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Tire Uniformity Tester for Automotive Service Industry with the Capability to Measure Lateral Forces

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ABSTRACT

The automotive service industry has long been aware of tire-related vehicle pull conditions; however, no method for quantitative diagnosis has existed for the technician until now. With the new StraightTrak™ Lateral Force Measurement (LFM) feature, the Hunter GSP9700 can measure lateral forces generated by a rolling tire. Using a load roller, it applies radial loads of up to 1400 pounds to the tire. The corresponding lateral forces produced between the tire and roller are then measured. By rotating the tire/wheel assembly both clockwise and counterclockwise, the system can calculate conicity values for a set of tires and then display net results from the twelve tire combinations on the steer axle. With this information, technicians can place tires to minimize pull.

Conicity values from this machine are compared to measurements made using tire uniformity machines from Akron Standard/ITW. Discussion of the results is provided in the “Accuracy” section of this paper, and graphical information is included in the appendix. Repeatability tests were also conducted for the StraightTrak™ feature. The testing procedure is discussed in the “Repeatability/Precision” section of this paper, and tabulated results are provided in the appendix.

INTRODUCTION

The industry needs equipment capable of measuring lateral force and recommending placement of tires about a vehicle. With the addition of StraightTrak™ Lateral Force Measurement (LFM), the GSP9700 offers solutions to tire related vehicle pull problems. To maximize the effectiveness of LFM, all other known sources of pull should first be reduced as much as possible. Improper or uneven tire inflation and excess aligning torque from suspension in need of adjustment can directly cause a pull, and can even increase the rate at which the lateral forces in tires change.

It remains that even after tire/wheel assemblies have been balanced, correct inflation has been set, and suspension has been properly aligned, a vehicle may still pull from a straight line. The cause of this pull can be an excess conicity difference between tires on the steer axle. Previously, diagnosis of such pull conditions involved the slow trial and error process of swapping tire placements in a certain order, in the attempt of finding the least offensive configuration. The amount of time involved in such a process is unpredictable and unfavorable for shops charging flat rates, or for customers paying for labor by the hour. While the StraightTrak™ function should not replace fundamental diagnostic procedures, such as visual inspection of tread wear, inspection for brake drag, measurement of tire pressure and ride height, and test driving, it has the potential to reduce the number of trial configurations and test drives.

1. What is accomplished with StraightTrak™ LFM?
    - Elimination or reduction of tire related drift/pull
    - Superior ride quality from increased vehicle straight-ahead stability
    - Prevention of problems or comebacks after rotations
    - Enhancement of steering stability and reduction in wandering
    - Reduction of driver fatigue due to pull

2. When should StraightTrak™ LFM be used?
    - Tire mounting and balancing process
    - Tire rotations
    - Alignment service

3. How is StraightTrak™ LFM used?
    - Determine minimum conicity offset configuration on steer axle to reduce/eliminate tire related pull conditions
    - Diagnose residual pull symptoms after alignment service

LATERAL FORCE BACKGROUND

Conicity and plysteer are the two primary components of lateral forces generated by tires. The definition for conicity used in this paper will be as defined by SAE "Surface Vehicle Information Report" journal J2047; it will not be used to indicate directly the actual geometry or the "conical-ness" of a tire. These forces are inherent in all tires and can change throughout the life of a tire. They can develop even while driving on a smooth, flat road, and exist even in new tires. While the effects of conicity and plysteer cannot be corrected through balancing or ForceMatching,™ the forces of individual tires can be used to counteract each other through strategic placement on a vehicle. The coordinate system used in this paper will be the tire force system as defined by SAE "Surface Vehicle Information Report" journal J2047. Refer to Figure 3 on page 8.

StraightTrak™ displays a "Least Vehicle Pull" configuration that minimizes the conicity offset on the steer axle. This will be the most effective placement for reducing tire-related pull conditions.

Conicity

> *Lateral force offset component which does not change direction with respect to the tire face due to a change of tire direction of rotation.*

Publications by Topping and Pottinger indicate that, "conicity force is a valid, approximate variable which is useful in predicting tire induced steering problems." As its name infers, conicity (sometimes even referred to as "tire camber") causes a tire to roll as if it were a cone – always turning towards the side of smaller circumference. This is most visible at the tread level of tires worn by excess suspension camber. However, significant conicity can come from underneath the tread as well. New, high quality tires may not have perfectly centered belts over the carcass. The sidewall to which the belts are closer will be stiffer than its counterpart and play the role of the larger end of the cone.

Conicity can also change in magnitude and direction over the life of a tire. Although change will occur with mileage under normal wear conditions and even with static aging if a vehicle is simply being stored, several factors can increase the rate of conicity change. It is important to consider these factors, which include improper inflation and suspension alignment that exceeds factory specifications, when using StraightTrak™ to diagnose a pull symptom.

Conicity measurements can be used to make accurate estimations as to which configuration will be most likely to minimize or eliminate a pull condition. The "Least Vehicle Pull" configuration will always minimize vehicle pull due to conicity. Quantitative predictions on pull magnitudes will vary per vehicle, especially when using alternate placement configurations. When selecting alternate configurations based on conicity magnitudes, it is important to remember that conicity magnitude is dependent on tire pressure and will decrease as tire pressure increases. Vehicles that specify higher tire pressures on the door placard may be less responsive to a given conicity difference than vehicles specifying lower pressures. Conicity's influence on pull is dependent on several other aspects of a vehicle as well, and will be addressed later.

Pull due to conicity can result in driver fatigue, especially over extended periods on long, flat roadways. In some cases, extreme magnitudes can combine in the same direction to yield uncomfortable conditions, resulting in pulls of two-second lane changes or less. An example of such a pull is included in the "Case Studies" section of this paper. The condition cited required significant correctional efforts at the steering wheel and made driving in heavy traffic hazardous. Excess tire wear from constant correction can also occur.

Plysteer

> *Lateral force offset component, which changes sign with respect to the tire face with a change in tire direction rotation.*

A common misnomer in the industry is to confuse plysteer as the source of tire related pull. While it does exist as a measurable quantity, it should not be associated with pull symptoms or confused with conicity. It is capable of causing a drift, or dogtrack attitude of the vehicle, and may cause the steering wheel to be off 12:00 when traveling straight. Although it can affect vehicle attitude and steering wheel orientation, it does so in the same manner as a thrust angle condition and is not accompanied by a pull. Like conicity, plysteer is present from the factory and changes with tread wear and age. Consistent influence on vehicle pull caused by plysteer has not yet been recorded, so this paper will not attempt to address plysteer issues in detail.

RESIDUAL ALIGNING TORQUE (RAT)

RAT is present in all tires. It is a torque that is produced by manufacturing issues and by various design criteria. This and other forces and moments created by tires are not measured on the GSP9700, or TUG machines. RAT can only be measured on “flat track” evaluation machines.

RAT has two components: Conicity Residual Aligning Torque (CRAT) and Plysteer Residual Aligning Torque (PRAT). Fortunately for us, the conicity force that we are able to measure is proportional to the CRAT and therefore we are able to determine meaningful information about the tire and suggest a vehicle placement that will make an improvement.

LATERAL FORCE TEST PROCEDURE

A tire is mounted onto the GSP9700 spindle just as is normally performed on traditional wheel balancers. As the spindle rotates, a load roller applies a predetermined radial force to the tire. After several revolutions, in the counter-clockwise direction, of bead seating and tire exercising, a sensor in the load roller assembly measures the change in radial runout of the tire/wheel. After the radial measurements are taken, a force sensor measures the forces exerted in the lateral (axial) direction. The drive system then reverses the spindle rotation to the clockwise direction. The force sensor again measures the forces exerted in the lateral (axial) direction. The machine uses the tire face axis system and the following equations, as specified by SAE J2047, to calculate conicity and plysteer:

$$\text{CONICITY, } F_{Y(CON)} = 0.5[F_{YO(CW)} + F_{YO(CCW)}]$$

$$\text{PLYSTEER, } F_{Y(PLY)} = 0.5[F_{YO(CW)} - F_{YO(CCW)}]$$

<u>Variable Definitions</u>

$F_{yo(CW)}$ = measured lateral force in clockwise rotation

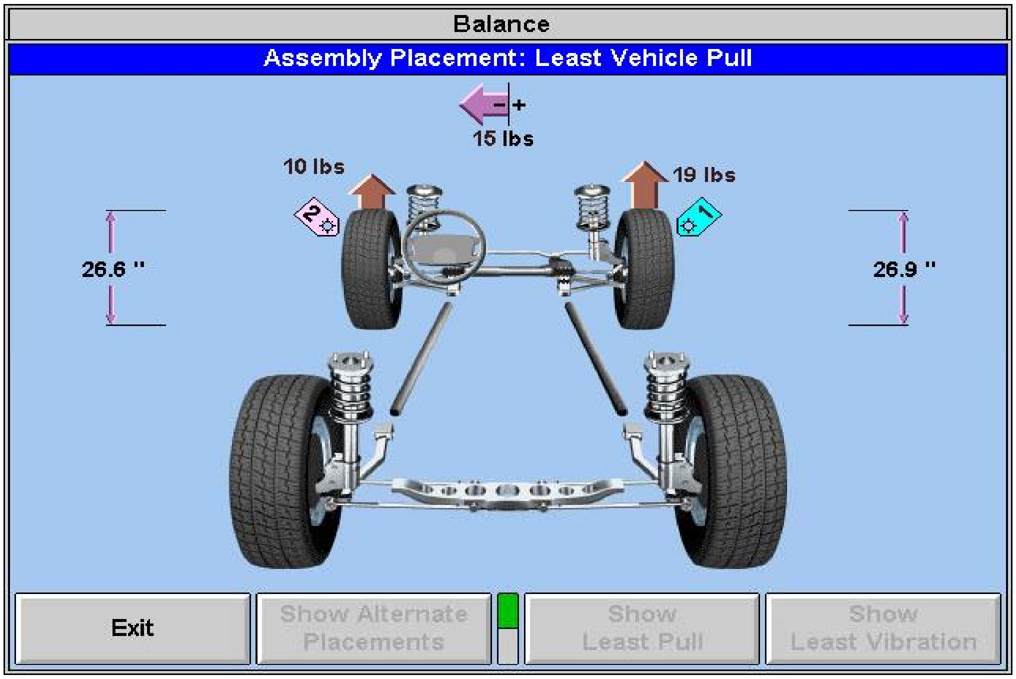
$F_{YO(CCW)}$ = measured lateral force in counterclockwise rotation

$F_{Y(CON)}$ = conicity component of lateral force

$F_{Y(PLY)}$ = plysteer component of lateral force

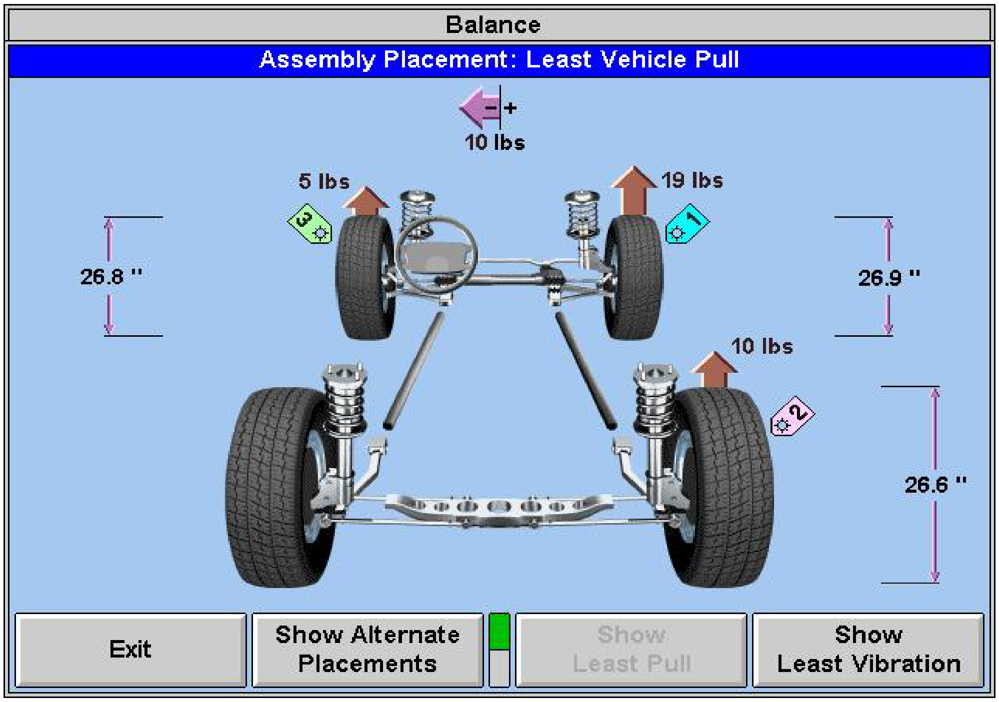
The display provides the operator with the information relating to the measured vibrations and forces exerted by the vehicle wheel, which are stored in memory. The tire is marked for identification. The operator then proceeds to measure and mark the additional tires for this vehicle. The GSP9700 will first provide the operator with suggested placement of the tires so that the net conicity exerted on the steer axle of the vehicle is minimized.

The screen plan below illustrates results displayed after two tires have been measured.



Screen 1

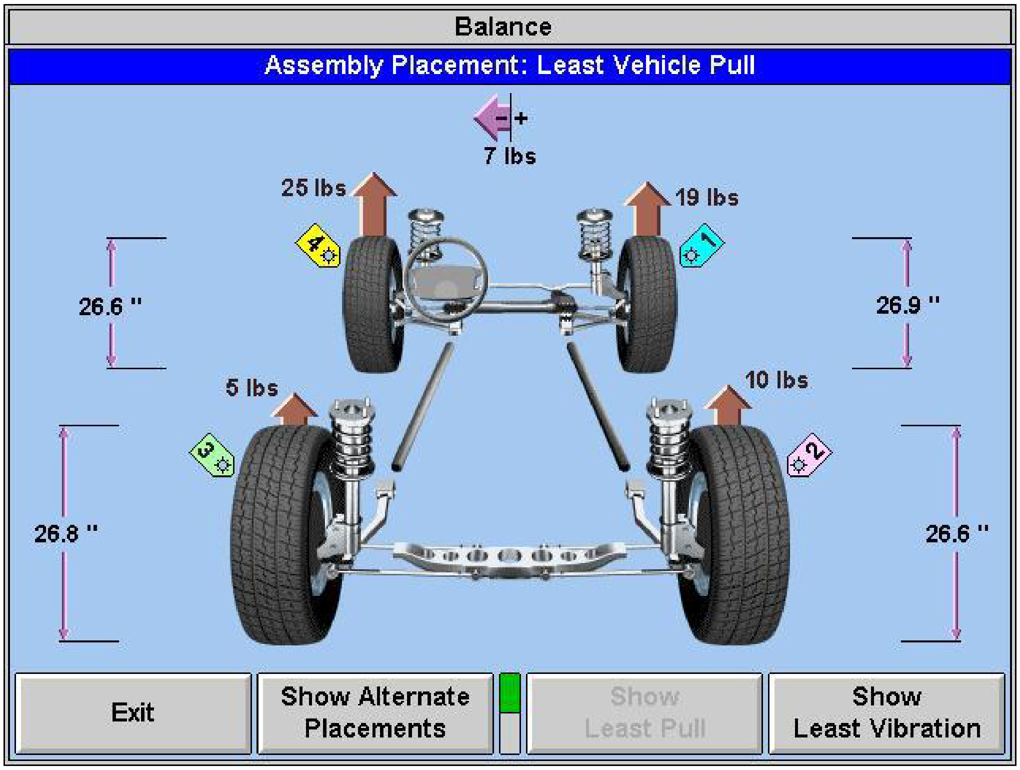
Below is an example results screen from the GSP9700 showing the “Least Vehicle Pull” configuration after three tires have been measured. The number (10 lbs) below the arrow at the top of the screen indicates the conicity difference between the front tires.



Screen 2

It will also provide alternate placements for tires and show the resulting conicity.

The following screen shows the “Least Vehicle Pull” placement result after four tires have been measured.



Screen 3

CASE STUDIES

Suspension alignment, tire pressures, and other factors were checked and corrected if necessary on all vehicles involved in the following case studies. Lateral force contributions from other sources were considered negligible and will not be addressed in the case study notes.
Test drives were performed in low traffic on interstate I-70 near Hunter Engineering along portions with minimal road crown and few surface irregularities. Efforts were made to minimize torque steer while maintaining a vehicle test speed of 60 mph. Below are the steps of the standard test drive procedure.

Test drive vehicle over prescribed test route.

a. Note steering wheel position when traveling in a straight line.
   Reference this as the clock position of the top of the steering wheel.
b. Note direction of pull and amount of pull.
   Amount of pull will be defined as a number. While driving in the middle of the lane, count the number of seconds needed for the outside tires to cross the line once the steering wheel is released. (E.g.: If the car pulls to the right, count the number of seconds for the right side tires to cross the line that separates lanes.) In these terms a 2 second pull is very strong, whereas a 12 second pull is very slight.

After an initial test drive, all four tires were measured using StraightTrak™ on the GSP9700. Subsequent configurations were always followed with another test drive. After case study testing was complete, vehicles were always placed in a “Least Vehicle Pull” configuration.

Case #1 – 95 Ford Taurus
In the initial test with corrected alignment and tire pressures the vehicle experienced a 2 second lane change to the right. StraightTrak™ indicated the presence of 70 pounds of conicity to the right on the initial front axle configuration. After remounting the tires in the recommended “Least Vehicle Pull” configuration, the pull improved to approximately a 7 second lane change to the left. The corresponding conicity on the front axle for the “Least Vehicle Pull” pairing was 9 pounds to the left. It should be noted that while a 7 second pull is still noticeable on a flat road, the 79 pound differential in tire configurations was enough to improve the condition from dangerous to tolerable.

Case #2 – 95 GMC Jimmy 4x4
In the initial test drive of this vehicle, no pull was apparent, and suspension alignment was within specification. Tire pressures were uniform and there was no brake drag. After measuring the tires on the GSP9700, StraightTrak™ provided that the front axle was initially subject to 8 pounds net conicity to the left. After arranging the tires in corresponding to the conicity on the front axle was 17 pounds to the left, the vehicle yielded a pull of approximately a 7 second lane change. Reversals of the front pair led to a pull in the opposite direction of approximately the same magnitude.

Case # 3 **–** 01 Mercury Villager
The initial pull for this vehicle was slight but noticeable at a 9 second lane change to the left. Arranging the tires to change conicity on the front axle by 18 pounds to the right resulted in a pull direction change at a stronger magnitude of 6 seconds to the right.

Case # 4 **-** 98 Plymouth Grand Voyager
The initial pull condition for this vehicle was slight as well, at approximately a 9 second left hand lane change from an initial configuration of 2 pounds of conicity to the right. Rotating the tires based on tread depth without crossing from side to side resulted in an 8 pound conicity change to the left which increased pull strength by 2-3 seconds (still to the left). Rotating the tires, based on conicity and current pull strength, to an alternate configuration that changed the conicity from the initial condition by 4 pounds to the right, resulted in the most suitable pull condition (approximately 11 seconds to the left). An arbitrary tire rotation based on tread depth, without LFM, would have created a pull condition. With the information provided by StraightTrak, ™ the technician could have considered the initial pull condition and reduced amount of time needed to perform a successful tire rotation.

Accuracy

Conicity values from the GSP9700 are compared to measurements made using tire uniformity machines (TUG machines) from Akron Standard/ITW. Ten tires were tested on five GSP9700 machines, a TUG machine provided by Smithers Scientific Services, and a TUG machine at General Motors. A graph displaying the correlation results, $R^2 = .9439$, is provided in the appendix. Refer to Figure 1 on page 7

Repeatability/Precision

Three different repeatability tests were run using six (four passenger, two light truck) test tires to monitor the GSP9700's ability to take consistent conicity measurements. Test one required mounting a tire/wheel assembly on the spindle and applying the load roller ten times without dismounting the assembly. Test two required removing the assembly from the spindle, and then remounting it in a randomly different position. It verifies that the mounting cones and wing nut are not a source of significant measurement variance. Test three involved removing the assembly from the spindle, breaking the bead from the seat and changing the angular position of the tire, re-inflating the tire, and then remounting the assembly on the spindle. It confirms that no significant conicity change comes from changing the circumferential orientation of the tire/wheel interface. Proper tire/wheel mounting technique is required for producing these results. Data tables including average values, standard deviation, and average standard deviation per test for each of the three tests are provided in the appendix. Refer to Figure 2 on page 7.

Limitations

Segments of road on which the test drives were conducted were kept consistent; however, pull magnitude counts were still susceptible to driver deviations. Although crown was minimal, some vehicles, which had little or no pull, eventually tended toward the side of the crown to which they were initially placed. Wind contribution was usually minimal, as the typical east/west wind coincides with the direction of travel along I-70.

Other factors not detectable by pressure gauges, alignment equipment, or the GSP9700 may also induce a pull condition. These factors include imbalanced hysteretic behavior among shock absorbers, uneven levels of friction or residual pressure between left and right sides of a steering system, varying stiffness of ball joints, and RAT.

CONCLUSION

With the StraightTrak™ LFM feature, the GSP9700 can measure conicity and provide information for tire placement about a vehicle to minimize pull. Of measurable lateral force components in tires, conicity is known to have the most influence on vehicle pull conditions. Based on this knowledge, the GSP9700 recommends tire placement combinations that minimize net conicity on a vehicle's steer axle. Using the "Least Vehicle Pull" configuration will optimize "straight tracking" for vehicles not noticeably influenced by other pull-inducing factors. Viewing the net conicity for alternate tire placements may allow the technician to correct a non-tire-related pull for a given vehicle.

While conicity is present in all tires, the significance of it in any one tire depends on the conicity magnitude and direction of the one opposing it on the steer axle. While pull strengths corresponding to particular conicity values (steer axle tire pairings) vary per vehicle, LFM provides a scale from which to make educated tire placement decisions. Each possible net conicity magnitude on the front axle is provided so a technician can decide which is most suitable for a given vehicle. Initial pull condition, vehicle weight, alignment settings, and wheelbase are among the important factors to consider when assigning tire placements on the front axle. While explicit relationships have not yet been developed to account for each factor, their qualitative tendencies are intuitive and reliable. Whether it is suggesting optimal placement for new tires on a vehicle or providing information to correct tire induced steering by used tires, StraightTrak™ is a useful tool for efficient diagnosis and rectification of tire related vehicle pull conditions.

ACKNOWLEDGMENTS

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CONTACT INFORMATION

Information on the Hunter GSP9700 may be obtained from the Hunter web site at www.GSP9700.com or by calling 1-800-448-6848 or 314-731-3020.

APPENDIX

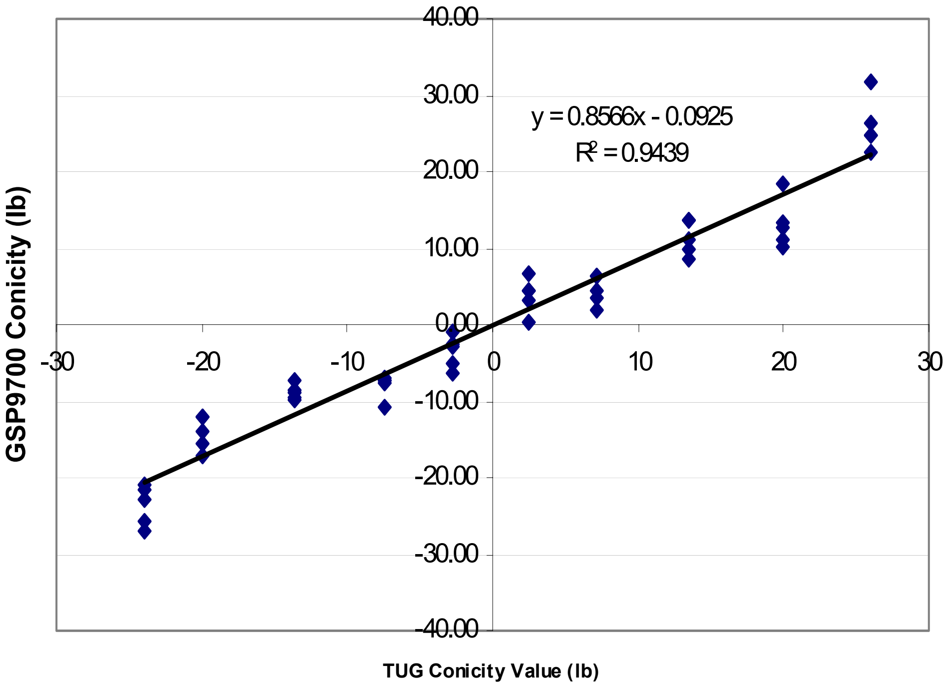

Figure 1. Conicity Correlation Graph

Conicity Measurements Without Spindle Remount

Tire Size	Pressure (psi)	1	2	3	4	5	6	7	8	9	Avg	Std Dev
P205/70 R15	30	-10.07	-9.34	-9.04	-9.58	-9.61	-9.77	-9.79	-9.79	-9.93	-9.66	0.31
P185/70 R14	30	16.06	16.25	16.25	16.34	15.77	16.24	15.52	15.26	15.62	15.92	0.39
P195/75 R14	30	17.71	17.02	16.88	16.47	16.08	16.14	15.78	15.70	15.49	16.36	0.72
P225/70 R14	30	68.08	67.06	67.10	66.23	65.02	67.52	64.18	66.12	65.87	66.35	1.24
LT265/75 R16	50	19.75	20.17	19.94	19.91	19.29	19.43	19.31	19.14	19.06	19.56	0.40
LT235/85 R16	50	61.75	60.73	60.66	60.06	60.08	59.43	59.79	59.54	59.48	60.17	0.76

Avg Std Dev
0.64

Conicity Measurements With Spindle Remount

Tire Size	Pressure (psi)	1	2	3	4	5	6	7	8	9	Avg	Std Dev
P205/70 R15	30	-9.03	-8.60	-8.64	-8.41	-8.06	-9.89	-9.33	-9.99	-10.06	-9.11	0.74
P185/70 R14	30	16.09	15.68	17.22	17.56	17.38	18.05	17.65	16.90	16.72	17.03	0.77
P195/75 R14	30	15.95	15.47	15.51	16.03	14.85	15.77	15.22	15.00	15.68	15.50	0.41
P225/70 R14	30	66.32	66.87	66.97	66.62	66.95	68.76	65.78	66.16	66.25	66.74	0.86
LT265/75 R16	50	20.20	19.27	19.05	20.12	19.68	19.88	19.15	20.46	19.13	19.66	0.53
LT235/85 R16	50	61.61	61.87	60.89	61.38	60.69	61.38	60.20	60.70	60.75	61.05	0.54

Avg Std Dev
0.64

Conicity Measurements with Spindle Remount and Tire/Rim Remount

Tire Size	Pressure (psi)	1	2	3	4	5	6	7	8	9	Avg	Std Dev
P205/70 R15	30	-11.88	-12.02	-12.53	-12.23	-12.38	-12.54	-12.54	-12.42	-12.68	-12.36	0.27
P185/70 R14	30	15.72	15.66	15.35	14.95	14.86	14.85	15.08	15.36	14.73	15.17	0.36
P195/75 R14	30	10.86	10.56	10.86	10.39	10.17	10.15	10.10	9.67	9.81	10.29	0.42
P225/70 R14	30	65.36	64.14	62.79	64.38	63.30	62.94	63.01	63.38	64.10	63.71	0.85
LT265/75 R16	50	18.11	17.97	17.75	17.79	17.53	17.58	17.41	17.32	17.42	17.65	0.27
LT235/85 R16	50	58.94	58.72	57.84	58.82	58.46	58.72	58.62	56.94	58.68	58.42	0.64

Avg Std Dev
0.47

Figure 2. Conicity Repeatability Data Tables

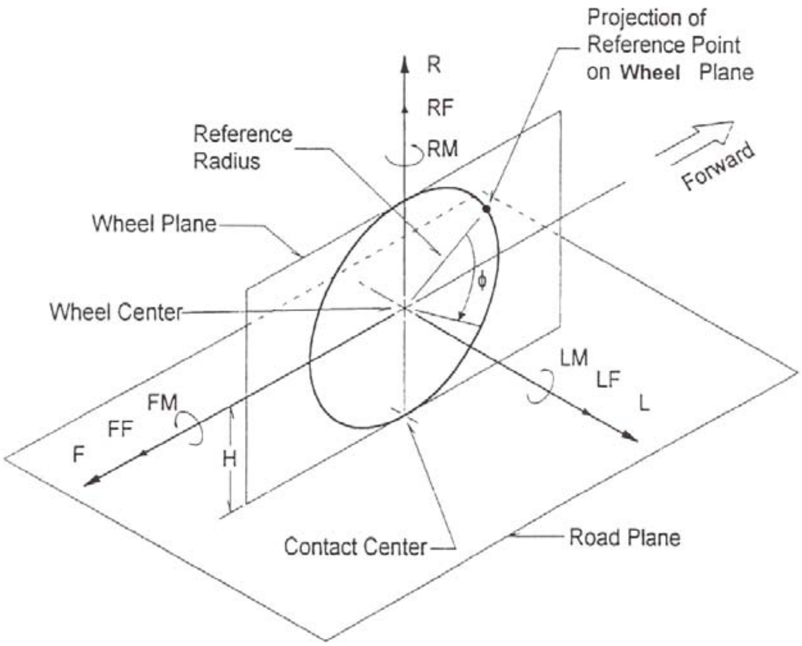

Figure 3. Tire Face System

REFERENCES

Pottinger, Marion G. and Andrew M. Fairlie. “Characteristics of Tire Force and Moment Data,” *Tire and Science Technology,* TSTCA, Vol 17, No. 1, January-March, 1989, pp.15-51.

Pottinger, Marion G. and Kenneth D. Marshall. “The Effect of Tire Aging on Force and Moment Properties of Radial Tires.” SAE 810066. 1981.

SAE Journal J2047. Issued 1998-02.

Topping, Richard W. “Tire Induced Steering Pull.” SAE 750406. 1975.

Triola, Mario F. Elementary Statistics Seventh Edition. Addison Wesley Longman, Inc. 1998.