Investigation into the Closing Force of Passenger/Goods Lift Automatic Power Operated Doors and Recommendations to Reduce the Risk of Injury to Lift Users

Daniel Meekin

Zurich Engineering, 6th Floor The Colmore Building, 20 Colmore Circus, Queensway, Birmingham, B4 6AT

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Abstract. Passenger lifts are primarily configured with automatic power operated doors to increase passenger flow efficiency. Injuries caused by impact and entrapment between closing powered lift doors do occur, even though safety devices are fitted which should prevent this happening [1]. There are different types of non-contact safety devices that should reverse a closing door to prevent impacts and entrapments. Innovation in technology has allowed these devices to become more effective. However, the devices still do not eliminate entrapment risks entirely. Additionally, many lifts still employ outdated and inferior devices because within the United Kingdom upgrades to improve safety are not mandatory.

1 INTRODUCTION

With lifts conforming to EN 81-20:2020, risks of entrapments between the closing door still exist due to the non-contact device's narrow infra-red beam. The purpose of which, in accordance with EN 81-20, is still to only detect in the event of a person crossing the entrance during the door closing movement [2]. Within the UK between 2002 and 2010, 266 people had been injured in lift related accidents, with the most common injuries sustained as the doors are closing [1].

A final measure of safety to prevent crushing injuries to passengers is limiting the closing force applied by the door operator. This should be less than 147 or 150 Newtons (N) in accordance with the relevant design standard at the time of installation. (It is also noted that closing forces could vary depending on other door safety features in accordance with BS 2655-1). 150 N is a pragmatic limit. This maximum force, however, is stipulated to prevent injury to lift users and is now a widely accepted figure which is laid down in standards and guidance worldwide to limit the risk of crushing injuries.

Unfortunately, automatic power operated door closing forces may not be routinely tested enough to ensure that forces are below the stipulated limit. There is a consensus that many lifts are in service which exceed the closing force limit due to a lack of routine testing. This project set out to understand if these concerns are valid and to seek areas of improvements for the safety of lift automatic power operated doors.

2 FIELD TESTING RESULTS FROM IN-SERVICE LIFTS

An analysis was completed using data from 48 in-service lifts. This provided 384 closing force measurements in total from different measurement positions. The two measurement positions were: top and bottom of the car door and top and bottom of the landing door. These measurements were taken at the ground floor and one other floor. The measurement positions at one landing are shown in Figure 1. A calibrated, spring-type force gauge with a range of 0 N to 159 N was used to measure the lift door closing forces. It is clear from the data obtained that there are lifts in service with closing forces exceeding stipulated limits. 27% of lift doors applied forces exceeding 150 N at one or more of the test positions. The following paragraphs show trends established during the analysis.

Figure 1: Image of landing and lift car doors showing measurement positions

2.1 Differences of measurement position on the same door

55% of doors have force measurements differing between the top and the bottom. The measured closing force was greater at the top on 91% of these doors. Two conclusions can be drawn from the data. Firstly, the measured closing force of doors does differ depending on the vertical position of measurement. Secondly, where these forces differ between the two measurement positions, peak force in most cases is at the top of the door. This is also confirmed by the average closing forces shown in Table 1. The reason is suspected to be due to mechanical losses when measured further away from the door gear.

Table 1: Average forces comparing different measurement positions

Measurement Position	Average Closing Force (N)
Ground floor - Car door - Top of door Ground floor - Car door - Bottom of door	106.1 101.6
Ground floor - Landing door - Top of door Ground floor - Landing door - Bottom of door	105.4 102.7
Top floor - Car door - Top of door Top floor - Car door - Bottom of door	109.8 103.5
Top floor - Landing door - Top of door Top floor - Landing door - Bottom of door	108.1 103.4

2.2 Differences between landings

59% of the tests have closing force measurements differing between landings. 60% of the measurements are greater at the upper landing where the discrepancies are identified. To confirm this, average measured closing forces are higher at the top floor at every comparison as shown in Table 2. Most lifts that were tested featured sprung landing door self-closing devices. Therefore, this difference is suspected to be due to the often-increased use of the ground floor and therefore strain to the spring resulting in reduced self-closing forces.

Table 2: Average forces comparing differences between landings

Measurement Position	Average Closing Force (N)
Top floor - Car door - Top of door Ground floor - Car door - Top of door	109.8 106.1
Top floor - Car door - Bottom of door Ground floor - Car door - Bottom of door	103.5 101.6
Top floor - Landing door - Top of door Ground floor - Landing door - Top of door	108.1 105.4
Top floor - Landing door - Bottom of door Ground floor - Landing door - Bottom of door	103.4 102.7

2.3 Differences between car and landing door

Measured closing forces are the same on 46% of the doors. Where differences of force are identified between the car door and landing door, the position of the highest force is split 53% and 46% respectively. Average closing forces are compared in Table 3. The difference of closing forces between the landing door and car door is negligible and suggests efficient coupling between the landing and car door.

Table 3: Average forces comparing car door and landing door differences

Measurement Position	Average Closing Force (N)
Ground floor - Car door - Top of door Ground floor - Landing door - Top of door	106.1 105.4
Ground floor - Car door - Bottom of door Ground floor - Landing door - Bottom of door	101.6 102.7
Top floor - Car door - Top of door Top floor - Landing door - Top of door	109.8 108.1
Top floor - Car door - Bottom of door Top floor - Landing door - Bottom of door	103.5 103.4

2.4 Differences between door drive types (linear and harmonic)

17% of lifts tested utilised harmonic door operators. 50% of the harmonic systems applied a closing force over 150 N and 88% exerted over 100 N. When compared to linear systems the figures are 23% and 48% respectively. The average measured closing force of harmonic operators is 123 N and for linear operators is 102 N. It is reasonable to state that harmonic door operators are likely to apply a greater closing force to lift doors when compared to systems utilising linear door operators. This is suspected to be due to the increased ease of adjustability of linear operators. Figure 2 shows the recorded differences.

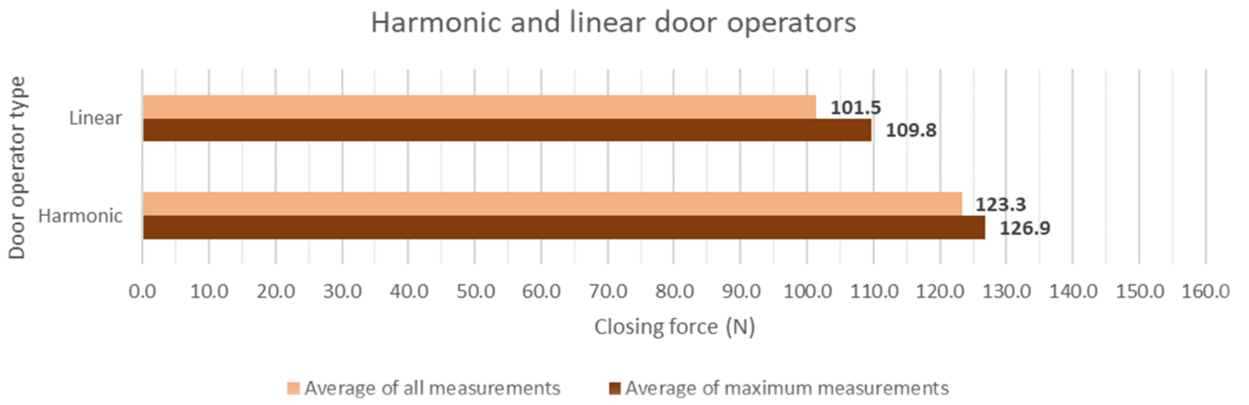

Figure 2: Chart comparing linear and harmonic car door operators

2.5 Differences between side and centre opening doors

69% / 31% of lifts tested featured side and centre opening doors respectively. Table 4 shows the average forces of the comparable doors. Harmonic door operators are not included within this comparison because they are mainly coupled with side opening doors within the data, and the type of door operator appears to have the greatest influence on forces as discussed in paragraph 2.4. For those with just linear door operators, it is evident that when configured with side opening doors higher closing forces are applied than with centre opening doors. 21% of centre opening doors applied a closing force of over 150 N compared to 26% of side doors. It is reasonable to confirm that lifts configured with side opening doors are generally set with higher closing forces.

Table 4: Average forces comparing side and centre opening doors

Door opening	Average Measured closing force (N)
Side	109.5
Centre	89.7

3. COMPARABLE POWERED AUTOMATIC DOOR SYSTEMS

Having established safety measures utilised with automatic power operated doors fitted to passenger lifts, it is prudent to investigate other powered door systems in seek of further potential safety improvements. Comparison with other door systems does identify additional measures that could be adopted to further improve lift safety by reducing door entrapment risks.

3.1 Train bodyside doors

Power operated doors fitted to trains are similar in principle to those fitted to passenger lifts. With trains, traction power should be inhibited until all bodyside doors are closed and locked. EN 14752:2019 is an 88-page document detailing the safety of bodyside entrances fitted to trains. This compares to 15 pages detailing lift door safety within EN 81-20:2020. Revisions of EN 14752 were published in 2005, 2015, 2019. Amendments to the 2019 document are also available for public review. This demonstrates that improvements to train bodyside doors are actively identified, quickly implemented and therefore safety is continually improved. Comparably, text on lift power operated doors from BS 2655:1970 remains largely unchanged within EN 81-20:2020.

The most basic safety measure used on train bodyside doors, that is not applied to passenger lift power operated doors, is the application of entrapment warning signs. These stickers are fitted to train doors and highlights danger to passengers.

There are some common safety measures shared between the two applications, such as non-contact safety devices which are already discussed. However, train bodyside doors include additional safety features. Some are detailed below:

- Automatic door closing is only enabled when there is nobody in the door portal for a specified time. The door portal is a specified area.
- There must be an audible signal that the doors are about to close, which is standardised to a specific pulse and frequency.
- There must be a visual indication both inside and outside of the train warning that the door is about to close.
- The door control system must contain loops to stabilise forces.
- Detection of obstructions must occur in less than one second.

3.2 Powered retail doors

Retail doors are perhaps the most utilised power operated door within the UK. Facilities usually leave the pedestrian no other option but to enter through the powered door. Risks presented due to high foot-flow through these types of doors are recognised within BS 7036-1, which stipulates that operational safety checks should be conducted periodically by the property occupier. For shops, hospitals and airport settings, these checks should be carried out at least weekly [4]. It is stated that the checks must include operational tests of safety devices and non-contact systems should be tested in accordance with BS 7036-2 [5].

In addition, BS EN 16005 also stipulates that tests of door closing forces 'shall be carried out in the worst conditions and configuration'. Included are locations of where to measure forces [6]. Daily or weekly checks are sometimes carried out on lifts by building occupiers, but this is often just to check that the machine is in service, possibly alongside a test of the in-car alarm/communication system.

Powered retail doors must also display 'keep clear' and 'automatic door' signs to give users advance warning of operation and inform them to keep away from the space where the power operated door travels in accordance with BS7036-0.

4 RECOMMENDATIONS

Simple procedures can be implemented by lift duty holders to improve the safety of lift automatic power operated doors. Building occupiers may carry out daily or weekly checks of the lift, but this is likely to just ensure that the lift is in service, possibly with a check of the car alarm and emergency communication system. It is recommended that checks to the lift doors and their non-contact safety devices are also carried out concurrently, or at intervals recommended by findings from a risk assessment. The checks would not be onerous, but should include a physical check of all landing doors with an operational check of the non-contact safety device. This would be similar to checks required on powered retail doors in accordance with BS 7036-1.

The operation of lift automatic power operated doors has specific risks to the safety of lift passengers. Passengers are either not aware of this or have become accustomed to the risk, possibly because lift use is now largely a necessity within daily life. It is common to witness lift passengers stalling a closing lift door by hand to prevent lift car departure, whether for themselves or to assist other lift passengers. Serious injuries and fatalities have occurred on rail networks due to similar entrapment scenarios. To detract against this practice and to protect train users, warning signs must now be placed at the train bodyside door which highlight the entrapment risk. It is recommended that a similar sign is also applied to lift doors. This would be a simple, cost-effective safety improvement which can be made by the lift duty holder to deter lift users from the practice of stalling closing lift doors by hand.

Improvements to the safety of lift automatic power operated doors can be made to the current design standard, EN 81-20. Progress towards safer lift automatic power operated door systems can be made when compared to the safety of train bodyside doors. EN 14752 contains safety features of train bodyside doors that could be adapted for use with passenger lifts. It is recommended that a review is undertaken to assess the feasibility of these as additional safety measures by BSI.

Modern non-contact safety devices fitted to passenger lifts consist of a narrow beam array fitted to the car door only. This offers limited protection to lift passengers as shown in Figure 3. Fitment of 'light curtain' non-contact safety devices to all landings, in addition to the lift car door as shown in Figure 4 would provide protection against the entire potential entrapment area. This would also protect against door opening entrapments, which is another risk not investigated during this project. It is understood that this would however involve major re-working of surrounding architrave at each landing for existing lifts, but could be incorporated into the design of new installations. The diameter of detected objects should also be reduced from 50 mm (EN 81-20:2020) to a measurement that would detect fingers of children and include the entirety of the closing doorway until the doors are fully closed.

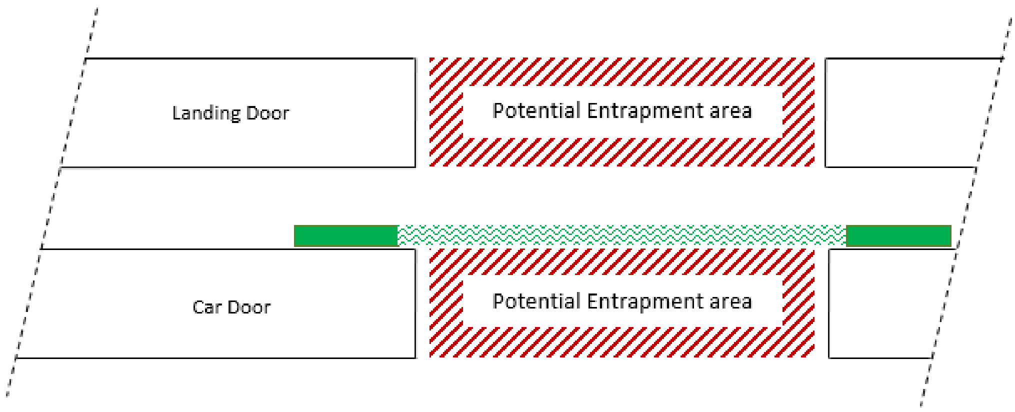

Figure 3: Overhead view diagram of lift door 'light curtain' with common mounting position (indicated green)

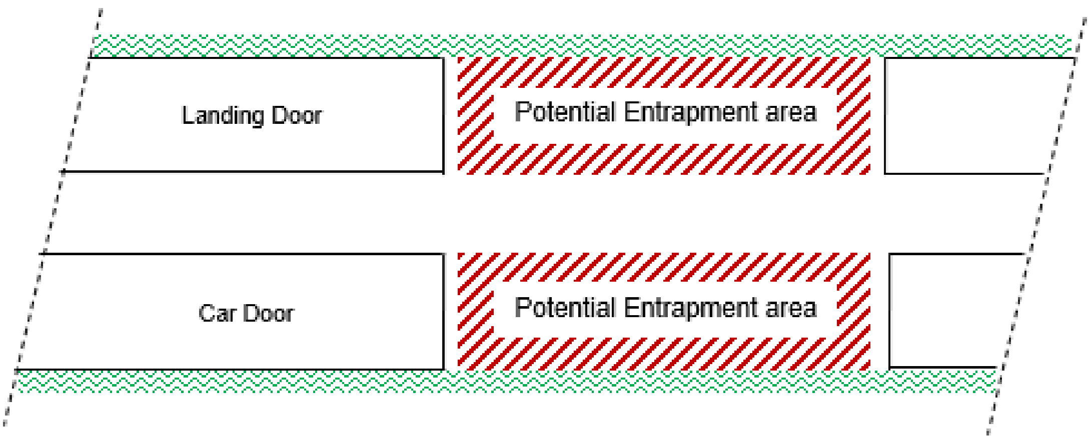

Figure 4: Proposed improvement to door 'light curtain' locations (indicated green)

Passive infrared (PIR) technology could be utilised to better protect entrapment areas of existing lifts. PIR light curtains utilise a single unit and are commonly used within security systems as shown in Figure 5. This technology could be adapted for use at lift landings and due to a single unit, may be a suitable modification to existing lifts because the upgrade would be less intrusive.

Figure 5 PIR intruder detection device [8]

Field investigation has provided data confirming that lifts fitted with automatic power operated doors are in service with door closing forces exceeding stipulated limits. It is strongly recommended that lift automatic power operated door closing forces are routinely checked by the competent person and maintenance personnel.

This investigation has established that a measurement should be taken from the top of the door, at what is assessed to be the least utilised landing. Closing force measurements should also be recorded where there is a change of lift door design between landings, such as foyers of large or extravagant buildings and following replacement of door components.

Closing forces are a protective measure [7] and 150 N is a maximum limit, not a target. It is recommended that lift duty holders carry out a risk assessment with the aim of setting door closing forces as low as possible depending on risk assessment findings. Considerations should include the environment of the lift and the demographic of passengers using the lift.

5 CONCLUSION

Acquiring closing force measurements of automatic power operated doors fitted to in-service lifts has facilitated a better understanding of a problem, whereby force limits exceed stipulated maximum figures. Analysis confirms that many lifts are in service with forces exceeding these limits. Evidence within this paper highlights the requirement for remedial action to reduce or mitigate the risk of impact and entrapment injuries to lift passengers caused by closing automatic power operated doors. Inspection bodies and maintenance providers who assess the safety of lifts should be measuring closing forces during thorough examinations and service visits.

Closing force limits are a final measure of safety to reduce the risks of entrapment injuries and lifts are fitted with safety devices to reverse door closing even before a door contacts the obstruction. Yet, for modern lifts designed to EN 81-20, entrapments can still occur. Improvements can be made to increase passenger safety and further reduce the entrapment hazard. Use of readily available technology and proven safety systems employed with other powered doors can be adapted for lift use to achieve this.

Lift owners and duty holders can take simple steps to reduce the risk of door crushing injuries to passengers. Application of simple warning signs to lifts may deter passengers from using their hands or arms to stall a closing lift door and would be a cost-effective improvement. Additionally, implementing extra checks to the routine testing of lift car alarms such as a functional test of the non-contact safety device and a physical check of the lift doors should also be considered. These measures will reduce the risk of injury to lift passengers and demonstrate a proactive approach to fulfil their obligations to protect the public and workers.

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BIOGRAPHICAL DETAILS

Daniel Meekin is a Senior Engineer for Zurich Engineering UK within their Technical Standards department. This extended abstract is summarized from a dissertation for his Bachelor of Engineering First Class with Honours in Mechanical Systems Engineering completed late 2021.