17th February 2021

Passenger restraints/control systems: Ride Inspection Bodies Action Note

TARGET AUDIENCE:

This action note is aimed at ride inspection bodies of high-speed amusement devices and all those responsible for the maintenance of these devices, where failure of a restraint to be properly locked could result in the ejection of passengers.

INTRODUCTION:

The document follows on from the action note published in July 2020 by HSE which was aimed at ride operators. HSE has investigated a number of accidents over an 18-month period, all involving ejection of passengers from high speed, rotating 'orbiter' type rides. HSE has identified that although the rides were made by different manufacturers, all had similar design and maintenance failings with the interlocking mechanisms of the passenger restraint systems.

BACKGROUND:

This note applies to rides where passenger containment is achieved with either 'over the shoulder' or 'lap bar' restraints (referred to as 'restraints' in this document).
The issues raised in this advice note apply on rides where limit / proximity switches (referred to as limit switches) are used to detect that the restraints are down and locked in place. This can either be as an indication to the operator, or as part of a "safety interlock" which will only allow the ride to start when all restraints are down and locked. In either case the limit switches are an important safety feature of the ride.

An example of an over the shoulder restraint is shown in figure 1.

Restraints may be automatically opened and closed or manually operated. There will be a locking mechanism to mechanically lock the restraints down and prevent them from opening during operation, this system can be monitored by limit switches see figure 2.

Figure 1: Photograph showing a ride with over the shoulder restraints

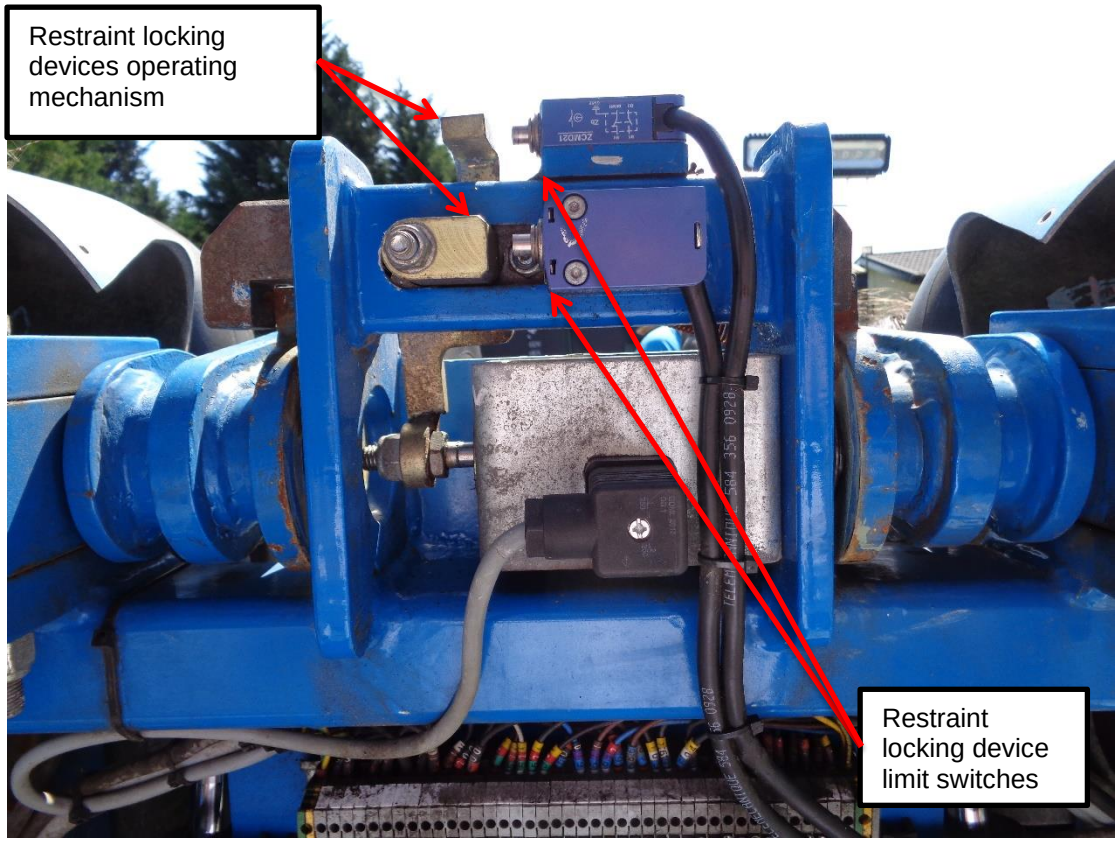

Figure 2: Restraint Locking device arrangement.

HSE findings

HSE investigations into the four incidents, and subsequent follow up sample inspections of similar rides found the following issues on the devices seen:

- Limit switches had failed in such a way that they always indicated that the restraints were down and locked even when they were not.
- Faults with limit switches were not detected by the control system.
- Faults with limit switches had not been identified during maintenance, and due to sample testing of limit switches, it is likely that some of these faults were not detected during the annual inspection.
- Limit switches had been modified to enable the ride to run regardless of the restraint position.
- Faults with switches were being reset by ride operators even though switches were known to be faulty.
- Switches were incorrectly adjusted to indicate that restraints were fully down when there was an excessive gap between the seat and restraint that was potentially dangerous.

Sample inspections of similar rides by HSE found failed interlock switches and prohibition notices were served to prevent the rides from being used until all faults were put right.

ACTIONS REQUIRED:

Ride Inspection Bodies

Examiners with competence in control systems should familiarise themselves with the issues described in this safety alert so that they can identify control system defects. More detailed information on what to look for is provided in appendix 1.

During in-service annual inspection, examiners should:

1. Test every individual restraint limit switch to ensure that all are functioning correctly. (HSG175 already includes the requirement to check safety interlocks and the integrity of the containment system). Note 1

2. If failed switches are found, they should be identified as safety-critical defects and the potential consequences of these failures should be included in the written report.

3. Before issuing a DOC, ride examiners should normally confirm by reinspection that any identified defects on passenger restraint systems have been rectified. In any case, the Ride Inspection Body must ensure that the necessary remedial work has been completed and tested by a competent person, and this should be adequately evidenced and documented before issuing a DOC. Note 2

4. If the restraint interlock arrangement is modified following identification of problems during an annual inspection, this should be classed as a safety critical modification and will require a partial design review to check the impact of any changes on the ride.

Notes;

Note 1, HSG175 in paragraph 164 describes a system of sampling which may be used when examining a number of identical components which can be individually identified. Due to the number of incidents with failed limit switches, this type of sampling system shall not be applied to restraint limit switches. This approach is as also advised in paragraph 163 of the Amusement Devices Safety Council, ***"****Safety of Amusement Devices: Advice for Inspection 2008 Part 1 In Service Annual Inspection"*

Note 2, As stated in HSG175 paragraph 171, "*A DOC should not be issued until the AIB is satisfied that all necessary remedial actions outlined in the inspection reports have been addressed and the device is safe for use."*

Bodies registered to carry out control system design reviews

New amusement devices and restraint monitoring control systems should be manufactured and installed to meet *BS EN 13814-1:2019* and be subject to design review the relevant pre-use inspections before the amusement device is put into use for the first time.

If a design review of the control system for a ride in service becomes necessary, and it is found that it does not conform to the relevant standards at the time of manufacture, or that the ride would be susceptible to the issues raised in this safety alert (i.e. switches that are likely fail in a way that gives rise to a potentially dangerous situation) then the modification should be rejected and attention drawn to this action note so that the designer can act to remedy the design.

HSE

This note is being passed to HSE NFIT Inspectors for information. In the coming year NFIT inspectors will be checking high-speed amusement devices where failure of a restraint to be properly locked could result in the ejection of passengers to make sure that restraint interlocks are functioning correctly, and that suitable thorough maintenance is being carried out on these rides.

GENERAL NOTE:

Please pass this information to ride controllers who operate this type of ride or equipment; or those who advise on/assess; those who specify, design, make, supply, install, maintain, or service this type of equipment.

All readers are advised to consider other available information and existing Safety Bulletins published by HSE on these products (see below for links).

APPENDIX 1 - TECHNICAL EXPLANATION:

The issues described in this safety alert are foreseeable problems that have previously been encountered on amusement devices and general industrial machinery.

Published document "*PD5304 - Guidance on safe use of machinery*" provides guidance on how to avoid the issues described in the safety alert.

The design of the control system is dependent on risk assessment and the required risk reduction contribution of the control system. This is usually expressed as a PL according to ISO13849-1 or as a SIL according to IEC 62061.

BS EN 13814-1:2019 provides minimum control system requirements for different designs of passenger restraint systems.

Positive/negative mode switching:

Note: Positive/negative mode operation refers to the method by which the contacts of the limit switches are mechanically operated. This should not be confused with the electrical contacts of a switch which can be either normally open or normally closed. It is possible to operate switches in the positive/negative mode with either normally open or normally closed contacts.

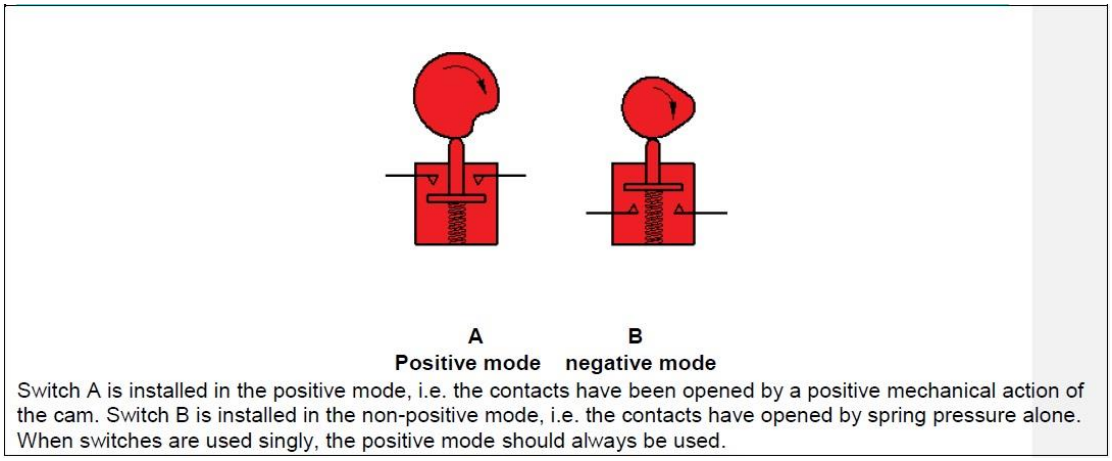

Figure 3: Diagram showing positive and negative mode switching, taken from PD5304.

The switches used to monitor the positions of restraints and secondary locking mechanisms on rides are often cam operated switches. Figure 3 shows two modes in which cam operated switches can be used for position monitoring.

In figure A, the cam pushes against the switch, pressing the plunger down, positively forcing the contacts of the switch apart. This is called 'positive mode' switching. There is just one position of the cam where the spring inside the switch can push the plunger up, allowing the switch contacts to close.

In figure B, the spring inside the switch pushes the plunger up, holding the switch contacts apart. This is 'negative mode' switching, negative because it relies on the spring rather than the positive action of the cam. With this arrangement, there is one point where the cam will push the plunger down, forcing the switch contacts together.

It is important for designers to think about the way in which limit switches are used when safety is dependent on the switches working. It is foreseeable that a switch is likely to fail in a certain way.

Two common modes of failure for cam-operated position switches are:

- The plunger gets stuck (or the spring breaks or becomes weak) and the plunger remains pushed in no matter what the cam does.
- The electrical contacts inside the switch weld together and then the spring is not able to push the contacts apart.

In most ride control systems, when the switch contacts are closed the switch provides a signal that allows the ride to run. When that signal is lost (when the contacts open), the ride stops.

Considering the mode of operation of the switches and the ways in which a switch is most likely to fail when used to monitor the safe position of a restraint;

- In the negative mode, if the plunger gets stuck in the fully in position or the contacts weld together, the switch will provide a signal that allows the ride to run regardless of where the cam (and restraint) was positioned. This is a dangerous failure mode.
- In the positive mode, if the plunger sticks or the contacts weld together, for the most part the cam pushes directly on the plunger and this pressure will positively force the switch contacts apart. Therefore, in this situation, if the switch failed the contacts would be open and this would prevent the ride from running. This is a safe failure mode.

For these reasons negative mode switching is generally regarded as being unreliable.

Most of the restraint interlock switches observed by HSE on the recently examined rides were fitted in the negative mode. This is why the rides were able to carry on running even after safety interlock switches had failed.

It is a requirement of the control system standards (ISO 13849-1 and IEC 62061) that when safety is dependent on switches, the switches should be used in a way so that if they fail, a dangerous situation is not created.

<u>Redundancy and cross monitoring</u>

It is possible to increase the reliability of an interlocking system by using two switches rather than one, see Figure 4 (A). Although the use of two switches can improve reliability, if they both operate in the same way and the electrical signals are connected together, it is possible for one switch to fail and the machine will continue to work normally. This is called an undetected fault. If steps are not taken to check the operation of the switches then over time this system provides no better reliability than using a single switch. This is because it is likely that at some point one switch will fail and the system will keep operating on just one switch, until that is, the second switch fails too.

Rather than connecting two switches in series, it is advisable to connect them separately in a parallel arrangement known as ‘dual channel’, see Figure 4 (B). A dual channel system provides redundancy on the switches and the cabling, it also enables monitoring of both channels to check when the switches are operated. This can be done using a ‘safety relay’ which can look for errors in the timings of when the two channels switch. For example, if one channel has failed closed and the other channel was switching as normal then this type of relay would detect this discrepancy and lock out the control system until the failed switch had been identified and repaired, this is known as ‘cross monitoring’ of the channels.

HSE has observed restraint systems where two switches have been connected together in series rather than connected as dual channel with cross monitoring.

A consequence of this single channel design was that functional test of the restraint, by opening then closing it and observing whether the ride ‘ready’ light changed state, would not have identified that one of the interlock switches had failed because the second switch in the pair would have changed state and operated the light. The only way to check that all the switches were operating correctly would be to test them individually.

Other problems have been identified where dual channel switches are connected properly but the redundancy is not maintained throughout the whole safety circuit, in particular through slip rings where a single signal was sent to turn off the ride motors. This then provides a single point of failure and lowers the safety integrity of the ride.

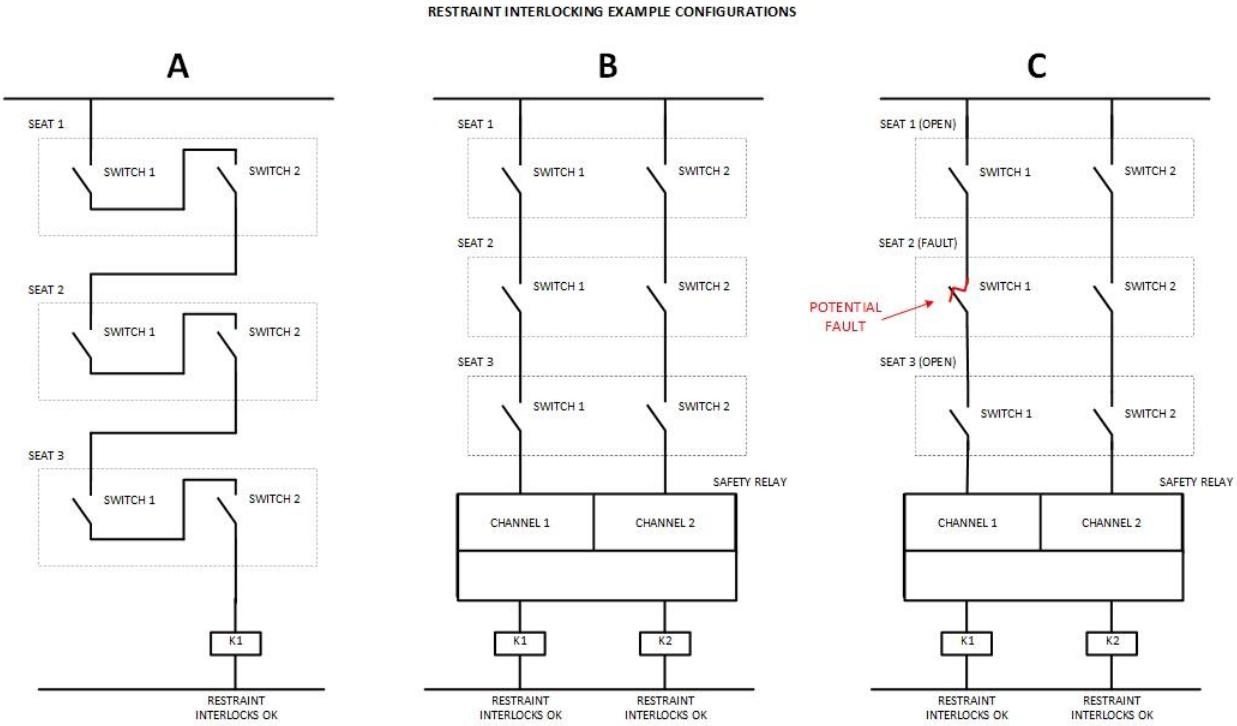

Figure 4 : Diagram showing possible restraint limit switch circuit arrangements.

Fault Masking:

Detailed guidance on fault masking is given in ISO TR24119:2015.

When designing safety interlock circuits, it is common to connect multiple volt free contact switches in series into a safety relay or safety programmable logic controller (PLC) which checks the circuit for operation of the switches and for faults.

When a fault develops on one interlock switch in the circuit, it should be detected by the safety relay/PLC which can lock out the operation of the ride and should not allow it to be reset until the fault is repaired.

Fault masking occurs when this fault is ‘masked’ by the operation of another (non-faulty) switch which is wired in series with the faulty one, see Figure 4 (C). This operation appears to the safety relay as if the original fault has been fixed and it therefore allows the ride to be reset even though the original fault is still present. Consequently, this can lead to an accumulation of faults being present in the safety circuit. This issue can occur in either single or dual channel circuit designs.

Ride operators should be aware of this problem so that they understand if the safety system locks out when operating one set of restraints, but this can be reset by operating another set of restraints, then this is an indication that there might be a masked fault present on the ride that will require maintenance to fix.

RELEVANT LEGAL DOCUMENTS:

The Provision and use of Work Equipment Regulations 1998 (PUWER), especially regulation 5 which puts a duty on employers to ensure that work equipment is maintained to be safe, and regulation 6 which says that equipment must be inspected before putting into service and at regular intervals to ensure safety.

The Health and Safety at Work etc Act 1974, especially Section 3 which is the duty to protect the safety on non-employed persons (e.g. members of the public) arising out of the way an undertaking is conducted.

The Health and Safety at Work etc Act 1974, especially Section 6 which puts a duty on designers, manufacturers and suppliers of work equipment to ensure that the equipment is safe.

FURTHER INFORMATION:

Further information on the safety of amusement devices is available at:
http://www.hse.gov.uk/entertainment/fairgrounds/index.htm

Previous Safety Bulletins at:
https://www.naflic.co.uk/wp-content/uploads/2020/11/TB501-HSE-action-note-on-passenger-restraints-control-systems.pdf

Inspection bodies and trade associations:
The Amusement Devices Inspection Procedures Scheme (ADIPS) [1]
The National Association for Leisure Industry Certification (NAFLIC) [3]

The Showmen's Guild of Great Britain (SGGB)

REFERENCES:

BS EN 13814-1:2019 Safety of amusement rides and amusement devices. Part 1: Design and manufacture

BS EN 13814-2:2019 Safety of amusement rides and amusement devices. Part 2: Operation, maintenance and use

BS EN 13814-3:2019 Safety of amusement rides and amusement devices. Requirements for inspection during design, manufacture, operation and use

PD 5304:2019 Published Document. Guidance on safe use of machinery

PD ISO TR24119:2015 Safety of machinery - Evaluation of fault masking serial connection of interlocking devices associated with guards with potential free contacts

BS EN ISO 13849-1:2015 Safety of machinery - Safety related parts of control systems. Part 1: General principles for design

BS EN IEC 62061:2005+A2:2015 Safety of machinery - Functional safety of safety-related electrical, electronic and programmable electronic control system

All standards and guidance documents listed above are available from British Standards Institute (BSI) : https://shop.bsigroup.com/

Amusement Device Safety Council (ADSC) design guidance "*Safety of Amusement Devices : Design*" 2nd Edition, available from https://inspectors.adips.co.uk/publications/

HSG175 Fairgrounds and amusement parks: Guidance on safe practice. Third Edition published November 2017, available from: http://www.hse.gov.uk/pubns/books/hsg175.htm