New Lift Rope Technology – Coated Steel Belts

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Keywords: Coated steel belts, flat belt, machine roomless elevator system, testing, and design

ABSTRACT

This paper provides an overview of the new GeN2™ machine roomless elevator system from Otis. In particular, details about the revolutionary new coated steel belt technology are discussed. Qualification of this new component is reviewed with emphasis on durability of the steel cord and polyurethane jacket. Examples and results of breaking load tests, bending fatigue and traction durability tests, and environmental tests (including low and high temperatures) are reviewed. The advantages inherent in this new lifting technology are reviewed and up-to-date successes are provided.

1. INTRODUCTION

Early in the year 2000, Otis Elevator Company launched a new product line known as the GeN2™ elevator system for low- and mid-rise applications. Duty ranges for the initial release were 630 and 1000kg duty load at speeds of 1.0 and 1.6 m/s. The principal differences between more traditional systems and this new system are that there is no machine room required, that a small, permanent magnet gear-less machine is used, and that load support and traction control are provided through revolutionary new coated steel belts. Coated steel belts replace the traditional round steel ropes and enable the use of much smaller diameter drive sheaves while still meeting worldwide safety code requirements of minimum D/d ratios of 40:1. This is accomplished in the coated steel belt through the use of 12 steel cords of 1.65 mm diameter encased in a polyurethane coating. The cordage, produced by Bekaert Company of Belgium, is a 7 x 7 construction using wires of 2,750 n/mm^2 tensile grade. This combination results in a belt with a minimum breaking load of 32.0 kN. Worldwide safety code requirements for a minimum factor of safety of 10:1 (or higher) are easily met. The new system which incorporates the new belt technology is shown in Exhibit 1. Notice the compact layout of the machine configuration created through the usage of 100 mm diameter sheaves enabled by the use of coated steel belts.

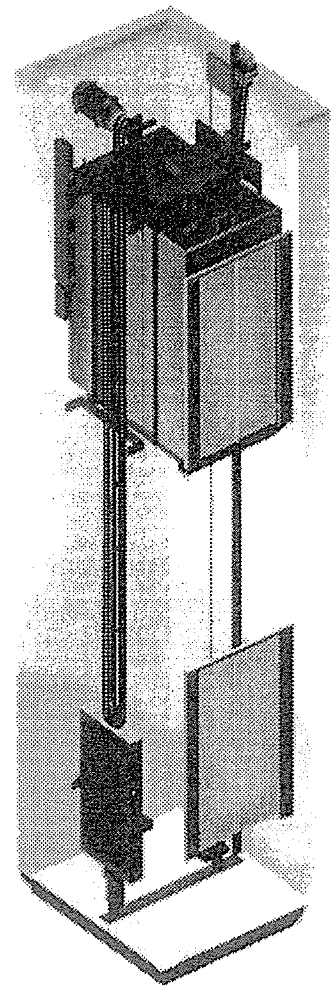


Exhibit 1

2. BACKGROUND

From a traditional standpoint, low- and mid-rise building elevator requirements were satisfied through the use of worm gear machines and round steel ropes placed in a separate machine room above the hoistway. Recent global developments in the elevator industry have shown various techniques to eliminate the need for the separate machine room and still use the traditional worm gear machine or gearless flat machine and round ropes. The objective of the Otis design team was to have a machine room-less system made possible with innovative ideas to create enhanced performance and reliability. The outcome of this basic design concept is what is now known as the GeN2™ system.

3. COATED STEEL BELT (CSB) DETAILS

As can be seen in Exhibit 2, the CSB is roughly 30 mm wide and only 3 mm thick and contains 12 equally spaced steel cords. Several iterations of both the cord design and the urethane jacket were necessary to achieve the specified durability and performance requirements. Additional details concerning the cordage design are shown in Exhibit 3, where it can be seen that different diameter wires are used to ensure minimum contact occurs between each of the seven wires of each strand, between each of the seven strands which compose the cords, and between the 12 cords themselves. This particular separation feature is enhanced during the CSB manufacturing process by injecting the molten urethane between the strands and the wires. In this way, the primary wire degradation mechanism of fretting is minimized and controlled. The CSB producer, ContiTech, of Germany, working in conjunction with Otis engineers, was able to improve and perfect the normal manufacturing process to provide the high quality belts necessary for this difficult application.

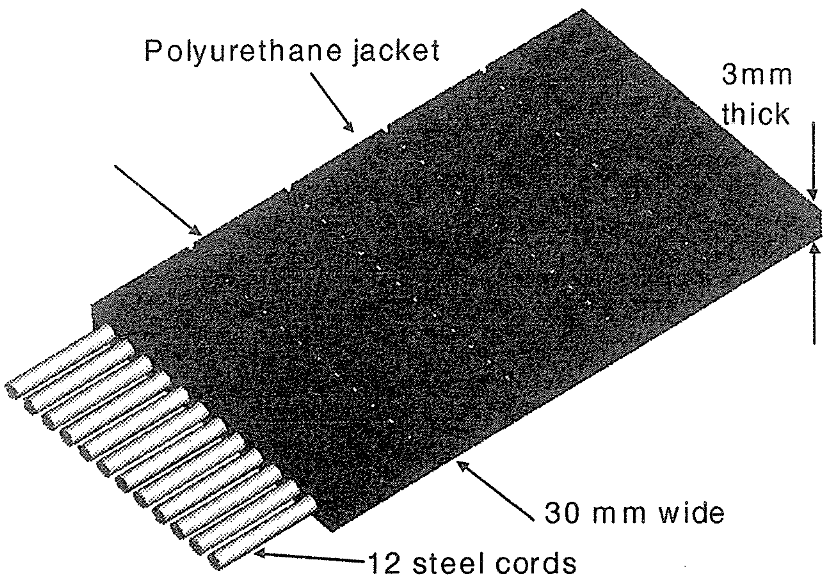
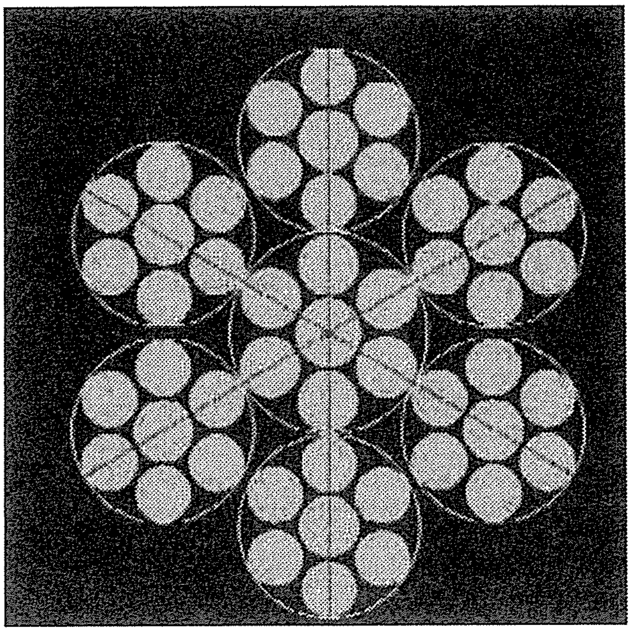


Exhibit 2



The construction of each cord within the CSB is similar to that of an IWRC elevator rope.

Exhibit 3

4. TESTING

Otis has had for many years a demanding round steel rope specification for traditional elevator roping applications. Included in this specification are requirements for rigorous bending fatigue tests performed at our test tower and at all of the approved worldwide rope sources. With this as a starting point, it was deemed mandatory to exceed the life capabilities of a qualified high-quality steel rope with the new CSB. Exhibit 4 shows an overview of the complete testing regime that the CSB went through. Each item listed had a detailed test program and statistically significant tests were run. A dossier was created for all items and tests before results were submitted for code approval, beginning in Europe.

It should be noted that the round rope bending fatigue life expectancy is 10 to 15 years and the CSB life was expected to be a minimum of 20 years. Many new bending fatigue machines were built and the testing requirements were doubled compared to the traditional round rope. The belt bending fatigue-testing machine is shown in Exhibit 5. The loading on the belt is 454Kg and the double bend sheave radii can be varied from 30 to 50 mm. For the usual round ropes, cycling for 600,000 cycles using 12.7 or 13 mm diameter ropes is done with a 70% residual strength requirement at the end of the test. In comparison, the CSB is run from 1.2 million up to 3 million cycles with the same 70% residual breaking strength requirement. This wide range of cycling requirements is explained by the fact that we started with our rough estimate of 1.2 million cycles, but detailed evaluations of the intended building usages showed that for usage rates which cover 97% of our elevators, there can be 12 million bends in 20 years. Since our testers give four bends per cycle, we now test for 3 million cycles. Over 100 bending fatigue tests have been run. A sampling of testing parameters and results is shown in Exhibit 6. Residual strength results after 3 million cycles have all been above 80%. One outcome of all this testing was a mathematical model used to predict CSB life for a new or revised applications.

CSB Testing - Overview	
Tensile Strength (MBL)	Tracking
Traction	Elastic Strain
Steel Cord Bending Fatigue	Chemical Compatibility
Traction durability (abrasion & ratio degradation)	Contaminants (oils, detergents, cleaners)
PTU Fatigue/Durability	Cord Pull-out
Creep	Environmental effects (Temperature, UV, ozone, salt fog)
Abrasion	Fire

Exhibit 4

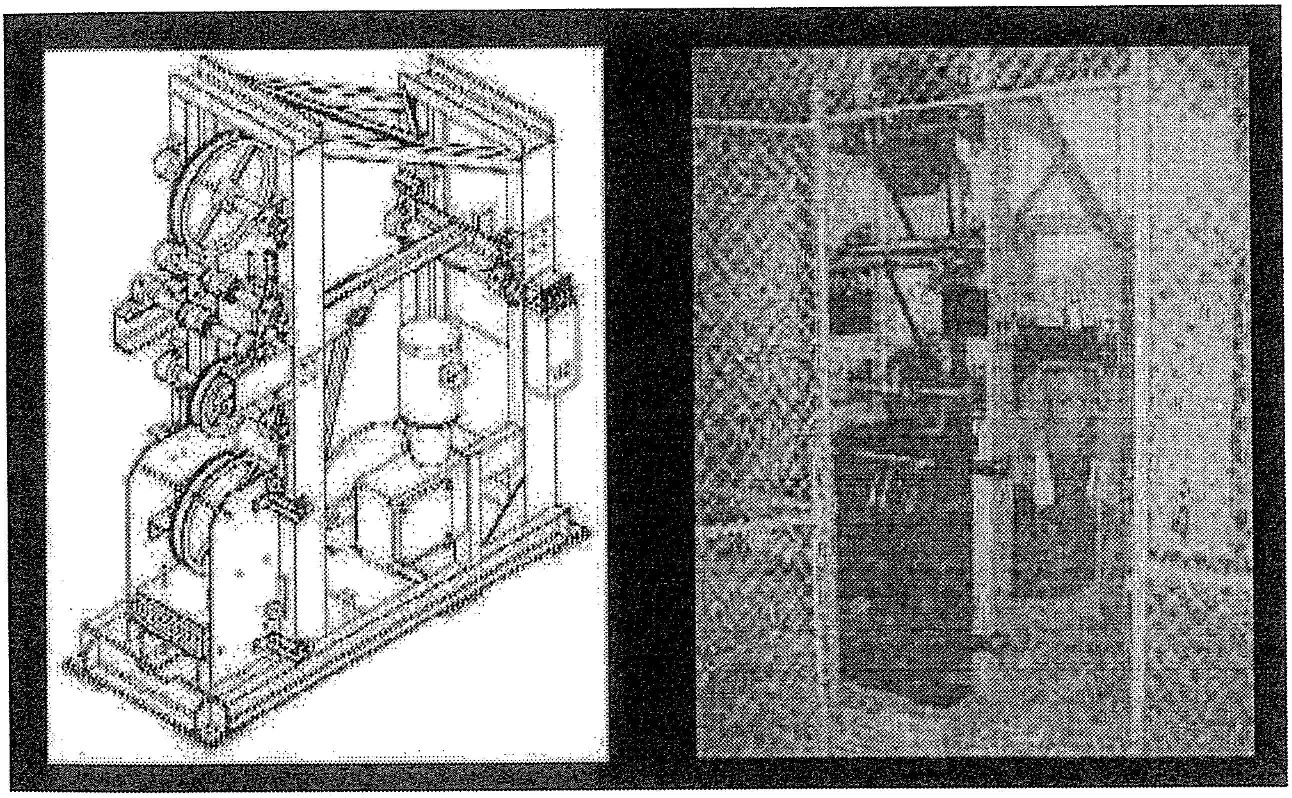


Exhibit 5

Belt Sample	Sheave Diameter	Cycles	Crown (Y/N)	Residual Strength
CP41B-01-01	100 mm	3 million	Y	27.02 kN
CP41D-16-09	100 mm	3 million	Y	34.83 kN
CP41D-23-32	100 mm	3 million	Y	26.40 kN
CP41D-17-11	80 mm	2 million	N	23.89 kN
CP41B-0A-17	60 mm	450 k	Y	27.02 kN
CP41B-0B-05	60 mm	450 k	Y	28.63 kN

Exhibit 6

Above chart shows relationship between sheave diameter, cycles and residual strength. As the diameter increases, we can obtain similar residual strengths at higher cycle counts. All were run with 1000lb (454) kg load.

Because the cordage is coated with a polyurethane to enhance traction characteristics and ride quality, it was deemed mandatory to use test machines to simulate traction and wear conditions typical for a hoistway. A totally new test machine was, therefore, designed to incorporate traction and wear anticipated in the worst case hoistway scenario. Exhibit 7 shows a schematic and an actual running tester which incorporates the aforementioned traction and wear characteristics. The critical T_1/T_2 characteristic for operating hoistways has shown to be well in excess of the minimum requirement of 1.65. The testing regime of 3 million cycles is also used on this machine and residual breaking strength tests at completion of tests again show 70%+ retained strength. Measurable wear up to 0.11 mm after almost 5 million cycles has been found on belts so tested using the current polyurethane compound.

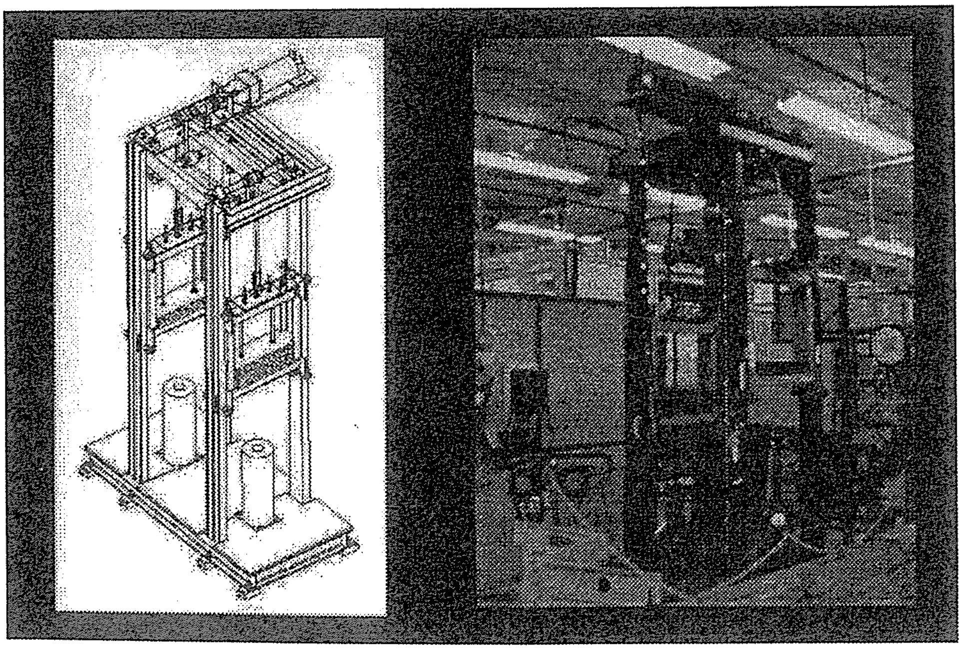


Exhibit 7

Another important testing item has been the tensile strength or minimum breaking load (MBL) of the belts. To guarantee the rated MBL of 32 kN mentioned in the introduction, more than 60 tests from three different production runs were completed. Results are shown in Exhibit 8. Statistically speaking, only one in 1 billion belts will fail at a MBL of 33.86 kN. Tests for MBL, bending fatigue, and traction durability are being done continually by the producer and by Otis.

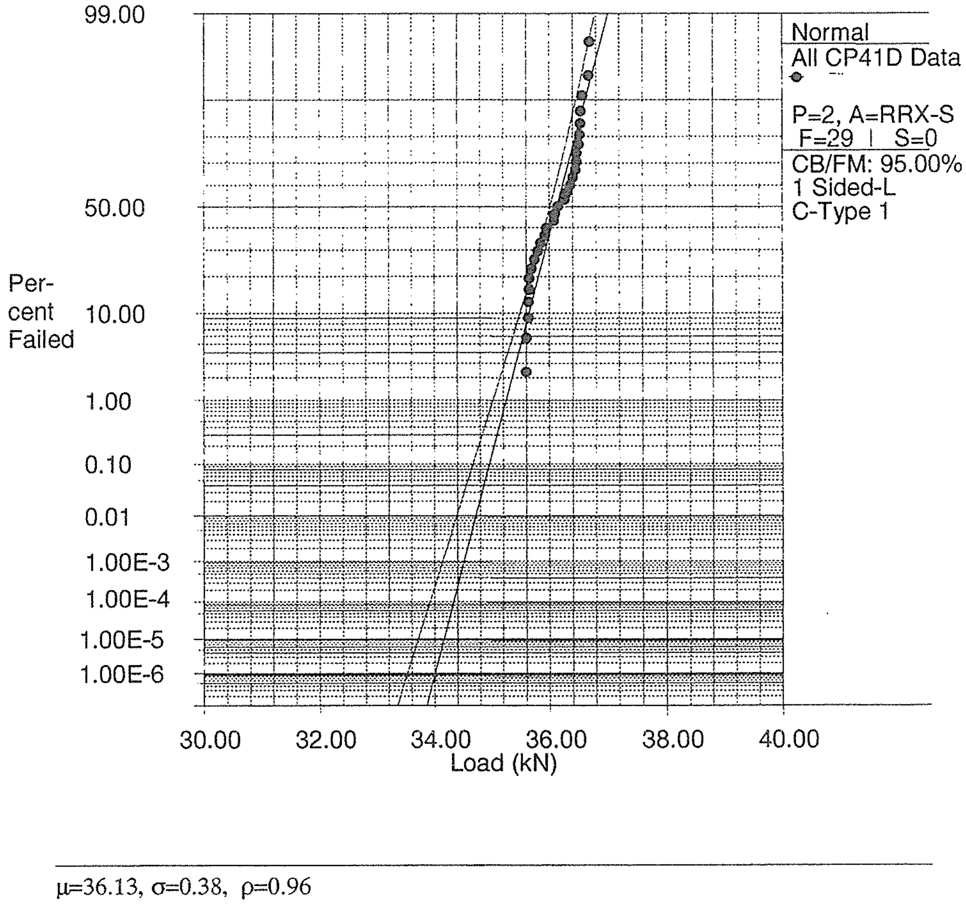


Exhibit 8

5. ENVIRONMENTAL TESTING

Because the new GeN2™ system will be sold worldwide, various operating conditions are likely to be encountered. It was deemed necessary from both a durability and a safety standpoint to be completely assured that this belt would be able to operate in all anticipated environments and under all contamination conditions. As a result, many tests have been done to verify CSB durability and adequate traction under such conditions as exposure to very high heat and humidity conditions, very low temperature conditions, and system operation under contaminated conditions such as oils, greases, water, etc. To achieve these test conditions, modifications were made to some of our bending fatigue and traction durability testers to actually run at temperatures up to 60°C and 95% relative humidity and refrigeration units were employed to test at -20°C. See Exhibit 9 for some details on tests and results. The CSB released product is CP41D.

CP41-03-01	100 mm	- 20 C	1.2 million	27.19 kN
CP41B-01-09	100 mm	- 20 C	1.2 million	20.68 kN
CP41C-07-02	100 mm	- 20 C	1.2 million	26.0 kN
CP41D-14-01	100 mm	- 20 C	1.2 million	28.40 kN
CP41D-16-11	100 mm	- 20 C	1.2 million	29.71 kN
CP41B-01-08	100 mm	60 C	1.2 million	32.41 kN

BFT temperature tests.

Belt Sample	Sheave Diameter	Temperature	Cycles	Residual Strength
CP41-03-08	100 mm	-20 C	810,000	29.98 kN
Cp41-03-07	100 mm	60 C	1,200,000	33.87 kN

TDT tests

Exhibit 9

Miniature test rigs were also developed so that contaminated samples could be run and maintained. In all of the testing described, results have shown that the current combination of urethane and steel cordage consistently produce acceptable operating conditions under the worst possible conditions.

A rather dramatic test was also done to verify adequate traction in the unlikely event that there was a fire in the hoistway. To accomplish this test objective, a running hoistway system first had the urethane coating burned off the belts, and then it was demonstrated under 125% full load conditions that there was adequate traction when the steel cords ran without coating against the mating sheaves. See Exhibit 9 for an overview of the belt condition.

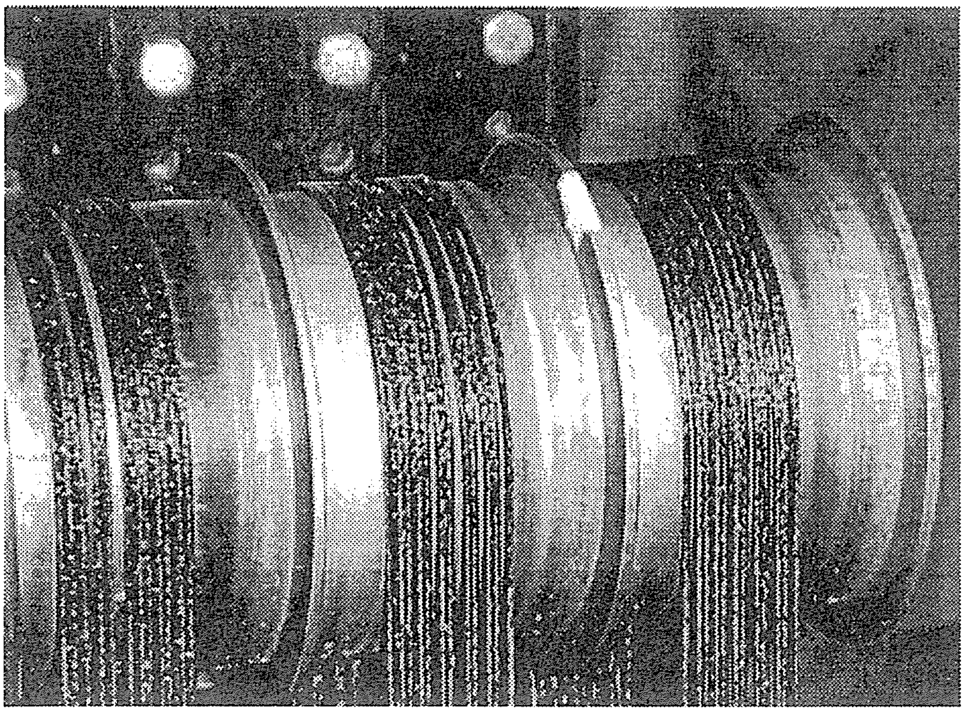


Exhibit 10

6. PROBLEMS ENCOUNTERED AND RESOLVED

In a new technology such as used in the GeN2™ system with belts, unanticipated problems are often found and must be resolved. The two main issues that were found revolved around 1) inspection methodologies for covered (coated) ropes and 2) tracking (lateral motion) of belts in long lengths. For the inspection issue, it was found that an available methodology known as magnetic flux leakage was available and is currently used by many elevator companies and testing companies to check the standard steel ropes of traditional systems. Specific designs to measure the magnetic flux leakage of the 12 cords in each belt were evaluated and tested during running of our bending fatigue and traction durability machines. Predictive models were developed to demonstrate that this method of inspection in fact can safely test and anticipate long-range degradation.

The difficult issue of belt tracking proved to be a large task to overcome. There is much documented literature about basic methods to control belt lateral motion, but this information proved to be based on empirical data and is relevant only to specific applications. Due to the lack of information regarding flat belt tracking, a project was initiated at United Technologies Research Center which included some very advanced dynamic analysis of the belt/sheave interface. This analysis led to the development of a physics-based flat belt tracking model. This model was used to determine critical belt and sheave design characteristics required for optimum tracking control. As a result, Otis had to work very closely with the belt producer, ContiTech, to carefully control the dimensional characteristics. Today's production process includes constant dimensional monitoring through a laser beam system. In addition, crown geometries for the associated sheaves were developed through a combination of modeling and testing. A third factor is continued close tolerance manufacturing of the elevator car frame and structure.

7. RIDE QUALITY

From an engineering standpoint, all of the aforementioned design, test, and evaluation were very interesting and enlightening. However, the basic is: How does the elevator system perform? To answer this question, many tests have been done at our Bristol Test Tower facility and in actual customer installations. It can be stated that our design ride quality parameters of 8 mg horizontal vibrations, 12 mg vertical vibrations, 62 dB(A) peak sound and 53 dB(A) average sound are met or bettered in customer hoistways.

8. UP-TO-DATE INFORMATION

As of Q1, 2001, Otis had received safety code approvals to sell the GeN2™ product in all of the 15 EU countries and all the remaining European countries and large-market African countries. Similar approval had already been obtained for Singapore, China, South Korea, Philippines, Thailand, Vietnam, and India. The approval process is underway and expected by Q2, 2001, for Malaysia, Australia, New Zealand, Hong Kong, Taiwan, and Indonesia. Japan is expected to be done in Q3, 2001. In Latin America, all major market countries' approvals are anticipated by Q2, 2001, or are already done. Finally, Mexico is approved already and America and Canada are anticipated in Q4, 2001.

All of the GeN2™ systems sold in Europe have the REM® elevator monitoring system installed, and there have been very few callbacks following turnover. It seems that many callbacks are associated with unauthorized hoistway entrance which creates a callback because the system automatically goes into inspection speed mode and proceeds to the first floor and the doors open and stay open. A service mechanic must come to reset the running system to eliminate this problem.

9. ACKNOWLEDGEMENTS

The author wants to gratefully thank Sandra Anderson, John Pitts, and Bill Perron for their help and support during the preparation of this paper.

10. BIOGRAPHY

Hugh J. O'Donnell is an Otis technical fellow at Otis Elevator Company's Engineering Center in Farmington, CT, USA. He earned a B.S. in Metallurgy from the Pennsylvania State University and an M.S. in Metallurgy from the University of Connecticut. He has spent more than 30 years resolving materials and processing issues and solving field durability and degradation problems. He received in the year 2000 the United Technologies Mead Award for development of the flat/coated steel belt for the GeN2™ elevator program. He has over eleven issued patents and eight patent applications pending.