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Dynamic Testing of Materials and Geometry for Transportation Wheels

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Introduction

Walt Disney World runs on urethane wheels. In our three themed parks , the Magic Kingdom, Epcot 94, and The Disney/MGM Studios, over 30 attractions rely on urethane wheels and parts for operation. Our reliance on these wheels and parts makes the quality and longevity of the urethane materials of primary importance to the day to day operation of our parks.

Over 50,000 urethane wheels and parts are in use every day just in the Florida parks. Many urethane materials used here are also used at Disneyland, EuroDisneyland and Tokyo Disneyland.

The 50,000 wheels and parts can be divided into just over 200 different types of wheels and parts. For example at Epcot 94's Spaceship Earth, there are vehicle load wheels, side guide wheels, upstop wheels, rotation cam wheels, door opening and closing cam wheels and drive wheels.

When these vehicle wheel types are multiplied by the 151 Spaceship Earth vehicles and 77 spacer vehicles, it becomes obvious that any reduction in the frequency of replacement, can represent significant cost reductions, not only in wheel costs, but also in the labor required for their replacement.

Of the 200 types of wheels, for most of our applications, our normal preventative maintenance cycle replacement occurs before the wheels wear out. In many cases, our change out cycles coincide with the average shelf-life of the materials.

About 4 percent of our wheel types represent the majority of our premature wear problems. This 4 % group includes:

> Load and upstop wheels where high speed, high load combinations cause heat build-up and fatigue, which then result in heat band color changes, surface depressions and finally cracking across and through the material.
>
> Drive wheels are also included in the 4 % problem wheel types. Drive wheels are low speed, high load, sometimes flexing wheels, subject to cut, tear, and abrasion.

Our wheels are transportation wheels and are subjected to varied combinations of dynamic forces which produce fatigue, heat build-up, surface abrasion, compression set, and cracking. Reduction of any or all of these through material enhancements or wheel geometry changes can result in dramatic increases in the life of a polyurethane wheel. Although the dynamic forces encountered in most wheel applications can be measured, which element (fatigue, heat, abrasion, etc.) and how much of each element is responsible for wheel wear and replacement, are not easily measured factors.

Testing Philosophy

Due to the difficulty of direct correlation of wheel life to any one listed physical property, we decided that comparative testing of materials and geometry differences, under the same dynamic loading conditions, was one of the easiest and most cost effective ways of testing wheels.

Also, new materials, processes and curatives are now being developed, which promise much greater resistance to wear, and therefore warrant comparative testing.

Certain decisions had to be made concerning test philosophy and approaches. We had already obtained from Walt Disney Imagineering, a wheel test dynamometer, which was used in the early 80's for drive wheel tests on Spaceship Earth wheels. We knew that new and better materials were available, and we had already listed our key problem wheels.

The test philosophy that we developed was as follows:

Provide Polyurethane Manufacturers with Wheel Information.

We provided the major manufacturers of urethanes with load, speed, force, dwell time, acceleration, short term loading and environmental information. We also gave them physical data on the wheel, including detail drawings, thickness of urethane and current materials used. We provided information on wear patterns and life history of the wheels.

Request Polyurethane Manufacturers' Recommendations

We requested recommendations for new material and/or geometry based on the wheel information provided. All requests were focused on each wheel application and solutions to that one wheel problem. We also restricted material recommendations to "off-the-shelf," non-proprietary urethanes that any processor could purchase and pour.

Production of Test Wheels by Experienced Processors

We then sought processors with experience in producing the urethane materials that we wanted to test. Our intent is to test new urethanes - not to test a processors ability to pour a new material. We also had assistance from technical representatives of the manufacturers, who attended and helped with the processing of new materials.

Testing Philosophy (Continued)

Consistently Re-Create the Same Wear Experienced in the Field

We tested control wheels on the test machine, with speeds, loads, and dwell time fixed, to re-create the same wear patterns and material failure experienced in the field. This required fine tuning the test machine to avoid melting of wheels, while still accelerating wheel wear to keep the test runs short. This also had to be consistent wear within a fixed time period, so that new materials and geometries could be compared using time to failure as the yardstick.

Test New Materials as "A-B" Testing

We tested new materials on the test machine, while carefully keeping all parameters the same as the control wheel tests. This way the wear patterns and time to failure could be directly compared. The test machine also qualified the strength and condition of the bond, and the failure mode of the material when it was different from the failure mode of the control wheel.

Field Testing

Once a material proved to be "better than" the existing material used in an application, and exhibited a normal wear pattern with no bond problems, we moved to field testing under controlled conditions.

The Test Machine

The Walt Disney World wheel test machine is a multi-purpose platform designed primarily for the testing of ride vehicle type wheels. The machine consists of a 6 foot diameter by 18 inch wide drum, that supports curved track sections which act as a rolling surfaces for wheel tests. The half-round pipe track sections can be removed for testing wheels on a flat surface. And in the case of Spaceship Earth drive wheel testing, we added removable platen sections over the half-rounds, in order to convert quickly from drive to load wheel testing. Additional enhancements to the machine are described under the drive wheel and load wheel testing descriptions.

The rotating drum is chain driven by a 20 HP DC-motor through a gear reducer. Maximum operating drum speed is approximately 145 rpm which equates to 45 linear feet per second.

An Emerson Quantum II digital DC drive was installed which allows the test machine to be interfaced with a personal computer (PC). Motor parameters, including start, stop, speed control, and motor current can be remotely viewed and modified on a real time basis. Drive settings can be configured for a particular test and stored on disk for later recall and use. The major importance of the DC drive is very accurate speed regulation. This allows us to maintain a constant speed for testing, without the applied load effecting the speed. The DC drive also allows dynamic braking.

Drive Wheel Testing

Spaceship Earth drive wheel testing was initiated to find a new material that would increase the life of drive wheels for the ride. The drive wheels are powered by electric motors and are located below the vehicles and propel them through the 18 story sphere. They are "self-energizing" and push up on a flat metal platen attached to the ride vehicle. (Like turning your car upside down and moving the road). The normal force of the wheels is 2400 pounds, the drive force is 700 pounds. Normal ride speed is 1.8 feet per second, an average of 14 hours per day in a dry, air-conditioned environment. The existing material is B-602 with a proprietary additive. Average life in severe locations is 1 month. In most locations it is 6 months or more.

The test machine was modified by installing curved platens on the outside diameter of the test machine drum. These platens were made of the same material as the ride platens, and coated with the same Metco coating. The three platens were located to provide three equally spaced "gaps" similar to the gaps between vehicles on the ride.

A drive unit from Spaceship Earth was placed beneath the test machine drum, to allow the drive wheel to engage the platens.

As the drive wheel engaged the platen, the drum is driven by the wheel at 2.5 feet per second (higher than ride speed). At the same time, the wheel test machine chain/gearbox drive is energized and commanded to run in the opposite direction, so as to oppose the driving force. This is minimized, so that only electric motor resistance is produced, and this resisting force on the drive wheel, simulates the forces on the ride.

Our initial tests of control wheels resulted in a smooth machining of the wheel surface from a 12 inch diameter to an 11 inch diameter. This was a wear pattern seen in the straight track sections of the ride, but not the normal faster type of wear pattern seen in curves. By turning the drive wheel platform 2.5 degrees, so that the drive wheel was at a 2.5 degree angle, we achieved a wear pattern on the drive wheels that could not be distinguished from normal wear at the ride.

Finally, several control wheels were tested and the wear patterns (cuts across the surface of the wheel, machining of the material, and chunking), were consistent. Time to failure for the control wheels occurred at 124 hours +/- 5 hours, with poor ride quality (chunking) at 80 hours +/- 5 hours.

Now we were ready to test new materials. The attached chart lists the "A-B" materials that were recommended by Uniroyal, Air Products, Miles, MacLan, and Thombert. It is important to note that this test was for new materials for a specific drive wheel application. The test is not a general comparison of materials and the results are applicable to only to this one specific drive wheel application.

SPACESHIP EARTH WHEEL TESTING

	LIFE	COEFF * FRICTION	FAILURE MODE	BOND BKG	WEAR PATTERN	TEMP DEGREES (F)
B-602 2% 83 Shore A	124 hrs Poor ride quality @ 80 hrs.	Slipped @ 400	Cracking & Chunking	No	Abrasion then cracking	128
L-83 100% 83 Shore A	Taken off @ 49 hrs.	Slipped @ 410	Severe cracking	No	Abrasion then cracking	130
PP-150 95 Shore A	162 hrs.	Slipped @ 175	Worn down to min dia.	No	Abrasion	130
PP-1095 95 Shore A	134.5 hrs.	Slipped @ 500	Worn down to min. dia.	No	Abrasion Small cracks towards end of life.	128
6008 83 Shore A	4 hrs.	Slipped @ 150	Severe cracking & chunking	No	Cracking & chunking	142
L-167 95 Shore A	128 hrs. Poor ride quality @ 80 hrs.	Slipped @ 300	Cracking & chunking	No	Abrasion then cracking	154
Cyanaprene A-7 QM 84 Shore A	21 hrs.	Slipped @ 400	Worn down to mid. dia.	No	Abrasion	138
Airthane PET - 80A 84 Shore A	Poor ride quality @ 22 hrs.	Slipped @ 400	Cracking & chunking	No	Cracking & chunking	136
Thombert Dyalon B 83 Shore A	Poor ride quality @ 27 hrs.	Slipped @ 450	Cracking & chunking	No	Cracking & chunking	126

* Coefficient of friction measured by wheel tester motor controller current setting (1 to 1000).

	LIFE	COEFF * FRICTION	FAILURE MODE	BOND BKG	WEAR PATTERN	TEMP DEGREES (F)
Vulkollan 27 92 Shore A	Poor ride quality @ 78.5 hrs.	Slipped @ 525	Cracking	No	Abrasion - then cracking	128
MS - 061 87 Shore A	Poor ride quality @ 58 hrs.	Slipped @ 525	Cracking & chunking	No	Cracking & chunking	130

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* Coefficient of friction measured by wheel tester motor controller current setting (1 to 1000).

Drive Wheel Testing (Continued)

In October, 1993, we installed two test wheels on the Spaceship Earth ride using the PP-150 urethane with Eastman CHDM-D curative. The actual performance on the ride exceeded our test machine results, and additional wheels are being added to the ride as phased field testing continues. Not only are we significantly reducing maintenance expenses, but we also expect ride quality to improve, because the new wheel material does not "chunk out," but wears smoothly to a smaller diameter.

Load Wheel Testing

As soon as drive wheel tests were completed, we converted the test machine for load wheel tests. Our load wheels are 9 to 12 inches in diameter and typically run on a pipe or round tube track. This point loading increases the stress and the fatigue factors for our wheels. A new material or geometry, that extends the life of these wheels would have a positive impact on most of our attractions.

The test wheel machine was fitted with four, half-round tracks that have the same radius as our standard tracks. Hydraulic cylinders are attached to four individual pivoting assemblies with load wheels. The hydraulic cylinders provide pressure to simulate vehicle loads, and also provide power to engage and disengage the wheels.

The cylinders allow us to operate the load wheels in 3-minute on and 3-minute off cycles to control internal heat build-up and to avoid melting wheels.

The hydraulic pressure is generated using a self-regulating, pneumatically driven hydraulic intensifier. The intensifier cycles as required to maintain system pressure that is set using a pressure regulator. After the regulator, the circuit is split into four branches (one for each test wheel) and each branch contains another pressure regulator and gauge for each wheel. The same load is applied to each test wheel. Pressure on each test wheel is 960 PSI.

Four independent remote temperature sensors were used during initial set-up and control wheel testing to confirm temperature control. These can be re-mounted on the machine for any future tests. In addition, the need to take temperature readings on the internal hub area became apparent as internal temperatures of the control wheels continued to rise after cracking had occurred. The change to a 3 minute dwell time was the result of excessive internal heat build-up using a 2 minute dwell time.

Some of our initial load wheel tests used variable speeds, stepped-up in increments, in order to speed the test process. However, we discovered by trial and error, that 15 feet per second could be used for constant speed testing and would re-create standard wear patterns in about 100 hours of testing.

Our L-167 existing load wheel material control wheel testing has been completed. The attached list shows the materials recommended by the manufacturers, which we will be testing for comparative life.

Load Wheel Testing (Continued)

The following materials are scheduled to be tested on the wheel test machine for load wheel applications:

Material	Mfr.	Recommendations
L-167/MOCA	Uniroyal	Control Wheel
LF-95 Polyether/MOCA	Uniroyal	Commonly used coaster material.
PET-95A/MOCA	Air Products	Dynamic material Better cross-linking
PET-93A/Lonzacure	Air Products	Dynamic new material & cure
Polaroid XPE-20	Air Products	Dynamic material
PP-150/CHDM-D	Uniroyal	High dynamics
PP-150/BD	Uniroyal	High dynamics Comparison
PP-1095/HQEE Blend	Uniroyal	High dynamics
Vulkollan-27	Miles	High dynamics
B-839/MOCA	Uniroyal	Dynamic new material
MS-081	Air Products	Dynamic material
Uralite 3271/PTMEG	Hexcel	Dynamic new material

Other Testing

Other wheel testing is also being conducted with geometry changes for conveyor wheels, other drive wheels and low speed applications in the field. Uniroyal has provided us with information from their tire model, that indicated that the addition of a concave radius on our wheels running on round track would increase life. The concave radius is twice the track radius, to allow turning in curves. The concave surface exponentially increases the contact area of the wheel and track. Our tests for these has just begun and we are gathering control data from the field. These wheels are being tested as geometry changes only.

Listed below are the other factors which we want to test on the machine, after materials testing is completed:

L-167 Control Material/Factor

Natural color vs Carbon black pigment

Natural color vs Yellow pigment

1% pigment vs 1-1/2% (maximum) pigment

Oven cure after demold vs 4 hour room temperature hold after demold with 16 hour oven cure, both cases

180 degree F polymer temperature vs 200 degree F polymer

Effects of excessive bubbles in material

95% Stoichiometry vs 97% Stoichiometry

All of the above listed process and material changes have been suspected of changing the dynamic properties of urethanes that are run at maximum capacity. A-B testing of these wheels will provide solid data for future process, additive and material control specifications.

In addition, we will be testing these properties on any new materials that we use.

Conclusion

Walt Disney World, in cooperation with the urethane industry, is seeking out and testing new materials, to jointly find improved performance and longer life urethanes for dynamic wheel applications. We hope to continue this joint effort and to succeed beyond our wildest expectations.

The Wheel Test Team

Walt Disney World Company

Randy Bevan	Applied Technology Funding
John Harrison	Testing Engineer
Trevor Larsen	Test Machine Enhancements Engineer
Mario Scarabino	Test Machine Drive Engineer
Scott Sorensen	Field Testing
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ACLA

Andy McIntyre	Material Recommendations

Air Products

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MacLan

Bob Lane	Material Recommendations &
Phil Lane	Test Wheel Processing
Dale Maslyn	
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Rollercoat

Joe Lancaster	Test Wheel Processing

Thombert

Dick Davidson	Material Recommendations &
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