Key Innovations and Technologies in Vertical Transportation Systems since 1980

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Abstract. Vertical transportation systems have been rapidly evolving since the 1990’s. Lifts without machine rooms have become common, many buildings of 100 or more floors have been built or are planned and new technologies for lifts are being introduced.

The common types of lifts produced in 1990 are explained as a baseline for explaining the innovations that have revolutionized lifts since then. These innovations include Variable Voltage Variable Frequency (VVVF) technology, the Insulated Gate Bipolar Transistors (IGBT), Permanent Magnet Alternate Current Motors (PMAC), Independent Wire Rope Core (IWRC) ropes, and Machine Room Less (MRL) lift technologies.

Two novel suspension means, coated steel belts and coated carbon belts, are new technologies that are changing lift designs are reviewed.

Systems that employ more than one lift per hoistway are explained. These systems can use ropes or they can be rope-less and employ magnetic levitation.

Two interesting new technologies that are profoundly changing the lift industry, Machine Learning and Robots are also examined.

1. The History of lifts
Lifts have existed for thousands of years. However prior to 1853 they had one major problem; if the suspension ropes failed the lift would fall and the passengers would be injured or die.

In 1853, Elisha Otis demonstrated a device, now known as the safety gear that arrested the lift’s fall when the ropes were cut [1]. This device made lifts safe and the lift industry was started.

Advances in structural engineering made tall buildings possible and safe lifts made them practical.

In the approximately 140 years following the invention of the safety gear, lifts slowly evolved. In 1990 there were two main types of lifts these were Traction and Hydraulic.
2. Traction lifts

Traction lifts consist of a car, hoist ropes, a machine, and a counterweight. See Figure 1, Traction Components.

The ropes were made of steel strands wound around a hemp rope core.

The machine was a pulley connected to a motor. For high speed lifts, the motor was a Direct Current motor and was powered by physically large variable voltage drive. Slow speed lifts with speeds below 2.5 m/s used a special alternating current motor with small inefficient variable speed drive. The motor of the slower lifts was fitted with a reducing gear.

In very tall buildings, a variation of the traction lift called a double deck lift was sometimes utilized. In double deck lifts the car had two cabins stacked one on top of the other. Double deck lifts still had one very large machine and one very large counterweight.

3. Hydraulic lifts

For low rise buildings up to around 8 to 10 floors, hydraulic lifts were often used. Hydraulic lifts consist of an oil reservoir, an oil pump, a set of control valves and a hydraulic ram (piston and cylinder). To move the lift in the up direction oil was pumped from the reservoir to the hydraulic ram. To go down, a valve was opened allowing the oil to flow from the ram to the reservoir. See Figure 2, Hydraulic Components.
Hydraulic elevators are lower in cost than traction elevators.

4. Key innovations that changed lift design

4.1 Variable Voltage Variable Frequency
The speed of an Alternating Current (AC) motor is directly proportional to the frequency of the power supply. In most of the world the AC power supplied is 50Hz. If a motor designed for 50Hz could be supplied with 25Hz it would rotate at half its design speed.

Lifts using VVVF technology were introduced in the 1980’s. In order to create the variable frequency a technology known as Pulse Width Modulation (PWM) was employed [2] [3]. The switching transistors used for these applications were limited to a switching frequency of around 3,000 Hz. The sine waves produced would be made up of 3,000 pulses each second.

The 3,000 Hz made audible noise and caused vibration in the motor. To address these issues, large air core inductors were used. The inductors caused the VVVF drive to be very large. However, this new technology worked well.

4.2 IGBT
A new type of transistor was developed in the 1980’s and found its way into lifts in the early 1990’s. This type of transistor is known as the Insulated Gate Bi-Polar Transistor (IGBT) [4].
The IGBT could switch at frequencies above 10,000Hz. At these frequencies no inductors were required for vibration or noise control.

The VVVF variable speed drive using IGBT’s was smaller than the Direct Current drives or the early VVVF drives.

4.3 IWRC
As previously mentioned, lift ropes were typically made up of steel strands wound around a non-load carrying core. In the 1990’s a new type of rope was introduced known by its construction as Independent Wire Rope Core (IWRC). In this rope, the fibre core was replaced with a steel load carrying core [5].

An IWRC rope could carry more load than a traditional rope of the same diameter or ropes of smaller diameter can carry the same load. Using smaller diameter ropes has several significant advantages:

1. Pulleys must be 40 times the diameter of the rope. The smaller pulleys make the machine more compact.
2. Smaller pulleys must turn more revolutions per minute (RPM) for the same lift speed.
3. Higher rpm’s means the motor must develop less torque for the same amount of power. (See formula 1 below) [6].
4. Lower torque motors are less expensive and physically smaller.

\[ P = \frac{\tau \times 2\pi \times \nu}{60} \]

Where:
- \( P \) represents power
- \( \tau \) represents torque
- \( \nu \) represents RPM

4.4 Permanent Magnet Alternating Current Motors
Lifts utilizing VVVF technology initially used alternating current induction motors. The induction motor had been in existence for around 100 years. In the late 1990’s Permanent Magnet Alternating Current Motors (PMAC) started to be used for lifts.

PMAC motors are, for any given power and torque, smaller and more efficient than induction motors [7].

4.5 Combined technologies
By utilizing VVVF motor control using IGBT transistors along with PMAC motors and IWRC ropes it was now possible to make a very compact elevator.

Traditionally, lifts had an equipment room on the roof of the building where the machine and control were located. The area of this machine room was often larger than the area of the lift shaft.

In the late 1990’s KONE elevator introduced a novel lift system that combined all these technologies and was so compact that no machinery space was required above the roof of the building [8]. The concept was extremely popular. KONE gained market share and all the other lift companies scrambled to develop similar products. The new lift type became known as an MRL, an acronym for Machine Room Less [8].
5. New Technologies

5.1 Belts
Two belt technologies were introduced.

In the early 2000’s Otis elevator introduced a coated steel belt [9]. The belt has the steel strands of a round rope. However they are laid out horizontally and coated with polyurethane. This permits the use of a sheave with a very small diameter (100mm). Consequently, the motor torque is greatly reduced.

In 2012 KONE introduced a carbon fibre belt [10]. The principal advantage of the rope is its low weight. In very tall buildings, steel rope begins to be unable to support its own weight. The carbon fibre rope solves this problem.

5.2 Building Efficiency
One way to measure building efficiency is determine the net useable floor space of a building as a percentage of the gross area. If one visits a 100 story building, one will find that a very large percentage of the lower floors are dedicated to lift lobbies and shafts.

Double deck lifts are one of the methods that can be used to improve efficiency. The big drawback of double deck lifts is that the two cabins must travel together as they have one hoist machine and one counterweight. In the early 2000’s ThyssenKrupp Elevator introduced a solution known as TWIN [11].

The TWIN lift consists of two complete lifts, two cabins, two machines, two sets of ropes, and two counterweights with the cars traveling on the same rails and using most of the same entrances. The individual cars can move independently.

An additional product was just recently introduced by ThyssenKrupp Elevator known as MULTI. In this scheme multiple lift cars can be in the same hoistway.

The lift cars a powered by linear motors and do not have hoist ropes [12]. The system uses one lift shaft for cars traveling up and another shaft for cars traveling down. At the top and bottom floors, the cars can transit horizontally from up to down shafts or vice versa.

A traffic analysis of this system performed by the author demonstrated a significant increase in net useable floor space when compared to a conventional lift system.

5.3 Robots
Professional service robots are appearing in the marketplace that will need to ride in lifts with humans [13].

There are four building types where professional service robots are being applied in increasing numbers. These building types are hotels, office buildings, residential buildings, and hospitals [14].
In hotels, service robots are being used for room service deliveries and for the delivery and movement of housekeeping carts.

In office, buildings robots are delivering packages and mail from sources outside the building as well as interoffice correspondence.

The growth of e-commerce has caused an increase of package deliveries to multi-story residential buildings. Robots are being used to make the final delivery from the lobby to the residential unit.

Hospitals have used pneumatic tube systems for delivery of medicines and the transport of medical records. Pneumatic tube manufacturers are now offering robots as an alternative to tubes [15].

Lift companies are developing interfaces to allow robots to call lifts and have the lifts take them to their destinations [16].

5.4 Machine Learning

Machine learning, a form of Artificial Learning (AI) is being applied to lifts in order to increase the up-time of lifts [17]. Machine learning makes predictions based on known properties learned from training data.

In a typical lift installation, a data collection device is connected to the lift that monitors the operations of the lift. Additionally any error codes issued by the lift’s control system are also collected. The lift continuously sends this data to a cloud computing facility where it is analysed.

The machine learning system then schedules routine maintenance, defines maintenance tasks, and even schedules special maintenance visits to make repairs prior to a part failing.

Machine Learning will totally change the lift industry. Lifts will become more reliable and operating costs will be reduced.

6. Conclusion

It can be seen that since 1990, lifts have incorporated many technological changes. These changes have made lifts more efficient and more reliable.

The rate of change is increasing and Machine Learning and other forms of AI will further improve safety, efficiency, and reliability.

7. References

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