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A NEW TIRE/WHEEL BALANCING METHODOLOGY BASED UPON ABSOLUTE FORCE CALCULATIONS

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A NEW DYNAMIC BALANCING METHOD BASED UPON ABSOLUTE FORCE REDUCTION ALGORITHMS

Reducing Unnecessary Wheel Balance Costs during the Correction Cycle

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Executive Summary

Wheel balancing will always be one of the most cost effective means of ensuring quality ride performance to consumers. As consumer demands for ride quality continue to increase; dynamically balanced tire and wheel assemblies remain an essential ingredient. As important as dynamic balance and uniformity correction may be on today's sensitive vehicle platforms; significant changes in wheel designs and the costs of balancing materials are increasing the costs associated with the dynamic balancing process. As a result of changes in tire and wheel applications and non-conventional weight placement, unnecessary use of correction weight has been recently discovered while studying conventional dynamic balancing algorithms. It has been determined that some of the costs that are increasing are unnecessary. These unnecessary costs have been able to be eliminated with revised dynamic balancing algorithms. Significant cost reductions in wheel balancing processes can be achieved with recently developed and simple to apply couple correction algorithms and have already proven successful in the service industry.

Plant engineers who implement OE and vehicle manufacturer balancing processes are encouraged to adopt new couple correction algorithms to gain the following results:

1. Reduce balancing correction weight use by 32% or more; without significant degradation in vehicle ride quality.

2. Single-plane, dynamic weight corrections can be increased by over 45% versus conventional two-plane weight corrections. This can increase throughput and reduce labor costs if weights are manually attached to the wheel.

3. The new algorithm reflects more positively when correction weight is used to assist in determining TWA uniformity.

4. Measuring the couple unbalance in terms of absolute engineering units is a more consistent form of measurement to analyze the dynamic effects of overall balance quality than relying on weight correction alone as locations of the balance weight change due to varying applications.

5. Force thresholds can be used to optimize correction weight usage based on specific vehicle sensitivity limits of static and couple unbalance measurement. Residual couple weight reduction can be fine tuned to maximize results.

Background

Since the early 1900's, tire manufacturers, vehicle manufacturers and the related service industry rely on static balance measurement as the primary tool for ride quality, uniformity measurement and quality control.

In the middle 1970's, electronic dynamic wheel balancers began to increase in popularity as automotive service equipment. Static and couple forces were both balanced out of the TWA. Two weights which were placed on different planes and separated from each other by two distances and diameters were phase vectored with electronics to cancel static and couple forces to within the design capability of the equipment. For decades, rim flanges were used with clip-on style wheel weights. This worked well because the locations were located as far as possible from each other on the wheel. Maximum effect was achieved to eliminate both forces. A dynamic balance was performed.

Most OE continued to balance wheels statically through the early 1990's while the service industry moved towards dynamic two-plane static and couple force cancellation to tolerances within the range of 2.5 to 7-gram increments beginning almost 20 years prior. Computer wheel balancers displayed two-plane dynamic resolution in 0.5-gram incremental weight units, which are based on the locations chosen.

By the 1980's, virtually all vehicles were being serviced with some type of dynamic spin balancer. In comparison to static balance, additional correction weight was now applied to balance or "zero" the wheel. Over the next ten years, more and more dealers' dynamic balanced their customer's tires when performing service. It does not come as a surprise that dynamic balance warranty claims in the service industry skyrocketed as the vehicle manufacturers released statically balanced assemblies on their vehicles. Around 1990, OE began to slowly implement dynamic balancers onto the assembly lines beginning with full implementation by 1996 and beyond.

The conventional dynamic balancer found in garage service since the 1970s measures static and couple forces in a similar manner to OE equipment however in a dynamic mode only displays the amount of correction weight used to cancel both static and couple forces. The two-plane balance correction vectored the static and couple forces to cancel them both with two unequal size correction weights. The actual couple and static forces were not used independently or treated with different priority in a two-plane correction weight application cycle.

Two Forces Expressed in Terms of Dynamic Correction Weight

Unlike traditional vehicle TWA applications of the past, modern applications vary greatly in size and mass. Conventional dynamic balancing uses two separately defined weight correction planes, and attempts to cancel both static and couple forces during the balance cycle. Industry use of incremental correction weight sizes in reality negates the ability to achieve total force cancellation. Fixed incremental weight size balancing of both static and couple forces actually do not fully achieve the assumed goal or force elimination, nor is it necessary to fully cancel the couple force to reach expected levels of superior ride quality. The correction weight unit based on two measured locations was used to eliminate both forces to the smallest possible denominator.

As a static and couple force remains constant, the correction weight changes as dimensions are relocated. Small changes in radius will change static force in significant amounts, however large changes in distance do not affect the couple force in similar magnitudes in relation to vehicle sensitivity. Static sensitivity has always been the more important of the two dynamic balance measurements. What has not been implemented into the dynamic balance cycle of the past, is that the amount of couple correction weight required to excite the vehicle and cause ride complaint is of much less effect than the same amount of static correction weight required to offset the static force. For example, acceptable ride sensitivity and the effect of a given correction weight unbalance can differ by ratios of 4:1 for couple weight vs. static weight (when placed on flanges of 15x7 wheel). When attaching the correction weight at narrower and wider applications the ratio of effectiveness can range anywhere from 1:1 on very wide wheels to infinity as the distances between the two-planes become closer. Two-plane balancing in most cases made no addition to correction weight added for static cancellation, but the couple correction was very susceptible to significant weight increases due to the overall reduction location due to alloy wheels and adhesive tape weight placement.

The act of conventional dynamic balancing minimizes the forces in the wheel. The resolution of the balancer is based on the performance of the platform to measure the smallest unbalance forces. As a result, the threshold is traditionally placed on the correction weight (either the smallest weight increment or resolution of the balancer) not the independent force levels. When dimension entry for location are used with correction weight canceling, the balancer doesn't know when to stop adding correction weight until the forces are completely cancelled to below the threshold of the smallest weight which is used. All vehicles are inherently much more sensitive to the unbalance correction weight of static force (shake) then couple force (shimmy). Static residual forces are affected by small amounts of correction weight while couple residual forces require large amounts of correction weight in comparison and the force has much less effect on the vehicle. Secondly, often by default the traditional dynamic balancing display of correction weight in two planes treats the correction weight the same regardless of its vectored position of the opposite plane. As result, this dynamic treatment of wheel correction weight assumes equal importance of the two measured forces. When the balance cycle attempts cancellation of both forces regardless of weight position chosen, this creates excessive amounts of couple correction weight applied that may likely be well below the threshold of what would affect ride quality. As a result, the conventional dynamic balancer will display correction weight to cancel both forces when in reality the cancellation of the couple force is not necessary.

Absolute Balance Forces Reduction vs. Dynamic Weight Elimination

Static unbalance force is measured in absolute engineering units of gm-mm, while the absolute couple unbalance force is a twisting moment, or torque and measured in gm-mm*mm **(Figure "A")**. The concept of using absolute unbalance force thresholds exploits the traditional method of relative dynamic weight elimination from tire balancing. The new algorithms bring to light previous shortcomings, which are quickly expanding due to today's wheel designs.

The couple correction of wheel weight added was not a single radius and mass for static, but two equal masses separated by equal distances and radius. The couple unbalance is a twisting moment. These equal correction weights applied to cancel the couple force require much greater mass to make changes in the force compared to static correction weight and its effect on sensitivity. This phenomenon is which had the added effect of adding couple weight of being able to cancel both static and couple unbalance in the tire and wheel. The static only form of wheel balancing could not measure the couple force and therefore would also become the norm. To balance or cancel the static and couple unbalance with correction weights placed on two distinct planes. For decades the wheels were dynamically balanced at the rims furthest positions away to minimize weight…the rim flanges.

Effects of Using Identical Weight Increments on Static vs. Couple Forces in Wheel Balancing

Correction weight has a greater affect on static unbalance force versus the same amount of weight and its effect on the couple twisting moment. When correction weight is used to resolve dynamic unbalance in an assembly, much more weight typically must be applied to affect the couple force and reduce it than the magnitude used to resolve the static unbalance.

Because of the inherent differences in the effects of correction weight mass on static force versus couple force correction, the use of correction weight alone in determining the level of excessive couple unbalance force can not be compared in the same manner static correction weight has been used for uniformity measurement. Eliminating the couple force from the TWA is not essential or the most efficient use of correction weight.

The new dynamic balancing algorithms put appropriate emphasis on couple force reduction, not complete couple force elimination. The intent is to leave a small residual couple force after the balance cycle. As correction weights are placed closer and closer together, the force remains the same but correction weight that is not used is significant. The couple force in terms of equivalent correction weight remaining is always equal in size and 180 apart from each other separated by distance. The new algorithm's couple force reduction level remains constant regardless of the correction weight locations chosen. A simple way to state this is, "if the force that causes a vibration is not exceeded, then the correction weight is not needed."

Recent trends towards larger tires combined with alloy wheels with one or both weight planes using adhesive weight increases the difficulties associated with traditional dynamic balancing couple correction. As a result, conventional couple correction is creating excessive costs associated with dynamic balancing.

During the balancing cycle, the new algorithms leave an intentional amount of residual couple force in the assembly, which is well below the threshold of vehicle sensitivity. This translates to a significant reduction in correction weights, which on every wheel balance will be located in two weight planes, 180·opposite each other and equal in size (assuming weight plane diameters are equal).

This new and simple to apply balancing algorithms can achieve significant benefits for OE and vehicle manufacturers.

Couple Weight Elimination in Conventional Wheel Balancing

The new balancing algorithms reveal that virtually all conventional dynamic wheel balancers have fundamental limitations in the way correction weight is calculated and applied during the balancing process. As a result, significant amounts of couple correction weight are being applied during balancing processes, which have no significant contribution to reducing vehicle vibration. Flangeless wheels often require narrow distances between the two weight planes and large increases in wheel weight are necessary to chase the reduction the couple force to a level that is unnecessary.

Draw Backs of Dynamic Balancing in Two-Planes with Fixed Weight Blinding Regardless of the Correction Weight Locations Chosen

Typically, the unbalance limit (or tolerance blinding) for both static and couple unbalance is set at a level slightly higher than the size of the smallest correction weight increment. This is done regardless of weight placement positions chosen to balance the wheel. When applied to couple correction the amount of weight has a much less effect as the distances between the two weights become closer. This is becoming common on allow wheels that no longer utilize one or both flanges of the wheel. Adhesive weight placement in general leads to more frequent “chasing of weights” and difficulty during the balance cycle because of diminished effectiveness based on an unnecessary threshold.

New Optimized Dynamic Balancing Utilizes Static Cancellation and Couple Unbalance Correction with a Residual Goal

This new method of wheel balancing computes correction weights based on the use of independent static (shake) and couple (shimmy) force limits and calculates the balance to include a residual couple correction left intentionally in the TWA. The absolute static and couple force is expressed in engineering units and displayed in a standardized unit of force measurement method using absolute forces of the tire and wheel unbalance instead of solely displaying correction weight related to it perspective two-plane weight locations. A bar graph display expresses the static and couple force in terms of absolute engineering units and tolerances instead of relative correction weight based on the specific location of the weight. Separate thresholds are used for the static and couple forces to trigger the correction. On the correction spin, elimination of the static force is made first priority and then a second tolerance is placed on the remaining couple force; intentionally leaving a small amount of residual couple force to maximize productivity and significantly reducing the amount of correction weight required.

Increasing the Frequency of Single-Plane Dynamic Balancing

New algorithms allow a small amount of residual couple force (residual correction weights) which are well below the vehicle vibration threshold, allows for large weight savings and the ability to frequently dynamic balance by shifting to a single weight placement almost 50% of the time instead of attaching two correction weights. Automatic static optimization and a tight audit on couple force perform a better overall dynamic balance, reducing vibration complaints to a more effective level than ever before achieved with conventional balancing processes.

New Balancing Algorithms Use Independent Force Limits and a Residual Couple Tolerance

The new algorithms can use a single default that is beneficial regardless of vehicle sensitivity to successfully appease the most stringent NVH ride quality expectations. A single set of limits, adjusted low enough for all vehicles will reduce the excessive and unneeded costs of correction weight and time associated with the unbalance correction.

An alternative to a fixed limit couple correction, a fully programmable tolerance and limits with multiple default limits are also possible. Independent limits of static and couple allow for changes when balancing different sized assemblies that tolerate looser tolerances due to less sensitive vehicle platforms.

Up to this point, conventional balancing has ensured that wheel assemblies are balanced to within the smallest possible wheel weight available regardless of weight position chosen. While this approach works well for static correction, it inevitably leads to problems when couple correction is made. As wheel designs deviated from traditional flange type corrections the balancer hypersensitivity, weight chasing and excessive amounts of weight use to address the couple force have become problematic. This issue has escalated in recent years with the proliferation of tape-on weight placement, flangeless outer wheel designs, larger diameter, and wider and heavier rotating assemblies.

New algorithms allow conventional two-plane dynamic correction to (a) optimize the static correction weight while (b) using an independent limit and residual correction tolerance for eliminating significant couple twisting moment. This minimizes weight and speeds the balance cycle, thus eliminating wasted check spins to add additional weight when balancing with tape-on weights.

APPENDIX

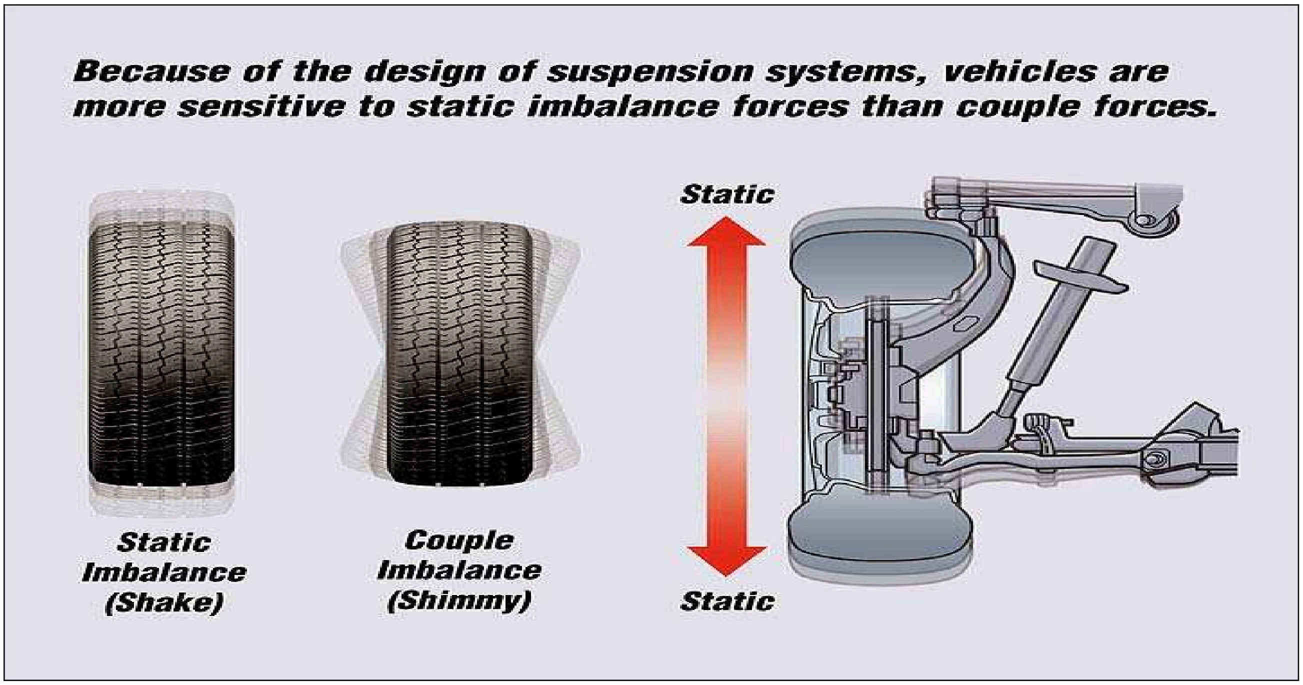
Figure "A"

Static 'Shaking' Force   Couple 'Twisting' Torque Force

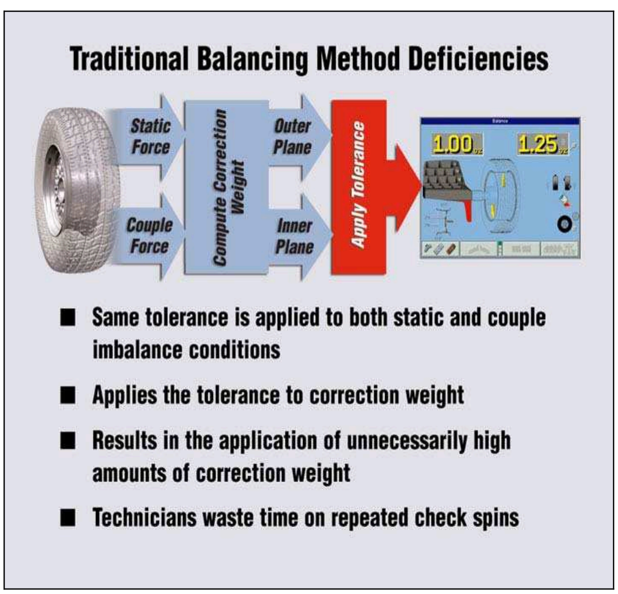
Static unbalance force is measured in absolute engineering units of *gm-mm*, while the absolute couple unbalance force is a twisting moment, or torque measured in *gm-mm*mm*. The measurement remains an absolute value as its correction weight, which expresses the force, varies as its location is changed.

The change in static force as a result of weight change at a fixed radius has large effects on vehicle sensitivity. The same amount of weight change at a given distance with the same radius has a much smaller effectual change on the couple force versus its affect on the static force.

Figure "B"



Figures "C"



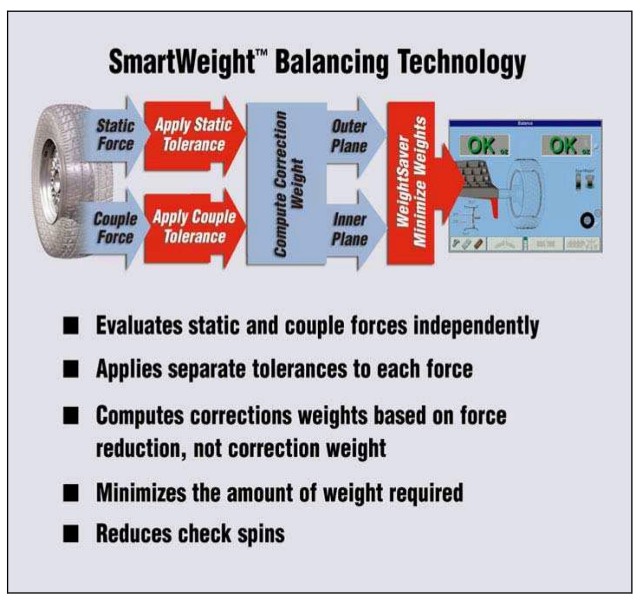


Figure "D"

Example of Individual Dynamic Wheel Balancer Weight Savings

Weight Savings

		<<-14"	15"->17"	18"->20"	21"->23"	24"->>	Total
Clip-Clip	Spins:	323	616	6	0	0	945
	Non-SmartWt:	603.00	1094.75	8.25	0.00	0.00	1706.00oz
	SmartWt:	427.00	795.25	6.50	0.00	0.00	1228.75oz
	Savings:	176.00	299.50	1.75	0.00	0.00	477.25oz
		29.2 %	27.4 %	21.2 %	0.0 %	0.0 %	28.0 %
	1 wt req'd:	197	323	3	0	0	523
	no wts req'd:	8	8	0	0	0	16
Clip-Tape	Spins:	1	28	0	0	0	29
	Non-SmartWt:	2.00	66.00	0.00	0.00	0.00	68.00oz
	SmartWt:	0.50	40.75	0.00	0.00	0.00	41.25oz
	Savings:	1.50	25.25	0.00	0.00	0.00	26.75oz
		75.0 %	38.3 %	0.0 %	0.0 %	0.0 %	39.3 %
	1 wt req'd:	1	20	0	0	0	21
	no wts req'd:	0	0	0	0	0	0
Tape-Tape	Spins:	9	126	130	17	1	283
	Non-SmartWt:	30.00	348.75	404.50	50.50	1.00	834.75oz
	SmartWt:	12.75	211.75	243.50	30.25	0.50	498.75oz
	Savings:	17.25	137.00	161.00	20.25	0.50	336.00oz
		57.5 %	39.3 %	39.8 %	40.1 %	50.0 %	40.3 %
	1 wt req'd:	7	72	73	12	1	165
	no wts req'd:	0	0	2	0	0	2

Totals	
Spins:	1257
Non-SmartWt:	2608.75oz
SmartWt:	1768.75oz
Savings:	840.00oz
	32.2 %
1 wt req'd:	709
no wts req'd:	18

Conventional dynamic balancing (Non-SmartWeight) uses fixed weight increments, which are kept the same for static and couple corrections. The conventional dynamic balance seeks to eliminate the static and couple unbalance to the smallest increment regardless of weight location and mass of the assembly. The static and couple forces are treated with equal importance. This function of conventional dynamic balancing is unnecessary to maintain TWA ride quality expectations.

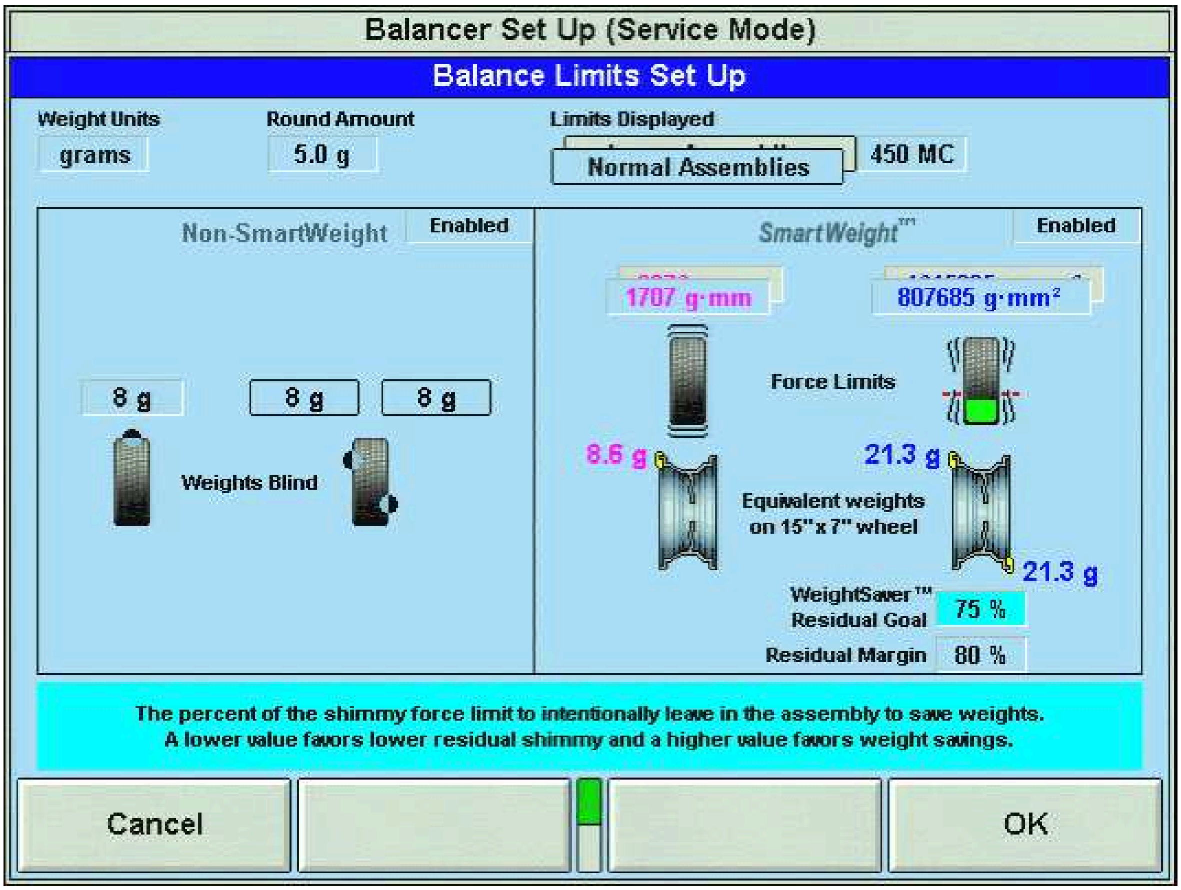
New dynamic balancing algorithms (SmartWeight) do not use similar fixed weight increments for elimination of static and couple forces. This allows the cancellation of absolute static force yet evaluates couple unbalance independently with the appropriate tolerance which is below the threshold of the vibration tendencies of the most sensitive vehicles.

Limits of static and couple forces may also be changed based on the mass of the assembly while weight rounding remains fixed to the smallest available increments. The static and couple forces are not treated with equal correction weight importance. This is necessary to maintain expectations in TWA ride quality and yet reduce unnecessary use of correction weight.

The optimized correction spin of new dynamic balancing algorithms seek to eliminate the static unbalance to the smallest weight amount available and then intentionally leave a residual amount of couple correction weight which is below the threshold for the vehicle to vibrate. This translates to the significant weight savings without ride quality suffering.

Figure "E"

How New Algorithms Compare to Conventional Dynamic Balancing Methods



Conventional dynamic balancing (Non-SmartWeight) using the fixed weight increments and fixed weight blinding of residual unbalance is tracked on every wheel balance and compared to the results of the balanced wheel with the new method. Weight savings can be exactly quantified.

Increases in the frequency of a single-plane dynamic balance compared to conventional two-plane correction are tracked and quantified. Time savings can be quantified.