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An implementation of risk-based inspection for elevator maintenance†

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Abstract

Elevators are devices that demand a high safety requirement. The elevator faults affect not only the operations of other assets but may also result in serious injuries or even death. Consequently, an elevator frequently requires the effective and appropriate maintenance strategy to sustain its functional operations. In this study, risk-based inspection, which is a technique for systematic decision-making to identify likely failed components and its consequences, is proposed for elevator maintenance due to a trade-off between economics and safety. The proposed technique is evaluated by using Korean disaster and failure statistic data. The results indicate that the proposed method offers an effective technique for elevator maintenance.

Keywords: Risk-based inspection; Failure statistics; Maintenance; Elevator

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1. Introduction

The advent of high-rise buildings in modern cities requires high-speed elevator systems to provide quick access within the buildings. These buildings require that elevators run at speeds faster than ever before. To attain this requirement, elevators achieve at the super high speed of 810 m/min, and handle capacity loads from 9 kN to 20 kN.

Elevators have various mechanical structures according to the rating speed and the maximum load capacity. Generally, elevators consist of three principal mechanical parts: traction machine, cage, and counterweight. The traction machine is installed in a machine room located on the top of a building. It is composed of traction motor, main sheave, and breaker. The counterweight is used to balance with the cage and connected to the second sheave of the traction machine through a moving pulley. The compensation rope and the sheave are used to eliminate the weight difference of both side ropes according to the cage position [1].

In elevator techniques, proper installation, ongoing maintenance, and inspection are required. Long-time continuous usage increases fault-occurrence probability, which requires troubleshooting quickly [2]. To assess the reliability and efficiency of the elevators, a maintenance program is a significant part of overall elevator system. Safe and reliable operations are of paramount importance to the owners, the management company, and the tenants as well as visitors who travel throughout these buildings daily. The targets of elevator maintenance are as follows:

- Prolong equipment life
- Improve equipment safety and reliability
- Reduce the cost of major repairs
- Minimize the inconvenience of equipment downtime

Since the elevator was introduced in the early 1910s, the Korean elevator industry has remarkably grown with 2,000,000 housing constructions in 1990. Currently, about 360,000 elevators are working in Korea, which is ranked 9th in the world. However, the number of people who have been rescued by 119 rescue teams owing to elevator accidents has reached the second-highest level of traffic accidents. The data obtained from the National Statistics Office on elevator accidents shows that there were 90 and 97 accidents in the years 2006 and 2007, respectively. These accidents are increasing annually as indicated in Table 1 [3]. Therefore, the demand for new technical solutions for lessening the safety accidents and breakdown is necessary. It provides a technical guide to promote the progressive, selective maintenance, and improvement of the safety of existing elevator. So, the aging elevators should be more effective, safer, more reliable and more comfortable through effective maintenance and improvement [4].

In this study, to reduce the probability of elevator breakdowns and increase safety, a risk-based inspection (RBI) for elevator maintenance is proposed and the most appropriate ways are sought to solve the fundamental problems in manag-

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Table 1. The number of accident and installation.

Year	Total number of installation	Number of accident	The incidence of accident (%)	Accident number per 10,000 persons
1998	159,230	28	0.0176	1.76
1999	174,261	12	0.0069	0.69
2000	190,187	22	0.0116	1.16
2001	208,497	28	0.0134	1.34
2002	231,562	16	0.0069	0.69
2003	259,850	40	0.0154	1.54
2004	289,808	25	0.0086	0.86
2005	314,495	42	0.0134	1.34
2006	336,311	90	0.0268	2.68
2007	359,098	97	0.0270	2.70

ing and maintaining elevators [5, 6].

2. Statistical analysis

2.1 Elevator accidents

Up to late 2007, the total number of elevators installed is 359,098 as shown in Table 1. The rate of elevator accidents per ten thousand elevators accounted for 1.54. In the damage accidents, death accounted for 148 people or 21.8%, the severe injuries accounted for 263 people or 39.8%, and less-severe injuries reached 266 people or 38.4%. In each cause of elevator accidents, users' errors accounted for 15.3%, poor maintenance accounted for 20.2%, while poor management and maintenance reached 11.9%, workers' errors and substandard manufacturing reached 6.1% and 3.9%, respectively. The rest took up with 6.7%.

2.1.1 Accident types and causes

Elevator accidents are increasing every year. Even though the same kinds of accidents have steadily occurred, the causes have not been eliminated yet. Accidents in relation to escalators or moving walkers among total safety accidents account for the highest rate of 20.3% as shown in Table 2. The rapid increase of the installed escalator triggers accidents to surge among most children and the aged.

Even though most citizens require high safety of elevators, accidents still rise owing to the absence of the double-function units of safety devices or the age of the elevators. Accordingly, efforts are made to improve the safety laws which are necessary for reinforcing public safety, across the world. Also, the same sorts of accidents frequently occur. At this point, when the lift laws are only applied for elevators to be newly-built, it is necessary to improve the safety level of aging elevators.

2.1.2 Risk assessment of accident by FMEA method

The failure mode and effects analysis (FMEA) technique determines how individual elements of a system can malfunction and what combinations of failure can result in an unsafe condition. Risk-based inspection (RBI) is the combination of the probability of failure and consequence of failure. Three types of RBI assessment are generally recognized as follows: qualitative approach which is based on descriptive data using engineering judgment, experience quantitative approach which is based on probabilistic or statistical models, and semi- quantitative approach, being an approach that has elements of both qualitative and quantitative methods. In this study, we adopt the semi-quantitative RBI approach to analyze elevators.

Table 2. Appearance of accident types.

Appearance of accident type	Rate (%)
Crushing riding after opening the landing door with emergency key	12.4
Occurrence from escaping and rescuing process	4.4
Occurrence by trying failure repair by elevator laymen directly	3.2
Worker accident by disobeying safety rules during working	8.0
User accident by disobeying safety rules during working	1.6
Thoughtlessness when the car enters in the car lift	4.0
Jamming and crushing in the gap between the car bottom and hoist walls	9.2
Poor components	15.9
User carelessness or disorder conduct	8.0
Maintenance carelessness	3.2
Dumb waiter	8.0
Accident on escalator and moving walk	20.3
Accident on a wheel chair lift for disabled persons	1.2
Others	0.8

A risk analysis is a series of logical steps that enable a systematic identification and study the hazards and their corresponding causes and effects. The identification of hazards, followed by an assessment of their severity and probability of occurrence shown in Table 3 [7], yields a measure of risk associated with the individual hazards. Through the use of an interactive process, each hazard and effect are evaluated and either eliminated or, if necessary, controlled by means of appropriate safety measures that reduce the corresponding risk to an acceptable level of safety as shown in Fig. 1. For this purpose, the best approach is to form a risk analysis team by selecting the members and choosing a team leader/moderator.

The cause and effect of each hazard in terms of probability of occurrence and the severity of its effects are assessed. The combination of severity and frequency of occurrence quantifies the risk associated with the hazard. The assessment results are evaluated in terms of residual risk and the acceptable level of safety. If the level of safety is unacceptable, further risk reduction measures are required and the following procedure should be used:

- Eliminate the hazard
- If the identified hazard can be eliminated, take the necessary measures to reduce the risk to an acceptable level of safety as determined by the lift technician.

Table 3. Relation between severity/frequency and corresponding risk level.

Frequency		Severity			
		I (High)	II (Medium)	III (Low)	IV (Negligible)
A	Highly probable	I A	II A	IIIA	IVA
B	Probable	I B	II B	IIIB	IVB
C	Occasional	I C	II C	IIIC	IVC
D	Remote	I D	II D	IIID	IVD
E	Improbable	I E	II E	IIIE	IVE
F	Highly improbable	I F	II F	IIIF	IVF

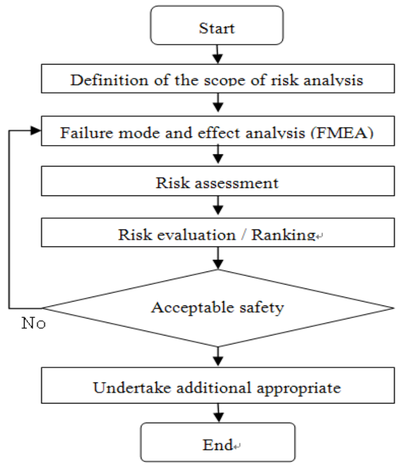

Fig. 1. Risk analysis procedure.

Table 4. Risk assessment examples of accident by FMEA method.

Item	Function	Failure mode	Assumed cause	Effect	Estimation of risk		Grade	Protective measures (risk reduction measure)	After protective		Effect
					S	F			S	F	
Brake contacts	Release and stop the function of break by running current point of contactor	Wear or fusion	The wear or fusion of contactor because of occurrence of excessive electric arc or capacity shortage	Injury, a serious wound or death because of starting with doors open or when over speed when ascending	I	D	2	•Select appropriate contact capacity for circuit design • Surge circuit supplementation of brake coil to absorb surge (3) Periodical check	1	E	Elevator
Brake release circuit	Release and stop the function of break by supplying and cutting off the current by using magnetic contactor	Jamming or fusion of contacts	Brake coil current Cut by one magnetic contactor		I	D	2	•Dual system of brake control circuit •Control circuit supplementation that can cut off the source of brake coil when safety switches operate	1	E	Elevator
Brake contacts of PLC circuit	Release and stop the function of brake	Movement incapacity or malfunction	Directly running brake contacts by PLC output port		I	D	2	•Brake control circuit supplementation operated by using a contactor without directly moving method for PLC circuit	1	E	Elevator
Brake	Release and stop the devices of car	Lining wear	Stroke of brake plunger is excessive		I	D	2	•Circuit supplementation which release of brake can be checked •Moderate adjustment about release power	1	E	Elevator Dumb waiter

- Inform the user of the residual risks.

If the risk evaluation still indicates that the remaining risk is not within an acceptable level of safety, the whole process has to be repeated as shown in Fig. 1 [3].

Table 3 indicates the relation between severity/frequency and corresponding risk level. The level of risk can be divided into four grades by using the combination of severity and frequency of the risk:

- Grade 1: Unacceptable (IA, IB, IC, IIA, IIB, IIIA), corrective action required to eliminate the risk
- Grade 2: Undesirable (ID, IIB, IIC, IIIC), corrective action required to mitigate the risk
- Grade 3: Acceptable with review (IE, IID, IIE, IIID, IVA, IVB), review required to determine whether any action is necessary
- Grade 4: Acceptable without review (IF, IIF, IIIE, IIIF, IVC~IVF), no action required

Table 4. Risk assessment examples of accident by FMEA method (continued).

Item	Function	Failure mode	Assumed cause	Effect	Estimation of risk S	Estimation of risk F	Grade	Protective measures (risk reduction measure)	After protective S	After protective F	Effect
Slip distance	Braking distance when car stop during the running in no load	Over stopping distance	Lack of braking capability	Injury or death because of starting with doors open or slip occurrence	II	C	2	• Periodical maintenance	2	E	Elevator Dumb waiter
Counter-weight	Weight change of car and counterweight	Control incapacity	The change of unbalance rate	Injury, a serious wound or death because of starting with doors open or slip occurrence	II	C	2	• Weight compensation of counterweight when the interior of a car is done • Periodical check	2	E	Elevator Dumb waiter
Door control circuit	Function for door opening and closing by the control signal	Starting with car door open	Door monitor circuit is designed in single circuit	Injury, a serious wound or death because of jamming or crushing of passengers	I	D	2	• Circuit supplementation by dual system of door circuit	1	E	Elevator
Earth of safety circuit	Function to stabilize power supply and protect men when leakage currents or electric shocks occur	No cut off fuse	If safety circuit is not earthed, in case of leakage currents, fuse is not cut off and take fire or starting with doors open	Injury, a serious wound or death because of fire or doors open or slip occurrence	I	D	2	• Earth of safety circuit • Periodical check	1	E	Elevator
Reverse phase prevention devices	Function to stop elevator operation when one of the three phases power disconnected by mistake	Reverse run	Reverse phase detect function was not operated or not installed	Shock of occurrence because of malfunction	I	C	2	• Circuit supplementation of reverse phase detect function • Periodical check	3	E	Ropes elevator Hydraulic elevator
Over load detection devices	The function to stop a start of car with door opening if people ride with overload	Slip of car	Riding more than the capacity of the car	Injury by crushing of car	I	D	3	• Circuit design of overload switch by normal close (B contact) • Periodical check of over load switch	2	E	Elevator

Table 5. The order of fault components.

Fault components	Number of cases	Rate (%)
Button and position indicator	2,448	23.3
Hall door	1,900	18.1
Car door	1,801	17.1
Controller	958	9.1
Car	820	7.8
Hoist way	484	4.6
Governor	386	3.7
Counterweight	179	1.7
Traction machine	77	0.7
Others	1,453	13.8
Sum	10,506	100.0

This study investigates elevator accidents resulting in poor safety parts, safety circuit, design and systems. This study also conducts an analysis on failure modes, estimates causes and effects of each category, and evaluates the risks and decided maintenance ranking. By establishing safety strategies, it can assure the safety of elevators.

Redundancy is a property of a system that is provided by using two or more elements to influence the final action of that system. Table 4 shows the result of risk assessment on accident by using Korea disaster statistics that is evaluating risk analysis by FMEA method. It is an aim to assure the safety of existing elevators by using maintenance. In Table 4, ‘S’ and ‘F’ mean the severity and frequency of the risk, respectively.

2.2 Elevator breakdown

The statistical analysis on elevator breakdown is implemented by using the data acquired in three years of two domestic manufacturers. The number of elevators installed in public housing and multi-use facilities is total 1174 units (682 for manufacturer A and 492 for manufacturer B). The total number of breakdowns is 10506 (3235 in manufacturer A and 7271 in manufacturer B).

2.2.1 Breakdown parts

A comparative analysis on the breakdown parts which are usually broken, such as button and floor indicator, hall door, car door, controller, and hoist way, is indicated in Table 5 in order of descending rate. Among these, faults of floor indicator, hall door, and car door account for about 58%.

2.2.2 Breakdown causes

Table 6 indicates that the causes of breakdowns owing to the change of adjustment parts, loosened/ destructed/ and destroyed breakdowns account for 66.64%. Other breakdowns resulting in sound or vibrations are of high ratio.

2.2.3 Analytic results of breakdowns

The breakdown parts are button and position indicator, hall door, car door, controller, and hoist way. The breakdown parts often derive from incapability in operating. The noise and vibration including sub standardized door and button cause much breakdown. The elevator malfunction is mainly the change and loose adjusted parts. The old worn-out, damage, destruction of component, poor conjugation, and alien substance-caused contamination breed such breakdowns.

- This result evidently shows that elevator buttons, floor indicators, old worn-out, and ill treatment triggers are the most enormous elevator damages and breakdowns.
- The alien substances-caused contamination and maladjusted parts in hall door and car door trigger are the second-most enormous breakdowns.
- Factors such as tensile blocks, balance chains in regulator, because noises, interphone and regulator switch are often out of order. Noises out of balance weight result from the relatively frequent breakdowns.
- All of the hall buttons and indicators are often switched and repaired. The damages owing to common quality maintenance difference from each manufacturer and users' carelessness in maintaining parts are analyzed as the major cause of elevator breakdowns.
- Among break-downs related to part durability, the short-durable switch contactor and magnetic contactor have to be substituted in advance, but they tend to be replaced after the breakdowns happen.
- The contamination-causing breakdowns can be prevented in advance about 9% by making regular maintenance and cleanliness. Parts that require special attention are hall door sill, car door sill, push button, hall door switch contact, and gate switch contact in that order.

2.2.4 Risk assessment of breakdown by FMEA method

The cause and effect of each hazard in terms of probability of occurrence and the severity of its effects is assessed. The combination of severity and frequency of occurrence quantifies the risk associated with the hazard. The assessment results are evaluated in terms of residual risk and the acceptable level of safety. If the level of safety is unacceptable, further risk reduction measures are required.

Table 7 shows the result of risk assessment of the elevator breakdown data obtained from domestic manufacturers using FMEA method. It is an aim to assure the safety of existing elevators by using maintenance. In Table 7, the results of the function of item, failure mode, assumed cause and the effect by failure are shown.

Table 6. Breakdown rate according to causes.

Breakdown causes	Rate (%)
Changed adjustment parts, looseness, transformation	46.2
Destruction, damage	20.2
Abnormal sound, vibration	4.6
Life excess, component aging, abrasion	4.0
Contact badness	2.8
Contamination	1.8
User carelessness	1.4
Malfunction	1.1
Jamming	0.9
Trip	0.8
Snapping of a wire	0.8
Others	15.5
Sum	100

3. Strategies for elevator safety

3.1 Elevator accidents

Elevator performance assessments are determined by the factors such as safety, reliability, ride quality, sound and vibration, including energy-consuming amount, traffic amount, traffic system efficiency, efficient maintenance, and door-opening and closing hours. Whenever elevator users enter an elevator, safety is the most direct effect. The quotient of reliability and comfort in relation to part breakdowns and durability serves as the sense of riding. The functions of electric motor, speed reducer and revolving body machine are the direct effects on reliability and sense of ride. However, it is difficult to make the right analysis on how they function well. Consequently, it takes some hours to find out problems or breakdowns so as to make ambiguous predictability on such problems or breakdowns. Most maintenance and management industries need to maintain and manage possible poor equipment, by gathering regular data with the aid of machine discrepancy-diagnosing equipment. And, it is a requirement to make premium management and maintenance of elevators by early detecting vibration damages and analyzing the damage frequency.

Table 7. Risk assessment examples of accident by FMEA method.

Item	Function	Failure mode	Presumption cause	Effect	Estimation of risk elements		Grade	Protective measures (risk reduction measure)
					S	F		
Button	Car calling registration, registration function of the desired floor	The button malfunction caused by super-annuation	Life superannuation, damage, the operational in-ability which is caused by variation of the regulation region	Use inconvenience of passenger	4	B	3	•Periodical inspection •The periodic part replacement which considers a useful life
Hall door device	The device to protect a passenger from being intercepted by door between the platform and hoistway when car departs	Operation standstill, noise and vibration	Interlock switch, the opera-tional inability which is caused by foreign substance etc. of the sill groove	The shock caused with noise and vibration, or breakdown confining	3	B	2	
Car door device	The device to protect a passenger from being fallen to the entrance and exit during the running	Operation standstill, noise and vibration	Adjustment badness of the switch type, variation and contact badness		3	B	2	
Control panel	The function to control the operation of the elevator	Operation standstill	Change of the adjustment part, superannuation and attrition, the operation inability which is caused by malfunction etc.		3	B	2	
Cage	Movement means of the passenger who is direct in the space where boards the passenger	Operation standstill, noise and vibration	Parts superannuation, varia-tion and coming loose, ad-justment badness		3	B	2	
Traction machine etc.	Power unit to lifting up and down the car by using the wire rope	Operation standstill and function loss	Parts superannuation, the damage of bearing, gear, unbalance, misalignment, looseness,		3	B	2	•The tendency management which leads the periodic measurement of the noise and vibration •The periodic parts replace-ment which considers a use-ful life

In this regard, this chapter is going to earmark the standardized value of potential vibration and noises by using data measured on the spot with the help of vibration and noise-measuring outfits in relation to predictability (precision) technologies. And then, this chapter is putting the analytic results of damage cases into elevator management and maintenance.

3.2 Elevator breakdown

Ride quality is one of the key indexes to evaluate an elevator's system performance. Elevator vibration is one of the other factors affecting passenger's feeling. The quantity of car vibration is related to external exciting energy, its frequency distribution and the robustness of system design.

The proposed value of Table 8 is conducting a statistical analysis on the measured value of ride quality and vibration of the traction machine. Thus, it is necessary to use the analysis as performance assessment standards. If such standards are exceeded, the causes need to be analyzed through FFT analysis. It is deemed that the measurement and analysis on elevator ride quality and vibration of traction machine in combination with prevention maintenance and prediction maintenance would guarantee the higher stability and reliability [11].

4. Case studies: performance assessment

4.1 Car resonance

For a driven machine with a rotating speed of 1460 rpm, which has a reduction gearbox of worm-wheel, the rotating frequency is 1460/60 = 24.33 Hz and the gear mesh frequency is 48.6 Hz because the worms have two threads. This elevator resonance occurs by resonance phenomenon, which is shown in Fig. 2, in the conjugation zone of cage frequency and the 48 Hz element as gear mesh frequency (GMF) combined with excited frequency of motor. For reducing the vibration, a dynamic absorber is employed as shown in Fig. 3.

4.2 Rail installment check by car vibration measurement

In the time domain, apparent impact appears every 5 meters periodically as shown in Fig. 4; for each guide rail, length is 5 m. It can be improved by readjusting the rail installment as shown in Fig. 5.

Table 8. Proposed performance assessment criteria.

Item		NEII (1.75m/s)	Hong Kong (acceptance criteria) less than 6 m/min	Proposed criteria (1.75m/s)
Car inside vibration	Horizontal vibration X axis	25	25	15 gal
	Horizontal vibration Y axis	25	25	15 gal
	Vertical vibration Z axis	25	25	15 gal
Traction machine vibration	Motor load (vertical/horizontal) Gearbox (vertical/horizontal)	-	-	2.8 mm/s rms
Car inside sound	Sound in car at rated speed	60	25	55 dB (A)

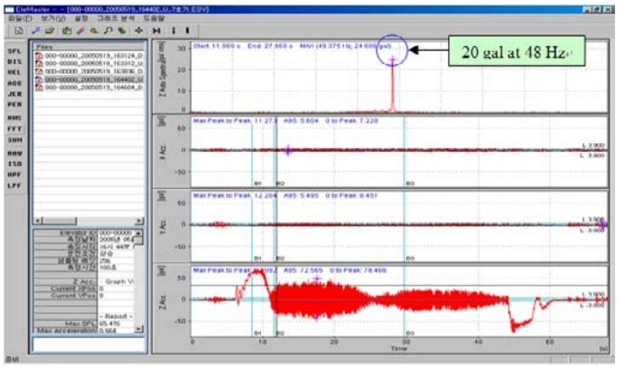

Fig. 2. Excessive vibration due to resonance (Z axis: 94 gal).

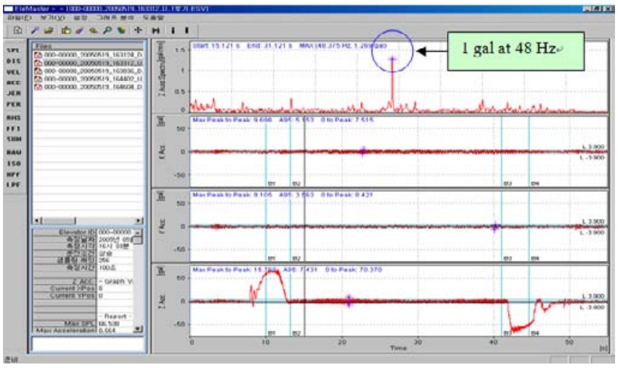

Fig. 3. Vibration reduction by dynamic absorber (Z axis: 7 gal).

4.3 Mechanical faults

Table 9 indicates frequency features of various faults that are obtained through a site inspection.

For a driven machine with a rotating speed of 1460 rpm, which has a reduction gearbox with a worm and worm-wheel, the frequency feature appears by 1X element (1460/60 = 24 Hz) dominantly because of elevator motor unbalance. Fig. 6 shows a measuring result at a site.

Table 9. Vibration frequency due to mechanical faults.

Fault	Characteristic frequency
Misalignment	Dominant 2X component
Unbalance	Dominant 1X component
Guide roller vibration	$\pi \times$ guide roller diameter $\times$ RPM
Bearing fault	Bearing fault frequency
Resonance	Coincidence of GMF element and cage frequency
Rail vibration	Periodic peak vibration waveform

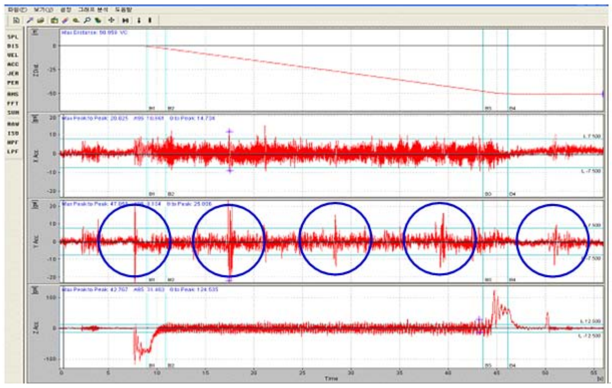

Fig. 4. Periodical vibration occurrence because of installation badness (Y axis: 25 gal).

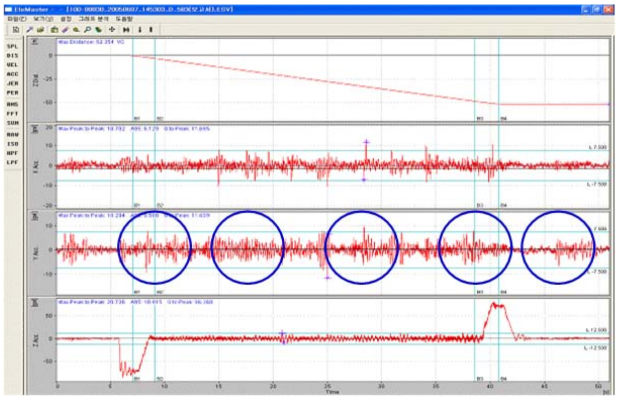

Fig. 5. Data of installation state of the rail after adjust (Y axis: 11 gal).

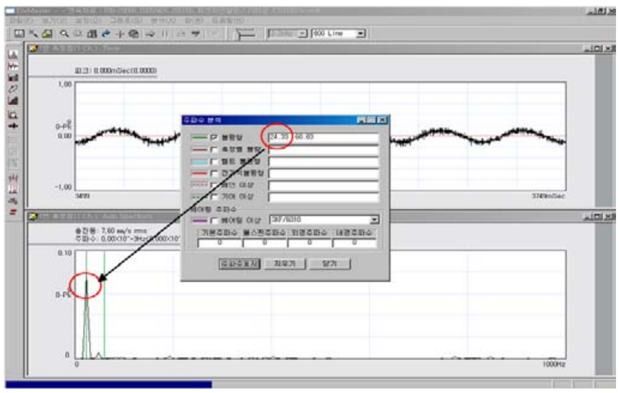

Fig. 6. Unbalance fault.

Table 10. Maintenance guidance for elevators.

Name of parts		Inspection method	Fault feature	Effect of breakdown	Counter-measure	Inspection cycle (month)
Traction machine	Reduction gear	Vibration waveform & FFT Analysis	• Dominant gear mesh frequency (above 2.8 mm/s, rms) • Unbalance, misalignment & bearing fault frequency • Increased noise & vibration	Shutdown	Adjustment or change for baseline value	3
		Visual	• Pitting in worm wheel		Change for baseline value	6
	Sheave	Visual, size verification	• Crack of sheave • Excessive wear of sheave groove • Excessive creep • Undercut residue • Excessive rope slip	Slip or fall	Change for baseline value	3
	Bearing	Vibration	• Bearing fault frequency • Increase of noise & vibration	Shutdown	Change for baseline value	3
	Oil seal	Visual	• Deterioration of seal • Leakage of gear oil	Vibration Noise	Change	3
Motor		Deterioration	• Weakness of insulation resistance • Abnormal vibration • Overheating	Shutdown Fire	Insulation reinforcement Change	3
Motor Bearing		Vibration	• Bearing fault frequency • Increase of sound & vibration	Shutdown	Change for baseline value	3
Brake		Visual, size, electric circuit	• Insulation weakness of coil • Plunger wear & deformation • Switch wear & rust • Crack & torsion of spring	Uncontrol movement	Change	1
Controller	Relay	Visual	• Wear of contact • Trembling of contact	Operation shutdown Opening departure	Change	1
	Main contactor	Visual	• Wear of contact • Melting • Capacity shortage		Change	1
	Brake contactor	Visual Surge waveform	• Wear of contact • Melting • Capacity shortage		Change Circuit complement	1 12
	Safety circuit	Visual	• Use of single brake and door circuit	Opening departure	Circuit correction	12
Governor		Operation test Visual	• Aging, wear • Not working	Fall of car	Repair Change	1
Door	Safety shoe	Visual Operation test	• Shoe deformation • Operational badness • Electric wire contact badness	Jamming accident	Repair Change Circuit correction	1
	Guide shoe	Visual Size inspection	• Wear, corrosion • Buried quantity of guide shoe (6 mm below)	Door separation Fall accident	Repair Change	1
	Hanger roller	Visual Operation test	• Urethane damage • Noise • Bearing fault	Noise, Vibration	Repair Change	1
	Interlock switch	Visual Operation test	• Aging, wear	Operation shutdown	Repair Change	3
	Door motor	Visual Operation test	• Insulation breakdown • Abnormal vibration • Motor overheating	Operation shutdown Noise Vibration	Repair Change	1
	Controller	Visual Operation test	• Insulation resistance Weakening	Operation shutdown Noise Vibration	Repair Change	1
	Door switch	Visual Operation test	• Aging, wear and carbonization of contact	Operation shutdown	Change	1

Fig. 7 shows the bearing frequency feature occurring because of bearing abrasion. In the time domain, the waveform feature appears by a period of 13.39 ms. In the frequency domain, the frequency feature is shown by ball pass frequency of outer race (74 Hz) as shown in Fig. 8.

For a driven machine with a rotating speed of 1460 rpm, which has a reduction gearbox with a worm and worm-wheel, the frequency appear to be double frequency ($2\times1460/60$ =

Table 10. Maintenance guidance for elevators (continued).

Name of parts		Inspection method	Fault feature	Effect of breakdown	Counter-measure	Inspection cycle (month)
Cage	Vibration Sound	Vibration & noise	• Increase of the vibration & noise - Resonance - Gear mesh frequency - Misalignment frequency - Unbalance frequency - Rail shock vibration - Guide roller vibration - Fan noise	Vibration Noise Operation shutdown	Repair Adjust-ment	6
	Button lamp indicator	Visual	• Button getting stuck • Aging, wear	User inconvenience Unnecessary operation	Repair Change	1
Guide rail		Visual Laser equipment	• Corrosion • Bending • Periodic vibration	Vibration Sound	Adjust-ment Repair	24
Rail guide Shoe		Visual	• Wear, aging • Vibration	Vibration Sound	Change Design change	3
Rail guide Roller		Visual	• Wear, aging • Vibration	Vibration Sound	Change Design change	3
Overload Device		Visual Counterpoise inspection	• Aging, performance degradation • Normal A contact • Overbalance ratio change	Slip Fall of car	Repair Design change	1
Protection against dust rubber		Visual	• Deterioration • Function loss	Vibration	Change	12
Safety gear		Operation inspec-tion	• Wear, corrosion • Malfunction	Fall	Change	3
Landing switch		Visual	• Aging, performance degradation • Malfunction	Operation shutdown	Change	3
Main rope		NDT Visual Size	• Wear, element wire rupture • Excessive slip • Wire rupture	Fall Sliding	Change	6
Limit switch, deceleration and terminal switch		Operation Visual	• Aging, damage • Return spring separation • Roller crack or damage	Operation shutdown	Change	3
Various fuse		Visual	• Fuse cutting	Operation shutdown	Change	1
Spring buffer		Visual	• Damage of spring • Spring rust	Malfunction	Repair Change	3
Oil buffer		Operation Visual	• Operation badness • Insufficient oil	Shock unabsorbed	Oil supply Repair	3

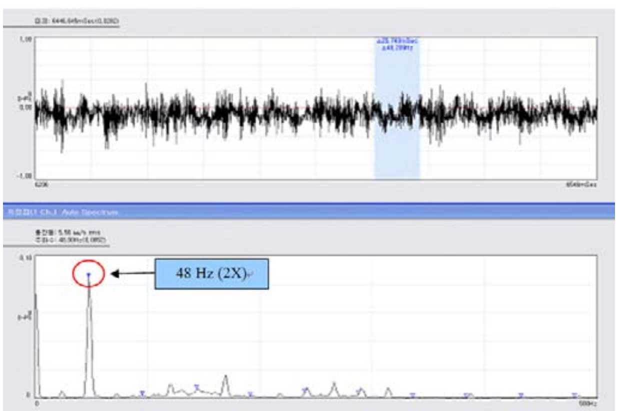

Fig. 7. Misalignment fault (48 Hz).

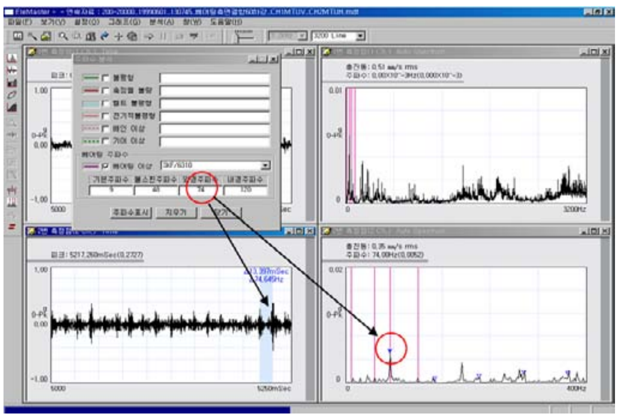

Fig. 8. Bearing outer race fault (74 Hz).

48 Hz) of rotating speed as shown in Fig. 8 due to misalignment.

5. Guidance for effective maintenance

Although elevator machines are designed, produced or/and installed through accurate quality maintenance, they could lose not only their original functions but also have low performance and safety accidents, without scientific management and maintenance. Thus, this research studies the possible deficiency arising from each part test, individual parts or systems. And, this study has conducted an examination about the effects on each part breakdown and steps against it along with their regular check-up period.

The management and maintenance strategies right for an elevator are expected to exert very important effects on preventive check-ups in accordance with the regular substitution period. Safety, reliability and comfort would contribute to managing and maintaining elevators. It is also indispensable to make a regular performance test. Table 10 shows an elevator maintenance guide that can inspect effectively according to fault feature and decide the appropriate inspection period [5].

6. Conclusion

This paper presents an investigation of risk management, elevator fault analysis, and life-cycle assessment based on studying and surveying of the elevator component replacement life-cycle. It also provides the elevator performance management development as well as elevator evaluation criteria to apply the condition prognosis and maintenance. The risk management by RBI method gives the proposed guidance for optimal RBI. This paper studies the risk assessment based on the elevator accident and breakdown statistics data by using FMEA techniques. We implement the RBI for the elevator maintenance on the site. This paper also predicts the remaining lifetime, optimizing the maintenance decision making for an elevator by using RBI. It then offers propositions on how to prevent elevator accidents for premium management and maintenance.

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