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Design of elements of imitator’s construction of physical loads of software and hardware platform of training complex

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Abstract. Training complexes are an effective and modern tool for training personnel working in conditions of increased risk to human health and life, which allow minimizing accidents and material damage. One of the actual problems of the use of simulators is the lack of realism of user movement in the virtual world. In order to solve this problem within this study, the task of a simulator design of physical loads is considered. The developed prototype simulator allows a comprehensive and realistic training of personnel in normal and emergency situations. The article describes the basic structure and functionality of the simulator, the geometric dimensions of the rolling belt are determined. The dependencies of determining the size of the drive shaft and the kinematic parameters of the drive are scrutinized. The listed parameters define the actual position of the student, dynamic loads (magnitudes of speeds, accelerations and torques) during the simulation of working and extreme situations. The obtained results will be applied for the physical simulation of the physical loads of the software and hardware platform of the training complex.

1. Introduction

At the mining industry any emergency situations (fires, accidents, emissions of toxic substances) cause considerable difficulties for rescue operations due to panic among personnel, insufficient preparation for the use of personal protective equipment. In order to minimize accidents, threats to human life and health, and material damage, it is necessary to regularly train workers in conditions as close as possible to real-life situations. However, the reproduction of emergency situations involves significant economic costs, and in most cases is impossible in principle.

The development of virtual reality technology allows solving this problem due to the possibility of modeling a wide range of emergency situations at industrial enterprises. Training complexes allow you to form sustainable skills in handling breathing apparatus, work out an evacuation plan, teach you how to use expensive equipment, and acquire skills. Training on a simulator allows not only to master theoretical skills, but also to develop the necessary set of practical competencies [1-2].

However, modern training complexes are not yet fully capable of putting a person into virtual reality [3-6]. The main disadvantage of existing systems is the absence of subsystems of imitation of real physical processes - for example, breathing in conditions of fire or smoke, movement on an inclined surface. At the moment, the question of the implementation of user movement in the virtual world is solved with the help of various kinds of controllers, which does not allow developing the physical skills of a person, and also destroys the sense of reality of what is happening.
Therefore, an urgent task addressed in this study is the development of a physical activity simulator that allows you to organize a realistic and natural movement of the user in virtual reality, to simulate different movement speeds and surface incline in real time.

2. Development of a prototype of an exercise simulator
At the first stage of solving the problem, it is necessary to develop a prototype of an exercise simulator. The prototype is a controlled bidirectional treadmill with the ability to change the angle of inclination (figure 1). The simulator allows you to undergo a comprehensive training in regular and emergency scenarios of activity, allowing you to improve the trainee's endurance performance, develop proper breathing skills using self-rescuers with systematic training in conditions as close to real as possible [3].

![Figure 1. Three-dimensional model of a physical activity simulator.](image_url)

The simulator of physical activity allows the learner to go the route of real length, required for evacuation or moving to a safe distance. It is possible to use the simulator in full equipment or to work out on him the rescue of a real person according to the scenario. These requirements should be taken into account when calculating the strength of the structure.

Additionally, the physical activity simulator should solve the following tasks [3-6]:
1. Determination of the degree of professional suitability of the student to overcome the increased physical exertion arising in specific or extreme types of work. This is necessary in the course of expert assessment or disability, when it is necessary to clarify the degree of the patient's ability to work.
2. Determination of the optimal schedule and intensity of training loads, assessment of endurance and maximum permissible loads.
3. Organization of a clarifying, early, differential diagnosis of the dysfunction of the cardiovascular system.

Proper design of the simulator design has a great importance for the working conditions of all associated mechanisms. The design of the elements of the rolling fabric acquires a particular importance here. For example, the belt base determines the actual location of the learner during the movement, and the choice of drive affects the speed and acceleration values during the simulation of training situations.

When choosing a belt, it is necessary to ensure high safety limits established during the calculation. This is due to the need to take into account the weakening of the belt at the junction of its ends and the presence of dynamic loads experienced by the belt during operation. These dynamic loads occur
during the simulation of the acceleration of the movement of the object in the simulation of emergency situations. Also significant dynamic loads occur during the start and braking of the belt.

The main geometric parameters of the belt are set by the national standard of the Russian Federation (GOST R 56441 - 2015). Guided by safety recommendations in an emergency, work personnel should not run in the mine. From this point of view, the speed of the belt should not exceed 6 km/h. However, to simulate emergency situations in other conditions, the speed of the belt can reach 15 km/h. This allows the learner to run if necessary. This functionality of the rolling belt allows you to increase the body's resistance to external loads, but in reality - to increase the chance of survival in an emergency.

In the construction of the rolling belt a slider-crank mechanism is applied to simulate the student's down come and lifting along an inclined plane (Fig. 2). The base of the movable blade 2 is attached with a hinged-fixed connection to the vertical support 1. The base is attached to the crank 3 from the side of the electric motor. The crank is supported on a linearly movable support moving along the guide 4.

![Figure 2. Principle diagram of work of physical exertion creation](image)

3. Determination of construction parameters of the simulator

Load capacity is the main parameter when selecting drive shafts. The design (diameter determination) shaft calculation takes into account the maximum transmitted torque from the strength condition for permissible torsion stresses. Further selection of the drive shaft in the design is carried out in the following sequence:

1. When carrying out the calculation of the physical load simulator we find the maximum load on the running belt and we select the type of belt according to its value.

2. After that, it is necessary to determine the necessary minimum allowable diameters of the drive shafts taking into account the coefficients of the strength of the belt, the tension and the wrap angle of the belt of the drive shaft.

3. Next, we determine the radial force $F_r$, influencing on the shaft and equal to the geometric sum of the tensions of the paths of the belt. This traction calculation involves determining the torque $T$ and the circumferential force $F_t$, acting on the drive shaft.

4. In conclusion, according to the obtained parameters, the drive shaft should be selected taking into account the load capacity determined from the results of the calculation of the shafts for static strength, fatigue resistance and the calculation of bearings for durability.
For the selected drive shaft, the allowable pressure of the belt on its surface is determined by the condition

\[
P = \frac{360F_r}{\pi D B \alpha} \leq \text{[p]},
\]

where \(F_r\) – resulting radial force from the tension of the paths of the belt; \(D\) is the diameter of the drive shaft; \(B\) – belt width; \(\alpha\) - angle of circumference of the belt of the drive shaft, deg. The amount of permissible pressure is determined by the material of the belt.

In order that the belt does not sag under the weight of the student, it is necessary to install intermediate supports. The durability and reliability of the belt is largely determined by the presence of intermediate supports. The pitch of the intermediate supports is selected depending on the width of the belt, the speed of its movement and the mass of the student.

Traction movement of the belt with the trainee provides the drive. The drive consists of an electric motor, a belt drive and a clutch connecting the motor to the belt drive.

A tensioning device is applied to create a guaranteed belt tension and to compensate for the belt draft. The choice of the type of tensioning device is carried out depending on the characteristics of the belt and its tension, as well as the angle of inclination of the rolling belt.

In order to estimate the belt tension, choose the type and power of the drive, calculate the torque, it is necessary to determine the resistance of the belt motion. The total resistance at steady motion of the belt is equal to the drive force of the drive and is determined by the formula:

\[
W \approx f \cdot L \cdot \left[ (g_a + g_b) f_{c.r.} + g_b \pm g_a \right], H
\]

where \(f\) – generalized coefficient of resistance, taking into account the working conditions of the exercise simulator;

\(L\) – length of the horizontal projection of the belt (the distance between the axes of the drive and the driven shaft of the belt), m;

\(g_a, g_b\) – linear gravity respectively: trainee and belt, \(\frac{H}{M}\);

\(f_{c.r.}\) – coefficient of resistance to movement of oncoming path of the belt;

A positive «+» sign is placed before the last member when modeling a trainee’s rise on an inclined plane, the «-» sign is placed when the trainee is descending.

Linear load from the belt:

\[
g_b = g \cdot m_b \cdot B \cdot \frac{H}{M}
\]

where \(m_b\) – mass of 1 m² of the belt;

\(B\) – width of the belt, m.

Traction calculation of the rolling belt involves the determination of the resistance of the belt on the considered section:

- on the running path

\[
W_{op} = g_b \cdot L_b \pm g_b \cdot h_b,
\]

- on the oncoming path

\[
W_{op} = f_{c.r.} \left( g_a + g_b \right) \cdot L_b \pm \left( g_a + g_b \right) \cdot h_b,
\]

where \(L_b, h_b\) – horizontal and vertical projection of the length of the belt of the considered section, m.

At the horizontal position of the belt \(h_b = 0\).

The maximum calculated belt tension on the friction drive shaft during steady motion is equal to the tension of the belt path oncoming on the drive shaft \(F_{op}\). The tension of the running path of the belt \(F_{op}\) from the drive shaft depends on the required tractive effort, determined by the angle of girth and the coefficient of friction of the belt on the surface of the drive shaft.
In the process of performing the calculation, the interrelated quantities $F_{op}$ and $F_{rp}$ of the belt paths are unknown quantities, which can be determined from the solution of two equations.

$$F_{op} = f_m \cdot F_{rp} + \sum W_{ni},$$

where $f_m$ – coefficient of local resistances;
$W_{ni}$ – resistance to the movement of the belt, not dependent on the tension of the belt.

The second equation is obtained according to the theory of Euler, which determines the relation between the tension of the oncoming and running paths of the belt in the absence of belt sliding on the drum:

$$F_{op} \leq F_{rp} e^\omega \alpha,$$

where $f_m$ – coefficient of friction of the belt on the surface of the drive shaft;
$\omega$ – girth angle of the drive shaft belt.

From the joint solution of equations (6) and (7) we obtain the formula for finding the value $F_{rp}$:

$$F_{rp} = \frac{\sum W_{ni}}{e^\omega \alpha (1 - f_m)}$$

Traction on the drive drum:

$$F_{dp} = F_{op} - F_{rp}.$$ (9)

Taking into account the equation (7):

$$F_{dp} = F_{op} \left( e^\omega \alpha - 1 \right).$$ (10)

Drive motor power:

$$P = \frac{K_{cc} \cdot F_{dp} \cdot \nu}{1000 \cdot \eta},$$

where $K_{cc}$ – coefficient of clutch of the belt with the drive drum;
$\eta$ – energy conversion efficiency of the drive:

$$\eta = \eta_{pm} \cdot \eta_{nn},$$

$\eta_{pm}$ – efficiency of power loss in the belt transmission;
$\eta_{nn}$ – efficiency of power loss on friction in bearings.

After determining the main sizes of the belt, the diameter of the drive shaft and the kinematic parameters of the drive, it is necessary to arrange the relative location of parts of the nodes in space. It is necessary to achieve maximum comfort during operation of the simulator and the minimum sizes.

With a general spatial layout, the following main issues need to be solved [7]:

1) choice of principal structural schemes;
2) estimated sizes of the nodes;
3) ways to achieve the required accuracy of the relative position of the nodes;
4) technical aesthetics of structure.

The final stage in designing the elements of the exercise simulator is the sketching of its main details. The sketch design documents should contain fundamental design solutions showing general information about the design and principle of operation of the designed product. Sketch study is the basis for the development of a technical project.

4. Conclusion

The design and determination of the structural elements of the physical simulator plays a crucial role in the creative process of experienced engineers. The variety of design solutions causes the need for a developer to rely on theoretical knowledge and practical experience. In this case, the designer must choose the best solution from a variety of possible solutions. In this process, the designer has to take into account the often conflicting technological and operational requirements for the designed structure. Often, the optimal decision is made only after comparative technical and economic calculations for competing design options.
The above method allows determining the main geometrical sizes of the rolling belt, the sizes of
the drive shaft and the kinematic parameters of the drive. All of these parameters define the actual
position of the student, dynamic loads (magnitudes of speeds, accelerations and torques) during the
simulation of working and extreme situations.

The resulted construction of the physical load simulator will be further integrated into the software
and hardware platform for training complexes. Further research will comprise the implementation of a
simulator control system based on tracking the user's movements.

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