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THE ERGONOMICS OF MACHINE GUARDING

Published by the
DEPARTMENT of LABOUR · NEW ZEALAND

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FOREWORD

Sections 15, 16 and 17 of the Machinery Act 1950 require moving parts of prime movers, every part of transmission machinery and every dangerous part of any machinery to be securely fenced unless it is in such a position or of such construction as to be as safe to every person employed or working on the premises as it would be if securely fenced.

These sections of the Act have received judicial consideration both in criminal and civil proceedings and the requirements of the law have been enunciated in several Court decisions. Instead of reproducing these decisions, we thought it would be more helpful to machine designers and owners to provide some guide to the principles which should be followed in the construction of machine guards based on human measurements.

A considerable amount of research and experimentation was undertaken by officers of the Department of Labour to obtain reliable data on human measurements and to determine the standards required to comply with the law.

This booklet contains the results of this research and should provide a uniform approach to machine guarding by everybody concerned with this problem.

We hope this information will be of assistance to designers and owners of machines.

Published by the Occupational Safety and Health Service
Department of Labour
Wellington
New Zealand

Issued: 1979

Pdf file for web site created April 2000

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THE ERGONOMICS OF MACHINE GUARDING

ERGONOMICS is an important and comparatively new science. It gets its name from the word erg, defined in the dictionary as a unit of work. Ergonomics, then, is the science of work—but in a limited kind of way. It deals with the relationship between man and his working environment, or more particularly, with the limitation which human size, strength, shape and function place upon the work a man can do. Because of these limitations, man's working environment needs to be planned to suit his capacities—his eyesight, his reach, his height, his strength, his speed of movement, and so on.

Ergonomics is not, strictly speaking, a scientific discipline in its own right, but it draws upon and co-ordinates in its field of interest the research and findings of other scientific disciplines. Principally, it applies anatomical, physiological, sociological, and psychological knowledge to the study of the working environment, including the machines man works with, the workplaces in which they are situated, the design of machine controls, seating, lighting, and other factors.

The findings of ergonomics, and especially data on human measurements, have an important influence upon the proper design of machine guards.

Reach

A person can reach—
- UPWARDS
- OVER
- AROUND OR ALONG
- INTO

These capacities are illustrated in Fig. 1. Reach is limited by the arms and, in the case of openings, by fingers and hands also. The distance a man can reach determines the minimum height of certain kinds of guards, or the minimum distance of barriers from the machines they are intended to fence.

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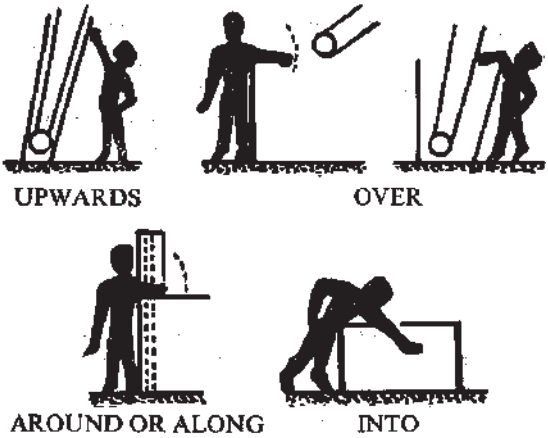

Fig.1 Showing various types of reach in relation to the guarding of machinery

Reach Upwards

Schroeder in *Anatomy for Interior Designers* places the average limit of reach when on tiptoes at 2400 mm. No doubt many can reach further, and it is probably for this reason that the *International Safety Code* published by the International Labour Office at Geneva establishes 2600 mm as the dividing line beyond which positional safety is assumed.

In New Zealand, the Department of Labour has adopted 2440 mm from the working surface as a reasonable limit of reach upwards. In doing so, it has applied administratively the tests laid down in two English legal decisions, Burns *v.* Joseph Terry& Sons Ltd (1950), and Carrol *v.* Andrew Barclay & Sons Ltd (1948), where it was decided that the question to be answered was: "Is a dangerous part *so fenced or so placed* as to give security from such dangers as may be a possible cause of injury to anybody acting in a way a human being may be *reasonably expected to act* in circumstances which may *reasonably be expected to occur?"*

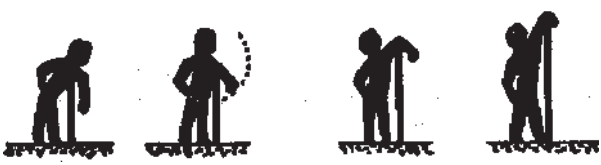

Fig.2 Reach over a barrier

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A dangerous part that is beyond an upward reach of 2440 mm is regarded as notionally safe by position unless the particular facts destroy that possibility. *On the other hand, a dangerous part that is within 2440 mm should be fenced.*

Reach Over Barriers

It is common practice with some types of machinery to fence it with a barrier and then regard it as safe by position. How far should it be from such a barrier?

Reach over a barrier is interrupted by the body at the point of contact with the barrier. Where the barrier is low, the body can be bent and therefore the extent of reach is longer than the arm. Where the barrier is at armpit height, reach is equal to the length of the arm. If the barrier is above shoulder height, interruption is at the elbow, or when higher still, at the wrist or fingers. This is illustrated in Fig. 2.

Figure 3 supplies a table showing the distance in mm that guards of

Distance of guards from transmission for guard heights of:-

Height of transmission from floor level	1220	1370	1520	1680	1830	1980	2130	2280	2440
2440	0	0	0	0	0	0	0	0	0
2360	230	230	230	230	230	150	130	100	
2280	380	380	380	380	300	230	180	100	
2210	530	530	530	460	380	300	200	0	
2130	610	610	610	530	460	300	200		
2060	680	610	610	610	460	300	80		
1980	760	680	680	610	460	300	0		
1900	840	680	680	610	460	230			
1830	840	760	680	610	460	0			
1750	910	760	680	610	460				
1680	910	760	680	610	380				
1600	910	760	680	610	380				
1520	910	760	680	610	230				
1450	910	760	680	530	0				
1370	910	760	680	460					
1300	910	760	680	380					
1220	910	760	610	0					
1140	910	760	610						
1070	910	680	530						
990	910	680	460						
910	840	610	300						
840	840	530	0						
760	760	380							
680	610	150							
610	530	0							
530	380								
460	0								
380									
300									

When the guard is positionned close to the transmission, consideration must be given to the size of any opening in the guard.

Fig.3

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various heights should be from dangerous parts (transmission machinery) of various heights to conform to these principles of average human reach.

A man's arm reaching over a barrier can describe a curve. It is the curve which determines at what distances from the barrier dangerous parts of machinery of varying heights are safe by position. series of curves experimentally determined are contained in the graph shown as Fig. 4. Each curve is marked with its relative barrier or guard height. These curves are the basis of the table in Fig. 3.

How are the table and graph used in practice?

Consider the table (Fig. 3) first. The left column gives the height of the transmission or dangerous part to be fenced. Imagine that this is 1370 mm. Place a ruler across the table immediately below 1370 mm in the left column, and the columns to the right will give the distances the guard should be from the transmission or dangerous part for the various guard heights given at the head of the columns.

The reach curves (Fig. 4) are interpreted in a similar fashion. To calculate again the guard distance for transmission 1370 mm from the floor or working platform, place a pencil at the point 1370 mm up the left side of the graph, and follow this line across to the right until it intersects the reach curves. Each of these is marked with the height of the guard to which it applies. At the point of intersection, place a ruler vertically and read off on the bottom scale of the graph the distance of reach. Thus, the 1370 mm line intersects the reach curve for a guard 1520 mm high at a point which indicates (reading the bottom scale) that a guard of the height should be placed 680 mm from the transmission. The other reach curves gives distances for guards of different heights:

Height of Transmission or Dangerous Part	*Height of Guard*	*Distance of Guards from Transmission, etc.*
1370 mm	1220 mm	940 mm
1370 mm	1370 mm	780 mm
1370 mm	1520 mm	680 mm
1370 mm	1680 mm	480 mm
1370 mm	1830 mm	Working clearance

The manner of measuring the guard distance is important. The distance of the guard is the *horizontal measurement from the plane of the guard of the height shown to the transmission or dangerous part. The point at which the*

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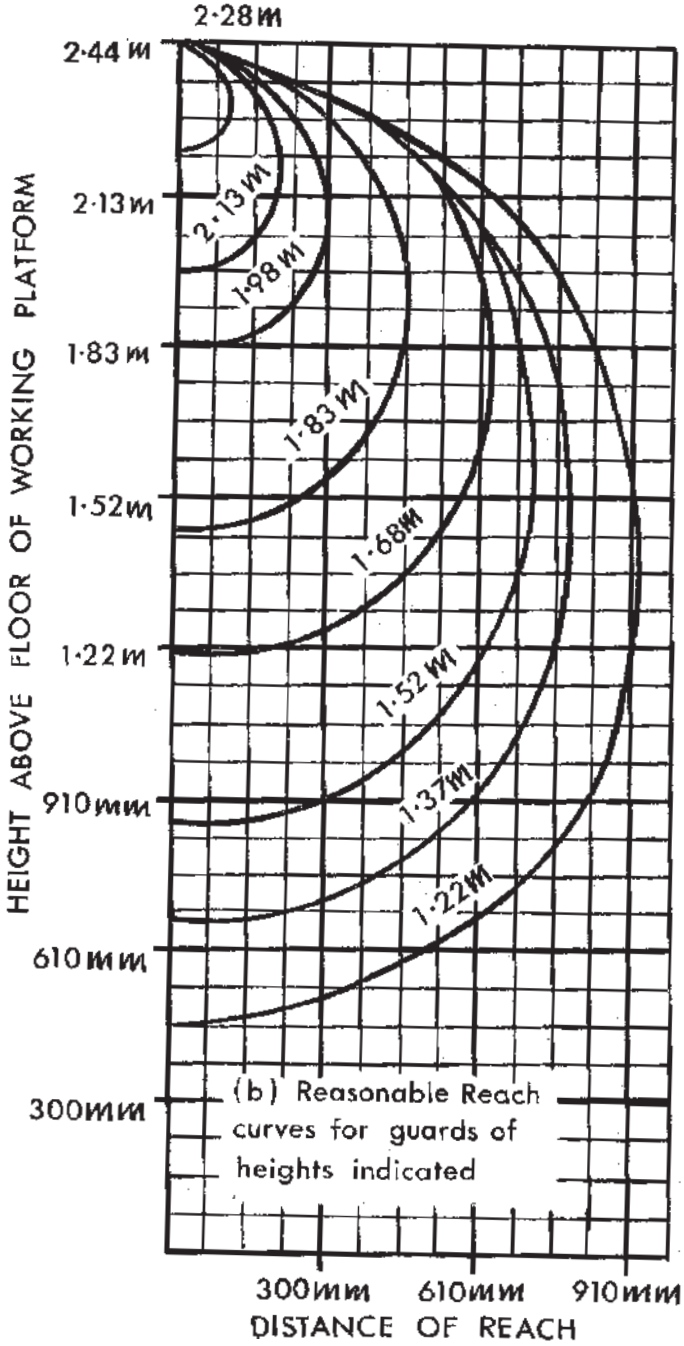
2·28m
2·44m
2·13m
1·83m
1·52m
1·22m
910mm
610mm
300mm
HEIGHT ABOVE FLOOR OF WORKING PLATFORM
2·13m
1·98m
1·83m
1·68m
1·52m
1·37m
1·22m
(b) Reasonable Reach curves for guards of heights indicated
300mm
610mm
910mm
DISTANCE OF REACH

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measurement is to be taken is where the transmission or dangerous part contacts the reach curve. This is not necessarily the part of the transmission that is nearest to the plane of the guard. This is made clear in Fig. 5, where the two illustrations of transmission nearest the plane of the guard do not enter the reasonable reach zone.

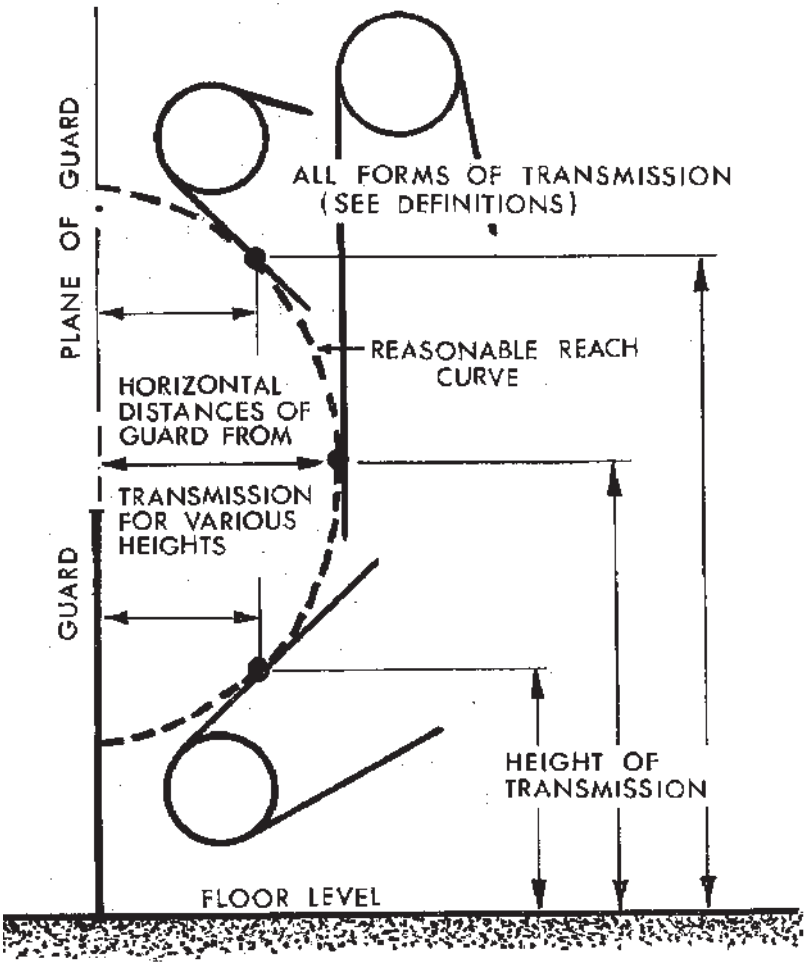

Fig.5 Illustrating how to measure guard distances

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Fig. 6 Reach into containers

Reach into Containers

Reach into containers is really the same as reach over barriers. The height of the side of the container determines the extent of the reach (Fig. 6.) By experience, the reasonable reach zone for containers of various heights can be determined in the same way as for barriers. This is shown in Fig. 7.

In order to present a complete range, the graph includes cases where an individual lies, for example, on the floor in order to reach into a container. It should not be overlooked that an unfenced opening permitting such an action is probably in breach of the secure fencing requirements of the law.

Reach Around Barriers

In this case reach depends upon the distance that the side of the barrier extends from the body position. When the body is close to a low barrier reach is longer than the length of the arm because the body may be bent.

A side on the barrier (Fig. 8a) means that reach is interrupted by the elbow joint. If the side is longer, the wrist interrupts reach. Where the barrier is horizontal (Fig 8b), reach again is interrupted by the elbow joint and wrist. Fig 8c shows the effective reach when the arm must be placed first through an opening and then around a barrier.

The reasonable reach values already given may be used as a basis for determining the extent of reach around barriers. The ability to reach around barriers is determined by the distance of the elbow joint and wrist joint from the reach curve (i.e., from the finger tip). In the experiments which led to the determination of reach curves, the elbow joint was found to be an average of 460 mm from the finger tip. Therefore, if an additional barrier is placed with its edge only 430 mm (or less) from the curve, the forearm cannot be fully bent around it. This is illustrated in Fig. 9.

However, if the arm is retracted until the wrist is near the edge of the additional barrier, the hand can be bent around the barrier and may reach the dangerous part if it is too close. It has been found by experience that it is not reasonable to expect the hand to reach as far as 200 mm around that point (Fig.10a).

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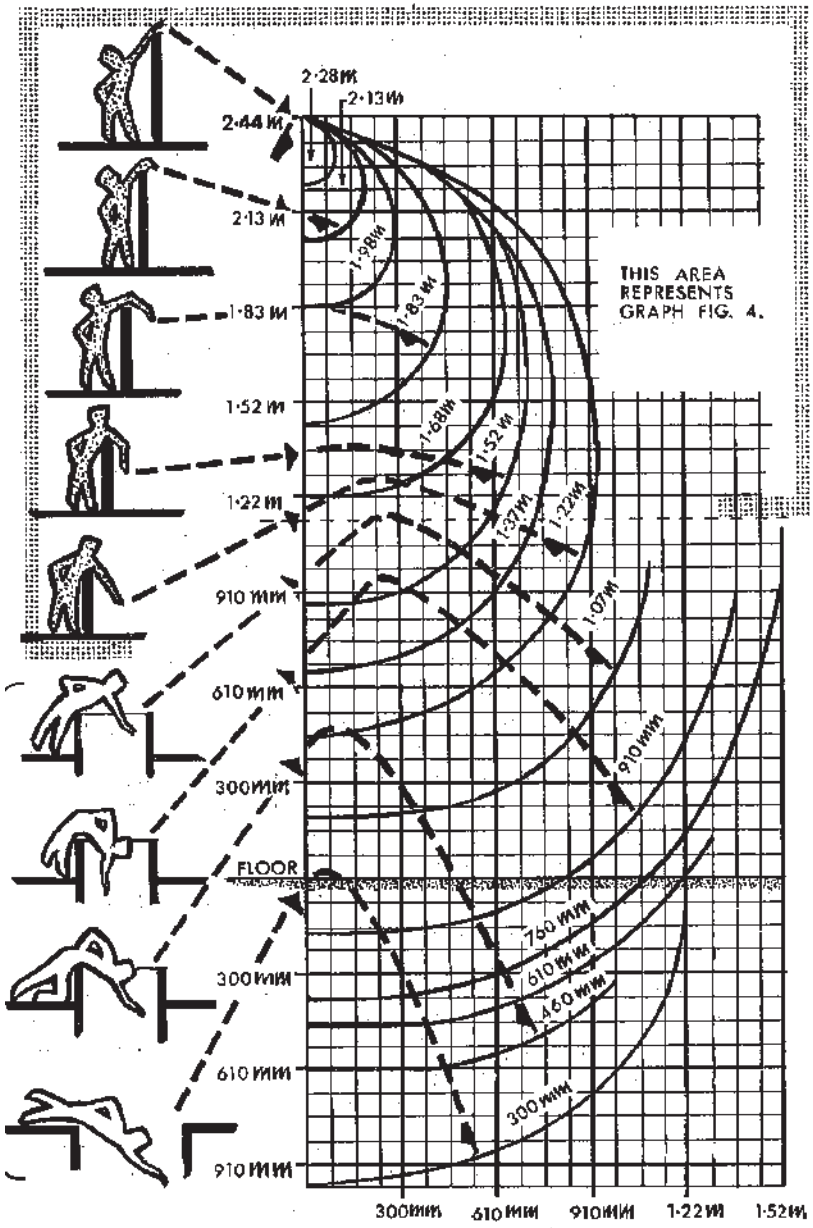

Fig.7 Reasonable reach curves for containers of various heights

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Fig.8 (a)

Fig.8 (b)

Fig.8 (c)

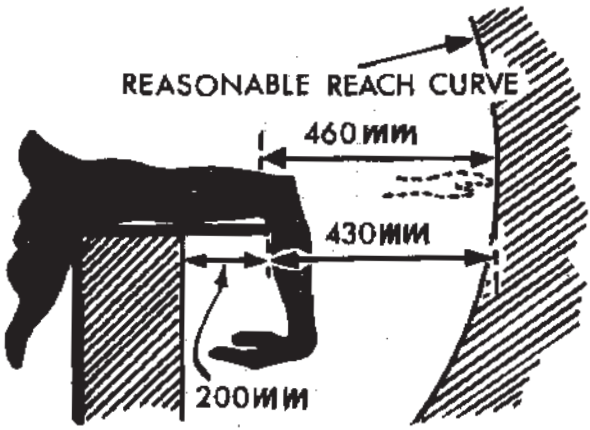

Fig.9 The ability to reach round this horizontal barrier is determined by the distance of the elbow joint from the reach curve. When the edge of the barrier is 430 mm or less from the reach curve, the shaded area can be reckoned to be "safe by position" since no part of the arm or hand can reach into it.

The reach of a hand bent round the end of a barrier will therefore be a curve of radius 200 mm with a centre point at the end of the barrier (Fig. l0b).

When the whole hand cannot be bent round a barrier or guard, it may be possible to bend the fingers round it.

The reach of the fingers alone has been found not generally to exceed an 80 mm radius (Fig. 10c).

The practical application of these findings is as follows:

(i) If the edge of the additional (horizontal) barrier is 460 mm or more from the reach curve, the whole forearm and hand can be

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bent round it, and therefore the additional barrier is ineffective in providing a safe area below it.

(ii) If the edge of the additional barrier is 430 mm from the reach curve, the forearm and hand can be partly bent round it as shown in Fig. 9, but the barrier has increased the safe-by-position area to the whole of the space shaded in the drawing. The arm can still reach out and down but not back under the barrier, but the hand can reach underneath the barrier to a distance of almost 200 mm from the edge.

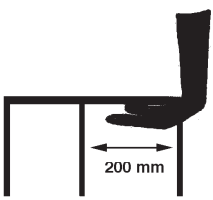

Fig.10 (a)

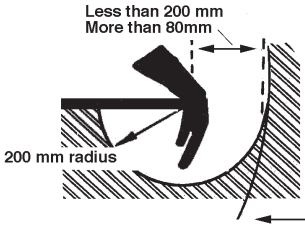

Fig.10 (b)

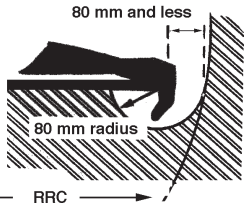

Fig.10 (c)

(iii) If the edge of the additional barrier is less than 430 mm from the reach curve, the arm can still be partly bent round it, though not so far as in Fig. 9. (Look at Fig. 9 and imagine the effect of widening the barrier, say, by 80 mm). The nearer the edge of the additional barrier is to the reach curve the less can the arm be bent round it, until at 200 mm from the reach curve it is no longer possible because the arm is fully extended forwards for the wrist to reach the edge of the barrier. In all these positions of the barrier, it is still possible for the *hand* to reach back underneath the barrier to a maximum of nearly 200 mm from the edge, and therefore this space below the barrier is unsafe (as well as any space in front of the barrier which can be reached by the bent arm and hand).

(iv) When the edge of the additional barrier is only 200 mm from the reach curve, the hand alone can be bent round it. Therefore any dangerous part should be beyond a 200 mm radius from the edge of the barrier. This is shown in Fig. 10b where the shaded area is safe by position. If the barrier *is less* than 200 mm from the reach curve, the bending of the hand becomes more restricted, until at 80 mm only the fingers can be curled under the barrier.

(v) If the fingers alone can be bent round the edge of the barrier, any dangerous part should be beyond 80 mm radius from the edge of the barrier. See Fig. 10c where the shaded area is safe by position.

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The reasonable reach curves are determined as in Figs 3 and 4. Thus, it the barrier is 1220 mm high, the graph in Fig. 4 shows that the reach curve will extend from a height of 460 mm to a height of 2440 mm and to a depth of 940 mm. Therefore, an additional horizontal barrier 460mm wide will be inadequate to prevent the arm being bent round it as it would leave a further 480 mm from the edge of the barrier to the curve. An additional barrier 510 mm wide would leave 430 mm between the edge and the curve, and would increase the safe-by-position space as in (iii) above. If the barrier were 760 mm wide, it would leave 180 mm from the edge to the curve and it would not be possible to fully bend the hand round it, thus increasing the safe-by-position area further. A barrier 860 mm wide would leave room for finger reach only, and except for a radius of 80mm from the edge of the additional barrier all the space beneath the barrier could be assumed to be safe by position.

Openings, Admitting the Fingers or Hand

It can be assumed for practical purposes that there is no reach possible through an opening less than 10 mm square as the fingers cannot be admitted (Fig. 11a). If the opening will admit one, two or three fingers, the reach is restricted by the roots of the fingers (Fig.11b). Hence the distance between the guard and the transmission needs to be no greater than the reasonable maximum length of the longest finger plus a clearance allowance.

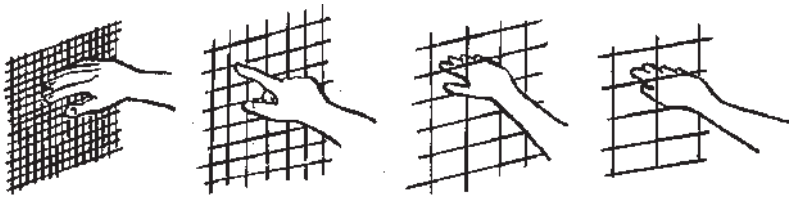

Fig.11 (a) *Fig.11 (b)* *Fig.11 (c)* *Fig.11 (d)*

If all four fingers can be admitted through the one opening, the size and shape of the opening will be an important factor in determining the extent of reach possible. In some cases, reach will be limited by the root of the thumb, and in others by the thickness of the hand, the wrist or the arm. In a case where reach is restricted by the root of the thumb (Fig. 11c), the distance necessary is the reasonable maximum length of a hand from finger tip to root of thumb, plus clearance.

However, it cannot be overlooked that the thumb can be folded within the palm of the hand. (Fig. 11d), and that the width of the hand in such

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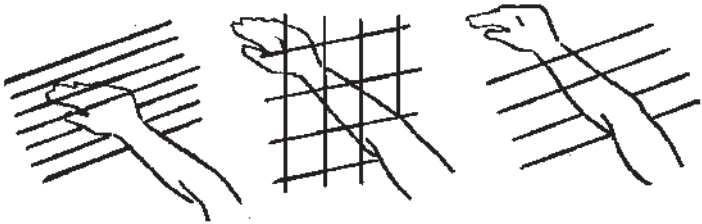

Fig.12 (a) *Fig.12 (b)* *Fig.12 (c)*

cases is the width of the palm. However, the depth of the hand is so increased that the reach through an opening is limited by the thickness of the hand and thumb folded in.

Where the opening admits four fingers and a thumb, reach is limited by the thickness of the hand as in Fig.12a, or of the wrist and arm at various points as in Figs.12b, 12c, 12d and 12e. Thus the distance of the guard from the dangerous parts is determined by the maximum reasonable length of fingers and hand, or of fingers, hand and arm at different points.

If the opening is sufficient to admit the whole arm and a portion of the shoulder (but excludes the head and trunk) the reasonable reach is assessed as the distance from fingertips to armpit—determined by experiment as not less than 840 mm. See Fig. 13.

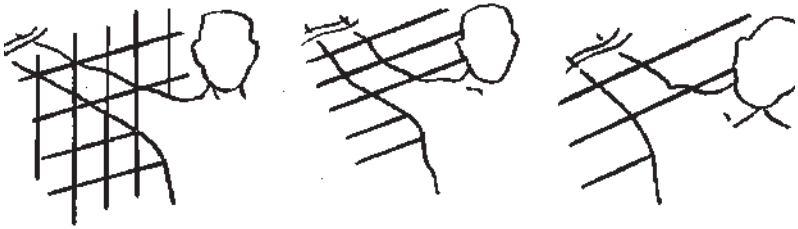

Fig. 12 (d) *Fig.12 (e)* *Fig.13*

Reach Through Elongated (or Parallel) Openings

Several formulae have been developed overseas to assess the maximum permissible sizes of openings for guards at different distances from dangerous parts, where the openings are elongated. Probably the two best known are those cited by Imperial Chemical Industries Limited and by H.A. Hepburn, B.Sc. (Eng.), A.M.I.Mech.E., who was at one time Chief Inspector of Factories in the United Kingdom. These two formulae have

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been modified by the NZ Department of Labour as a result of its own measurements on a number of persons, and the following formula is now being applied by the Department:

$$Y = \frac{X}{10} + 6\text{mm}$$

where x equals the distance of the opening from the transmission or dangerous part and y equals the maximum permissible opening in the guard.

Example: 200/10 + 6 = 20 + 6 = 26 mm opening. This formula is not valid for distances in excess of 760 mm. (i.e. 82 mm opening).

The formula is plotted graphically in Fig. 14. The continuous line "safe average" was first drawn to full scale from a point equivalent to a 12.5 mm opening at 44.5 mm distance on the "small woman" graph to the point "large man". This line excluded two points on the small woman" graph and was found to be unwieldy when expressed as a formula. A line was then drawn from a point at zero distance equivalent to a 6 mm opening to an upper point at 82 mm equivalent to "large man (actual)". This line provided a convenient formula and embraced all but one point on the "small woman" graph, this point being only 1.5 mm below the line. The "safe average" line on the graph is equivalent to the Departmental formula quoted above.

Departmental Assessment of Reach Values Through Openings

The preceding paragraphs contain the theory and results of experiments on which the Departmental requirements are based. These requirements are the practical application of this theory, and are as follows:

Elongated (Parallel) Openings

(i) Openings up to 6 mm apart can be treated as so small as to be insignificant. Therefore, the guard is virtually the same as sheet and a working clearance of 25 mm is all that is required.

(ii) Openings above 6 mm apart but not greater than 13 mm will admit part of a finger. Therefore, the distance required is 50 mm, that is part of a finger plus a working clearance.

(iii) Openings in excess of 13 mm but not greater than 82 mm are subject to the formula:

$$y = \frac{X}{10} + 6 \text{ mm}$$

(iv) The distance between the guard and the dangerous part in the case

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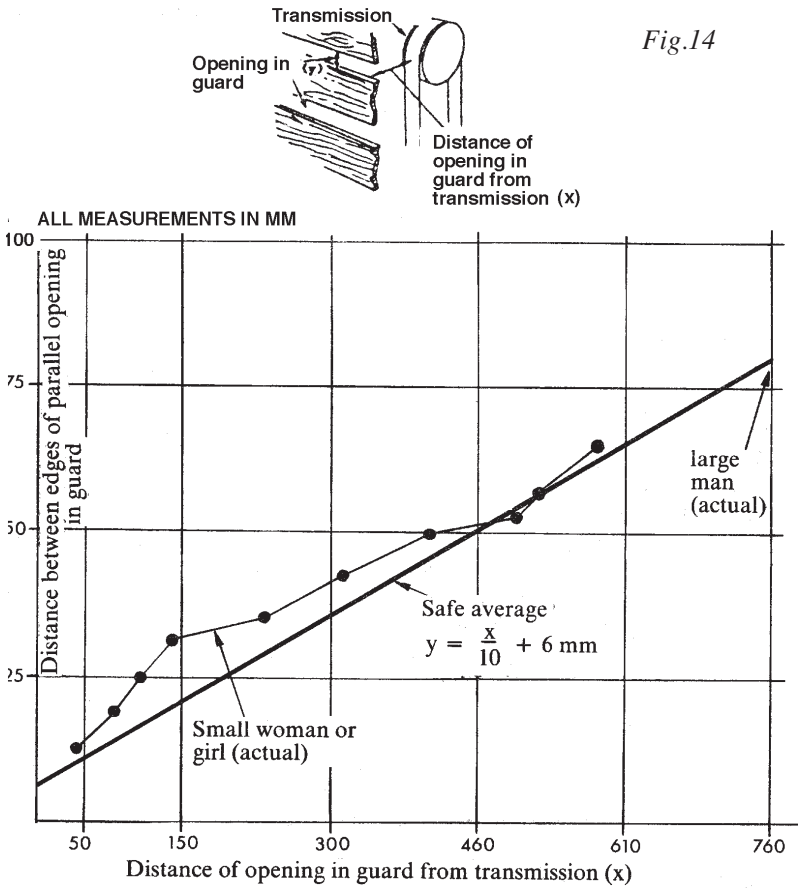

Fig.14

of an opening between 82 mm and 152 mm should not be less than 840 mm.

(v) Openings in excess of 152mm are subject to the reasonable reach values over guards set out in the early part of this booklet.

Square Openings

Although strictly speaking a square opening is a parallel opening, it has been found that the general rules above for parallel openings cannot be satisfactorily applied to small square openings because the length of the parallels is circumscribed by the other sides of the square — i.e., they are not *elongated* openings in the sense used above.

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The following rules apply to square openings:

(i) For openings up to 38 mm square, apply distances as given in Fig. 15. (These distances may also be applied to round openings of diameters equivalent to the squares indicated, and to other shapes such as rectangles and diamonds of diagonal measurement up to 54 mm).

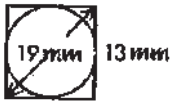
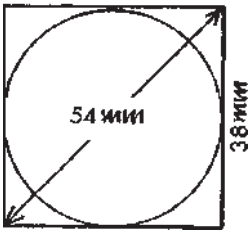
Openings in guard (up to and including dimensions shown)	Distance between guard and dangerous part	How distance derived
	25 mm	Virtually same as sheet, working clearance only
	50mm	Part of finger length plus working clearance
	100mm	Finger length plus working clearance

Fig.15

(ii) Square openings above 38 mm but not greater than 82 mm are subject to the formula:

$$Y = \frac{X}{10} + 6 \text{ mm}$$

(iii) The distance between the guard and the dangerous part in the case of an opening between 82 mm and 152 mm square must not be less than 840 mm.

(iv) Openings in excess of 152 mm square are subject to the reasonable reach values over guards set out earlier.

Round Openings

(i) Openings up to 38 mm diameter: follow rule (i) for square openings. See Fig. 15.

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(ii) Openings between 38 mm and 50 mm diameter: the minimum acceptable distance between the opening and the dangerous part is 152 mm. For an explanation, see note below.

(iii) Openings over 50 mm and up to 82 mm diameter are subject to the formula:

$$Y = \frac{X}{10} + 6 \text{ mm}$$

(iv) Openings in excess of 82 mm diameter: apply reasonable reach values over guards.

NOTE: It has been ascertained by experience that an opening 38 mm square is the maximum safe opening permissible at a distance of 100 mm from the dangerous part. Where the opening is 50 mm square, a small hand can be inserted, thus making it necessary to apply the rule of reach through openings. In the case of an opening 44 mm square, a small hand can almost be squeezed through, but in any case the reach through this opening is at least 114 mm.

Experiment has also shown that whereas a small hand can be inserted through a 50 mm square opening, it is not possible to do this with a round opening of 50 mm diameter, though it is possible if the diameter is increased to 57 mm.

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