Lift Energy Efficiency Standards and Motor Efficiency

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Keywords: ISO25745-2, energy consumption

Abstract. The ISO25745-2 standard provides a systematic frame work for evaluating and ranking the energy consumption of various lift systems. The standard approximately models the drive system (motor and inverter) with a constant efficiency where the power lost is directly proportional to the shaft power out. The efficiency of the real system is, of course, dependent on the operating speed and the load in the car. This paper explores the effect of the constant efficiency assumption by comparing the calculated energy consumption of the ISO model to a more complete model that includes the dependence on speed and load. The magnitude of the deviation depends partially on the type of equipment used; permanent magnet motors can be reasonably approximated as constant efficiency, but efficiency of induction motors is highly dependent on the torque required for a given application. The paper also quantifies the customer value by relating the energy consumption calculations to operating cost.

1 INTRODUCTION

Energy efficiency and sustainability continue to become increasing important to government, industry, and the general public. The lift industry is no exception. In recent years, ISO has developed standards to evaluate and rank lift system energy consumption. The intent is to give our customers a simple and consistent way to evaluate energy consumption of the various product options. Precisely calculating any real lift system's energy consumption is, however, complex. For a standard to be useful, though, it is necessary to make many simplifying approximations. This paper investigates the effects of how the standards simplify motor losses.

2 BACKGROUND

The ISO25745-2 standard estimates the lift power consumption using a fairly simple method which is reviewed here. At a high level, energy consumption is separated into two components: non-running energy and running energy. The non-running energy component is based on measurements of the lift at idle and, if applicable, in reduced power standby modes.

The running energy component is also based on measurements. The energy consumption of the lift is measured for two round trip runs. The first run, called the reference cycle, is from the bottom landing to the top landing and then back to the bottom landing with an empty car. The second run, called the short cycle, is also with empty car and just long enough for the car to reach its full speed. Based on these two data points, the standard models the general running energy consumption with one fixed term for starting and stopping and a second term linearly proportional to the load in the car and the distance traveled. To estimate the running energy consumption for a given lift, the standard describes a way to use the model by applying estimates for average travel distance and average load in car. Implicit in this model is the assumption that the motor energy consumption is directly proportional to its output energy, or, in other words, that the motor efficiency is constant.

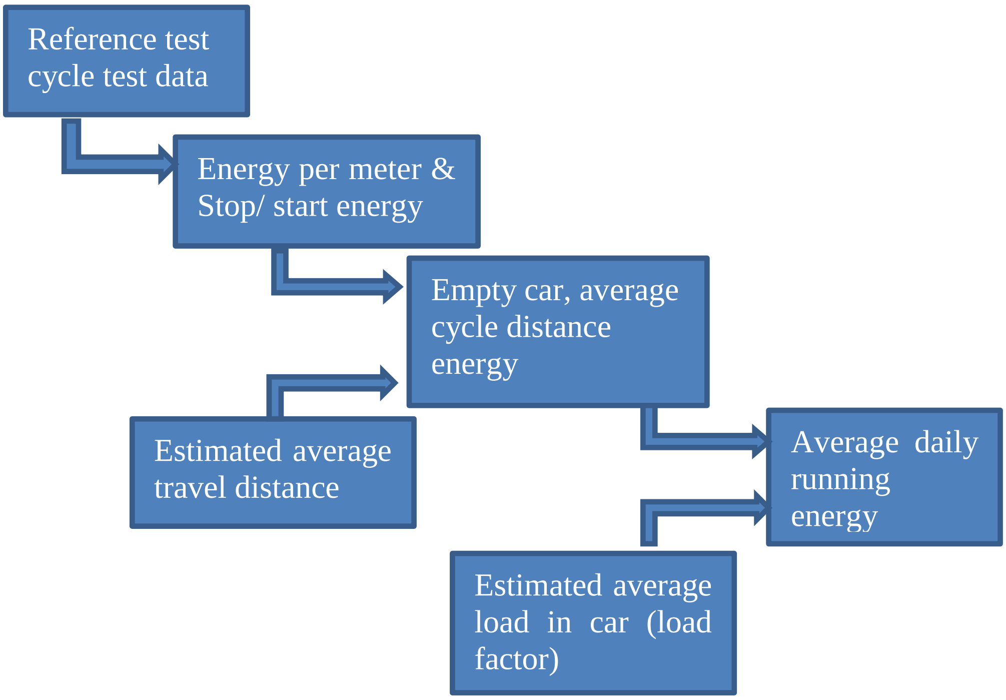

Figure 1 ISO25745-2 running energy consumption calculation flow diagram

ISO25745-2 is written in terms of energy consumption. For a given run, some portion of the energy used is useful work, and the remaining portion is losses from various sources. This paper distinguishes between general energy consumption and losses and focuses specifically on the energy losses.

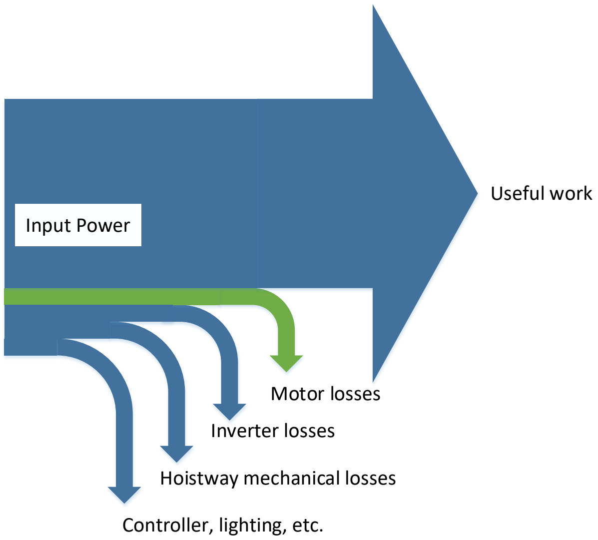

Figure 2 Energy flow diagram

To better understand the effects of the constant efficiency assumption implicit in the ISO method, two different methods to estimate motor energy losses are reviewed. The simplest method is to characterize motor losses in terms a motor's efficiency where efficiency, η, is simply

$$\eta \equiv \frac{P_{out}}{P_{in}} = \frac{P_{out}}{P_{out}+P_{loss}}. \qquad (1)$$

In this case, the user simply calculates the required mechanical power out and uses the motor's nameplate efficiency to compute losses as

$$P_{loss} = P_{out} \cdot \left(\frac{1}{\eta} - 1\right). \qquad (2)$$

This method is simple and does not require specialized knowledge or detailed information about the motor.

A motor's efficiency, however, is not a single, fixed value and depends on its operating point, or the torque and speed at which the motor is operating. For example, a motor may be 90% efficient when running at its rated torque, but only 70% efficient when running at 25% of its rated torque. A motor's losses can more accurately be expressed as the sum of copper losses and iron losses. Copper losses are the resistive losses caused as current passes through the motor winding and can be computed as

$$P_{cu} = 3\left(I_{ph}\right)^2 R_{ph}. \qquad (3)$$

Where

I_{ph} ≡ motor phase current, and

R_{ph} ≡ motor phase resistance.

In the case of the induction motor, the current can be decomposed into two orthogonal components: torque current, I_t, and magnetizing current, I_m as

$$I_{ph} = \sqrt{{I_t}^2 + {I_m}^2}. \qquad (4)$$

Further, the torque current can be approximated as

$$I_t = \frac{\mathrm{T}}{k_T}. \qquad (5)$$

Where

T ≡ motor torque, and

k_T ≡ motor torque constant (normally in Nm/A).

Therefore, copper losses are computed as

$$P_{cu} = 3\left(\left(\frac{T}{k_T}\right)^2 + {I_m}^2\right) R_{ph}. \qquad (6)$$

Iron losses are a combination of eddy current and hysteresis losses that are caused by the changing magnetic field in the motor's armature laminations. Iron losses are approximately proportional to motor speed raised to the power of 1.5. (Note: the actual exponent may vary between 1.5 -2 based on the details of a given motor.) This is expressed as:

$$P_{fe} = \left(\frac{\omega}{\omega_{rated}}\right)^{3/2} P_{fe,rated}. \tag{7}$$

Where

$P_{fe,rated} \equiv$ iron losses at rated speed

$\omega_{rated} \equiv$ rated speed.

Total motor losses are simply approximated as the sum of copper losses and iron losses. This method requires more information about the motor than the efficiency method but returns a more accurate result. The table below compares the information required by the two methods.

Table 1 Loss model input parameters

	Efficiency Model	**Cu, Fe Loss Model**
Operating Point	P	T, ω
Motor Parameters	η	R_{ph}, k_T, I_m, $P_{fe,\ rated}$, ω_{rated}

3 ANALYSIS & METHODOLOGY

Given a set of basic lift parameters, usage conditions, and motor parameters, the average motor losses may be calculated. The analysis procedure is described here.

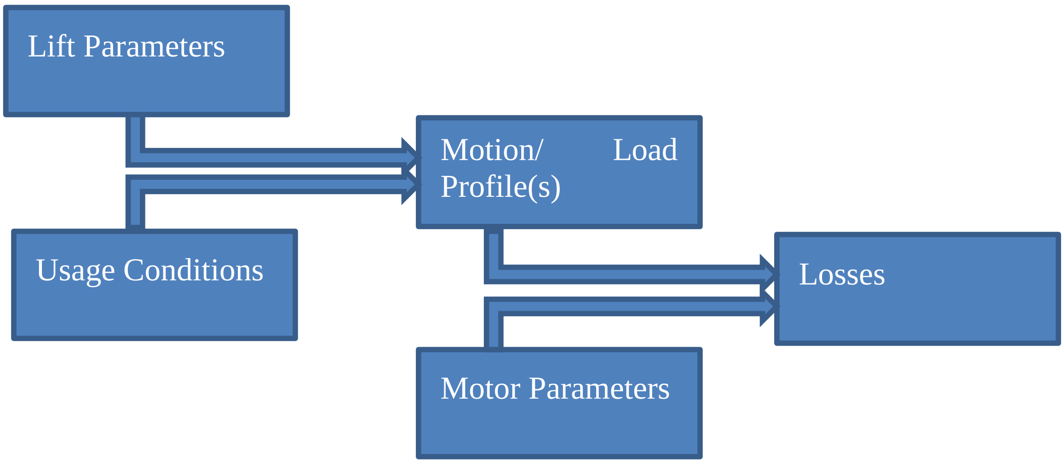

Figure 3 Loss model flow diagram

A sample low-rise lift system is considered. The basic lift parameters are shown below.

Table 2 Lift parameters of sample lift

Duty	630kg
Speed	1.0m/s
Rise	20m
Acceleration	0.8m/s²
Effective System Inertia	2kg-m²
Sheave Dia.	80mm
Starts per Hour	60

From these parameters, time histories are calculated for velocity, acceleration, motor torque, and motor power. The method for calculating these profiles well described in [2], [3].

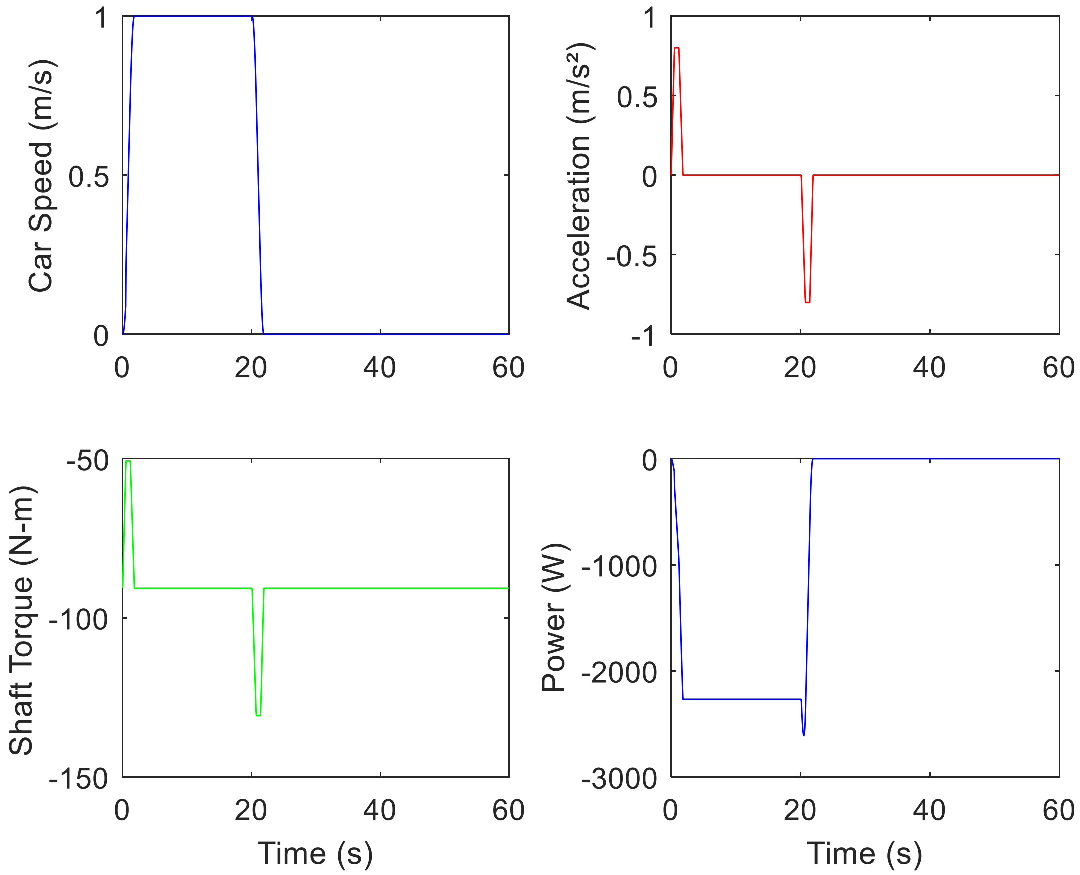

Figure 4 Sample lift run profile

Of course, the velocity and torque profiles depend on the specific lift usage parameters, including the load in the car and the travel distance. To approximate real lift usage, a range of travel distances and loading conditions are considered. Load and travel distance distributions are considered as shown below.

Table 3 Assumed load and run distance distributions

Load in car (% duty)	Percent of runs
0%	50%
25%	30%
50%	10%
75%	10%
100%	0%

Run distance	Percent of runs
3m	16%
6m	17%
10m	17%
13m	17%
16m	17%
20m	16%

Two example motors are considered and shown below. These examples are fictitious, but typical of real motors in this size range.

Table 4 Sample motor parameters

	PM motor	Induction motor
Rated torque	125N-m	125N-m
Rated speed	477rpm	477rpm
Rated current	15A	15A
Magnetizing current	--	8A
Phase Resistance	1.2ohm	1.2ohm
Iron losses @ rated speed	200W	200W
Rated efficiency	86.1%	83.4%

Motor loss can be computed as a function of time based on the efficiency and copper/ iron loss. The loss vs. time curves are computed using (2) for the efficiency method and as the sum of (6) and (7) for the copper/ iron loss method. Then, the average loss per run can be computed directly from each time history.

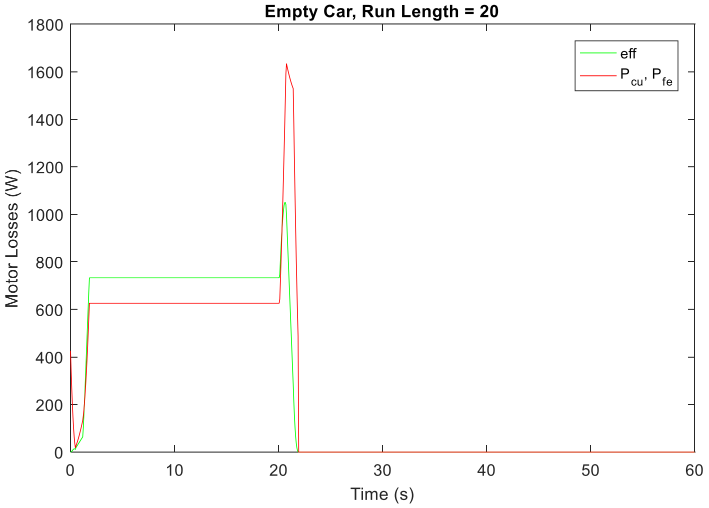

Figure 5 Motor loss over time for two models

The average loss per run is computed for each combination of run distance and load in car shown in Table 3, and the resultant average loss per run is computed as a weighted average as

$$P_{loss\_avg} = \sum_j n_s \cdot \left(\sum_i n_{l,i} \cdot P_{loss}(l_i, s_j)\right). \quad (8)$$

Where

$P_{loss\_avg} \equiv$ average loss per run considering all operating point,

$P_{loss} \equiv$ average loss per run for a single operating point,

$l \equiv$ per unit load in car,

$n_l \equiv$ fraction of runs for a given load in car,

$s \equiv$ travel distance, and

$n_s \equiv$ fraction of runs for a given travel distance.

4 RESULTS

Based on the methods above, average losses are computed using both the efficiency model and the copper/ iron loss model. This is done for the PM motor and the induction motor.

4.1. PM Motor Comparison

As shown below, the efficiency method predicts roughly 6% lower losses than the copper/ iron loss method. For most purposes, this discrepancy is likely acceptable and the efficiency model may be used as a reasonable approximation.

Table 5 Loss model results for PM motor

	Average Motor Loss per Run [W-hr]

Efficiency Method	1.7
Copper + Iron Loss Method	1.8

4.2. IM Motor Comparison

For the induction motor, the efficiency method predicts 19% lower losses than the copper/ iron loss method. This is greater than the difference calculated in the PM motor case, and may be significant.

Consider a case where a customer is deciding between a lift system using a PM motor and a system using an induction motor. Using the efficiency method suggests the difference in energy consumption is small. Using the copper/ iron loss method, however, may lead him to a different conclusion.

Table 6 PM, induction loss model comparison

	Average Motor Loss per Run [W-hr]		**Difference**
	PM	**Induction**	
Efficiency Method	1.7	2.1	19%
Copper + Iron Loss Method	1.8	2.6	31%
Difference	6%	19%	

Notice that the induction motor efficiencies are slightly lower than the PM motor at rated torque. At low loads, they are substantially lower. The magnetizing current is constant, and at low loads the associated resistive losses become dominant. This means that when the lift is close to the balanced condition, the constant efficiency model will significantly under predict the losses.

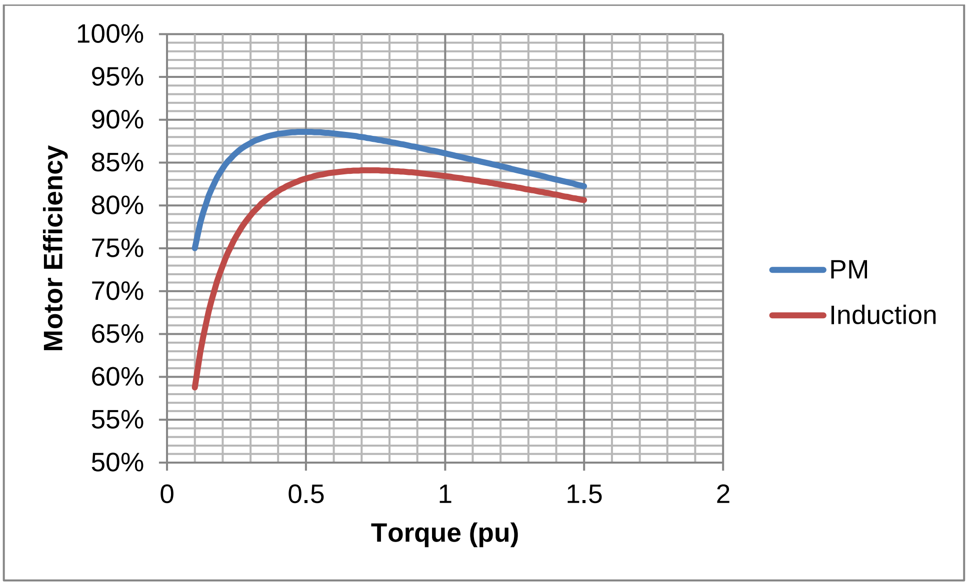

Figure 6 Induction and PM motor efficiencies by operating point

4.3. ROI of increased motor efficiency

It is well accepted that PM motors are more efficient than induction motors. For most customers, it is simply a matter of quantifying these savings against any additional costs. Below is a summary of the calculated savings with the constant efficiency assumption and the savings with the operating point model. In the example case considered, here, the two models result in significantly different conclusions; the efficiency method underestimates the potential savings by roughly 50% as compared to the copper + iron loss method.

Table 7 Five year energy cost savings from PM motor

Efficiency Method	$43.8
Copper + Iron Loss Method	$87.6

*Assuming 300 starts per day, 0.20 $/kW-hr

5 CONCLUSION

The ISO25745-2 standard creates a common language for lift manufacturers and customers about energy consumption and gives customers a simple way to compare products among manufacturers. The case considered in this paper, though fictitious, demonstrates that the standard does have some implicit limits. The standard is, for example, useful for contrasting a geared lift against a gearless lift. The standard may not, however, be as useful for detecting differences in two similar gearless lifts.

The primary goal of this paper is to simply make users of the standard aware of this limitation so that they may avoid misuse. The constant efficiency assumption implicit in the ISO standard will tend to underestimate the differences in energy consumption between PM and induction motors.

Other tools to evaluate energy consumption differences in lift motors are available, but their benefits must be weighed against the relative cost and complexity they introduce. Some options include:

- Creating an optional procedure in the ISO standard that includes at least one additional test case with a non-empty car;
- Creating a standard method for analytically determining power consumption and losses that includes a more complete motor model similar to that described in this paper;
- Characterizing motor (and drive system) power consumption separately from the rest of the lift system.

It is also suggested that further research study this effect beyond the fictitious low-rise application considered in this paper. Specifically, load distribution, traffic distribution, and motor size sensitivity should be investigated.

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