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Final Project Report

Design of a Theatrical Escalator

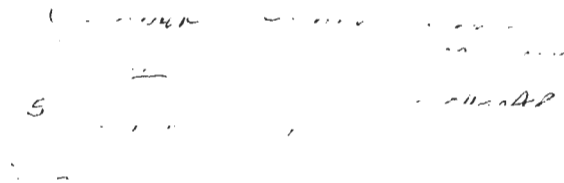
Please find attached to the written report:

- 1) Specifications of components
- 2) A material cost estimate
- 3) Handwritten calculations of speed and horsepower required
- 4) Basic CAD drawings of an individual carriage section and the entire escalator system

I originally intended to produce a complete working design of an escalator, constructable by skilled theatrical carpenters and achievable within budgets of large educational theatres. Due to the complexity of the problem, I have not produced complete working plans. Instead I have a basic mechanical system and the information necessary to continue on with a complete design.

My escalator uses a basic design similar to that of any modern commercial escalator. The first component is the individual carriage, shown in the attached drawing 1. Each carriage is a 1'-0" X 1'-0" right triangle, framed in 1" 14 gauge steel tubing (hereafter just "tubing") and surfaced with 3/4" AC plywood. Because of overlap between carriages in use, the escalator has an effective rise of 0'-8" and run of 1'-0".

Attached to each end of each carriage are two track rollers. They are 1.5" in diameter and have internal ball bearings. I selected track rollers with attached threaded studs, for easy bolting through holes in the tubing frame. Each roller has a theoretical capacity of 4,840 lbs, many times greater than the load they will carry.



Each track roller sits on a separate track in the escalator. Immediately above the upper roller a single link of a large roller chain is welded to the frame. This chain is what makes the escalator move and holds the pieces together.

Real escalators have curved fronts instead of triangular carriages. When looking at the overall system, we'll see that this is an important simplification with only minor reduction in realism.

Drawing 2 shows a section of the entire escalator system. The most important features are the guide tracks that track rollers sit on. These guide tracks are made of 1/4" thick steel bar, 1" in width, laid horizontal and welded to the exterior support frame (not shown). The bottom set of rollers on each carriage (when in the upright position) are supported by two separate tracks. Drawing 2 shows how the lower track follows the angle of the escalator, flattens out at the top, then curves through a quarter circle. At the appropriate point, the track is replaced by a second track on the other side of the rollers, and the carriages are underhung instead of resting on top of the track.

The upper track has only one half to it. It follows a similar path but ends after the quarter circle. There is no need for it to continue through the underhung area.

The roller chain is indicated in a heavy dotted line. It is attached just above the upper roller (in the upright position). This roller chain is ANSI #80 chain, with a 1" pitch (length of an individual link). It has a tensile strength of 3,300 lbs, entirely adequate for the loads involved in the escalator.

The shape of these guides is crucial, specifically in the "turn around" sections. Drawing 2 shows an acceptable curve that carriages can actually pass through based on maintaining a constant distance between roller chain attachment points.

The escalator is driven by a large sprocket and three-phase motor, connected through two speed reducing gear boxes. Hand calculations to determine the speed required and horsepower required are attached also. The result is the following:

The escalator is driven by a 3 HP three-phase motor which has a constant draw of 8.4 amps. It operates at 1760 RPM, driving a 1.125" shaft. This shaft couples to a series of two 10:1 right angle worm drive speed reducing gear boxes. Through these the 1760RPM is reduced to 176 RPM at the 60 tooth, ANSI #80 drive sprocket which bears directly on the roller chain in the escalator. With a diameter of just under 20", this sprocket drives the escalator at a speed of 90 feet per minute. 90 fpm is equivalent to a low speed real escalator. Higher speed escalators for long distances may move as quickly as 180 fpm.

A final important detail in the system is use of strips and pads of ultra high molecular weight plastic. Strips are attached to the exterior steel frame and small tabs are attached to the carriages so that horizontal rocking will not result in excessive friction or damage to the system.

Drawing 2 shows only the upper "turn around" of the system. The system can be extended to relatively large sizes as desired, but the roller chain and drive motor used are appropriate for an escalator with a rise of 10' and a load of approximately one person every other step.

Attached costs are based on this same 10' escalator. A surprisingly large number of carriages- 60- are required for just this short distance. 50% of the escalator cost as estimated is in the large number of relatively expensive track rollers. Prices were estimated using McMaster Carr, and it is likely a much better price could be negotiated working directly with a supplier. The estimated material costs of just over \$8,000 are still entirely reasonable for medium to large scale educational or regional theatre productions.

There are several interesting decisions I made during the design process. As mentioned, the carriages are triangular rather than having a slanted face, which I believed would be inappropriately difficult to construct with theatrical resources. When moving diagonally or horizontally, the carriages still line up tightly. However, because of the flat face there will be a brief period in the transition from slope to flat area when there will be a gap between carriages. It is crucial for safety that any escalator riders are aware of this.

The design uses a very large sprocket and a speed reduction of 100:1. This choice, though seemingly inefficient both for space and for cost because it requires two reducing gear boxes, was necessary to ensure components rated for appropriate horsepower transmission. The gear boxes are actually rated for less than the 3HP the motor can produce. This is expected to be safe due to the relatively low duty cycles in theatrical use, and the conservative estimate of horsepower required.

Due to time constraints I did not perform detailed design of the support frame or motor and transmission mounting, or direct interfacing with floor surfaces. These are relatively straightforward technical design problems. A motorized handrail may also be added and powered from the same motor relatively easily, but again is not included in this design.

Components:

- 1) 1" square 14 gauge mild steel tubing, ~\$1.00/ft
- 2) 1" wide 1/4" thick steel flat bar ~3.00/ft
- 3) 3/4" AC Plywood ~\$40/sheet
- 4) ANSI Roller Chain #80 3,300lb working load, 1" pitch, 5/8" width, ~7.65/ft
- 5) Track Rollers sealed, stud style attachment, 0.9° crown, 1.5" diameter roller, 5/8" diameter shaft, 1.5" length shaft, 4,840lb capacity \$18.88 each
- 6) 60 tooth 1" pitch ANSI roller chain sprocket, 19.68" diameter, accepts shafts 1.125" and up, \$128.02 each
- 7) 10:1 Right Angle Worm Gear Speed Reducer, rated at 2.06HP, \$300 each
- 8) 1760 RPM 3Phase motor, 3HP, 1.125" shaft, 8.4 amps ~13"X8" form factor, \$193.80
- 9) UHMW, 0.125" thickness X 1/2" width straps, \$0.48/ft

Cost estimate based on 10ft height escalator unit, 60 carriages total. Half of the carriages are "taken up" in changing direction at any time, and one quarter are returning, so only about 15 steps are on the top side. Estimates for framing steel are very rough but intended to be conservative. Full design of the support frame was not carried out due to time constraints.

All parts are readily available from McMaster-Carr and/or most lumber or hardware stores. Significant savings may be gained in some areas, specifically track rollers, by working directly with a supplier.

Construction costs are not included. A VERY rough estimate would be 50/50 labor and materials, for a final cost of approximately \$16,500.

Item	Cost/Unit (\$)	Units required	Sub cost (\$)
3/4" AC ply	40	8	320
Carriage Steel Tubing	1	1080	1080
Track Rollers	18.88	240	4531.2
Roller Chain	7.65	42	321.3
Sprocket	128.02	1	128.02
10:1 Speed Reducer	300	2	600
3HP 3Phase Motor	193.8	1	193.8
UHMW Strips	0.48	42	20.16
Guide Steel Bar	3	70	210
Framing Steel Tubing	1	800	800
Misc. Electrical	2	25	50
Misc. Hardware	1	100	100
Total:			8254.48

Calculations:

Speed desired: 90 feet/minute (standard low speed escalator)

$$\sim 20'' \text{ s procket} \quad 19.86 \cdot \pi = 61.82'' \text{ circumference}$$

$$90 \text{ fpm} \cdot 12 \frac{\text{in}}{\text{ft}} = 1080 \frac{\text{in}}{\text{min}} \Rightarrow 1080 \frac{\text{in}}{\text{min}} \cdot \frac{1 \text{ rotation}}{61.82 \text{ in}}$$

$$\approx 17.5 \text{ rpm}$$

Horse power required:

10'-0" height = 15 steps assume max load puts 1

200lb person on 1st 4 steps

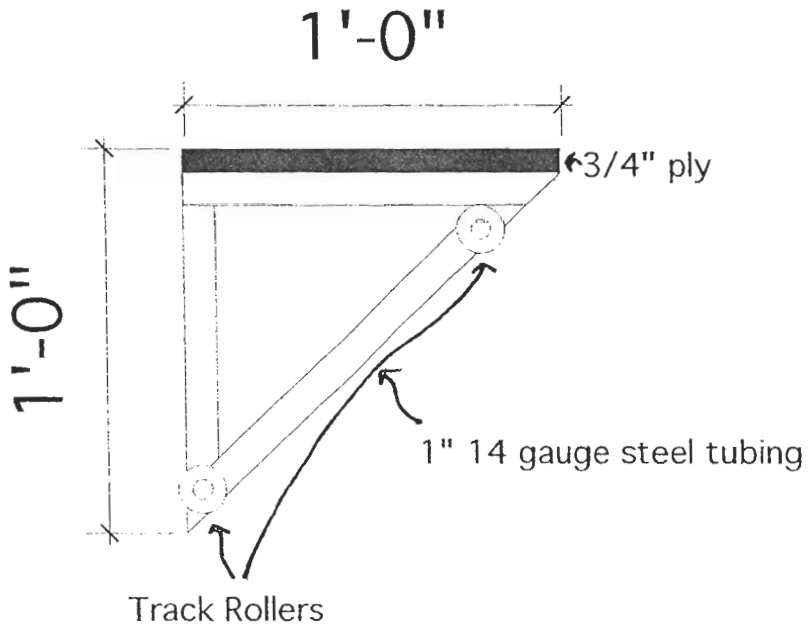
vertical component of velocity = $763 \text{ in/min} = 63 \text{ ft/min}$

$$\frac{63 \text{ ft} \cdot 1900 \text{ lbs} \cdot 1}{\text{min} \quad 60 \text{ min}} = 2.86 \approx 3 \text{ HP required}$$

550

at this upper limit.

Drawing 1: Individual Carriage



Drawing 2: System Section

