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Research Article

The Design of A One-Man Passenger Electric Elevator

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Abstract: The one-man Passenger electric elevator described in this paper is designed primarily to carry one person according to the specifications of the client. The electric elevator is moved by an electrically powered machine that drives hardened steel traction sheave over which the ropes are suspended. It has advantages over the staircase, ladder and the hydraulic elevators. The specifications on the design and drawings conform to approve international standards. This work is a reference design for a one-man passenger electric elevator for emergency exit in high rise buildings..

Keywords: Passenger, elevator, electric, hoist way.

INTRODUCTION

Elevators are hoisting and lowering mechanisms equipped with cabin or car or platform (as the case may be) that moves along guides in a shaft, or hoistway, in a substantially vertical direction and transport passengers or goods (freight) or both between two or more floors or levels, as in a building or a mine[1].

The term *elevator* generally denotes a unit with automatic safety devices[2-4]; the very earliest units were called hoists. Elevators consist of a platform or car traveling in vertical guides in a shaft or hoistway, with related hoisting and lowering mechanisms and a source of power. The development of the modern elevator profoundly affected both architecture and the mode of development of cities by making many-storied buildings practical.

Elevators are desirable in all multistory buildings for movement of passengers and freight. They may be required by local building codes for any buildings over two stories high or for transportation of disabled persons. Elevators, however, are not usually accepted as a means of egress, because no cohesive strategy has been established to assure proper operation of elevators in an emergency.

The modern power elevator is largely a product of the 19th century. Most elevators of the 19th century were powered by steam engines, either directly or through some form of hydraulic drive[1]. In the early 19th century, hydraulic plunger elevators were used in some European factories. In this type of elevator, the car is mounted on a hollow steel plunger that drops into a cylinder sunk into the ground. Water or some other fluid forced into the cylinder under pressure raises the plunger and car, which fall by gravity when the fluid is released. A forerunner of the modern traction elevator was in use in Britain in 1835. In this case the hoisting rope passed over a belt-driven sheave, or pulley, to a counterweight traveling in guides. The downward pull of the two weights held the rope tight against its sheave, creating sufficient adhesive friction, or traction, between the two so that the turning sheave pulled the rope along.

Electric Elevators

The electric motor was introduced in elevator construction in 1880 by the German inventor Werner von Siemens. His car, carrying the motor below, climbed its shaft by means of revolving pinion gears that engaged racks at the sides of the shaft. An electric elevator was constructed in Baltimore, Maryland, in 1887, operated by an electric motor turning a revolving drum on which the hoisting rope was wound. Within the following 12 years, electric elevators with worm gearing connecting the motor and drum came into general use except in tall buildings. In the drum elevator, the length of the hoisting rope, and therefore the height to which the car can rise, are limited by the size of the drum; space limitations and manufacturing difficulties prevented the use of the drum mechanism in skyscrapers.

Description, Types and Classifications

Elevators are designed for various purposes and are of different types. They are passenger elevators and freight elevators.

Passenger elevators are designed primarily to carry persons. They include hospital elevators which are also passenger elevators but employ special cabins, suitable in size and shape for transportation of patients in stretchers or standard hospital beds and of attendants accompanying them.

Freight elevators carry freight, which may be accompanied only by an operator and person and persons necessary for loading and unloading it.

Elevators are also described as roped electric or hydraulic type. For the roped electric elevator the cabin is suspended from wire ropes and counter balanced by a counter weight that mirrors the operation of the elevator.

The Electric elevator is moved via an electrically powered machine that drives hardened steel traction sheave over which the ropes are suspended. Electric elevators are used exclusively in tall buildings and many low buildings.

Hydraulic elevators are raised and lowered by an oil pumping system which actuates a plunger or piston. They are frequently used for passenger elevators serving up to five or six floors and for low-rise freight service.

Classifications:

Elevators are broadly classified as low-rise, medium-rise, and high-rise units. Low-rise elevators typically serve buildings with between 2 and 7 floors; medium-rise elevators serve building with between 5 and 20 floors, while high-rise elevators serve buildings with more than 15 floors. The speed of the elevator is indexed to the rise of the building so that the overall flight time from bottom to top, or vice versa, is approximately the same. A typical flight time is about one minute. Typical speeds for low-rise elevators are up to 200 ft/min (1.0m/s). Typical speed for medium rise elevators is up to 400 ft/min (2.0m/s). High rise elevators typically travel at speeds of up to 1,800 ft/min (9.0m/s).

DESIGN DEVELOPMENT AND CONSIDERATIONS

The availability of the materials chosen for the design and cost was of primary consideration. They were chosen on the basis of properties such as strength, reliability, thermal considerations, corrosion, wear resistance, safety, weight, shape and size, surface finish, cost of production, Human factor, serviceability lubrication and maintenance.

DESIGN ANALYSIS

Sheave, beams and floor systems design.

Unit stresses, calculated without impact, in a steel guide rail or its reinforcement, caused by vertical forces, should not exceed 15ksi, and deflection should not exceed 0.006m. Guide-rail supports should be capable of resisting horizontal forces with a deflection of not more than 1/8 in.

Elevator hoist way design

A hoist way is a shaft in which an elevator travels[2-4]. To provide access to an elevator cabin, the shaft enclosure has openings, protected by doors with safety devices, at landings. In a pit at the bottom of the hoist way, are buffers or bumpers (see figure 1) installed to stop a descending cabin or counterweight beyond its normal limit of travel, by storing or absorbing and dissipating its kinetic energy.

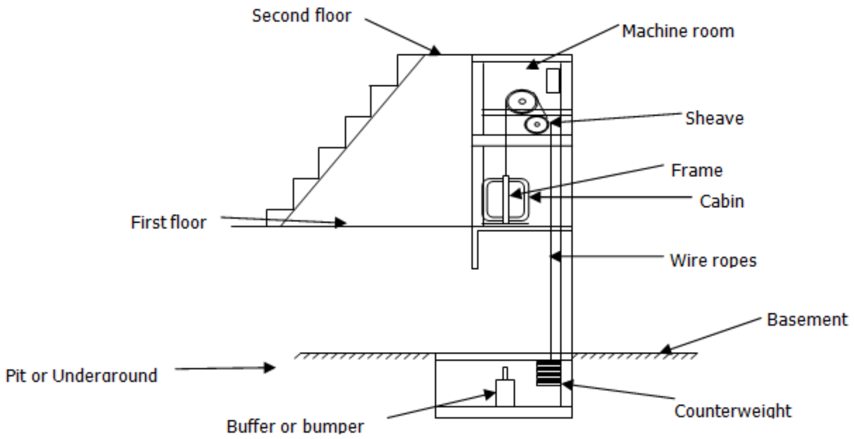


Fig. 1: Electric elevator with driving machine at top of hoistway.

Efficiencies and Energy Dissipation per Cabin Meter

The overall efficiency and energy dissipation varies greatly from elevator to elevator, depending on the design, hoist way conditions, loading conditions, acceleration and deceleration profiles, number of stops, etc. For a load of 1,150kg for *geared traction elevators* driven at 500mm/s by SCR-controlled DC motor or VVVF-controlled ac motor, typical values are as follows: Efficiency 60%; Energy dissipation 4.5Wh (16MJ).

A winding-drum machine gear drives a grooved drum to which thehoisting ropes are attached and on which they wind and unwind. For contemporary elevator, the winding-drum drive system is applied only to dumbwaiters and light duty residential units such as this.

Elevator Control

The system governing starting, stopping, direction of motion, speed, acceleration and deceleration of the cabin is called *elevator control*. Multi-voltage control (also known as variable-voltage control) or rheostat control has been commonly used for electric elevators, due largely to the relative simplicity of controlling the dc motor. The advent of larger power transistors has resulted in control systems known as ***Variable-voltage, variable-frequency control*** (VVVF) that can be applied to ac motors to produce smooth starting and stopping equal to the classic dc elevator control system.VVVF is a means used to produce smooth acceleration, deceleration, and stopping of common **ac** motor at non-synchronous speeds. VVVF control offers much higher efficiency than that realized through **dc** motor and is gradually replacing the various means used to control **dc** motors, along with the motor.

Multivoltage control usually is used with dc motors. For elevator control, the voltage applied to armature of the motor is varied. Because buildings usually are supplied with ac power, the variable voltage generally is obtained from a motor-generator set that coverts ac to dc. This type of control commonly is used for passengers' elevators because it combines smooth, accurate speed regulation with efficient motor operation. It also permits rapid acceleration and deceleration and accurate cabin stop, with low power consumption and little maintenance.

Car Leveling at Landings

Elevator installation should incorporate equipment capable of elevator cabins level with landings within a tolerance of 0.013m under normal loading and unloading conditions. Because changing cabin loads vary the stretch of the hoisting ropes, provision should be made to compensate for the variation and keep the cabin platform level with the landing.

Terminal Stopping Devices (Safety device)

For safety, provision would be made to control cabin movement as it approaches a terminal landing and to keep it from passing the terminal. For the purpose, special speed-limiting and stopping devices are needed.

An **emergency terminal speed-limiting device** is required to reduce cabin speed automatically as the cabin approaches the terminal landing. This should be done independently of the functioning of the operating device, which actuates the elevator control, and of the normal terminal stopping device if it should fail to slow the cabin down as intended.

The **normal terminal stooping device** slow down and stop the cabin at or near a terminal landing independently of the functioning of the operating device. It should continue to function until the final terminal stopping device operates.

The final terminal stopping device is required to interrupt automatically the electric power to the driving-machine motor and brake after the cabin has passed a terminal landing. But this device should not operate when the cabin has been stopped by the normal terminal stopping device. When the final terminal stopping device has been actuated, normal cabin operating devices should be rendered incapable of moving the cabin.

Counterweights.

Counterweight is used for maintaining traction between the hoisting ropes and driving sheave. Power requirements of the driving machine for moving the cabin is reduced by hanging a counterweight on the hoisting ropes**.** The weight of the counterweight usually is made equal to the weight of the unloading cabin and the ropes plus about 40% of the rated load capacity of the cabin.

A counterweight usually is made up of cut steel plates set in a steel frame. Moving up as the cabin moves down and down when the cabin move up, the counterweight is kept in a fixed vertical path by upper and lower guide rollers that are attached to its frame and roll along a pair of guide rails.

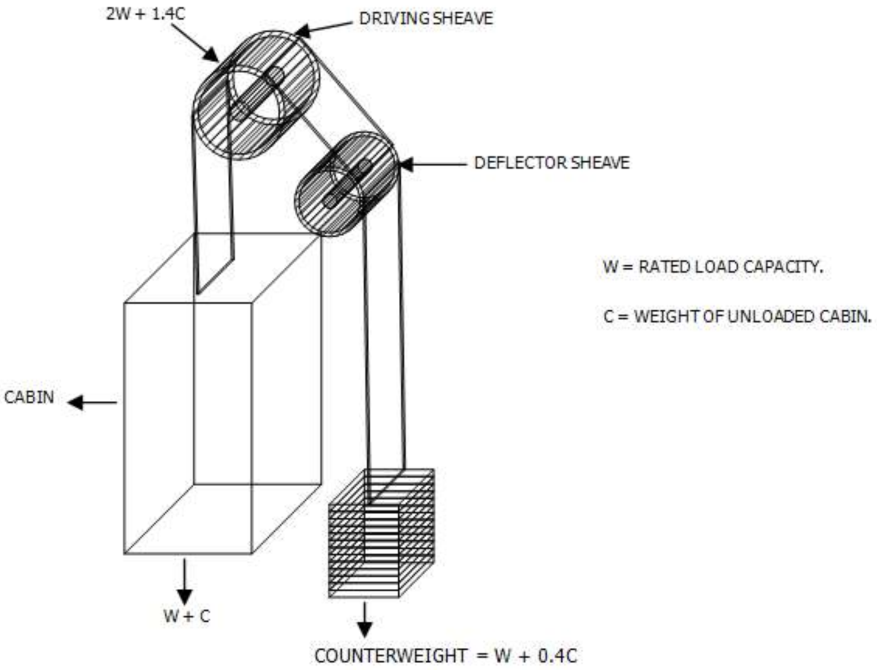


Fig 2: Arrangement of hoisting rope, cabin and counterweight

Roping for Elevators.

American National Safety Code for Elevators, Dumbwaiters, Escalators and Moving Walks (ANSAI17.1) requires that a cabin should be suspended from at least three hoisting ropes for traction-type machines and two ropes for winding-drum machines. At least two ropes are needed for a counterweight. All these ropes should be at least 12.7mm diameter.

The simple arrangement of hoisting ropes, cabins and counterweight for example is called **1:1roping** because cabin speed equals rope speed. The ropes are attached to the top of the cabin frame, wound around the driving sheave, bend around a deflector sheave, and then extend downward to the top of the counterweight. This rope arrangement is also known as **single-wrap roping** because the ropes pass over the driving sheave only once between the cabin and the counterweight. The 1:1 single-wrap roping often is used for-high-speed passenger elevator.

Design speeds

The assumed speed for this elevator is 500mm/s.
Mass of the passenger = 250kg (Assumed)
Area of the cabinet
A = Outer area – Inner area
= (1850 x 600) – (1770 x 521)
=1110000 – 922170 = 187830mm^2 (x10^{-2}) cm^2
Area, A = <u>1878.3cm^2</u>
The width = 521mm = 52.1cm
The volume of the cabinet
= Area x width
= 1878.3 x 52.1
= <u>97859.43cm^3</u>

Since the cabinet is made from Aluminum 6061 – T6, density = 2.7g/cm^3
Mass of the cabinet, M_c is obtained from
Mass = density x volume
= 2.7 x 97859.43 = <u>264220.461g</u>
M_c = 264.2205kg ≈ 264kg
Let Mass of the passenger, M_p = 250kg
Counter weight, C_w from the standard = W_p + 0.4C
Where W_p = weight of the passenger
C = weight of the cabinet
Counterweight, C_w = [250 + (0.4 x 264)] x 9.81
= (250 + 105.6) x 9.81
= <u>3.488KN</u>
Weight of the passenger W_p = 250 x 9.81= 2453N
= 2.453KN
Weight of the cabinet = 264kg
The assumed speed, V_e at which the cabinet + passenger move = 500mm/sec
V_e = <u>500mm/sec</u>
The elevator has to move through a distance (S) of 2150mm
When the elevator moves from the downstairs to the upstairs, the final velocity V_f = 0, then using Newton's third law equation of the motion
$V^2 = U^2 - 2as$
$+U^2 = +2as$
$U = V_e$
$V_e^2 = 2as$
$a = \frac{V_e^2}{2s}\left(\frac{mm^2}{mm/s^2}\right)$ = <u>58mm/s^2</u> = 0.058m/s^2
The linear acceleration at which the passenger + cabinet moves = <u>58mm/s^2</u>

Tension in the rope

The forces that determine the tension in the rope, T_r are the weight of the cabinet, passenger and the counterweight

Consider the free body diagram (F.B.D) below

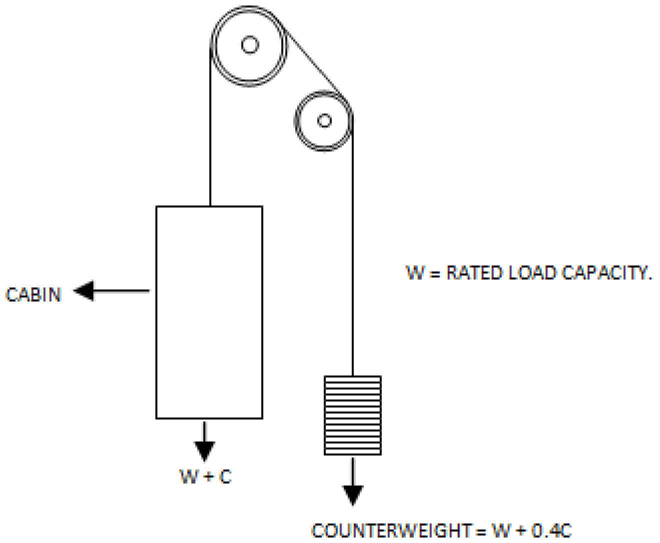
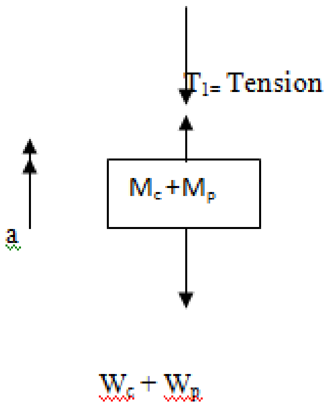


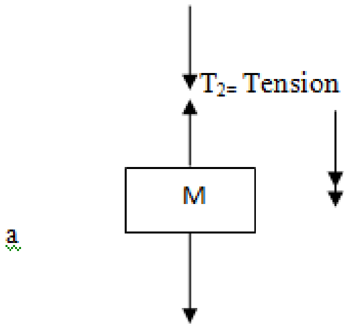
Fig 3: Free Body Diagram

F.B.D

For the passenger + cabinet side



For the counterweight side



C_w

For the passenger + cabinet

$T_1 - (W_c + W_p) = (M_c + M_p)a$

$T_1 = (W_c + W_p) + (M_c + M_p)a$

$= (M_c + M_p)g + ((M_c + M_p)a$

$= (M_c + M_p)(g + a)$

= (264 + 250) (9.81 +0.015)

= (514) x (9.825)

T_I = 5050.05N

T_I = <u>5.05KN</u>

On the counterweight side, when the elevator moves downward

$T_2 - C_w = M_a$

$T_2 = M_a + C_w$

$T_2 = M_a + C_w$

T_2 = <u>5.333KN</u>

To find the diameter, D of the drum, for the elevator to move through a distance S_1 the drum has to complete ***n*** number of turns

i.e. πD x n = S

πDn = S

D = S/nπ

$= \frac{684}{n}$ (i)

From the speed V_e = 500mm/s

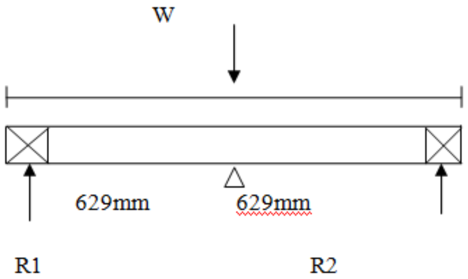
Velocity = distance/time = S/t

t = S/V

Where t = time required for the elevator to reach the distance, S

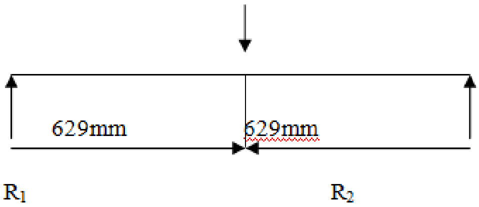
T = 2150/500= 4.3<u>seconds</u> .Linear speed V_e = r*w*

For the reactions, on the bearing supports



Assuming that all the loads are concentrated at the centre,

$$W = W_c + W_p + C_w$$



Resolving the forces, vertically,

$\sum Fy = 0$

$R_I + R_2 = W_c + W_p + C_w$ ------ (i)

Taking moment about R_1,

$(W_c + W_p + C_w) \times 629 = R_2 \times 1258$

$R_2 = 4.3KN$

$R_1 = R_2 = 4.3KN$

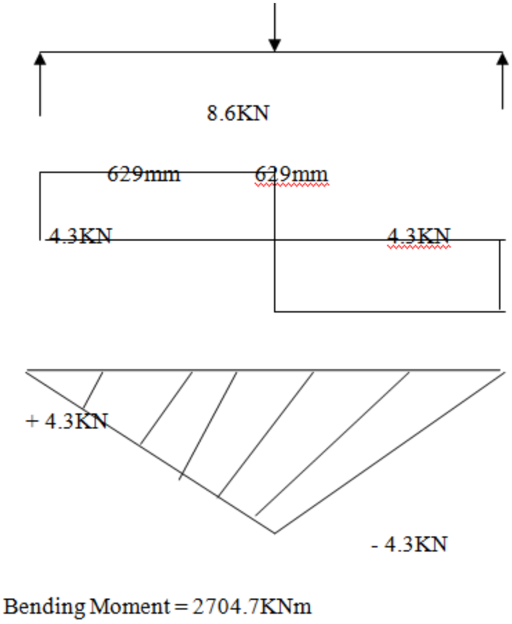


Fig 4: Shear Force Diagram

CONCLUSION

Though there are other designs of elevators available, cost-effectiveness, durability and ease of operation factors were considered here; such that there is no doubt about the advancements shown here.

This design has some notable advantages which include:

- The ability to carry reasonable load of 250kg at a time.
- Possibility of entering through one side and exiting in the other.
- The movement of the cabin at a safe speed with linear acceleration at which the passenger and cabinet moves is $58mm/s^2$ which means that within 4 seconds (flight time) the passenger is already in the next floor.
- The inclusion of a rubber type buffer which is cheaper as against the hydraulic and spring types.
- This design is the electrical type, so cost of maintenance is cheaper compared with the hydraulic type which uses oil and needs extra motor to pump it. The oil leakages and hose burst are all eliminated. In the other designs such as the traction type where there are direct drives, there is a brake shoe attached to the drum which makes them cumbersome.

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