Escalator Terror

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Jim Stevenson

DuPont Circle, Washington DC

The "Moving Up" post[1] recalled an unforgettable moment in my past, when I still rode the Washington Metro somewhat sporadically (my youth was spent riding busses, before the advent of the Metro). It was the first time I confronted the escalator at the DuPont Circle stop. I was going to a math talk with a friend and we were busy discussing math when I stepped onto the escalator. Suddenly, I looked up and saw the stairs disappearing 188 feet into the heavens and froze ([1], [2]). I have always been afraid of heights, and the escalator brought out all the customary terror. There was of course no turning back. And then people started bolting up the stairs past me, not always avoiding brushing by.

My hand was clamped to the handrail in a death grip. I had to hold on even tighter as the sweat of fear made my hands slippery. In such situations I often feel a sense of vertigo or loss of balance. It was then that I thought the handrail was moving faster than the steps so that I was being pulled forward. I couldn't tell if it was the vertigo or an actual movement. In any case, I periodically let go and repositioned my death grip. After an eternity, it was over, and I staggered out into the street. Needless to say, on our return I sought out the elevator. Fortunately, it was working—not always the case in the Washington Metro.

Once my brain was functioning a bit, I pondered the question of the relative speeds of the handrail and steps. How could they be synchronized? But after a while I left it as an interesting curiosity.

Solution. Now the "Moving Up" post prompted me to return to the question. I had a few ideas, but I thought I would see what was available on the internet. Basically the solution was fairly straight-forward, though it happily involves some simple math.

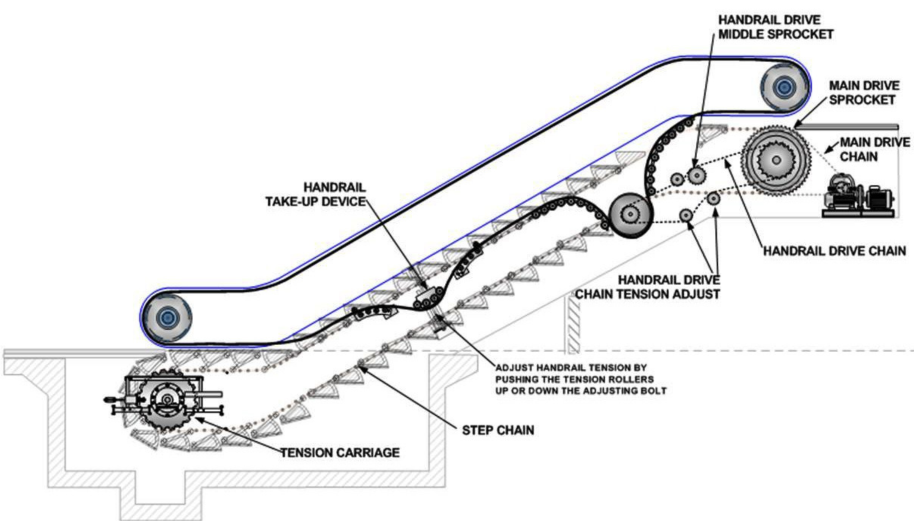

Figure 1 Escalator Schematic[2]

[1] https://josmfs.net/2021/04/24/moving-up/

[2] http://www.electrical-knowhow.com/2012/04/escalators-basic-components-part-two.html

If we zoom in on the drive mechanism of Figure 1, we see that sprocket wheel that moves the steps is linked by a chain to the wheel that moves the handrail (Figure 2). The motion of the chains, steps, and handrail are all represented by tangential velocities to rotating wheels.

Consider the following annotations from Figure 2:

- R = radius of main step drive sprocket
- r = radius of concentric handrail drive sprocket
- v = velocity of main drive chain
  = velocity of steps
  = $R\omega$ where ω is the rotation rate of main drive sprocket
- R' = radius of handrail drive wheel
- r' = radius of concentric wheel connected to main drive wheel
- v' = velocity of handrail drive chain
  = $r'\omega'$ where ω' is the rotation rate of the handrail drive wheel

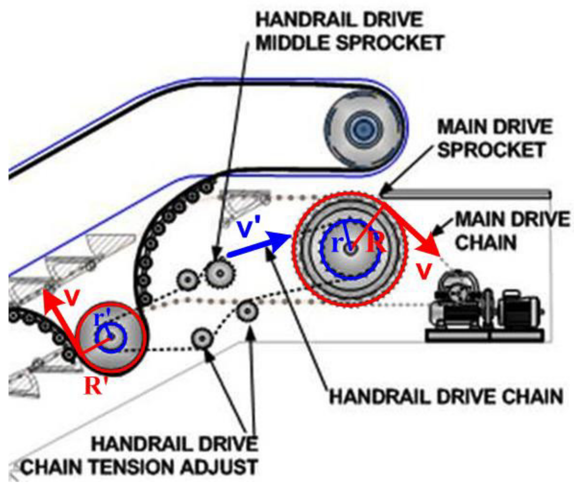

Figure 2 Drive Mechanism Zoom

Since the main drive sprocket is rotating at the constant rate ω, $v/R = \omega = v'/r \Rightarrow v' = (r/R)v$. We want the handrail to move at the same speed as the steps, so we want $v/R' = \omega' = v'/r'$, or $v = (R'/r')v'$, which will occur if $R'/r' = R/r$. So keeping a constant ratio between the pairs of concentric wheels on the main sprocket wheel and the handrail wheel is the critical condition for the handrail and steps to move at the same speed. The two wheels themselves can be different sizes, but their smaller

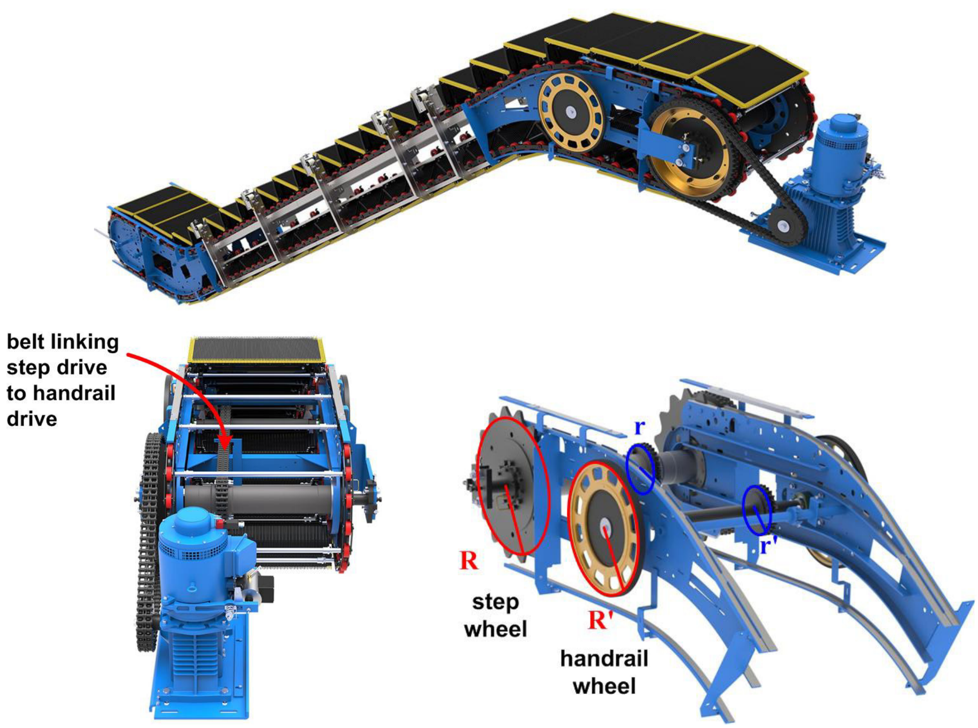

Figure 3 La Grazia Escalator Company Components[3]

[3] https://la-grazia.com/escalator-component-gallery/

concentric wheels must maintain the same ratio with the larger wheels.

Figure 3 shows components of an actual escalator manufactured by the Italian company La Gracia. The step sprocket wheel and handrail wheel are identified along with their respective radii pairs R, r and R', r'. It looked to me like the handrail wheels might be a tad smaller than the step wheels, but I assume the ratios would be the same.

Misinformation. In searching for the answers to the escalator handrail-step synchronization I made some unsettling discoveries. A diagram explaining the escalator mechanism at the Britannica website (Figure 4) had the handrail moving around the small wheel connected to the smaller wheel on the step sprocket wheel. The handrail should have been moving around a larger wheel whose radius to the smaller wheel equaled the ratio of the wheels on the sprocket wheel. This was a major error.

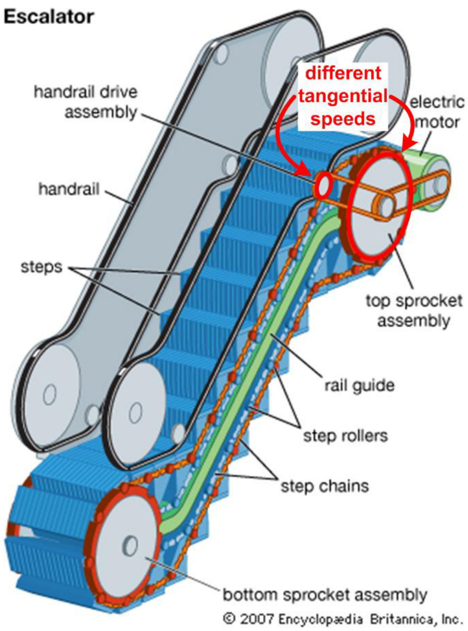

Figure 4 Handrail Steps not synced[4]

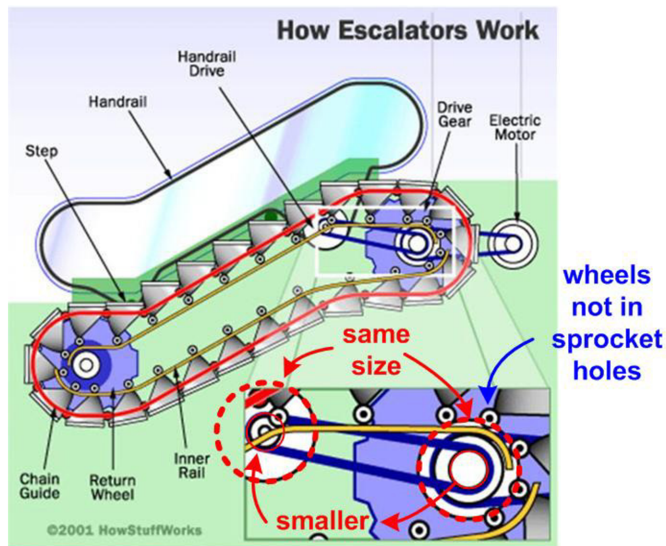

Figure 5 Handrail and Steps may not be synced[5]

Similarly the diagram for How Stuff Works (Figure 5) at least has a larger wheel for the handrail, but its ratio to the smaller wheel being driven by the step sprocket wheel looks bigger than the ratio of the corresponding wheels on the step sprocket wheel. This could have just been a poorly rendered drawing. But the real mess-up was not having the steps remain in the indentations on the step sprocket wheel; they end up floating down to run along a yellow guide bar and then magically float around the wheel underneath. This was just sloppy execution that rendered the drawing incomprehensible.

Both of these incorrect diagrams raise the question again of how reliable information is on the internet. Everything should be evaluated carefully, often with multiple sources.

Final Thoughts. Considering the actual implementation of the wheels and chains as shown in Figure 3, I realized such bulky things are not as precise as the mathematical lines on a diagram. In particular, how do you measure the radii of the wheels involved? A sprocket wheel has edges that go up and down and so no fixed radius. Moreover, the handrail and step chains are thick and may effectively elongate whatever radii are established. How big an error would these ambiguities introduce into computing the ratios of the concentric wheels and how much would this error effect the

[4] https://cdn.britannica.com/81/99781-004-E98B5F8A/Diagram-escalator.jpg
[5] http://foreverpoints.blogspot.com/2014/08/escalators.html

synchronization of the handrail to the steps in a 188 foot-long escalator? Given that all these components are made of metal and not tunable electronics, how could they be manufactured precisely enough to avoid errors in the ratios? I don't know the answers to these questions, but it seems unlikely that there would be an exact match. So my perception of a mismatch in the speeds of the handrail and steps was probably correct, but I am impressed that it was so slight (and grateful that the error made the handrail move forward rather than backward!). Maybe there is something I am missing in the analysis.

References

[1] Johnson, Matt, "What are the 10 longest Metro escalators?" 8 July 2014. (https://ggwash.org/view/34875/what-are-the-10-longest-metro-escalators)

[2] Dupont Circle Station, *Wikipedia* (https://en.wikipedia.org/wiki/Dupont_Circle_station)