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Foot Control Activation - Reciprocating vs. Pivoting

by Ralph L. Barnett[1] and Peter Barroso, Jr.[2]

Abstract

Discriminating between the two most widely used foot control concepts, open-sided and side-shielded, requires, among other things, an understanding of reciprocating and pivoting foot motions. In single cycle machine operations, it was found that the hands are steadier when foot controls are activated by pivoting about the heel as opposed to reciprocating. Furthermore, the study reveals the counterintuitive result that the reciprocating motion delivers slightly more activations per unit time than the pivoting action. If safety is not a consideration, stroke-rate, operator comfort and hand steadiness are maximized when foot controls are actuated by "riding the pedal" or "hold down/release."

I. INTRODUCTION

There are many circumstances that necessitate the use of foot controls. A machine's productivity in the manual mode often requires that the operator's hands be utilized during the entire operational profile. A plethora of controls may require all of the operator's appendages. In situations where the hands can become entrapped, prudent safety management may require emergency stop foot switches or foot valves. Intervention systems for carpal tunnel syndrome arising from two hand hostage controls may adopt foot controls.

Open-sided and side-shielded foot switches, shown in Figures 1a and 1b respectively, are typical of the foot control candidates found in industry. They may be used to activate machines using four strategies:

1. *Riding the pedal:* One foot is continually poised above or just touching the foot pedal until a machine stroke is required. The foot then depresses the foot pedal eventually returning to its position above the pedal. It is never withdrawn from the foot control. "Riding the pedal" is analogous to a hunter "keeping his finger on the trigger." When a power press operator, for example, keeps a foot deployed over the pedal, accidental activation may occur during episodes involving sneezing, reaching forward, slipping, a tired foot or being bumped forward. "Riding the pedal" is the most prevalent cause of accidental activation of power presses.

1a. Typical Open-Sided Switch | *1b. Typical Side-Shielded Switch*

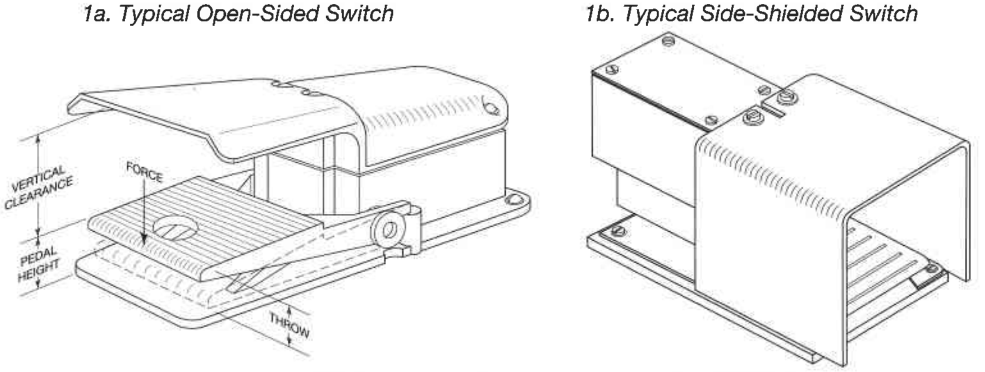

Figure 1 - Foot Control Characteristics

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2. *Pivoting:* Starting with both feet on the floor, one foot is pivoted about the heel and swung into the foot control. It then depresses the foot pedal and swings back into its original position on the floor. "Riding the pedal" does not occur; furthermore, the active foot never lifts or shifts its heel. This strategy is only available with open-sided controls.

3. *Reciprocation:* Starting with both feet on the floor, one foot is inserted into the foot control by a forward movement followed by a depression onto the foot pedal. This foot is then moved rearward into its original (starting) position. "Riding the pedal" does not occur. During reciprocation, all of the operator's weight is supported by the non-active foot. This operating mode may be used with either open-sided or side-shielded controls.

4. *Hold Down/Release:* On machines incorporating a single cycle mode of operation the operator holds the foot pedal in a depressed position. The machine is stroked by momentarily lifting the toe and returning it to the fully depressed condition. The single cycle circuitry allows only one stroke per depression.

The "hold down/release" strategy is less prone to accidental activation than "riding the pedal" since there are simply more ways to inadvertently depress the pedal than to release/depress. Nevertheless, the "hold down/release" strategy is not typically encountered in the workplace for single cycle operations. On the other hand, it's quite popular for continuous operations where the process is monitored by an operator who keeps the pedal depressed until an emergency intervention is called for whereupon the operator removes his or her foot from the control.

The two common activation strategies, pivoting and reciprocating, are explored for standing operators working in the single stroke mode. Open-sided controls are used in all tests as they are the only ones which allow pivoting and reciprocating. This paper studies operator comfort and hand steadiness.

II. OPERATOR COMFORT

Is it less fatiguing to trip a foot control using the pivoting mode or the reciprocating mode? Adopting the notion that "easier leads to faster," one may quantify *activity ease* by measuring maximum stroke rates for each mode under speed provoking conditions. Accordingly, two test protocols were formulated for the pivoting and reciprocating modes with the following common characteristics:

Goal

For each of the four foot control candidates in Figure 2, the operators tried their best to maximize the number of activation strokes in a 30 second period. This short time interval was selected to minimize endurance effects which may not be encountered in the workplace.

Position

Each foot control was held in a fixed position established by the subject operator. Tripping was performed from a standing position.

Practice

One practice run was performed for each foot control candidate and tripping method.

Fidelity

Strict adherence to the definitions of pivoting and reciprocating were enforced by the test monitors.

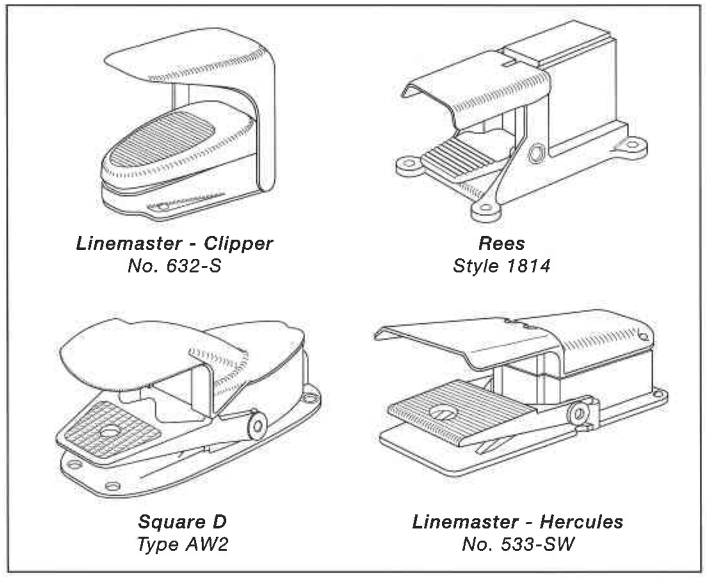

Figure 2 - Foot Control Candidates

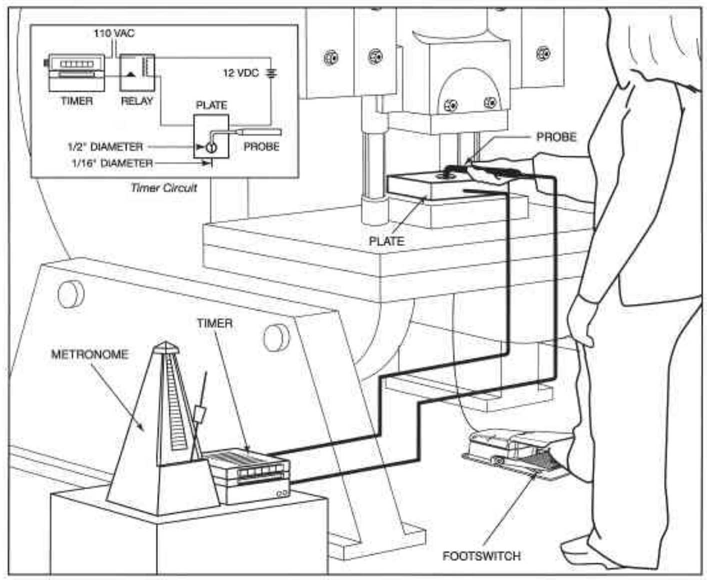

Figure 3 - Hand Steadiness Test Set-Up

Incentive

Striving for one's best score was influenced by the following factors:

- The operators were proctored by an authority figure.
- The test program was conducted as a contest with published results.
- Peer pressure
- Machismo

The first test program was conducted in 1980 and used thirty-six male and three female students from a senior engineering class. Four foot controls were operated from an unencumbered standing position. The stroke rates are listed in Table I for the male students together with the foot control characteristics defined in Fig. 1a. A minimum force is recorded for each candidate that represents the force applied to the lip of the foot pedal which just activates the control. Table I indicates that for each of the four popular foot control candidates the reciprocating action is slightly faster than the pivoting action. Only modest differences are found among the stroke rates for the various styles.

Open to continue →→

In 1983, a second test program was conducted using an operator population ranging in age from 17 to 67 years; fifteen males and eight females. The protocol was similar to the 1980 program with one additional constraint; the operators were asked to maintain a 1/16 inch diameter probe in the center of a 1/2 inch diameter hole in a horizontal plate located 37 inches above the floor as illustrated in Fig. 3. The 1/2 inch diameter was determined during a protocol development program involving nine male and five female student subjects. Each centered a probe for 30 seconds in various diameter holes while standing with both feet fixed on the floor. One contact error was made in 420 seconds using the 1/2 inch diameter hole.

Table II tabulates stroke rates for male and female operators in the pivoting and reciprocating modes during a probe centering exercise. The following observations are relevant:

- In every instance, the reciprocating action is found to be somewhat faster than the pivoting action.
- The male is slightly faster than the female under equivalent circumstances.
- The unencumbered stroke rates are uniformly greater than the stroke rates obtained while attempting to keep a probe centered.
- The differences among the various foot control candidates are modest.

III. HAND STEADINESS

The requirement for steady hands arises in the precision placement and removal of parts from a machine's point of operation, holding of workpieces in a fixed position throughout a machine cycle, gauging of dies under dynamic conditions, and the simultaneous application of hand and foot controls. To measure hand steadiness, a position location task was designed involving the centering of a 1/16 inch diameter probe in a 1/2 inch diameter hole drilled in a horizontal plate held 37 inches from the floor. Figure 3 indicates that the plate was held in a small O.B.I. power press and that a metronome was used to pace a steady state tripping activity. Two types of operator error were studied; probe-plate contact and total contact time. The number of contacts made between the probe and the plate was measured by a simple counter triggered by electrical continuity. A timer was substituted to accumulate the total contact time. The common protocol characteristics for the two test programs were:

Goal

For each foot control candidate, the operators tried to minimize, depending on the program, either the frequency of probe contacts or total contact time while executing activation strokes every 2 seconds for a 30 second period. This corresponds to a production rate of 30 strokes/minute which is reasonably brisk. The controls were tripped in either the pivoting mode or the reciprocating mode.

Position

After positioning by the operators, the foot controls were restrained in a fixed location. Operators used their dominant hands to guide the probe.

Practice

One practice run was executed for each foot control candidate in each activation mode.

Fidelity

The operators were monitored to stay in rhythm with the metronome while strictly adhering to the definitions of pivoting and reciprocating activation for the standing position.

The hand steadiness test program was conducted in 1983. Contact frequency tests were performed using a sample population with subjects ranging in age from 16 to 59 years; twenty-one males and eight females. The same four foot control candidates were used that were studied in the previous test programs. No plate contact was recorded for any of the twenty-nine test subjects when they centered the probe under non-operating static conditions; both feet held stationary on the floor for a 30 second period.

The frequency of contact errors for the pivoting and reciprocating activation modes is displayed in Table III where the data for the four foot controls have been combined; the same number of tests was performed with each candidate. No difference was found between the pivoting and reciprocating modes for either male or female subjects. On the other hand, with respect to "error rate," the male is significantly lower than the female.

When hand precision is required throughout a task, its complement, *imprecision*, can be measured directly as total contact time between the probe and plate. Following the same protocol used in the contact frequency study with the substitution of a timer for the counter, a fourth and final test program was conducted in 1984 using subjects ranging in age from 17 to 59 years; they consisted of eighteen males and eight females. The three foot control candidates used are characterized in Table IV, i.e.:

1. *Linemaster, Clipper, No. 632-S*
2. *Rees, Style 1814*
3. *Linemaster, Hercules, No. 533-SW*

The results of the total contact time determinations are tabulated in Table IV where the pivoting mode demonstrates a clear advantage over the reciprocating mode for every candidate and for both male and female operators. The male performance is considerably better than the female.

IV. CONCLUSIONS AND OBSERVATIONS

1. During rapid reciprocation, an operator is balanced and supported on one leg most of the time. The other leg and foot undergo large movements. In contrast, pivoting requires very small rotations of one leg and foot while both legs always share the operator's weight. Maintaining one's balance using only one leg is much more difficult than standing flat-footed on one leg with the heel of the other planted in one position. Based on this observation, it was hypothesized that higher stroke rates and steadier hand control would be achieved using the pivoting activation method.

2. In every experiment the reciprocating action was faster than the pivoting action. We are reminded once again of the quotation by Thomas Henry Huxley (1825-1895), "The great tragedy of Science – the slaying of a beautiful hypothesis by an ugly fact."

3. Four popular open-sided foot controls were used in the various testing programs. For each candidate the reciprocating stroke rate was slightly higher than the pivoting rate. This finding was obtained for male and female subjects operating in the standing position with their hands unencumbered or with their hands committed to a probe centering task. As expected, the encumbered scenario led to lower stroke rates than the unconstrained operations.

4. There were only small differences in stroke rate among the four candidates. Nevertheless, the simple Linemaster Clipper was always superior.

5. In every experiment the males were somewhat faster than the females.

6. As a practical matter, when hand steadiness is not important our experimental data do not support any favoritism among the foot control candidates, male and female operators or reciprocating and pivoting activation schemes. The mean values for comparable events are all close and their associated coefficients of variation are all large.

7. Foot control tripping schemes that minimize the frequency of probe-plate contact errors are useful in situations where it is critical to avoid accidental activation of hand controls while simultaneously executing foot signals. The "error-rates" for the pivoting and reciprocating modes were found to be statistically identical in the experiments summarized in Table III. Based on a small sample population of females, the males appear to be significantly more efficient.

8. Where precision hand placement is required throughout a machine's cycle, the total probe-plate contact time is an appropriate statistical variate for correlating contact error. In this arena, the pivoting mode is significantly better than the reciprocating mode as originally hypothesized. Combining the results summarized in Table IV for the three foot control candidates, we find that the mean contact time for male-reciprocating is 29.06% greater than for male-pivoting; female-reciprocating is 46.84% greater than female-pivoting. The male performance is found to be more "error free" than the female.

9. All of the foregoing findings are useful for comparing the two most widely used foot control concepts; the open-sided and side-shielded models. To reduce the probability of accidental activation, side shields were incorporated into foot controls to limit the corridors which access the foot pedal. The reduction is dramatic and usually precludes advertent tripping by the pivoting method.

   a. The open-sided models will be less fatiguing than the side-shielded ones because operators are able to switch between the pivoting and reciprocating modes without significant compromise in the stroke-rate.

   b. The side-shielded models offer no relief from the demands of continual reciprocation except "riding the pedal."

   c. Neither the open-sided nor side-shielded models offers an advantage where only initial hand accuracy is required.

   d. When hand steadiness is necessary throughout a machine cycle, the open-sided models used with pivoting action are substantially better than the side-shielded models which must be activated by reciprocation. This conclusion assumes that safety considerations preclude "riding the pedal" as a viable method.

   e. When riding the pedal is acceptable, either the "riding the pedal" or the "hold/down release" strategies will provide support on both feet throughout the machine cycle. These activation scenarios lead to almost error free hand performance and may be used with any style foot controls.

   Experience with these tripping modes was accumulated during the protocol development program and during the second, third, and fourth test programs. Each program included a 30 second probe centering task where operators kept both feet fixed on the floor. The protocol development program used fourteen subjects; a single probe-plate contact error was observed in 420 seconds of probing. In the second test program twenty-three subjects participated in the static probe task with a combined probing time of 690 seconds; one of the operators made a single contact and another made three contacts. In the third test program no contacts were made; twenty-nine subjects logged a combined probing time of 870 seconds. The fourth test program involved twenty-six subjects with a combined static probing time of 780 seconds. Four participants accumulated 0.62 seconds of probe-plate contact time giving an error rate of 0.62/780 or 0.0795%. During the dynamic testing phase, 171.47 seconds of probe-plate contact error were logged during 4680 seconds of probing; here, the error rate is 171.47/4680 or 3.66%. The static error rate is only 2.2% of the dynamic error rate.

   f. When hand steadiness is important, "riding the pedal" and "hold down/release" are far and away the most efficient activation strategies for foot controls. As a consequence, the motivation is enormous for abandoning the safer pivoting or reciprocating activation methods.

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Table I - Foot Controls: Characteristics and Stroke Rates

Foot Controls	Pedal Height (in.)	Vertical Clearance (in.)	Activation		Reciprocating Strokes / 30 sec.		Pivoting Strokes / 30 sec.	
			Throw (in.)	Min. Force (lbs.)	Mean	St'd. Dev.	Mean	St'd. Dev.
Linemaster - Clipper No. 632-S	1.375	3.0	0.375	7.0	48.72	8.95	47.06	8.90
Rees Style 1814	1.5	3.0	0.50	12.0	48.36	10.40	44.89	8.58
Square D Type AW2	1.5	2.625	0.50	5.0	47.66	12.59	42.03	11.70
Linemaster - Hercules No. 533-SW	1.75	2.625	0.75	7.5	46.69	7.73	43.86	7.91

Table II - Foot Controls: Strokes/30 Sec. While Centering Probe

Foot Controls	Male				Female			
	Reciprocating		Pivoting		Reciprocating		Pivoting	
Linemaster - Clipper No. 632-S	Mean	46.67	Mean	44.40	Mean	44.88	Mean	42.00
	St'd. Dev.	6.30	St'd. Dev.	5.12	St'd. Dev.	3.31	St'd. Dev.	4.84
Rees Style 1814	Mean	43.00	Mean	39.53	Mean	40.25	Mean	36.63
	St'd. Dev.	6.04	St'd. Dev.	4.37	St'd. Dev.	3.73	St'd. Dev.	4.78
Square D Type AW2	Mean	40.13	Mean	39.13	Mean	38.88	Mean	35.25
	St'd. Dev.	6.77	St'd. Dev.	3.85	St'd. Dev.	6.22	St'd. Dev.	6.45
Linemaster - Hercules No. 533-SW	Mean	45.00	Mean	42.60	Mean	42.25	Mean	38.88
	St'd. Dev.	4.46	St'd. Dev.	4.67	St'd. Dev.	3.77	St'd. Dev.	5.41

Table III - Frequency of Probe-Plate Contacts - 30 Second Event

Tripping Mode	Male (Errors Per Thirty Seconds)			Female (Errors Per Thirty Seconds)		
	Total Number of Contact Errors	Contact Errors Per Operator		Total Number of Contact Errors	Contact Errors Per Operator	
Reciprocating	152	Mean	1.81	79	Mean	2.47
		St'd. Dev.	1.25		St'd. Dev.	1.82
Pivoting	156	Mean	1.86	77	Mean	2.41
		St'd. Dev.	1.25		St'd. Dev.	1.81

Table IV - Total Probe-Plate Contact Time - 30 Second Event

Foot Controls	Male				Female			
	Reciprocating (Seconds)		Pivoting (Seconds)		Reciprocating (Seconds)		Pivoting (Seconds)	
Linemaster - Clipper No. 632-S	Mean	0.95	Mean	0.59	Mean	1.86	Mean	1.14
	St'd. Dev.	1.06	St'd. Dev.	0.53	St'd. Dev.	1.96	St'd. Dev.	1.18
Rees Style 1814	Mean	0.82	Mean	0.63	Mean	1.78	Mean	1.16
	St'd. Dev.	0.87	St'd. Dev.	0.52	St'd. Dev.	1.99	St'd. Dev.	1.18
Linemaster - Hercules No. 533-SW	Mean	1.25	Mean	1.12	Mean	1.94	Mean	1.50
	St'd. Dev.	1.45	St'd. Dev.	1.26	St'd. Dev.	2.04	St'd. Dev.	1.66

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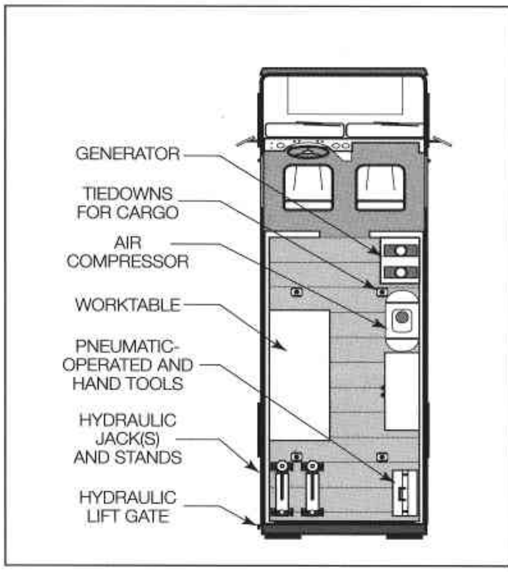

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