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The Analysis of Excitation Sources and the Dynamic Responses in Lift Systems

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ABSTRACT

Traditionally, lifts were equipped with machine rooms that contained the drive unit and hoisting motor. Machine room-less lifts (MRL) now have these components located in the shaft and are required to achieve acceptable values of vibrations, airborne noise and structure borne noise. The transmission paths of noise and vibration indicate that they originate from various sources. The possibility to predict the response of systems and sub-systems can reduce development time and allows for specific design changes at an early stage. In the design phase the calculation of system natural frequencies and sub-system natural frequencies enables identification of resonance conditions. The identification of fundamental and harmonic frequencies of all components within the lift system enables quick allocation of excitation sources. The following discussion will briefly examine simulation techniques and identify the basic formulas involved in identifying excitation frequencies. The paper continues with methods of data analysis techniques.

INTRODUCTION

Lifts are highly complex dynamic systems that require detailed simulation and analysis in order to achieve acceptable levels of ride quality in the lift system. In the design phase of a lift system, it is important to have a prediction of the noise and vibration, firstly at a system level and secondly at a subsystem level. The system level addresses the complete lift system and the sub-systems can be further categorised as: machine, suspension media, guide rails, car and counterweight.

Therefore, it is necessary to integrate simulation and analysis into the design process in order to accelerate component and system development.

The results of the simulation and analysis drive the choice of the design solutions and can be considered as predictive engineering. The first step is to analyse the structural behaviour based on the calculation of natural frequencies and mode shapes.

In order to understand the dynamic analysis of a lift system, a mathematical model of the system must be developed to fully understand the response of the system and the systems natural frequencies.

Understanding the main sound sources and excitation frequencies enables targeted definition of design changes, in order to avoid critical resonance phenomena. A resonance phenomenon occurs when an excitation frequency is near the natural frequency.

Design and simulation are therefore imperative at an early stage of a project. Combining this with advanced measurement and analysis, it is possible to understand the noise and vibration propagation path and validation of the theoretical models.

SIMULATION

With simulation tools, such as Acoustic prediction tool, Liftsim and Matlab it is possible to predict the system and subsystem components behaviour. Simulation of systems allows for analysis over a wider range of load and size configurations compared to actual testing and reduces the costly task of physical testing. Moretti [1] suggests that in order understand the systems response, it important to simulate the sub-systems from excitation to response.

New technologies, software programs and the ever increasing availability of computational capabilities have driven the simulation opportunities in the lift industry today. Originally, simulation tools were first introduced in order to guarantee the integrity of components at a sub-system and system level, ensuring that they comply with code requirements. Predictive engineering is applied early in design phases, allowing structural simulation of load and stress analysis for verification purpose.

Today, simulation tools have been adapted to give an engineer the freedom to evaluate also aspects of lift ride quality and critical design decisions. The simulation of system and components at a development stage will help to define system and component specifications.

Roberts [2] indicates that simulation and virtual prototyping is a key factor to achieve cost effective means of designing lifts, in order to meet the expectations of the ever increasing demands on ride quality.

EXCITATION FREQUENCIES

With the knowledge of the excitation, at a system level to a subsystem level, together with the simulation and analysis of the structural behaviour, it is then possible to predict the response.
The calculation of the excitation frequencies will enable identification to see if the frequency is a velocity dependent frequency or not. Excitation frequencies for lift systems are generally dependent on the rated speed of the lift, the corresponding roping factor and the geometry of lift components, e.g. the radius of rotating parts. Detailed information on bearing design and elements will help to identify if a faulty bearing is the cause of a disturbance. Once all the relevant information about the system and the components is available, the excitation frequencies can be calculated. The basic formulas required are as follows.

The rotational frequency, rpm of the motor traction sheave, is calculated as:

$$RPM = \frac{i * v * 60}{\pi \frac{D}{1000}} \tag{1}$$

Where i is the roping factor, v is the rated speed and D is the diameter of the traction sheave.
In equations 1 to 4, the diameters are in millimetres instead of meters, they are divided by 1000 for the conversion to meters.
The rotational frequency of the motor traction sheave in Hz, is calculated as:

$$f_{sheave} = \frac{i * v}{\pi \frac{D}{1000}} \tag{2}$$

The rotational frequency of the magnetic poles in Hz is calculated as:

$$f_{MagneticPoles} = \frac{i * v * p}{\pi \frac{D}{1000}} \tag{3}$$

p is the number of magnetic pole pairs.
Excitation frequencies in Hz for roller guide shoes are calculated as:

$$f_{RollerGuide} = \frac{v}{\pi \frac{D_{Rg}}{1000}} \tag{4}$$

Where v is the rated speed and D_{Rg} is the diameter of the roller guide.

Rope Lay excitation frequencies in Hz are calculated as:

$$f_{RopeLay} = \frac{i * v}{L_{RopleLay}} \tag{5}$$

Where i is the roping factor, v is the rated speed and $L_{RopleLay}$ is explained by Janovsky [3].

For evaluation of all excitation frequencies, It is recommended to calculate the data in an excel table. With the data consolidated in a table, it is possible to identify the fundamental frequencies and the corresponding harmonics.

DATA ANALYSIS

Data recording and data analysis are very important aspects of excitation identification. Today in the lift industry, there are numerous hardware and software packages available and utilised by field personnel, in order to record and analyse data sets. For quick measurements in the field, on problem installations, or to validate consultation specifications they are quite a handy tool and can be utilised by most field technicians. Unfortunately, most of them are very limited in the sampling rates and do not offer adequate analysis of the sound recorded, due to the fact that they only record the noise level and not the sound pressure.

With advanced measurement and analysis tools, it is possible to understand the noise and vibration propagation path in order to validate the theoretical models.

To examine the spectrum of a signal, the time domain must be converted to the frequency domain. This technique is known as *Fast Fourier Transformation (FFT).* Spectrograms are a very efficient way to represent data, and to compare and understand excitation and resonance frequencies throughout the entire trip.

An example of this is demonstrated in Figure 1, where a resonance conditions have been clearly identified by their intensity. The darker the colour indicates higher frequency amplitudes that can be related to time and the position in the shaft.

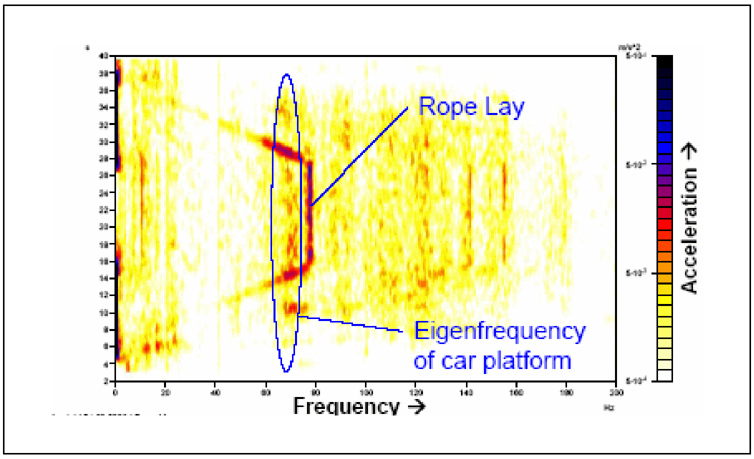

Figure 1. Spectrogram

CONCLUSION

The principles of dynamics form the foundation for the analysis and design of engineering systems. Lifts have to be designed in order to avoid the excitation frequencies that result in a resonance condition. The identification of natural frequencies and mode shapes are essential, in order to develop lift systems to operate optimally, within the buildings that they are designed for. The design of a lift system must not only consider the ride quality felt by passengers in the car. The objective is to achieve adequate ride quality with a combination of minimum transmissions of structure-borne noise and vibrations into the building structure and adjacent rooms.

Identification of all possible excitation sources and vibration transmission paths will allow for targeted design concepts to ensure adequate isolation is present, in order to mitigate disturbances from the system.

Today's lift market is changing from the typical layouts where a machine room was supplied, to cost driven versions of MRL lifts. MRL lifts therefore have to be designed differently in order to compensate the higher shaft noise levels, vibrations and structure borne noise values.

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