New interlock classifications

Since the 2006 version of AS 4024.1602 there has been significant advances in the technology of interlock devices, there has also been a transition in the types of devices used in industry. In recent years there has been development of interlock devices that provide higher levels of tamper resistance and diagnostic capabilities. The 2014 version of AS 4024.1602 has new classifications that better represent these interlock technologies. These classifications are then used in the standard to demonstrate aspects such as how to avoid defeat of the interlock systems, determine CCF tolerance and quantify the DC of the interlock system.

The new classifications are separated depending on the following criteria:

- Actuation principle – This determines if the switch is a mechanical or non-contact device.
- Coding – The device is either coded or uncoded. The higher the degree of coding the more tamper resistant the device is. Coding is classified into 3 sub classes:
  - Low level coding – 1 to 9 variations in coding
  - Medium level coding – 10 to 1000 variations in coding
  - High level coding – Over 1000 variations in coding

Table 1 shows the classifications for interlock devices.

<table>
<thead>
<tr>
<th>Actuation Principle</th>
<th>Actuator Example</th>
<th>Type</th>
<th>Coding Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanical</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uncoded</td>
<td>Limit switch, Hinge switch</td>
<td>1</td>
<td>None</td>
</tr>
<tr>
<td>Coded</td>
<td>Tongue interlock</td>
<td>2</td>
<td>Low level</td>
</tr>
<tr>
<td></td>
<td>Trapped key interlock</td>
<td></td>
<td>Medium to High level</td>
</tr>
<tr>
<td>Non-contact</td>
<td>Uncoded</td>
<td>3</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>Magnetic, inductive</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coded</td>
<td>Coded magnetic</td>
<td>4</td>
<td>Low level</td>
</tr>
<tr>
<td></td>
<td>Coded RFID</td>
<td></td>
<td>Medium to High level</td>
</tr>
</tbody>
</table>

Table 1: Classifications of interlock devices

New interlock classifications

Designing the interlock system to avoid CCF is a major design consideration for achieving PL according to AS 4024.1503; it is also integral to achieving SIL according to AS 62061.

The method to avoid CCF is explained in Annex F of AS 4024.1503. In this method the designer is presented with different measures that can be used in their system design, each measure is worth a certain score. As the designer achieves the requirements of each measure the cumulative score increases, once the designer achieves a score of 65 they have achieved the CCF avoidance requirements. Table 2 shows a summary of the measures and their associated score.
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New interlock classifications

<table>
<thead>
<tr>
<th>Measure against CCF</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Separation/Segregation</td>
<td>15</td>
</tr>
<tr>
<td>Diversity</td>
<td>20</td>
</tr>
<tr>
<td>Design/Application/Experience</td>
<td>20</td>
</tr>
<tr>
<td>Assessment/Analysis</td>
<td>5</td>
</tr>
<tr>
<td>Competence/Training</td>
<td>5</td>
</tr>
<tr>
<td>Environment</td>
<td>35</td>
</tr>
</tbody>
</table>

Table 2 - Summary of CCF measure and associated scores, AS 4024.1503

As can be seen in Table 2, Diversity is a significant measure when the designer is attempting to reach a score of 65. The general requirements in AS 4024.1503 are vague on different approaches to achieve diversity; this led to confusion of how diversity could be achieved for common safety functions such as interlock systems.

AS 4024.1602 now includes some guidance on how to achieve diversity in common interlock arrangements.

Diversity with Type 1 interlocking devices

One technique to achieve diversity when using Type 1 (Uncoded, mechanical device) interlocking devices is explained in clause 8.3.2 of AS 4024.1602. Here the combination of direct and non-direct mechanical action is used.

In Figure 2, an example of direct and non-direct mechanical action is demonstrated. In this example a sliding guard is shown in its closed state; the guard will slide to the left to open.

In this example limit switches are used because they are Type 1 interlocking devices.

Switch S1 is direct mechanical action mounted because the guard will directly actuate the switch when it is opened, by rolling on top the device.

Switch S2 is non-direct mechanical action mounted because the guard will roll off the switch when opened.
New interlock classifications

This is not a new concept and has been part of the standards for many years, however AS 4024.1602 now defines that the above arrangement will achieve the complete 20 points for Diversity as part of the CCF method in AS 4024.1503. This is clarity that was required as designers come to grips with the new requirements of AS 4024.1503.

Power medium diversity

Some machines have two or more energy sources required for hazardous movement, for example hydraulic and electrical energy. In this case diversity can be achieved by having two independent interlocking devices, each of which interrupts the supply from a different energy source.

AS 4024.1602 states that 20 points of Diversity can be claimed for the CCF method according to AS 4024.1503.

Switch S2 is non-direct mechanical action mounted because the guard will roll off the switch when opened.

Quantify the DC of series connected interlock functions (*Coming soon)

In order to achieve a PL or calculate a SIL, the DC of the system must be determined. In industry it is common to observe multiple interlock guards wired in series, this can reduce the amount of safety inputs needed in the safety relay system or safety PLC. The method to determine DC is explained in Annex E of AS 4024.1503, however there is no guidance given on how to evaluate series connected interlock guards.

The DC achieved by series wired interlock guards can be complex to evaluate. The potential of masked faults in the system can be influenced by the following application characteristics:

- How many guards are wired in series?
- How many are guards are used frequently?
- How many individual devices are used on each guard?
- What wiring configuration is used?
- What type of evaluation is used to detect faults?
- What type of cable is used?

As you can imagine this has caused significant confusion on how to determine the DC achieved by series connected interlock guards.

Clause 8.6 of AS 4024.1602 will shortly provide a solution for this problem. The clause references a technical report, ISO/TR 24119, which will provide a simple method to evaluate the maximum DC achieved by series connected interlock guards. This technical report is currently in draft stage, but hopefully will be released later this year and provide much needed clarity of this issue.

Design to minimise defeat possibilities

The previous sections of this paper explain various ways that AS 4024.1602:2014 can assist with transitioning to design methods such as PL or SIL. However the most significant improvement with this new standard is the defined process to avoid defeat of interlock guards. Many of the aspects and measures are not new, but this standard now provides a structured process to follow. This should result in improved compatibility between machine function and interlock guards.

Figure 3 shows the flow diagram that designers can use to ensure motivation to defeat is minimised and resistance to defeat is present where needed.
As seen in Figure 3, the first step is to implement basic measures, an example of these basic measures includes:

- Correct fastening of switches
  - Loosening of position switches, actuators and cams must require a tool
  - Type 1 position switches may require permanent fixing, such as pins or dowels
  - Self-loosening should be avoided

- Switch should be mounted appropriately
  - Access should be provided for maintenance
  - Switch should be mounted to protect against foreseeable damage
  - Switch should not be used as a mechanical stop
  - Type 1 or 2 switches should be direct mechanical action mounted, with direct opening action contact elements

Once the above basic measures are ticked off, the designer can use the method explained in Annex H of AS 4024.1602 to determine if a motivation to defeat the interlock system exists. This is a new method introduced with this version of the standard and provides guidance that has never been available before.

Table 3 is an example of how the method in Annex H of AS 4024.1602 is documented. The process includes 4 steps:

1. All modes of operation of the machine are identified, eg Mode 1 = Automatic and Mode 2 = Maintenance (Listed as headings in Col 2 and 3)
2. All tasks should be listed as the rows of the table. An “x” is to be used to indicate what mode of operation the task needs to be performed in. (Listed in Col 1)
3. The next column (Col 4) indicates whether it’s possible to perform the task in that mode without defeating the interlock guard
   a. If the answer is ‘no’ then improvement of the machine design or implementing new modes of operation is mandatory
4. The following columns (Col 5 and above) identify if other benefits of defeating the interlock exist when completing that task
   a. These benefits will need to be addressed as per the flow diagram depicted in Figure 3
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New interlock classifications

<table>
<thead>
<tr>
<th>Task</th>
<th>Col 2</th>
<th>Col 3</th>
<th>Col 4</th>
<th>Col 5</th>
<th>Col 6</th>
<th>Col 7</th>
<th>etc</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start-up</td>
<td>Automatic</td>
<td>Maintenance Mode</td>
<td>Task possible without defeating</td>
<td>Faster to complete task</td>
<td>Better visibility</td>
<td>...</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mode</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Machine</td>
<td>x</td>
<td>Yes</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>operation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Material</td>
<td>x</td>
<td>No</td>
<td>++</td>
<td>++</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>feeding</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>etc</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td></td>
</tr>
</tbody>
</table>

Benefit of defeat: 0 = None, + = Minor, ++ = Substantial

Table 3 - Example of documenting motivation to defeat process

In Table 3, there are 2 modes of operation and 3 tasks.

For machine start-up, the task needs to be performed in Automatic mode and it is possible to complete the task without defeating the interlock guard. The following columns also indicate that no other benefits are achieved by performing this task with the interlock defeated.

For material feeding it can be seen that this task needs to be performed in Automatic Mode, however the task is not possible in this mode without defeating the interlock guard. The material feeding task requires the ability to jog the machine with the interlock guard open, but the automatic mode won't allow operation with the interlock guard open. This result will require a new mode of operation to be added to allow the material feeding task to be performed in a safe way.

For machine operation it can be seen that this task needs to be performed in Automatic mode and it is possible to complete the task without defeating the interlock guard. The following columns indicate that there is a substantial benefit of improved visibility when defeating the interlock guard. The designer should consider what design measures could address this benefit, eg: Using a guard that provides the required visibility. If there are no design measures available then the designer would need to implement additional measures to minimise defeat possibility.

Additional measures to minimise defeat possibility are used to address residual motivation to defeat once all possible design measures and alternative modes of operation have been exhausted.

The measures are reliant on the level of coding incorporated by the interlock devices. The lower the level of coding; the more measures are required to avoid defeat, examples of measures used are:

- Mounting out of reach – Mounting the interlock device in a position that is out of the reach limits of the operator
- Physical Obstruction/Shielding – Mounting the interlock device behind physical obstructions, so the operator can’t easily access the device
- Mounting the interlock device in a hidden position
- Status monitoring or cyclic testing - These two techniques are systems that ensure the interlock device’s function is tested, thus the test will detect if the device has been defeated
- Non-detachable fixings – These fixings prevent the switch, actuator or both being removed from their intended position in order to defeat the safety function
- Additional device – Utilising two independent devices for the interlock function, thus if one device is defeated the safety function will still operate

Table 4 indicates what measures are implemented for the different classifications of interlock devices.
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New interlock classifications

<table>
<thead>
<tr>
<th>Measures</th>
<th>Type 1 or 3, except hinge switch</th>
<th>Hinge Switch</th>
<th>Type 2 or 4 with low or medium coding level</th>
<th>Type 2 or 4 with high coding level</th>
<th>Trapped key system with medium or high level coding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mount device out of reach</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shield device</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mount device in hidden position</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Status monitoring/ cyclic testing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-detachable fixing for switch and actuator</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-detachable fixing for switch</td>
<td>M</td>
<td></td>
<td></td>
<td>M</td>
<td></td>
</tr>
<tr>
<td>Non-detachable fixing for actuator</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td></td>
</tr>
<tr>
<td>Additional device</td>
<td>R</td>
<td>R</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

X = measure should be considered, M = measure is mandatory, R = measure is recommended

Table 4 - Additional measures to minimise defeat possibility

Conclusion

In conclusion the new version of AS 4204.1602 provides assistance for designers to achieve the requirements of AS 4024.1503:2014. The standard provides guidance on how to design interlock systems to avoid CCF and will provide a method to evaluate the DC of interlock functions that are series connected.

The other significant improvement of this standard is the process to minimise the probability of defeat. This method ensures that interlock guards will be designed with the operation of the machine in mind. This will reduce the motivation for operators to defeat the interlocking systems. The process also provides a method to select the appropriate interlocking devices to address any residual motivation to defeat the interlock system.

References

AS 4024.1503:2014
AS 4024.1602:2014