Total Safety Approach on Elevator Doors

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ABSTRACT

Throughout time, elevator passengers have been protected between automatic sliding doors with mechanical safety edges, photo eyes, light curtains and other means of sensors. Common to all solutions is that they are incapable of protecting persons from the leading edges of the doors. The results of suddenly closing doors range from frightened to falling and severely injured people. In addition, the awareness of accidents caused by entrapment of fingers and hands during opening, especially pronounced with glass doors, is on the rise. If European Safety Standards for Machines would be applied to elevator doors, by law all elevators would have to be shut down immediately as they do not comply with the regulations in force! The proposed paper describes risk assessment for elevator doors according to the EU Machine Directive and outlines a new concept of door sensors that elevates safety into a higher realm.

1. INTRODUCTION

Three different door protection systems are in operation and marketed: Through Beam Light Barriers, Mechanical Safety Edges and Light Curtains. There are additional systems in use but they play an insignificant role today. These types of door protection devices have been discussed in detail by everybody involved with door protection. The main disadvantages of all these systems are their incapability to protect the passengers against the dangerous parts of an elevator, namely the leading edges of the doors. Danger for a passenger occurs when he can be hurt by or squeezed between the door wings (either with the car doors or the landing doors as well as with the doors and the slam post).

Another possibility for danger could also be the passenger approaching an elevator who is startled by the sudden door closing. Especially elderly people tend to be shocked, fall down and seriously injure themselves.

A worst-case scenario would be a child's hand squeezed between the doors (not detected by the door sensor), the door contact signal "doors closed", the elevator starts to travel and the hand is cut off. This case can happen if the "doors closed" contact is activated too early.

2. RISK ANALYSIS OF AN ELEVATOR DOOR

An automatic elevator door is a power-operated machine that presents a risk for personal injury. A sensor shall provide protection by causing the door to revert to a safe condition before a person can be placed in a hazardous situation. The European Standard EN 1050 describes the procedure of the risk assessment for a machine.

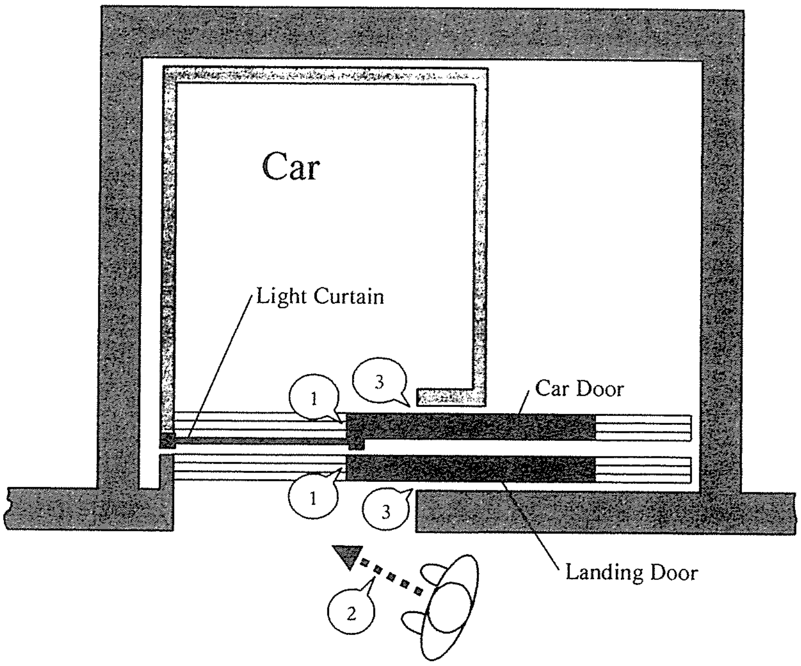

Fig. 1: Dangerous zones of elevator doors

A first look to elevator doors shows a risk of being pinched between the leading edge of center opening doors or the leading edge of a side opening door with the slam post (1). These dangerous areas were the topic of many door safety discussions in the past. But there are some other dangerous areas on elevator doors. One problem is the sudden closing of the door if somebody approaches from a side hallway in a flat angle towards the door (2). A person approaching a closing door in such a way could be thrown back into the hallway and could loose their balance. Serious hip, wrist or shoulder injuries occur in this case because the person is falling down sideways without any protection. It is obvious that the 3D light curtains available today do not protect against this case of accident because they do not detect people approaching an elevator door from an angle!

Another safety problem is the gap between the door panel and the post during an opening of the door (3). Children's hands are especially vulnerable for two reasons: First, children can't resist pressing their nose against a glass landing door, and observing the hustle and bustle on the streets or in a department store lobby. Second, the friction of glass is much higher than stainless or painted steel, which causes the hand to stick on the surface and pulls it into the dangerous gap. Fig. 1 shows the dangerous zones on an elevator entrance. Note that these dangerous zones are still <u>not</u> protected by mechanical safety edges; standard light curtains and 3D light curtains.

Before we can dive into possible solutions for a total safety approach on elevator doors some definitions have to be made.

3. WHAT DOES FAIL SAFE MEAN?

The definition of this term means, "If a part or the whole system, which is safety related, fails, the system shall go to the off-state". In the case of elevator door sensors, the doors should open and remain open until the failure is fixed. Assuming the output relay contact of the door protection device is welded (or stuck), it is impossible for this device to reopen the doors. The elevator doors now are very dangerous and susceptible to a potential accident! There are many other possibilities when door protection devices can fail to "un-safe". In my opinion, the wording fail-safe should not be used anymore in the context of standard door protection systems, e.g. photo eyes or light curtains, unless specific standards like EN 954 are met.

4. DEFINITION OF THE REQUIRED SAFETY LEVEL

There are standards from the machine industry, which already define levels of safety. In Europe it's EN 954, in the United States of America it's the OSHA standard 1910.212. EN954 classifies safety levels into five categories:

1. Class B: Basic safety, no qualification of anything
2. Class 1: Qualified and reliable components used
3. Class 2: Testable systems that must be tested before every dangerous motion
4. Class 3: Redundant systems with limited detection capability
5. Class 4: Redundant systems with full detection capability

It is obvious that existing door protection devices fall under Class B, possibly under Class 1. However, the above-mentioned standards use the term "fail-safe" only with classes 2 and above. Hence, none of the existing door protection devices can claim as to be "fail-safe"! The above-mentioned standards also define the necessary class based on the type of injury that may occur. If the injury can heal without any permanent damage then Class 2 devices can be used. If the injury can result in either death or handicap, then Class 3 or Class 4 devices must be used. It is obvious that automatic elevator doors must protected with Class 2 devices. In practice, Class 2 devices are relatively simple if the door drive supports "testing". "Testing" means, that the door sensor must be tested prior to the door closing.

5. OBJECT SIZE

The same standards as well as related standards define "object sizes". This introduces the problem of the risk analysis on one hand and the technology available on the other. The standards say that a dangerous motion must stop before the "object" reaches the dangerous point of operation (which is obviously the leading edge of the door). It means that not only the size of the object is important but also the speed of the object and the stopping time of the machine (in our case the doors). The related speed in this case stated in the standards is 1.6 m/s (moving person). When we assume that the door sensor has a response time of 50 ms and the door has a stopping time of 200 ms, the safety distance has to be (200 ms + 50 ms) x 1600 mm/s = 400 mm outside the landing door and inside the car door. This calculation method is valid with an object size of 14 mm in diameter (finger tip). If the object size is 30 mm (wrist, child's arm), we have to add another 128 mm to the above calculated safety distance. A closer look to Fig. 1 again shows that this safety distance from the car door towards inside of the car is not practical because people always stand closer than 500 mm to the car door. On the other hand, persons in the car are not exposed to danger because they know that they are close to the dangerous elevator door. This knowledge keeps them back at a safe distance. In addition, people cannot approach the car door from inside the car with a speed of 1.6 m/s due to the limited acceleration distance.

6. OBJECT REFLECTIVITY

"Object reflectivity" is defined in the standard IEC 61496, which defines the requirements of safety sensors for machine guarding. If reflective sensors shall be built "fail-safe" it is necessary to define the object reflectivity. This standard states that test pieces shall have a reflectivity of 1.6 to 2.0 % (black test piece) and 80 to 90 % (white test piece). The black test piece refers to an investigation performed by "Berufsgenossenschaftliches Institut für Arbeitssicherheit", 53754 Sankt Augustin, Germany. It was the purpose of this scientific research to find the diffuse reflectance coefficient of different materials used for clothes and shoes. All these objects must be reliably detected in order that reflective sensors can be built fail-safe (IEC 61496, Part 3).

7. WHAT LEVEL OF PROTECTION SHOULD BE ACHIEVED?

Taking these facts into consideration, a state of the art door protection device should meet the following requirements:

1. It should prevent any part of humans from any danger at the leading edges of doors
2. It should prevent closing the doors when people approach an elevator (at landing) even in a flat angle from one side (see figure 1, note 2)
3. It should detect objects at any place in the dangerous zones (refer to figure 1) with a size of 30 mm in diameter, length of 300 mm, diffuse reflectance of 1.8 % and 90 %
4. It should not fail "un-safe" if anything fail-safe related to the safety device fails (Class 2)
5. The response time of the sensing device should be less than 50 ms
6. The stopping time of the door should be less than 200 ms
7. The sensing height should start less or equal than 30 mm above sill and should reach a height of 1800 mm
8. The sensitive area shall not extend significantly into the car area. Otherwise the doors re-open too often due to persons standing too close to the car door. 25 mm is recommended.
9. The sensitive area shall reach 528 mm into the lobby to provide enough safety distance for fast approaching persons.

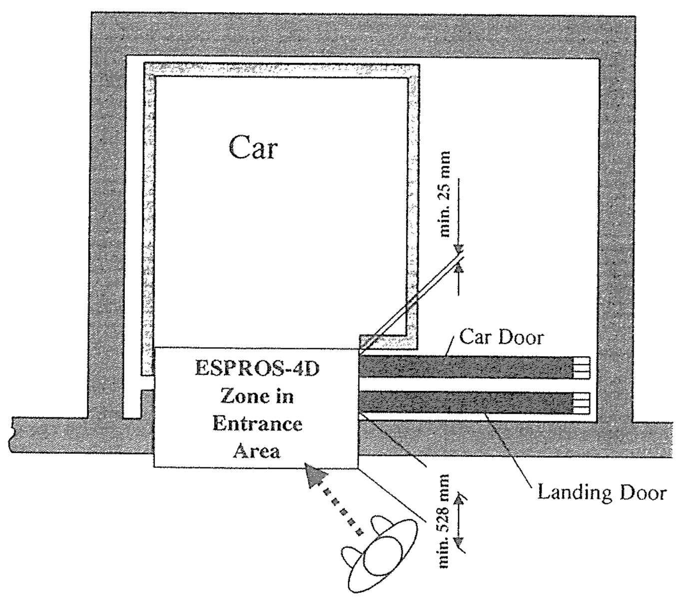

Fig. 2: ESPROS-4D Sensing Zone

8. PROTECTION OF THE ENTRANCE AREA

The above-mentioned level of protection can be achieved with two new technologies developed and patented by CEDES. The artificial vision sensor ESPROS-4D (Electro Sensitive Protection Optimized System), protects the whole entrance area. It automatically recognizes the car sill to define the inner limit of the detection zone. It does the same with the landing door sill where it adds approx. 500 mm of detection zone towards the lobby. During closing of the doors, the sensor automatically follows the door closing using origin-transformation procedures. The beauty of this type of sensor is that it is very small, has no moving parts, and is installed to the door drive looking down where it does not require traveling cables.

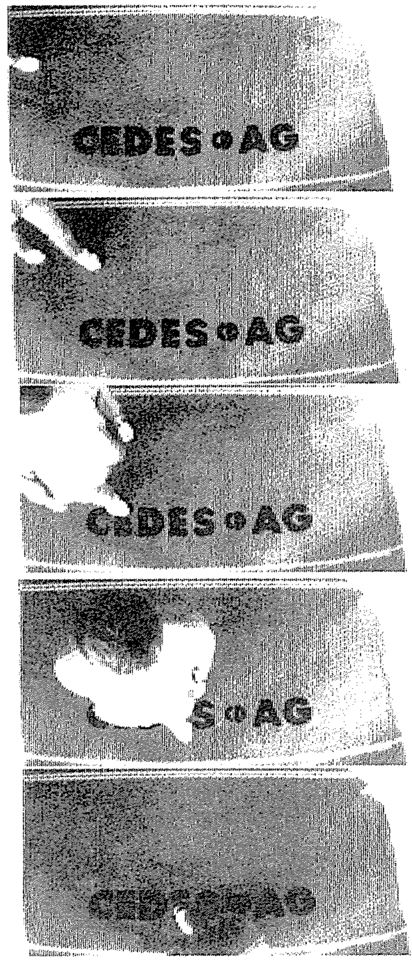

Fig. 3: Dynamic Picture Sequence with ESPROS-4D

This sensor not only detects objects between or in front of elevator doors, it also detects sideways approaching objects. Therefore, it is not only 3D but also a 4D-Sensor (Space plus Time in Motion). The following drawings and pictures show the detection zone of ESPROS-4D.

It is obvious that this kind of sensor is able to do much more than detecting objects in the entrance area. It can be used to identify persons, to count the number of persons standing in the lobby waiting to be served by an elevator, to compute the floor space in an elevator car occupied by passengers and goods, and to detect movement direction (refer to Fig. 3) etc.

Tremendous technological investment is necessary to make such a sensor become viable. First, a very powerful computer on a chip must be available to act as a "number cruncher". In the present design, over 6 million pixels have to be evaluated in one second with sophisticated picture recognition software. Second, the design must be made as cost effective as possible so the acceptance of this new technology does not fail in regards to prices. It must be competitive with standard light curtains sold today. If easy installation is taken into consideration, ESPROS-4D is doubtless very competitive!

9. PROTECTION DURING DOOR OPENING

The second new technology is CCPS, the CEDES Child Protection System. It is a reflective sensor, which monitors the dangerous area of the door panel and the door post. Such sensors are available today from many manufacturers. However, the crucial problem is the wiring of the sensors on the landing doors. Every sensor has to be logically "AND-ed" with the floor position so only the landing door sensors on the stop floor are activated. In addition, the output signal of this logic has to be fed to the

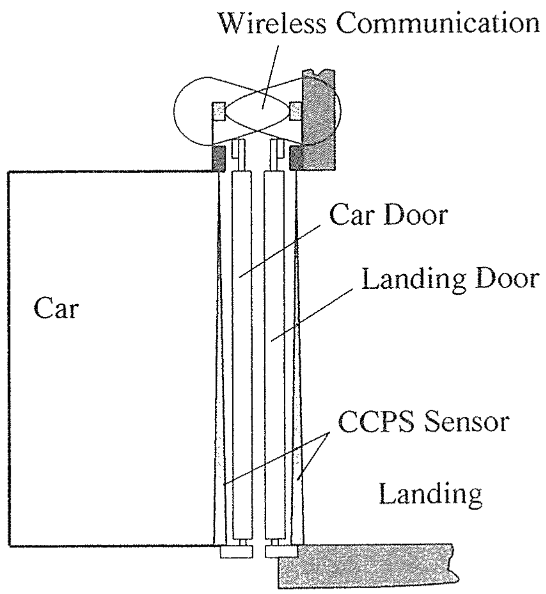

Fig. 4: CCPS Concept

door drive on the car using the traveling cable. CEDES has developed a wireless solution to overcome this problem. The status of the landing door sensor is transmitted wireless to the door drive on the car top. Fig. 4 shows the concept of this new technology.

10. CONCLUSIONS

Elevator door protection systems should be defined based on the risk of an accident that may occur, and in accordance with well-established standards. They should also be based on the incorporation of latest technical advances and knowledge from similar areas like machine guarding. There should be no compromise due to the fact that most of the systems available on the market today do not offer the necessary level of safety. Only the latest sensor technology is able to fulfill the safety requirements in order to reduce the number of accidents and law suits in connection with elevator doors.

REFERENCES

European Standards: *Machinery Directive 89/392/EWG*

European Standards: *EN 954, Safety of Machinery*

International Standard: IEC 61496, Electro-Sensitive Protective Equipment ESPE

German Standard: DIN V VDE 0801: *Principles for computers in safety related systems*

Meier, P. et al. (1998). *Safety at Machinery in Europe, CEDES AG*

Reinert, D.; Bömer, T.: *Modern sensors as protective devices for the safety of machinery. 3. Eurolab Symposium of the Organisation for Testing in Europe: Testing and analysis for industrial competitiveness and sustainable development. 05.-07.06.1996, Berlin - Vortrag. Berichtsband Volume 1, S. 215-224*

BIOGRAPHICAL DETAILS

Beat De Coi, born 1957 in Switzerland completed an apprenticeship as a mechanical designer in Switzerland. He developed mechanical parts for military radio systems where he became familiar with the design of products for very harsh environments. After this first industry experience he continued his studies and he received a BSc. in Electronics (Dipl.-Ing. FH) in 1984 from Juventus Schools of Zurich. In 1986 he founded CEDES AG to develop and manufacture optoelectronic sensors. In 1992, he decided to study Operations Management and Logistics at the Graduate School of Business Administration of Zurich (MSc.) in parallel to his job as a managing director of CEDES. In 1998, De Coi was nominated as "Entrepreneur of the Year" in Switzerland and in 1999 he received the KMU-Oscar; an award for the most innovative entrepreneur. In 2000, he decided to go back to his technical roots. He handed over his job as a Managing Director to Ernesto Maurer and became vice president in research and development. He is still Chairman of the Board of the CEDES Group.