Design Factors for the Location and Arrangement of Control Actuators

Weiyu Sun[1], Junmin Du[2,3], Huimin Hu[4(✉)], and Xuehuan Hu[1]

[1] School of Energy and Power Engineering, Beihang University, Beijing, China
[2] School of Transportation Science and Engineering, Beihang University, Beijing, China
[3] Airworthiness Technologies Research Center, Beihang University, Beijing, China
[4] Ergonomics Laboratory, China National Institute of Standardization, Beijing, China
huhm@cnis.gov.cn

Abstract. Location and arrangement of control actuators have a significant impact on operation safety and efficiency. In order to benefit from the proper location and arrangement of control actuators, a large amount of factors need to be considered in the design process. In this paper, three types of main design factors were summarized through literature research, including operators physical characteristics, task operation properties and control actuators features. Meanwhile, the priority of these factors (detailed in indexes) were determined by questionnaire investigation. The results showed that the top priority indexes were anthropometric dimensions, limbs reachable area, comfortable area, operation accuracy, visual checking, avoiding interference, friction, the control actuators type of hand and foot manipulate, the control actuators functions of on/off or start/stop, safety or emergency device, importance of control actuators, and operator habits.

Keywords: Control actuators · Location and arrangement · Design factors

1 Introduction

Location and arrangement are concerned significantly during the design process of control actuators. They have strong impact on operation safety and efficiency. If the location and arrangement of control actuators are unsuitable, misoperations and low efficiency may be caused. Even more, operators fatigue and joint diseases may occur. Proper location and arrangement of control actuators are essential for improving operation safety, efficiency, comfort, and reducing operators' fatigue and potential healthy risk in the field of automobile and aircraft industry, machinery etc.

In the design process, a large amount of factors should be considered for obtaining proper location and arrangement of control actuators. Many guidances and standards have been published to instruct the design of control actuators location and arrangements by different organizations and departments all over the world, such as ISO 9355-3: 2006, BS EN 894-4: 2010, GB/T 14775-93 etc. Although those guidances and

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standards mentioned many design factors for the location and arrangement of control actuators, the key point of each document is quite different with each other, and the design factors are relatively scattered. Moreover, there is no guide to represent the priority of these factors, which sometimes make the designer feel difficult to balance them during the design period for control interface.

This paper aims to summarize the design factors for the location and arrangement of control actuators, and determine the priority of these factors (detailed in indexes). Literature research and questionnaire investigation were carried out focusing on the control actuators' location and arrangement. Three types of main influence factors were summed up, including the operators physical characteristics, task operation properties and control actuators features. Total 47 indexes of these factors were conducted and investigated. The priority indexes in the design of control actuators location and arrangement were obtained. The results are helpful for understanding the design factors of control actuators location and arrangement, as well as providing references for human machine interface design.

2 Main Design Factors of Control Actuators Location and Arrangements

2.1 Literature Research

Multiple standards were reviewed, including international, European and Chinese standards. The key words for literature searching were control actuators, location, arrangement, control region, control area and control actuators design. Literature analysis focused on the design requirements of control actuators location and arrangements. The analysed standards primarily included ISO 9355-3: 2006 (International standard), BS EN 894-4: 2010 (European standard), GB/T 14775-93 (Chinese national standard), etc.

Based on the analysis of these standards, three types of main design factors for location and arrangement of control actuators were summarized. They were operators physical characteristics, task operation properties and control actuators features. The details are described as following.

2.2 Three Types of Main Design Factors

2.2.1 Operators Physical Characteristics

The operators physical characteristics include anthropometric dimension and operation postures.

(1) Anthropometric dimensions

Anthropometric dimensions contribute to the reachable area of limbs. It is the first considered factor for the control actuators location and arrangement design. The operation areas are various for people with different height and limbs length. Therefore, in the design process of control actuators location and arrangement, users' body dimensions should be considered seriously, so as to satisfy the reachable requirements

of most people, avoid unreachable problems, and locate control actuators with proper locations.

Anthropometric dimensions are classified to static and functional dimensions. Static dimensions refer to dimensions which are measured when human body are static. The measurement of static dimensions are carried by different postures, including standing, sitting, kneeling and prone postures [1]. Height, eye height, shoulder height, elbow height, sitting height, sitting eye height, sitting cervical height, sitting shoulder height are all belong to static dimensions.

Functional dimensions refer to reachable area when people participate in some functional activities. Functional dimensions are measured in dynamic mode of human body. They are the motion range dimensions produced by joint movement angle and limbs length.

Most countries or states have their own standard on local population anthropometric dimensions. In China, the national standard GB/T 5703—1999 (*Human body measurement infrastructure for technical design*) regulates 32 static dimensions and 13 functional dimensions in standing and sitting postures. These dimensions are given at 1, 5, 50, 95, 99 percentile respectively [2]. The proper position of control actuators, related to human reachability domains, should be determined by anthropometric data of appropriate percentile. For example, automobile driver seat is usually designed based on the anthropometric dimensions from 5 percentile of female to 95 percentile of male, thus to satisfy most people with seating comfortably.

(2) Operation postures

Operation postures have significant effect on operation energy consumption, reachable area and operation stability, thus influence on the selection of control actuators location and arrangement [3].

First of all, the maximum force of certain limb changes dramatically with different postures. Therefore, the postures influence body energy consumption a lot, and then influence operation duration time, fatigue and health. In order to improve the operation endurance and mitigate the negative effects on human health, operators' postures must be considered when designers determine the control actuators location and arrangement.

Second, operation postures influence limbs reachable area. For instance, the reachable areas are quite different between the standing and sitting posture. Obviously, the reachable height of upper limbs in standing posture are much more taller than that in sitting posture. The location and arrangement of control actuators is definitely different in these two postures, no matter operating by hand or by foot.

Finally, operation postures affect operation stability. For example, human body stability is not high in standing posture, although the flexibility is high because people can turn around and move the body to operate. On the contrary, the operation stability is relatively higher in sitting posture, which could reduce operation error rate.

In the design process, when operation postures are not determined, designers can choose appropriate location and arrangement of control actuators to help operators operating with comfortable postures. On the other hand, when the operation postures have been determined, location and arrangement of control actuators can be optimized to reduce fatigue and improve comfort of operators.

2.2.2 Task Operation Properties

Task operation properties include operating accuracy, speed and force, efficiency, visual checking, tactile detect, sensibility to errors, wearing gloves and easy cleaning. Task operation properties have dramatic impact on the location and arrangement of control actuators.

(1) Operation efficiency

High efficiency requirement of task operation means that the control actuators should be easily detected and reached, so that the control actuators should be arranged in places close to human body or to the most frequently used controls. Meanwhile, the efficiency also requires that the control actuators should be arranged in a regular and orderly way. The number of control actuators around the certain control actuator should be limited. The distance that need to be completed by hand or foot should be reduced via putting the control actuators on suitable locations. For instance, in cars, the position of handbrake is close to the operation lever. It is convenient for driver to move hand from operation lever to control handbrake, which is very important in emergency condition. This arrangement can not only reduce the recognizing and judging time, but also can reduce the possibility of operating error, so as to improve the operation efficiency [4].

(2) Speed

To satisfy the high requirements of speed, the control actuators are generally required to be placed in a convenient location, as well as a comfortable position. Continuous operation would decrease the operation speed gradually if the position of control actuators causes discomfort to operators. The comfortable position keeps a suitable distance with human body, neither too far nor too close. Too far from human body costs longer time to contact control actuator. Too close to human body may not allow limbs to extent completely and may cause uncomfortable postures. In addition, appropriate distance between control actuators is needed under the condition of high speed requirement. Large distance is helpful for avoiding misoperations, but would increase operation duration time.

(3) Force

Considering force requirement, the determination of control actuators location should be combined with human limbs movement characteristics. When large operation force is needed, control actuators should be located in positions centered with human torso, so that the relative large force can be exerted by operators. These positions should not only satisfy the requirements of force, but also should not cause excessive consumption of human body energy.

(4) Visual checking

When the visual detect is needed in operation, operators must observe and operate the control actuators simultaneously, otherwise mistakes may occur. Control actuators should be arranged in the field of vision and close to human body, so as to reduce the time to observe and recognize. Feedback device (if any) should keep appropriate distance with control actuators. For example, if the feedback device is a display,

the distance between the display and the control actuators should allow operators to catch the feedback information quickly and clearly. At the same time, the direction of information display should be consistent with the movement direction of the control actuators, that is display-motion consistency.

(5) Tactile detect

When there is a requirement of tactile detect in operation, operators' attention is usually occupied fully by other things, or the control actuators locate far from the operators. If the task operation need tactile check, the control actuator should be arranged in positions easy to be operated and keep a suitable distance with surrounding control actuators in order to reduce the possibility of misoperation. In other words, the control actuators should locate within the reachable area of human limbs. There should be as few as possible control actuators around the target control actuator so as to avoid misoperation. It is noteworthy that the operators' hand or foot movement from the initial position to the target control actuator should not be hampered by other control actuators. An example is the location of the accelerator and brake pedal in cars. The two pedals are in a short distance with each other, and there is no other control actuator between them. Drivers get benefits from this design because their attention are mainly painted on road, then moving the foot from the accelerator pedal to the brake pedal primary relies on tactile detection.

(6) Sensibility to errors

The more sensitive to errors, the more important the task operation is. This kind of task operation is the key factor affecting operational safety. In order to make the operators to reach and operate control actuators accurately and quickly in emergency, the control actuators should be located in positions that can be easily observed and reached by the operator.

(7) Wearing gloves

Hand sensibility decreases and finger becomes thicker when operator wears gloves. The most concerned problem is misoperation. Enlarging the distance between control actuators is an effective way to avoid misoperation.

(8) Easy cleaning

Some machines has the requirement of easy cleaning. The control actuators on these machines should be enlarged, so as to provide enough space for cleaning.

2.2.3 Control Actuators Features

Control actuators features refer to physical features, functions and using environment of control actuators.

(1) Physical features

Physical properties of the control actuator include the type, color, shape, dimensions and size. In order to lower the visual errors, as well as decrease the recognization time, the control actuators could be grouped by the principle of similarity according to type, color, shape or size. If the type of control actuators is different, the proper distance

between them should be determined by combination with motion way of control actuators [5]. For example, the distance between knobs and buttons should guarantee fingers to operate freely without obstacle if these two types of control actuators are used together.

(2) Functions of control actuators

Functions of control actuators include emergency, switch operation and general operation. Various functions usually contribute to various locations. It is well known that control actuators used in emergency should be located in striking and maneuverable places so that operators can react quickly and correctly. But for the control actuators for general operation, because of its less impact on safety and low error sensitivity, they are just required to be located in human limbs reachable area.

(3) Using environment

Using environment refers to spaces or surfaces for locating and arranging control actuators. The limitation of space or surface size make the range for locating control actuators reduced, and the distances between control actuators limited. Locations of control actuators may be differed when the size of space or surface is different, In this situation, the location and arrangement of control actuators should be designed with the consideration of using context, combining with other factors, such as human limbs motion characteristics and control actuators function.

3 Priority Indexes of the Design Factors

3.1 Method

Many detailed indexes were involved in the three types of factors described above related with the design of control actuators location and arrangement. In order to find out the priority indexes, a questionnaire survey was carried out. Total 47 indexes, which may have influence on control actuators location and arrangement design, were included in the questionnaire, shown as following.

- Type of control actuators (hand and foot manipulate, voice and eye control)
- Dimensions of control actuators
- Function of control actuators (on/off or start/stop, general control actuators, safety or emergency device)
- Anthropometric dimensions (anthropometric static dimensions, functional dimensions, limbs reachable area and comfortable area)
- Task operation properties (operation accuracy, speed, force, visual checking, tactile detect, avoiding interference, friction, wearing gloves and easy cleaning)
- Operation movement characteristics (movement type, movement axis, movement direction, movement continuity, angle of rotation for continuous rotary, repetitive movement, duration time, order, static posture holding time, supporting)
- Hand grip characteristics (grip type, hand part of applying force, applying force method)

- Grouping (whether to group, frequency of transforming operation between different groups, distance in group, distance between groups, number of control actuators in a single group)
- Importance of control actuators
- Using frequency of control actuators
- Correspondence with visual display
- Coding
- Operator habits

The participants were asked to evaluate the importance of each index according to their experience. A five-point Likert scale was used in the evaluation, ranging from "not important at all" to "very important".

3.2 Participants

Total 26 participants coming from machinery company and automobile company attended the investigation. Their ages were from 26 to 45 years old. Their career experiences were 3 to 24 years. For their job title, 17 of them were designers of control actuators, 9 of them were testers of control actuators. The investigation scene is shown in Fig. 1.

(a) Designers of control actuators

(b) Testers of control actuators

Fig. 1. Investigation scene

3.3 Results

By the analysis on the investigation data, the top priority indexes for control actuators location and arrangement were found out. The top priority indexes were regarded as having larger impact on the location and arrangement, and should be considered firstly in design period. Besides, the secondary priority indexes were also obtained.

(1) Operators physical characteristics

All of the indexes in anthropometric dimensions were evaluated as the top priority indexes, including anthropometric static dimensions, functional dimensions, limbs reachable area and comfortable area. Besides the anthropometric, operator habits was also evaluated as the top priority indexes.

For the secondary priority indexes, most of the indexes in hand grip characteristics were regarded as in this level, including hand part of applying force (finger/palm), applying force method(normal/tangential direction). In addition, movement type (linear/rotary), movement axis, and movement continuity (continuous/discrete) of operation movement characteristics were also considered as secondary priority indexes.

(2) Task operation properties

The top priority indexes were operation accuracy, visual checking, avoiding interference, and friction. Operation force were considered as secondary priority index. Other indexes of the task operation properties were evaluated as less important, such as operation speed, tactile detect, wearing gloves and easy cleaning.

(3) Control actuators features

The top priority indexes were the control actuators type of hand and foot manipulate, the control actuators functions of on/off or start/stop, safety or emergency device, importance of control actuators. The distance between control actuators with similar functions or different functions, whether grouped or not, were regarded as the secondary priority indexes.

All other indexes that not belonged to the top or secondary priority indexes were evaluated as not priority. Those indexes can be considered later in the design period.

4 Conclusion

Through the literature research related with the design of control actuators location and arrangement, the three type of main design factors were summarized, including operators physical characteristics, task operation properties and control actuators features. According to the investigation of detailed indexes of these design factors, the top priority indexes were found out, which should be considered firstly in the design period. These top priority indexes were anthropometric static dimensions, functional dimensions, limbs reachable area, comfortable area, operation accuracy, visual checking, avoiding interference, friction, the control actuators type of hand and foot manipulate, the control actuators functions of on/off or start/stop, safety or emergency device, importance of control actuators, and operator habits. In addition to the top priority indexes, the secondary priority indexes were also presented.

The research results are useful for human machine interface designers to comprehend the design factors and priority indexes in the design process of control actuators location and arrangement. What's more, the design indexes concluded in this paper can be used to evaluate existing location and arrangement of control actuators with problems of uncomfortable operation, high rate of misoperation or heavy load of operation.

It is helpful for checking out the problems in the existing interface and amending the unreasonability related with location and arrangement of control actuators.

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