Modernising a Paternoster

Michael S Bottomley

Lerch Bates Ltd, Dean Clough, Halifax HX3 5AX, West Yorkshire, UK,
michael.bottomley@lerchbates.eu

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Abstract. This paper describes the processes involved in modernising a fifty year old paternoster in a grade 2 listed, University building with 22 occupied floors. The contribution of the paternoster to the vertical transportation of the building is assessed. Key components of a paternoster lift are described and the operation of the device is explained. The accident history of the device is detailed and the design features to reduce risk are explained and reference is made to a recent fatality on a paternoster in the Netherlands. Unforeseen difficulties during the construction phase are discussed and the solutions adopted are demonstrated. The project is reviewed and its success is considered. The paper concludes that without a working paternoster the Arts Tower Building could not accommodate its current population.

1. INTRODUCTION

An early form of Paternoster was installed at Oriel Chambers in Liverpool in 1868 [1] and thought to be designed by its Architect Peter Ellis. Subsequently the paternoster was “invented” and built in 1884 by the Dartford, England, engineering firm of J & E Hall and was known as the Cyclic Elevator [2]. The name paternoster ("Our Father", the first two words of the Lord's Prayer in Latin) was originally applied to the device because the paternoster cars travel in a loop and are thus similar to rosary beads used as an aid in reciting prayers.

Paternosters were popular throughout the first half of the 20th century as they could transport more passengers per given floor area than ordinary lifts. They were more common in continental Europe, especially in public buildings, than in the United Kingdom. They are rather slow typically travelling at about 0.3 or 0.4 meters per second, thus allowing a passenger transfer time of about 1.5 seconds within a safe transfer zone.

The Arts Tower at the University of Sheffield is a grade 2 listed building. The scope of its listing covers internal as well as external features. It was built between 1961 and 1965 and designed by Gollins, Melvin,Ward & Partners with 22 occupied floors and 78 metres rise. The design population was 1740 and vertical transportation was provided by 2 conventional 1250Kg lifts and a paternoster with 38 cars. There are only two small stairwells serving all the floors in the building. The lower ground floors and mezzanine floors have additional stairs to cope with the peak passenger transfer to the large lecture theatres on the lower ground floor and the adjacent library accessed via the mezzanine.

The lifts and paternoster were originally installed by Schindler in 1964 and were operational at the official opening of the building by Queen Elizabeth the Queen Mother in 1966.

Following a fatal accident in Newcastle in 1970 all paternosters were modified to include a car stability tracking system to help prevent a car pile-up when reversing direction of travel between the up shaft and down shaft. In 1995 D&A lifts modernised the lifts and paternoster. A further more detailed modernisation was carried out between 2009 and 2011 by Stannah lift services (lifts) and Industrial Marine Lift Services (paternoster).

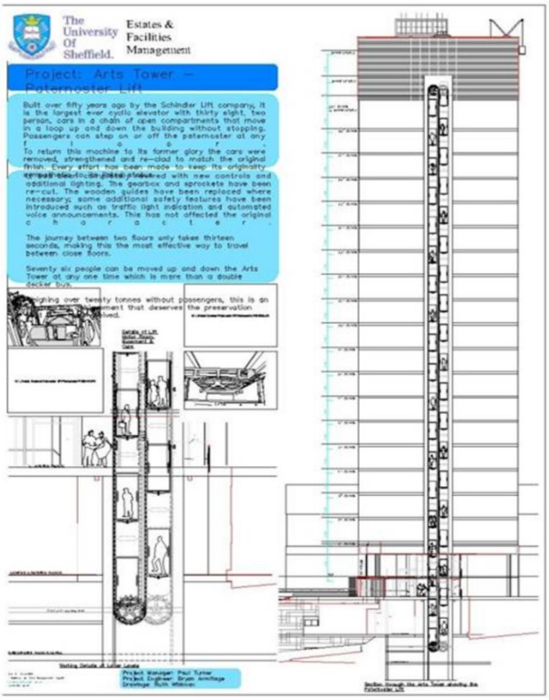

Figure 1 The University of Sheffield Paternoster display board.

2. STANDARDS APPLICABLE TO PATERNOSTER MODERNISATION

It is a source of irony that most Paternosters in the UK were installed prior to the publication of BS2655 part 5 1970 [6]. This part of an old British Standard specifies engineering and safety requirements for paternosters and though withdrawn the standard remains the only specific reference source currently available for paternosters. BS 5655 part 11[7] suggests itself as a source of recommendations for the modernisation process. BSEN81 part 80[8] suggests itself as a reference for the modernisation process. Unfortunately the communality of components between lifts and paternosters is much less than might be anticipated and so these lift specific standards are of some limited guidance to a paternoster modernisation designer. Some fundamental principles however can be readily adopted from these standards:-

1) "Do no harm" always make the modernised device safer than the original.
2) Assess risks and research safety records to focus on problem areas.

The essential health and safety requirements of the Supply of Machinery Regulations [9] would apply to new paternosters but existing paternosters are not subject to those requirements and similarly problems exist in defining legal references in LOLER [4] and PUWER [5].

2.1 Paternosters and the law

There is a common misconception that the use of a Paternoster is illegal. LOLER regulation 47a [4] refers to paternosters and allows for the absence of car doors and limits the practicality of edge protection to safety handles and landing barriers (for when the machine is stopped). Several sources state that new Paternosters cannot be installed and though legal restrictions do not seem to be in place the real issue is that few manufacturers would be prepared to design and CE mark such a product today.

2.2 Paternosters and suitable users

Children may not appreciate the risks presented by paternoster travel and may try to lift flaps and come into contact with other objects. Disabled, infirm or intoxicated passengers are much more at risk of injury on a paternoster. The use of Paternosters by the elderly is problematic as there are several features of aging which increase the difficulties that paternosters present. Reaction times slow down with age. The ability to balance on one foot on a moving object and simultaneously transfer body weight from one foot to the other decreases with age and level of fitness. All users become more competent with practise and accidents with experienced users are rare.

All these comments could of course apply equally to escalator usage. It may be politically incorrect to state (but it is never the less true) that suitable paternoster passengers should be fit and able bodied aged between 18 and 70. This demographic describes over 95% of a typical University campus.

2.3 Paternosters and the movement of goods

Paternosters must not be used to transport goods. There have been many accidents involving ladders or boxes getting trapped between a landing floor and a car ceiling or a car floor and a landing header. The simple chord protection over each landing entrance cannot ensure safety. Even carrying a heavy or large briefcase can increase risks.

2.4 Why modernise a paternoster?

If there is no established standard to work to and normal edge protection measures are impractical it may be prudent to consider why modernise a paternoster at all? This paper refers to the modernisation of The Arts Tower Paternoster and application of any learning outcomes from this paper should be tempered by the design constraints applicable to this Grade 2 listed building. The real question that is being answered is why paternoster was modernised.

If the Paternoster was not to be kept in use due to its listing it would have to have been left as a static display and hence the area of the paternoster shafts would have been lost. The small foot print of the building and the internal listing requirements meant that increasing the size of existing lifts or adding more lifts to the group was impossible. A traffic survey was carried out in March 2008 and found that the paternoster transported up to 60 persons in an up peak 5 minute period whereas the lifts only managed to transport 40 persons. If the Arts Tower were to survive as a working academic building then without the paternoster the population above the mezzanine floor would have to be reduced by up to 60%. At the time of the survey the University were in contract with a Main Contractor who was starting a £70 million project to modernise the building over a three year period. Just as the University was about to embark on the paternoster project their external consultant who had run the previous modernisation project reported some very bad news. The load chains and main drive gearing were inspected by a “specialist” and declared unsafe due to wear in the gearing and support bearings and stretch on the load chains. The machine which had become very noisy, was taken out of service as a precaution by the University. Prior to receiving the traffic survey report the modernisation had been put on hold. Given the report’s conclusions this was not a viable option.

2.5 The Modernisation of the Arts Tower Paternoster

Lerch Bates were appointed by the University of Sheffield to run the Paternoster Modernisation in 2009 after their own research led them to conclude they needed another source of advice. Three independent surveys of the chain condition concluded that the chains were suitable for use for the foreseeable future as only superficial chain link extension was measured after 53 years operation. The first problem for the Consultant to address was to identify suitable potential candidates for the paternoster modernisation. The starting point was the manufacturer, existing maintenance contractor and the University lift modernisation approved list. A series of meetings was held with potential contractors so that the nature and scope of the works could be explained ahead of invitations for an expression of interest for the contract. Eventually six contractors returned an expression of interest. An analysis of the safety reports was completed on the paternoster since the last modernisation and risk assessments were carried out in order to produce the modernisation specification.

2.6 Development of the Modernisation specification

The University of Sheffield's Estates department had access to the safety records of incidents relating to the Paternoster. These records reached back to the time of the previous modernisation. The incidents fell into three clear categories:-

1) Incidents involving trapped goods (ladders in several cases)
2) Incidents involving trapping between fixed and moving handrails
3) Falls from the paternoster cars (2 incidents both involved intoxicated passengers).

A risk assessment using the format of ISO TS14798 2006 was carried out and identified deficiencies in design and deviations from BS2655 Part 5. Certain changes were proposed some of which the University and or English Heritage would not accept and hence the specification did not include the following items:-

a) Provision of a large computer display at ground floor showing a video giving user instructions for the safe use of the paternoster. Fixed notices following BS2655 Part 5 were retained.
b) Infra-red passenger detectors in place of the chord switches above each landing entrance. The University did allow these but on the top entrance only retaining the chord switches on other landings.
c) No method of preventing falls from the paternoster cars was adopted as any method considered that prevented a fall increased another type of risk. There had only been 2 falls in the last 15 years and in both cases the students involved were found to be under the influence of alcohol. The Handrails and car flap signage required by BS2655 Part 5 help reduce the likely hood of falls to an acceptable level. The handrails were modified to reduce the risk of trapping.

A summary of the specification requirements is found in Annex 1.

2.7 Project progress

The job was tendered in the summer of 2009 and five compliant tenders were received. The successful tenderer was Industrial Marine Lift services of Heywood Greater Manchester. Industrial Marine (as their name implies) specialise in lift and escalator repairs and modernisations on ships. The nature of their work relies on the high level of engineering skills of their fitters and their ability to problem solve in a challenging environment.

Site work began in 2010 by erecting full height hoardings over each entrance, removing the paternoster cars and scaffolding the paternoster shafts. A long period of degreasing and cleaning all the shafts steel work and components was followed by sealing and repainting. The cars were stored on University premises about half a mile from site and the intention was to refurbish the cars during the period whilst the gearing was removed to Highfield Gears of Huddersfield who were chosen to replace the machine components. During this period two separate events changed the course of the project and left new unexpected challenges.

Asbestos was discovered in the sub-basement of the Arts Tower and this effectively meant that the paternoster shafts which enter into the sub-basement had to be sealed and no access to the pit was possible until the material was removed. This led to a six month delay in site works.

Meanwhile an inspection of 30 of the 38 paternoster car slings after cleaning and sand blasting showed signs of structural failure. In most other places in the world this would have been a show stopper. Here at the University of Sheffield however there is the Sheffield University Metals Advisory Centre (SUMAC) based just across the road. Adrian Taylor a senior consultant for SUMAC was engaged and one of the faulty slings was fitted with strain gauges. The car was refitted in the paternoster shaft and the strain gauge reading were recorded. The results were analysed and a suitable structural modification to the gearing alignment and each car was identified. Interestingly the car bracing was a modification of the additional bracing that Schindler had retrofitted in the 1970's. The new gearing was installed and then correctly aligned by Highfield Gears Engineers. The modified car was sent on another series of test runs with the stain gauges and the results were shown to be within acceptable elastic limits. The problem was resolved and maintenance checks were refined to include ongoing monitoring of the issue.

Once the asbestos was removed and air tests proved negative the major site works began in earnest in Jan 2011.

During the course of the works English Heritage carried out a series of surveillance visits and were satisfied with the appearance of the refurbished cars which were significantly lighter than before despite being clad in stainless steel rather than aluminium with an additional MDF lining. They were also happy with the redesigned car and landing handrails. The original handrails created a pinch point between the static landing handrails and the moving car handrails. The redesigned ramped surfaces deflected limbs rather than trapping them. This had previously been cause of injury on 2 occasions.

To assist passengers time their entry and exit the existing listed landing floor legends were back lit with colour LED's. The indicators were illuminated red at all times a lift car floor was not within + or – 200mm of a landing level and illuminated green when a car is within that zone.

The existing motorised brake was replaced with a brake compliant to EN81-1. The drive control was changed from star delta to VVVF and the control system was designed by ILE Controls of Leicester to include a comprehensive diagnostic system and a more accurate car stability tracking monitor.

By August 2011 the Arts Tower Building modernisation project was nearing completion and the paternoster program had to be accelerated to meet the start of the new term on 21/9/2011. Extensive safety checks were carried out on all the new and retained equipment and on 20/9/2011 the refurbished paternoster was ready to put in to service.

3 COMPLETION A WELCOME RETURN TO AN OLD FRIEND?

During fresher's week the new students showed less enthusiasm for the newly modernised paternoster than expected. There were a few teething problems and a contractor trapping a ladder in the roof of a car in the first week was not welcome news. When the rest of the students returned to the newly refurbished building the reaction was much more positive. Over the next few months the machine operation as a whole had become smoother and quieter in operation and now three years on the ride is very satisfactory. The use of the building had been revised and in place of seminar rooms, Administration offices, Human Resources and the Estates Department were deployed in to the building. This reduced both the population above mezzanine and the volume of passengers due to the hourly changeover of students in lectures and seminars. The newly refurbished lifts had the advantage of direct into floor approach, fast acceleration and door times which improved lift performance. The VT service to the building was significantly improved but the paternoster still transported the majority of passengers.

3.1 A worrying post script

In November 2013 Dr Richard Peters received an email concerning a fatality on a Paternoster in the Netherlands. Once again the continued use of Paternosters was reviewed by HSE with a critical eye. This latest accident occurred in March 2013 when an 81 year old man fell to his death though a fractured floor flap. The author was immediately contacted by Dr Peters and within 24 hours the condition of the flaps, hinges and retaining angles was checked at the Arts Tower. It was concluded that a similar accident would not be possible due to the design of the Schindler equipment which has substantial mild steel supporting frames under the car and landing flaps and the condition of the components which were renewed on refurbishment and found to be good. Once again the Arts Tower Paternoster had survived.

4 CONCLUSIONS

The Paternoster modernisation was a success which delivered a smoother quieter machine with significant improvements to safety driven by analysis of accidents over the previous fifteen years:-

Improved car and landing handle design reduced the risk of trapping and is a method of fall protection whilst in transit.

Improved printed brush mat signage on the car flaps instructs passengers to stand back from the void thus reducing the risk of a fall in transit.

Traffic Light signals on each landing assist inexperienced users to time their entry and exit and reduce the risk of tripping.

The final thought is however for how much longer can the Paternoster survive? We live in an increasingly risk averse society which seeks remedies in the courts in a way which did not exist in the 1960’s when this Paternoster was designed. There have recently been a series of very small claims at the Arts Tower for incidents which when seen on cctv appear nothing more than stumbles. ISO TS 14798 correctly identifies the fact that “There can be no absolute safety.., as residual risks can remain… a product or process can therefore only be relatively safe.” [3]

Relativity like beauty is a construct of social and cultural influences which change over time and so only time will tell if the author was the last Consultant to modernise a working paternoster.

REFERENCES

[1] Oriel Chambers in Liverpool in 1868, “In the Footsteps of Peter Ellis.” Graham Jones

[2] Cyclic Elevator, *Wikipedia Paternoster entry*

[3] ISO TS 14798 2006 (N.B. ISO TS 14798 2013 was not published at the time of the project.)

[4] Lifting Operations, Lift Equipment Regulations 1998 (LOLER)

[5] The Provision and Use of Work Equipment Regulations 1998 (PUWER)

[6] BS2655 part 5 engineering and safety requirements for paternosters.

[7] BS5655 part 11 Recommendations for the installation of new and the modernization of electric lifts in existing buildings.

[8] BS EN81 Safety Rules for electric and hydraulic lifts.- Part 80 - Rules for improvement of safety of existing passenger and goods passenger lifts

[9] The Supply of Machinery (Safety) Regulations 2008

ANNEX 1 SCOPE OF REFURBISHMENT OF THE ARTS TOWER PATERNOSTER

Removal of Paternoster Cars

Carefully remove in correct sequence the remaining 37 paternoster cars so as to avoid an excessive out of balance load on the machine. Degrease clean and label all removable parts including guide shoes to ensure they are refitted to the original position. Transport all 38 cars from site and store in a safe and dry internal location. Allow for storage for a period of 26 weeks. Remove the cast iron paternosters and carry out Non Destructive Testing of the castings. Replace worn bushes as required. Report any defects observed during testing. Any replacement castings required will be subject to an agreed variation order.

Refurbishment of Paternoster cars

Transport the paternoster cars individually or in groups to an approved specialist lift car fabricator. Refurbish each lift car to the standard and finishes shown in ANNEX 2.
The works required are as follows:-
Strip out old carcass back to framework. Inspect framework and report any irregularities if necessary use Non Destructive Testing methods.
De-grease completely, sand down to suit, and paint up original framework in black anti rust paint.
Line out three walls and car ceiling in 12mm plywood face off in following finishes:-

- Walls – Rimex Cambridge or G Tex Stripes 0.8mm fluted stainless steel
- Ceiling – White laminate
- Rear of panels to be painted in intumescent paint

Install new flooring to be in 25mm WBP plywood with a hinged front section in following finishes. Repair or replace hinges as necessary.

- Floor – agreed colour non slip vinyl
- Front hinged section – non slip red material signage with all wording required by BS2655 part 5.

Install two special handrails per paternoster car made which are tubular with a sheeted centre section, so as the rail cannot present a trapping hazard either individually or with the similar handrails to be installed on each landing.
Install two angled/sloped bottom sections to stop hinged floor sections remaining in an upright position if lifted.
Install new paternoster car signs, to size and wording defined in BS2655 part 5..
Install access panels in three paternoster cars only in full group for access to certain shaft equipment.
To be a small hinged opening/lockable doorway (x3).
Replace any damaged bows and supporting steel work.
Install new hoods and aprons and replace as necessary all associated framing angled/square as per site dimensions, replace any missing screws.

- Faces in Cambridge stainless steel
- Associated framing black.

Load chains

The load chains have been inspected independently by Reynold Chains and Allianz Engineering and have been declared suitable for continued use. Works under this specification are therefore limited to providing a new suitable automatic lubrication system for the chains.

Top Gearing

Provide suitable scaffold platform at the top of the paternoster shaft. Suspend & secure lifting chains. Dismantle & strip out all transmission related equipment. (Guarding and associated fasteners left on site for storage). Remove Transfer and transport all necessary components to approved specialist gear manufacturers works. Fully dismantle, clean and inspect worm gear unit. Re-cut existing worm wheel & manufacture oversize mating worm shaft. Replace all bearings & oil seals; Rebuild, test (standard no load) & paint. Supply first fill of oil. Manufacture & fit new oversize spur gear drive pinion. Dismantle, clean & crack test chain wheel/driven spur wheel assemblies. Verify, by dimensional comparison, suitability of gears for transposition to provide "new" driven tooth flanks. Lightly re-cut worn flanks. Re-assemble with new main spherical roller bearings & pack with initial charge of grease. Dismantle, clean & crack test idler spur gear. Investigate & effect, if appropriate, conversion from plain to rolling element bearings. Re-cut gear teeth to eliminate wear. Re-assemble unit. Dismantle, clean & inspect transfer shaft. Check for straightness. Manufacture & fit new oversize spur gear drive pinions. Supply new plummer block bearings as original. Return to site all transmission system components. Assemble & install and align transmission system. Record all relevant data. Connect electrics. Apply marking blue to gears. Carry out short low speed test run. Record contact patterns obtained (sellotape transfers & photographs). Attach existing chains and run the machine.

Non Destructive Test paternoster chain pins and report any defects.

Bottom gearing and guards and cross beam

Remove bottom sprocket guards. Check the condition of the sprocket and report any defects. Replace the sprocket bearings. Install new bottom sprocket guards. Check condition of cross beam and replace if necessary.

Paternoster Car Guides, Spear points and Chain Guides

Install suitable scaffolding in the Paternoster shaft Replace the damaged sections of Car Guide and Spear points as required. Replace the damaged sections of Chain Guide as required. Remove scaffolding on completion of works.

Reinstallation of refurbished Paternoster Cars

Transport the refurbished lift cars back to site either individually or in groups subject to available storage. Allow for witness inspection of each batch on site by The Vertical Transportation Consultant prior to reinstallation. Check overall cab dimensions, alignment and square. Reinstall 37 Paternoster Cars in correct sequence to avoid excessive out of balance loads. Reinstall the last car at the end of the project prior to final testing.

Electrical Refurbishment

Remove the existing electrical installation retaining only the Landing indicator mechanical components.
Install the following equipment on each landing level:-

- New chord switch across the underside of each landing flap
- 3 off Emergency stop buttons with legend in 10mm high letters
- Two colour (red and green) led illumination in the existing landing floor indicators. Install magnet switches at each landing (and magnets on each car) so that the indicators are illuminated green when a car is within +/- 200mm of floor level and red at all other times.
- Intercom speaker
- Between each landing install recessed LED lighting to give >50 lux illumination in the cars at all points of travel.

Install at the Ground floor a key switch to operate in accordance with BS2655 part 5 clause 2.11.2

Install new shaft lighting to give >50 lux at all areas.

Install interlocked lighting in the top and bottom transfer area so as to interrupt the paternoster control safety circuit in the case of light failure in those areas.

Install photocells to detect car misalignment in the transfer areas.

Install slack chain switches

Install pit stop switch

Install interlocks to pit area access doors

Install additional infrared switch to top landing header flap.

Install 2 off emergency stop switches, one in either side of the machine room

Rewire the electrical installation of the paternoster in accordance with the traditional electrical wiring requirements of this specification.

Install a new VVVF control panel manufactured by approved supplier with remote monitoring system.

Install a remote monitoring station in the porters lodge. NB. IP connections in Machine room and Porters lodge by the University.

Improve machine room lighting to>200lux all areas plus emergency light.

Install an intercom system a to allow 2 way private communication between the Machine room, pit and ground floor as well as public announcements to the intercom speakers on the other levels.

Install voice annunciators to announce standard phrases on restarting the machine which connect to the intercom system.

Landing Equipment Refurbishment

Modify the lower ground floor central architrave so that it can be easily removed with the use of hand tools.

On each landing entrance carry out the following works:-

- Rub down fill and repaint the landing architraves.
- Install new signage in accordance with BS2655 part 5 clause 2.9.2
- Check the landing flaps, hinges and retaining devices, repair or replace as necessary.
- Recover the landing flaps
- Repair or replace landing infill panels.
- Install new handrails to same design as car handrails.

BIOGRAPHICAL DETAILS

Michael Bottomley joined Lerch Bates in 2002 after working for Gregson & Bell Lifts for 21 years. He holds a degree, with honours, in Engineering and Marketing from the University of Huddersfield, and has over 33 years' experience in lift engineering and lift design. In 1999 he was the second lift designer in the UK to achieve Notified Body approval under the Lifts Regulations. He is a member of the International Association of Elevator Engineers and a Past Chairman of the CIBSE lifts group.