WHITE PAPER

SAFETY DISTANCE CONSIDERATIONS FOR DEVICES AS ADDRESSED IN THE UPDATED ANSI B11.19 STANDARD

Part 5 of 6 in a series addressing the new edition of ANSI B11.19

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Introduction

When applying engineering control devices to reduce risk to individuals in the workplace, there are many topics to consider. A basic understanding of the performance and design requirements for individual components used for risk reduction is crucial to ensure the proper devices are selected for safety applications. In recent years, much attention has been given to the concept of functional safety, with great concentration on Performance Levels (PL) according to ISO 13849-1 and Safety Integrity Levels (SIL) as defined in IEC 62061. The five core pillars of functional safety have been the subject of many standards, articles, and training courses in recent years.

However, one of the key topics which should not be forgotten or overlooked is the concept of *safety distance*. *Safety distance* is defined as “the minimum distance an engineered control (guard or device) is installed from a hazard such that individuals are not exposed to the hazard.” *Safety distance* considerations addressed in the newest edition of ANSI B11.19 specific to guards and other protective structures was examined in Part 4 of this white paper series. This included discussion of the basic machine safeguarding tenet described with the acronym *AUTO* – a person should not be able to reach *Around, Under, Through* or *Over* a guard to reach the hazard.

As it turns out, the *AUTO* principles also apply to protective devices to provide effective risk reduction for individuals. Figure 1 represents application of a light curtain with disregard to the *AUTO* concepts. Furthermore, other related considerations must also be considered, such as angle of the sensing field (detection zone), depth of field, and minimum / maximum height requirements. This white paper is intended as a basic introduction to these concepts, with added focus given to the additions and modifications made in the recent revision to ANSI B11.19.

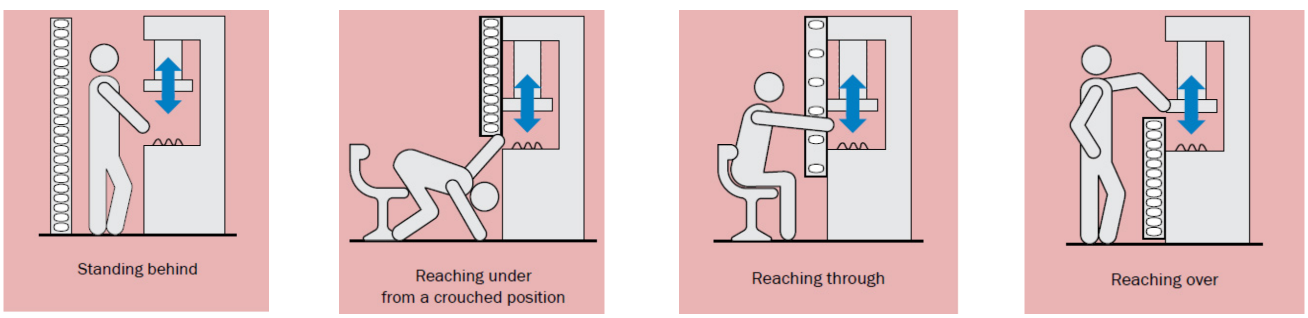

Figure 1 – Improper application of the *AUTO* principles

New Variables

A brief overview of variables was explored in Part 4 of this white paper series. As discussed there, variables are an important element of many standards where results are dependent upon other factors. A variable is a symbolic name or reference to information. Although the represented information can change, the operations on the variable remain the same.

While the previous (2010) edition of ANSI B11.19 had nine variables related to *safety distance* considerations for devices, the enhanced guidance provided in the 2019 edition required seven additional variables to add increased clarity. Additionally, the new edition of ANSI B11.19 is now more closely aligned with similar requirements in several international (ISO and IEC) and European (EN) standards to achieve a comparable level of risk reduction. As discussed in the previous white paper of this series however, the international and European models for standardization separate specific topics into individual standards, whereas ANSI B11.19 has combined many of these topics into a single document – treating each variable as unique. Therefore, all of the previous variables that have been used to address *safety distances* for devices have been updated in the new edition. To further aid the reader, a table has been added to the standard that compares the new variable names with the variables used in the previous edition of the standard, as well as international standards addressing similar topics.

Calculating Safety Distance

When applied to reduce risk to individuals, engineering controls must be located at a distance from any associated hazard(s) within the span of control such that individuals will not be exposed to a hazard(s). This distance is referred to as the *safety distance*. Measures to fulfill this requirement include:

- provide a device that an individual cannot reach over, under, around, or through, and/or
- initiate a protective stop that causes the hazard(s) to achieve a safe condition prior to the individual reaching the hazard(s).

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The information in ANSI B11.19 addressing *safety distance* can – and should – be used as a guide for locating a device to control or prevent access to the hazard, but may result in conservative distances. Determining the location, dimensions and configurations of the device is necessary to prevent the individual from reaching the hazard, and can be impacted by the size and design of the engineering control specified. Furthermore, additional measures (such as other physical structures, risk reduction measures, or control measures) may be necessary to minimize the *safety distance.*

Due to the many considerations associated with determining the *safety distance* for a protective device, the details addressing the calculation have been separated into their own annex in the 2019 edition of ANSI B11.19 (Annex H). This informative material individually addresses each of the factors comprising the *safety distance* equation shown in Table 1.

$$D = (K \times T) + d_{ds} + Z$$

Where:

D =	safety distance of a device
K =	maximum speed that an individual can approach the hazard
T =	total time to achieve a safe condition
d_{ds} =	reaching distance associated with devices
Z =	supplemental distance factor(s)

Table 1 – Equation for *safety distance* of devices

SAFETY DISTANCE (*D*)

The concept of locating protective devices at a sufficient distance from the associated hazard(s) is not new to industry. The federal regulation for the safety of mechanical power presses, OSHA 29 CFR 1910.217, introduced the concept of *safety distance* for point of operation devices such as light curtains, two-hand controls and two-hand trip devices when it was revised in 1975. While this is the only regulation from OSHA addressing minimum *safety distances*, it is widely referenced throughout the agency for guidance on the topic of *safety distance*.

Also referred to as “minimum distance” or “separation distance” in other documents, this calculated value is represented in ANSI B11.19-2019 with the variable *D*.

APPROACH SPEED (*K*)

Many engineering control devices provide protection to individuals by detecting the presence (or lack of presence) of a person and then initiating a protective stop command. For such devices, one of the key factors in the calculation for the *safety distance* is the *approach speed* of an individual toward the hazard zone. Many factors should be considered when determining this *approach speed*, including hand and arm movement; twisting of the body or shoulder, or bending at the waist; and walking or running. While international standards currently present multiple values, the value widely accepted in North America has been 1.6 m/s (63 in/s). Other values (typically greater) can also be used in the *safety distance* formula as determined by a risk assessment, but should be accompanied by clear documentation and validation (such as statistically valid modelling and experimentation). However, the 1.6 m/s (63 in/s) value for *approach speed* has been used successfully across various machine types with stationary hazard zones for decades, going back to the 1975 revision of OSHA 29 CFR 1910.217, and again in various consensus standards, including each edition of ANSI B11.19. *Approach speed* is most often represented with the variable *K*.

TIME TO ACHIEVE A SAFE CONDITION (*T*)

Another crucial element when determining safety distance is the total time necessary for the hazard to achieve a safe condition. Historically, a ‘safe condition’ was considered to be achieved when all motions that could result in a hazard had achieved a complete stop. However, current approaches to machinery safety have acknowledged monitored speeds greater than zero that achieve acceptable residual risk in some industries or applications. Common examples include the manual reduced speed of 250 mm/s (9.84 in/s) for industrial robot applications, or 10 mm/s (0.39 in/s) closing speed for presses and press brakes. A detailed listing of type-C standards with reduced-speed values greater than zero are included in the new Annex Q of ANSI B11.0-2020 (*Safety of Machinery)* titled *“Achieving a Safe Condition with Reduced-Energy”*.

In other instances, a ‘safe condition’ has been acknowledged as the completion of the hazardous portion of the machine cycle. Using the press again as an example, a hazard is present during the closing portion of the cycle (the down stroke), but not while opening (the up stroke).

Given the elements of the safety-related parts of the control system (SRP/CS) involved in the safety function, many factors must be considered when determining the *time to achieve a safe condition*, represented with the variable *T*. The total *time to achieve a safe condition* can be affected by the:

a) reaction time of the engineering control device [represented as T_d]
b) reaction time of the safety-related logic interface [represented as T_i]
c) reaction time of the actuator control system [represented as T_c] and
d) reaction time of the machine and the type of actuator (e.g., clutch/brake mechanism, motor/drive, valve, etc.) [represented as T_s]

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A noticeable modification in ANSI B11.19 from the previous edition is the further breakdown of the time associated with the input and logic elements of the SRP/CS. Since the first edition of the standard in 1990, the variable T_r was used to represent the combined response time of the engineering control device and its interface. In the fourth edition, however, this time element has been deconstructed further into T_d and T_i as listed above to provide further clarity of the issue. This is especially useful when utilizing network systems to integrate elements of the SRP/CS such as SICK's Safe EFI-Pro System, where the affect on overall response time of the logic elements (T_i) must be accounted for.

Figure 2 – Example of an engineering control device (T_d) and its interface (T_i)

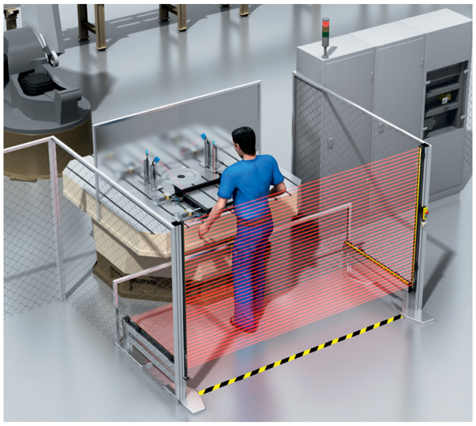

Figure 3 – Example of SICK deTec4 cascade with two guest systems (host/guest1/guest2)

Depending on the complexity of the machinery and/or the risk reduction measures applied, multiple elements (devices, logic controllers, etc.) may be interfaced in series, therefore introducing a cumulative delay within a given subset of the time factor. For example, the SICK deTec4 light curtain family offers the ability to cascade light curtains in a configuration with a host device and up to two guest devices as shown in Figure 3. When integrated in this fashion, the response time of the guest device(s) will be slower than the response time of the host device. When represented in the formula, the total response time (T_d) of the second cascaded light curtain would be determined as $T_{dhost} + T_{dguest1} + T_{dguest2}$.

In addition, some types of machinery may be equipped with a safe condition monitoring system (previously referred to as a "stopping performance monitor" and represented with the variable T_{spm}). Such a system is used to assure that a gradual increase in the time to achieve a safe condition caused by the degradation of components does not exceed the time used to calculate the *safety distance* for the device. When a safe condition monitoring system is applied according to the relevant requirements in a machine-specific (type-C) safety standard, the calculated factor, now represented as T_{scm}, must also be added to the total time used to calculate the *safety distance*.

Time delays associated with all elements of the safety function must be accounted for when determining the overall *time to achieve a safe condition* ($T = T_d + T_i + T_c + T_s + T_{scm}$). When designing new equipment, the total time T is often calculated based on data provided by component suppliers. However, a comprehensive approach to functional safety requires the actual value for T be validated (e.g., measured) before allowing new equipment to be put into use. Nevertheless, all risk reduction systems existing in the workplace today require periodic inspection and validation of the *safety distance*, and component data is not always available. This responsibility lies with the machinery user to establish a procedure for the inspection and testing of the risk reduction measure(s), perform periodic testing on a regular basis, and document the results. In some cases, modifications may be required to ensure the protective device is still providing the expected level of safety; this could include repositioning the device at a new *safety distance*, or improving the *time to achieve a safe condition* by applying (or improving) mechanical or electronic braking. As it relates to the *time to achieve a safe condition*, this periodic test is often in the form of a stop time measurement. Fortunately, the new edition of ANSI B11.19 now includes a new informative annex (Annex J) describing a standardized approach for the measurement and calculation of machinery system performance to achieve a safe condition; more details on this and other annexes will be addressed in the next white paper in this series. Additionally, a number of qualified service providers exist who can assist with this periodic testing and associated documentation requirements, including SICK Services.

Figure 4 – Stop Time Measurement Service from SICK

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As described in federal regulation OSHA 29 CFR 1910.217, the formula still used today for determining the *safety distance* for engineering control devices is simply $D = K \times T$. As we will see below however, current best practices and industry consensus standards account for additional considerations that factor into a more effective and appropriate consideration of *safety distance.*

REACHING DISTANCE (d_{ds})

When determining the appropriate *safety distance* for engineering control devices, one of the biggest – and most confusing – topics to consider is the *reaching distance associated with engineer control devices* (d_{ds}). This consideration represents the amount of distance an individual can reach prior to detection by the device. Previous editions of ANSI B11.19 referred to this as the "depth penetration factor" and represented it with the variable D_{pf}, while international standards have referenced this same aspect as the "intrusion factor," represented as *C*.

This additional *reaching distance* is dependent upon many criteria, including:

- type of engineering control device selected to initiate a safe condition
- dimension of the selected engineering control device
- location of the selected engineering control device with respect to the reference plane (e.g., floor)
- sensitivity of the selected engineering control device

As described above, the requirements of OSHA 29 CFR 1910.217 do not require any additional consideration of reach factors when applying engineering control devices to mechanical power presses, with one exception. When a light curtain is applied and used for presence sensing device initiation (PSDI), an "additional depth penetration factor" is required under OSHA 29 CFR 1910.217(h)(9)(v). However, the caveat to this exception is that OSHA has established rigorous restrictions for the use of PSDI on mechanical power presses, as discussed in a previous blog post from SICK.

Due to evolving techniques and best practices in industry, the guidance for *reaching distances* has seen many modifications in the 2019 edition of ANSI B11.19. While the previous edition addressed ten different considerations affecting *reaching distance*, the new revision has doubled that to twenty different topics, while also modifying two of the previous solutions. The many topics addressing *reaching distance* considerations will be addressed in further detail later in this white paper.

SUPPLEMENTAL DISTANCE FACTORS (*Z*)

The one issue affecting *safety distance* historically overlooked in standards has been the concept of *supplemental distance factors*. This additional distance factor, represented with the variable *Z*, may be necessary depending on the application, equipment, and engineering control device selected. Prior to the new edition of ANSI B11.19, this topic was never addressed in earnest in any safety standard. Instead, the engineer applying the risk reduction solution to the machine had to rely solely on the equipment or device manufacturer's guidance, which is often buried deep within the operating instructions.

Addressing the concept of *supplemental distance factors* in the standard is an effort by the experts to remind designers that additional considerations may be necessary based on the overall solution. Examples of supplements provided in ANSI B11.19 include the following, but do not represent an all-inclusive list:

- general safety supplement due to device measurement errors or tolerance range
- reflection-based measurement errors
- lack of ground clearance of moving equipment
- decreasing brake torque of moving equipment

The variables used for these *supplemental distance factors* may differ between suppliers, or even components, but nevertheless must be considered when determining the overall *safety distance* used to select, dimension, locate, and configure engineering control devices.

Reaching Distance Considerations for Engineering Controls – Devices

As referenced above, *reaching distance associated with engineer control devices* (*dds*) is the element that most often presents difficulties when determining the appropriate *safety distance*. Whenever an engineering control device is reducing risk to individuals by initiating a protective stop command, an additional requirement is that the device must be located at a distance from any associated hazard(s) within the span of control of that device such that individuals will not be exposed to a hazard(s). This is where implementation of the *AUTO* concept described earlier is applicable to a device. Detailed guidance on *reaching distances* is provided in Annex I of ANSI B11.19-2019, and has been significantly modified from previous editions of the standard. Highlights of the changes are outlined below.

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LOCATION OF SAFETY-RELATED MANUAL CONTROL DEVICES

Using *location of safety-related manual control devices* (SRMCD) as a risk reduction measure was introduced in Part 3 of this white paper series. As discussed, the location of SRMCD can be an effective measure to reduce risk, and has been cited in several standards for nearly 15 years. However, there has never been clear guidance to designers or validators to determine what location was sufficient – until now.

Figure 5 – Example of SRMCD (manual reset device) accessible from outside the safeguarded space

Safety standards have historically only provided guidance for determining the *reaching distance* associated with devices as a step toward determining the *safety distance* of the device from the associated hazard so individuals are not exposed to the hazard. Since this data is based upon human body measurements, it is also possible to apply the methodology in other ways. During the recent revision to ANSI B11.19, it was identified that the reaching distances used to reduce the probability of contact with a hazard zone(s) can also be used to identify sufficient location of SRMCD. Fundamentally, *reaching distances* are used to determine the distance a person can reach before detection by a device (generation of a signal to the SRP/CS). This can be applied as part of the safety distance to a hazard zone (when combined with the additional factors of *approach speed, response time*, and *supplemental factors* as discussed above), or to determine the separation distance to an SRMCD, such as a safety-related manual reset (see Figure 5). Actuating an SRMCD while still being detected by the device will prevent the hazardous condition from occurring when the control logic is implemented correctly. Therefore, the information provided in Annex I of ANSI B11.19-2019 is now broader in its application to reduce risk to individuals.

Vertical Presence-Sensing Devices

Presence-sensing devices are often applied in a vertical orientation, such as light curtains, multi-beam devices, and even area scanners. In international standards, this is referred to as *orthogonal approach* of an individual to the detection zone. Figure 1 illustrates how the *AUTO* principles apply to vertical presence-sensing devices.

As we will explore, the same approaches applied to physical barrier guards as discussed in Part 4 of this white paper series also apply to vertical presence-sensing devices. However, the results will differ due to the differences between a physical element an individual can lean or press against and the detection of an individual with electro-sensitive devices.

REACHING OVER A VERTICAL PRESENCE-SENSING DEVICE

Part 4 of this white paper series addressed the current alignment between the new edition of ANSI B11.19 and the international standard ISO 13857 as they relate to *reaching distances* associated with reaching over a physical barrier guard. The data presented in ISO 13857 is based upon global anthropometric data of the adult workforce. Similarly, the 2010 edition of ISO 13855 introduced a comparable table to address the additional distance a part of the body can reach towards the hazard zone prior to actuation of the safeguard. This additional variable, represented in the ISO standard as C_{RO}, is based on the same global anthropometric data as used in ISO 13857. However, the results are different because an individual can lean on the top edge of a physical guard but cannot lean on the top beam or edge of a detection zone. This leaning factor results in slightly larger *reaching distances* when reaching over a physical barrier.

Figure 6 – Example of vertical presence sensing devices (area scanner and light curtain)

At the time this data was published in ISO 13855, the 2010 edition of ANSI B11.19 was already in the final stages of processing leading up to publication. During the drafting of the current edition, however, the B11.19 writing subcommittee of experts decided to align with ISO 13855. Therefore, while the guidance for reaching over a presence-sensing device is new to ANSI B11.19, it is in fact well-tried in practice due to wide use in the international marketplace.

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REACHING THROUGH A VERTICAL PRESENCE-SENSING DEVICE

Figure 7 – Testing *effective detection capability* of a safety light curtain

As mentioned earlier, the concept of *safety distance* has long been applied to vertical presence-sensing devices. Historically, the primary concern with presence-sensing devices mounted vertically (greater than 30° to the direction of approach) has been the *reaching distance* associated with the distance a finger or hand can penetrate the sensing field of the device before reliably triggering an immediate stop command. In the United States, the established limit for finger or hand detection has been with an object sensitivity of 64 mm (2.52") or less. Conversely, the threshold in European and international standards has been 40 mm (1.57") or less. To further add to the confusion, the formula used to determine the amount of penetration possible has and remains different between the two competing methodologies. In the United States, the formula and upper threshold for finger and hand detection has remained the same in the 2019 edition of ANSI B11.19.

The only modification to this consideration, however, is the introduction of the term *effective detection capability*. Whereas all previous standards only address "detection capability" (also referred to as "minimum object sensitivity"), the new standard now acknowledges that some devices can be modified by the installer to increase the detection capability; hence the *effective* *detection capability* which should be used when determining the amount of reaching distance through a vertical sensing field. Blanking is a common feature of safety light curtains where the detection capability of the device can be modified, and therefore must be accurately accounted for.

When the vertical detection zone of the presence-sensing device has an *effective detection capability* greater than 64 mm (2.52"), it is then only reliable for the detection of the arm or body of an individual. In such cases, the reaching distance is equivalent to the arm length. In previous editions of ANSI B11.19, the arm reach was considered to be 900 mm (35.43"). However, international standards have long established the standard adult arm length as 850 mm (33.46") when not leaning on a physical obstruction. Therefore, the 2019 edition of ANSI B11.19 has now harmonized with the appropriate arm reach when applied to vertical presence-sensing devices.

REACHING UNDER A VERTICAL PRESENCE-SENSING DEVICE

Requirements have long been established for the maximum gap of 300 mm (11.81") from adjacent walking / working surfaces to the bottom of a sensing field, which aligns with international guidance. However, previous standards only specified the vertical gap, but provided no information related to the associated *reaching distance*. Similar to the new considerations for reaching under guards, existing human body measurements were utilized to provide brand new guidance to ensure individuals cannot access a hazard or SRMCD by reaching under the detection zone of a vertical presence-sensing device.

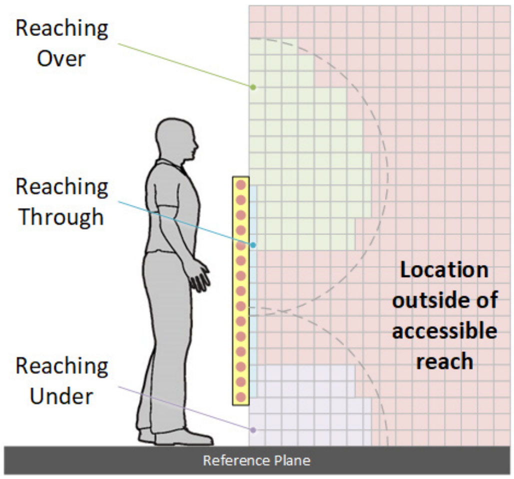

Figure 8 – Consideration of all reaching factors

For applications where the bottom edge of the detection zone is very near the walking / working surface, the same formula for finger and hand detection can be applied to determine how much horizontal penetration beyond the sensing field will occur before detection. For the more common application where the first beam is closer to (but not greater than) 300 mm (11.81") from the reference plane, a new table is provided in the standard to help determine the appropriate amount of *reaching distance* to consider in the overall *safety distance* calculation.

COMPARISON OF REACHING DISTANCE CONSIDERATIONS FOR VERTICAL PRESENCE-SENSING DEVICES

All applicable parameters must be considered when determining the overall *reaching distance* associated with vertical presence-sensing device. A final determination must then be made for sizing and/or location of each device to effectively reduce risk. This means that the *safety distance* of a vertical detection zone is determined based upon review of all relevant application concerns: reaching over, reaching through and reaching under a sensing field, as shown in Figure 8.

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Figure 9 – Example of a horizontal presence-sensing device (area scanner)

Horizontal Presence-Sensing Devices

Presence-sensing devices may also be applied in a horizontal orientation, such as area scanners, light curtains, and pressure-sensitive safety mats. In international standards, this is referred to as *parallel approach* of an individual to the detection zone. The overall *safety distance* is still determined according to the formula in Table 1 and requires an additional *reaching distance* as well. However, the horizontal application of a presence-sensing device requires attention to additional considerations to ensure an adequate and effective reduction of risk.

REACHING OVER A HORIZONTAL PRESENCE-SENSING DEVICE

The principal concern with presence-sensing devices mounted horizontally (less than or equal to 30° to the direction of approach) has been the *reaching distance* associated with the distance an arm can extend beyond the outermost edge of the sensing field of the device before an individual is detected, triggering an immediate stop command. In the United States, the established limit for the *reaching distance* has and remains to be 1,200 mm (47.24"). This value meets or exceeds the current requirements in International standards, but has been proven in use to be a sufficient distance.

HEIGHT OF A HORIZONTAL PRESENCE-SENSING DEVICE

In addition to the *reaching distance*, the *height of a horizontal sensing field* must be determined to ensure reliable detection of an individual at the appropriate *safety distance*. For electro-optical presence-sensing devices like area scanners and light curtains, the *effective detection capability* must be considered when determining the appropriate *height of a horizontal sensing field* from the walking / working surface. Considering the tapered shape of the lower leg between the knee and the ankle, it is important to understand that sensing fields with a larger *effective detection capability* must be mounted higher than devices with a more precise *effective detection capability*, as shown in Figure 10. A formula has been in use in industry for nearly 20 years to determine the minimum *height of a horizontal sensing field*. Additionally, the maximum height limit has been established as no more than 1,000 mm (39.37"), with a strong recommendation to consider 300 mm (11.81") as an effective mounting height to prevent undetected access beneath the detection zone (e.g., crawling underneath the *sensing field*).

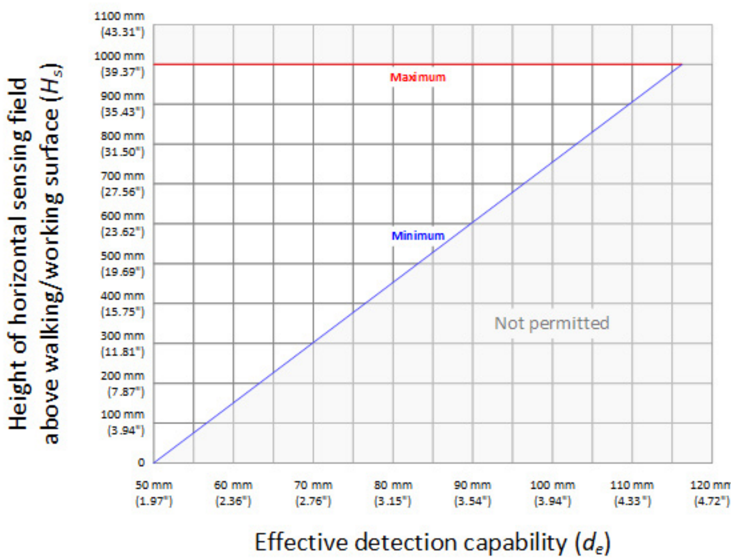

Figure 10 – Allowable *height of a horizontal sensing field*

DEPTH OF A HORIZONTAL PRESENCE-SENSING DEVICE

Another consideration for all horizontal presence-sensing devices is to have an adequate *depth of sensing field*. This minimum depth is necessary to avoid the possibility for an individual to step over the sensing field undetected. The two considerations addressed in ANSI B11.19 are outlined in Table 2.

It is very important to recognize that the *depth of field* consideration is <u>different</u> than the *reaching distance* factor discussed earlier. The *reaching distance* is used to determine the <u>minimum</u> *safety distance* from the edge of the sensing field to the nearest hazard zone(s). The *depth of field* issue is an additional factor which must be applied, and may possibly result in the leading edge of the detection zone extending beyond the minimum *safety distance*, as show in Scenario 2 of Table 2.

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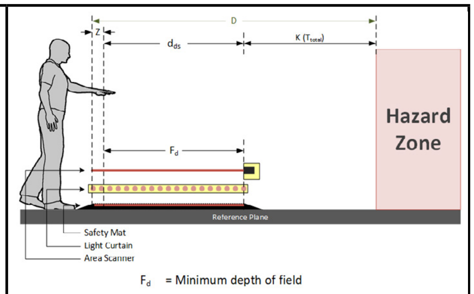
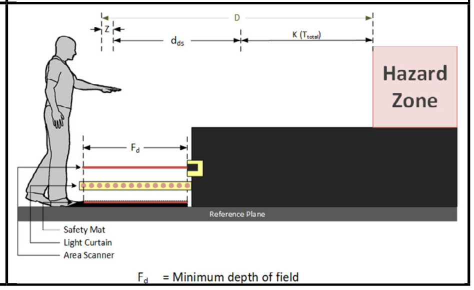
1. Individual can step over the sensing field undetected EXAMPLE: clear space exists between the detection zone and the hazard zone Minimum depth of field ≥ 1200 mm (47.24”)	
2. Individual must stand within the sensing field EXAMPLE: any access into the hazard zone requires stepping into the detection zone due to supplemental measures (engineering controls, protective structures, physical obstructions or other fixed elements) Minimum depth of field ≥ 900 mm (35.43”)	

Table 2 – Scenarios affecting *depth of field* of horizontal presence-sensing devices

DISTANCE FROM END OF HORIZONTAL SENSING FIELD TO NEAREST OBSTRUCTION

The final consideration to consider for applications with horizontal presence-sensing devices is related to preventing whole body access. Part 3 of this white paper series outlined additional risk reduction measures which must be considered when whole body access exists. However, preventing the situation where an individual(s) can be completely inside the risk reduction measures defining a perimeter or safeguarded space alleviates the additional concerns for whole body access.

The new edition of ANSI B11.19 introduces guidance which harmonizes with international standards to assist engineers in determining an appropriate distance from the inside edge of the horizontal sensing field to the nearest obstruction to prevent whole body access. As discussed above, the height of a horizontal sensing field must be determined, and is a function of the *effective detection capability* of the device. The inverse of the same formula is used to determine the maximum possible gap at the inside edge of the detection zone to ensure reliable detection of individuals as a function of the *height of the horizontal sensing field*.

Actuating Controls

Actuating controls are manual control devices used to initiate or maintain machine motion(s) or other machine function(s). In some applications, manual actuating controls can be applied as risk reduction measures by ensuring the location of an operator at a fixed location during the hazardous portion of the machine cycle. Historically, these devices were referred to as “hostage controls.” In order for these devices to effectively reduce risk however, the fixed location of the manual control device must be at a calculated *safety distance* accounting for all of the considerations identified in Table 1.

TWO-HAND ACTUATING CONTROLS

Two-hand control devices are possibly the most common application of manual actuating controls used for risk reduction. These devices require the synchronous use (within 500 ms) of both of the operator’s hands to initiate a machine cycle and concurrent use during the hazardous portion of the machine cycle. However, another type of actuating control requiring the use of both hands of the operator are two-hand trip devices. While similar to two-hand control, two-hand trip requires the synchronous use of both of the operator’s hands to initiate a machine cycle only; the hands can then be removed from the actuating controls during the hazardous portion of the machine cycle.

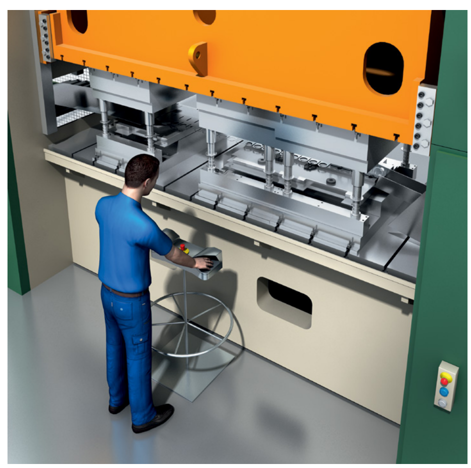


Figure 11 – Example of a two-hand control device

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Regardless of which type of two-hand actuating control system is used, *safety distance* still applies, as does the concept of *reaching distance*. The value used as the *reaching distance* for two-hand actuating controls has historically been zero in North America. However, the international standard ISO 13855 (and its predecessor, EN 999) has required a minimum reaching distance of 250 mm (9.84”). The only exception to this distance is if encroachment of the hands or part of the hands towards the hazard zone is eliminated while the actuator is being operated, for example by adequate shrouding. In this case, the *reaching distance* value can be set to zero.

With the latest edition of ANSI B11.19, alignment has been made with the international approach, which now distinguishes different *reaching distance* values depending on the design of an application to restrict encroachment of the hands and forearms. When encroachment is restricted, the recommended *reaching distance* value remains at zero. However, a new value has been introduced for applications without appropriate shrouding. This new value exceeds the previous distance used overseas of 250 mm (9.84”), which only accounts for the breadth of the hand. Based on research and other standards, the new recommended minimum *reaching distance* value is now 550 mm (21.65”). This distance represents the full length of the adult forearm and hand, acknowledging real-world cases where individuals have operated two-hand actuating controls with their elbows while reaching toward the hazard zone. Although slightly more restrictive, this new minimum distance ensures adequate protection of individuals while accounting for foreseeable misuse of two-hand actuating controls.

SINGLE ACTUATING CONTROLS

Similar to two-hand actuating controls, single actuating controls can also be used as a risk reduction measure. In order for adequate risk reduction to be provided however, such devices must either be used in conjunction with additional measures, such as reduced energy (speed, force, pressure, etc.), or positioned at an appropriate *safety distance* so the operator cannot reach the hazard before the hazardous situation(s) has ceased. Common examples of single actuating controls are individual pushbuttons or footswitches. In the case of foot-operated switches used to control or initiate a hazardous situation, it is important to note that the device must be protected to prevent accidental actuation by falling or moving objects and from unintended operation by accidental stepping onto the device. In other words, footswitches used to initiate a hazardous machine cycle must have a protective cover to ensure only intentional actuation by an operator.

Guidance for determining *reaching distance* for hand-actuated single actuating controls has been available for quite some time. Traditionally, a value of 2,000 mm (78.74”) was used. However, the new edition of ANSI B11.19 has increased this recommended distance to 2,200 mm (86.81”) to align with scientific research.

A brand new consideration added to the standard is the *reaching distance* consideration for foot-operated actuators. Although the associated distance is new to standards, it is again based on anthropometric data found in international standards. The recommended minimum *reaching distance* value proposed in ANSI B11.19-2019 is 2,500 mm (98.43”). Other values may be used when based on a risk assessment, and should account for each individual application, such as the height of the hazard or the orientation of the workplace (e.g., presence of obstructions limiting direct access to the hazard zone from the location of the single actuating control).

New Guidance for Engineering Controls – Devices

Speaking of new *reaching distance* considerations added to the fourth edition of ANSI B11.19, an additional three engineering control devices are now addressed with new guidance to be applied when determining a sufficient *safety distance*.

SINGLE BEAM PRESENCE-SENSING DEVICES

While single beam presence-sensing devices have been on the market for many years, little attention has been given to these devices to ensure adequate risk reduction. Most often, multiple single beam systems are used together, or a single system is used with mirrors, to create multiple parallel beams, thus creating a multi-beam system. However, some single beam systems are applied individually for the reduction of risk to individuals and therefore, guidance is necessary.

Figure 12 – Example of single beam presence-sensing devices

The current edition of ANSI B11.19 now addresses single beam devices, and this guidance is aligned with ISO 13855 which is used in international markets. First, it is important to recognize that single beam devices must only be used as a risk reduction measure when installed to reliably sense the presence of an individual accessing a hazard zone(s). A single beam device is not suitable as the only

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means for detecting whole body access (a topic discussed in Part 3 of this white paper series). Instead, a single beam device is typically used in combination with other engineering controls (guards or devices) that restrict the opening(s) such that it is not possible to pass the presence-sensing device without being detected.

The *reaching distance* guidance provided in the standard only considers when single beam devices are used parallel to the ground and the beam is broken by a person's body in the upright position. In this application, a *reaching distance* of 1,200 mm (47.48") should be used. Furthermore, a height of 750 mm (29.53") from the reference plane is recommended, as this has been found in industry to be a practical solution to the problems of inadvertent access by stepping over or bending under the beam.

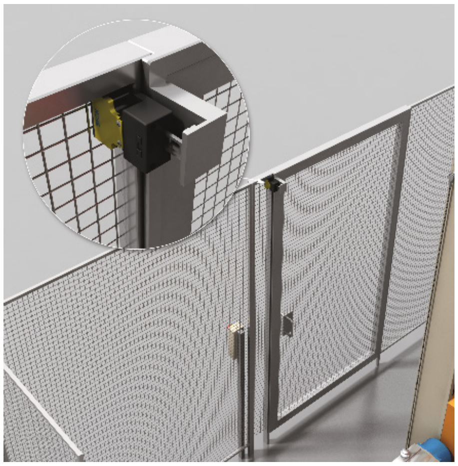

Figure 13 – Example of an interlocked guard

INTERLOCKED GUARDS WITHOUT GUARD LOCKING

Interlocking portions of physical barriers has been a reliable solution for reducing risk to individuals in the workplace for decades. Part 4 of this white paper series provided a detailed outline of the requirements for interlocked guards. One of the most basic requirements of an interlocked guard is that immediate stop command must be initiated when the guard is opened. Therefore, a *safety distance* calculation must be performed to ensure that the distance between the guard and the hazard(s) is sufficient as addressed above. If sufficient distance determined by the calculation is not possible for the application, guard locking interlock devices may be required, which prevent the guard from opening until the hazard(s) achieves a safe condition.

Surprisingly, previous discussions addressing *reaching distance* for interlocked guards typically never went beyond the considerations of reaching through fixed openings in the guard (e.g., mesh fence). With the updated guidance in ANSI B11.19, this thinking should now also expand to considerations of reaching over or under the barrier portion of the interlocked guard, as addressed in the previous white paper in this series.

However, interlocked guards are interfaced to the safety-related parts of the control system (SRP/CS) of the equipment. As mentioned previously, *reaching distances* are used to determine the distance a person can reach before detection by a device (generation of a signal to the SRP/CS). This is no different for interlocked guards without guard locking. Regardless of the interlock device used, some movement of the guard may be possible before a signal is initiated. This movement of the guard directly translates into an increased opening where part of the body may gain access toward a hazard zone(s). Consequently, the new edition of the standard now addresses this concern. Essentially, the amount of opening is determined by the design of the interlock switch selected, as well as the design of the associated movable barrier.

For electromechanical interlock devices, some amount of travel can occur before the normally closed (NC) contacts are forced open to generate a stop command. With non-contact interlock devices, a distance should be specified by the supplier where switching off is assured; this is often dependent upon the direction of travel between the switch and the corresponding actuator (parallel or perpendicular). These small distances can be exaggerated when well-meaning designers or maintenance personnel attach the actuator to the movable barrier with a chain or cable. Often, this modification is made in an effort to reduce stress on the interlock device due to frequent use or misalignment of the interlocked guard. However, this modification has a dramatic effect on the overall *reaching distance* which must be accounted for in the application. In either case, the amount of travel of the interlocked guard before initiation of an immediate stop command must be determined. This distance is then used with the guidance for reaching through guards with slotted openings to determine the amount of penetration an individual is afforded before detection by the interlocked guard.

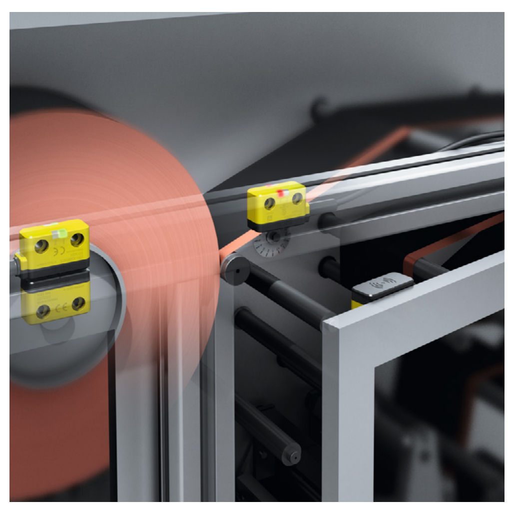

Figure 14 – Example of an interlocked guard using a coded non-contact STR1 interlock device from SICK

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The consideration of increased access openings with interlocked guards becomes more complex when using hinge (rotary cam) style interlock devices, as shown in Figure 15. Safety hinge switches are used for monitoring rotatable protective devices, such as swiveling gates and hinged doors. The hollow or solid shaft of the actuator forms a fixed and positive connection between the interlock device and the door hinge. These devices offer a high level of protection against tampering. However, they also introduce an additional complexity to the overall *safety distance* calculation. Whereas other interlock devices have a pre-defined travel distance before actuation (which can be directly translated to an opening size, and thus a *reaching distance*), hinge switches have an actuating angle. This means that wider access doors will have a larger access opening before actuation.

Figure 15 – Example of rotary cam style interlock devices

e = (c sin α) – Wg

Where:

- *e* = opening size
- *c* = width of the interlocked guard
- *α* = actuating angle of the hinge switch
- W_g = thickness of the interlocked guard

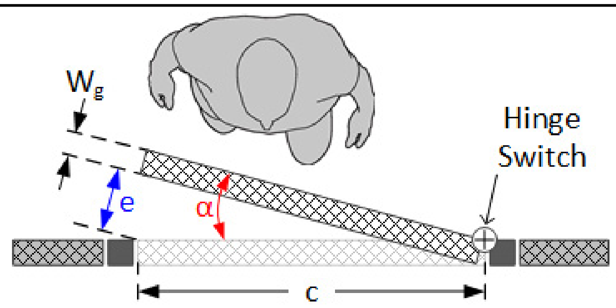

Table 3 – Formula for determining opening size before actuation of a guard interlocked with a hinge switch

To solve for the *reaching distance* in these applications, some basic trigonometry is required. The actuating angle of the hinge switch should be specified by the supplier. This information, along with the width of the movable portion of the interlocked guard, as well as the thickness of the interlocked guard, are all that is needed to determine the opening size, as show in Table 3. Once the opening size is determined, the same guidance for reaching through guards with slotted openings can be applied to determine the amount of penetration by an individual before initiation of a stop command.

Figure 16 – Example safety edge applied for clamping/crushing contact hazards

PRESSURE-SENSITIVE EDGES & BUMPERS

The final new addition to ANSI B11.19 regarding *safety distance* guidance addresses pressure-sensitive edges and bumpers. These devices have been in use for many years, but no type-B (general application) standards had yet addressed the issues related to proper selection and application of these devices as risk reduction solutions. As the name suggests, pressure-sensitive devices require an applied force for actuation. Safety edges and bumpers are applied on (or opposing) a moving object to reduce risk due to contact with the person's body.

The two most frequent types of contact between moving parts and areas on a person's body are *clamping/crushing contact* and *dynamic contact. Clamping/ crushing contact* (also known as 'quasi-static') includes clamping or crushing situations in which part of a person's body is trapped between a moving part and another fixed or moving part as shown in Figure 16. When any part of a person's body is impacted by a moving component and can recoil or retract from the hazard without clamping or trapping the contacted body area, this situation is referred to as *dynamic contact* (also known as 'transient' contact).

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Unlike all of the other engineering control devices addressed in this white paper, pressure-sensitive edges and bumpers rely on the stopping distance of the hazard, instead of the time for the hazard to achieve a safe condition. Therefore, the formula in Table 1 does not apply. Moving components will continue to move some finite distance after the stop command is initiated. If the profile of the safety edge or bumper is not selected appropriately, injury may still occur; rather than being struck directly by the moving component, the individual may be struck by the mounting rail of the pressure-sensitive device before the motion has ceased and still be harmed. Therefore, a safety factor must be applied. A common value used for this safety factor is a multiplier of 1.2, although a higher factor may be necessary depending on other conditions, such as:

- rated load
- machine actuator
- static or dynamic situations
- design and construction of the safety edge / bumper device
- probability of misuse / misapplication
- use of a drive system that is subject to change (e.g., braking system that is subject to deterioration)

For *clamping/crushing contact* applications, the device profile selected must account for the stopping travel of the hazardous motion (with a safety factor applied). The remaining overtravel available must then exceed the minimum gap to avoid crushing of the exposed part(s) of the human body. [NOTE: ANSI B11.19-2019 also provides minimum gap dimensions for eight parts of the human body which can be applied to the pressure-sensitive device profile selection.]

For *dynamic contact* applications, the stopping travel of the hazardous motion (with a safety factor applied) defines the minimum overtravel of the device profile after actuation, which should be defined by the device supplier.

Conclusion

Selecting engineering control devices to initiate a safe machine condition (e.g., an immediate stop command) is one of the most common approaches to risk reduction when access to machinery is required to perform an identified task. Experienced safety engineers and designers rely on a wide range of engineering control devices implemented into safety solutions to create safe productivity in the workplace.

However, effective risk reduction requires more than selecting the appropriate device technology and applying the concepts of functional safety to the control system. The basic principle of *safety distance* must be considered to ensure the machine has achieved a safe condition before an individual can access the hazard(s). A thorough understanding of how and when an individual is detected by the device, including how much of the body may reach toward the hazard(s), must also be applied.

Advances in best practices continue to evolve, guided by experience and scientific study. Standards such as ANSI B11.19 reflect best practices (so-called “state of the art”) which can and should be applied to a broad range of machinery – both existing in use as well as new to the market. Table 4 identifies the many factors to consider when determining *safety distance*, as well as the *reaching distance* considerations for various device applications. This table also identifies which aspects have been modified from the previous edition of ANSI B11.19, in addition to the many new attributes added to facilitate effective application of engineering control devices.

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Parameter	Variable (2019)	Determination	Status (from ANSI B11.19-2010)	Applicable to Location of SRMCD
SAFETY DISTANCE FORMULA FOR ENGINEERING CONTROL DEVICES				
Safety distance	D	$(K \times T) + d_{ds} + Z$	MODIFIED Enhanced with supplemental distance factor	No
Approach speed	K	1.6 m/s [63 in/s]	No change	No
Time to achieve a safe condition	T	Application dependent	No change	No
Reaching distance associated with devices	d_{ds}	Application dependent	No change	YES
Supplemental distance factor	Z	Application dependent	NEW	No
REACHING DISTANCE CONSIDERATIONS ASSOCIATED WITH VERTICAL PRESENCE-SENSING DEVICES				
Reaching over a vertical presence-sensing device	d_{do}	Based on table (Table I.3 in ANSI B11.19-2019)	NEW	YES
Reaching through a vertical presence-sensing device	d_{dt}	**Finger/Hand** **d_e ≤ 64 mm [2.52"]:** 3.4 (d_e - 7) mm [3.4 (d_e - 0.275) in]	No change	YES
		Arm/Body **d_e > 64 mm [2.52"]:** 850 mm [33.46"]	MODIFIED Reduced from 900 mm [35.43“]	YES
Reaching under a vertical presence-sensing device	d_{du}	**Finger/Hand** **H_{db} ≤ 64 mm [2.52"]:** 3.4 (d_e - 7) mm [3.4 (d_e - 0.275) in]	NEW	YES
		Arm/Body **64 mm [2.52"] < H_{db} ≤ 300 mm [11.81"]:** Based on table (Table I.4 in ANSI B11.19-2019)	NEW	YES
REACHING DISTANCE CONSIDERATIONS ASSOCIATED WITH HORIZONTAL PRESENCE-SENSING DEVICES				
Reaching distance associated with devices	d_{ds}	1200 mm [47.24"]	No change	YES
Height of a horizontal sensing field from reference plane	H_s	15 x (d_e – 50) mm [15 x (d_e – 1.97) in]	No change	No
Depth of horizontal sensing field	F_d	**Individual can step over the sensing field undetected:** 1200 mm [47.24"]	No change	No
		Individual must stand within the sensing field: 900 mm [35.43"]	No change	No

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Parameter	Variable (2019)	Determination	Status (from ANSI B11.19-2010)	Applicable to Location of SRMCD
REACHING DISTANCE CONSIDERATIONS ASSOCIATED WITH SINGLE BEAM PRESENCE-SENSING DEVICES				
Reaching distance associated with de-vices	d_{ds}	1200 mm [47.24"]	NEW	YES
Height of a horizontal sensing field from reference plane	H_s	750 mm [29.53"]	NEW	No
REACHING DISTANCE CONSIDERATIONS ASSOCIATED WITH TWO-HAND ACTUATING CONTROLS				
Reaching distance associated with de-vices	d_{ds}	**Without shroud:** 550 mm [21.65"]	NEW	No
		With shroud: 0 mm [0"]	No change	No
REACHING DISTANCE CONSIDERATIONS ASSOCIATED WITH SINGLE ACTUATING CONTROLS				
Reaching distance associated with devices	d_{ds}	**Hand-actuated controls:** 2200 mm [86.61"]	MODIFIED Increased from 2000 mm [78.74"]	No
		Foot-actuated controls: 2500 mm [98.43"]	NEW	No
REACHING DISTANCE CONSIDERATIONS ASSOCIATED WITH INTERLOCKED GUARDS WITHOUT GUARD LOCKING				
Reaching distance when reaching through a protective structure	d_{gt}	Application dependent; based on table (Table E.3 in ANSI B11.19-2019)	NEW	No
Opening of an interlocked guard with a hinge switch	e	$(c \sin \alpha) - W_g$	NEW	No
PROFILE SELECTION CONSIDERATIONS ASSOCIATED WITH PRESSURE-SENSITIVE EDGES & BUMPERS				
Profile selection for crushing/clamping contact Available overtravel (remaining profile compression distance after stopping travel of hazard with safety factor)	-	Application dependent; should exceed minimum gap to avoid crushing of the exposed part(s) of the body (Table 1 in ANSI B11.19-2019)	NEW	No
Profile selection for dynamic contact Overtravel after actuation (profile compression distance after actuation of device	-	Application dependent; should exceed stopping travel of hazard with safety factor	NEW	No

Table 4 – Summary of considerations for *safety distance* calculations and *reaching distance*

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This white paper is meant for guidance only and is accurate as of the time of publication. When implementing any safety measures, we recommend consulting a safety professional.

For more information about safety standards and regulations, contact SICK Safety Standards and Competence Manager Chris Soranno at chris.soranno@sick.com, or visit our web site at www.sick.com.

Bibliography

Below is a list of the references cited in this White Paper and are accurate as of the time of publication.

Document	**Publication Year**	**Title**
ANSI B11.19	2019	Performance Requirements for Risk Reduction Measures: Safeguarding and other Means of Reducing Risk
ISO 13849-1	2015	Safety of machinery – Safety-related parts of control systems – Part 1: General principles for design
IEC 62061	2005	Safety of machinery – Functional safety of safety-related electrical, electronic and programmable electronic control systems
ANSI B11.19	2010*	Performance Requirements for Safeguarding
29 CFR 1910.217	1975	Mechanical power presses
ANSI B11.0	2020	Safety of Machinery
ISO 13857	2019	Safety of machinery – Safety distances to prevent hazard zones being reached by upper and lower limbs
ISO 13855	2010	Safety of machinery – Positioning of safeguards with respect to the approach speeds of parts of the human body
EN 999	1998*	Safety of machinery – The positioning of protective equipment in respect of approach speeds of parts of the human body

* *superseded*

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