Economically Efficient Green Hydraulic Lifts

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ABSTRACT

The general trend in the lift industry is towards lifts with lower energy requirement. Hydraulic power units with inverters were introduced to decrease energy consumption for heavily used lifts. Since existing solutions are generally more demanding and rather costly these systems have not found enough appeal yet. A compact, simpler and cost-effective solution to compete with advantages of the conventional hydraulic elevator system is necessary to make energy-efficient solutions more attractive.

With the use of an inverter the pump outputs just enough flow for the momentarily targeted speed. When pump leakage increases due to higher load and/or oil temperature, the car speed decreases which results in longer travel time and uncomfortable ride. Therefore, pump flow should be regulated according to the load and oil temperature to assure targeted speeds and good ride-quality.

In this paper, a sensor-less load compensation solution that basically consists of a control valve and an inverter with sophisticated hydraulic software module is introduced to assure targeted speeds under all load conditions. The solution has no sensoric interface between the control valve and the inverter, works with open loop control and also provides an extra energy saving mode. All these advantages not only make the solution an energy efficient one but also an economically-efficient one as well. The paper gives the details of the solution and features implemented in the development of the control valve and the advanced inverter software.

INTRODUCTION

Use of an inverter with the Permanent Magnet Synchronization machine (PMS) has been the most accepted development in the lift industry. This is called as “the new or the latest drive technology”, which reduced operational energy consumption considerably and also enabled engineers to construct Machine Room-Less lifts (MRL). Focusing on the energy consumption issue and using it as a marketing tool, MRL installations have managed to obtain an increasing trend in the market. As a result of that hydraulic lift installations are said to be reduced up to 40% globally.

“The new technology“ has been reflected like it provides always the most energy efficient solution, perfectly suits every installation and energy can be always regenerated and dumped into the grid. However, the mentioned benefits of the existing “new technology” are not remarkable and mostly leads to higher energy consumption when it is used for low-usage lifts [1] where, the investment for the new technology may never be gained back during the life-time of the lift [2]. This is because of the fact that the inverter and its peripheral devices are costly and require energy to be active even when the lift is at stand-by [3].

On the other hand, future developments in drive technology and competition in the market is expected to reduce or eliminate stand-by energy consumption (matrix converters) and lower inverter prices considerably. In this respect, suitable vvvf solutions that are simple, inexpensive, easy to maintain and offer high compatibility will be used widely in low-rise buildings in coming years.

APPLICATION OF INVERTER DRIVE ON HYDRAULIC LIFTS

Hydraulic lifts had been largely utilized in low-rise buildings because of their superior properties such as high reliability, low initial cost, easy and cost effective installation, high ride quality and low servicing cost. In addition, they have the best records in safety and robustness against natural disasters like earthquakes.

Having a more challenging market, hydraulic lift manufacturers have also given the first priority to energy saving factors in their designs. Energy-efficient power units that employ an inverter drive, so called the new-generation power units, have been introduced to the market long ago. However, utilization of the new generation power units has not found sufficient appeal yet. This is because while concentrating on the marketing issue to have the state of the art solutions, advantageous properties of hydraulic lifts have been ignored in many cases. By doing so practical, reliable and low-cost ingredients of hydraulic lift have been left instead, more demanding, impractical and expensive solutions have been introduced.

Having failed to address the main objectives of new-generation power units properly, solutions either became so primitive or rather complicated and costly. In many cases a conventional power unit with the addition of the inverter drive is presented as the state of the art. In fact, simply adding an inverter does not necessarily lead to energy savings [4]. Moreover, employing the inverter without justifying its 95% efficiency would only increase energy bills.

Alternatively there exist more demanding and costly solutions [5], which besides the inverter, need additional components like pressure and temperature sensors, flow meter, encoder, electronic control card etc. In these solutions, the inverter is used mostly both in up and down directions with the help of exclusive inverter software. Application of such systems, no matter how good ride quality they give and how little they vary the oil temperature, are in general away from meeting real market needs; unnecessarily extended pay-off time (beyond the renovation period), difficulty in finding competent technicians and increased servicing needs are some to pronounce.

REQUIREMENTS FROM NEW GENERATION CONTROL VALVES

High usage or low stand-by power: to reduce stand-by energy consumption and obtain maximum benefit.

Low cost: to have reasonably short pay-off period and to meet market expectations. At present, inverter, control valve and sensoric systems keep the price of the new-generation hydraulic solution high. Particularly inverters are having 2 to 4 times higher prices than the conventional control valves. Therefore, a suitable solution should justify the use of an inverter with an inexpensive control valve and a simplified system design.

Minimum number of interfaces/components: to assure simplicity, reliability, easy maintenance, low cost and also to eliminate the need for highly-qualified technical personnel.

High compatibility: to be fitted easily on existing lift controllers and power packs in order to respond renovation needs.

Exclusive software: to assure ease of use, safety, good ride-quality and low energy consumption.

EV4 NEW GENERATION CONTROL VALVE

There can be many ways to engage a control valve with an inverter to obtain a new-generation valve. The most important question is how to satisfy inexpensive and simple solution with good ride quality. Fig. 1(a) shows some new-generation applications. Here, the closed-loop control solution (requires a submersible encoder and interface electronics) with the electronic (requires a flow meter and an electronic card) or mechanical valve increases the cost of the system considerably. Simplicity of the system may be further disturbed with the existence of pressure, proximity or/and temperature sensors. In terms of energy-efficiency and initial investment, application of such systems can only be justified for very high-usage lifts (over 700 cycles/day).

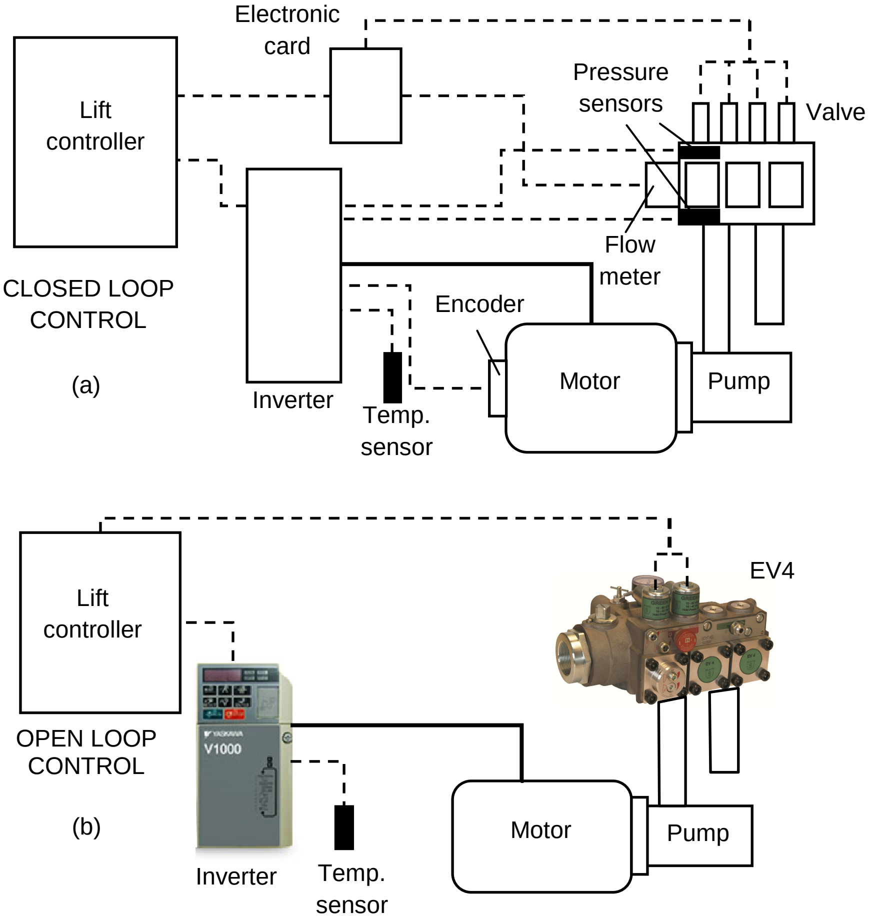

Figure 1. (a) Standard closed loop control solutions (b) EV4 open-loop control solution.

Knowing the market needs and evaluating truly necessary requirements from the new generation power unit, the new-generation control valve, EV4 has been developed, as shown in Fig. 1(b). EV4, which inherently offers the same advantageous properties of electro-mechanical valves, is a simplified version of an electro-mechanical valve. It was designed to employ a V1000 inverter for up travel whereas down travel is managed by the electro-mechanical means. EV4 has no interfaces with its peripheral devices and does not require sensoric for load compensation. Since up travel is controlled by the inverter, up solenoids and adjustments were removed from the valve and by-pass transition stage was cancelled, which simplified both the valve and the system set-up considerably. To lower the initial cost and simplify the system requirements further, open-loop control has been implemented. Thus, the need for a costly submersible encoder was eliminated. The real supremacy of the system comes from the exclusive inverter software, which eases the use of the system and provides excellent travel characteristics. The software was designed to sense the load condition to allow necessary compensation for the motor output. The software is also intelligent enough to modify transition times, when necessary, to assure good ride quality. Moreover, the inverter can be optionally used for the down travel to control down speed and to improve ride-quality without needing any modification on the valve. An inexpensive temperature sensor was also included in the system to account for the effects of oil temperature variation. Optionally, the car may be run either at a constant speed mode, where the lift speed is kept constant, or at an energy saving mode (Maximum speed mode), where the speed of the car is lowered according to the load in the car [6].

APPLICATION OF THE METHOD

The EV4 valve is an electro-mechanical type and it was designed to allow inverter to take control of the complete speed regulation of the up travel. In this way only necessary flow rate is supplied to the valve and no oil is by-passed. As a result, less energy is consumed during up travel, which increases the efficiency of the system and also reduces oil heating. Using the inverter also reduces motor starting current and the size of the electric energy meter.

On the other hand car load and oil temperature influence the leakage of screw pump drastically, which may cause speed and the total travel time of the lift to vary considerably (Fig.2). In some cases, when oil temperature or/and car load is extremely high, speed of the pump during levelling phase may not provide positive flow and lift stands still (zero speed) which is illustrated by the dashed-dotted line in Fig. 2. Therefore, a suitable solution should allow for the compensation of pump leakage by adjusting the speed of the pump.

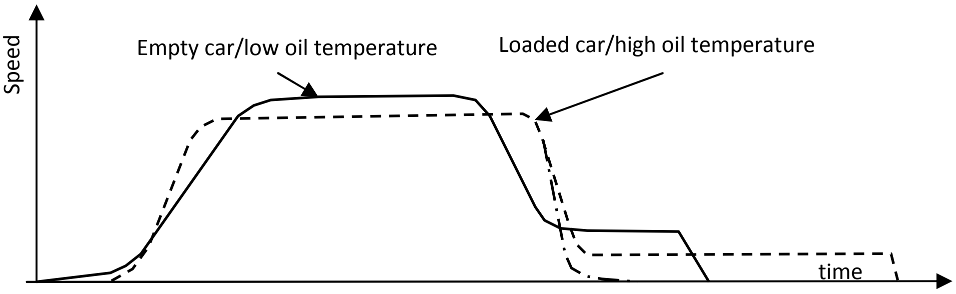

Figure 2. Ride-quality and travel duration variations with car load/oil temperature.

Initial Settings

In order propose a simplified and cost-effective solution V1000 inverter, which also contains computing, memory and monitoring modules, was utilized. At a very initial stage of the set-up process, the user selects the oil type from a menu. As the selection is performed, necessary viscosity and temperature parameters are assigned to the registers.

In the second stage, the user inputs lift data and pump performance data (obtainable from pump manufacturers) according to the working pressure range of the lift. Inverter then reads the current temperature ($Temp_2$) and processes oil and pump performance data to obtain motor speeds (speed frequencies) in Hz for the full, levelling, inspection and secondary full speeds. Additionally, temperature control gain ($Gain_{temp}$) and leakage speed frequencies for empty and loaded car pressures are also calculated. For simplicity these are given parametrically below:-

$$f_k \text{ [Hz]} = f(a_i, Temp_2) \tag{1}$$

$$Gain_{temp} = f(a_i) \tag{2}$$

where, f_k : calculated speed frequencies [Hz], a_i input data (pump performance and oil-type).

The software also allows the user to input these variables manually in case the data is not available or the pump is old and worn.

Car Load and Oil Temperature Compensations

V1000 inverter software was re-designed to include some compensation procedures to sense the car load and regulate the motor speed. The inverter can monitor at least one of the internal inverter parameters such as, output current, torque producing current or internal torque reference, which is mostly used, and also measures constantly the oil temperature by means of a temperature sensor. The monitored parameter is then compared with a pre-set reference value to determine the load condition at recent oil temperature.

To obtain the pre-set reference values and the necessary control gains precisely the inverter software has been armed with a teaching mode option. At “Teaching Mode” a probe (teaching) run is performed with the empty car to capture the reference parameters. This is shown in Fig. 3 where, capturing locations of full and levelling speed torque references, T_{2full} and $T_{2leveling}$ are shown. Knowing T_{2full} , $T_{2leveling}$ and their corresponding speeds, other torque references for secondary full speed ($T_{2second}$) and inspection speed (T_{2ins}) are calculated with interpolation.

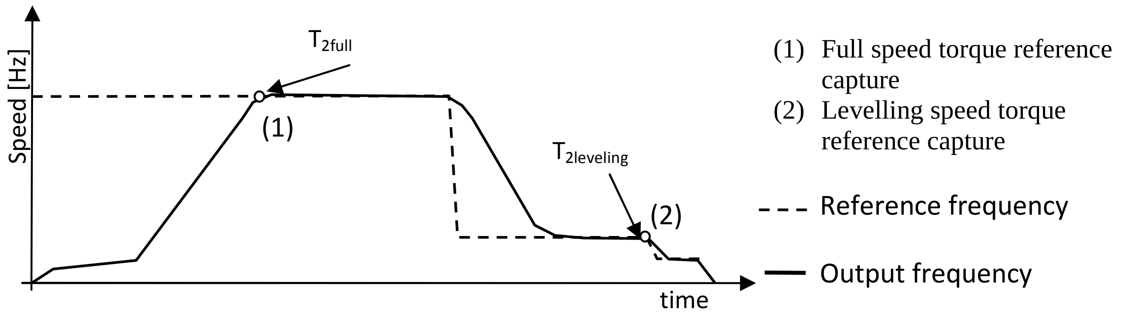

Figure 3. Capturing torque references, T_{2full} and $T_{2leveling}$ during a teach run

In Fig. 4 derivation of lift speed with respect to empty and loaded car speeds is shown. Here, T_1 and T_2 are torque references that are captured at loaded and empty car probe runs respectively. From Fig. 4, speed n_x for a captured torque of T_x may be written as:-

$$n_x = n_2 - \frac{\Delta n_i}{\Delta T_i} * (T_x - T_2)^\gamma \tag{3}$$

where, γ : constant, T_x : captured torque, T_2 : torque reference captured at empty car probe run at a reference temperature $Temp_2$, Δn_i : difference in measured speeds, ΔT_i : difference in captured torque references. Thus, $\frac{x}{n_2}$, which is the amount of speed loss in %, can be simplified as:-

$$\frac{x}{n_2} = \mathrm{Gain}_{torque} * (T_x - T_2)^\gamma \tag{4}$$

Knowing T_2, the lift and pump performance data Gain_{torque} can be calculated.

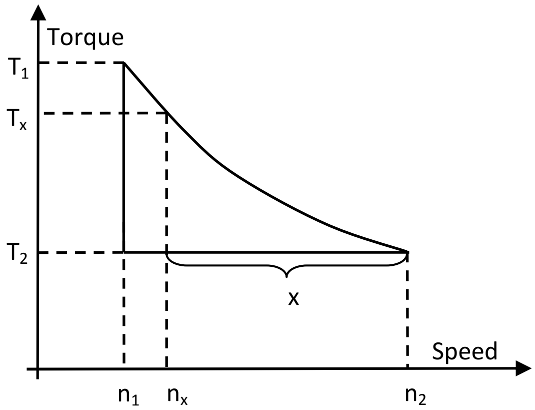

Figure 4. Derivation of lift speed from the reference parameters obtained through the probe runs.

$$\mathrm{Gain}_{\mathrm{torque}} = \mathrm{f}(\Delta \mathrm{n}_{\mathrm{i}}, \Delta \mathrm{T}_{\mathrm{i}}{}^{\gamma}) \tag{5}$$

Thus, new speed frequency can be calculated as:-

$$\mathrm{f}_{\mathrm{new}} = \mathrm{f}_{\mathrm{old}} * \left(1{+}\mathrm{Gain}_{\mathrm{torque}} * (\mathrm{T}_{\mathrm{x}} - \mathrm{T}_2 * \mathrm{I})^{\gamma}\right) \tag{6}$$

$$\mathrm{I} = \mathrm{Gain3} * \mathrm{f}(\mathrm{Temp}_2, \mathrm{Temp}_{\mathrm{x}}) \tag{7}$$

"I" is a special function that accounts for the variation of system resistance to flow as oil temperature varies. Similarly temperature calculation can be derived as below;

$$\mathrm{f}_{\mathrm{new}} = \mathrm{f}_{\mathrm{old}} * \left(1 + \mathrm{Gain}_{\mathrm{temp}} * (\mathrm{Temp}_{\mathrm{x}} - \mathrm{Temp}_2)^{\theta}\right) \tag{8}$$

where, θ : a constant, Temp_x : measured oil temperature, Temp_2 : oil temperature reference.
The resulting equation for both load and oil temperature compensations may be given by:

$$\mathrm{f}_{\mathrm{j_{new}}} = \mathrm{f}_{\mathrm{j}} + \mathrm{f}_{\mathrm{level}} * \left(\ \mathrm{Gain}_{\mathrm{torque}} * (\mathrm{T}_{\mathrm{xj}} - \mathrm{T}_{2\mathrm{j}} * \mathrm{I})^{\gamma} + \mathrm{Gain}_{\mathrm{temp}} * (\mathrm{Temp}_{\mathrm{x}} - \mathrm{Temp}_2)^{\theta}\right) \tag{9}$$

where, j indicates speed frequencies of full, secondary full, inspection or levelling speeds, f_{level} is the speed frequency of levelling speed, T_{2j} and Temp_2 are reference frequencies for load and oil temperature. In operation mode, T_2 and Temp_2 remain unchanged but T_x and Temp_x are measured for each run by the inverter to calculate the speed frequencies under the actual load and oil temperature condition. Speed compensation due to oil temperature variation is applied throughout the travel whereas, that due to car load variation is applied after reading the torque at point 1 in Fig. 3.

Down Speed Compensation
When electro-mechanical valves are used for down travel, speed of the car increases with increasing oil temperature and system pressure (car load). This may result in jerky starts, rapid accelerations and hard decelerations, and jerky stops when working pressure range is large. The total travel time also changes due to varying speed and levelling duration. This is depicted in Fig.5.

Some of the new-generation valves can also be used for down travel. In that, while the pump/motor shaft is rotated in reverse direction by the hydraulic force of the oil column, the inverter controls the shaft rotation to regulate the speed of down travel. Here, the energy generated by the system is burned into a resistor, which prevents hydraulic oil getting heated further. However, such a solution complicates the valve design, increases the system cost and can only be justified with high-usage.

An inexpensive, simpler and easier way of controlling down travel ride-quality is introduced by the V1000 inverter software for low- and mid-usage lifts. In that, to control downward speed variations, controlled upward flow is produced when car load and oil temperature are excessive. During down acceleration, the motor torque (T_{x_down}) is measured and a up-flow ramp is determined to provide smooth acceleration and constant speed. This is shown in Fig. 5 where, the dashed-dotted line shows uncontrolled down travel under loaded car or/and high oil temperature. The compensations optionally can only be applied during acceleration and deceleration stages, which is shown with the dashed line (Energy saving mode), or during the complete travel, which is shown with the solid line (Constant speed mode).

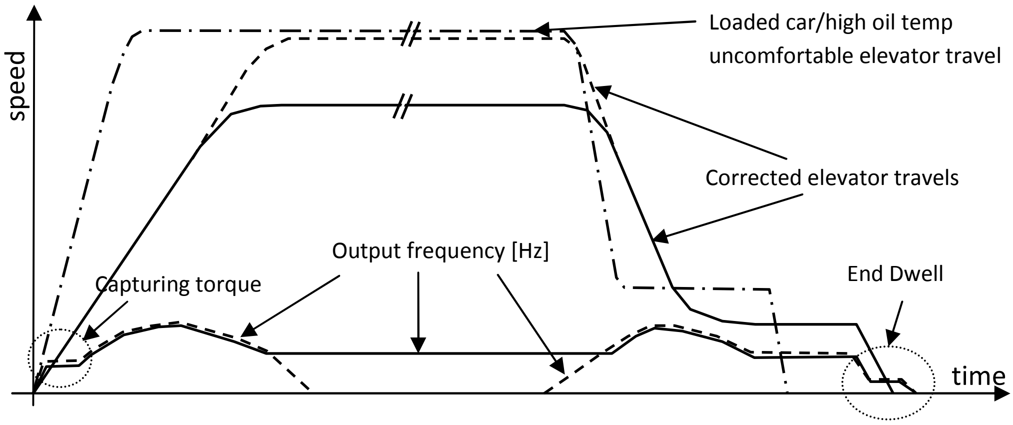

Figure 5. Application of load &oil temperature compensations in down direction.

Travel Modes. At constant speed mode, lift speed is kept constant whereas, at energy saving mode (also called maximum speed mode), speed of the lift is modified with respect to the car load. In that, car load and oil temperature compensations are applied normally for the levelling speed however, the full speed is limited by a pre-set limiting torque value, T_{x_limit}. This is shown in Fig. 6. When the measured torque during the run exceeds the limiting torque, T_{x_limit} (eg. point 1 in Fig.6) then the speed frequency takes the value of output frequency until the end of the full-speed run. This is indicated with point 2 in Fig. 6. In this way maximum allowable motor torque will not be exceeded when the car load is excessive. Conversely, the lift could travel at close to the maximum speed when the car load is low. In energy saving mode the deceleration path/time is also recalculated for each run to assure fix levelling duration. The energy saving mode may allow lower motor sizes to be employed and may lead to lower energy consumption.

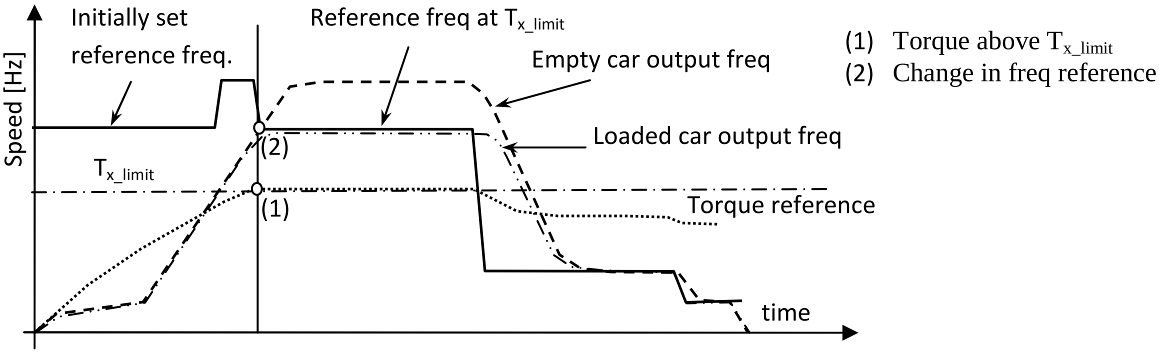

Figure 6. Load and temperature compensations.

Deceleration Time Compensation

When the full speed is modified to a lower speed then levelling travel time, L may become considerably long and create uncomfortable ride. This may happen for example, at *energy saving mode*, as lift speed changes with varying car load. In Fig. 7, L and L’ show levelling durations of normal and modified travels that are illustrated with solid and dashed lines respectively. Here, levelling duration of L’ becomes rather long. In order to have a fixed levelling time, L levelling duration and/or deceleration path of the modified travel is altered.

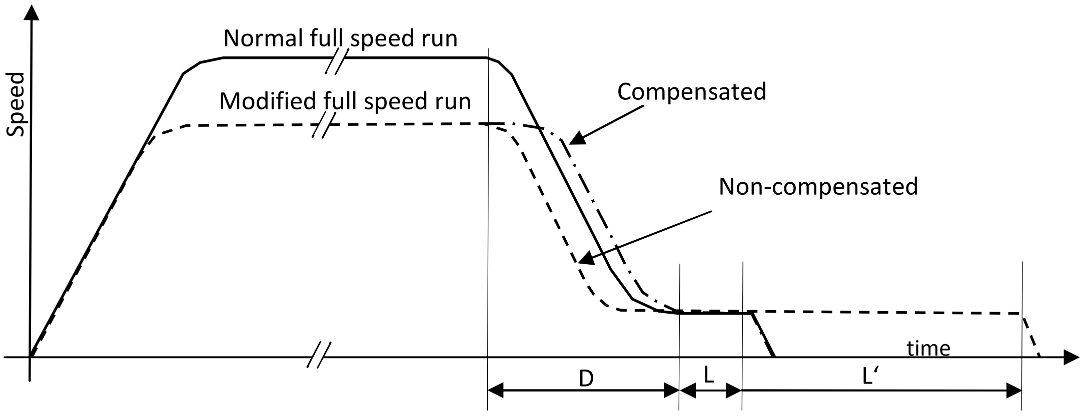

Figure 7. Deceleration path/time compensation.

Additional Procedures for Better Ride Quality

In Fig. 8 some of the additional properties of the inverter software are shown. These were introduced basically to assure high ride-quality. Some of these are:-

Start dwell: A special soft start procedure that is defined with the leakage frequency Q1 and ramp frequency Q2, and ramp times Q3 and Q4, which allows smooth and quick take-off.

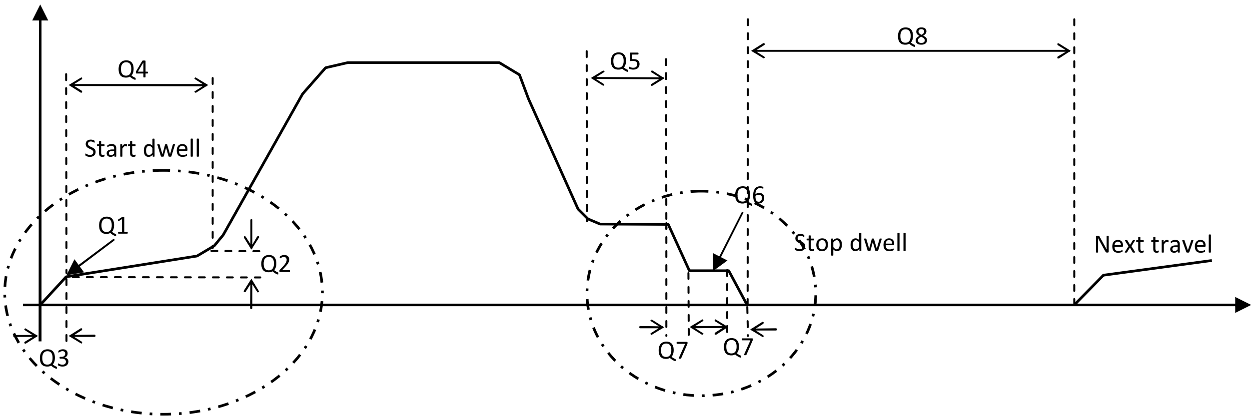

Figure 8. Some of the additional procedures used by the inverter software.

Stop dwell: To assure short levelling duration, smooth and accurate stop, fully compensated Q6 dwell (leakage) frequency was implemented.
Levelling duration check: to provide better ride-quality levelling run duration is checked and when necessary, corrective actions are taken.
Long waiting durations: The time between two consecutive runs is measured to assure smooth take-off after long waiting durations.

SUMMARY

Most of the new generation hydraulic power units are only suitable for high-usage lifts while they put up with high stand-by energy consumption, high initial cost, impractical and complicated set-up. With the present inverter technology, solutions that are simple, cost-effective, service-free and easy to install seem to meet market requirements and could acceptably be utilized on low-usage lifts.

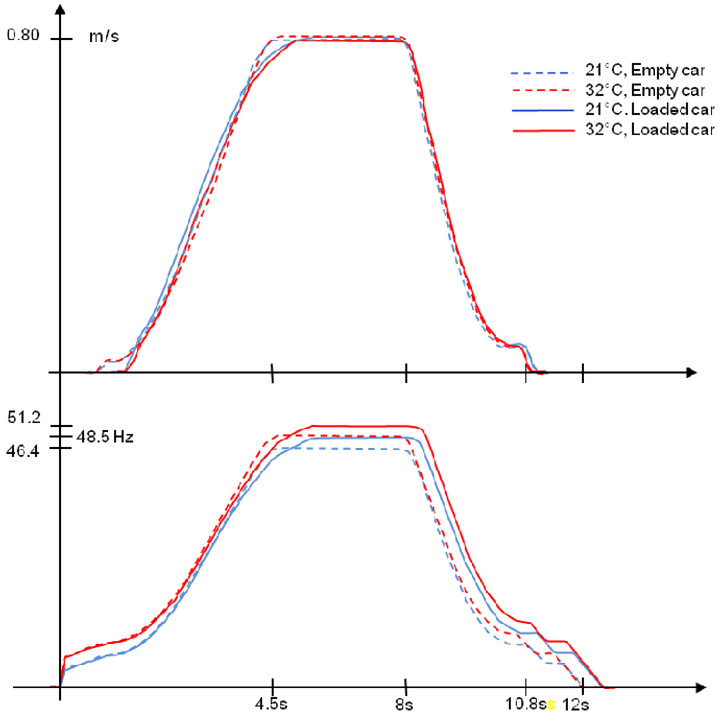

Figure 9. Speed and travel duration control by EV4

EV4 valve and V1000 inverter, using open-loop control and sensor-less load compensation with the use of special inverter software introduces a cost-effective and simplified solution for the new generation power units. The solution employs open-loop control routine together with specially designed procedures to assure good ride-quality. It can easily be applied to both up and down travels without increasing the complexity of the system by using either the constant speed mode or energy saving mode. In addition, the solution can be integrated with existing power units easily for renovation needs. In Figure 9, an example for the speed and total travel duration control of the EV4 valve is shown under varying oil temperature and car load.

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BIOGRAPHICAL DETAILS

Dr. Ferhat Celik received his BSC degree from Istanbul Technical University and later obtained his MSc and PhD degrees from University of Manchester. He worked for Istanbul University as an Assistant Professor for 6 years before joining Blain Hydraulics, where he acts as the International Coordinator and is also in charge of R & D of Electronic valves. Dr. Celik is a member of the committees in ELA and AYSAD, and a member of Consulting Committee of Asansor Dunyasi.