

Study on Ergonomic Analysis of Excavator Cab

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Abstract—Excavators are the leading construction machinery used to mine ore and soil. It has an irreplaceable role in the completion of construction machinery tasks. Given to enable the absolute safety, it is of great necessity to analysis how to make drivers have better driving and operating experience. Therefore, this paper aims to analyze the cab of the excavator from the perspective of ergonomics. The cab design that meets the comfort requirements can be beneficial for improving the safety performance and ensuring the high efficiency of the excavator operation.

Index Terms—ergonomic, excavator cab, safety, driving experience, operating experience

I. INTRODUCTION

Excavators are the key construction machinery for mining ore and soil. In the completion of those construction activities, excavators have taken an irreplaceable role. With the development of society and the economy, the world's mineral resources are decreasing, labor costs are rising but the demand for excavators is growing. The global excavator market scale was USD 44.12 billion in 2018 and is expected to reach USD 63.14 billion by 2026, with a CAGR of 4.7% over the forecast period [1]. Besides, drivers have higher requirements for the comfort and safety of the working environment. The construction sites of excavators are mostly in harsh environments such as forest areas, underground, and mines. The driver of the excavator will face uncertain troubles, including dust hazards, light pollution, toxic gas hazards, high temperature and heat stroke, low-temperature frostbite, and noise hazards [2].

Therefore, this paper targets to analyze the cab of the excavator from the perspective of ergonomics. It is of great necessity to analysis how to enable drivers with better driving and operating experience, with the aims to guarantee absolute safety.

II. BACKGROUND

Excavators are earth and stone construction machinery and equipment, which are generally used in earth and stone excavation, farmland water conservancy projects, municipal administration, and gardens.

The working environment of the excavator is relatively harsh, the working time is long, and the labour intensity is too high, so higher requirements are put forward for the fatigue resistance of the operator. The application of ergonomics in the design of excavator products can

achieve an overall improvement in the safety performance, efficiency and operating comfort of the excavator. High requirement towards comfort tends to be increasingly crucial points in automobile design. As long time spent in their cars - sometimes more than eight hours a day - operators for the exactors or machinery equipment are inclining to comfortable internal design of these machines [3].

The comfortable performance of the excavator cab will directly affect the driving feeling, as fatigue of the operator can be greatly declined by the convenient operation. Fatigue will weaken the driver's alertness, increase reaction time and the possibility of accidents. It can be concluded that better driving quality contributes to comfort operation [2].

Therefore, the design of the cab that caters to comfort requirements plays the crucial role in improving the safety performance and ensuring the high efficiency of the excavator operation.

III. BODY

A. Analysis of Driving Cab

The design of the driving vision of a car is based on the position of the driver's eyes (called the vision points) as the positioning reference. The field of vision of the excavator cab can be mainly divided into two parts, the front field of vision and the rear field of vision. The front field is the range from the line of sight through the front cab glass and the area around the excavator cab. The area that can be viewed assisted by a rearview mirror or other equipment is called the rear field of view. The rearview mirror mainly determines the range of rear visibility [4].

At the same time, the driver's horizontal sight line also directly determines the overall distribution of the device. Theoretically speaking, a range of 15° above and below the horizontal sightline is the best visibility angle for the driver. It is necessary to ensure that the line of sight within this range should be optimally applied, while a range of -70° , -60° above and below the horizontal sightline is the standard line of sight for the driver [5].

Therefore, the overall layout of the excavator cab should be reasonably distributed in horizontal sightlines according to the importance of visibility towards the machine, as other angles are blind areas of sight. If the driver wants to see things in the blind area, reflectors should be required. Since excavators are generally being operated in complicated conditions, the top of the cab is designed to be sealed without skylight to prevent dangerous accidents.

The space design of construction machinery mainly includes the prescribed external dimension, interior space (length, width, and height), and driver's headspace and foot space. People's operational experience is also related to the space with the equipments.

For excavators, it should remain to be open from the front and left and right field of vision, which enables the operator with great visibility to observe the operating state of the working device. Therefore, in the modeling for the front vision of cab, it is generally made by three plane trapezoid composed of the tower space or arc space.

When considering the comfort of the excavator cab, the time spent in and out of the cab for each body part should also be taken into consideration, which is also a key step in analyzing the cab, as shown in Fig. 1.

Body part	Number if times cited in the questionnaires
Head/neck	26
Right foot	17
Left foot	12
Left thigh	10
Right thigh	9
Right shoulder	5
Upper back	3
Left shoulder	3
Lower back	2

Figure 1. Number of times each body part was cited as hindering ingress/egress [6].

B. Analysis of Seat

The size of the excavator is relatively large. If accident happens, the injury to the driver is more severe than that of other types of vehicles. Therefore, when designing a seat, safety should be the priority concern, with comfort follows.

Accidents of Excavator are mainly falling objects and rollover accidents. The safety design of the seat should provide a certain degree of protection for the driver in the rollover accident [7].

Firstly, the seat needs to be made of a high-strength material to avoid secondary injuries to the driver. Secondly, in the rollover accident, the seat belt is the primary protection for the driver. A qualified and competent seat belt can reduce the impact of knocking on the driver and protect the driver's head, chest, and other essential parts from crashing to the windshield or operating equipment due to forward impact. Finally, in addition to operational comfort, the seat's headrest can also be applied to protect the drivers neck. The safety of Shandong Lingong LG6250E excavator is not good, as it should place more seat belts on the cockpit chair and more headrests to protect the head. In the next section, comfort of the seat will be analyzed in details.

The driving and operating experience of people are also correlated to the comfort of the seat. It is reported that an uncomfortable sitting position can lead to fatigue and illness [8]. Therefore, man-machine data related to comfortable sitting posture should be taken into reference by designer.

The analysis applies to two extreme human scales: the fifth percentile female and the 95th percentile male. For the driver's working position, the envelope of the working

space depends on the position of the driver's body. As the Fig. 2 shows, several functional measurements are vital parameters in the vehicle, including elbow, shoulder, hip, knee, ankle, and torso angles. Moreover, Fig. 3 is demonstrating the comfortable angles adopted for the driver's seating posture, which is beneficial for designer to design the seat [9].

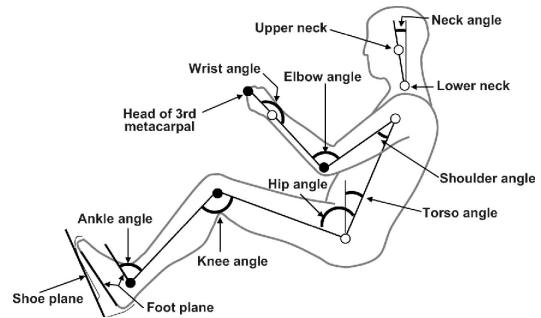


Figure 2. Parameters of driver's work position [9].

Torso orientation	27°
Angle of shoulder joint	22°
Angle of elbow joint	127°
Angle of hip joint	99°
Angle of knee joint	119°
Angle of ankle joint	103

Figure 3. Adopted comfortable angles for the driver's seating posture [9].

Initially, the seat of the LG6250E excavator was higher, which designs to give users a more comprehensive view. However, when sitting in the cockpit seat for a long time, the user's body tends to be tired. If the cab chair can be upgraded in accordance with the above data, the user experience of cab will be significantly improved.

C. Analysis of Controller

The controller performs the function of transmitting the manipulation information of the human to the machine, which then cooperates with the display to form the interface connecting the man-machine. The safety performance of the controller is of great significance to improve the overall safety of the man-machine system. The reasonable controller can increase comfort and reduce fatigue of the drivers, which then improve their work efficiency.

On the contrary, if the design of the controller is not reasonable, it will increase the workload of the driver and rise the probability of misoperation; Moreover, hidden danger of safety and loss of life and property are of high occurrence possibility. The controller of excavator cab is mainly discussed from manual control device and foot control device.

The manual controller of the excavator is mainly the driving control handle, which consists of a metal rod and the hand holding the ball at the top. When using driving control handle, the operation is not consistent, as the excavator operations is not only to control the motion of the vehicle but the action of mining. Therefore, the driver's arms will shift in amplitude and operating force, requiring a combination of physiology and mechanics

principle to control handle in handball part of the safety design.

Therefore, the center of the excavator operating handle should be within the comfortable range for hand movement. At the same time, if the forearm turns up frequently when the handle is pulled to the right with the handle operating in high frequency, the forearm muscles tends to be sore and numb. Therefore, those possibilities of fatigue should be avoided as far as possible. At the same time, the manipulator should be within the field of vision of human and can be easily operated as the movement of the hand is within the field of vision of the eye.

The center position of the foot pedal shall be less than 20cm above the ground. Fig. 4 below shows the included Angle between the thigh, calf, and foot surface when the user controls the pedal. Therefore, the arrangement of the traveling pedals of the excavator shall be 200mm away from the seat surface, and the height from the centerline of the pedal to the ground shall be 15cm[10].

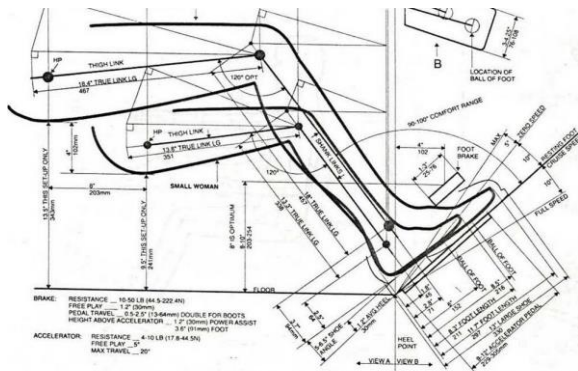


Figure 4. Measurement of foot controller [10].

The Fig. 5 shows the distribution of pedal force in different side-looking postures. Since the backrest can provide the most favorable support to the near-horizontal application direction, it can achieve the maximum pedal control force. However, if people work with their feet too high, their leg muscles can not maintain for continuously work. Therefore, the thick arrows in figure 5 above, drawn about 70 degrees from the plumb line, are the best way to push [11].

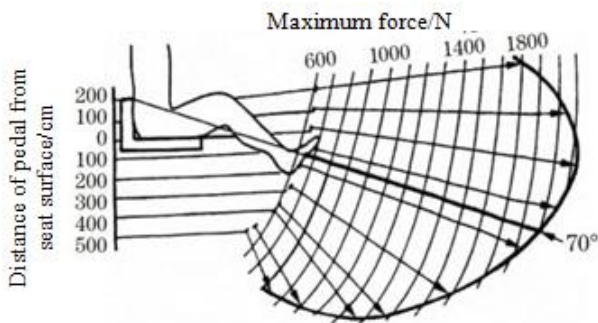


Figure 5. Pedal force in different positions when sitting [11].

D. Analysis of Display Device

The instrument, the essential component, is the medium of man-machine information interaction, from

which various parameters can be obtained during equipment operation.

Three main safety requirements should be taken into consideration in designing the instrument: first, clear and intuitive visual presentation of the instruments is required, and the expression of information should minimize the time and attention spent by readers, so as to achieve correct and efficient results. Second, recognition difficulty should be recognized in determining the location of the instrument. According to a survey, the line-of-sight distance from the operator's eye to the display platform is 550mm to 710mm, and within this range, the human eye is less likely to feel tired. Based on the horizontal line of sight seen by human eyes, a downward tilt of 15° to 40° is the best viewing angle for people. Within this range of angles, people can view objects most clearly and comfortably [12]. Therefore, relevant information or essential operation should be arranged in a dynamic reading range. In particular, starting, stopping, running state, warning, and other information requiring constant attention should be reasonably arranged according to the actual situation to ensure the in time noticing of those information.

E. Analysis of Thermal Environment

The thermal environment generally includes temperature, humidity, airflow velocity, and thermal radiation. In the indoor environment, temperature and humidity are crucial factors that affect the excavator cab, and have an essential impact on the driver's operation safety, though their control scope are very limited. Once it exceeds the limit that the human body can suffer, it will be severely harmful for the body.

Comfortable temperature refers to the temperature at which people feel comfortable, both physically and subjectively. Allowable temperature refers to the range of temperature that does not affect people's physical and mental health and is suitable for working. The allowable temperature is generally controlled within the range of comfortable temperature ± (3-5) °C. The excavator is mainly being operated in outdoor environment, especially at noon, with the temperature rising rapidly. Without cooling equipment, the driver is prone to nausea, heatstroke, and other troubles. When the temperature is lower than 10 °C or higher than 29 °C, work efficiency of drivers, as is being estimated, is at lower level [13].

Humidity, an essential item in the environmental evaluation index, refers to the degree of air dryness and humidity for the excavator cab. It is generally believed that people feel relatively comfortable with the humidity ranges from 30%-70% [13]. The indoor thermal environment of the cab should be controlled within the permitted range through the cooling and dehumidification functions of the air conditioner, ensuring the safety and comfort of the driver's operation.

F. Analysis of Vibration Environment

The influence of vibration on the human body is mainly determined by three factors: vibration intensity, vibration frequency, and exposure time. As the amplitude increases and reaches a certain level, the nervous system

of the human body will gradually feel in great tension. In this condition, the visual acuity declines, balance ability weakens and other problems occur in accompany. If the amplitude is too large, it will even have psychological and physiological effects on the human body, resulting in pathological damage or lesions [14]. Meanwhile, vibration time is also an important factor affecting human perception. As the time lengthens, the impact of vibration on all aspects of the body will be obvious. On the contrary, short-term moderate vibration can bring certain benefits to the human body. In the design of the excavator cab, as the driver is sitting for a long time, both vertical and horizontal vibration will have a particular influence on the driver. As the human body is a flexible system, it has natural vibration frequencies, beside different resonance frequencies of the internal organs.

When the vibration frequency of the excavator is close to that of some human organs, resonance will occur, and the vibration amplitude will increase rapidly. Resonance can cause a series of physiological reactions, such as discomfort, nausea. Even worse, the vibration will cause the instability of the hands and feet of the driver. Not only the accuracy of the driver's operation will be reduced, but also the accuracy of the operation will be significantly affected. When the excavator is operating, the driver is generally in a sitting position and limited by the movement. Under such condition, the resonance phenomenon is difficult to alleviate, and the vibration produces growing influence.

When the vibration amplitude becomes more substantial and lasts longer, the driver tends to have adverse reactions, such as local pain, the urgency of urination, headache, and even breathing difficulty.

G. Analysis of Noisy Environment

Any sound, as being defined, that interferes with regular work and rest of people is the noise. Environmental noise will interfere with information grasping and lead to errors in information transmission. Meanwhile, several factors are being weakened, including people's emotional state, concentration on work, and even the work efficiency. The influence of noise on people's psychology is mainly manifested in: it leads to bad moods such as irritability or upset [15].

Physiologically, the noisy environment often induces the problem occurring in the auditory system, central nervous system, cardiovascular system, respiratory system, and visual organs.

People working in the noisy environment for the long run will have much damage to their ears. Repeated exposure to the vibration with huge noise such as excavators will often cause irrecoverable damage to the ears, or even lead to complete loss of hearing. Noise-induced hearing loss occurs when sensitive hair cells in the cochlea are damaged.

After testing, the sound power of temporary LG6250E excavators is 90dB. According to relevant investigation reports, noise-exposed to 85dB or above is more likely to damage hearing [16]. Therefore, this kind of excavator cab performs worse in sound insulation.

H. Analysis of Aesthetics

Color can change people's subjective perception of objects. Among three aspects as color, material, and form, color is first perceived by the human body and forms an impression and feeling. Moreover, the color selection of control and display equipment should mainly follow the principles of easy identification, which can calm down the driver and allow them to focus on the working state. However, it should be noted that the bright and beautiful color matching hinders the accuracy and visual comfort of the driver.

Designers must also pay attention to the environment when matching colors for engineering products. For example, if the working site of the excavator is by the sea, blue should be avoided in selecting the product color. If the working site of the excavator is in the desert, the product should not be yellow. In general, the color scheme should be in line with the public aesthetic, with black, white, grey, blue, red, and yellow as the primary colors. On the premise of keeping the color harmony, the color collocation of the whole excavator cab can highlight the essential functional parts.

In my opinion, the color aesthetics of excavators can be unified into several key points:

- 1) Reflect the safety of products, with the role of warning people
- 2) Reflect the corporate culture and increase brand recognition
- 3) Reflect the harmony and integrity of the product and the environment
- 4) Meet the requirements of various work locations

IV. CONCLUSIONS

Given to the rapid development of society, increasingly considerations and protection for drivers of construction machinery will be implemented, and the safety ergonomics theory in the construction machinery industry will be extensively applied.

The design with drivers as the main body can improve the safety and convenience of operation and improve the work efficiency of drivers. Further research can be analyzed as follows: further deepen safety research should be implemented in protecting drivers. At present, advanced cars and ordinary family vehicles have made significant progress in safety performance and the comfort of driving experience. Although the cost of engineering vehicles is limited, there is still ample space for development and progress, due to the highlighted attention of society to outdoor workers and the increasing people's requirements for working conditions. Engineering vehicles still have significant room for improvement, especially in the digital application, such as safety monitoring, troubleshooting, artificial intelligence, and other aspects,

This report focuses on the study of driving area and driver safety ergonomics. It also concluded several factors that have influenced the driver's safety in the operation condition. The NVH (noise, vibration and heat) have been detailed discussed for bettering the design,

while the aspects including the devices applied have also illustrated in how it influences the safety issue. When conditions are favorable, digital virtual design research on the whole cab can make the safe and ergonomic design of the cab better applied. Especially in the operation of excavators, it is still worth exploring whether the force altering caused by dynamic changes will affect the safety performance of the cab.

Limited by experimental equipment and conditions, this paper has not yet quantitatively evaluated the effects of the design results of the human-machine interface on drivers' cognitive characteristics and job performance, and future work will be conducted through numerical computational methods incorporating engineering cognitive psychology. Encountered with harsh outdoor environment and unpredictable danger, the structural safety of excavator cab and the stability of materials still need to be further studied. Moreover, the future analysis direction of excavators will be located at the intelligence mechanization. In future excavator research, intelligent algorithms will be introduced to carry out numerical evaluation model research in order to obtain better data through the closed-loop feedback process of "quantization-optimization-re-quantization", which will enable designers to make scientific judgments and make excavator design more suitable for future construction sites.

CONFLICT OF INTEREST

The author declares no conflict of interest.

AUTHOR CONTRIBUTIONS

Yonghao Zhu conducted the research, wrote the paper and polished the paper. All authors had approved the final version.

ACKNOWLEDGMENT

The authors wish to thank Professor Giacomini Joseph. This work was supported in part by a grant from Brunel University.

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