SAE International

SURFACE VEHICLE RECOMMENDED PRACTICE

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Operator Controls - Off-Road Machines

RATIONALE

This standard has been revised to update reference standards and to remove Agricultural Tractors from the scope.

1. SCOPE

1.1 General criteria are presented as guidelines for: control device location, resistance, and actuation of hand and foot controls by the machine's operator. The criteria are based upon physical limitations as defined by human factors engineering principles.

1.2 This SAE Recommended Practice applies to upright seated operators of Road Building and Maintenance, and Specialized Mining Machinery categories of off-road, self-propelled work machines as identified in SAE J1116. The criteria presented should apply to most situations. Each situation, however, must be evaluated as to its own function and its relationship to other functions to achieve the desired operation action in normal and emergency situations with high probability. The values for control displacement and resistance apply only to what is required to achieve the desired performance of the function being controlled for the 5th through the 95th percentile person as defined in ISO 3411.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest issue of SAE publications shall apply.

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2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or 724-776-4970 (outside USA), www.sae.org.

SAE J1116 Categories of Off-Road Self-Propelled Work Machines

SAE J1362 Graphical Symbols for Operator Controls and Displays on Off-Road Self-Propelled Work Machines

ISO 3411 Earth-moving machinery - Human physical dimensions of operators and minimum operator space envelope

ISO 6405-1 Earth-moving machinery-Symbols for operator controls and other displays-Part 1: Common symbols

ISO 6405-2 Earth-moving machinery-Symbols for operator controls and other displays-Part 2: Specific symbols for machines, equipment, and accessories

ISO 6682 Earth-moving machinery - Zones of comfort and reach for controls

3. DEFINITIONS

3.1 CONTROL

Device actuated by a person to effect a response of the machine, its equipment, or its tools.

3.1.1 Frequently Operated Control

A control with an average operational interval of 5 min or less between actuations during a normal operational cycle. This control is the same as the primary control defined in ISO 6682.

3.1.2 Infrequently Operated Control

A control with an average operational interval of more than 5 min between actuations during a normal operational cycle. This control is the same as the secondary control defined in ISO 6682.

3.2 CONTROL DISPLACEMENT

Movement of a control through its operational range.

3.3 CONTROL RESISTANCE

The force exerted by the operator to effect a control displacement.

3.3.1 Normal Operational Resistance

Force applied to achieve the desired control function under normal operating conditions.

3.3.2 System Malfunction Resistance

Force applied to achieve the desired control function whenever a malfunction occurs that affects the system's performance or whenever the system serves as a back-up to another primary system such as loss of power resource.

3.3.3 Minimum Control Resistance

Force applied necessary for functional input to the operator senses.

3.4 FORWARD

Direction the operator faces while seated in the operator's seat with the machine and the operator's seat in the position for straight, forward travel as defined by the manufacturer.

3.5 MINIMUM CONTROL STRENGTH

Ability of the control system to withstand a single excessive application of effort or load by the operator without being destroyed or impeding its primary function. The control device may be deformed as long as the primary function can be accomplished.

4. GENERAL CRITERIA

4.1 Enclosure Space Envelope

The minimum normal operator enclosure space envelope and the minimum clearance between the operator controls and enclosure surfaces are provided in ISO 3411.

4.2 Control Response

4.2.1 A control actuation should produce the expected functional response, movement rate, and direction of movement.

4.2.2 Controls shall provide a positive sensory feedback (visual, audio, touch, etc.) of actuation and/or position to the operator.

4.3 Control Location, Displacement Resistance

4.3.1 Control location and direction of movement and reference to the operator while in the normal operation position for that control.

4.3.2 Frequently operated controls, including their displacements shall be located within the zone of comfort as defined in ISO 6682.

4.3.3 Infrequently operated controls including their displacements, shall be located within the zone of reach as defined in ISO 6682.

4.3.4 Control location relative to the operator may be adjustable to enhance compatibility of different size operators.

4.3.5 A control shall not be located where it could cause ambiguity as to its direction of motion to actuate a function. Location of a control on a 30 to 60 degree sloping surface should be avoided if its direction of motion to achieve the same function is dependent upon the plane of the control's mounting surface. For example, a lever control for a raise/lower function should not be located on a 30 to 60 degree sloping surface since its recommended direction of motion changes when it is moved from a vertical to a horizontal plane.

4.3.6 When a sequence of controls is repeated on another panel, the sequence of controls should be the same for each panel.

4.3.7 Control displacement and control resistance shall comply with the values in Table 1.

4.3.7.1 Infrequently operated control's displacement and resistance are not to exceed the boundaries set by D_3 and R_3 shown in Figure 1 with values from Table 1.

4.3.7.2 Frequently operated control's displacement and resistance are not to exceed the values for X and Y as computed by using the formulas of Figure 1 and values from Table 1.

The formulae are dependent equations, solved by selecting values for the dependent variable.

4.3.8 Control resistance necessary to actuate a control that has been affected by a system malfunction may be higher than specified for normal operation resistance. The values specified for maximum system malfunction resistance in Table 1 are intended to provide boundary conditions for operator activation during and at the time of the malfunction.

4.3.9 Minimum control resistance shall be sufficient to avoid inadvertent actuation by the force of the hand or foot resting on the control during anticipated operating condition. As a general guideline, it should not be less than specified in Table 1 when actuating controls on a moving machine.

4.3.10 Minimum control strength should be at least five times the anticipated normal and malfunction operator effort considering the function of the control and its relative location and direction of motion.

4.4 Direction of Movement

4.4.1 Direction of movement of controls should be consistent with the related motion of the controlled item. Other factors should also be considered such as past practices, general trained responses, emergency reactions, ease of operations, interaction with other controls, and strength requirements.

4.4.2 The direction of movement prescribed in Figure 2 shall be followed if there are no significant overriding factors.

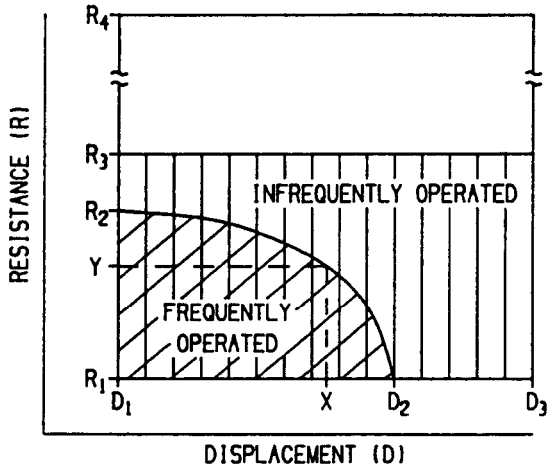
TABLE 1 - CONTROL DISPLACEMENT AND RESISTANCE

CONTROL Except (2) Steering Wheel (3) Brake Controls Figure 1 Ref.	Displacement Units	Displacement Minimum D_1	Displacement Maximum Frequent Operation D_2	Displacement Maximum Infrequent Operation D_3	Resistance Units	Resistance Minimum R_1	Resistance Maximum Normal Operation Frequently R_2	Resistance Maximum Normal Operation Infrequently R_3	Resistance Maximum System Malfunction R_4
FINGER OPERATED									
Linear Motion Type									
Membrane Switch	mm	0.4	1.2	1.6	N	2.0	8.0	10.0	20.0
Push Button	mm	2.0	6.0	8.0	N	2.5	10.0	13.0	25.0
Slide/Toggle Rocker Switch	mm	3.0	25.0	32.0	N	2.5	10.0	13.0	25.0
Thumb Wheel									
a. discrete motion	mm	5.0	16.0	20.0	N	3.0	12.0	15.0	30.0
b. continuous motion	mm	–	–	–	N	2.0	8.0	10.0	20.0
Rotary Motion Type									
Selector switch - stop to stop	deg	10.0	30.0	40.0	N m	0.15	0.6	0.75	1.5
Key Switch/Rotary knob	deg	30.0	90.0	120.0	N m	0.15	0.6	0.75	1.5
Continuous Adjustment knob	deg	–	–	–	mN m	10.0	40.0	50.0	100.0
HAND OPERATED									
Linear Motion Type									
Push button	mm	10.0	30.0	40.0	N	5.0	20.0	25.0	50.0
Push-pull									
a. Knob	mm	10.0	30.0	40.0	N	3.0	12.0	15.0	30.0
b. Handle	mm	15.0	45.0	60.0	N	12.0	48.0	60.0	120.0
Lever (6)									
a. Longitudinal	mm	100.0	300.0	400.0	N	20.0	80.0	100.0	200.0
b. Transverse	mm	60.0	190.0	250.0	N	15.0	60.0	75.0	150.0
c. Vertical	mm	80.0	240.0	320.0	N	15.0	60.0	75.0	150.0

TABLE 1 - CONTROL DISPLACEMENT AND RESISTANCE (CONTINUED)

CONTROL Except (2) Steering Wheel (3) Brake Controls Figure 1 Ref.	Displacement Units	Displacement Minimum D_1	Displacement Maximum Frequent Operation D_2	Displacement Maximum Infrequent Operation D_3	Resistance Units	Resistance Minimum R_1	Resistance Maximum Normal Operation Frequently R_2	Resistance Maximum Normal Operation Infrequently R_3	Resistance Maximum System Malfunction R_4
Rotary Motion Type									
Crank	turns	–	–	–	N m	0.4	1.6	2.0	4.0
Handle	deg	20.0	60.0	80.0	N m	0.5	2.0	2.5	5.0
Wheel	turns	1.0	4.0	5.0	N m	3.0	12.0	15.0	30.0
Steering (see Figure 3)									
FOOT OPERATED									
Push Button	mm	15.0	45.0	60.0	N	20.0	60.0	90.0	180.0
Pedal									
Ankle Action									
a. Toe Operated	mm	20.0	60.0	80.0	N	12.0	48.0	60.0	120.0
b. Heel and toe	mm	8.0	24.0	32.0	N	12.0	48.0	60.0	120.0
Leg & Foot Actuated									
a. No back support	mm	30.0	90.0	120.0	N	30.0	120.0	150.0	300.0
b. With back support	mm	30.0	90.0	120.0	N	75.0	300.0	375.0	700.0

NOTE 1—The relationship of resistance to displacement may reduce the maximum value of the frequently operated control displacement or resistance value. See 4.3.7 and Figure 1.
NOTE 2—See 5.1.5 and Figure 3 for steering wheel normal operation and system malfunction resistance values.
NOTE 3—See 5.2.5 for brake controls resistance values.
NOTE 4—See 4.3.10 for minimum control strength requirements.
NOTE 5—Minimum resistance may be lower than specified if the control is primarily actuated when the machine is not in motion such as the backhoe controls on a backhoe loader.
NOTE 6—Displacement of Hand-operated Lever controls are for bidirectional control, for unidirectional use 1/2 these values.
NOTE 7—When controls are operating at “minimums,” there shall be adequate sensory feedback to the operator per 4.2.2.



DEFINITIONS:

X = Maximum control displacement for frequently operated control with resistance of "Y" where:

$$X = D_1 + \sqrt{\left[(D_2 - D_1)^2\right]\left[1 - \frac{(Y - R_1)^2}{(R_2 - R_1)^2}\right]}$$

Where Y is a known value in the Range R_1 to R_2

Y = Maximum control resistance for frequently operated control with displacement "X" where:

$$Y = R_1 + \sqrt{\left[(R_2 - R_1)^2\right]\left[1 - \frac{(X - D_1)^2}{(D_2 - D_1)^2}\right]}$$

Where X is a known value in the Range D1 to D2

D_1 = Minimum control displacement
D_2 = Maximum control displacement - frequently operated control
D_3 = Maximum control displacement - infrequently operated control

R_1 = Minimum control resistance
R_2 = Maximum control resistance - frequently operated control
R_3 = Maximum control resistance - infrequently operated control
R_4 = Maximum system malfunction resistance

EXAMPLE:

Hand operated lever. Longitudinal motion (Table 1; 2.1.3a).

Values from TABLE 1;2.1.3a

D_1 = 100 mm R_1 = 20 N
D_2 = 300 mm R_2 = 80 N
D_3 = 400 mm R_3 = 100 N
R_4 = 200 N

SOLUTION	
Y (N)	X (mm)
40	289
60	249
70	210
75	180

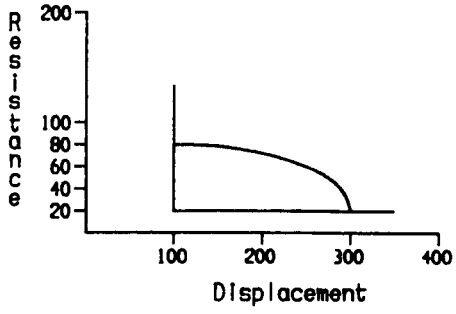


FIGURE 1 - COMPUTATION OF MAXIMUM CONTROL DISPLACEMENT AND RESISTANCE FOR FREQUENTLY OPERATED CONTROLS (REFERENCE 4.3.7 AND TABLE 1)

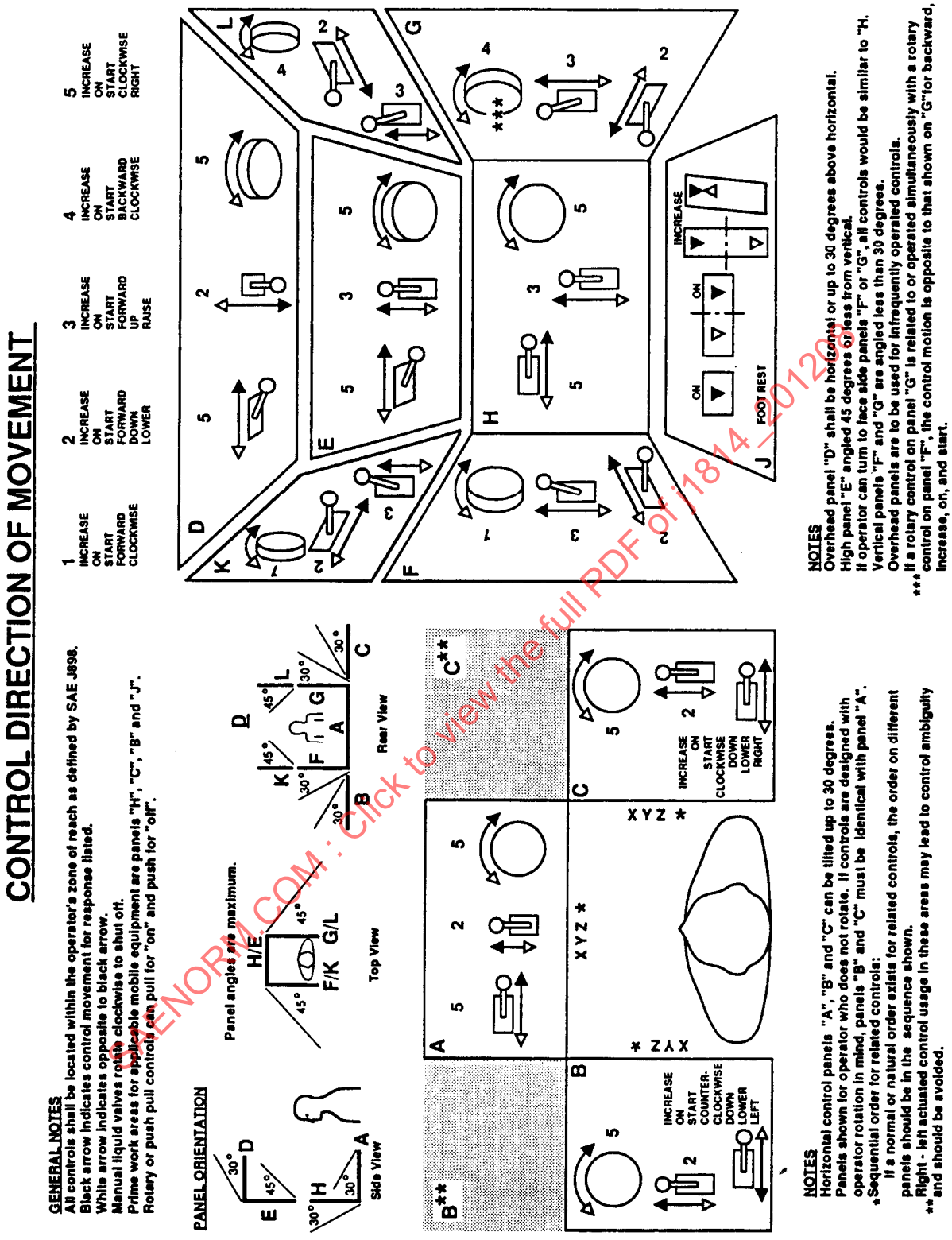


FIGURE 2 - CONTROL DIRECTION OF MOVEMENT

4.5 Control Arrangement

4.5.1 Machines, which frequently require hand coordination to simultaneously control machine travel and tool operations, should have machine travel motion controls operated by one hand and tool controls by the other. If the control system is designed to permit simultaneous operations of the travel motion and tools by combined function controls, there should be continuous contact with the control to achieve these functions.

4.5.2 Space between controls shall be sufficient to allow operation without unintentional actuation of adjacent controls. Suggested minimum clearances between controls are as follows:

a. Finger tip operated - 10 mm - if control resistance is 10 N or less

b. Hand operated (palm grasp) - 25 mm - if control resistance is 50 N or less
50 mm - if control resistance is greater than 50 N

c. Foot operated - 50 mm

Additional spacing should be provided for operators wearing cold weather or other protective clothing, reference ISO 3411.

4.5.3 Overlapping of control zone locations is permissible to provide independent and simultaneous control action.

4.6 Identification

4.6.1 Control functions and movements shall be identified, preferably by symbols, so that the operator can determine the proper control function and movement without trial and error. If symbols are used, they shall comply with SAE J1362, ISO 6405-1, or ISO 6405-2 where applicable.

4.6.2 Identification is not required for controls which have universal recognition by virtue of their shape, locations, arrangements, and method of actuation such as a steering wheel, foot-operated clutch pedal, service brake pedal, and accelerator pedal.

4.7 Combined Functions Control

A control with combined functions is acceptable. It should follow the guidelines of this document where applicable.

4.8 External Forces

Control actuators, control linkages, and other vulnerable components shall be arranged or protected to minimize actuation or damage by external forces such as being stepped on, grabbed, and hit by obstacles (e.g., brush).

4.9 Pedal Surface

Pedal surfaces shall be slip-resistant. Stops at edge of the pedal should be provided when needed to help prevent the foot from slipping off.