Safety and Buffer Testing without Weights

by John Koshak

Learning Objectives

After reading this article, you should have learned that:

◆ The use of alternative testing systems have been in use for two decades in Europe.

◆ The equation $F = ma$, when m (mass) and a (acceleration) can be directly measured, can be used to accurately calculate F (f).

◆ Accelerometers in common use today are ridiculously sensitive and accurate. With accurate data, near-absolute results can be calculated and verified.

◆ The results from alternative testing systems successfully challenge the notion that test weights are necessary.

◆ The A17 committee has language proposed that will allow this technology, assuming the proposal passes the consensus process.

Introduction

The use of alternative testing systems of safeties and buffers has been permitted and used outside North America since the early 1990s and provided acceptable results according to inspection officials in Europe. After long success with alternative test systems, the A17/B44 [in the years this was introduced, B44 and A17 were not together] community drafted allowance language in the Mechanical Design Committee, TR 95-73 (later renumbered TN 02-2275), which is currently at the Mechanical Design Committee for action on the latest ballot. In order to see firsthand how one type of system works and what the results are, a comparative test of the system was done at a major university on three duplex traction elevator groups. This article presents the results of these tests for the reader's analytical evaluation.

Conventional A17.1/B44 Test Methods

Category 5 tests require testing of safety retardation forces[1], brake retardation forces[2] and traction forces[3] using test weights. The Category 5 safety test requires full load in the car, running the car at rated speed and tripping the governor to prove the safety actuation, and recording the stopping force by measuring slide marks on the rails. Acceptance testing requires full load in the car, running the car at governor overspeed and measuring slide marks on the rails.

The brake tests require overloading[4] the car to prove the brakes' stopping and holding forces.

The traction test requires placing the empty car at the top floor and running the counterweight onto the buffer and continue to run up to prove the car is not picked or the motor stalls due to too much traction, then placing the fully loaded car at the bottom floor and running the car down onto the buffer and continuing to run down and prove that neither the counterweight is picked, nor the motor stalls due to too much traction. Too little traction is tested during the course of testing by virtue of the car not slipping traction; however, there are no specific parameters for a test.

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Value: 2 contact hours (0.2 CEU)

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These tests are necessary to ensure that degradation of components from the original design and installation has not occurred and affected system compliance. These traditional tests have been proven to be an effective demonstration of code compliance and were the only possible methods of ensuring continuing code compliance throughout the life cycle of the elevator until instruments were developed to directly measure these effects such as the Henning ELVI system.

Disadvantages of Conventional Testing Methods

Safety Tests

The disadvantages of full load/full speed safety tests are well known. The tests remove safety-shoe material in such quantities that ultimate replacement of the shoes is required or can cause unknown system response during the next required actuation of the safety. Longer duration retardations with full load may possibly damage cab components and rails and rail mounting systems. Another disadvantage is that the safety is required to stop a freefalling car and, therefore, the system's response to a freefall must be determined without actually cutting all the suspension members, something that is not tested today and is only inferred by test results with suspension means intact. The current method of finding and measuring the slide marks is not exact and therefore another disadvantage. Finally, another disadvantage is the management and handling of test weights themselves. This can be hazardous to handlers, and, if clearly shown to be unnecessary, allowance for testing without test weights will lead to fewer injuries and less damage to property.

Brake Tests

The use of test weights to set brake adjustment requires adjusting and testing to be a time-consuming task and, therefore, less likely to be done. This is a disadvantage, as many brake tests can be overlooked and left untested where AHJ inspections are not witnessed or with less frequency than suggested by A17.1/B44. If the tests could be done without test weights and with high accuracy, there would be more compliant brakes based on the ease of brake-force verification alone.

Traction Tests

The disadvantage of the present methods include lack of consistent testing in jurisdictions where inspections are not consistently done and the lack of detailed information of traction reserve left in the system. The parameters for the test are very broad, and while this may indicate reserve, they do not provide any measurable verification of wear data to infer when the traction reserve may disappear. Having a tool that can provide a direct measure of this traction force for future reference is invaluable for verification for code-compliance and design purposes.

If the disadvantages of present testing methods can be overcome and provide equivalent test results, safety is preserved. This is the most important goal in ensuring that the elevator is in compliance.

ELVI Test System

The ELVI system is comprised of three major components: a laptop computer with software, rope-tension measuring gauges with an output into the laptop and an accelerometer output into the laptop with precise synchronization between the two subsystems. The counterweight is weighed independently, recorded into the laptop ELVI program, and then the rope gauges are moved to the car ropes where the car weight is recorded and left for the duration of the testing.

The first dynamic test is to run the car at speed onto the safety with the ELVI program running. It records the rope force (as a function of rope tension) and the accelerometer output. While still on safeties, the second test is performed by running the car at inspection speed in the down direction to record the changing rope tension, which is proportional to system traction when the exact mass of the car and counterweight are known. The third test is to run the car up off the safety, run down to the bottom
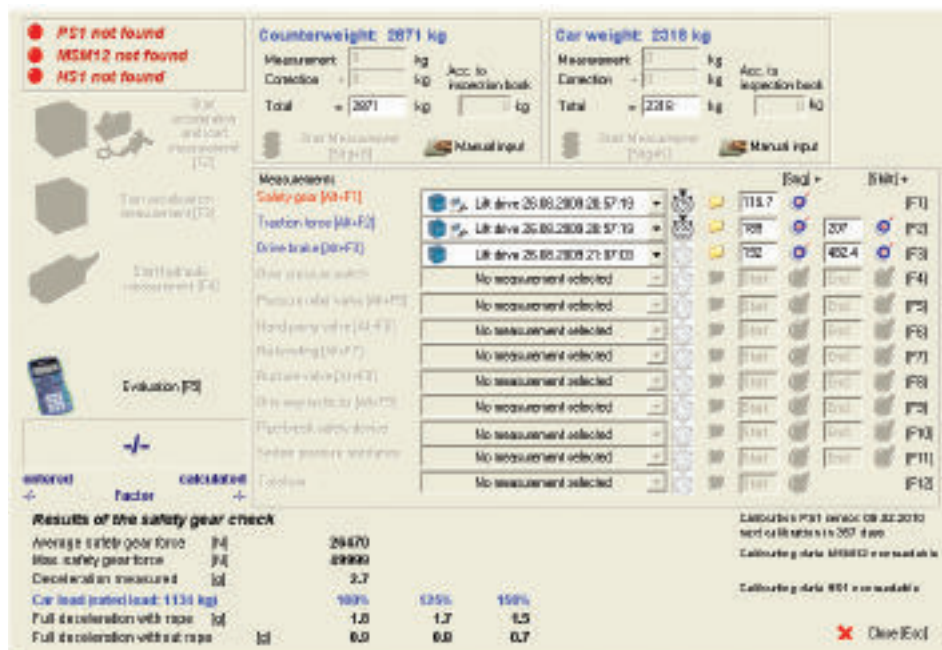

Figure 1: Safety test result screen

and then run up at rated speed into an emergency stop. This measures the brake force. If an emergency brake is present, a second brake test of only the emergency brake is performed the same way. Finally, the car is run down again, then up again to record both the machine and emergency brakes setting simultaneously.

The results can then be printed for easy reading and recording into the Maintenance Control Program (MCP) and for AHJ submission. Sample screenshots of the ELVI system reporting are shown in Figure 1. The results are shown at the bottom of the screenshot. This safety stopped the empty car at 2.7 g$_{(peak)}$ and is calculated to be capable of stopping the elevator with suspension means intact with:

◆ 100% load at 1.8 g$_{(peak)}$
◆ 125% load at 1.7 g$_{(peak)}$
◆ 150% load at 1.5 g$_{(peak)}$

A significant benefit of the ELVI system is the ability to calculate the safety force directly and, therefore, calculate the retardations without suspension means attached, again calculated above at 100% load to be at 0.9 g$_{(peak)}$, with 125% load at 0.8 g$_{(peak)}$ and 150% load at 0.7 g$_{(peak)}$.

The brake test results are shown at the bottom of Figure 2. The tests were all passed; they are individual and reflect the normal or emergency brake. When the tests are done, the system needs to have the notation for reference.

The traction force results are shown at the bottom of Figure 3. This value is calculated in both the static and dynamic phases. The results show that the static traction force is 2.13 times the code-required traction force based on the exact T1 and T2 loading measured at the beginning of the tests and resultant measured coefficient of friction at the sheave grooves.

On this unit, the dynamic traction force is 1.96 times the required force.

Further data is provided such as what load in the car would begin to cause loss of traction at 3,796 kg static and 3,296 kg dynamic loads. Based on the rated load of the car input at the start of the test, the rated load factor can be calculated and displayed. Finally, based on the T1 and T2 values measured with the ELVI system, absolute counterweight balance is displayed.

Rope Tension Gauges

The ability to provide this level of detail is a result of the use of rope tension measuring gauges that have a 2.5% accuracy of weight measurement of the car and counterweight. In terms of equivalent measurement, we would typically have to get an appropriately sized scale, then pick the car or counterweight to measure the weight. This is a time-consuming
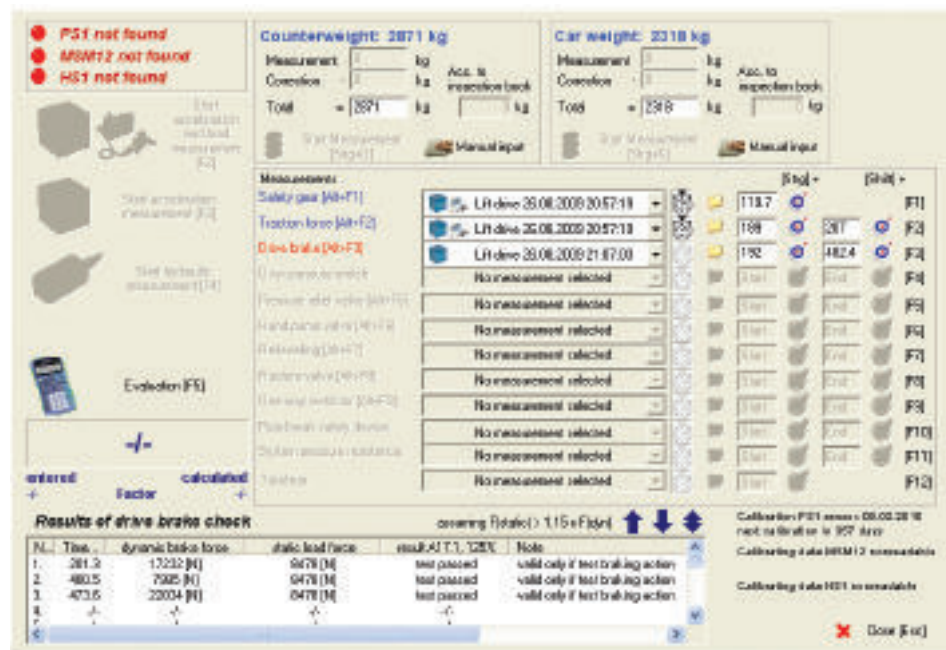
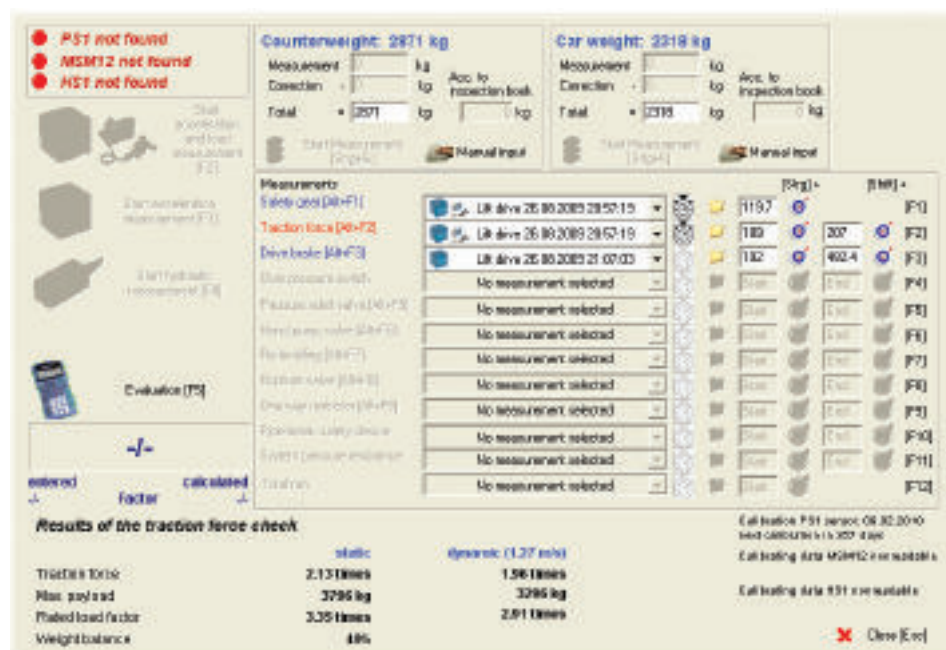*Figure 2: Brake testing result screen*

Figure 3: Traction testing result screen

solution and one that is rarely done unless specified on a new job and even more rarely on an existing job. The ELVI system then inserts the actual data values of these measurements into the testing software and calculates masses for later use in calculating force and determining code compliance for the safety, brake and traction tests.

Table 1 is a breakdown of the actual counterweight and car weights of six cars tested at the university. It is critical to note that none of the car data plates had an accurate car weight. Henning, other alternative test system providers, and most consultants, inspectors and owners would agree that this data is rarely correct. This inaccuracy is illustrated by the counterweighting differentials directly measured by the ELVI system. Note that in only one in six jobs was the counterweighting correct; all were designed to be 40%. This inaccuracy was verified by using test weights to balance the cars, and the ELVI system proven to be accurate, much to the surprise of university personnel.

This inaccuracy, in weight, illustrates several points. First, later adjusting that relies on the crosshead data plate accuracy and assumed counterweighting will have a very high likelihood of being incorrect. When these weight balances are outside the capacity of a Ward-Leonard system, for instance; it is difficult to maintain ride stability throughout the temperature and load range. With newer solid-state drive systems such as all of the units tested at the university, there is system compensation, which tends to cover these inaccuracies up to the power capacity of the solid-state drive system. Second, any alternative testing system that does not measure the weights and assumes these to be correct will not be accurate. Third, it is Henning's experience that these inaccuracies are just as prevalent in Europe and Asia, providing the rationale for developing its system in order to eliminate an unknown from their test system results.

This is a key consideration for allowing the use of alternative testing systems in North America; the testing at the university indicates that the proposed code requirements should require the masses to be weighed. It is also important to note that assumed incorrect weights can lead to improper code rulings of weight changes made throughout the life cycle of the elevator.

At the National Association of Elevator Contractors' educational seminars in Orlando in September 2009 (ELEVATOR WORLD, December 2009), a German testing agency with another alternative test system, was asked about the weight inaccuracies. The response was that it is only critical to measure the weights when the safety slide marks on the rails are near the extreme ends of code compliance. This appears to miss the point in a controlled environment where the weights are likely accurately
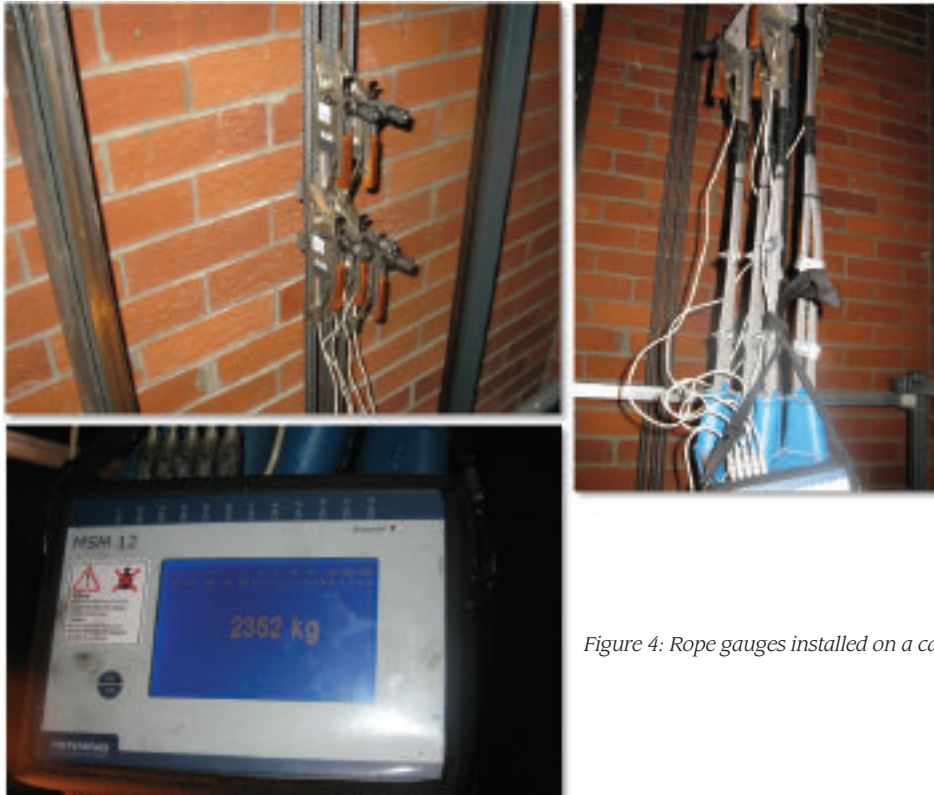

Figure 4: Rope gauges installed on a car

Weight Balance Results: ELVI System Vs. Actual					
	ELVI System			Actual	
Car ID	Empty Car [kg]	Counterweight [kg]	Weight Balance	Empty Car [kg]	Counterweight [kg]	Weight Balance
A1	2109	2649	48%			
A2	1710	1941	20%			
B1	2209	2654	40%	UNKNOWN without physically weighing the car or relying on crosshead data plate or paperwork		
B2	2241	2733	43%			
C1	2318	2871	49%			
C2	2345	2880	47%			

Table 1

recorded. This may be acceptable, although ripe for error. In North America, where the requirement for data plates did not exist for many years, this requirement is a must to ensure that the weight inaccuracy not prejudice any alternative testing system simply because of an incorrect weight assumption.

Slide measurements can also be fraught with error, as the measurement of them tends to be inaccurate in combination with inaccurate weights. This can and likely does lead to inaccurate retardation results. With the ability and relative ease of measuring the weights from all present alternative testing systems, this should be a requirement in allowance for the alternative testing systems, given the inaccuracies measured at the university and the presumption that most elevators will either have inaccurate weights on the data plate, weight that is not printed on the data plates or no data plate at all.

Safety Force Measurement

Current A17.1/B44 Category 5 safety test pass/fail criterion for the type B progressive safety is a reading of slide marks left on the rails after a safety set with rated load at rated speed. The slide marks can only indicate an average retardation rate. The Type B safeties, generally having one large average retarding force with retarding-force peaks, will produce multiple retardation rates depending on the mass it is stopping, its initial velocity, surface conditions of the rails and shoes, rail joints and temperature. This can vary results from one test to another. If more exact information were available, then variables might be accounted for, but gross unknowns could certainly be eliminated.

In general terms, the retardation rate of any stop is derived from the fundamental formula:

$F = ma$ (Equation 1)

where F = force, m = mass and a = acceleration.

With conventional safety testing, the slide marks on the rails provide an indication of a based on empirical evidence and historically calculated accelerations. However, since it only uses one data point (the length of the slide), it can only provide an average retardation rate referred to in terms of g force (the acceleration of gravity). As mentioned in the previous section on car weights, unless it is directly measured, "m" is assumed if only using crosshead data plate information, making this assumption suspect. The "m," in all cases, is assumed by the tester and is not from a code-required measurement.

In North America, the code requires that the type B progressive safety slide be within a minimum/maximum slide range (indicating an average retardation rate of greater than 0.35 g minimum and less than 1.0 g with rated load. 1.0 g represents acceleration due to gravity equaling 9.8 m/s^2. (0.35 g would be 9.8 m/s^2 x 0.35 = 3.43 m/s^2, for instance.) Due to the loading differences from empty to full load in the elevator, there are occasions when the same retarding force to stop a fully loaded elevator will result in excessive retardation rates when the elevator is empty or lightly loaded, creating a greater-than-1 g average. It is also likely that when the safeties do set due to an overspeed condition, it is when the elevator is lightly loaded. This is the case the vast majority of the time elevators are used.

In addition, embedded in the retardations are very high peak accelerations of such duration that can be injurious to users as well. The use of slide marks giving an average "a" cannot reveal this key information to assist in finding and potentially reducing these potentially dangerous accelerations by design. With the development of accelerometer recording systems and high speed computing interfaces, many systems can

display the actual retardation rate into the hundreds of a second range. This kind of fundamental measurement is becoming standard in design and testing in the industry.

Accelerometer

The ELVI system also uses an accelerometer to precisely record three axis(x, y, and z; front to back, side to side, and up and down) of acceleration, with a sampling rate of 2 kHz. With this level of detail, it is possible to see peak accelerations and the duration for which the accelerations existed. This is important because the visibility of high accelerations for longer durations can be used to potentially design them out by safety designers, reducing potentially dangerous stops. It can also be used to assist in identifying what may have caused excessive retardations after the fact. Using International Organization of Standardization (ISO) filtering described in ISO 18738 and ISO 8041, a true average retardation can be seen, weighted to human response.

The accelerometer affixes to the crosshead near the roller guides to reduce the effects of crosshead oscillation produced during the stopping of the elevator (Figure 5). The white device is a wireless transceiver that communicates to the rope-tension sensor device when the ropes gauges are mounted near the hitchplates on 2-to-1 roped systems. The white cord is a USB cable going to the laptop computer and software system.

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Figure 5: Accelerometer magnetically attached to crosshead

The ELVI system waveform results of an empty car test and a full load test of car 13349 are illustrated in Figures 6 and 7. An analysis of these two screenshots and how the data is evaluated and put into Table 2 for reference will explain how the comparison of no load to full load is made and how prediction is possible.

The ELVI system calculates the average safety forces not over the whole stopping process. It looks for the interval where the safety is fully engaged when the deceleration is more or less constant. The rest of the stopping process is the safety beginning to engage. While there is some retardation, the full force is only developed when the safety shoes are fully engaged. Velocity reduction prior to that should not be used because it is different from safety to safety. It doesn't represent any specific force, only the force as it is being developed up to full force, and it is usually nonlinear and, therefore, unpredictable. The braking force during the full safety engagement is constant. (It does not change when you change the load in the car.)

Figure 6 shows two waveforms: one is the z axis through a 100-Hz low-pass filter, and the second is velocity change of the elevator from 1.25 m/s calculated through an integration of the z axis accelerometer data during the retardation phase over time (y axis). The z axis also illustrates the peak acceleration seen at time = 138.880 of approximately 18 m/s , 18/9.8 = 1.8 $g_{(peak)}$. The average acceleration of the stop during full engagement of the safety is a ratio calculated by dividing change in velocity (v_i - v_0) divided by change in time (t_2 - t_1). In this case, the initial velocity when the safety is fully engaged is time = 138.925, velocity = 0.8 m/s until zero velocity at time = 139.055.

$$a = \Delta v / \Delta t \qquad \text{(Equation 2)}$$

where Δ = change, a = acceleration, v = velocity and t = time.

The initial velocity was 0.8 mps, and the stopping time was 0.13 seconds, yielding an average acceleration of 6.1 m/s ^{2}.

$$g_{(avg)} = a/g \qquad \text{(Equation 3)}$$

where g = 9.8 m/s ^{2}. The $g_{(avg)}$ is, then, a ratio of 6.1 m/s^2 / 9.8 m/s^2 = 0.6 g. This is the number we use to describe code limitations, for instance.

In the full load test shown in Figure 7 for the same car, the full braking of the safety retardation begins at time = 188.780 with a duration until velocity is zero of 0.160 seconds (188.940 − 188.780). With the initial velocity at the point of full safety engagement of 0.8 m/s and the stopping time of 0.160 seconds, it
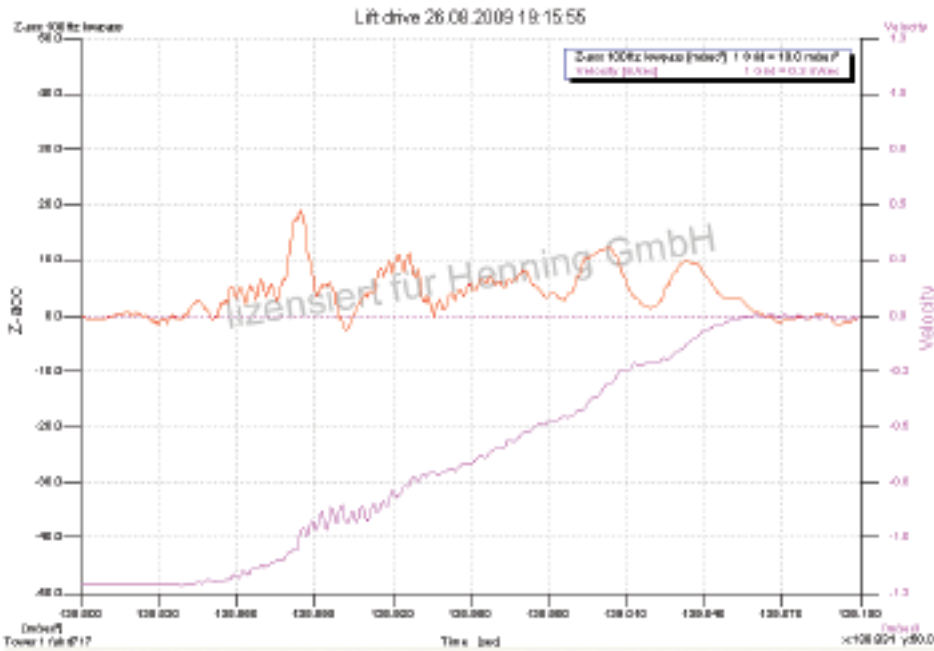
Figure 6: Empty car safety actuation: 100-Hz waveform, car C2
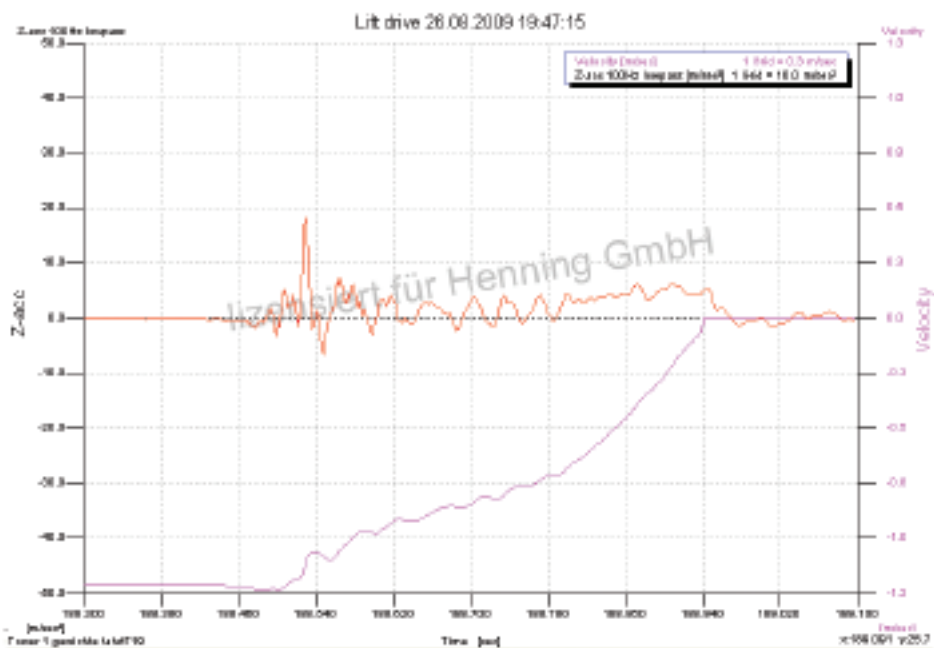
Figure 7: Full load safety actuation: 100-Hz waveform, car C2

yields an average acceleration of 5 m/s². The $g_{(avg)}$ is, then, a ratio of 5 m/s² / 9.8 m/s² = 0.5 g. Relative to an empty car in Figure 6, the fully loaded car in Figure 7 shows a longer duration of stopping, as is predictable given the higher mass. With a longer duration retardation, the predicted $g_{(avg)}$ in Table 2, column 4 is lower than the empty car accelerations shown in Table 2, column 2.

The differences between Table 2, column 8 and column 10 illustrate why the inaccuracy of slide distance measurement is critical in determining compliance and shows how this can lead to incorrect conclusions. The large variances may likely be a result of these cars being lower speed, only up to 1.25 m/s (250 fpm). The error would be less at higher speeds. The Table 2, column 9 slide distance data, however, is clearly inaccurate, given the ELVI system's waveform measurements of the same stops at which the slides were measured and the ability to record the accelerations exactly.

The ELVI system's empty-car test predicted results are not directly comparable to the actual full load test results using slide marks left on the rail. The exact measurement of slide marks is not usually possible without applying dyes to the rails. Contaminants, oxidation, rail surface finishing, and shoe surface can lead to more or less scratching and, therefore, inaccurate slide distances (Table 2). Looking at Figure 6 and Figure 7, the $g_{(avg)}$ values are calculated on the actual waveform times and velocities, which are clearly evident. In Table 2, the actual full load for car 13349 shows a value of 1.1 $g_{(avg)}$, as opposed to the predicted and verified value of 0.5 $g_{(avg)}$, illustrating the inaccuracy of using only the slide marks to determine retardations. The 1.1 is calculated with the slide distance assumed to be accurate. The acceleration curve was not 1.1 g, as the measured slide would lead one to believe.

Predicted Safety Test Results

The ability to predict the performance with full load by only using an empty car is based on several things: determining the force of the fully engaged safety, calculating the average accelerations and the ability to calculate the force with different masses. With two knowns, m and a, F is a relatively simple calculation. F can be calculated using an a = 6.4 m/s² and an m of the actual measured mass of the system (Equation 1). With the actual force now known, F can be used to calculate the acceleration of any mass substituted into the formula $F = ma$ to determine what that acceleration would be solving for a.

$$a = F/m \qquad \text{(Equation 4)}$$

where F = force, m = mass and a = acceleration.

This value is output from the ELVI system and populated into Table 2, column 5 and. For Car C2, it is 0.7 $g_{(avg)}$ (See Table 2, car B1, full load (predicted) with ropes). Comparing this to the actual recorded full load results of car 13349 in column 8 (Table 2, car C2, full load with ropes (actual), ELVI system result), the actual results clearly compare favorably to the predicted results.

Freefall Stopping Indication

During the safety test, the ELVI system combines accurate rope-tension measurement and recording, precisely synchronized (measuring m, or mass) with the accelerometer recording (measuring a) in order to calculate force (F) of the safety itself. This rope-tension information is used to determine the inertial jump of the counterweight and, therefore, can be used to calculate the F of the safety with and without the counterweight connected in the system. This provides a much higher certainty than with using assumed values for a and m used by other systems. Further, it can provide peak and average forces, which are again a useful measure of the retarding forces provided by the safety.

There are other contributing forces that must be considered in the safety stop, such as rotational inertia of sheaves, inertia of suspension member and traveling cable masses, and inertia of compensation system masses. However, we are only discussing acceptance and periodic testing, where the resultant contributions of these forces would be the same with or without a load and remain unchanged from test to test. Therefore, the effects recorded during testing are both included and not

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Type B Safety Test Results: ELVI System Vs. Actual								
	ELVI System Results					Full Load with Ropes (Actual)		
Car ID	Empty Car (Actual)		Full Load (Predicted)					
			With Ropes		Without Ropes		ELVI System Result (g_{avg})	Slide (mm)	Slide[3] (g_{avg})
	(g_{avg})	(g_{peak})	(g_{peak})	(g_{avg})	(g_{peak})	(g_{avg})			
A1	0.9	2.3	1.2	**0.5**	0.9	0.3	**0.7**	152	0.7
A2	1.1	4.7	2.5	**1.0**	2.2	0.9	---[1]	140	0.7
B1	0.8	1.4	0.7	**0.4**	0.2	0.1	**0.3**	197	0.5
B2	1.1	1.8	0.9	**0.5**	0.8	0.4	**0.5**	324	0.3
C1	0.6	2.7	1.8	**1.0**	0.9	0.5	---[2]	356	0.5
C2	0.6	1.8	1.2	**0.7**	0.3	0.2	**0.5**	152	1.1

Table 2: Note that during the recording of the full load test, the accelerometer moved; during the test, no recording was made (user error); and that these values are calculated based on the slide distances measured

necessary to detail. Since the resulting output is absolute in terms of accelerations and force, comparing one test to a later test is valid without other contributing elements, since these contributions will not have changed.

This is the first time force has been able to be measured directly and provides another clear indication of code compliance – one that was not available outside test towers. This is important, as job conditions vary from test-tower conditions, and as age and use may change the safety components' force considerably.

The rope tension is shown here as a black line in the lower half of the chart in Figure 8. The rope tension is steady at approximately 1,700 kg at the beginning of the recording, then begins changing with the actuation of the safety at time = 105.117 and goes to its lowest loading of approximately 50 kg at time = 105.315. This reduction in tension, synchronized in time with the waveforms of the safety acceleration and velocity, allows a mathematical result of the contribution of the attached counterweight and, thus, allows the safety force to be determined alone. Said

differently, when the safety begins stopping the elevator, the counterweight continues up due to inertia, effectively eliminating any contribution to the stopping force, and the retardation at the beginning and at the end of the stop can be separated into safety force alone providing the stopping. This allows a view into the ability of the safety to stop an unsuspended car and making a determination of the ability to protect against freefall.

The results do not just give a pass/fail indication, but a rich image of the inner workings of the entire safety stop. The direct calculation of *F* by the ELVI system is a leap in technology that allows many measurements to be possible without destroying components, overstressing elements and disrupting building operation.

Brake Force Measurement

The driving-machine brake and emergency brake have static and dynamic stopping requirements in A17.1/B44[5] slightly different than those of EN 81-1[6]. First, it must retard a moving car during an emergency stop with dynamic frictional force. Generally, static friction force is higher than dynamic friction force; the frictional materials in common

use in the elevator industry are no different.

Present conventional testing verifies the forces, ensuring a minimum level of force, but cannot reveal reserve brake force. This is a distinct disadvantage, given that loss of reserve brake force can lead to slippage, should deterioration go unnoticed. Having a tool that can measure actual brake force (including some reserve) and provide a clearer picture of total force is, therefore, much easier to maintain in code compliance. Having a tool that can also quantify exact forces illustrates changes over time for determining effective maintenance procedures.

A criticism of no-load testing is that test weights are necessary to provide a higher inertial energy to retard, due to the higher masses when test loads are on board the elevator. This is not entirely correct. The brake is only stopping a differential load; the difference between counterweights is generally 40-50% by design, and rarely is an elevator at full load. An empty car test is nearly a full-load differential in the vast majority of load cases. Therefore, this test is valid for essentially all dynamic stopping cases. To provide test weights for the extreme differential is the tradeoff for a testing system that can measure the force directly and predict how the system will respond, illustrate the reserve clearly and remove the need to have test weights.

A second criticism is that the car frame and platform are not exercised to the real-world, full-load retardation. This is offset by the inherent safety factors required for these components. The system undergoes acceleration during stopping; the difference in mass (lack of load) does not add significant stress to consider a proof of continued design compliance. It is also not
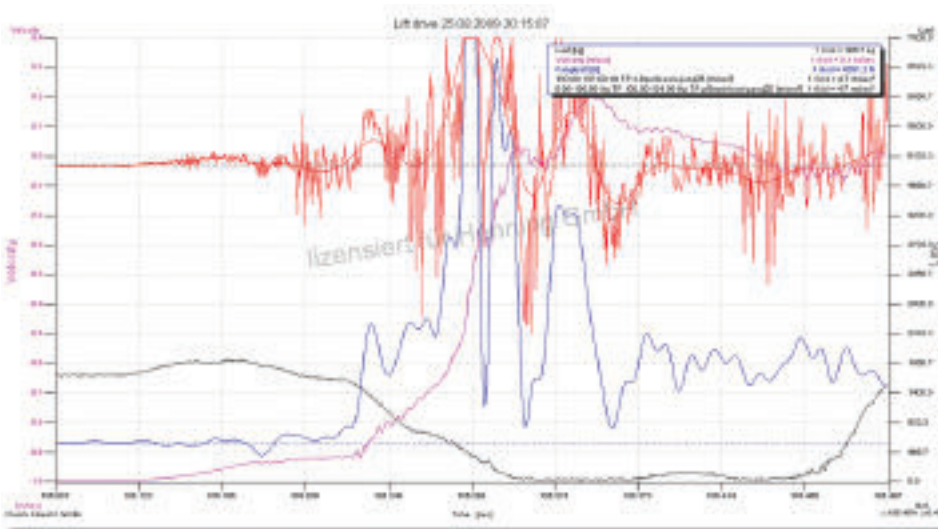
Figure 8: Rope tension waveform

considered in the pass/fail criterion of conventional testing. It is valid to assume the design at empty load retardations amply test the system, and that further loads and stresses are accounted for by code-required strength requirements.

With the ELVI system, the actual acceleration and distance the elevator travels, along with the rope tension and the results, are given as a pass/fail indication. This ability to measure the dynamic braking force allows the predictability. Once the dynamic force is known, then any mass can be substituted into $F = ma$. Converted into the $m = F/a$ formula and with two knowns, F and a, it can be determined that a mass equaling 125% will or will not be decelerated, and therefore will pass or fail. Knowing the force allows for measurable results for later comparison to determine if brake force degradation is occurring. The pass or fail criteria are based on A17.1 values.

Traction-Force Measurement

Traction-force testing is critical to demonstrate continued compliance to design and maintenance criterion in the code. The loss of rope material (crown wear), the loss of sheave material (incorrect rope tensioning), debris accumulation (dirt, grease and rouge) and inconsistent rope lubrication are common failures that can not only affect rope life, but equally important, affect traction force. Having a tool to measure the traction force directly and then retesting more frequently becomes a long-term solution to observe any degradation of the traction force – hopefully, prior to loss of traction.

The ELVI system tests traction by determining the change in the suspension ropes' tension during traction movement with the car stationary and calculating the traction force directly. This test is performed with the car on its safety (after the safety test), then operating the drive machine in the down direction, with a rope tension sensor on every rope. The change in total rope tension is proportional to the traction force developed, while the traction sheave turns under the stationary ropes. This provides a direct measurement that is quantifiable for later comparative measurements. With a direct measurement of the change in force, the reserve traction can be calculated and written into a report. When this test is done today, the results can be compared to future tests for examination of the system for degradation, if any.

The use of rope tension in this fashion is a result of specific design changes to the rope-tension gauges to make them accurate to within 2.5%. This innovation allows the measurement of the ropes, from the car top, in a quick, dependable and easy procedure. Making it easy ensures that the test will be done more readily and often. At any time, the traditional tests can also be done to compare results. This report is stored in an electronic file and can be printed to be put into the MCP as a job record. The results do not just give a pass/fail indication, but also a percentage of traction reserve, which is unavailable today. This makes the ELVI system a very useful tool for evaluating traction over the life cycle of any traction system.

The distinction between static and dynamic friction force is important to note (Figure 9). When the elevator is stopped, it takes more force to initiate rope slippage over the sheave than is required to keep the ropes slipping. It illustrates that the friction is higher statically than dynamically. These forces reflect code compliance for the two cases: static loading loss of traction and dynamically during an emergency stop, which indicates whether the car will be slowed by the available traction.

In the "Traction Test" box, note that the rope tension (black) waveform has a negative peak at approximately time = 103.120, then a steady negative line reading left to right at time = 104.890. The negative peak represents the static traction force the system overcame to make the sheave turn, then the dynamic traction force required to continue to spin the sheave as represented by the flat line prior to stopping motion at time = 111.145. This test is done with the car on safeties; therefore,

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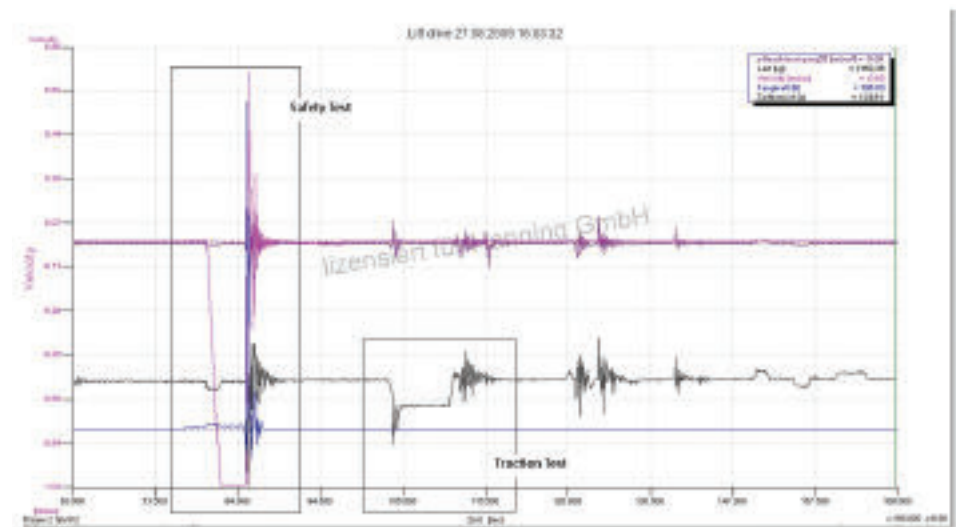
Figure 9: Safety and traction test waveform example

the car speed is zero. Looking at Table 3 below, the two traction factors are the "Static" peak force when the car is on safety. The "Dynamic at Rated Speed" is based on the actual traction force measured during an emergency stop. The use of a value can then be used as the comparative value for future tests. The ELVI system provides outputs of pass or fail based on A17.1 requirements.

Table 4 illustrates that the CAR A1 elevator has two times the necessary static traction force and 1.88 times the necessary dynamic traction force. It is not possible to reduce traction to test the validity of the system; however, in time, as seen outside North America, elevators experiencing a loss of traction will be obvious when tested with the ELVI system. Though it would have been illustrative to see low traction on one of the cars at the university for the purpose of this report, these results clearly indicate that proper design and good maintenance of these elevators is the norm.

Advantages of the ELVI System
Safety

The use of a measuring system that ensures equivalent results without the use of test weights eliminates the hazards associated with moving test weights, and the wear and tear on the technicians, building and elevator system. By measuring directly on elevator system components, the ropes and the crosshead, information previously unobtainable is clearly evident in the results. The ELVI system provides a direct measurement of relevant elevator forces that have been previously only extrapolated from slide marks left on the rails. By using the ELVI system, embedded retardations of high value and duration can be identified with relative ease and can begin the process of exact design of safety devices accounting for these previously unseen retardations. Since the only new time spent using the ELVI system is the adding of rope sensors, there are little added minutes to using the system. In fact, the time saved getting weights to the job and moving them from car to car is eliminated, thereby reducing the testing time to that of speeding the car onto the safety.

Brakes

With the attachment of accurate tension gauges on the ropes and performing an emergency stop, accurate brake adjustment and testing no longer require hours of coordination of test weight delivery and labor to get a close adjustment of brake force. With the ELVI system, adjustment is a 15-minute procedure providing a simple brake test method.

Traction

The ease of measurement of traction is new to North America with the advent of the ELVI system. With the precise measurement available, the groove wear, rope wear, and effects of oil and rouge can easily be recorded, and corrections can easily be planned. Reserve traction is as easily seen as reading a voltmeter in an electric circuit. The ELVI system removes the mystery of potential slipping traction by directly recording traction forces. Problems can be eliminated before an incident occurs. With a traction value, reserve traction is known, and historical degradation (if any) can be plotted and used to determine groove/rope relationships when trying to troubleshoot traction issues. This takes less than 5 minutes.

Ride Quality

In addition to the test system, Henning developed the "LiftPC Mobile Diagnosis" for measurements according to ISO 18738, Ride Quality Standard using the same hardware components and another software system. Identifying causes of vibration can be difficult without tools

Brake Test Results: ELVI System with No Load Vs. Actual with 125% Load Downward								
	ELVI System (Dynamic)				Actual (Static)			
	Machine Brake		Emergency Brake		Machine Brake		Emergency Brake	
Car ID	125%	Lower, Stop and Hold	125%	Lower, Stop and Hold	125%	Lower, Stop and Hold	125%	Lower, Stop and Hold
A1	Pass	Pass	-	-	Pass	Pass	-	-
A2	Pass	Pass	-	-	Pass	Pass	-	-
C1	Pass	Pass	-	-	Pass	Pass	-	-
C2	Pass	Pass	-	-	Pass	Pass	-	-
B1	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
B2	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass

Table 3

Traction Results: ELVI Vs. Actual								
	ELVI				Actual			
	Static		Dynamic at rated speed		Empty Car Up		Full Load Down	
Car ID	Traction Factor	Max. Capacity [kg]	Traction Factor	Max. Capacity [kg]				
A1	2.00	3178	1.87	2856	Pass	Pass	Pass	Pass
A2	1.87	1920	1.77	1720	Pass	Pass	Pass	Pass
B1	1.93	3043	1.82	2736	Pass	Pass	Pass	Pass
B2	2.12	3411	1.98	3041	Pass	Pass	Pass	Pass
C1	2.13	3796	1.96	3296	Pass	Pass	Pass	Pass
C2	2.09	3672	1.92	3192	Pass	Pass	Pass	Pass

Table 4: Traction test results

with which to record it, and the ELVI system together with the optional "LiftPC Mobile Diagnosis" software module can discriminate and help identify vibrations caused by a machine bearing, a roller guide, noise from a solid-state drive or gears.

**Summary of Results
from the University Testing**

The Henning ELVI system was evaluated on three pairs of traction elevators within the rope-gauge load range of the ELVI system. All tests included recording actual weight measurements, including surprise confirmations of grossly inaccurate counterweighting. In all cases, the predictions of the ELVI system tested with no load were confirmed when compared to the full load test.

The inaccuracy of the reported weight values on the layouts and the crosshead data plates was surprising. After first becoming acclimated to the tools, the mechanics at the university pushed and pulled test weights to discover that the tool was, in fact, reporting the correct values, though the data plate said otherwise. One car was counterweighted at 20% (which the majority of people present believed was improbable), though after extensive weight and balance tests, the con-clusion of the ELVI system was proven. Another elevator showed the counterweighting to be 56%, another large swing from the expected 40% that was later proven by testing with actual weights.

The simplicity of using the ELVI system's measurement tools and the accuracy were evident by the last day of testing. The last elevator was completely tested in 30 minutes, including the confirming use of test weights to verify the *T1/T2* counterweighting and doing two tests – one with no load and one without load. The ELVI system was easy to learn and operate once the personnel were familiar with it. The rope testing also includes an individual rope tension comparator, which can be used to adjust tension to within a 2.5% tolerance, complying with the tensioning requirement in A17.1a-2008, 8.6.4.1.3.

Recommendations

Based on the successful results of the testing, the use of this methodology met Henning's intended design performance of measuring an empty car and predicting performance with overloads. It has been suggested that the North American code require a baseline test in conjunction with an acceptance test; however, the base-line concept is by itself not necessary. Given that the ELVI system provides pass/fail results, it is clear that later periodic tests will also pass or fail based on system degradation over time and these results can then be compared.

This tool is still a new concept in North America, and before it is solely relied upon, all elevators should undergo both empty and full load testing and again at the first five-year test to ensure accuracy in the long term.

Actual masses must be known, and it should be required to have these documented in the MCP and in any instrumentation used for alternative testing, given the weight inaccuracies observed in elevators less than 10 years old.

Certification of calibration and mandatory recalibration of these test instruments should also be included in the code requirements.

Overall, this technology is exciting for elevator professionals because of the level of detail it provides. Until now, these types of measuring systems have been limited to research facilities and laboratories. Now, with a rugged design, the ELVI system has brought precise tools to the field that could revolutionize elevator testing in the future.

Additional Screenshots

Car A1

Car A2

Car B1

Car B2

Additional Screenshots

Car C1

Car C2

References

[1] **ASME A17.1a-2008/CSA B44.1-08, 8.6.4.20.1 Car and Counterweight Safeties.** Types A, B, and C car safeties, except those operating on wood guide rails, and their governors, shall be tested with rated load in the car. Counterweight safety tests shall be made with no load in the car. Tests shall be made by manually tripping the governor at the rated speed. The following operational conditions shall be checked (Item 2.29.2.1): (a) Type B safeties shall stop the car with the rted load within the required range of stopping distances for which the governor is tripped (Item 2.29.2.1.).

[2] **ASME A17.1a-2008/CSA B44.1-08, 8.6.4.20.4 Braking System.** For all passenger elevators and all freight elevators, the brake shall be tested for compliance with applicable requirements. Place the load as shown in Table 8.6.4.20.4 in the car and run it to the lowest landing by normal operating means. The driving machine shall safely lower, stop, and hold the car with this load. Also, see 8.6.4.20.10(a). [and (Item 2.17.2.1).]

[3] **ASME A17.1a-2008/CSA B44.1-08, 8.6.4.20.10 Emergency Stopping Distance.** Counterweight traction elevators shall be tested for traction drive limits to ensure that (a) during an emergency stop initiated by any of the electrical protective device(s) listed in 2.26.2 (except 2.26.2.13), except buffer switches for oil buffers used with Type C car safeties at the rated speed in the down direction, with passenger elevators and freight elevators carrying their rated load, cars shall stop and safely hold the load.

(b) if either the car or the counterweight bottoms on its buffers or becomes otherwise immovable
(1) the ropes shall slip in the drive sheave and not allow the car or counterweight to be raised
(2) the driving system shall stall and not allow the car or counterweight to be raised

[4] The overload is determined by the type of use of the elevator – either passenger or freight.

[5] **ASME A17.1a-2008/CSA B44.1-08 2.24.8.3 Driving-Machine Brake.** The driving-machine brake, on its own, shall be capable of
(a) holding the car at rest with its rated load (see 2.16.8 and 2.26.8)
(b) holding the empty car at rest
(c) decelerating the empty car traveling in the up direction from the speed at which the governor overspeed switch is set. Any decelerations not exceeding 9.m/s² (32.2 ft/s²) is acceptable provided that all factors such as, but not limited to, system heat dissipation and allowable buffer striking speeds are considered.

[6] **EN 81-1, 1998, 12.4.2 Electro-mechanical brake 12.4.2.1.** This brake on its own shall be capable of stopping the machine when the car is travelling downward at rated speed and with the rated load plus 25%. In these conditions the retardation of the car shall not exceed that resulting from operation of the safety gear or stopping on the buffer. [All the mechanical components of the brake which take part in the application of the braking action on the drum or disk shall be installed in two sets. If one of the components is not working a sufficient braking effort to slow down the car, travelling downwards at rated speed and with rated load shall continue to be exercised.

John Koshak is head and founder of Elevator Safety Solutions, Inc. Directly prior to reactivating the company in September 2008, Koshak served as director of Codes and Standards for North America for ThyssenKrupp Elevator. He was formerly in research at ThyssenKrupp Research, Innovation and Design. Koshak got his start in the industry in 1980 with Westinghouse Elevator Co. and has worked for Dover Elevator, Amtech Elevator and Adams Elevator Equipment Co., where he was vice president of Technical Support. He was a National Elevator Industry Educational Program instructor from 1982 to 1991, designed the LifeJacket™ hydraulic elevator safety and holds several patents for elevator-component designs. Koshak is a member of the ASME A17 Standards Committee and a regent of the Elevator Escalator Safety Foundation.

Learning-Reinforcement Questions

Use the below learning-reinforcement questions to study for the Continuing Education Assessment Exam available online at www.elevatorbooks.com or on page 179 of this issue.

◆ In North America, what do current Category 1, 3 and 5 testing of the safety, brake and traction provide?
◆ What will a current code-required test verify?
◆ Which body is currently debating the approval of using alternative testing for use?
◆ Globally, how many years has the use of alternative testing for inspections been done?
◆ When is it valid to understand the first principles of any method of testing?
◆ What is the basis of alternative testing?
◆ What does the ELVI system accurately measure?
◆ When mass and acceleration are measured and known, what other factor is known?
◆ When force is calculated, why can it be used in calculations with different loading conditions?
◆ Why are car and counterweight masses critical to know?

ELEVATOR WORLD Continuing Education
Assessment Examination Questions

Instructions:

◆ Read the article **"Safety and Buffer Testing without Weights"** (page 129) and study the learning-reinforcement questions.

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1. During which of the following are test weights required for safety testing?
   a. Routine testing.
   b. Periodic testing.
   c. Category 1 testing.
   d. Category 5 testing.

2. When is freefall testing of a car-mounted safety required in A17/B44?
   a. Never required.
   b. Periodic testing.
   c. Category 1 testing.
   d. Category 5 testing.

3. Moving the traction sheave down with the car on safety will:
   a. increase the rope tension on the car side of the sheave.
   b. have no affect on the tension of the rope at all.
   c. decrease the tension of the rope on the counterweight side of the sheave.
   d. decrease the rope tension on the car side of the sheave.

4. ELVI system rope-tension gauges have an accuracy of:
   a. 1.0%.
   b. 1.5%.
   c. 2.5%.
   d. 3.5%.

5. Actual accurate car weight data is:
   a. generally unknown.
   b. always known.
   c. rarely known.
   d. not important.

6. Slide marks after a safety set indicate the:
   a. force of stopping in inches.
   b. average retardation rate.
   c. instantaneous retardation rate.
   d. speed of the car.

7. With a Type B safety, the maximum allowed retardation is:
   a. based on speed.
   b. not less than 0.5 g.
   c. not greater than 0.75 g.
   d. not greater than 1.0 g.

8. Retarding force when the safety is fully engaged is:
   a. declining.
   b. constant.
   c. increasing.
   d. zero.

9. Predicting performance of a retarding device with different loads requires knowing:
   a. acceleration and speed.
   b. force and speed.
   c. mass and speed.
   d. mass and acceleration.

10. Loss of traction force can result from:
    a. high machinery-space humidity.
    b. accumulation of debris on the rope.
    c. changes in car loading.
    d. opening and closing of the doors.

11. What is the basis of alternative testing?
    a. The assumption of certain factors.
    b. The accurate calculation of speed and time.
    c. The accurate measurement of mass and acceleration.
    d. The assumption of reliable historical measurements.

12. What does the ELVI system accurately measure?
    a. The buffer spring constant and rate of compression.
    b. The safety spring force and shoe friction.
    c. Acceleration and crosshead deflection.
    d. Rope tension and acceleration.

13. When mass and acceleration are measured and known, what other factor can be known?
    a. Speed.
    b. Force.
    c. Resistance.
    d. Current.

14. When force is known, it can be used in calculations with different loading conditions, because the force:
    a. is constant.
    b. varies predictably at different speeds.
    c. goes up at a known rate.
    d. goes down at a known rate.

15. Car and counterweight masses are critical to know because:
    a. assuming the masses will yield unknown results.
    b. the speed becomes a variant in the calculation.
    c. the acceleration of a system cannot be determined accurately.
    d. the force cannot be calculated accurately, and calculated results will not be accurate.

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4.	a	b	c	d	12.	a	b	c	d
5.	a	b	c	d	13.	a	b	c	d
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