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Modeling the energy consumption of a lift

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ABSTRACT

A semi-rigorous and generalized model has been developed to determine the electrical energy (Watt-hour) consumed by the motor of a typical lift in each step of an upward or a downward travel cycle. The model has been validated comparing its output with the actual readings taken from an energy meter (installed at the terminal of the motor) for several cycles of the traffic according to the existing route map for a real-life lift. The developed model can be used as a decision support tool by the energy managers of high rise buildings to revise the route map of a group of lifts time to time depending upon the needs. With the model they can simulate intended variations in the floor and traffic plans and compare their impacts upon the energy consumption. As an example the developed model has been demonstrated for the system of three lifts located in the 20 storied main building of BRAC University.

1. Introduction

With growing urbanization the land is becoming scarce in large metropolitan and densely populated cities so that high rise buildings are booming in all the sectors i.e. residential, commercial and institutional. An important service in these buildings is the elevators or lifts that share about 4% [1] of the overall energy consumed by the buildings. So the importance [2] of reducing energy consumption by lifts can hardly be exaggerated.

For enhancing the energy efficiency of a lift the works [1–8] focused on retrofit i.e. upgrading the technology or system renovation such as rewinding the motor, replacement of the existing motor by an energy efficient one, introducing electronic drive system for variable speed, use of super capacitors, control of motor's magnetizing and stator current, etc. But retrofit is an expensive way for reducing the energy consumption of an already installed lift system. On the other hand, a good deal of research has been done on call management and reducing users' waiting time [9–19] or reducing energy consumption [20–23] for a group of lifts through scheduling them on-line using various algorithms. In those works it was proposed that the lifts would be assigned to serve passengers analyzing the calls from different floors in any interval of time such that waiting time or energy consumption is reduced. However, such on-line scheduling whether for reducing waiting time or saving energy would result in confusion among users as how to queue up and which lifts go where. The choice of lift by the consumers would then be not intuitive rather need to be learned. Furthermore, the algorithms used in those works were computationally involved and would require very fast processors and special sensors to capture on-line information on the traffic as input. Obviously implementations of the reported works [1–23] require substantial investment and extra maintenance of the customized gadgets installed. The works [24,25] characterized the energy consumption by a particular group of escalators through regression analysis of the observed number of users and corresponding power intake over a period rather than modeling the dynamics of an escalator's components. Moreover, the way an escalators operates (e.g. moves continuously and transports passengers just in one direction either up or down and is dedicated only between two consecutive floors) and the way it is used by the passengers (e.g. a passenger can walk on the moving escalator independently of others for quick disembarkation) make its modeling different from that of a lift.

It should be noted that even if a lift is retrofitted still there is scope for further enhancement of the energy efficiency by evolving energy saving route maps with acceptable waiting time. For doing this in a simpler way a generalized model for determining the energy consumption of a lift needs to be developed. It appears that this is yet to be reported in the literature.

The energy consumption of a lift depends mainly upon the electrical energy spent by its motor for each movement of the lift between two stoppages. In the work [26] a model has been presented to determine the maximum size of the motor at the design stage of a new lift. In this paper that model [26] has been modified to develop a model to compute the electrical energy consumed by a given sized motor of an already installed lift for each step of its upward or downward travel cycle. The acceleration, run, deceleration and leveling stages of a lift in its movement between

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List of principal symbols

NP_max	number of maximum passengers allowed in a lift
MPP	average mass (kg) per passenger
M_lift	mass of the lift cabin in kg
M_cw	mass of the counterweight in kg
M_cable	mass of the total number of cables (ropes) for a lift
L_cable	length of each cable in meter (m)
M_u_cable	mass per unit length (kg/m) of each cable
N_cables	number of cables in a lift
M_drum	mass of lift's drum in kg
J_m	inertia of the motor in kg m^2
J	the total inertia of the lift in kg m^2
r	outer radius of the drum (m)
g	acceleration due to gravity
GR	gear ratio
P_{ospec}	specified rated power output of the motor in kW
v	linear velocity (m/s) of the lift
ω_d	angular velocity of drum in rad/s
ω_m	angular velocity of motor in rad/s
a	linear acceleration of lift (m/s^2)
a_drum	acceleration of drum (rad/s^2)
t_acc	time (s) for which the lift moves with an acceleration 'a'
t_dec	time (s) for which the lift moves with a deceleration 'a'
$t\_run(k,i)$	time (s) for which the lift runs at a uniform velocity 'v' in the ith step of kth cycle
$NP(i)$	number of passengers at the ith stoppage from where the ith step begins
$stop(i)$	floor number at the ith stoppage
h_avg	typical floor height
ah_gnd	difference between typical floor height and ground floor height
$T\_acc(k,i)$	acceleration torque (N m) in ith step of kth cycle
$T\_load(k,i)$	load torque (N m) in ith step of kth cycle
η	efficiency of motor
$E_{e}\_(k,i)$	electrical energy (Watt-hour) consumed by the motor in the ith step of kth cycle

two stoppages have been considered in a simplified way. The developed model has been validated comparing the energy computed by it with the actual readings taken from the energy meter installed at the terminal of a real-life lift motor for several cycles of the traffic according to the existing route map for the lift. From the model the factors influencing energy consumption by the lift motor in a cycle are identified and their relative contributions assessed. Considering these factors and any specific requirements of a building such as privileged access to a lift for certain floors, various route maps and traffic patterns with acceptable waiting time can be simulated using the developed model and their energy consumptions compared. Eventually from these the best route plan consuming the least energy for a group of lifts can be decided which will result in fixed floor destinations for each lift so that users know which lift goes where.

The application of the developed model has been illustrated for an example system comprised by the three lifts located in the 20 storied main building of BRAC University, a leading private university in Bangladesh attended by nearly 4000 students.

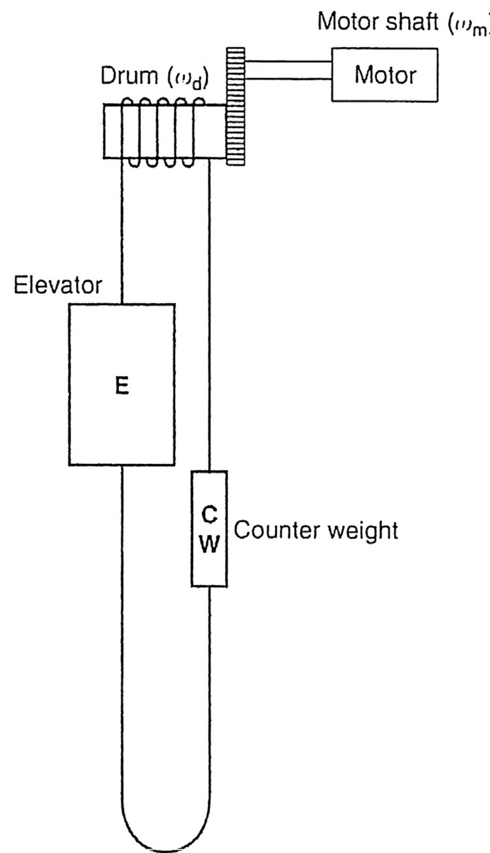

Fig. 1. A lift system (the gear is not shown explicitly).

2. Review of the model used to design maximum size of motor

The procedures presented in [26] to determine at the design stage the maximum size for the motor of a lift system represented in Fig. 1 have been systematically formulated by the present work and shown below.

The maximum steady state torque on the motor, T_{FL} (in N m) corresponding to the maximum number of passengers allowed is computed using Eq. (1).

$$T_{FL} = (NP\_max \times MPP + M\_lift - M\_cw) \times g \times \frac{r}{GR} \quad (1)$$

The shaft power (horse power i.e. hp) required of the motor just to provide the steady state torque T_{FL} is

$$P_{FL} = T_{FL} \times \frac{\omega_m}{746} = T_{FL} \times \left(\frac{v}{r}\right) \times \frac{GR}{746} \quad (2)$$

where motor angular velocity $\omega_{\rm m}$ is equal to drum angular velocity $\omega_{\rm d}$ (=v/r) multiplied by gear ratio.

The motor inertia J_m in kg m^2 corresponding to P_{FL} (in hp) is estimated as

$$J_m \approx \frac{P_{FL}}{100} \quad (3)$$

The total system inertia J is then sum of the estimated motor inertia, load inertia (i.e. inertia by total mass that produces force tangential to the drum) and the drum inertia referred to motor shaft. Eq. (4) shows this.