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A Critical Review and Investigation of Machine Room Less (MRL) Elevators

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Abstract

Machine room less (MRL) elevator drives offer advantages over conventional traction drives such as a higher energy efficiency, low weight, and more design freedom and better utilization of hoist-way space. MRL drives have emerged as the superior choice in most high rise applications. Currently a majority of MRL drives are mounted on a guide rail spanning beam which forces safety and stabilization components to act as load bearing component and degrades ride quality. The MRL drives are also difficult and costly to inspect and maintain if located in such a configuration. Alternate methods of mounting MRL drives on hoist-way spanning I beams if utilized can eliminate eccentric hauling leading to better utilization of guide rails and an improved ride quality. A hoist-way spanning support configuration also aids in decreasing inspection and maintenance costs by improving ease of access and increasing safety. Thus a properly located MRL drive can provide best possible operating parameters for a high rise application with lower costs of inspection and maintenance over the elevator lifetime.

Keywords: Elevator; MRL; Beam; Inspection; Elevator; Design

Introduction

Elevators are vertical transport systems that are utilized for efficient transport of passengers and goods between different efficient transport of passengers and goods between different floors (landings). An elevator differs from other hoisting mechanisms in that it runs at least partially on guide rails. The elevator is a mass transit system (conveyor) whose design has evolved rapidly from that of a simple drum and rope traction system to traction less and machine room less systems. Elevator usage has grown exponentially in India but the adoption of newer technologies such as the MRL drive or Hydraulic drive systems is lagging behind because of additional costs of maintenance and inspection involved as convenience of machine room diminishes.

It becomes imperative to establish MRL elevators as a superior choice and provide additional future changes that provide advantage of MRL drive during operation and the convenience of a machine room during inspection and maintenance. Such an elevator drive will provide least cost of maintenance and inspection for the customer over the elevator lifetime.

Literature Review

Present advantages of MRL drives

Celik [1] reports that Hydraulic elevators are more suited to small rise buildings and freight applications. This report after experimentally mapping the performance of different elevator drives under varying parameters of passenger capacity, severity of service, travel and speed finds that Hydraulic elevators have advantages over traction drives in low rise applications

- Substantially lower initial cost of equipment and its maintenance for a given capacity hydraulic elevator equipment cost up to 40% less than traction equipment
- More building space utilization as the hydraulic elevator utilises up to 12% less space than an equivalent traction elevator, as the hydraulic system imposes no load on the column the column size can be reduced
- Effective for high load requirements such as freight elevators
- Lowest cost down speed amongst all elevators as gravity is utilized as the motive force

However Hydraulic elevators have deficiencies and disadvantages in areas that MRL drives excel in. Hydraulic elevators have only proven to have an advantage over MRL drives in low speed, low rise high capacity applications.

The report concludes that MRL drives despite their superiority in high rise applications have costly and difficult maintenance regimes because the machine is located in the top of the hoist-way or, on or under the cab, reaching it can be difficult. Accidents during construction and servicing of the elevator are more likely. In case the car is stuck, the machine cannot be serviced from the top of the car, other methods may need to be attempted.

The performance of hydraulic, conventional traction and MRL (machine room less) drives were studied for varying conditions of speed, travel, capacity and severity of service and states that among Hydraulic elevators, and traction drives, Hydraulic elevators impose the least load on the hoist-way and have least cost of construction and operation however due to their slow nature and requirement of environmental clearance to dig oil wells they are only utilised in low rise buildings and other applications where Hydraulic elevators prove advantageous and traction drives cannot be used. Between conventional traction and MRL drives, MRLs give better ride quality more efficient performance, better product life and higher speeds than a similar conventional drive however a conventional drive imposes load only on the building structure where as an MRL exerts load on the hoisting support and MRL hoisting support has to be designed accordingly

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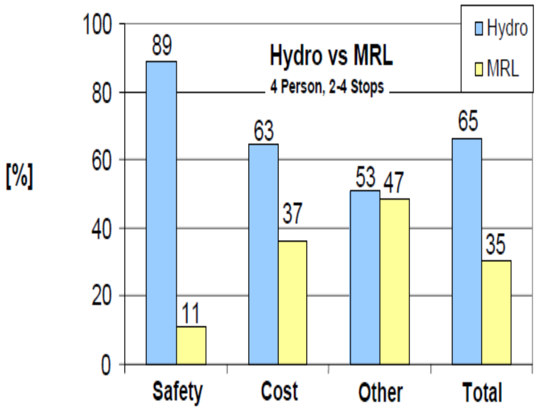

Figure 1: Comparable advantages MRL drives [1].

(Figure 1). Though having a higher initial cost MRL systems are more suitable for use than conventional system. F Celik concludes by stating that in the near future elevator market will be dominated by MRL and hydraulic drives sharing a majority of the market share.

The results were summarized as in the following Table 1 and Figure 1, hydraulic and MRL drive elevators are compared with each other with respect to various design constraints in low rise buildings. Total assessment mark of 3 is divided among the two elevator systems for each and every design constraint and the percentage marks for safety, cost, other and total points are shown in a graph. The points awarded for different conditions may vary for among assessors but the general trend is very unlikely to change.

Tetlow [2] states that apart from their advantages in performance over conventional drives, MRL drives also offer many design advantages. MRL drives provide major space savings which is especially important in high rise buildings. The drive can be mounted on overhead beams or on deflector beams.MRL increases the design freedom for architects and engineers, however MRL has several design considerations which differ from those for conventional drives. Interior cab design is governed by limitations on cab weight because MRL machines are smaller than traditional traction models; permissible cab weight is less than with traditional traction machines. Different MRL drive locations have differing ventilation needs. Placement of drive affects the hoist-way mounting the machine on the guide rails transferring weight down to the pit floor, suspending the machine from one or more beams tied into the building in the overhead area impacts structural calculations.

The author summarises the advantages of MRL elevators as

- The costs of MRL installation in terms of both contractor time and materials are less than those associated with traditional elevators for the following reasons:

1. MRL installations require fewer construction materials and less work time: No well holes to be drilled; no pits to be waterproofed; no requirement for a structural machine- room slab.
2. Some models may be installed from the ground up, thus eliminating the need for scaffolding.
3. Some MRL installations do not require a crane to hoist machine or control equipment to the penthouse floor or to hoist a structural machine-room slab as required for traction elevators. This increases safety and lessens the project management challenges inherent in some elevator designs. For instance, hydraulic elevators may require a crane to place the plunger and cylinder in the well hole.

- Installation procedures for MRL technology are highly visible and therefore offer more control over the work environment

However MRL has design considerations which defer from that of a conventional drive housed in a separate machine room, and Tetlow suggests conversion of conventional system to MRL system should take place by gutting of elevator hoist-way and reinstalling required supports and rails.

Asvestopoulos [3] reports Elevator equipped with gearless permanent magnet synchronous motors are the more efficient type of elevator because of the limited energy consumption during travel but have significantly higher power consumption during standby.

The summarised investigation of energy efficiency of elevator is

- Doolaard reported on a comparison of the relative energy consumption of hydraulic elevator, traction elevator and carried out energy measurements for these systems, during a travel of 3 floors in both directions. Results were then normalized by dividing with the mass of the car.
- Schroeder has developed a generalized equation to calculate the annual consumption of energy of elevator per square meter of the building space. Use was made of eqn (1) to calculate the daily consumption of energy, where R is the motor rating in Kilo Watts, SD is the number of starts per day and T is a time factor expressed in seconds and dependent type of drive and

Safety Advantage	Hydraulic	MRL
Installation and maintenance	Driving equipment is safer easier and quicker	Drive assembled in the shaft, passers-by exposed to danger
Relative safety	89% safe	Safety 11%
Cost Advantage	Hydraulic	MRL
Equipment	Cost is least among all types	MRL costs are 30% higher
Installation	Installation costs are lower	Installation costs are higher by 25%
Maintenance	Costs are moderate	Subjected to degrading working environment and replacement is expensive
Energy	Energy costs are higher than MRL drives	MRL can be 80% more energy efficient
Relative savings	63% savings	37% savings
Other advantages	Hydraulic	MRL
Noise	Noise is dampened	Noise is present due to presence of MRL in hoist-way
Speed	Only suitable for low speeds	Suitable for high speed applications
Ride comfort	Similar to that of MRL	Similar to that of hydraulic
Car space	Larger car can fit in same space	Car size is limited by counterweight space
Relative advantages	Other advantages 53%	Other advantages 47%
Total Relative advantages and value	65%	35%

Table 1: Summarization of results in [1].

number of floors travelled. E=R×SD×T/3600…. (1)

- In the study, 33 elevators of different types were studied and analysed. This study separated the drive consumption and the standby consumption of energy. The most important finding of this report was that standby consumption of elevator sometimes is the 80% of the total consumption of energy. The percentage of standby consumption for a type of elevator drive increases, as the daily usage gets lower. This was a matter of concern in low residential buildings with low traffic conditions.

Methodology

The methodology for energy measurements of elevator defines reference trip as follows:

1. Reference begins trip with open elevator door
2. Elevator doors are closed
3. Travel in a particular direction using the full height
4. Opening and closing of the elevator door
5. Travel in opposite direction using the full height.

Observations made: please follow Tables 2 and 3.

The results were summarised as follows:

- Traction elevators with counter weights consume less energy than conventional hydraulic elevators during all travel.
- It is obvious from Table 4 that during travel a MRL elevator consumes less energy than other types. The use of the permanent magnet technology in place of Gearbox leads to reduced losses and increases the efficiency of MRL elevator.
- To attach balancing weight in hydraulic elevator can improve the energy efficiency of the elevator
- The High standby consumption has a large effect on the total consumption of energy of an elevator, especially in low traffic applications.
- Though elevator systems utilize a very small fraction of the total energy consumption in a building, the total energy consumption of the many millions of elevator is a matter of significance. Energy efficiency of elevator is a major challenge for elevator industry. Manufacturers are working on improving energy efficiency.

Elevator	Hydraulic	Geared traction	Traction MRL
Nominal load in KG	375	300	630
Nominal speed in m/s	.5	.6	1
Travel in m	3.47	12.16	3
Stops	2	4	2
Motor rating in KW	6	3.5	4.6

Table 2: Specification of measured life [3].

Elevator	Hydraulic	Geared Traction	Traction MRL
Travel energy consumption in W-hr	18.5	24	9.7
Standby Consumption in W	37	25	85

Table 3: Overview of results [3].

Elevator	Hydraulic	Geared Traction	Traction MRL
Specific energy consumption in mW/Kgm	7.1	3.28	5.02

Table 4: Results after normalization [3].

Sachs [4] reports that an elevator consumes 5% of total building electrical supply for a low to medium rise building. Elevator consumption also includes consumption for HVAC, lighting and other auxiliary services.

The methodology followed was

1. Energy calculations based on first principle
2. Direct measurement of energy use under varying conditions and parameters
3. Simulations based on first principles, engineering data, and traffic models

The results of the study were

- Elevators are engineered systems rather than manufactured products and are tailored or designed to each installation. Reduction in elevator energy consumption if included as a design parameter ensures that the elevator is designed for maximum efficiency
- MRL drives with regenerative braking give the best performance, regenerative braking converts energy dissipated as heat during braking back into the system as electric energy and are more energy efficient
- Using advanced control systems or software which utilize algorithms to carry out proactive actions such as relocation of all elevators in a lobby to the ground floor in the morning when maximum people enter the building can help save 5% more energy in all drive types
- Lighting tax on energy can be reduced by using LED lighting and analog panels instead of haptic panels,use of LED also reduces elevator cooling load by a small amount
- Utilising various methods in conjunction can yield an energy saving of 30–35% within elevator classes.

Thus it becomes critically important to phase out less efficient drives for MRL or hydraulic drives. The savings in power consumption alone justify the added cost of redesign and the cost of MRL refit.

Overall consensus obtained from literature review is that though MRL drives provide better performance and energy efficiency they have higher inspection and maintenance costs.

Improvements in present MRL configuration

According to Andrew and Kaczmarczyk [5] the guiding system defines the datum of the spatial relationship between the elevator and the building which it serves, ensuring that the elevator car and counterweight follow an accurately defined path through the building with appropriate clearance from equipment associated with the elevator operation(e.g. landing entrances). In consequence of its function in maintaining the car in a pre-defined path, the guide rail system will impose forces, particularly lateral forces, on the elevator car via the guide shoes. Although, as implied above, these forces will be relatively small in normal operation, the quality of the ride experienced by passengers is directly related to the quality of the alignment and straightness of the guide rail system. During safety gear operation in particular, the loadings due to the deceleration of the car, and its subsequent support after stopping, are transmitted to the foundation via the guide rails which, in consequence, are subjected to significant buckling forces.

Gibson [6] guide rail mounted MRL causes an eccentric hauling of the car; it is prevented from tilting by the guide shoes or rollers pressing on the rails. The rail acts as a beam supported by the brackets and it must have sufficient strength to carry these forces and sufficient stiffness to keep front edge of the platform level with the landing as loads enter or leave the car. This forces the safety and stabilization component to act as a load carrying component. The MRL drive can be supported on a hoist-way spanning beam configuration to eliminate these drawbacks and provide for easier access to drive for maintenance and inspection.

Advantages of a hoist-way spanning I beam as MRL support as opposed to a guide rail spanning beam are:

- Elimination of eccentric hauling, superior positioning of MRL sheave
- Controller Cabinet may be located in shaft access way decreasing distance between controller and drive
- Ease of inspection and maintenance increases, relative safety increases.

For design of hoist-way spanning MRL Drive support Stephen [7] states Macaulay's method is a favored method of beam investigation within many 'mechanics of solids' modules. This method is a first exposure to generalized functions (e.g. Dirac delta, step, and ramp), with meaning given over to the bracket notation, typically of the form [x-a] n; if the argument within the bracket is negative, that is, if $x<a$, the term is ignored, while if positive, that is, if $x>a$, it is treated normally. These terms arise when calculating the internal bending moment within a beam structure produced by uniformly distributed loading (UDL) when there are n=2, concentrated (or point) force loads when n=1, and point moments when n=0. The load is located at x=a. Having so derived an expression for the bending moment which, using this notation is valid at any location along the beam, the moment–curvature relationship for the (limited-slope) Euler–Bernoulli model is: $M= \pm EI\, d^2v/dx^2$

Where the positive or negative sign depends upon the sign convention employed. This allows calculation of the transverse deflection, v(x), by integrating relatively simple functions twice with respect to the axial coordinate, x. In practice, the integration is performed with respect to the argument of the bracket, rather than x, in order to keep the bracket and its meaning intact. For example, x integrates as $x^2/2$ in the normal way, but [x-b] integrates as $[x-b]^2/2$. Treated normally, $\int(x-b)dx=x^2/2-ax+C_1$, where C_1 is a constant, whereas if integrated with respect to the argument, $\int[x-a]\ dx=[x-b]^2/2+C_2$, where C_2 is also a constant. The difference lies in the value of the two constants of integration, the latter expression having the additional constant term $a^2/2$; this difference is resolved so long as the constants are evaluated with the meaning of the brackets taken into account as per Macaulay.

Further according to INSDAG [8] for beam design the elastic critical moment, M_{cr}, is applicable to a beam of I section which is simply supported at ends. In practical situations, support conditions, beam cross section, loading etc. vary from this case. Deflection is calculated assuming a simply supported beam with no consideration given to actual beam support lengths which are only taken into account in the practical stage to check for beam failures. The lateral restraint provided by the simply supported conditions assumed in the base case is the lowest and therefore M_{cr}, is the lowest. It is possible, using other restraint conditions, to obtain higher values of M_{cr}, for the same structural section, which would result in better utilization of the section and thus saving weight of material. Lateral buckling involves three kinds of deformations, lateral bending, twisting and warping, hence it is feasible to think of various types of end conditions. But, the supports should either completely prevent or offer no resistance to each type of deformation. The effect of various support conditions is taken into account by way of a parameter called effective length. The concept of effective length involves the various types of support conditions. For a beam with simply supported end conditions and no intermediate lateral restraint, the effective length is equal to the actual length between the supports. When a greater amount of lateral and torsional restraints is provided at supports, the effective length is less than the actual length and alternatively, the length becomes more when there is less restraint. The effective length factor would indirectly account for the increased lateral and torsional rigidities provided by the restraints.

If it is found that the web fails in buckling or bearing, it is not always necessary to select another section; larger supports can be designed, or load carrying stiffeners can be locally welded between the flanges and the web. Stiffeners are checked for buckling and bearing in accordance to structural design practices. Web bearing illustrates how concentrated loads are transmitted through the flange/web connection in the span, and at supports when the distance to the end of the member from the end of the stiff bearing is zero.

The bearing resistance is given by

$P_{bw}=(b1+nk) \times t \times p_{yw}$

Where b1 is the stiff bearing length

n=5 except at the end of a member

$n=2+0.6be/k \leq 5$ at the end of the member

Where b1 is the distance to the end of the member from the end of the stiff bearing.

k=(T+r) for rolled I- or H-sections T is the thickness of the flange t is the web thickness.

p_{yw} is the design strength of the web.

The Beam deflections obtained may be verified by carrying out FEM analysis in a FEA tool like Ansys. However to obtain converging and accurate results there has to be very accurate representation of real world dimensions, operating conditions and boundary conditions. The element type chosen for analysis also affects the results obtained.

Gargi Majumder [9] studied the maximum deflection and stress analysis of a simply supported beam under different types of loading. The theoretical calculations were done by using the general Euler-Bernoulli's beam equation. The computational analysis was done on ANSYS software. Comparing the numerical results to those obtained from ANSYS, showed excellent accuracy of the theoretical calculations. It was noted that in case of deflection the Element type. TET8 Node element gave a closer value in all types of loading than the Element type. BRICK 8 Node element. This inference is exactly opposite in case of stress analysis.

Impact of new designs on inspection and maintenance

While MRL technology has established itself as the superior choice for high rise applications, residential buildings often find MRL inspection and maintenance costs to be prohibitive. Economy in Inspection and maintenance could remove a major drawback of MRL elevators and allow more residential buildings to move from traction elevators to the more efficient MRL elevators.

Chew [10] reports in spite of regular and stringent inspections according to elevator maintenance laws defects are prevalent. From analysis, a defect was observed to have adverse effect on (1) economy, (2) system performance; and (3) safety and comfort. These factors determine the level of seriousness of a defect and were considered to establish the significance of a defect. A frequent defect may have insignificant effect, but a very serious defect may occur rarely.

The three major impacts were defined as:

- Economic loss: considerable financial damages sustained as a result of the defect, e.g. call back if users are caught in a stalled car due to deactivated safety switches or faulty circuits.
- System performance loss: here the system performs significantly below normal operating efficiency due to the defect, e.g. repeated opening and closing of car door.
- Safety and comfort loss: affected safety of the users and maintenance personnel as a result of the defect, e.g. opening of fire elevator car door in fire floor if the lobby smoke detector is faulty.

It was established that among many defects in vertical transport system, most of the defects can be prevented by considering three major maintainability criteria, namely, design and specification, construction or installation, and inspection and maintenance (I and M). It was found that among 28 significant defects, 12 were design related, 10 were due to faulty installation or poor construction quality and inadequate I and M practises were responsible for 19 defects. The maintenance quality was largely subjective with regard to cleanliness and lubrication it was established that the most important contributing factors for maintainability is good maintenance, next comes good design and material specification, followed by workmanship during construction or installation. This report highlights the importance of maintenance and inspection for MRL drives. New configurations of MRL drive which house it on a hoist-way spanning structure at top or bottom of shaft make inspection and maintenance easy and reduce costs, thereby reducing costs over the elevators lifetime.

Ishikawa [11] re affirms the importance of economy in inspection practices. Traditional inspection approach was to carry out inspection at the end of manufacturing or assembly process Ishikawa criticizes this approach as it does not promote and process improvement and requires an average of 15% inspectors to line workers. Citing inspection as being too little too late too ineffective Ishikawa postulates problem prevention by carrying out root cause analysis instead of depending on inspection alone to fix errors before they are committed again.

Cliff Matthews [12] states in order to implement an effective QC program, the company decides which specific standards the product or service must meet. Then the extent of QC actions must be determined .Real-world data may be collected and the results and corrective action decided upon and. If too many unit failures or instances of poor service occur, a plan must be devised to improve the production or service process and then that plan must be put into action. Finally, the QC process must be ongoing to ensure that remedial efforts, if required, have produced satisfactory results and to immediately detect recurrences or new instances of trouble. A well-structured Designer Quality Control Plan helps to ensure that designs are economical, constructible, maintainable and appropriate for their locations and surroundings.

The steps suggested are

1. Inculcate good design principles
2. Identify design inadequacies
3. Cost analysis/Value engineering

Use of MRL drives housed in the shaftway in accessible locations satisfies all three of the steps. Use of MRL drive in particular increases energy efficiency of the system whereas use of hoist-way spanning configuration for MRL drive support targets and eliminates design inadequacies of earlier iterations of elevator drive support.

Conclusion

Machine Room Less drives represent current pinnacle of elevator drive technology and have made other traction drives obsolete. MRL drives offer best operating parameters including costs, energy efficiency, ride quality. When compared to other types of drives for high rise applications and are being preferred to hydraulic drives in low rise applications. However MRL drives currently in use have few disadvantages including less seismic safety, eccentric haulage of cabin, difficulty and increased costs of inspection and maintenance. Most of these disadvantages occur due to older method of Supporting MRL drives on a Beam spanning the Guide rails. Use of alternate configurations with the drive housed in the hoist way at top or bottom locations (use of pit floor may be made when moving from hydraulic to traction drives) eliminates majority of disadvantages associated with MRL drives. Lower costs of inspection and maintenance over the elevator lifetime will also encourage widespread use of the highly efficient MRL drives.

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