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ABSTRACT

A series of tests were conducted utilizing a tire test machine built to measure forces during a tire tread separation event. Tires were prepared by cutting between the two steel belts inward from the shoulder area. Cuts were varied in size and location to generate different types of tread separation events (ex: long, short, partial, inboard, and outboard). The tests document the longitudinal and lateral forces generated while the tread is detaching during different types of tread separation events. The results demonstrate that magnitude and duration of forces depend upon the ature of the tread separation event. Additional documentation includes high speed and real time video of the tread separation events to provide insights into tread detachment modes and mechanisms of measured force response.

INTRODUCTION

A tire tread separation event is a unique type of tire disablement that occurs while a motor vehicle is in use at highway speeds. A tire tread separation is characterized by all or part of the tread and typically the outer steel belt peeling off of the carcass of the tire due to centrifugal forces. Tread separation events are known to be a cause of motor vehicle crashes as demonstrated through testing, research, and crash investigations. A vehicle's response and change in handling characteristics due to a tread separation event can be broken down into two distinct phases. Phase one is during the tread separation event itself. That is the phase when the tread is in the process of detaching from the carcass of the tire and is interacting with the vehicle's structure and the ground. Phase two is the period that occurs after a tire's tread has detached and detrimental changes to a vehicle's handling characteristics can be measured.

.·or the purpose of this research the duration of the tread separation event encompasses the period of time that the tread and outer steel belt initially begin to peel or lift from the tire sufficiently to interact with vehicle components to the time that the tread completely detaches and ceases to interact with vehicle components (phase one). Some tire tread separation events never propagate to a point of complete detached of the tread, and are referred to as a partial tread separation event.

Tire tread separation events are widely described as causing vibration, noise, and deviation from the intended path of a motor vehicle. The flailing end of the detaching tread coming in contact with the vehicle's structure and ground causes vibration and noise. In addition, the tire has become imbalanced and is no longer round leading the tire to roll eccentrically about its spin axis. A flailing detached tread hitting the vehicle is evident in the damage that occurs in a separating tire's wheel well. The noise and vibration can be measured in controlled tests and has been reported as a general observation by numerous authors.

A deviation from the intended path during a tire tread separation event is also widely observed. Objectively measured vehicle accelerations, heading angle changes, and yaw rates were recorded during tread separation event tests reported by Dickerson (1999). During these tests, the vehicle's hand wheel angle is held fixed for various experimentally produced tread separation events so that the vehicle response to the event is measured directly. Utilizing identical test methods as employed by Dickerson, the authors (2001) objectively documented a range of vehicle turning responses ranging from minor pulling to rapid and uncontrolled veering of the test vehicle on both an SUV and a four door sedan.

Gardner (1998) reported longitudinal braking forces due to a tread separation event in controlled testing of three different vehicles with a rear tire experimentally prepared to separate. The vehicles included an SUV, a station wagon, and a ¾-ton pickup truck. Gardner's tests generated average peak drag forces associated with the separating tire tread of 166.7 lb, 252.2 lb, and 122.4 lb respectively for the three vehicle types. The average duration of the events were reported as 0.367 sec, 0.350

sec, and 0.582 sec respectively. Gardner's study focuses on very short complete tread separation events.

Other studies of vehicle controllability during a tire tread separation event are reported on by Fay (1999) and Kline (1999). In both studies, the test was conducted on a closed test track with the driver fully aware that the tire was going to experience a tread separation. Like the Gardner study, these studies focus on very short, complete tread separation events. Regardless, these authors reported a small lateral acceleration associated with the event with a corresponding steering wheel torque.

A Department of Transportation study by Ranney, Heydinger and et. al. (2003) using the National Automotive Driving Simulator (NADS) facility reported driver response to a tread separation event modeled as a half sign function with peak longitudinal brake force of 100 pounds and total duration 4 seconds. The phase one separation was two seconds. The Gardner, Fay, Kline, and DOT studies provide information on a single type of tread separation event. Studies of real world accidents demonstrate a wide range of tread separation events occurring well beyond those reported by the above authors.

PROBLEM

This study set forth to measure longitudinal and lateral forces that a tire undergoing a tread separation event may generate. Test results presented in this paper expand on previous reports in that longitudinal and lateral forces are recorded and analyzed for a variety of tread separation events. Tires were prepared to cause short and long duration separation events and separation events with the tread moving inboard, remaining centered, and moving outboard. Finally, because separating tire treads do not always detach the same, this study sets forth to measure a distribution of forces and force duration during tread separation events. The variety of tread separation types evaluated greatly adds to data available for analysis when evaluating the cause of real world crashes.

METHOD

A test machine was constructed capable of measuring longitudinal and lateral forces that may be developed during a tread separation event. Tires are prepared by partially cutting between the two steel belts. Instruments consistent with the recommendations of SAE J266 are affixed to the test machine.

The test procedures consist of driving a truck with a test machine attached along a straight asphalt roadway and at a constant speed while a tread separation event is occurring.

Test Machine

The test machine is built from a modified 1994 Ford Explorer rear frame and suspension. Components are removed from the differential disabling the limited-slip feature. Because the rear body is not present, ballast is provided to achieve natural suspension deflections. The test machine is affixed to the rear of a Ford F250 truck weighting approximately 8000 pounds. The truck and test machine are rigidly coupled allowing their combination to be analyzed as a rigid body. Load cells are attached that measure longitudinal and lateral forces generated in the test machine. Figure 1 shows the couple and load cell configuration of the test machine.

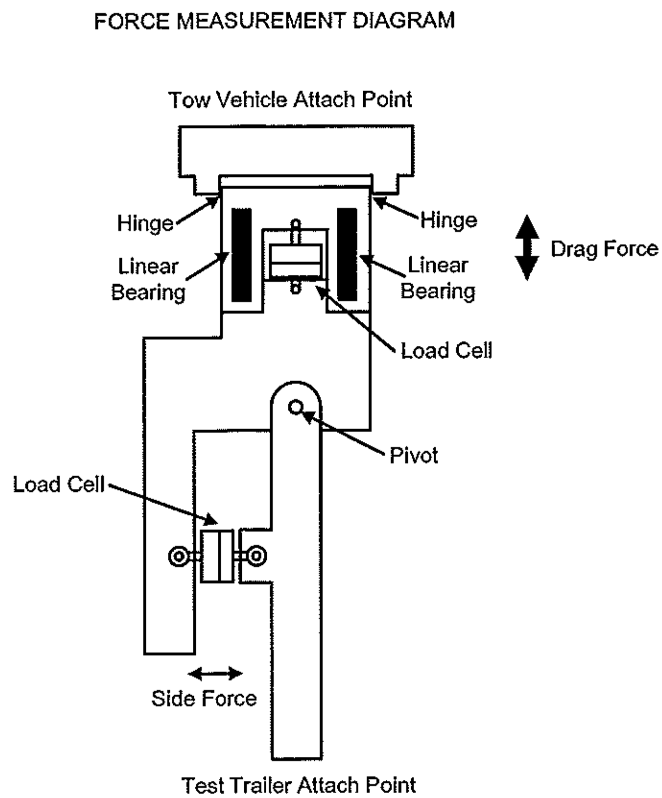

Figure 1, Couple and load cell configuration of test machine

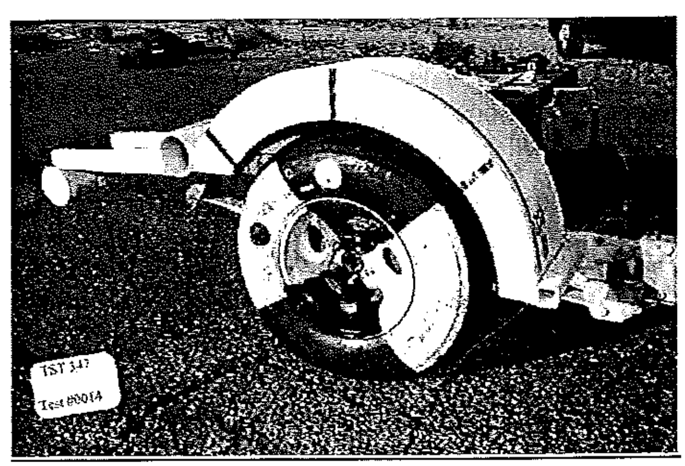

Figure 2, Configuration of rigid wheel well

A rigid wheel well is mounted over the right side tire. The rigid design assures that the wheel well geometry remains fixed from test to test. The rigid wheel well is painted white prior to each test to maximize the visibility ' failing tire tread contacts. Figure 2 illustrates the basic configuration of the wheel well.

Test Tires

The reported tests were conducted with Michelin P235/75R15 LTX AT tires. The rims are aluminum 15X7. Each tire was prepared for testing by cutting between the two steel belts inward from the side a fixed distance. In addition a cut was made through the tread parallel with the cords of the tires outer steel ply. The tire preparation was varied to produce different failure modes as listed in Table 1.

Test #	RS tire #	Comments
F	3	slow/partial
G	4	slow/partial
H	6	fast
I	7	outboard
J	9	inboard
K	8	outboard
L	11	slow
M	10	inboard
N	12	slow

ıble 1, List of test tire preparation

Test Instrumentation

Test instrumentation in use during testing included: two - 2000 lb load cells measuring the longitudinal and lateral force; an accelerometer mounted over the axle measuring test machine vibration; and a Datron velocity sensor. All data is digitally recorded at 100 samples per second. A break wire triggered by the separating tread ply is installed at the leading edge of the wheel as an event switch. Video cameras are mounted to record the tread separation events. Photographs document the test before and after the tread separation event.

RESULTS

Part of the test data analyses involves calculating the lateral force response recorded during the tread separation event. Calculating lateral force assumes that the test is conducted on a straight heading, at a constant speed and that the test vehicle combination is a rigid body (no slip is generated at the tires). Plotting and interpretation of the final data is made after zeroing and applying a 2nd order Butterworth low pass 1 Hz digital filter. Table 2 summarizes response for each analyzed test. Triangular shaped force-response curves are observed in shorter duration tread separation events as shown in Figure 3. Longer recorded tread separation events produced force-response curves that have a trapezoidal shape as shown in figure 4.

Accelerometer data failed to record following test run F. For those tests with the acceleration data, analyses show higher amplitude acceleration beginning when a tread separation event initiates. Increased vibration amplitude coincides with the break wire event and visual observation of the video recorded tread separation events.

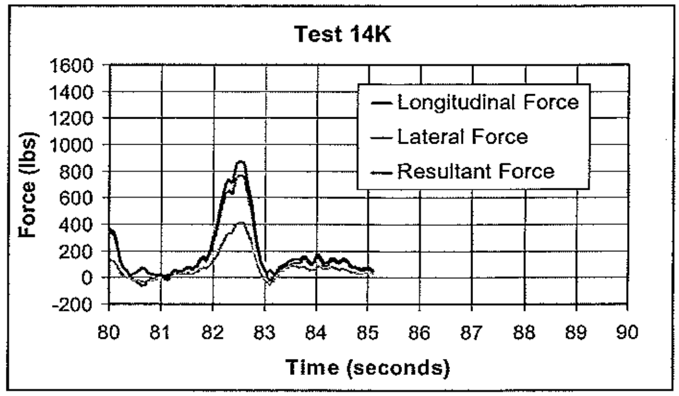

Figure 3, Sample of shorter duration response

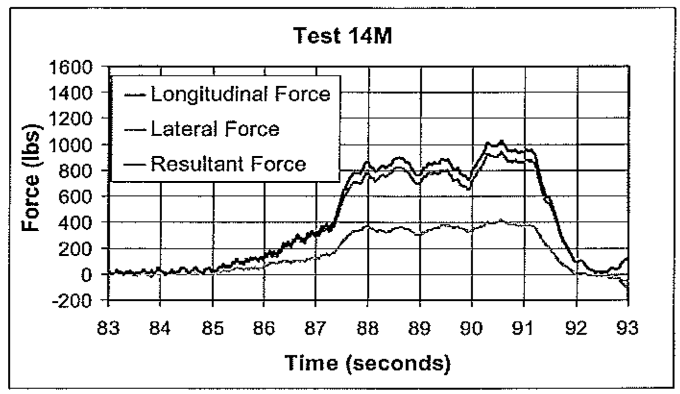

Figure 4, Sample of longer duration response

Review of the motion pictures reveal that a high-speed camera records great detail of a tread separation event, however, a real time video with high shutter speed provides adequate motion documentation. The motion pictures in combination with post test analysis, including analysis of the tread transfer marks on the wheel well, provide insight into the kinematic response of the tire tread during its detachment.

Two distinct tire detachment modes were observed with additional variations depending upon tread movement and duration of the tread separation event. The two main modes of detachment involved (1) peeling of the tread (leading) versus (2) lifting of the tread (trailing). The peeling (leading) mode of detachment propagates more rapidly and is more likely to result in a detached tread piece that approximates the circumference of the tire. The Lifting (trailing) mode of the tread separation propagates slower, generating longer force events and is more likely to result in smaller tread pieces. In most of the experiments a combination of peeling and lifting modes of tread detachment occurred.

Test #	Duration I, trigger to end, (sec)	Duration II, principal response, (sec)	Longitudinal		Lateral		Resultant Peak Tow Load (lb) zeroed
			Peak Tow Load (lb) zeroed	Impulse (lb*sec)	Peak Tow Load (lb) zeroed	Impulse (lb*sec)	
F	> 26.4	> 26.4	938	8913	416	3968	1026
H	2.2	1.0	327	202	152	75	361
I	2.6	1.5	737	480	412	265	844
J	13.4	12.2	1057	7984	472	3332	1151
K	*1.5	1.4	771	566	412	290	874
L	*1.2	1.2	639	427	362	249	733
M	*7.4	7.4	940	3730	419	1643	1029
N	4.7	1.4	564	571	291	269	635
*Indicates those test that triggered early							

Table 2, Summary of test analysis

CONCLUSION

1. Tire force response depends upon how a tire's tread separates.
2. Peak resultant force due to complete tread separation event was recorded in the range of 361 lbs for event duration of 1.0 seconds to 1151 lbs during a 12.2 second event.
3. A partial tread separation event was recorded with duration in excess of 26.4 seconds and produced the largest impulsive response.
4. Treads that moved inboard typically produced longer duration events and correspondingly higher impulsive response.
5. Peak longitudinal forces generally increased with separation event duration, while the peak lateral forces remained relatively the same for all tests.
6. Modes of tread separation from the tire can involve both lifting (trailing) and peeling (leading). In a single tread separation event both failure propagation modes often exist.
7. Lifting (trailing) modes of tread separation propagate more slowly than peeling (leading) modes. They generate longer force events and are more likely to result in smaller tread pieces.
8. Peeling (leading) modes of detachment propagate more rapidly and are more likely to result in detachment of a tread piece that approximates the circumference of the tire.
9. The longer duration tread separation events produced multiple pieces of broken tread. Single pieces of tread were observed in the shorter duration separation events.
10. The longer recorded tread separation events produced force-response curves that have a trapezoidal shape. Triangular shaped force-response curves are observed in the shorter duration tread separation events.

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