how U doin'?

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Elevator Design*

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Contents

1 Problems

电梯设计问题

电梯厂向一个总楼层为 20 层小区出售电梯，根据用户需求设计电梯运行系统，需要回答以下问题：

1. 从一楼进电梯，到顶层出电梯所用的最短时间如何计算？通过调研，针对具体实例计算出最短时间向用户说明。
2. 分析人体血压受电梯启动和停止的影响，给出具体的量化关系。针对健康人能够承受血压的范围，向用户说明电梯加速减速的合理操作范围。
3. 考虑到电梯失灵可能自由下落，需要结合人体膝关节的特点，设计电梯锁死系统，保证乘梯人安全，请给出合理设计方案。

*This article was typeset by Mark Taylor using the LaTeX document processing system.

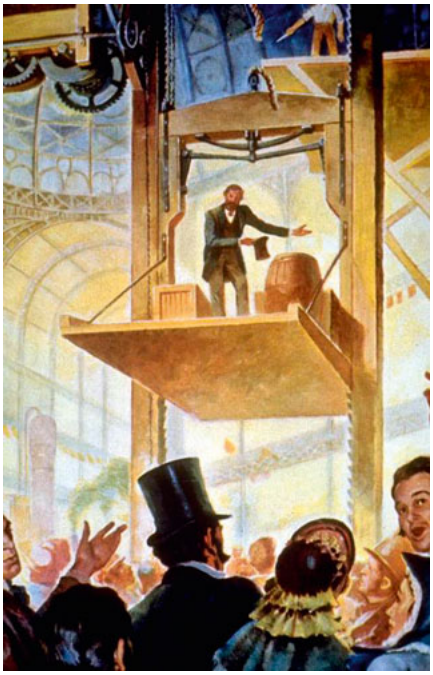
Before addressing the problems, let's delve a little bit into the elevator's history and its principles (how elevator works), the background of which will help us better understand & analyze the problems.

2 Background

2.1 History

The invention of the elevator was a precondition for the invention of skyscrapers, given that most people would not (or could not) climb more than a few flights of stairs at a time. For most people, when they finished climbing 7 floors then they would be out of breath. (PS: Since secondary school, I've invariably been living in the top floors of dormitory buildings, which had 6 or 7 floors but without any elevators 😂. Unbelievable!!) So, the occurrence of elevators, though not technically, fairly boost the development of skyscrapers. People hate climbing stairs! In modern world, it's unimaginable to consider a building without any elevators, even a building of seven stories high (e.g. a residential building, a library, etc.).

In the 1800s, elevators that operated on a cable system were deemed unreliable and dangerous, because, if the ropes broke, the elevator plummeted to the bottom. Freight could be damaged, but, more importantly, passengers were often killed by the fall. Scary, isn't it? Then some brilliant mechanic named **Elisha Otis** invented a safety elevator that prevent the destruction.



Otis Spectacle

While working in a factory in 1852, Elisha Otis and his sons came up with an elevator design that employed a safety device. A wooden frame at the top of the platform would snap out against the sides of the elevator shaft if the ropes broke, essentially functioning as a brake. Otis called it the "*safety hoist*" and dramatically demonstrated this design at the 1854 New York World's Fair (see picture Otis Spectacle). He rode the platform high into the air and then had the rope cut, but, thanks to the brake, it only fell a few inches before stopping. Otis founded an elevator company, Otis Brothers, which installed the first public elevator in a five-story New York department store in 1874. Electric elevators came about in the 1880s.

And now the Otis Elevator Company is the world's largest manufacturer of vertical transportation systems, principally focusing on elevators, moving walkways, and escalators.

Nowadays, there are four main types of elevators: hydraulic, traction, machine-room-less, and vacuum. **In this article, we merely discuss traction elevators**. View the differences among these types of elevators here.

For more information about the history of elevators see http://otiselevator.umwblogs.org/adoption/, https://www.cnn.com/style/article/short-history-of-the-elevator/index.html, & https://science.howstuffworks.com/innovation/inventions/who-invented-the-elevator1.htm.

There are also a couple of YouTube videos that I downloaded & uploaded to my website, view history part here.

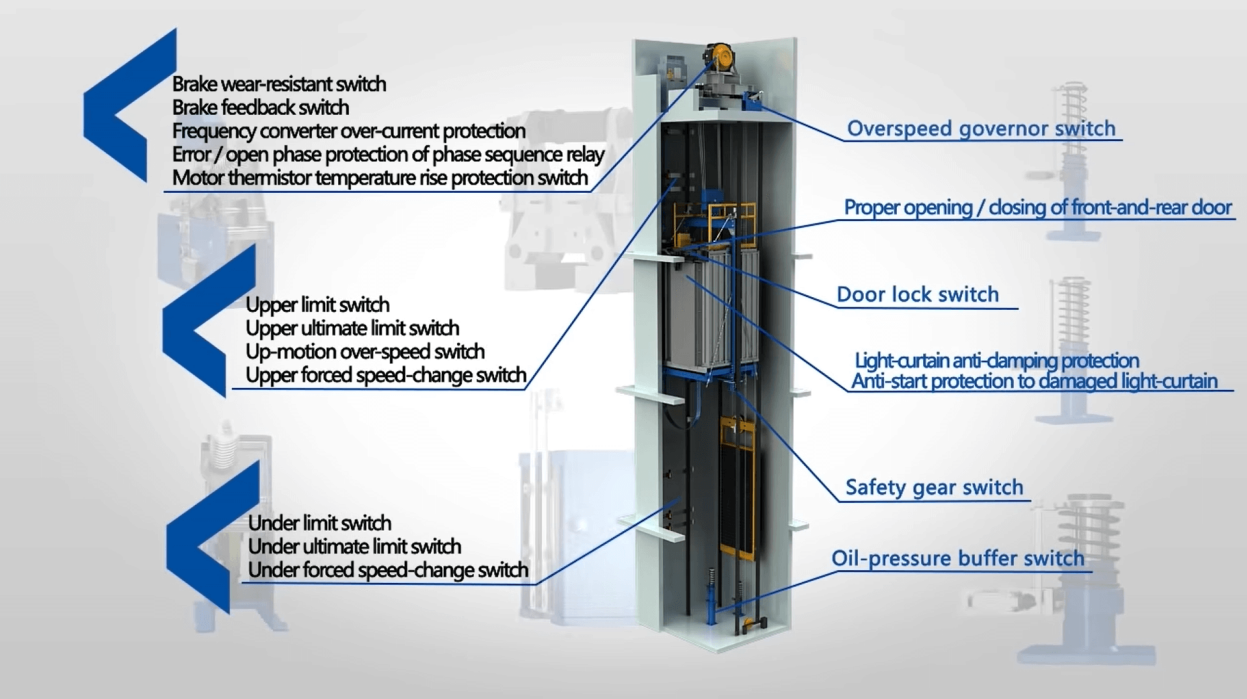
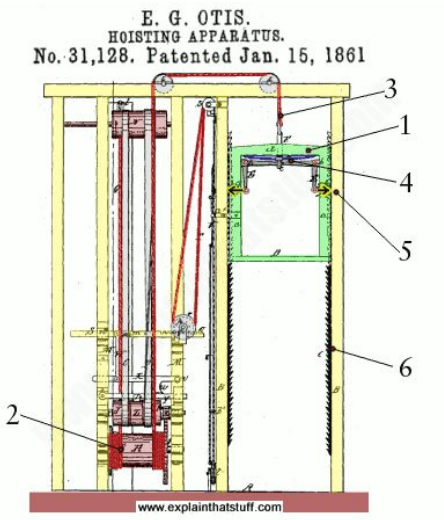


Figure 1: Modern elevators safety gears

2.2 Principles



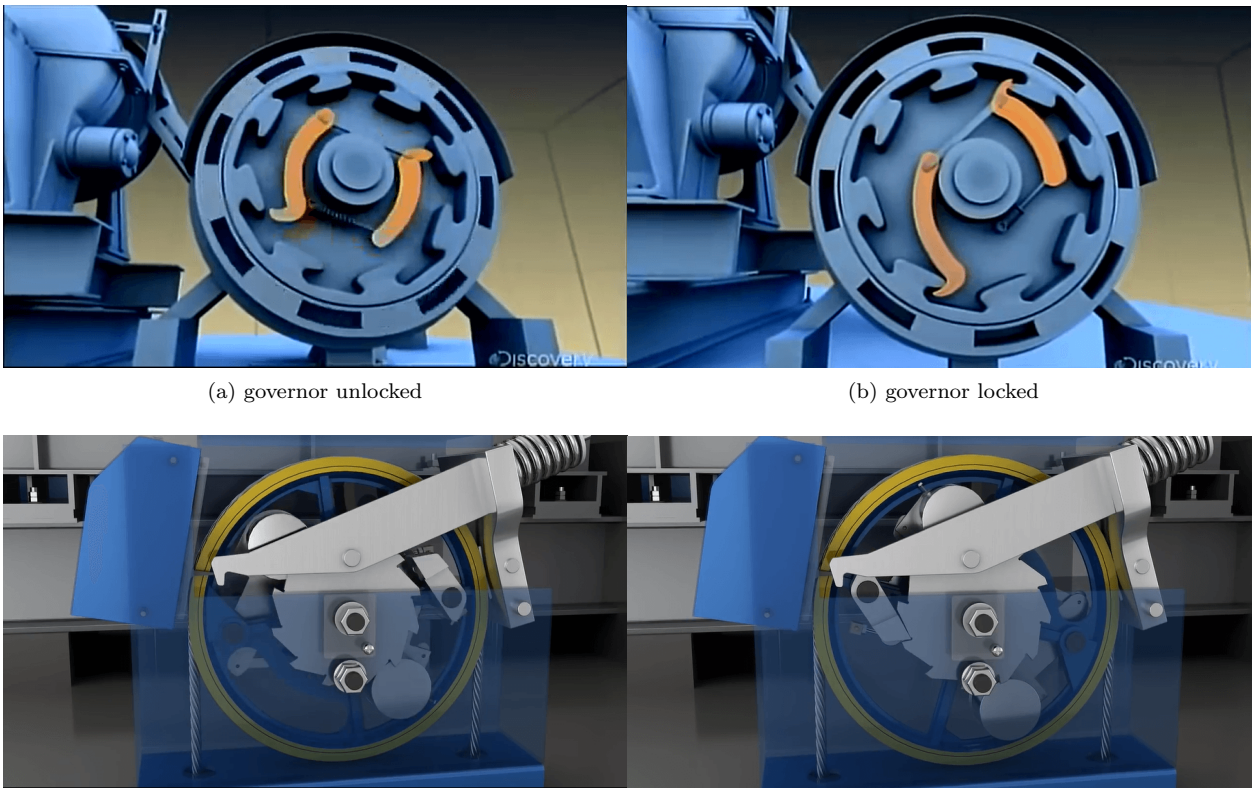
Otis's safety hoist

The graph in the left illustrate the principle that Otis's safety hoist applied. The main idea is that when the rope breaks, the arms marked by 4 in the graph will be ejected (Newton's 2nd law of motion), thus preventing it from directly plummeting to bottom.

Yeah, this is the prototype of early elevators, ugly though, the Woolworth Building[1] adopted this elevator system and made itself the tallest building in the world from 1913 to 1930.

Of course, modern elevators (see figure 1) are much more advanced than it. They possess *multiple safety guarantees*. As we shall see, a modern elevator generally has a *counterweight* on the other end of the rope to offset the weight of car so that the motor has an easier job moving the elevator load. It usually about half the weight of a fully loaded passenger elevator. So, on an average ride, the two are perfectly balanced. All the motor needs to do to move the car is provide a nudge to tip the balance one way or the other. This system saves energy as well as wear and tear on moving parts. Once the car is moving, the motor's only job is to control one of the two falling objects. Both the car and counterweight are attached to guide rails inside the shaft, they keep everything from swaying back and

[1]The Woolworth Building is an early American skyscraper designed by architect Cass Gilbert and located at 233 Broadway in Manhattan, New York City. It was the tallest building in the world from 1913 to 1930, with a height of 792 feet (241 m). More than a century after its construction, it remains one of the 100 tallest buildings in the United States.



(a) governor unlocked

(b) governor locked

(c) another version: governor unlocked

(d) another version: governor locked

Figure 2: Governor locks when overspeed is detected

forth and also give a backup set of brakes something to grab onto. If anything goes wrong with the motor, Hydraulic fluid is cut off and that automatically releases this brake that seizes the ropes for a quick stop. Technically one of these steel ropes is enough to hold up both the car and the counterweight, the rest are there for backup in case one snaps. Even if the whole set is cut, don't worry, it still won't plummet since this machine has a built-in fail-safe. There's a governor[2] located beside the motor with its own pulley and separate cable attached to the car. There are two spring-loaded metal hooks (see figure 2 subfigure (a)) called fly weights inside the governor. If a car-free falls and the governor spins too fast, centrifugal force pushes the hooks out. They cease ratchets on the fixed inner rim and stop the pulley. the governor's rope jerks on an arm on top of the car and this locks the brakes.

The idea of the rope elevator is simple enough - one side goes up the other goes down. It just took a couple of thousand years to figure out how to stop it. It's easy enough to drive but without breaks we'd rather walk. (View YouTube video *How Elevator Works* here , and view YouTube video *Elevator Brake Systems* here)

[2]The governor, which is located in the machine room or overhead depending on the elevator design, is a speed monitoring device on traction elevators that triggers the safety mounted on the car frame when the elevator over-speeds in either direction.

3 Analysis & Solutions

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3.1 Problem 1

3.2 Problem 2

3.3 Problem 3

4 Appendix

Hello from the Beatles.😃