Design and Test of Self-Rescue Safety Belt for Power Line Operation at Heights

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Abstract. The self-rescue ability of electric power workers is of great significance to the safety of workers. However, the current use of safety belts can only ensure that operators do not fall to the ground, but it is not convenient for operators to carry out independent rescue and return to the wire. In this paper, a new type of safety belt design scheme is proposed to improve the self-rescue ability of electric power workers. The biggest difference between this new type of safety belt and the current one is that it integrates a new type of buffer bag, which integrates pedal belt and can help operators change their posture and climb up. Through the test of the safety belt with the new buffer bag, it is found that the new safety belt not only has the basic safety protection ability, but also can effectively assist the operators to carry out self-rescue, which greatly improves the safety protection level of the workers of power lines.

1. Introduction

In some operations high above the ground, because of the relatively narrow working space, high difficulty and greater danger, there are always warnings of safety signs. Another indispensable protective measure is the safety belt, which is worn by operators when working at heights, to prevent workers from falling and to protect workers from or reduce personal protective equipment caused by falling. Therefore, whether the performance of safety belts can meet the need to protect users' safety in use is of vital importance [1]. In China, safety belts are classified into three categories according to the nature of their workplaces: fencing safety belts, regional restricted safety belts and falling suspension safety belts [1]. The main research object of this paper is the safety belt for operation at heights of power system, which belongs to the type of falling suspension safety belt.

As early as 1985, the national standards [3] for safety belts have been formulated and promulgated. The technical performance indicators of the former Soviet Union have been extensively used as references in the contents of the early standards. And it has been used until 2009. Over the past 20 years, the standard has played an important role in quality supervision and market supervision. However, with the improvement of production technology and the emergence of new materials, the standard version 85 no longer meets the needs of safety belts. In the 2009 edition of safety belt standards [4], the standards have changed greatly in view of the differences between domestic standards and foreign standards, as well as the requirements of avoiding restricting technological progress and
absorbing foreign standards. Due to the continuous improvement of technology, advanced design abroad is also affecting the design and style of safety belts in China. In the past, safety belts were heavily single-belt or single-belt. However, with the progress of the times, users also have more requirements for security in the use process. Therefore, full-body safety belts are gradually coming into our sight.

At present, in the norms of operation at heights of power system, although it has been generally required to use safety belts to ensure the safety of operators. However, because the operation of power lines is mostly in the field, it is difficult for line operators to carry out rescue work once they fall behind. If rescue is not timely, it will probably lead to casualties. In fact, due to the small drop distance and the protection of cushion packs and all-around safety belts, the operators have the ability of self-rescue in most cases. However, the current all-around safety belts do not have the function of assisting self-rescue, resulting in the passive waiting for rescue of the fallen personnel, which leads to the fact that the fallen personnel can only passively wait for rescue. There are great safety risks. Therefore, the main work of this paper is about how to improve the self-rescue capability of the whole body self-rescue safety belt.

This paper is organized as follows: Section 2 produces the autonomous rescue requirements and characteristics of the electric safety belt, i.e. the design objectives of the new type safety belt; Section 3 introduces two different design ideas and compares their advantages and disadvantages; Section 4 tests the optimal design according to the national standards.

2. Design requirements
In this section, design requirements of the autonomous rescue safety belt for electric operation are discussed in detail.

In the process of operation of electric power, especially in line construction, it is often tens of meters or even hundreds of meters high from the ground. Once the operator falls in line inspection, even if he is not injured, if the rescue is not timely and long-term suspended at heights, it is very likely to lead to casualties. At this time, if the safety belt can assist the falling personnel to rescue independently and let them climb back to the wire, it can completely avoid the occurrence of such accidents. The following two requirements must be met in order for the safety belt to assist the operator in self-rescue:

1) Safety belt should be able to assist the person falling to change his posture
When the operator falls behind, he will be in a hanging posture. This posture is suitable for long-term hanging and waiting for rescue, but it is not easy to focus on self-rescue. Therefore, there must be ways to help them change their posture; the ideal state is the chest suspension.

2) Safety belt should be able to assist rescue workers to climb back to the wire independently
If there is no auxiliary device, it is very difficult to climb the safety belt rope at heights by pure arm force after the operator who uses the conventional whole body safety belt falls down the wire. It is necessary to have auxiliary equipment to help him climb back to the wire.

3. Design schemes and comparison
Methods. According to the above design requirements, we can list two kinds of implementation ideas and give the corresponding implementation schemes as shown in Table 1 below. At the same time, we also give the evaluation of its implementation difficulty.
Table 1. Design ideas and comparison

| Design requirements | Realization Ways | Design ideas | Difficulty | Dangerous degree |
|---------------------|------------------|--------------|------------|-----------------|
| Change body posture | By arm force | Changing Hanging Point by Arm Force | Hard | High |
|                     | By arm force and legs | Use pedal belt to assist in changing hanging point | Easy | Low |
| Auxiliary return line | By Arm force | Use climbing ropes and lifts | Hard | Low |
|                     | By arm force and legs | Use pedal straps to assist climbing | Easy | Low |

Optimum scheme. From the comparison results in Table 1, it can be seen that whether changing the body posture or assisting return line, simply using arm force and the combination of hands and feet is not only difficult to achieve, but also dangerous. Therefore, the optimal solution to the problem should be the combination of hands and feet.

Under the guidance of this idea, the detail ways of realization are as follows:

1. Use pedal straps to assist posture changing
   Using pedal belt, the operator can use pedal to climb a certain distance, release the back hook and hang it to the front hook, thus changing the suspension mode from the back to the chest, so as to facilitate subsequent climbing.

2. Use pedal straps to assist climbing
   If the pedal belt is long enough and the pedal force is utilized while the arm grabs the safety belt and climbs upward, the traverse can be returned. However, the top of the long enough pedal band needs to be suspended on the line, and the pedal band needs to be folded up under normal conditions, otherwise it will affect the operation. In view of this, the improved scheme draws lessons from the idea of safety belt buffer pack, folds and binds normally, and pulls open and hangs down by human gravity when falling. According to this idea, the upper end of the folding pedal belt is connected with the buckle of the safety belt, and the lower end is connected with the buffer package, which can achieve the above purpose.

Following this idea, the schematic diagram of the improved electric power safety belt structure with self-rescue capability is shown in Fig. 1 below. Figure (a) is in the initial state and figure (b) is in the state after falling with pedal strap unfolded and buffer package ripped.
The image of state of posture change after falling is shown in Fig. 2. Figure (a) shows the initial state after falling, figure (b) presents state of posture after change, and figure (c) shows the state of autonomous climbing.

4. Experiment results and discussion

**Standard adopted.** At present, the latest national standards for safety belts are the of "Safety Belt" and "Safety Belt Testing Method" version 2009[4]. In the standards, the overall static and dynamic load testing methods of safety belts and the overall static load testing methods of falling suspension safety belts are required. The standard of the 2009 edition is consistent with the basic requirements of the European Standard[5], that is, the overall static tension is not less than 2kN. For the safety of the
falling suspension safety belt, considering the human safety in the process of falling suspension, referring to domestic and foreign statistical data, the peak value of impact force in the dynamic mechanical properties of the standard of the 2009 edition is set at no more than 6kN.

Fortunately, the advantage of the improved design of the safety belt in this paper is that only folding pedal belt is added without changing the existing body of the full-body suspension safety belt, thus avoiding the complex testing process of the performance of the safety belt body, and only need to test whether the folding bag of the pedal belt can be opened normally and its loading capacity.

**Experiment design.** According to the analysis above, experiments for the new safety belt include two aspects, one is opening capability, and another one is carrying capacity. According to Statistics in State Grid, the weight range of normal line workers is 50kg to 100kg. By using safety factor 2, the maximum open weight is 25kg, and minimum load weight is 200kg. By using pedal strap with minimum load weight 220kg and folded by fragile strapping tape, the following experiment results are shown in Table 2 and Table 3 with 10 samples for each test.

| Serial number | Sample weight (kg) | Results |
|---------------|-------------------|---------|
| 1             | 10                | failed  |
| 2             | 12                | failed  |
| 3             | 14                | success |
| 4             | 16                | success |
| 5             | 18                | success |
| 6             | 20                | success |
| 7             | 21                | success |
| 8             | 22                | success |
| 9             | 23                | success |
| 10            | 24                | success |

| Serial number | Sample weight (kg) | Results |
|---------------|-------------------|---------|
| 1             | 180               | success |
| 2             | 190               | success |
| 3             | 200               | success |
| 4             | 210               | success |
| 5             | 220               | success |
| 6             | 230               | success |
| 7             | 240               | success |
| 8             | 250               | success |
| 9             | 260               | failed  |
| 10            | 270               | failed  |

**Results discussion.** With the help of pedal strap, new safety power line operation is endowed with self-help ability, but the maximum open weight and minimum load weight must be up to standard. Through the experiments carried out, it can be concluded that the new safety belt meets the requirement of latest national standard version 2009. Moreover, two samples have been used successfully in construction site of Zhejiang electric power company.

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