
Comfortable earth moving machinery

Knowledge and experiences from the Eurocabin project

Editors

F. Krause

R.E. Bronkhorst

M.P. de Looze

This publication can be ordered at:

TNO Work and Employment

P.O. Box 718

2130 AS HOOFFDORP

The Netherlands

Fax: +31 23 554 93 94

E-mail: receptie@arbeid.tno.nl

Price: EUR 20 excl. VAT

ISBN 90-6743-977-0

© 2003 TNO Work and Employment

© Figures 16.2 and 16.3 Hans Rakhorst and Figures 16.4 and 16.5 Lodewijk Vormer

Editors:

Frank Krause, Robin E. Bronkhorst, Michiel P. de Looze

Print:

PlantijnCasparie Heerhugowaard

No parts of this manuscript may be reproduced in any form, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, or otherwise, without prior written permission from the publisher.

7 Joystick controls and consoles: the implications of joystick use for the design of the joystick console (or control console)

Frank Krause

TNO Work and Employment, Hoofddorp, The Netherlands

7.1 Joystick controls

Joysticks are widely used as controls in heavy equipment. They have often replaced larger and more forceful movements necessary for lever control and have the advantage that one can control two machine tool movements in one handle. Through electronic switches even more movements or functions can be operated. Joysticks are appreciated by the operators. Therefore it is safe to conclude that joysticks have improved both operator comfort and productivity¹.

The older large lever controls had risks for work related musculoskeletal disorders (WRMD's). The use of joysticks has reduced these risks. The joystick has however replaced the larger forceful movement by a more static posture with more localized small movements. This may have possible adverse effects for localized fatigue build up and on the longer term WRMD's. Also more functions are added to the joystick through extra buttons and switches. They too may influence the onset of WRMD's as the positioning and amount of extra functions are not necessarily based on knowledge about human factors.

There is still quite a lot unknown about joysticks and their use in heavy equipment. Long term health effects are not well known. Not a lot is known about the optimal size and shape of the joystick relative to the user and the tasks or about the number of extra functions and their positioning. This requires research.

The new challenge of creating optimal joystick controls cannot be isolated from the joystick configuration in the workplace-operator interaction.

'New' controls change workplace requirements. The operator-seat-control interaction is different for a short, finger operated joystick than for the joysticks that are used in most earth moving machinery. Therefore depending on the type of joystick the requirements may differ. In this chapter we will focus on the larger joysticks because generally bucket and boom controlling joysticks are designed with the intention to be manipulated using a closed grip. That operators use different ways of controlling the joysticks is discussed shortly further on.

¹ From research among over 300 operators at BAUMA 2001 we know that the ability to be productive with a machine plays a large role in machine appreciation.

Before making some comments about the design of your console we would like to mention some basic requirement regarding the operator-seat-control interaction. They are based on:

- the static posture that is maintained during work;
- the precision handling;
- the intended grip;
- the intensity with which a machine is used².

Also changes in working population and the levels of ergonomic standards add to the requirements the workplace should meet. All of this of course has consequences for console design.

7.2 General workplace requirements

From a human factors point of view the following criteria are considered to be important:

• (regular) arm support near the elbow is necessary	when trunk and upper arm are in a relative static position during work, as is the case in joystick controlled earth moving machinery, proper arm support should be provided to unload shoulder muscles. Good arm support can also provide extra stability to the trunk and reduce the load to the lower back by carrying some of the weight of the upper body. This could reduce the risks of back problems
• angle between upper arm and trunk should be minimal	the angle between upper arm and trunk should not be more than 20 degrees, as this can cause shoulder problems, especially with the unsupported arm
• extreme angles of the wrist should be avoided	the design should not force the user into extreme joint angles. It may, however, be difficult to prevent operators from operating the joystick in a more risk full posture (see further)
• upper legs supported, horizontal or slightly tilted from the knee downwards	these criteria basically apply to all upright seated work-places hip and knee angle should more or less correspond. If
• knee angle 90°-110°	the knee angle is a lot larger than the hip angle it will
• hip angle 95°-110°	influence the pelvic tilt

² 2,000 operating hours/year in the Netherlands is no exception.

For the workplace this would mean that it should meet the following requirements:

- the seat should be adjustable in fore-aft direction, to allow differences in buttock-knee length, and preferred knee angle;
- the seat should be height adjustable because of differences in lower leg length;
- the seat pan and backrest should be tiltable;
- hand controls should be adjustable preferably fore-aft as well as in height; this is necessary to position the controls depending on one's trunk and upper arm posture and the length of the lower arm;
- arm support should be height adjustable and preferably in width.

Anthropometry

The adjustability ranges, one chooses to build into a product, should be considered carefully. In the Netherlands it can be seen that on one side of the range Dutch men are becoming taller, on the other side however, due to a multicultural environment, also shorter people will become part of the operator population. Therefore it is increasingly important to offer very wide adjustment ranges to make a machine comfortable for all intended users.

7.3 Joystick gripping

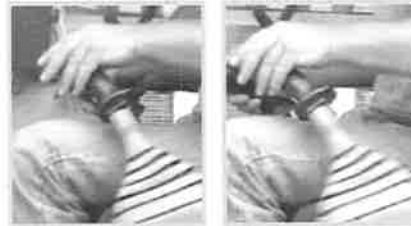
As stated before, in most earth moving machinery the joystick is designed in a way that it intends the user to grip the joystick with the closed hand while operating it. In practice however, various ways of gripping and moving the joystick can be seen. They are likely to be connected to factors such as joystick size, angular range, optional buttons, operator preference, operator motor skills, hand size and other anthropometric variables as well as disturbing machine movements.

Roughly the gripping techniques can be divided into the following:

hand grip
closed fist



hand grip
open hand



finger grip
side handling



finger grip
top handling



The photos are from hydraulic excavator operators. Except for the 'finger grip top handling' the shown techniques were also observed in wheel loader operation.

Apart from the above mentioned factors, the technique may also result from the alignment of joystick and operator, e.g. the finger grip top handling may result from a seated position that is too high compared to the joystick. This of course should be avoided.

Finger gripping may also be chosen for other reasons. With this grip the elbow remains rested on the armrest and does not have to slide. The fixating of the elbow may render more control over the precise moving of the joystick.

7.4 Review of consoles generally found in earth moving equipment

Against the above mentioned criteria and requirements, TNO reviewed the consoles that are used in the machines of the Eurocabin participants. From this we learnt that recent consoles can be improved.

Fore-aft adjustability

In general the controls can be adjusted in fore-aft direction relative to the seat by sliding the seat relative to the consoles. This fore-aft adjustment mechanism is not optimal as it forces an adjustment sequence that is also considered not optimal (see further). Because the seat slides relative to the joystick, first the joystick position must be changed. After that an operator can change the fore-aft position of the seat relative to the pedals and viewing requirements. This may introduce a sub optimal positioning of the joystick relative to the operator.

From other research we know that seat height and fore-aft position are considered being very important by operators. Operators might only use the joystick adjustability to adjust their fore-aft position in the cab, therefore leaving the position of the joystick relative to themselves sub optimal.

Height adjustability

With most consoles, if the operator adjusts his seat to get a proper seat height, the joystick does not follow. As a consequence, operators with short or very long lower legs may find the controls too high or too low respectively. The seat position will therefore be a compromise between an optimal position relative to the floor/pedals or relative to the joystick. If the seated position is too low relative to the joystick, it may lead to elevated shoulders which can cause muscle problems in this region. If it is too high, it may result in the above described top handling technique.

In some machinery the control consoles are attached to the seat construction. These consoles move up and down together with the seat height adjustment. This is considered to be good. Still, the console cannot be adjusted to the differ-

ences in elbow height that exist between people³. Although this lack of adjustment should not be considered as a large problem, it does not mean that one should not strive to improve the adjustability.

Arm support

Mostly if arm support is available, it is provided by armrests connected to the seat. Height adjustment is generally brought about by changing the angle of the armrest. If the angle is changed, the amount of arm support is reduced: point pressure and shear forces are introduced leading to more discomfort (see figure 7.1). Additionally in some seats the armrests can slide in their mountings for approximately 2 cms. This mechanism is not suitable in situations where different operators utilize the vehicle and may want easy quick adjusting.

In our opinion such a mechanism is no longer adequate. Proper arm support should be provided.

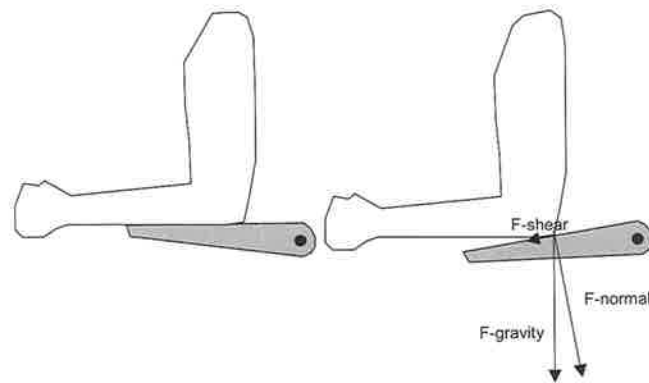


Figure 7.1 Armrests

Arm support is sometimes provided by an armrest connected to the console (see figure 7.2). This armrest can be adjusted relative to the joystick. This adjustability range is less functional as the vertical position of the fore arm of short and tall users will differ only slightly relative to the joystick.

We believe it to be more important to be able to adjust the armrest height (and joystick height) relative to the seat surface as this distance can differ strongly between users.

³ For the Dutch population the difference in elbow height between a short person (p5) and a tall person (p95) is almost 10 cm.

Modern interiors: progress or not?

Further on in this book we will mention that the automotive industry has a strong influence on the interior design of industrial vehicles. This could also be observed at the Bauma 2001, where several wheel loader manufacturers showed driver cabs with car-like dashboards. The 'wrap-around' trend is followed by some as they extend the dashboard to the right side (see figure 7.3). The right hand controls are fitted into the console and have little or no adjustability, whereas in other designs the joystick can at least be adjusted in fore-aft direction. The progress in the field of styling the cab compartment is therefore counteracted by the lack of adjustability. From a human factors point of view this is not advisable.



Figure 7.2 Armrest connected to console



Figure 7.3 Joystick in wrap around console

7.5 Future design challenges: towards new consoles

The requirements seat-armrest-console combinations should meet are made clear through an ideal sequence of adjusting the workstation to the operator, based on a cab in which pedals form a fixed point. This ideal sequence would be:

1. seat height and seat pan angle;
2. backrest;
3. seat-pedal distance;
4. steering wheel (where applicable);
5. armrest and joystick height, simultaneously;
6. joystick distance;
7. fine tuning of joystick height and position.

In this adjustment sequence the operator can choose his optimal seating position relative to the pedals and visual tasks he has to perform. As armrests and joy-

sticks are adjusted relative to the shoulder, they should come later in the process⁴.

A consequence of the simultaneous adjustment of the arm rest and joystick height is, that armrests and control consoles need to be linked and fitted above the height adjustment mechanism. By doing so they will also be fitted above the spring assembly, which is good.

To be able to fit 90% of the operator population the combination should be able to move up and down 10 cm, from approximately 19 cm above compressed seat surface to 29 cm. In Dutch office seats the standard for armrests is 20 to 27 cm (NEN 1812).

In the middle position armrest and console should be aligned in such a way that the joystick endplate is equal to or slightly under armrest level. (see figure 7.4). The armrests should not be wider apart than 50 cm. Ideally they can also be adjusted slightly in- or outwards.

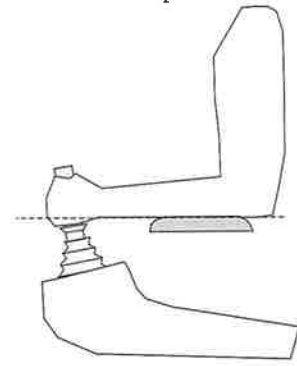


Figure 7.4 Armrest-joystick alignment

Because of the large angular range the operation of the joystick requires a translation of the fore-arm when gripping the joystick with the hand. To avoid uncomfortable friction between the armrest and the fore-arm it should be considered to allow the armrest surface to slide 7-8 centimetres.

Regarding armrests it pays to take a look at the office seat market as they offer the widest range of features.

⁴ An addition should be made. Depending on the construction of the seat and controls there can be some freedom in the sequence of adjustment. If the joystick console does not move together with the seat, joystick adjustment comes end in line. If seat, arm support and joysticks move together up-down and fore-aft, the joystick adjustment relative to the operator can be done separate from other adjusting of controls (steering wheel) and adjusting to controls and fixed points (pedals, view).

A fore-aft adjustment is necessary. The mechanism should be such that the console moves relative to the seat instead of the other way around as is the case in present consoles. The drawbacks of this system were described above. When defining the range of adjustment, not only differences in fore-arm length are to be considered, also some flexion of the upper arm should be allowed.

Then, to fine tune the grip position of the hand relative to the joystick, either the joystick should be able to move easily up and down in the console, or the console should be able to move relative to the armrest.

To achieve a large freedom for the operator to choose his own preferred technique is far more difficult. Without changing the position of the joystick axis it would involve a larger range of up-down adjustability. However, when changing to a finger grip top handling, the position of the joystick axis should be changed to avoid extreme wrist angles and create a movement pattern inside the range of motion of the wrist. Creating such an adjustment feature is far more difficult (see figure 7.5).

In cranes it can often be seen that operators work with the trunk slightly bent forward. This changes the arm position as well. The fore-arm is not horizontal but pointed downwards. To be able to accommodate the console to such behaviour, it should be able to pivot around an axis near the elbow (see figure 7.5). This adjustability feature however can be debated for earth moving machinery.



Figure 7.5 Armrest - joystick configuration

7.6 Concluding remarks

- A large adjustability also has its drawbacks. As often can be seen in the office seat market users, that know how to optimally adjust their seat and also do this, are a minority. As in the office seat business it should be seen as a

challenge to design a seat-control configuration that is easily and intuitively adjustable.

- From above we can learn that it are actually not only the seat, armrest and control console that cannot be seen separately. Also the form, size, extra switches, movement range and pivot point of joysticks should be considered, to gain an optimal balance between productivity on one side and health on the other. In this respect there is still work to be done.