Elevator Ride Quality

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Abstract

Standards have been developed by Standards Australia and expanded under International Organization for Standards ISO18738 to address and more completely define ride quality in terms of measurement instrumentation, terminology, methodology, and analysis. The standards draw heavily on ISO8041 for the evaluation of human response to elevator motion, and the experience of members of the elevator industry. These new standards however, do not establish what is, or what is not, acceptable in terms of ride quality, since that has to be considered a moving target as mechanical and control systems continuously improve. Specifically, the standards define all terminology including peak to peak vibration, velocity, acceleration, and jerk and the precise analytical methods to be utilized to evaluate those quantities. Further, it specifies characteristics for the instrumentation used to record elevator motion, as well as the field measurement methodology. The standards ensure that elevator ride quality will be evaluated quantitatively, breaking with earlier methods that were poorly defined.

Introduction

The measurement of elevator ride quality (frequently called ride comfort) has become an extremely important subject over the past several years. It is now often part of specifications for new and modernized elevator systems. It is also a competitive issue for elevator and escalator companies because it is a strong indicator of the quality of design, installation, and service of the elevator and escalator systems. However, in the past, ride quality had never been highly defined and was left to individual interpretation. There have been later attempts to more rigidly define it as a measurable quantity, but this was accomplished only partially. Finally, a standard has been under development in Australia to more completely define ride quality in terms of measurement instrumentation, terminology, methodology, and analysis. The Australian standard has also been submitted to the ISO (International Organization for Standardization) and has formed the basis for the draft ISO 18738 '**(Lifts (elevators) - Measurement of Lift Ride Quality**'. These standards however, do not try to establish what is, or what is not acceptable in terms of ride quality. What was considered good from a ride quality standpoint 10 years ago, would not necessarily be considered acceptable today. What is considered acceptable today may be entirely unacceptable in a few years. Therefore, the most important issue is to define exactly what ride quality is, how it is to be measured, and how it is to be interpreted.

Qualitative Measure of Ride Quality

Although in the past, ride quality was not formally or completely defined, there was a working definition as well as an implied methodology and analysis. The working definition was that ride quality was a description of elevator ride due to elevator motion and sound, as determined by elevator company personnel, consultants, building managers, building owners, and the riding public. The interpretation was based on a personal evaluation of vibration and sound that is felt and heard in the elevator. The implied methodology was to ride the elevator, listen and feel. The analysis was to compare and conclude using experience and memory. The presentation of results was to state that the ride was either acceptable or unacceptable. This entire process had severe limitations and would easily lead to irreconcilable confrontation between the elevator companies and consultants and building owners. It could also have a significant impact on elevator component suppliers (drive, ropes, etc.) that were not directly involved in the contract if ride quality was determined to be unacceptable. This would begin the search for the undefined causes of poor ride quality.

The problem with the qualitative approach was that it depended on entirely undefined individual human feelings and hearing. These were, and often are, controlled by financial involvement in the project, good day - bad day interpretation by the rider, psychological factors (part of the riding public will find no elevator acceptable), and position within the elevator. The determination of acceptability was variable and non-repeatable. Clearly, people are not calibrated. After appearance, ride quality was the one thing about which all parties involved could have an ‘informed’ opinion. Because of these problems, it became readily apparent that a new definition and method was necessary.

Quantitative Measure of Ride Quality

Analog Instrumentation

Beginning in the 1960s, technology became available that was developed for the aerospace industry, that could be adapted for the measurement of vibration in elevator cars. Sound level measurement instrumentation had already existed for some time. It was generally understood that physical motion was the factor that determined ride quality. Further, it was accepted that vibration, jerk, and sound level were the quantities that had to be measured if ride quality was going to be quantified in any meaningful way. At the time there were only two types of readily available sensors that were useful in measuring vibration, accelerometers and velocity sensors. Velocity sensors were not particularly effective in measuring a broad band of frequencies although they were very easy to use. Accelerometers covered a larger range of frequencies and could be operated in any orientation, but were somewhat more difficult to use. However, they were often used in scientific and engineering studies. Recording of the signal from the sensors were most often made using paper strip chart recorders. This allowed the elevator engineers to study the vibration produced by the motion of an elevator in detail.

After the recording it was necessary to evaluate the signal in terms that could be quantified and explained. The level of a signal was often assessed by its amplitude. Specifically, the maximum of a signal that was recorded on a strip chart was often characterized by its peak to peak magnitude (figure 1).

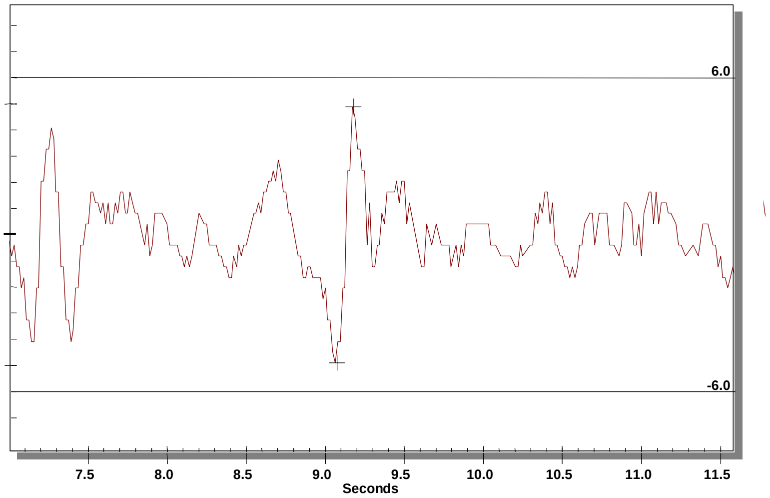

Figure 1

Measurement of double amplitude was the easiest to make on a strip chart recording, particularly when it was not clear just where the zero line was. Accelerometers provided an output in units of acceleration, and the most commonly used unit of measure was the g (1 g = the acceleration of gravity = 1000 milli(g)s = 9.81 m/s^2 = 32.2 ft/s^2 = 981 gals). In general, the maximum peak to peak was found for the recording. The maximum was then used to characterize the level of vibration associated with a specific elevator.

Unfortunately, recordings made on strip charts do not easily lend themselves to analytical methods for deriving information. Any measurements had to be made by placing a scale on the paper chart, then measuring by hand.

The consequence of this operation is that two people could make two different measurements from the same chart. Once again, individual interpretation was allowed to creep into so-called quantitative measurements.

Another important factor that was usually ignored was the effective bandwidth of the measuring equipment. The bandwidth is the frequency range over which the equipment could accurately measure. The bandwidth of the system is affected by both the bandwidth of the sensor, as well as the bandwidth of the mechanical chart recorder. Early accelerometers were generally divided into two classes. The first class could measure from 0 Hz to only a few Hz (DC response) accurately. They were often used in tilt or navigation applications. They could effectively be used to measure the acceleration and deceleration of an elevator, but were not useful in measuring vibration. The other class of accelerometers were AC response accelerometers that could measure from 1 or 2 Hz up to the kilohertz range. They were acceptable for measuring vibration, but were ineffective in measuring the acceleration and deceleration of an elevator. The strip chart recorder could typically measure from 0 Hz up to a few hundred Hz, but that was entirely variable depending on the manufacturer. Finally, the people who had assembled the equipment for the purposes of making so-called ride quality measurements had often added simple low pass filters between the accelerometer outputs and the strip chart recorder to eliminate 'noise'. The filters were usually implemented with available resistors and capacitors. The actual characteristics of the filters were generally left undefined.

Because of the wide variation in the equipment used for the measurement of elevator ride quality, it was inevitable that there would be wide variation in the measurements. Several companies could go into an elevator and make measurements, and finish with entirely different results, and all be correct. What is measured is controlled by how it is measured.

Digital Instrumentation

In the 1970's new portable instrumentation for the recording of analog signals had become available. Capturing the motion data in a digital format allowed the application of analytical methods for ride quality evaluation. It also offered an easy method for evaluating the performance characteristics of elevator systems. Additionally, new accelerometers had become available that had a frequency response from 0 to several hundred Hertz. The combination of new recording capabilities and new sensors allowed for an entirely different way of evaluating elevator ride quality and elevator performance. A significant advantage was the elimination of interpretation by the operator with regard to vibration levels since that could be derived analytically. Non-technical personnel could make quantitative measurements that were quite repeatable. However, even with the advance in instrumentation, and the application of analytical methods there still remained the lack of standardization regarding the quantities that were to be measured and the methodology that was to be used.

First Standard

In April of 1984 Mr. Earl Abraham published a paper (Performance Criteria: Car Ride Quality, Elevator World, April 1984) concerning elevator ride quality. In his paper, Mr. Abraham concluded that vibration should be measured over a defined frequency range, 1 to 10 Hertz (measured in terms of acceleration), and sound level should be measured using A-weighting, to quantify elevator ride quality. He also specified exactly what should be considered excellent, acceptable, and poor in terms of vibration level. At the same time, he stated that the riding passenger is actually sensitive to jerk (the rate of change in acceleration). It should be noted that Mr. Abraham relied on strip chart recordings, not digitally recorded or analyzed data.

The effects of Mr. Abraham's paper were significant and widespread and had both positive and negative results. Some of the positive ride quality measurement aspects included previously assumed but undefined points. They were: 1. vibration should be measured over a specific frequency range (1 to 10 Hertz), 2. ride quality, with regard to vibration should be measured in terms of peak to peak vibration, 3. vibration sources could be identified by frequency and 4. discussed terminology for ride quality measurements. Some of the negative aspects included: 1. Jerk is a ride quality parameter and 2. The specified frequency range was not a standardized measure of human response to vibration.

The core points of Mr. Abraham’s paper have shown up widely in consultants specifications on ride quality, worldwide.

Discussion of Ride Quality Measurement Issues

Mr. Abraham’s paper provides an effective starting point for the discussion of the issues related to ride quality measurement. In the past, it has been assumed by many users of the instrumentation to measure vibration and sound, that the measurements made could be applied directly to ride quality. The assumption was that an increase in the measured vibration level is directly related to an increase in human perception of that vibration. Stated in terms of frequency response, it was assumed that people sensed vibration equally at all of the frequencies that a given instrument could measure accurately. Mr. Abraham’s statement on the bandwidth to be measured (1 to 10 Hertz), was a great departure from that assumption. Unfortunately, from that statement, it was quickly assumed by many in the industry that people responded equally to all frequencies between 1 and 10 Hertz, and did not sense vibration frequencies less than 1 Hz or greater than 10 Hz. From a ‘real world’ standpoint, filters that completely attenuate frequencies less than 1 Hz or frequencies greater than 10 Hz are not realizable. Also, this band of frequencies did not correlate with those specified in earlier and later versions of ISO2631 used for the measurement of human response to vibration. However, it did help lay the foundation for the acceptance that there had to be a standardized approach to the measurement of ride quality.

The main problems with Mr. Abraham’s, and industry related approaches to the measurement of ride quality, was a decided lack of detailed definition of terminology and definition of field measurement methodology. In as much as the use of instrumentation is to minimize personal interpretation, it is important to clearly define what quantities are to be measured, how they are to be measured, and the specific analytical approaches to the evaluation of motion and sound data.

Australian Lift Ride Quality Standard

In 1995 a committee was organized by the Lift Manufacturers Association of Australia (LMAA) to address the lack of standards in the measurement of lift ride quality. Later, a subcommittee (ME/4/12) was formed under Standards Australia to continue and formalize the work that had been started under the LMAA. Members of the committees and attendees of meetings included individuals from the lift industry in Australia, Finland, Japan, and the United States and included manufacturers, consultants, an academic, and instrumentation manufacturers. The committee’s goals were to:

1. evaluate existing technology & techniques for the measurement of ride quality
2. identify the differences in the instrumentation and analysis techniques used
3. formally define ride quality metrics and all related terminology
4. develop a field measurement methodology
5. establish minimum instrumentation characteristics for manufacturers

a. The evaluation of the existing technology and techniques confirmed that there was a minimum of ten different approaches to measuring ride quality. Based on the known characteristics, all ten of the instruments could have been placed in the same elevator and all ten would have supplied entirely different measurements of vibration levels, sound levels, jerk, and velocity. Often, even within the same elevator company, several different approaches to measurement were utilized.

b. The differences in measurements were identified as being the result of many factors and included:

  1. types of sensors being utilized
  2. bandwidth of instruments and filter slopes

3. the frequency range of vibration that was believed to be relevant to human response
4. analytical (i.e. programming) techniques that were applied to instrument acquired data to evaluate vibration level, elevator acceleration and deceleration, velocity, and jerk
5. field methodology that was employed
6. the specific portions of the elevator ride that were deemed to be relevant
7. definition of terminology

c. Based on the discussions within the committee, it became clear that basic terminology was not formally defined. It varied within the industry and also within a company. In particular, the loose definitions allowed for variation in how peak to peak vibration, jerk, acceleration, and velocity were calculated.

d. Because of the lack of definition of terminology, there were many analytical techniques created to derive measurements from digitized motion and sound data. As an example, the concept of adjacency (refer figure 2) varied based on the equipment used or programming techniques. If the data had been collected using a strip chart recorder, the interpreter would likely have ignored the vibration about the zero line to find the maximum peak to peak value. This is analogous to low pass filtering. Unfortunately the interpretation could change from individual to individual. This technique was also approximated analytically by at least one elevator company. Another analytical technique that was developed was to measure the maximum and minimum values within a sliding one second window. This is a technique that is easily programmed. A third technique is to simply use the mathematical adjacent peak to peak.

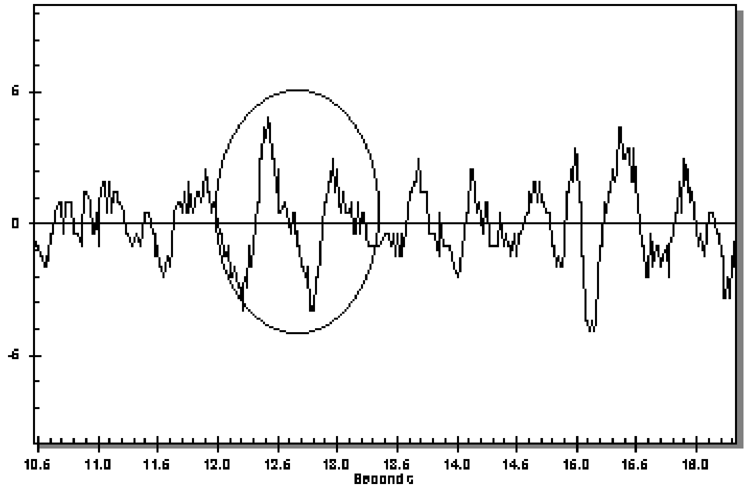

Figure 2

e. Field methodology varied from company to company and often within the same company from region to region. The location of the sensors was the most common difference.

f. The specific portions of the elevator motion that were analyzed were often dependent on personal preferences.

g. Although the elevator industry used the same terminology, the meanings of the terms were often tied to hardware design or implementation for a specific company.

Technical Issues in Standard Development

The most fundamental issues of concern were related to instrumentation characteristics and measurement methodology. It was realized that the instrumentation would likely be utilized for both the measurement of ride quality and performance. It was also understood by committee members that the evaluation of vibration and sound within an elevator should provide measurements such that an increase in vibration and sound levels as measured by an instrument, should as closely as possible, correspond with an increase in perception of that vibration and sound by a rider of the elevator. To accomplish this, it was decided that ISO2631, ISO8041, and the IEC651 standards should be applied. ISO2631 and ISO8041 addressed human response to vibration. ISO8041 was used as directly as was practical because it focused on the instrumentation requirements for the measurement of human response to vibration defined in ISO2631. IEC651 was utilized to address measurement of sound levels.

Required Instrumentation Characteristics

The required characteristics for an instrument to meet the previously mentioned criterion included:

1. 3 Axis Simultaneous Measurement
2. Bandwidth: 0 to 80 Hz
3. Rolloff: 12dB per Octave
4. Sampling Rate: 256 SPS Minimum
5. Range: 250 milli(g)s
6. Resolution: 1 milli(g)
7. Cross Axis Sensitivity: less than or equal to 3%
8. Pressure Exerted on Floor by Instrument: greater than or equal to 60 kPa (approximately human foot pressure)
9. Sound Measurement: IEC651 Type 2, A-Weighted, Fast Response
10. Sound Measurement Range: 2 dB less than the minimum sound level within an elevator, to 5 dB greater than the maximum sound level
11. No Data Compression Techniques shall be applied

It was decided that an instrument with the above minimum characteristics would allow measurement of vibration and sound for the purposes of determining ride quality, and the evaluation of performance characteristics of the elevator system. Industry experience indicates that vibration in an elevator typically has a spectral content of 80 Hz or less (with most of the motion having a spectral content of less than 20 Hz). Rotating elements such as rollers and sheaves have rotation frequencies of less than 10 hertz. Gear mesh frequencies are typically less than 30 hertz. Structural elements such as the car frame generally have resonant frequencies of less than 60 hertz. Control systems generally induce vibration at frequencies less than 35 hertz.

Measurement Methodology

It was important to specify the ‘how’ for ride quality measurement to ensure consistency of results. The method is quite simple and is well described in the standard. It was only necessary to agree on the conditions of measurement, instrument placement, and the number of recordings to make (up and down). The measurement steps are:

1. Place instrument in center of lift, Microphone at 1 to 1.5 meters above the floor, pointing toward the doors (figure 3).
2. X axis is perpendicular to the plane that contains the rails (typically x is toward the doors), Z axis is vertical, Y axis is perpendicular to X & Z (typically toward rails)
3. Preferably one operator will be in the elevator (maximum 2)
4. Record full run from lowest floor to top floor (begin recording prior to door closing, continue recording through full run, end recording after doors have fully opened).
5. Record full run from top floor to bottom floor.
   (It should be noted that recordings made in this fashion include sound from the lobbies at the terminal floors, noise associated with the door operators, and the full motion of the elevator)

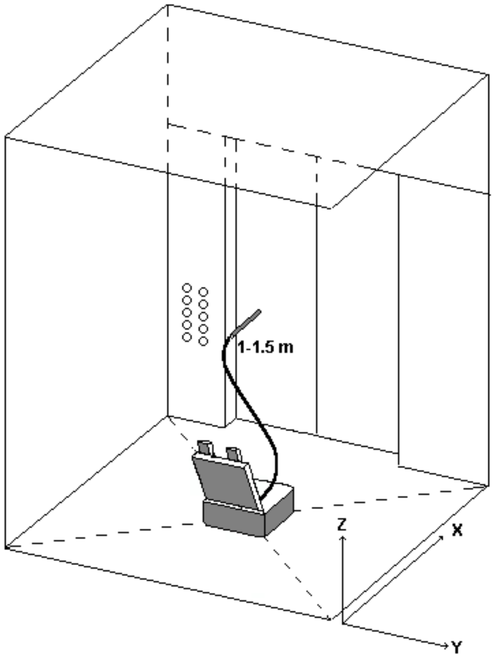

Figure 3

Definition of Terminology & Analytical Techniques

The analysis of the collected data is a fairly involved process. However, an important goal of the committee was to ensure that the data could be evaluated with a minimum of interpretation by an operator. As such, the terminology of ride quality and performance parameters were made in terms of how each parameter could be found analytically.

Figure 4 exhibits the time histories of a typical elevator recording. They are, in descending order, sound level (decibels), and the acceleration channels x (front to back), y (side to side), and z (vertical). This is the unfiltered data from which all measurements can be derived.

It is clear that not all parts of the recording are related to the motion of the elevator and therefore should not be included in the evaluation of ride quality. The working definition that had been used in the past was that vibration should be evaluated while the elevator is travelling at full speed. Unfortunately this could keep a large part of the elevator motion from being evaluated while the elevator was accelerating or decelerating. On many elevator systems, the full speed could be a very small percentage of the full run. To ensure that the entire duration was evaluated it was decided to establish strict 'boundaries of calculation'.
These boundaries are defined such that:

Boundary 1: beginning of recording (at least 0.5s prior to beginning of door closing)
Boundary 2: 0.5 m from its start position
Boundary 3: 0.5 m from its final position
Boundary 4: end of recording (at lease 0.5s after end of door opening)

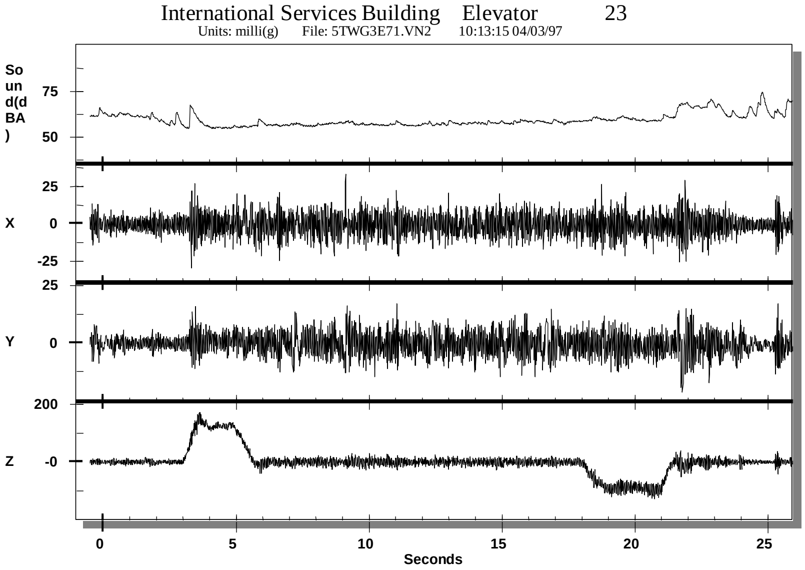

Figure 4

The boundaries are marked in figure 5. Specifically, vibration is to be evaluated between boundaries 2 and 3 for the horizontal channels (x & y). This is to ensure that vibration associated with door motion will not be evaluated as ride quality. The z channel is evaluated somewhat differently. The committee developed a novel and clever approach for evaluating the vertical axis motion. The approach was to evaluate the vertical motion with respect to jerk and no jerk zones. It is evaluated between boundaries 2 and 3 during periods of constant acceleration (i.e. jerk is a minimum) and separately, where jerk is a maximum (i.e. changing acceleration) for the entire recording. Sound level is to be evaluated between boundaries 2 and 3 for sound associated with elevator travel, and prior to boundary 2 and after boundary 3 for sound associated with door operators and the lobbies.

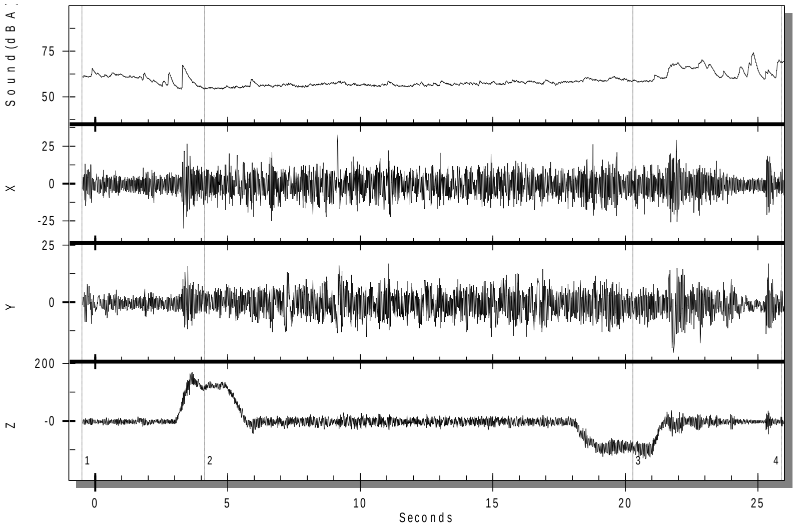

Figure 5

From the unfiltered data, it is necessary to process the data so that the signal corresponds with the human response to the motion and characterize the level of the signal. Based on ISO2631 and ISO8041, vibration level would typically be evaluated from the root mean square (RMS) time history. The committee decided to depart from the standards in this instance to more closely conform with the history and experience of the elevator industry. The industry had generally only utilized maximum adjacent peak to peak vibration (based on various techniques). It was also decided by the committee that ride quality should also be measured both in terms of the mathematical maximum adjacent peak to peak, and the typical (analogous to average) adjacent peak to peak vibration level. If ride quality measurements relied on only maximum peak to peak, then a singular event (such as that caused by a rail misalignment) would characterize the entire ride as being poor. The measure of the typical adjacent peak to peak is calculated by finding the peak to peak magnitude that is greater than or equal to 95% of all of the peak to peak measurements found within the boundaries of calculation (called A95).

The ‘ride quality’ time histories are derived by applying the whole body x, y and whole body z weightings as represented in figure 6 as defined in ISO8041. Simply stated, human response to vibration is dependent on frequency and orientation. The peak response in the horizontal is at 1.6 Hz and at 5 Hz for vertical motion. The approach has been utilized successfully in Physical Measurement Technologies’ EVA-625 system and software.

As is clear in figure 6, the application of the weightings results in dramatically different motion time histories (compare with figure 5). It is also obvious that there are large peak to peak excursions during the ‘jerk phases’ (i.e. changing acceleration, note figure 6). The analysis of the vertical axis motion with regard to jerk and non – jerk zones allows the entire vertical axis motion to be evaluated regardless of the length of time that the lift is travelling at full speed. The maximum adjacent peak to peak values are marked with crosses (+), while the maximum peak to peak that occurred during the ‘jerk phase’ of the acceleration (i.e. jerk >0.3 m/s^3) is marked with circles (vertical channel only). It is important to note that the utilization of ‘human response” weighting by elevator and service companies allows them to address vibration that people can feel while ignoring vibration that people are not feeling, thus reducing time and cost.

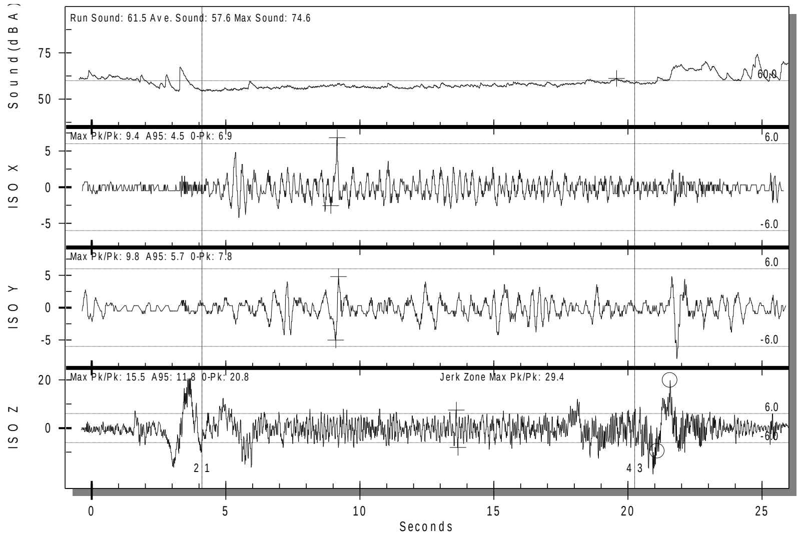

Figure 6

Although jerk, acceleration, velocity, and distance are not considered ride quality metrics within the standard, jerk is utilized to identify regions to be evaluated on the vertical channel, while distance is used to place boundary markers. Additionally, acceleration and velocity would normally be reported as part of the evaluation of an elevator system. As such, it was necessary to clearly define each of those terms.

As stated previously, a typical instrument for ride quality measurement, measures motion using accelerometers (i.e. acceleration measurement). However, the elevator industry has normally interpreted acceleration as being related to the net vertical motion of the elevator. In spectral terms, it is the low frequency components of the vertical axis motion. The committee had decided to define 'lift acceleration' as the 10 Hz low pass filtered vertical axis time history. The definition is important since jerk, velocity and distance are all derived from the acceleration time history. The filter is specified as a 2 pole butterworth. As an example, figure 7 shows the unfiltered vertical axis motion time history (top) with the derived acceleration time history (bottom). Although the actual control related acceleration has a decidedly lower frequency content than 10 Hz, it was decided that the 10 Hz filtering would allow the identification of problems with the control system. The maximum, and A95 acceleration is specified to be reported, where acceleration A95 is the level of acceleration that is greater than, or equal to 95% of all of the acceleration points found, between 5% and 95% of full speed (increasing). Similarly, the maximum and A95 deceleration is reported, where A95 deceleration is found between 95% and 5% of full speed (decreasing). A95 acceleration and deceleration can be thought of as sustained acceleration and deceleration.

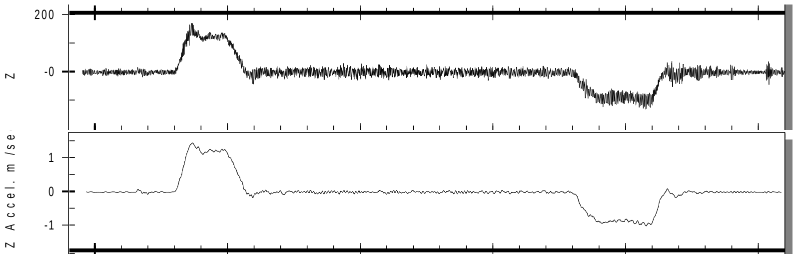

Figure 7

Jerk by definition is the first derivative of acceleration. The jerk time history would therefore be the instantaneous slope of the acceleration time history. The elevator industry essentially only deals with jerk during the acceleration and deceleration phase of the elevator. Normally it is a programmed quantity for the elevator control system (input) and the output was not typically measured. The United States NEII specification directed that jerk to be measured as sustained jerk. Unfortunately, how one analytically defines sustained jerk was never described. The committee adopted an approach developed by Physical Measurement Technologies to quantify 'lift jerk'. The approach was to calculate the slope of the best fit line of 0.5 seconds duration at every point of the acceleration time history. Simply stated, at each point of the acceleration time history, a line is fit to the acceleration data, 0.25 s before that point, to 0.25 s after that point. The slope of that line is calculated using least squares. Each slope is plotted as a jerk point in the jerk time history (figure 8).The maximum jerk is reported.

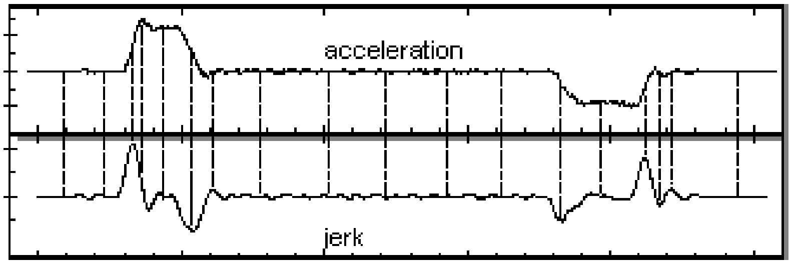

Figure 8

The velocity and distance time histories (figure 9) are also derived from the acceleration time history. Simple running integration (velocity, top) and double integration (distance, bottom) are employed to develop the time histories. The velocity and V95 velocity is reported, where V95 is the level of velocity that encompasses 95% of all of the velocity points where the elevator is travelling at 95% or greater of full speed. There are no reporting requirements for distance.

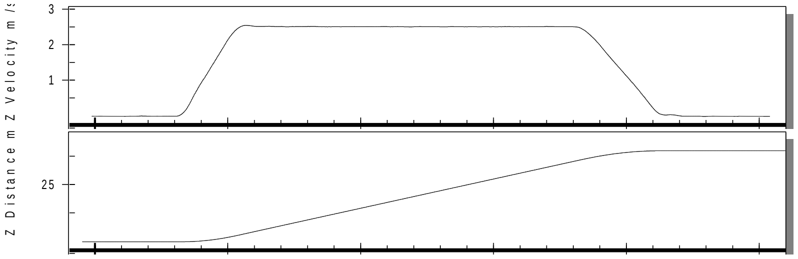

Figure 9

Conclusion

For the first time, strict definitions of terminology, establishment of methodology, explanation of data analysis techniques, and clearly detailed instrumentation requirements will allow lift companies, consultants, and regulatory agencies to evaluate elevator systems comprehensively. The essential points of the new standard include:

1. An instrument shall be utilized with clearly defined minimum characteristics
2. A specific field measurement methodology shall be followed to collect motion and sound level data
3. Terminology is defined in terms of how each term is quantified
4. Defined processing techniques shall be applied to the motion and sound data including; a. the motion data shall be weighted according to ISO8041, whole body x, y, z; b. vibration levels will be characterized within specific boundaries for each axis as the maximum mathematical adjacent peak to peak magnitude as well as the typical mathematical adjacent peak to peak magnitude.
5. Ride Quality measurements shall be reported to include: maximum peak to peak and typical (A95) vibration levels for each axis, measurements of maximum and typical sound levels, and a measure of jerk, acceleration, deceleration, sustained acceleration, sustained deceleration, velocity and sustained velocity.

The application of comprehensive standards on ride quality offers the ability to significantly improve lift quality and minimize argument. The development of standards on ride quality through Standards Australia and ISO has already had worldwide implications. The lift industry is international in scope, where even local lift companies are often closely associated with multinational manufacturers. Additionally, each multinational lift company has local offices in almost every country. Many aspects of the work that has been conducted in the development of the standard is already being utilized in many countries.

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