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COMPARATIVE ANALYSIS OF COMFORT PARAMETERS OF ELEVATORS AFTER INTEGRAL MODERNIZATION PROJECTS

Mateus Antônio Rocha Dadalt
Fábio André Gubiani
Herbert Martins Gomes
Universidade Federal do Rio Grande do Sul, Graduate Program in Mechanical Engineering, Av. Sarmento Leite, 425, sala 202, 90050-170, Porto Alegre, RS, Brazil.
mateus.dadalt@ufrgs.br , fabio.gubiani@ufrgs.br , herbert@mecanica.ufrgs.br

Abstract. *Over the period of use, elevators need to be updated to ensure their functionality, safety, an extension of service-life, and passenger comfort. The necessary modernization process replaces essential components for the full functioning of the elevator. This work quantitatively evaluates the gain in the degree of comfort of travel concerning vibration and over-acceleration caused by displacement to check the improvements. Measurements were carried out on non-modernized elevators and after being fully modernized in the same building. A seat pad device with an accelerometer and a VI-400Pro device was used to measure the vibration transmitted to the human body, standardized inside the cabin during elevator journeys. Subsequently, the data were processed in the Matlab software. The measurements are carried out by the methodology indicated by ISO 18738:2003, comparing the results thus obtained with the values referring to passenger comfort following ISO 2631-1:1997 and literature. The analysis of the results obtained from the data processing shows that considering the vibration, all trips are considered comfortable, but there is a decrease in vibration for the modernized cases. Regarding over-acceleration, all values obtained from the old elevators are unacceptable, while the modern ones are in the pleasant to an acceptable range.*

Keywords: *elevators comfort, elevators modernization, vibration, weighted acceleration, jerk.*

1. INTRODUCTION

One of the fundamental factors for the concepts of modern architecture was the development and popularization of elevator technology. As buildings became larger, the demand for faster, more efficient, comfortable and safer equipment grew. Because it is the transport of human beings, the degree of comfort of the trips becomes a relevant parameter for your project. Although the amplitude of the vibration of a functioning elevator does not threaten the health and safety of passengers, values that cause discomfort to the user can be achieved, and this can be the determining factor in a negotiation of sale of installation or maintenance service contract. With the increasing use of elevators and after many cycles of use, even with a well-executed maintenance plan, the life of the components comes to an end, and the technology of the equipment is outdated, requiring updates. With the evolution of this industry, lift companies are looking for innovations that bring an experience of more safety and comfort for passengers during travel.

For Howkins (2006) the comfort of the transport of lifts is very subjective, because it depends on quantifiable aspects, such as vibration and non-quantifiable, such as the perception of aesthetics and sense of security. It is possible to quantify the experience objectively by changing the effect of gravity on the passenger's body caused by the variation in the acceleration of the equipment. This combination of subjective and objective aspects is classified as human experience in elevator transportation. According to Guo (2019), most of the lower amplitude vibrations do not threaten the health or safety of passengers, but these can reach values that bring discomfort. This demonstrates the importance of vibration analysis and control to improve the comfort of elevator travel.

The present work deals with a comparative study of the results of vibration measurements in a group of four elevators of the same building, where two of these were modernized entirely recently. A total of 90 measurements were made, 34 of them in elevators before modernization and 56 of them in modernized elevators. The goal is to obtain and process enough data to quantitatively state the gain in travel comfort after the equipment upgrade. The trips will not be evaluated in relation to possible damage to health in terms of exposure to vibration, since from the analysis of the results obtained by Biasuz (2011) and other authors, the vibration dose values for an eight-hour journey of all trips measured by him are 2 orders of magnitude below the limit considered healthy for the human body.

This work aims to evaluate quantitatively and qualitatively the gain in comfort of elevator trips after modernization projects, through comparisons of the results of vibration measurements and the rate of change of acceleration in time (Jerk), in the axial z direction, in elevators about to be modernized and recently modernized of the same building. The instrumentation of the measurements and the processing of the data are carried out according to the BS ISO 18738:2003 standard, and the evaluation of the results considers the reference values of the international standard ISO 2631-1:1997 and the reference Howkins (2006), specialized in elevator comfort. This analysis is relevant to show the benefits of component upgrades of lifts that have many cycles of use since their installation.

2. LITERATURE REVIEW

In 1924, Otis installed the first elevator with a signal-controlled system in the Standard Oil Building, also in New York City. This system automatically controlled acceleration, speed between floors and deceleration as the elevator approached the indicated floor, providing greater comfort to passengers. Currently, elevator technology has everything from equipment monitoring systems for predictive failure analysis connected to the internet network to traffic management software. By setting parameters in the elevator control modules on the equipment control panel, it is possible to define the machine operating conditions that interfere with travel comfort, such as the angular velocity of the motor during leveling, the speed reduction time until leveling and the starting torque of the engine.

Traction systems are composed of induction motors connected to the power grid, in which the frequency, current and voltage are controlled by an inverter system in conjunction with an electronic speed controller module, adjusting the torque of the motor and therefore the speed of the cab according to its position inside the racing box and the floor to which the call was made. The coating material of the cabs and doors ceased to be, mostly, wood and became steel. In addition to being lighter, they suffer less wear and tear over time, maintaining a good aesthetic appearance for longer time.

There are several manuals from elevator manufacturers that indicate (for example the one from Atlas-Schindler, 2020), in a simplified (and not mandatory) way, the operating speeds of the elevators as a function of the distances of the routes to be made by the elevators. However, these recommendations do not indicate or take into account the levels of acceleration or comfort that these speeds can generate in elevators, especially if they do not have properly certified maintenance and facilities.

2.1 Modernization of elevators

In addition to adding value to the building, elevators should convey comfort and safety and be in excellent condition to make travel for building inhabitants and visitors more delightful. However, according to the years of operation, the equipment suffers wear and tear due to frequent use. The life cycle of elevators can vary according to the intensity of their use, the quality of the installed product and maintenance. In addition, there are some external factors such as environmental conditions, destination of equipment, such as service elevators in residential buildings, even vandalism of users. Although a reliable maintenance service can keep the elevator running safely for 12 to 15 years as on any machine, the end of the life of the components will be reached.

After an evaluation of the equipment in which, for logistical and economic reasons, it is concluded that it is no longer sustainable to maintain it, the solution is a project to modernize the equipment. To meet different needs, such as upgrading obsolete components, increasing energy efficiency and adjusting to the taste of the owners, the work can be performed in two ways: partial or integral. The partial modernization is one in which it is foreseen the punctual replacement of the most complex components, such as the traction machine, even the simplest, such as the buttonholes, however, it does not require the exchange of the elevator structure. Integral modernization is indicated when it is necessary to replace all the equipment, being able to reuse only some components of the old elevator, such as guides, counterweight structure and support cables.

2.2 Comfort and quality of elevator trips

The theme of comfort in elevators, especially elevators of tall buildings that require greater speed has become increasing as indicated in the work of Hernelind and Roivainen (2017). In the same work, there are suggestions for solutions based on the active control of vibrations by means of actuators in the slide system of the elevator cab. In addition to the problem of comfort regarding vibration, sound comfort has also been a theme for several articles such as the work of Monge and Gómes (2020). Zhang (2017) claims that the comfort of elevator travel is defined in a personal way through the perception of the human body under a vibratory environment, including physical and psychological effects. As Howkins (2006) states, the quality of vertical locomotion in lifts is difficult to quantify, since these subjective aspects influence the perception of users, such as the aesthetics of the cabin. These circumstances inherent to the individual in the evaluation can also be related to the feeling of security that the equipment transmits to the user.

The BS ISO 18738:2003 standard defines how measurements should be made and what parameters are relevant to determine the quality of elevator travel. It establishes that the characteristic of locomotion depends on the sound levels inside the cabin and vibration on the floor relevant to the perception of passengers associated with the movement of the transport. Vibration consists of movements inherent in bodies endowed with mass and elasticity.

According to Rao (2011), any repetitive movement in a time interval is considered a vibratory movement. The amount of times a cycle repeats in one second is called frequency, measured in cycles per second, or Hertz (Hz). The inverse of the frequency is called the period, measured in seconds. ISO 18738:2006 defines vibration as the variation over time of the magnitude of acceleration and is expressed in units of m/s^2. Regarding the movement of the elevators, according to

Howkins (2006) one can assume a main behavior of vibration in the vertical direction (which is the movement of ascent or descent elevator) and secondary horizontal vibrations and of lower intensity, deriving, in most cases, to clearances and / or movements of the loads (people) that are inside the elevator cabin. These vibrations (vertical and horizontal) are slightly dampened and, in the conditions of stopping and starting the elevator, they closely resemble free vibrations, since the cabin system, cables and counterweight closely resemble a system of a degree of freedom.

3. TRANSMISSION OF VIBRATION TO THE HUMAN BODY

When in contact with a vibrating surface, the vibratory energy will be absorbed by the body, as a consequence of the attenuation promoted by the tissues and organs. The way vibration affects health, comfort, perception, and motion sickness is a function of the frequency content of the vibration. The body's perception of vibration is dependent on how the body responds to variation in acceleration, velocity, and displacement, either singularly or in combination. For the case of elevator travel, the evaluation of the transmission of vibration to the human being according to ISO 2631-1:1997 applies to movements transmitted to the whole body, as a whole, in a coordinate system with the origin at a considered point of entry of vibration into the body. In the case of this work: the feet of a standing person.

For each assessment of the way in which vibration affects the human body and for each direction in which it is to be evaluated, weighting filters are applied to the acceleration signals picked up by the instrument used to measure it. For this work, W_k is used for the direction of the z-axis, in the direction of the spine, and W_d for the x-directions, in the front and back directions, and y, in the lateral direction, according to Table 1 and item b) of Figure 1. In relation to the cab axles, the x-axis corresponds to the direction of the door and the bottom of the cab, the y-axis to the sides of the cab, and the z-axis corresponds to the axis of the elevator's direction of ascent. According to Biasuz (2011), the filters serve to consider only the signals that will affect certain parts of the body. Frequency ranges are defined from the natural frequencies of the limbs that make up the human body. The range of frequencies considered with potential influence on the human body ranges from 0.5 Hz to 80 Hz for comfort.

Table 1. Guide to the application of weighting curves (ISO 2631-1:1997).

Frequency Weighting	Health	Comfort	Perception	Motion sickness
W_k	z- axis, seat-surface;	z-axis, seat-surface; z-axis, standing, vertical recumbent (except head); x-,y- and z-axis, feet(sitting);	z-axis, s seat surface; z-axis, standing vertical recumbent;	-
W_d	y-axis, seat-surface; x-axis, seat-surface;	x-axis, seat surface; y-axis, seat surface ; x-and y-, standing horizontal recumbent; y-and z-, seat-back;	x-axis, seat surface; y-axis, seat surface; x-and y-axis, standing horizontal recumbent;	-
W_f	-	-	-	vertical

Frequency weighting can be done in analog or digital form. The weighting curves can be seen in Figure 2 including the limitations for frequency band.

3.1 Vibration-related comfort assessment

According to ISO 2631-1:1997, vibration comfort assessment is an estimate of the vibratory effect in healthy people whose bodies are subjected to periodic, random and/or transient oscillation during travel. For the comfort of people standing, vibration occurs according to the three axes of translation (x, y and z) on the main surface that supports the body. The method of evaluation according to the standard is measurements of the weighted effective value (or RMS, Root Mean Square) of the acceleration, which must be calculated according to Equation (1):

$$a_w = \sqrt{\frac{1}{T}\int_0^T a_w^2(t)\, dt} \quad (1)$$

where $a_w\,(t)$is the RMS acceleration weighted in (m/s²) and T in (s) is the duration of the measurement. The frequency weightings used for predicting the effects of vibration on comfort are as stated earlier, for the case of people standing, W_d and W_k. These weightings should be applied with the multiplicative factors k, such that on the x-axis), W_d, k_x = 1, on the y-axis (pavement vibration), W_d, k_y = 1, on the z-axis (pavement vibration), W_k, k_z = 1.

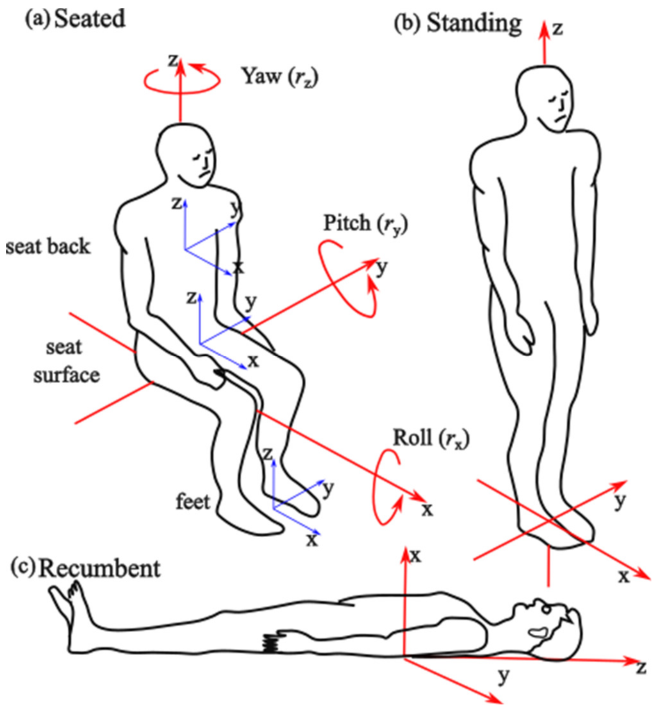

Figure 1. Basicentric axes of the human body (ISO 2631-1:1997).

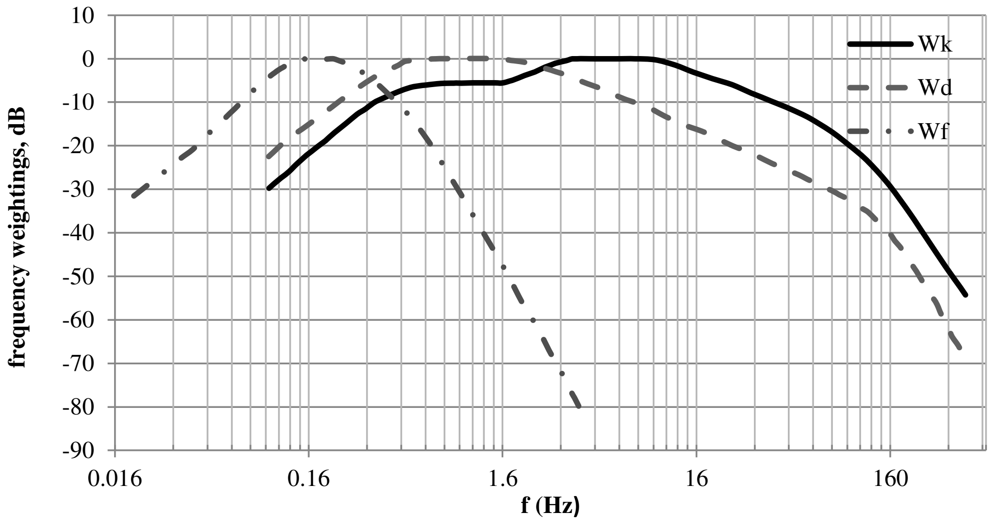

Figure 2. Weighted frequencies for the x, y and z axes (ISO 2631-1:1997).

From these values, applying the square root of the sum of squares of the acceleration of each component (x, y and z axes) multiplied by the square of the specific multiplication factor (vector sum), we obtain the total RMS acceleration weighted a_v corresponding to the total vibration, according to Equation (2):

$$a_v = \sqrt{k_x^2 a_{wx}^2 + k_y^2 a_{wy}^2 + k_z^2 a_{wz}^2} \quad (2)$$

where a_v is the total effective value of the weighted acceleration in m/s², k_x, k_y and k_z are the respective multiplier factors for each axis and a_{wx}, a_{wy} and a_{wz} are relative weighted acceleration values on the x, y and z axes, respectively. This value is compared with the limits determined by ISO 2631-1:1997 to determine the degree of travel comfort, as shown in Table 2.

In general, the limits of a passenger's comfort or discomfort due to the various vibration amplitudes are difficult to determine because of each person's susceptibility. In addition, environmental factors such as the local temperature, the passenger's expectation, and the activity they perform during the trip, such as reading or eating, change their assessment of comfort. Because of this, the ISO 2631-1:1997 standard establishes approximate indications of the probable reactions to the various amplitudes for this evaluation due to vibration, as indicated by the perception scale in Table 2.

Table 2. Comfort scale (ISO 2631-1:1997).

RMS total acceleration	Perception scale
< 0.315 m/s²	not uncomfortable
0.315 – 0.63 m/s²	a little uncomfortable
0.5 – 1 m/s²	fairly uncomfortable
0.8 – 1.6 m/s²	uncomfortable
1.25 – 2.5 m/s²	very uncomfortable
> 2.0 m/s²	extremely uncomfortable

3.2 Evaluation parameters of elevators

The BS -ISO 18738:2003 standard only establishes what the measurements should be and what the relevant parameters are for comparison, since the limit values are merely illustrative regardless of whether the elevators are residential, commercial or conventional. Thus, this standard specifies how vibration parameters are to be evaluated.

3.2.1 Aceleration

According to Zhang (2017), acceleration is quantification of the description of intensity of a vibration in the whole body, so all types of comfort assessment are based on it. In the case of elevator rides, people may feel lighter or heavier because of the presence of acceleration, and he says that it can affect them psychologically and physically. Howkins (2006) states that acceleration will be perceived as good as long as it remains constant. According to BS ISO 18738:2003, limits should be used to define the regions over which quantities of signals are calculated. Figure 3 shows the acceleration regions resulting from the elevator movement that should be considered for analysis, which are: *(i)* Limit 0: 0.5 s before the door begins to close (start of movement); *(ii)* Limit 1: 500 ms after the movement has begun; *(iii)* Limit 2: 500 ms before ceasing movement; *(iv)* Limit 3: 0.5 s after the door opens (end of movement).

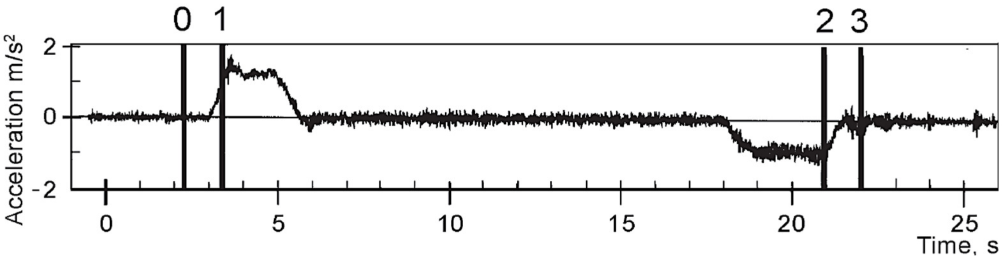

Figure 3. Regions for evaluation of acceleration in elevator trips (BS ISO 18738:2003).

3.2.2 Jerk

Howkins (2006) defines over-acceleration as the rate of change of the acceleration of the z-axis, expressed in m/s³ as in equation (3).

$$Jerk(t) = da_{wz}(t)/dt \tag{3}$$

This is the most important variable parameter of elevator travel to control, as the human body responds more quickly to changes in the rate of acceleration (jerk) than to changes in speed (acceleration). With changing acceleration, the forces on the human body change, and if they are severe enough, passengers will feel very uncomfortable. Howkins (2006) defines comfort limits related to jerk, as seen in Table 3. The ISO 18738:2003 standard defines that the maximum Jerk value should be considered when making a comfort assessment. The typical over-acceleration curve is shown in Figure 4.

Table 3. Guide values for characterization of jerk (Howkins, 2006).

Jerk	User perception
< 2.0 m/s³	pleasant
2.0 – 6.0 m/s³	pleasant
> 6.0 m/s³	unpleasant

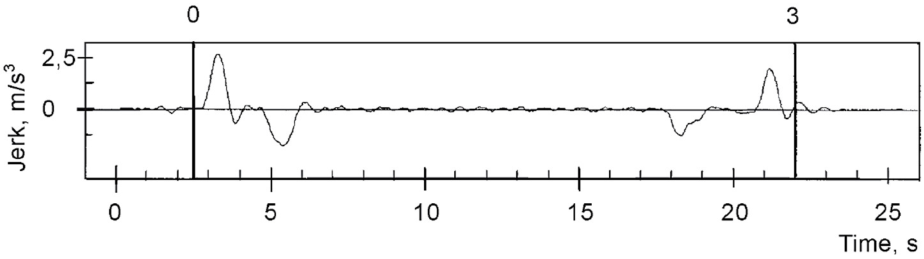

Figure 4. Jerk signal for a full trip in an elevator (BS ISO 18738:2003).

4. METHODOLOGY

The assessment of the comfort of the travel of lifts consists of an application of the methodology indicated by the BS ISO 18738:2003 standard. The characterization of the results obtained has as parameter the values provided by ISO 2631-1:1997 for vibration and with the values indicated by Howkins (2006) for over-acceleration.

4.1 Measurement device

Measuring cabin vibration during travel requires the use of an accelerometer, a transducer that converts kinetic energy into an electrical signal. The one used in this work is a triaxle transducer. In addition to the transducer, a device is needed that analyzes, weights at frequencies indicated by standard and stores vibration data. We used the VI-400Pro instrument, S/N 12430, a portable vibration meter and analyzer that instantly measures in four signal input channels. For this work, three of the channels were used to measure triaxle vibration. This equipment is capable of performing the weighting of frequencies digitally. In addition to measuring vibrations, the equipment must have enough internal memory to store the recorded data at a rate of at least 200 Hz in measurements of up to one minute. The configuration of the VI-400Pro is carried out through the software QuestSuite Professional II that allows you to define what will be the weighting curve by frequency employed for measurement as indicated above.

4.2 Elevator instrumentation

The vibration measurement shall be measured in a coordinate system originating at a considered point of entry of the vibration into the human body. Following the guidance of ISO-18738-2003, for the instrumentation inside the cab it is necessary that the seatpad is positioned in the center of the cab, as indicated in Figure 5. With the help of the feet, they are supported under the device to have better fixation, avoiding that measurement interferences occur, such as the rotation of the seatpad under the floor during the trip. The correct positioning of the accelerometer is important for the evaluation of vibration exposure to be consistent. The orientation of the measurement axes shall coincide with the indicative orientations of the standard (Figure 5).

The accelerometer is positioned following the triaxle coordinate system as defined by ISO-18738-2003. In addition to the correct alignment of the axes of the accelerometer, it is necessary that it be positioned as close as possible to the central imaginary axis of the transport, for this, it was used as a reference the marking of the grout of the new cabs and the door opening line for the old cabs. According to ISO 2631-1:1997, all measurements were made with only one person inside the cab. The directions of the transducer axes were: (a) horizontal direction x – in the direction of the cab backdoor; (b) horizontal direction y – in the lateral direction of the cab and (c) vertical direction z – in the direction of the axis of the elevator's cabin.

Figure 5. (a) Positioning of the transducer inside the cabin. (b) Foot on top of the transducer to ensure contact. (c) Overview of the instrument in the cabin. (d) Modernized cabin.

4.3 Tested Elevators

The elevators measured are electric and were in working condition. The building whose elevators were evaluated is in Porto Alegre, RS, being therefore commercial elevators, with many cycles of use throughout the day. The elevators were characterized according to their positions in the lobby, classified as modernized or old, according to Table 4, and identified with a number of construction site generated by the manufacturer responsible for modernizing the equipment.

Table 4. Elevator characteristics.

Construction Site Nº	Position in the lobby	Classification	Number of measurements
142905	President	Modernized	27
142906	Lateral	Modernized	29
142909	President	Not modernized	18
142910	Lateral	Not modernized	16

The 142905 and 142906 elevators had their modernizations completed, and the equipment released for use on 05/05/2021. The specifications of the traction machines are in Table 5.

Table 5. Characteristics of traction machines.

Construction Site Nº	Speed (m/min)	Load capacity (kg)	Command Panel	Power (HP)	Year
142905	150	1500	FDG M28	26.2	2021
142906	150	1500	FDG M28	26.2	2021
142909	150	1400	AC2, relay	40.0	1971
142910	150	1400	AC2, relay	40.0	1971

The measurements were taken in the weeks of June 2021. The modernized equipment has its preventive maintenance plan running monthly since its release. No information was found on the maintenance plan of the old elevators. There were limitations in the measurements of the old elevators caused by the characteristic of the elevators and the precariousness of the equipment. The old elevators only answered calls to a few floors because of the specificity of the traffic of each equipment on each floor. The modernized elevators serve all floors, therefore, 7 trips common to the four equipment were made, totaling 31 measurements. Random trips were also made through the race box on the four pieces of equipment to get more data. The trips made in each elevator can be seen in Appendix A.

The control systems present in the FDG (Frequencedyne Gold) control panel of the modernized elevators allow to numerically define parameters related to the rate of change of acceleration, unlike the old equipment. One of the stages of the modernization process is the adjustment of this parameter in search of the deceleration and acceleration curve that generates the most comfortable trips possible. The elevators with AC2 control panel the relay have the characteristic of sudden starts and stops due to their mode of operation.

4.4 Data Processing

The procedures for vibration assessment defined by ISO 2631-1:1997 include the method of treating the vibration signal as a function of time and the representation in frequency bands. To define the Jerk during processing, the acceleration signals in the axial *z* direction recorded by the device were filtered by a filter corresponding to the z direction. After, by recommendation of the standard, a low-pass filter of 10 Hz should be used in order to have an attenuation of 3dB at approximately 1.5 the cut-off frequency of 10Hz in order to maximize the signal-to-noise ratio and linear phase delay in the range of frequencies of interest. This post-processing process was implemented in the MATLAB R2012 software, the result can be seen in Figure 6. Once filtered, the data is fitted to a curve generated through a spline (a series of polynomials joined by points that meet the criterion of smoothness and differentiability). This recommendation of the standard aims to obtain a smooth curve that represents the acceleration and that can subsequently evaluate its derivative to find the jerk curve. The evaluation of Jerk should be done by evaluating the maximum value of occurrence in regions "0" and "3", indicated in Figure 6.

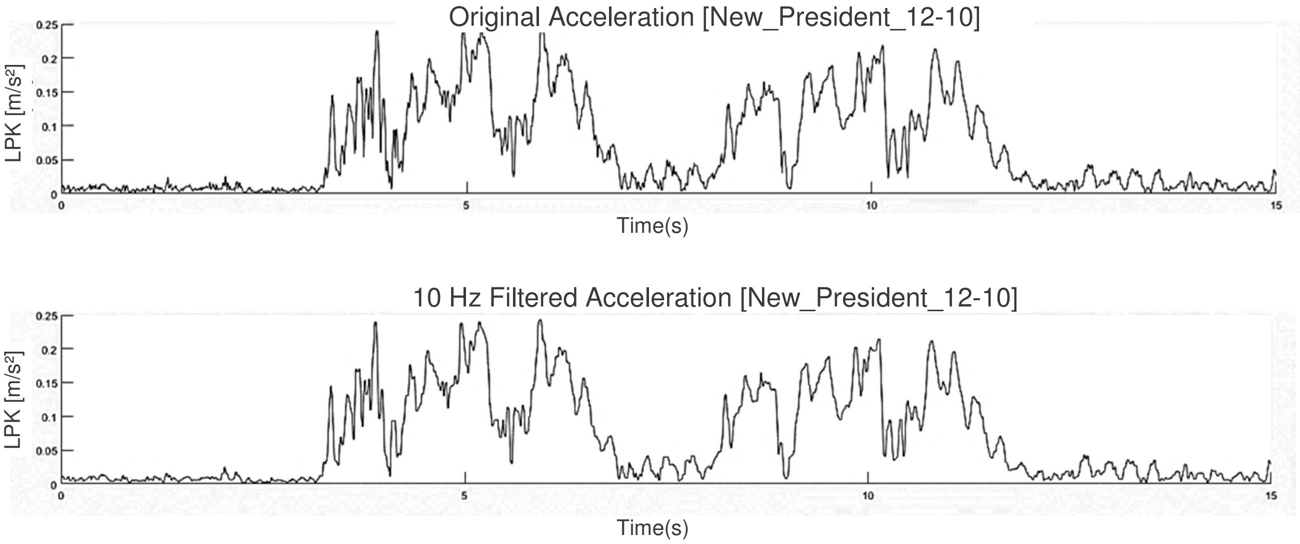

Figure 6. Acceleration before and after the 10 Hz filter respectively.

5. RESULTS AND ANALYSES

The measurements were performed in order to reproduce the reality of the daily use of the equipment by the passengers of the building. Data collection was performed with a mean total acquisition time of 24 seconds. The categorization of each trip as well as the numerical values obtained in relation to over-acceleration can be seen in Appendix B. As stipulated by ISO 2631-1:1997, and based on the results presented in Appendix B, the four devices are in the considerable range for evaluation of total RMS acceleration. According to the parameter of Howkins (2006) for over-acceleration, modernized elevators are in the range of pleasant to acceptable, while in all non-modernized lifts the measured values are considered unacceptable.

5.1 Evaluation of the elevator parameters

To obtain the graphical visualization of the parameters, the Matlab 2012 software was used. For the evaluation in sections 5.1.1 and 5.1.3, the descent trip between floors 12 and 10 performed in the elevator before and after modernization was chosen to compare with what was expected by ISO 18738:2003.

5.1.1 Aceleration

Figure 7 and Figure 8 show the typical graphs of travel acceleration in elevators measured with the RMS values obtained by the VI400-Pro commercial equipment and graphed with Matlab R2012.

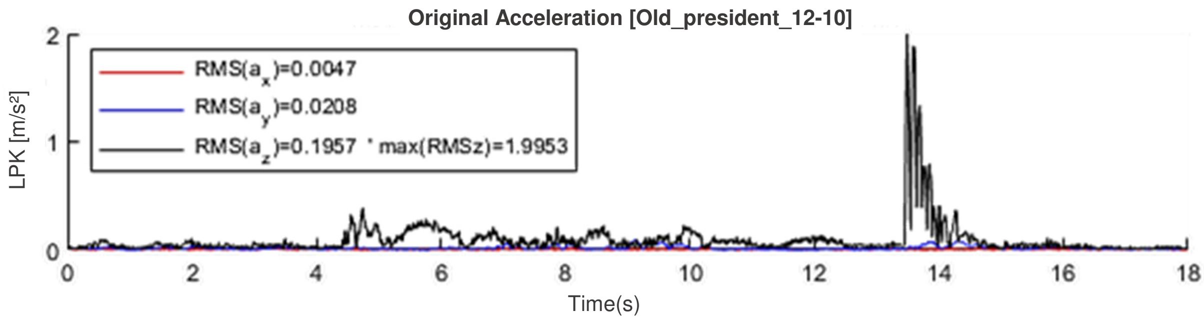

Figure 7. RMS acceleration in each axis of the former president elevator travelling from the 12th to the 10th floor.

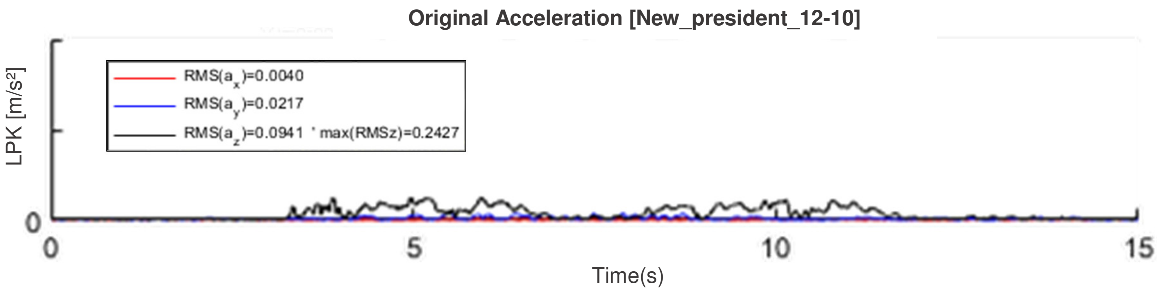

Figure 8. RMS acceleration in each axis of the modernized elevator travelling from the 12th to the 10th floor.

A sign of the acceleration was expected to be repeated during the start and stop. In Figure 7, it can be seen that for the old elevator, the start occurs with less vibrations, but there is a peak of acceleration in the axial z direction during its stop, in which the passenger feels the intense impulse upon arriving at the destination floor. This feature was repeated in all the old elevators. This mismatch is expected in an AC2-controlled relay elevator with a long time of use. In Figure 8, it is observed that the acceleration and deceleration regions of the curve are more similar, and there are no outlier peaks of acceleration at any time. This feature was repeated in all modernized elevators, showing that there is greater control over the parameter.

5.1.2 Comfort evaluation concerning total RMS accleration

Table 5.1 shows some information from the measurements of the total RMS accelerations for each of the lifts evaluated considering all the measurements made. In Appendix C, the same table is found only considering the trips common to the four elevators. The values found for each trip of each elevator are found in Appendix A.

Table 6. Results for full RMS acceleration by elevator among all measurements.

Construction Site Nº	Elevator	mean a_v (m/s²)	max a_v (m/s²)
142905	President modernized	0.072	0.102
142906	Lateral modernized	0.086	0.098
142909	President not modernized	0.166	0.202
142910	Lateral not modernized	0.175	0.263

In all elevator measurements, total RMS acceleration values were found in the range considered comfortable, but the average total RMS acceleration found in modernized elevators is approximately half that found in the old elevators. As expected for vibration measurements in elevators, effective RMS acceleration in the z-axial direction had the greatest influence. In the case of older elevators, there are two orders of magnitude greater than in the axial x direction and an order of magnitude greater than in the axial y direction.

5.1.3 Comfort assessment in relation to over-acceleration

Table 5.2 shows some information of the measurements of maximum over-accelerations for each of the elevators evaluated considering all the measurements made. In Appendix B, the same table is found only considering the trips common to the four elevators, and also information about the categorization of each trip in relation to the maximum over-acceleration found. The values found for each trip of each elevator are found in Appendix A.

Table 7. Results for maximum Jerk by elevator among all measurements.

Construction Site Nº	Elevator	Mean *Jerk* (m/s³)	Max *Jerk* (m/s³)	Comfort according to Howkins
142905	President Modernized	1.33	1.96	Pleasant Jerk < 2.0 m/s³
142906	Lateral Modernized	1.49	2.19	Acceptable 2.0 < Jerk < 6.0 m/s³
142909	President not modernized	15.45	20.88	Not acceptable Jerk > 6.0 m/s³
142910	Lateral not modernized	12.79	18.80	Not acceptable Jerk > 6.0 m/s³

6. CONCLUSIONS

The evaluation in relation to the comfort parameters defined by the ISO 18738:2003 standard allowed to show in a quantitative way the benefits brought by a project of integral modernization of elevators. It is also concluded that the vibrations in the axial z direction are predominant in relation to the other directions for the calculation of total RMS acceleration. In relation to the limits proposed by the ISO 2631:1997 standard of total vibration transmitted to the human body during the route, all trips made in the elevators remained in the range of comfortable, but there was a reduction of vibration of approximately 54% for the modernized cases when compared to the old ones. The trips made in the non-modernized elevators were characterized by RMS acceleration peaks in the z-axial direction on floor arrivals.

Regarding the classification suggested by Howkins (2006) for maximum over-acceleration, 100% of the trips made in the old lifts are considered unacceptable, while for the modernized elevators, approximately 93% are considered pleasant and 7% acceptable. There was a reduction of about 90% of the maximum Jerk measured in the modernized elevators compared to the old elevators. It is observed that in all the trips of the old elevators, only on arrival at the floor that the value of over-acceleration reached the unacceptable level.

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