Iterative three-step method
(ISO 12100:2010, figure 1)
3 Step Method: Protective Measures by the DESIGNER

1. Inherently safe design measures
   - Guards
   - Protective Devices

2. Complementary Protective Measures
   - Components & elements to achieve Estop function
   - Measures for escape & rescue of persons
   - Measures for isolation & energy dissipation
   - Provisions for easy & safe handling of machines & heavy component parts
   - Measures for safe access to machinery

3. Information for Use*
   - At the machine: warning signs, signals, warning devices
   - In the instruction handbook

* Designer provides which the USER implements as Complementary Protective Measures
# Risk Reduction Measures

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<td>Warnings &amp; Awareness Means</td>
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<td>Limit Interaction</td>
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<tr>
<td></td>
<td>Eliminate or reduce human interaction</td>
<td>Escape &amp; rescue</td>
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<td>• Less hazardous materials</td>
<td>Safe access</td>
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<td><em>Reduced</em></td>
<td>Safe handling</td>
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<tr>
<td></td>
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<td>Energy isolation</td>
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<td>• Speed</td>
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<td>• Movement (range of motion)</td>
<td>Estops ...</td>
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<td></td>
<td>• Reduced</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Reduced movement (range of motion)</td>
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</tr>
<tr>
<td></td>
<td>• Guards</td>
<td>Lights, beacons</td>
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<td></td>
<td>• Interlocks</td>
<td>and strobes</td>
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<td></td>
<td>• Protective Devices</td>
<td>Audible alarms</td>
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<tr>
<td></td>
<td>• Safety controls, logic &amp; functions</td>
<td>Signs, labels or</td>
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<tr>
<td></td>
<td>• Safety parameters &amp; configurations</td>
<td>markings</td>
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<tr>
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<td>• ...</td>
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</tbody>
</table>

- **Most preferred**
- **Least preferred**

**Process or layout design, redesign or modification**

- Elimination
- Substitution
- Limit Interaction
- Safeguard
- Comp Protective Measures
- Warnings & Awareness Means
- Administrative (organizational) Controls
- PPE

- Process or layout design, redesign or modification
- Less hazardous materials
- Intrinsic safety (no “boom”)
  - Reduced
    - Energy
    - Speed
    - Movement (range of motion)

- Eliminate or reduce human interaction
- Automate tasks
- Modify layout or process flow
- Reduced movement (range of motion)

- Guards
- Interlocks
- Protective Devices
- Safety controls, logic & functions
- Safety parameters & configurations
- ...
What Does This Mean?

• Inherent - “existing in something as a permanent and inseparable element...”
  – For safety, this would mean “built in”, not “added on”
  – More a philosophy and way of thinking than a specific set of tools and methods
First Discussed in Process Safety...

- Eliminate or reduce the hazard by changing the process or materials to use materials or conditions which are non-hazardous or less hazardous
  
  - Integral to the product, process, or plant - cannot be easily defeated or changed without fundamentally altering the process or plant design

  EXAMPLE
  
  - Substituting water for a flammable solvent (latex paints compared to oil base paints)

- These concepts were embraced by the machinery sector.
Inherently Safe Design Measure

According to ISO 12100 (same as ANSI ISO 12100)

• 3.14 inherently safe design measure: protective measure which either eliminates hazards or reduces the risks associated with hazards by changing the design or operating characteristics of the machine without the use of guards or protective devices.

NOTE: See 6.2 <ISO 12100>.
ISO 12100, Clause 6: Risk Reduction

6.1 General

6.2 Inherently safe design measures

6.2.1 General
6.2.2 Consideration of geometrical factors and physical aspects
6.2.3 Taking into account general technical knowledge of machine design
6.2.4 Choice of appropriate technology
6.2.5 Applying principle of positive mechanical action
6.2.6 Provisions for stability
6.2.7 Provisions for maintainability
6.2.8 Observing ergonomic principles
6.2.9 Electrical hazards
6.2.10 Pneumatic and hydraulic hazards
6.2.11 Applying inherently safe design measures to control systems
6.2.12 Minimizing probability of failure of safety functions
6.2.13 Limiting exposure to hazards through reliability of equipment
6.2.14 Limiting exposure to hazards through mechanization or automation of loading/unloading operations
6.2.15 Limiting exposure to hazards through location of setting and maintenance points outside danger zones
Linkage From ISO 12100 to ISO TS 15066?

Inherently safe design measures **eliminate hazards or reduce the associated risks** by a suitable choice of design features of the machine itself and/or interaction between the exposed persons and the machine. <ISO 12100, 6.1>

NOTE 1: This stage is the **only** one at which **hazards can be eliminated**, thus avoiding the need for additional protective measures such as safeguarding or complementary protective measures.

- PFL robots have inherently safe design measures to enable having collaborative applications where additional protective measures are not needed.
6.2.2.1 Geometrical Factors

a) Machinery is designed to maximize direct visibility of the working areas and hazard zones from the control position.

b) Form and the relative location of the mechanical components parts: for instance, crushing and shearing hazards are avoided by increasing the minimum gap between the moving parts, such that the part of the body under consideration can enter the gap safely, or by reducing the gap so that no part of the body can enter it (ISO 13854 and ISO 13857).
6.2.2.1 Geometrical Factors

c) Avoiding sharp edges and corners, protruding parts: in so far as their purpose allows, accessible parts of the machinery shall have NO
- sharp edges,
- sharp angles,
- rough surfaces,
- protruding parts and
- openings which can “trap” parts of the body or clothing.

Sheet metal edges shall be deburred, flanged or trimmed, and open ends of tubes which can cause a “trap” shall be capped.

d) Achieve a suitable working position and provide accessible manual controls (actuators)
6.2.2.2 Physical Aspects *Includes* Limiting

a) actuating **force(s)** to a sufficiently low value so that the actuated part does not generate a mechanical hazard;

b) **mass and/or velocity** of the movable elements, and hence their kinetic energy;

c) **emissions** by using measures for reducing

1) **noise** emission at source (see ISO/TR 11688-1),

2) emission of **vibration** at source, such as redistribution or addition of mass and changes of process parameters [for example, frequency and/or amplitude of movements...,

3) emission of **hazardous substances**, including the use of less hazardous substances or dust-reducing processes (granules instead of powders, milling instead of grinding), and

4) **radiation** emissions, including, for example, avoiding the use, limiting the power, designing the source so that the beam, increasing the distance between the source and the operator ....
6.2.4 Choice of appropriate technology
   a) Mechanical stresses
   b) Materials and their properties
   c) Emission values

6.2.8 Observing ergonomic principles
6.2.11 Inherently Safe Design & Control Systems

• Design measures of the control system shall be chosen so that their safety-related performance provides a sufficient amount of risk reduction (see ISO 13849-1 or IEC 62061).

6.2.11.7 Safety functions implemented by programmable electronic control systems
Collaborative Operation...

<table>
<thead>
<tr>
<th>Techniques</th>
<th>Benefit(s)</th>
<th>Inherently Safe Design Measure(s)</th>
<th>ISO 12100 references</th>
</tr>
</thead>
</table>
| Safety-rated monitored stop | Ease of resumption/ restart; Increased life of contactors; Decreased floor space; Ergonomics improvement (vary fixture height to operator height) | 6.2.8 Observing ergonomic principles  
6.2.11 Applying inherently safe design measures to control sys  
6.2.12 Minimizing probability of failure of safety functions  
6.2.13 Limiting hazard exposure with equipment reliability |                                |
| Hand-guided         | Requires safety-rated monitored speed & stop. Safety-rated soft axis and space limiting could be required.  
Ease of resumption/ restart; Increased life of contactors; Personal control of robot system; Ergonomics improvement (robot system does the work, not person) | 6.2.8 Observing ergonomic principles  
6.2.2.1 Consideration of geometrical factors (direct visibility)  
6.2.11 Applying inherently safe design measures to control sys  
6.2.12 Minimizing probability of failure of safety functions  
6.2.13 Limiting hazard exposure with equipment reliability | Note: If hand-guiding is provided in a PFL robot, then these requirements are not applicable – see PFL. |
**Collaborative Operation...**

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</table>
| **Speed & Separation**<br>Requires safety-rated monitored speed & stop. Safety-rated soft axis and space limiting could be required. | Optimize production  
• Vary operation speed depending on human proximity  
• Ease of resumption/ restart  
Increased life of contactors | 6.2.11 Applying inherently safe design measures to control sys  
6.2.12 Minimizing probability of failure of safety functions  
6.2.13 Limiting hazard exposure with equipment reliability | |
| **Power and force limiting**<br>Requires safety-rated monitored stop. Safety-rated soft axis and space limiting plus other safety functions could be required. | Ease of resumption/ restart;  
Increased life of contactors;  
Possible decrease of floor space;  
Ergonomics improvement (robot system does the work, not person);  
Possibility of no guards (fenceless) and no protective devices | 6.2.2.1 Consideration of geometrical factors (all)  
6.2.2.2 Consideration of physical aspects (all)  
6.2.8 Observing ergonomic principles  
6.2.11 Applying inherently safe design measures to control sys  
6.2.12 Minimizing probability of failure of safety functions  
6.2.13 Limiting hazard exposure with equipment reliability | |
Inherently Safe Design Measures for PFL

- **Passive** safety design measures address the mechanical design of the robot system  
  *Ref: TS 15066, 5.5.5.4*

  - **increasing the contact surface area:**
   - rounded edges and corners;
   - smooth surfaces;
   - compliant surfaces;

  - **absorbing energy, extending energy transfer time, or reducing impact forces:**
   - padding, cushioning;
   - deformable components;
   - compliant joints or links;

  - **limiting moving masses.**
Inherently Safe Design Measures for PFL

• **Active** safety design measures address the control design of the robot system which can include the following: *Ref TS 15066, 5.5.5.4*
  
  – **limiting**
    • forces or torques;
    • velocities of moving parts;
    • momentum, mechanical power or energy as a function of masses and velocities;
  
  – **use of**
    • safety-rated soft axis and space limiting function;
    • safety-rated monitored stop function;
    • sensing to anticipate or detect contact (e.g. proximity or contact detection to reduce quasi-static forces).
Inherently Safe Design Measures...

- There are inherently safe design measures in all “contemporary” robots and robot systems.
  - Passive and Active

- Robot systems with Speed & Separation Monitoring and/or Power & Force Limiting have MORE inherently safe design measures than “traditional” robot systems.
  - Remember that a robot system is the robot, end-effector, and workpiece.

- PFL robots could have many safety functions by the SRP/CS or they can be limited by payload and physical properties.
PFL Inherently Safe Design Measures

• The application of these <inherently safe design measures> and other related measures shall address the expected exposure of the operator, as determined by a risk assessment.

• NOTE A combination of safety functions can be required, e.g. the force limiting safety function can be effective only up to a certain speed limit. In such a case, an additional speed limiting safety function would be necessary.

• In the event that one or a combination of passive or active risk reduction measures do not adequately reduce risk, the use of other risk reduction measures, including guards or safeguarding, may be required.

• Any clamping event between the collaborative robot system and human body regions shall occur in a way such that the person shall be able to escape independently and easily from the clamping condition.
The Journey…

Heavy, dirty, difficult work for people. Robot systems results in a less hazardous workplace for people than when the people were doing the robot system’s work.

Any impact by robot systems is high risk. Sensors, protective devices & safety-related functions mostly EXTERNAL to robot systems.

Complex systems and installations

Dirty, dull, awkward and non-ergonomic work for people. Robot system does the hazardous work (load/unload part) and Power/force limited robot means impact is LOW RISK. Sensors and safety-related functions (protective functions) are mostly INTERNAL to the robot and used for safely controlling risks of the robot system.

Complex but more likely to be very simple systems and/or partial task automation.
# Safety and Robot System Applications...

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<tr>
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<td></td>
</tr>
<tr>
<td>Process design, limiting access, layout; safety-related functions <strong>of the robot system SRP/CS</strong>;</td>
<td>Process modifications, reduced energy, compliant (soft) materials; safety-related functions of the <strong>robot system SRP/CS</strong> can include <strong>safety-rated</strong>:</td>
</tr>
<tr>
<td>Hard axis limits or safety-rated soft axis and space limits</td>
<td>monitored speed &amp; stop, soft axis and space limits</td>
</tr>
<tr>
<td>Safety functions for the integration of protective (safety) devices</td>
<td>Joint: angular position &amp; speed</td>
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<tr>
<td>Robot: max momentum &amp; applied force</td>
<td></td>
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<tr>
<td>Safeguards and SRP/CS (Safety-Related Parts/ Control System)</td>
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<tr>
<td>Fixed &amp; interlocked guards</td>
<td><strong>If needed, more...</strong> guards &amp; protective devices + safety functions</td>
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<tr>
<td>Sensitive protective equipment</td>
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Information for Use: similar for both

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