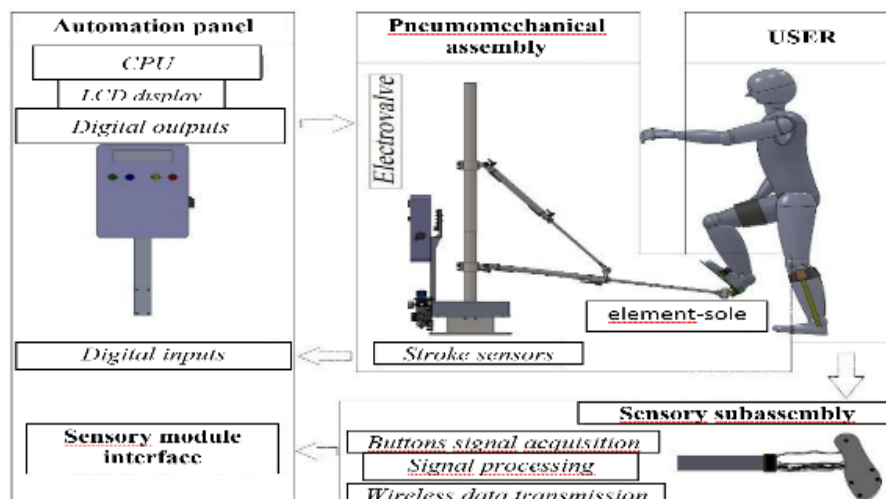


Fig. 1. Schematic representation of the architecture of the handling system

a) A pneumomechanical assembly consisting of:

a.1) The lower subassembly, used to perform the horizontal rotational movements of the assembly, these having the role of causing the user to move to the left or to the right, thus supplementing the

movement actions imposed on the athlete by a partner / coach, in accordance with the requirements of the exercise in question.

The main features of this subassembly are:

- allows to change the direction of travel, to the left or to the right, depending on the changes of the user's center of gravity, detected by means of a sensory system mounted on the support leg of the athlete concerned. If the center of gravity is positioned toward the inside of the athlete's support foot, the subassembly will rotate counterclockwise, unbalancing the user and thus causing him to try to rebalance dynamically, and if the center of gravity is positioned towards the outside of the foot of its support leg, the subassembly will rotate to the right, causing the user to become unbalanced and thus causing the user to try to rebalance dynamically again;
- allows to change the speed of movement / rotation, depending on the needs of the user.

a.2) The upper subassembly, used to perform the vertical displacement movements of the device, these having the role of causing the user to move forward or backward, thus supplementing the actions of forced displacement to one of the aforementioned directions, imposed the athlete by a partner / coach, in accordance with the requirements of the exercise in question. The main features of this subassembly are:

- allows the direction of travel to change, up or down, depending on changes in the user's center of gravity, detected by a sensory system mounted on the support leg of the athlete concerned. If the center of gravity is positioned towards the tip of the athlete's support foot, the subassembly will move in front of the user, the manipulated foot support, unbalancing him and thus causing him to try to rebalance dynamically. , and if the center of gravity is positioned towards the heel of the athlete's support leg, the subassembly will move towards the user's back, the manipulated foot support, causing the user to become unbalanced and thus causing the user to react again;
- allows to change the speed of movement / rotation, depending on the needs of the user;
- allows the start / end of the action at the user's command, so that he has control at all times.

b) A sensory subassembly, which contains a portable electronic module and a sensitive module containing a set of five return micro-buttons located on a shoe insole. The sensitive module is used to determine the position of the support at the level of the user's support foot. This position of support is in fact an approximation of the position of the user's center of gravity during the movement imposed on him by the handling system. If the user is with one of the feet suspended in the air, he can achieve a state of balance when his center of gravity is positioned inside the triangle formed by his thumb, toe and the heel of his supporting leg. In the case of displacement imposed by a partner / handling system, the position of the user's center of gravity can be approximated as follows:

- if the support is made predominantly at the user's toe, the center of gravity is positioned outside the foot of the foot in question, on its proximal-frontal side;
- if the support is made predominantly at the user's toe, the center of gravity is positioned outside the foot of the foot in question, on its distal-frontal side;
- if the support is made predominantly at the heel of the user's foot, then the center of gravity is positioned outside the foot of the foot in question, on its back;

The main advantages of the sensory subassembly are:

- small size;
- portability and energy autonomy during each working session;
- wireless data transmission - this allows the unrestricted performance of movements performed by the human user in order to rebalance.

c) A subassembly of the central electronic unit, called an automation panel, used for the management and implementation of all the functions of the system concerned, as well as their related actions, either on the basis of a predefined cyclogram, which can be dynamically modified to the information provided by the sensory subassembly is also taken into account, either on the basis of orders received directly from the human user. Thus, this subassembly will control the solenoid valves responsible for actuating the pneumatic cylinders, which implement the necessary movements of the system in question.

The data flow between the sensory subassembly and the automation panel ensures the dynamic configuration of the movement cycle that the human subject will perform. The entire manipulation

system is designed in such a way that, depending on how the sensitive subassembly, the sensory subassembly micro-buttons are pressed, the control software, which manages the entire activity of the manipulation system, will send to the drive system. pneumatic of the mechano-pneumatic subassembly, those commands that will keep the human subject in a continuous state of imbalance, forcing him to continuously adjust his posture to maintain balance.

The designed handling system allows the implementation of individualized movement cycles, whose movement parameters are adapted according to the needs of each individual.

4. The description of the mechanical structure of the manipulation system designed for the use in athletes' training for the development of neuromuscular control

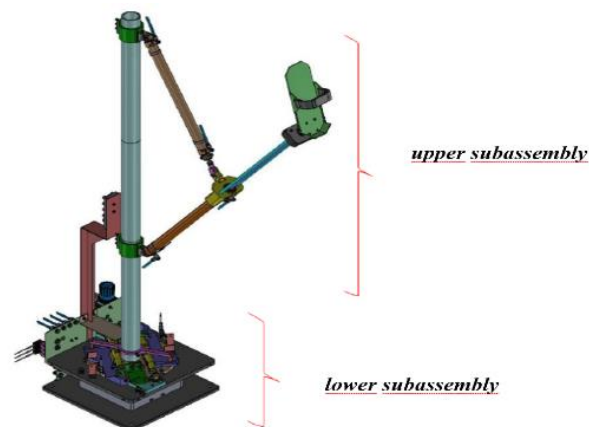


Fig. 2. The perspective view of the handling system

The manipulation system designed to be used in performance training in athletes, in order to allow the development of neuromuscular control / dynamic and static balance, strength and endurance of the lower limbs and mobility of the coxo-femoral joints of athletes, represented in fig. 2, consists of the following subassemblies and basic elements:

a) The lower subassembly

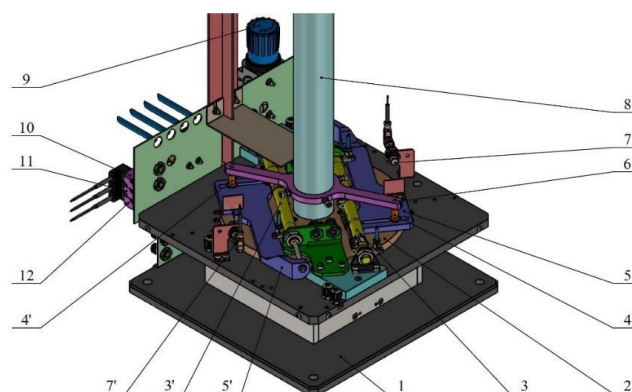


Fig. 3. The perspective view of the handling system highlighting the elements of the lower subassembly

The lower subassembly consists of a housing 1, a disc 2, a pair of rotating pneumatic cylinders (3, 3 ') two spacers 4 and 4', respectively, a pair of connecting rods (5, 5 '), a stabilizing element 6, a pair of inductive sensors (7, 7') a support column 8, a pressure regulator 9, a group of solenoid valves (10, 11, 12) , a pair of inductive limit switches (13, 13 ') and a pair of throttles (14, 14') , located on the cylinder pneumatic 3, a pair of throttles (15, 15 ') and a pair of inductive limit switches (16, 16') , located on the pneumatic cylinder 3 '(see fig. 3) , a central shaft 17, a pair of radial-axial bearings

(18, 18'), a pair of sliding washers (19, 19'), a protection cap 20 (see fig.4.5) and a pair of limiting pins (21, 21'), see fig.6. The inductive sensors 7 and 7' have the role of detecting the touching of the stroke ends of the rotating pneumatic cylinder rods 3 and 3', respectively, in case the stroke end sensors 13, 13', 14, 14' show defects.

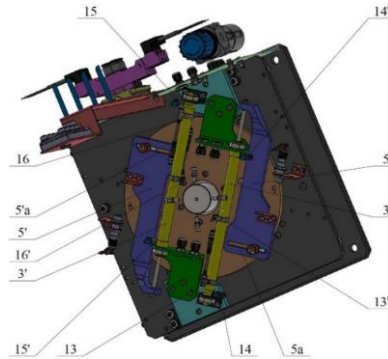


Fig. 4. Top view, in perspective, of the handling system, highlighting the elements of the lower subassembly

The rods of the two rotating pneumatic cylinders 3 and 3', have the free ends fixed on the connecting rods 5 and 5' respectively, the bodies of the pneumatic cylinders being fixed on the housing 1 (see fig.4.4). The support column 8 is welded to the disc 2, which is fixed, with screws, to the central axis 17, the latter being rotatably mounted on the housing 1, by means of the pair of radial-axial bearings (18, 18'), see fig .4.5. The two connecting rods 5 and 5' have two transverse channels 5a and 5'a respectively (see fig.4.4), which have the role of allowing the transmission of the movement from the disc 2 to the stabilizing element 6 and therefore the transmission of the movement from the pair of pneumatic cylinders. (3, 3'), in support column 8. In this way, by means of the two connecting rods 5 and 5', the translational movement from the two pneumatic cylinders 3 and 3', which act simultaneously (i.e. the rods of both pneumatic cylinders advances and retracts, respectively), is transformed into a rotational movement at the level of the support column 8.

The two pairs of throttles, (14, 14') located on the rotating pneumatic cylinder 3 and (15, 15') located on the rotating pneumatic cylinder 3', respectively, have the role of allowing the adjustment of the speeds of movement of the rods of the two pneumatic cylinders. remember, which must be equal to each other on both the forward and the reverse stroke, but also equal between the forward stroke and the retraction stroke. The two rotating pneumatic cylinders, 3 and 3', respectively, are actuated by the same solenoid valve 10. This translates into the simultaneous action of the rods of the two rotating pneumatic cylinders, 3 and 3', respectively, on the two connecting rods 5 and 5', respectively.

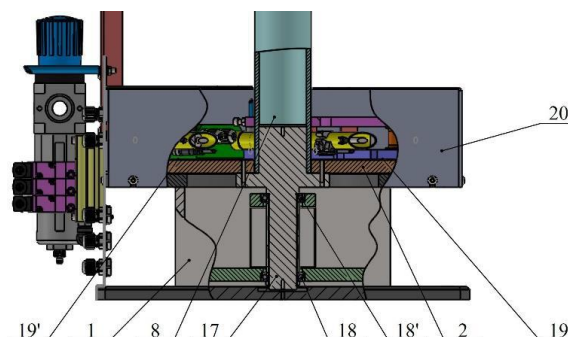


Fig. 5. Side view of the handling system, with rupture at the lower subassembly

The two spacers 4 and 4' respectively (see fig.4), in addition to the role of fixing the stabilizing element 6 on the disc 2 and transmitting the movement from said disk to the element in question and that of maintaining the coplanarity between the lower faces of 5 and 5' connecting rods also have

the role of keeping the distance between these connecting rods and the disc 2 fixed (this distance is determined by the thickness of the sliding washers 19 and 19'). In this sense, the stabilizing element 6, which is fixed by means of the screws on the support column 8, prevents the vertical movement of the two spacers mentioned above (see fig.5).

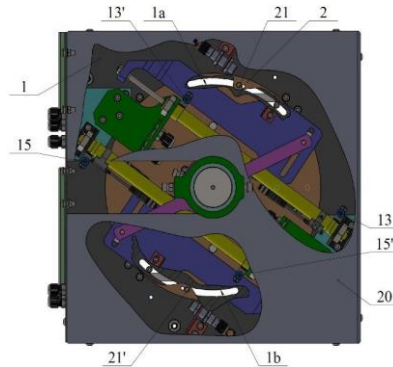


Fig. 6. Top view of the handling system, with rupture at the lower subassembly, to highlight the mechanism of transformation of the translational movement, printed by the two rotating pneumatic cylinders 3 and 3', in rotational motion, at the level of the support column 8

On the disc 2 are mounted two limiting pins 21 and 21' respectively, which have the role of preventing the seizure of the mechanism of transformation of the translational movement into rotational movement, previously mentioned, in case of a failure at the limit sensors 13, 13', 14, 14' and / or at the level of the inductive sensors 7 and 7', situation in which the movement of the rods of the rotating pneumatic cylinders 3 and 3' respectively, is blocked by the forced contact between the aforementioned pins and the ends of the two circular channels 1a and 1b, made in housing 1 (see fig.4.6). These two channels are coradial and have the center of rotation coinciding with the center of the disk 2. Also, the axis of rotation of the support column 8 coincides with that of the disk 2, and the two circular channels 1a and 1b are equal, respectively, their length being the same as the maximum permissible stroke length of the rotating pneumatic cylinder rods 3 and 3' respectively.

b) The upper subassembly

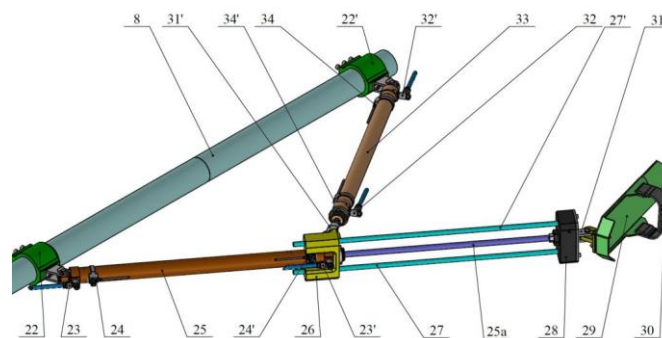


Fig. 7. Perspective view of the handling system, highlighting the elements of the upper subassembly

The upper subassembly consists of an advancing pneumatic cylinder 25, with the free end mounted articulated on a collar 22, placed in a row or on the support column 8 (mentioned in the description of the lower subassembly), a pair of inductive sensors (24, 24'), mounted on the aforesaid pneumatic cylinder, a pair of rods (27, 27'), which slide freely through a guide piece 26, a sleigh element 28, fixed on the upper ends of the rods 27 and 27', a sole element 29 or sole element 29' (see fig.4.9.a and fig.4.9.b), on which a fastening system 30 is placed, of "VELCRO" type, two hinge elements 31 and 31' respectively, a pneumatic tilting cylinder 33 having the free end mounted articulated on a collar 22', fixed in turn or on the support column 8, a pair of throttles (32, 32') and a pair of end-of-

stroke inductive sensors (34, 34') , mounted on the tilting pneumatic cylinder 33. The forward pneumatic cylinders 25 and the tilting cylinders 33, respectively, articulated to the clamp 22 and the clamp 22' , respectively, can rotate in the median transverse plane of the system in question. The free end of the rod 25a, of the pneumatic feed cylinder 25, is fixed to the sleigh element 28.

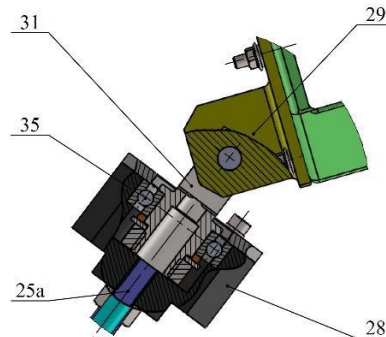


Fig. 8. Section view at the level of the lower subassembly, highlighting the elements that contribute to the transmission of movements from the handling system to the manipulated leg of the user

The hinge member 31 is fixed to the inner ring of a radial bearing 35 , the outer ring of which is mounted inside the sleigh member 28, which allows the hinge member 29, mounted articulated on the hinge member 31, to rotate. both in the frontal plane and in the plane containing the upper face 29a, of the sole-element 29 (see fig.4.8 and fig.4.9.a), this being extremely important to avoid injuring the user, his manipulated leg being able to achieve natural movements in the joints involved.

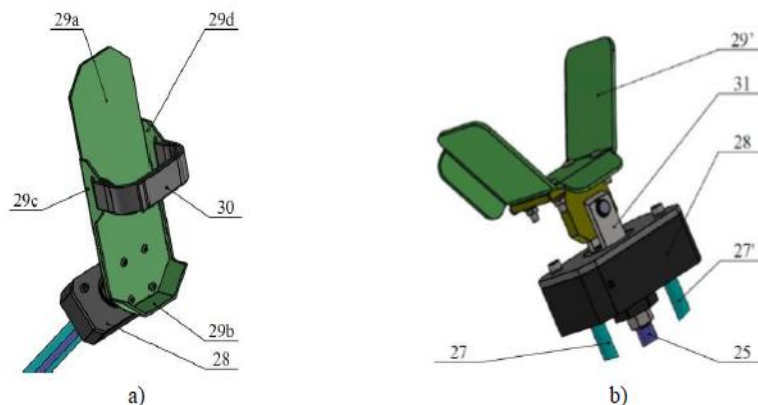


Fig. 9. Perspective view of the sole-element of the handling system, with the highlighting of its two constructive variants: a) the sole-element 29 - in the variant with fixing elements of the manipulated foot, of the user; b) sole element 29' - in the version without fasteners of the manipulated foot, of the user

The free end of the rod 33a, of the tilting pneumatic cylinder 33, is mounted articulated on the hinge element 31' , rotatably fixed, in turn, on the body of the guide piece 26. The latter element is fixed on the end from the rod of the advancing pneumatic cylinder 25 so that advancing or retracting the rod 33a of the tilting pneumatic cylinder 33 raises or lowers the base member 29. Advancing or retracting the rod 25a of the advancing cylinder 25 causes the base member 29 to move closer or further away from the support column 8. combining the movements of the two pneumatic cylinders mentioned above, the two-dimensional displacement of the sole element 25 is obtained.

The role of the sole element 29 is to support and fix the manipulated foot of the human subject (user), subject to analysis, during the imposed cycle of movement. Accidental movement of the user's manipulated foot to the left, right, or back is impeded by the shape of the sole member 29, which has a dorsal wall 29b and two side walls 29c and 29d, respectively (see Fig. 8). Accidental movement of the user's manipulated foot to the front, or detachment of it from the sole-element 29, is prevented

by the fastening system 30, located on the element in question (see fig.4.8). The choice of a "Velcro" fastening system was also determined by the need to untie it relatively quickly, in case of force majeure (for example, if the user is suddenly affected by a severe muscle cramp, at the foot of support or manipulated, which may cause him to stop moving urgently). The pair of rods (27, 27') has the role of taking over some of the stresses exerted on the rod 25a, the pneumatic cylinder 25, during the three-dimensional movement of the sole element 29, by the user, in response to the changes of direction imposed by the handling system in question. The two pairs of throttles, (23, 23') located on the advancing pneumatic cylinder 25 and (32, 32') respectively located on the tilting pneumatic cylinder 33, have the role of allowing the adjustment of the speeds of movement of the rods of the two pneumatic cylinders previously mentioned, which are actuated by solenoid valves 11 and 12 respectively.

By properly positioning the two clamps 22 and 22', respectively, on the support column 8, it is possible to move the sole element 29 in such a way that it reaches closer or farther to the ground, the ceiling, or the column of support 8.

5. Conclusions

The paper presents a mechatronic system that can perform motion cycles based on a predefined cyclogram. By means of a remote control, the user can control the vertical movement of the subassembly which ensures the support of its manipulated foot, to the desired height and then its controlled descent, so as to allow it to change its maximum angle between the lower limbs. as required by the exercises dedicated to obtaining the positions but at the same time to provide him with an element of support in case he becomes unbalanced or tired.

The system can be easily embedded into other much complex equipment, such as those used in neuromuscular control training, biomechanics, medicine and physical therapy.

Acknowledgments

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