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Braking system redundancy requirements for moving walks

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ABSTRACT

The reliability of the braking system of moving walks plays a major role in the safe exploitation of these people movers. According to the requirements of the new standard ISO 22201-2, the reliability of a braking system of a moving walk has to correspond to safety integrity levels SIL1 till SIL3. In order to determine the required safety integrity level, a reliability analysis of a braking system has been performed using a probabilistic method and the Weibull distribution model. This paper presents the results of this reliability analysis and shows the necessity of redundancy of the braking system of public service moving walks. The results for the proposed redundant design show a higher reliability level and less reliability degradation in time than compared to braking system designs without redundancy. Based on these results and using a probabilistic and diagnostics approach, a suggestion for an intelligent system for preventing failure in a braking system is presented in this paper. This system maintains a required safety level of the braking system of a moving walk and predicts possible failures of the braking system.

1. Introduction

Moving walks and escalators are passenger conveyors. They are for example used in airports, grocery stores, transport terminals, fair grounds and railway stations. These conveyors carry many people in public places every day. Therefore, the operational safety of these conveyors is very important. Although moving walks and escalators have safety precautions, there are still accidents in practice. Some of these have tragic consequences, including casualties. Many tragic accidents happen because people, that use the conveyor, fall. According to Consumer Product Safety Commission (CPSC) data, 16 people were killed on escalators in the period 1997 till 2006 in the USA caused by a fall on an escalator [1]. CPSC estimated that this is about 75% of all accidents for this period of time. About 2.5% of all escalator stops lead to passenger falling [2].

The Washington Post described an escalator accident in which six passengers were injured. An "overspeed fault", which shut down the escalator' motors, automatically engaged the brakes. Officials said that all three brakes were engaged but that they failed to slow down the escalator. The first brake because it was covered in oil, the second brake because it "showed wear" and the third brake even though it was in "good condition" [3]. This example demonstrates that it is not enough to just apply redundant brakes without a diagnostic system, even in case of three brakes. The most important aspect is to conduct appropriate maintenance, to plan inspections and to replace/repair components in time. This replacement/reparation should be based on data obtained from a diagnostic system and on a prognosis of the equipment condition. The construction of escalators and moving walks is very similar which allows comparison of accidents. In case of all kinds of accidents (falls, caught in/between) the conveyor has to be stopped within an acceptable braking distance to avoid injury [2]. This implies that a brake system in all cases acts as the actuator of the safety system for injury preventing.

The standard EN 115-1, safety of escalators and moving walks, recommends equipping these conveyors with two types of brakes: an operational brake and an auxiliary brake [4]. The installation of auxiliary brakes is required only for inclined moving walks under special conditions. Auxiliary brakes, also called emergency brakes, shall be of the mechanical type. The most widely used types of brakes for operational braking are hydraulic and electromagnetic brakes [2]. Hydraulic brakes allow proportional control easier than electromagnetic brakes. Their brake torque can be controlled proportionally by changing the oil pressure [2]. This allows intelligent braking where the brake torque can be adjusted in accordance to the requirements. Intelligent braking is better than conventional braking because the maximum deceleration rate of the conveyor can be controlled. However, it is impossible to design an intelligent system that is 100% reliable [2]. But it is possible to estimate risks and to improve the reliability of an intelligent braking system.

These days more and more solutions for intelligent braking systems appear. Patents of the CONE corporation and the

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Nomenclature

a	Deceleration of moving walk [m/s^2]
d	a diameter of pulley of moving walk [m]
l	a value of allowable displacement of walking surface at rest condition [m]
v	Current speed of moving walk [m/s]
v_0	Final speed of moving walk [m/s]
t	Time [s]
t_1	The beginning of pulse from brake controller
$t2$	the beginning of pulse from incremental sensor
t_3	The end of short pulse
t_4	The end of normal pulse
t_{day}	Operation time per day [s]
t_{per}	Time of periodic repair
$F(t)$	Weibull cumulative distribution function
N_{max}	Maximum number of pulses per revolution
N_α	Minimum number of pulses per α-rotation
α	Angular displacement [°]
β	Shape factor of Weibull distribution
η	Characteristic life of Weibull distribution [h]
λ	Failure rate [t^{-1}]
λ_{DU}	Dangerous undetected failure rate [t^{-1}]
ALARP	As Low As Reasonably Practicable
BC	brake controller
BS	braking system
MC	main controller
MP	mechanical part
RBD	reliability block diagram
RBS	braking system with redundancy
SIL	safety integrity level
PFH	Probability of dangerous Failure per Hour
1oo2D	1-out-of-2 architecture with additional diagnostic channels

ThyssenKrupp elevator innovation center made a contribution for the improvement of a braking system for passenger conveyors. CONE presented a method for regulating the brakes independently of the load [5]. ThyssenKrupp suggested solutions of constant braking distance regardless of the load [6], which requires a proportional brake. There are no doubts that the overall reliability of moving walks increases because of an improvement of the braking system. However, what kind of improvements should be done to increase the reliability and are they necessary or not?

Reliability improvement can be achieved in several ways. The first way is by adding redundancy to a system. The second way is by using diagnostics. The third way is a combination of the first and the second way. Unfortunately, often people that consider safety questions of passenger conveyors suggest redundancy as a reliability improvement measure, without justification of why the conveyor needs it and whether it is sufficient. Indeed, at the design stage of projects, “the redundancy allocation is a direct way of enhancing reliability” [7]. The decision to apply redundancy for a braking system however is very complex. It is a question of additional equipment, changing design and requiring extra funding. Sometimes redundancy is excessive, sometimes it is necessary. The choice depends on a few parameters such as safety requirements for the conveyor, rate of reliability degradation and the conditions of exploitation.

European standard EN 115-1 defines operating conditions of moving walks for public transport. Moving walks should be “suitable for intensive use, regularly operating for approximately 140 h/week with a load reaching 100% of the brake load for a total duration of at least 0.5 h during any time interval of 3 h” [4]. “The load conditions and additional safety features should be agreed to between the manufacturer and the owner reflecting the traffic levels which exist…” [4]. Operating conditions depend on the duration of work per day, the people flow, the existence of a “spare” moving walk to replace a broken machine at any time. If people flow is small or if there is a second moving walk for people transportation during repair of the first one, redundancy is not necessary. It is enough to provide a machine with a diagnostic system in this case. If the people flow is quiet large and if there is no “spare” moving walk, a redundant system with diagnostics of failures is necessary. For example, the machine has to be in operation 24 h per day, 7 days per week like moving walks in Los Angeles World Airports [8]. The question of reliability of a braking system for moving walks with such operating conditions and the lack of a spare moving walk is one of the most important. The operational condition of 24/7 is hard. Repair a moving walk in that case is possible only at a limited period of time. This is especially topical for airports and big malls. Therefore, the focus of this paper is on an operational braking system with a hydraulic type of brakes for public service moving walks with lack of a spare moving walk and operating conditions ‘24/7’.

The aim of the present work is to estimate safety integrity requirements for a braking system of moving walks, to develop a method of reliability analysis of a braking system in accordance to international and European standards, and to define necessity of redundancy of a braking system. The results obtained in this work confirm the necessity of a redundant br7aking system for moving walks with described operating conditions. Introduced intelligent system will be able to maintain the necessary safety integrity level (SIL), not only for the braking system, but also for other technical systems with degradation of their reliability parameters over time. Two modes of maintenance will be discussed: economical and full. This approach can help project managers to choose the most appropriate mode of maintenance for their company.

The structure of the paper is organized as follows. Section 2 considers a method for determination of safety integrity requirements and a reliability analysis of a braking system of moving walks. This section also presents a redundancy architecture, diagnostic system and intermediate results. Section 3 gives general results, a comparison of obtained graphs of PFH increasing with/without redundancy and introduces an intelligent system for SIL maintaining. Section 4 presents conclusions, discussion and future work.

2. Theory and calculations

This section outlines the method of probabilistic (reliability analysis) and diagnostic approaches of failure prediction. Calculations presented in this section, illustrate a common method for defining the necessity of redundancy of a braking system. The calculations are for illustration purposes only and cannot be considered as direct calculations for any type of braking system.

2.1. Method of SIL requirements determination

As a guideline for the analysis of the safety integrity level of a braking system of moving walks, the standards IEC 61508 and ISO 22201-2 are chosen. The method described in the IEC 61508, consists of two stages: determination of the safety integrity level