APPROACH TO ADJUSTING LAMPS' HEIGHTS AND ANGLES: DESIGN AND IMPLEMENTATION OF AN ELEVATING DEVICE FOR ILLUMINATION IN SLEDGE TESTS

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Abstract: In order to achieve the aim of adjusting heights and angles of lamps in sledge tests, detailed requirements were analyzed, and the implementation scheme was devised. The prototype of the elevating device was designed to validate the effect. Both the power circuit and the control circuit were researched on to power and control the 4 3-phase asynchronous motors respectively. An effective solution was provided to the adjustment of the essential parameters in sledge tests' illumination. Manual control and remote control modes were both designed and employed to make the necessary adjustments possible. On-site application validated that the elevating device was effective and could be used to adjust parameters relevant with lamps' spatial positions.

Keywords: acceleration sledge, elevating device, illumination, sledge test, inclination angle

1. INTRODUCTION

As the device for simulating real crashes and conducting dynamic tests, sledge plays an important role in the field of passive safety [1]. Sledge can be classified into 2 types, i.e., the acceleration type and the deceleration one, and both are widely used in verifying and validating the safety performance of products such as seat belt, child restraint system, airbag, and automobile seat [2-4]. Being a complicated system, sledge contains various sub-systems and subordinate devices, including but not limited to lighting system. Especially, the lighting system is of great importance in ensuring the reliability, objectivity, repeatability and accuracy of testing results, for evaluating a dynamic test needs qualified illuminations [5]. The state of good illumination could be achieved with extremely efficient lighting that allows even the smallest details to be seen in tests. Generally, the core component of lighting system is the lamp, e.g., LED light source, and filament bulb [6-7]. However, the lamps' heights and angles should be adjusted from time to time to ensure the optimum illumination in dynamic tests.

In accordance with the requirements of ISO/IEC 17025:2017, testing and calibration laboratories should have necessary equipment and instruments that can influence testing results for conducting relevant activities. Meanwhile, measuring instruments should meet the accuracy and/or uncertainty requirements, so as to provide the effective results. In the testing process, it is vital to acquire the video that shows satisfactory clarity and integrity. As the raw date of dynamic tests, high-speed video could help achieve the recurrence of the whole test

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by a playback, thus making it possible to measure and record the information about injury and/or safety performance that mainly relies on high-speed image acquiring device for acquisition. High-speed camera is essential, and only when the lighting system provides proper illumination can it function normally and lead to satisfactory videos. Therefore, the quality of high-speed images and videos depends on the performance of lighting system to a great extent, i.e., the lighting system could influence the evaluation of testing results indirectly.

Generally speaking, lamps are installed to various kinds of fixing or elevating devices. Fixing devices cannot be adjusted, and therefore the lamps' heights and angles cannot be changed. If the light intensity and quantity of light source is high enough to achieve satisfactory illumination, the need for lamp' height and angle adjusting can be ignored. Nevertheless, the requirement exists for adjusting the parameters in most cases. Therefore, owning an elevating device with the function of adjusting become an essential prerequisite for carrying out sledge tests for many factories and laboratories. Furthermore, the more functions the device has, the more complicated the design scheme is. In other words, a complicated elevating device means the building will bear a heavy load, and later-stage maintenance will be laborious and expensive. Actually, increasing and decreasing the heights, and rotating around X axis, which is identical to the direction of impact, are the basic motion and rotation.

As for compact impact sledge, it is easier to achieve the aim of adjusting lamps' heights and angles comparatively, for its work area is smaller than sledge with larger thrust. In the field of inspection of automotive parts related to passive safety, compact impact sledge is very popular because of its unique advantages. In the current research, the theory employed to design the elevating device and achieve the purpose of adjusting is applicable to acceleration and deceleration sledges' illumination control. Based on the methodology, the illumination conditions are hopefully to be improved even for large-size sledges, since measures of adjusting the lamps' height and angles begin to take effect when the luminous intensity of light source reaches the peak value and cannot be utilized further. Furthermore, the auxiliary ways and means include but are not limited to adjusting relevant parameters. However, it is most convenient and reliable to change the illumination in that way, in addition to changing the photoelectric parameters of lamps themselves. The emphasis of the research was therefore placed upon the design of a kind of elevating device used to achieve the purpose of adjusting lamps' heights and angles, and upon its dual-control mechanism. The scheme involves the use of 3-phase asynchronous motors, magnetic contactors, wireless control module, and other necessary mechanical and electrical components [8-10].

2. METHODS

2.1. Schematic design

In order to obtain high-speed videos of sledge tests' visual details normally, and safeguard equipment, instruments and on-site operators against damages or injuries caused by light sources, the illumination system should meet specified requirements. Firstly, the improvements of ambient temperature and dummy's skin temperature should not exceed the limits, although too much infrared light is generated in the process of illumination [11]. Secondly, on no condition should excessive electromagnetic radiation be generated and interfere with the data acquisition system or other sensitive systems. Generally, the requirements of regulations and technical standards such as IEC 61000-6-2, IEC 61000-6-4, DIN EN 50081-2 and DIN EN 50082-2 should be taken into consideration, as for the light sources. Thirdly, the protection function of the system should not be ignored that could keep on-site operators from the harm of ultraviolet rays. Fourthly, the system should have self-protection ability that prevents the equipment from any damage brought about by a power outage, overload and other unexpected situations. Finally, parameters such as the luminous intensity, luminous efficiency, colour temperature and colour rendering index of each light source should meet test requirements. In addition, the elevating device to which lamps are installed should be properly designed in the aspects of quantity of lamps, cable layout, electrical cabinet layout, electrical power, and communication interface, etc. Furthermore, the bearing capacity of the building's roof is also an important factor that should be considered in the design of an elevating device.

The parameters of light field is influenced greatly by the structure and adjustment of elevating device, e.g., the distance between light source and the sledge, inclination angle of lamp-bearing device, the size of the device, and the distribution of lamps could all have an effect on illumination. As shown in Figure 1, the inclination angle of elevating device θ, the distance between elevating device and sledge top surface h, are the most obvious factors that influence effective illumination area and luminance in the area directly, assuming that light travels in straight lines in the air, and the luminous intensity of light source is a constant invariant. Therefore, it is of significant importance and easier to achieve the goal of adjusting illumination in tests if the height-adjusting range and angle-adjusting range are wide enough. Determination of the overall dimension of the elevating device depends on site conditions, complexity of the mechanical structure, and requirements about the light field, etc. The emphasis of designing the elevating device can be placed on methods of adjusting lamps' heights and angles, based on which it could be an effective process with low cost.

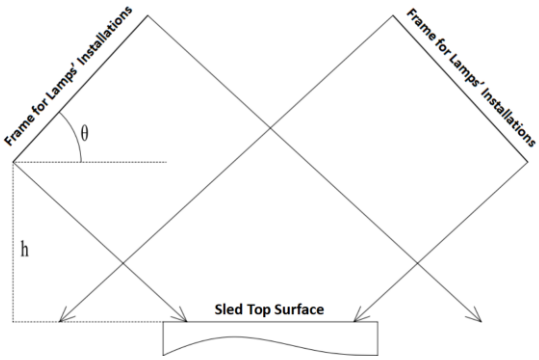

Fig. 1. Relation between elevating device and illumination for sledge.

The on-site conditions, efficiency and convenience of use should be taken into consideration, when the elevating device is used. Generally speaking, manual control and remote control modes are both applicable to the adjusting process in view of the actual demand. Besides, the inclination can be achieved by changing the difference value between 2 motors' elevating heights. As shown in Figure 2, workflow of the elevating device was devised, and the adjustment of lamps' heights and angles was designed to be conducted in the sequence defined in the workflow.

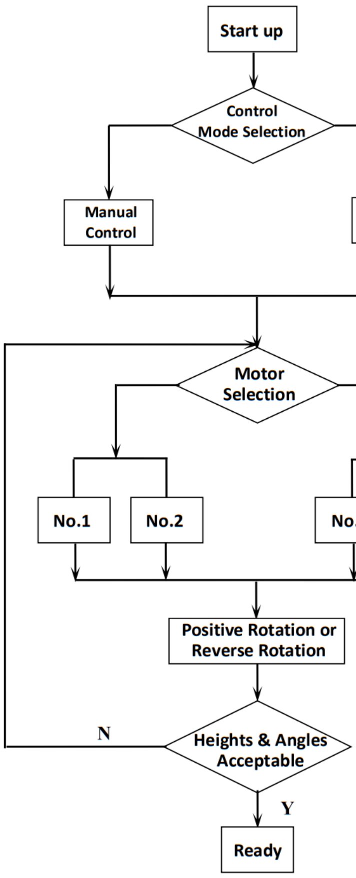

Fig. 2. Workflow of the elevating device.

2.2. Mechanical structure

The prototype of the elevating device was designed and built based on 3D modelling technology, as shown in Figure 3. The mechanical structure is composed of welded steel frames used to bear the loads, wire ropes, 4 3-phase asynchronous motors, frames constituted by aluminium profiles used to install lamps, and some connectors mainly. Holes were drilled in cement beams for fixing welded steel frame. Long bolts were placed in the through holes drilled in the cement beams and welded steel frame, then the bolts and nuts were fastened enough, and in the process, holes in the beam and holes in the frame were concentric. Meanwhile, the bearing capacity of the building's cement beams was considered and utilized properly, which was not exceeded by the whole weight of the elevating device including the welded steel frame.

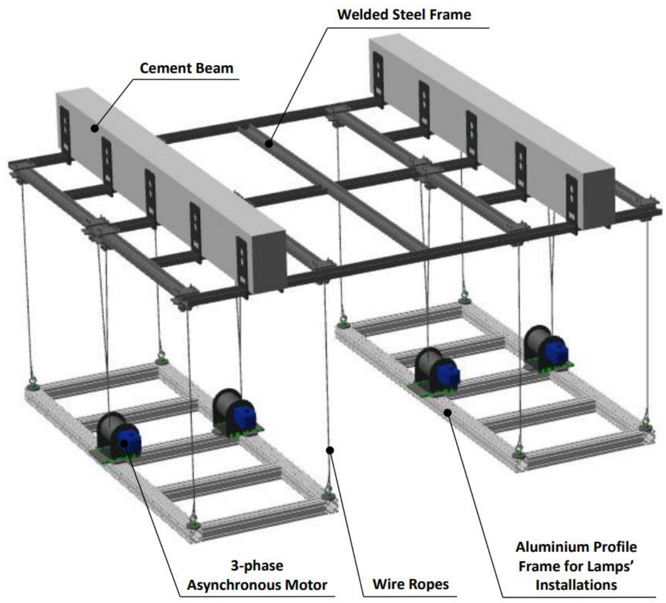

Fig. 3. 3-D display of the elevating device.

The 3-phase asynchronous motors were all installed to the aluminium profile frame. As the carrier of lamps, the aluminium profile frame is light, and it is convenient to form different shapes and structures using aluminium profiles and corresponding connectors. The welded steel frame and aluminium profile frame were connected to each other by the wire ropes passed over the pulleys, and motor's rotations could pull the wire rope. Since the motors were also installed to the aluminium profile frame, the positive and reverse rotations of 3-phase asynchronous motors could consequently cause the elevating and demotion of aluminium profile frame. Therefore, the heights of lamps could be adjusted. When one of the 2 motors that are installed to the same aluminium profile frame rotates and the other does not rotate, the angles of lamps can be adjusted. By winding and unwinding the wire ropes, it is easy and convenient to adjust the heights and angles of lamps. As shown in Figure 4, schematic diagram of elevating lamps indicates the theory of the elevating device. Figure 5 displays the elevating device above the acceleration sledge, and lamps have been installed.

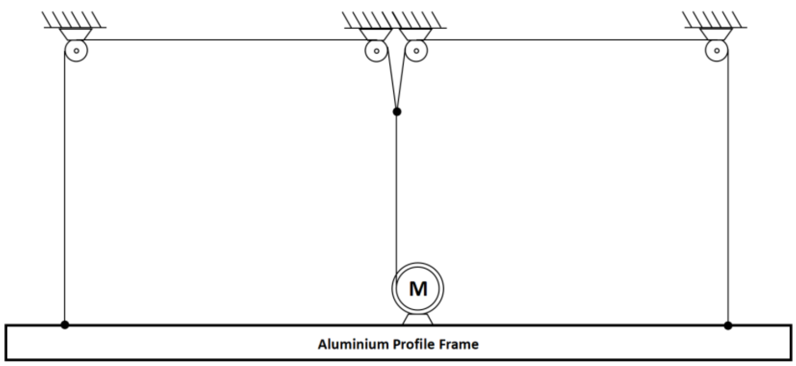

Fig. 4. Schematic diagram of elevating lamps.

Fig. 5. Elevating device and the acceleration sledge.

2.3. Dual-control mechanism

Control system is used to control the switch between positive and reverse rotations of the 4 3-phase asynchronous motors, and the switch between the 2 control modes that incorporate the manual control and the remote one. Generally, programmable logic controller (PLC) can be chosen as the unit for control, and the control process can be finished successfully with the combined actions of electric relays, and contactors, etc. Furthermore, the aim of controlling the motors can also be achieved by employing press-buttons or electric knobs, and contactors, without the use of PLC, for proper logical matching of adequate buttons / knobs and contactors can help achieve part of PLC's function. Comparatively, the latter method without using PLC has more advantages, for it is cheaper and more reliable than the former one. Therefore, the manual mode of control was based on the latter method without using PLC. The remote control mode was designed to control the on-off of any contactor, by means of remote control module including the signal sender and signal receiver. Switch between the 2 control modes can be conducted by simply turning the electric knob. Besides, the positive and reverse rotations of all the 4 motors can be controlled individually in each mode.

As shown in Figure 6, the wiring diagram of the control part displays how the contactors, press-buttons, and electric knob are connected and combined to achieve the function. In the power circuit, 12 contactors were used to control the on-offs of the 4 3-phase asynchronous motors, as displayed in Figure 7. In the control circuit, the receiver of remote control module was involved to achieve the functions of choosing motors, and switch between the positive and reverse rotations of the 4 motors in the remote control mode. The switch between the 2 control modes was made possible by SA0 electric knob. Only 1 control mode is available at any time, and the other mode ceases to be effective at the same time.

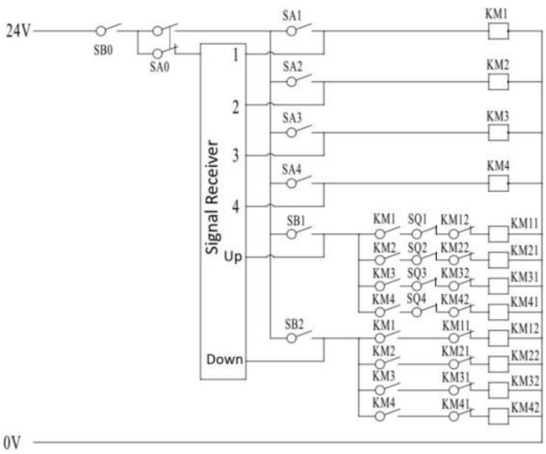

Fig. 6. Wiring diagram of control circuit:
SB0-emergency stop, SB1-elevation, SB2-demotion, SA0-switch between control modes, SA1-motor No.1, SA2-motor No.2, SA3-motor No.3, SA4-motor No.4, SQ1-upper limit for motor No.1, SQ2-upper limit for motor No.2, SQ3-upper limit for motor No.3, SQ4-upper limit for motor No.4.

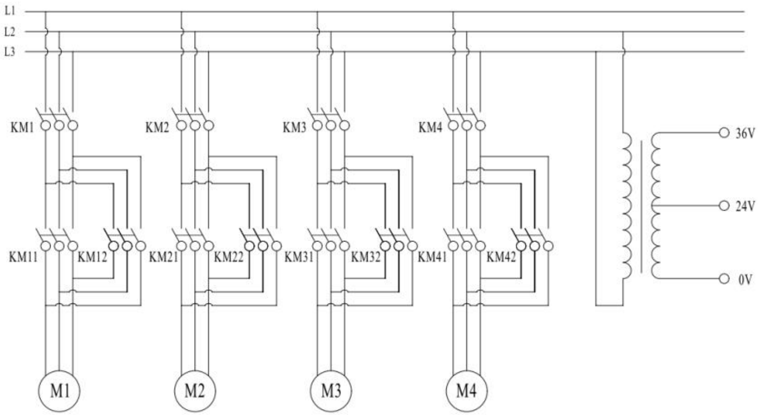

Fig. 7. Wiring diagram of power circuit.

The signal sender of remote control module is able to function within 20 meters, and satisfies the requirements of laboratory use. As shown in Figure 8, the remote control is a hand-held device to send signals.

Fig. 8. Remote control.

3. RESULTS AND DISCUSSION

The design of the elevating device makes it possible and convenient to adjust the heights and angles of lamps used for sledge tests' illumination. Actually, various approaches exist to achieve the goal, although the approach in the research is comparatively more feasible. Nevertheless, taken the cost and reliability into consideration, the fast realization becomes another obvious advantage that is popular with factories and laboratories of small scale. Therefore, the scheme of elevating the lamps proves to be effective.

In addition, the difference between the elevating heights of the 2 3-phase asynchronous motors installed to the same aluminium profile frame forms lamps' inclination angle. To some extent, the angle can be adjusted, thus changing the irradiation direction of lamps. As shown in Figure 9, both the heights and angles of lamps can be adjusted, since the aluminium profile frame to which lamps are installed will have different spatial positions when motors work. Besides, there are upper and lower limits for lamps' heights, because of length limitation of wire ropes. Similarly, inclination limits also exist, such as θ_1 and θ_2 shown in Figure 9.

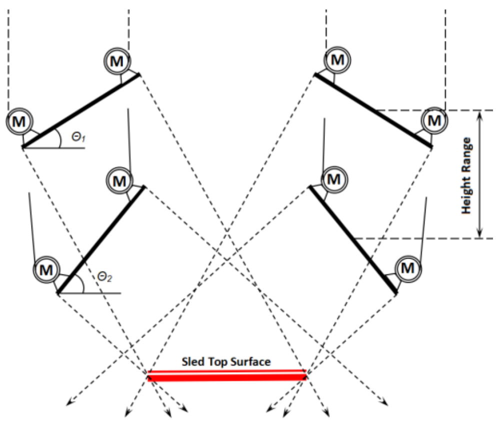

Fig. 9. Elevating limits of the elevating device in tests.

Design and implementation of the elevation system provide an appropriate approach to adjusting the lamps' heights and angles in accordance with the requirements about illumination for dynamic tests. On-site application validates the scheme's effectiveness further, and the illumination requirements are satisfied completely.

Since illuminance is related to luminous intensity, incident angle and the distance from light source to the object irradiated, it is obvious that the elevating device is able to adjust the illuminance by changing the incident angle and the distance. Therefore, it is necessary to assess the variance range of illuminance by accurate measurements, and only in this way can the importance of designing and employing the elevating device for dynamic tests be made clear. The illuminance meter displayed in Figure 10 was used to measure the parameter when elevating device made the lamps' spatial positions and angles at different levels. In the process, a total of 16 lamps were used, and the lamps were all set to be of the 100% continuous wave operation mode. The lamps were evenly distributed on the right frame and on the left frame, and bilateral symmetry was strictly ensured. The sample point was selected from the longitudinal centre line of sledge's top surface randomly. Once selected, it was fixed, i.e., the sample point was in the same position in each test. The experimental results are listed in Table 1, and indicate that the luminance can vary very much with the changes of elevating device's relevant parameters. However, the luminance is nearly constant if the lamps are fixed at a certain height, and with a certain angle, as for some sample point on the top surface of sledge. Lack of adjusting function or failure to satisfy the height and angle requirements is a great disadvantage, especially when it comes to dynamic tests for different products in a laboratory. Nevertheless, a wide range for adjustment is sometimes essential, and one of the most feasible solutions is employing the elevating device. Figure 11 shows the comparison between elevating device in the research and the stationary-type device that is fixed on a certain spatial position without changes of coordinate values, as for the range of illuminance. It is certain that the adjusting range of illuminance has been extended to a great extent when the elevating device is used, although the lamp's luminous intensity remains unchanged. Besides, it is impossible to achieve the adjustments when the device of stationary type is employed, if other parameters of lamps are invariant constants.

Fig.10. Illuminance meter.

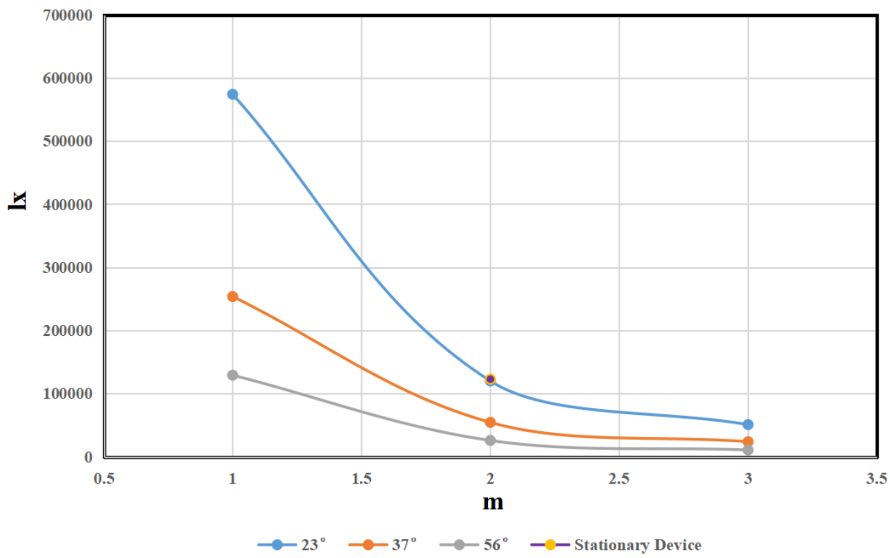

Fig. 11. Comparison between illuminance of lamps installed on devices of 2 different types.

The elevating device is not only oriented to illumination for small sledge, but it is also applicable to mid-sized and large sledges' test illuminations. It is flexible to use the aluminium profile, and frames of different sizes, shapes, and structures can be made to accommodate to different illumination requirements. The length of wire rope can also be perceived as an important factor in adjusting the heights, although the maximum height-adjusting range is half of the distance from roof to floor theoretically. A multi-function elevating device with a wide adjustment range can save time and effort, and bring great convenience for sledge tests. Hence, further research could still be conducted on the aspect.

Table 1. Results of illuminance when the elevating device was used.

Incident Angle	Distance from Light Source to Sample Point		
	1m	2m	3m
23°	573860 lx	119937 lx	50843 lx
37°	253701 lx	54382 lx	23766 lx
56°	129118 lx	25792 lx	10729 lx

4. CONCLUSIONS

A kind of elevating device was designed and made to achieve the aim of adjusting heights and angles of lamps for sledge tests' illuminations. The 3-phase asynchronous motors, contactors, press-buttons, and electric knob were involved in the process. Proven technology in industrial control and the relevant electric components provided a solution to the illumination-derived problem. The device has been put into use and proves to be effective in a laboratory accredited according to ISO/IEC 17025:2017. It is validated that lamps can securely be installed to the aluminium profile frame. The height range's and inclination angle's adjustments both meet the relevant requirements. Besides, the elevating device has a low weight, a simple structure, reliable operation, and a comparatively wide adjustment range. The system of high cost performance being the lamps' attitude adjustment device, surpasses the system of stationary type, for the latter one cannot adjust the heights, and even angles of lamps.

There is no doubt that various solutions exist to the adjustment of lamps, e.g., using devices with the structure similar with that of fork lifting platform, and employing the electric servo cylinder as the executive mechanism, which have positive effects on the adjustment range, appearance, and strength of the elevating system as well. However, the cost is undoubtedly higher than the cost of the elevating device in the research. If there is no other special requirement, the scheme of elevating and adjusting lamps in the research can be seen as a good case for changing the essential parameters of illumination in sledge tests.

Furthermore, it can be concluded that the adjusting range of illuminance has been extended greatly with the use of elevating device, even if parameters of light source remain unchanged. Therefore, it is an effective and convenient alternative to adjust the on-site illuminations, according to the experimental data. Based on the approach to adjusting lamps' heights and angles, high speed videos can be applied in sledge tests without any restrictions in illuminations, especially if in coordination with the adjustments of light source's relevant parameters. Further research can be conducted to explore ways to increase degrees of freedom for the elevating device, automatic control methods, and lightweight design, etc.

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