

NEW DYNAMIC BALANCING ALGORITHMS BASED UPON COUPLE FORCE REDUCTION & STATIC FORCE ELIMINATION

Reducing Unnecessary Wheel Balance Costs During the Correction Cycle

This wheel balancing technology is protected by the following U.S. patents: 6,952,964, 7,320,248, 7,328,614.

Additional U.S. and foreign patents are pending.

Rev B

David M. Scribner

Copyright 2007 Hunter Engineering Company

These new balancing algorithms are also offered to OEM's, tire-wheel suppliers and manufacturers who use industrial balancing equipment. With this recent invention, manufacturers and assemblers can dramatically reduce correction weight use and material waste. The necessity of this has all come about because today's wheels are different than they used to be in the 1970s when dynamic balancing first began in the tire service industry. There are many manufacturers and assemblers that do not use optimized dynamic balancing algorithms and therefore condemn too many tires and wheels for requiring excessive correction weight.

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 balance weight change with varying placement positions.
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 best 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 repair industry almost 20 years prior moved towards dynamic two-plane static and couple force cancellation to tolerances within the range of 2.5 to 7-gram correction weight increments. Many computer wheel balancers even displayed two-plane dynamic resolution in fixed 0.5-gram incremental rounding units regardless of the correction weight 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 tire 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 displayed the amount of correction weight used to attempt to always 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 weight rounding function of the balancer unnecessarily remained fixed regardless of the correction weight placement locations chosen. 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 never fully achieves the assumed goal of force elimination or balancing to “zero”. Furthermore it is not necessarily important to fully cancel the couple force (or couple correction weight) to reach expected levels of superior ride quality within the vehicle. The incremental correction weight unit was used on two determined locations to attempt 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 and correction weight 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. A common mistake as a result of fixed two-plane rounding of wheel weight increments is to allow the service balancer in a two-plane dynamic mode to not place a correction weight priority on static cancellation, but actually treat the two plane couple correction with higher priority. Furthermore, the couple correction was very susceptible to significant weight increases and changes without a significant overall reduction in force when used on modern wheels with closer locations and adhesive tape weight placement.

The act of conventional dynamic balancing minimizes the forces in the TWA. The resolution of the balancer is based on the performance ability of the platform to measure the smallest unbalance forces. As a result, the threshold is traditionally placed on the correction weight smallest increment (or finest resolution of the balancer) not the independent force levels. When dimension entry for correction locations are used with correction weight canceling to “zero” alone, the balancer doesn't know when to stop adding correction weight. The balancer tries to recompute unbalance until the forces are completely cancelled to below the threshold of the smallest weight which is used. As weight positions (couple force distances and radius) become closer as found on today's wheels, the smallest incremental weight size becomes ineffectual and a waste of correction weight. All vehicles are inherently much more sensitive to the unbalance correction weight of static force (shake) than couple force (shimmy). Static residual forces are affected by small amounts of correction weight while couple residual forces require much larger

amounts of correction weight in comparison, while the couple twisting force expressed in incremental correction weight units ends up having 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 correction weight assumes equal correction weight influence on the two measured forces of static and couple. When the balance cycle attempts cancellation of both forces with fixed weight increments 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 can be stated 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 units and thresholds are far superior over the traditional method of using correction weight relative to placement position commonly used in dynamic balancing. The new algorithms in dynamic balancing expose previous shortcomings. The shortcomings of traditional dynamic balancing are quickly increasing due to the proliferation of today's wheel designs.

The addition of wheel weight to cancel couple correction of a TWA differs greatly from the weight required to cancel a static force. The correction weight used for couple correction is not like 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 twisting force compared to static correction weight and its greater effect on vehicle sensitivity. Dynamic balancing has the added effect of combining couple weight and static weight to cancel both static and couple unbalance. The static only form of wheel balancing could not measure the couple force and therefore a two plane dynamic balance has become the norm.

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

For decades the wheels were dynamically balanced at the rim's furthest positions away in order to minimize weight...the rim flanges. Today, with a constant couple force and differing wheel designs, the weight placement choices become closer...and the weight amounts required to correct imbalance dramatically increase for the same couple correction. 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 reduce it than the correction weight amount used to resolve the static unbalance that affects the vehicle.

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 vibration problem solving and uniformity measurement. Eliminating the entire couple correction weight amounts called out at varying locations on the TWA are not essential nor the most efficient use of correction weight.

The new dynamic balancing algorithms put appropriate emphasis on couple force reduction, not complete couple force or correction weight elimination. The intent is to

leave a small residual couple force after the balance cycle that does not contribute to vibration yet translates to large correction weight savings. This remaining insignificant couple twisting force in terms of equivalent correction weight can always be seen as equal in size and 180 apart from each other and separated by a 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.

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 all 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 its 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 allowing a small amount of residual couple force (residual correction weight) well below the vehicle vibration threshold, allow frequent single weight dynamic balancing approximately 50% of the time instead of using two correction weights. The small allowance of couple allows static elimination and single weight placement. A single weight dynamic balance saves large amounts of service time. Automatic static minimization and a tight audit and adjustment of couple force perform a better overall dynamic balance, reducing vibration complaints to a more effective level than ever before achieved with conventional dynamic 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 increment 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 move away from traditional flange type corrections, the traditional method of couple correction based on fixed weight increments increase balancer hypersensitivity, weight chasing and excessive amounts of weight use to address the couple force. This has made traditional dynamic balancers 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.

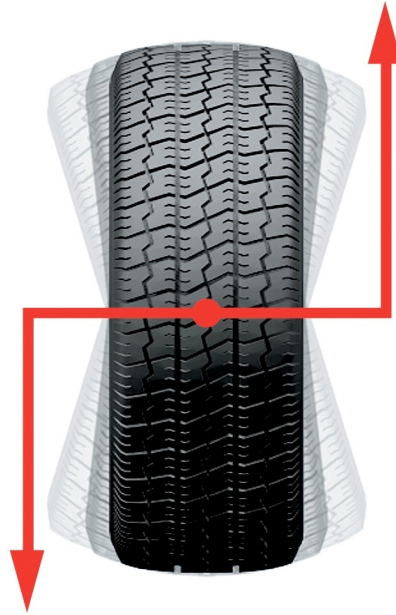
APPENDIX

Figure “A”

Static ‘Shaking’ Force



Couple ‘Twisting’ Force

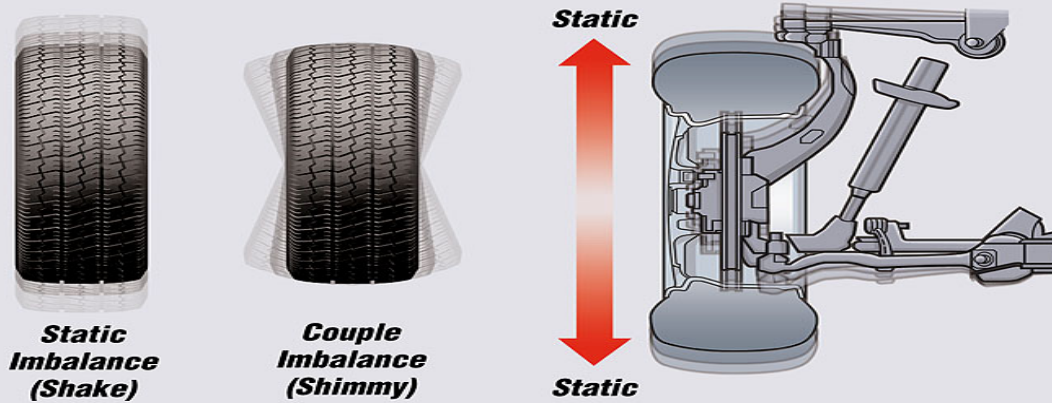


Static unbalance force is measured in absolute engineering units of $gm\text{-}mm$, while the absolute couple unbalance force is a twisting moment, or torque measured in $gm\text{-}mm\text{*}mm$. The measurement remains an absolute value as its correction weight, which expresses the force, varies as 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 when used for couple correction at a given distance with the same radius has a much smaller effectual change on the vehicle sensitivity.

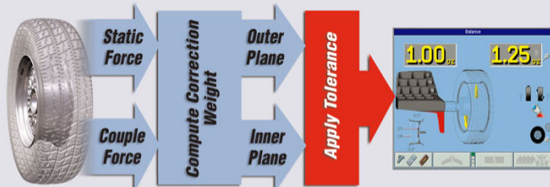
Figure “B”

Because of the design of suspension systems, vehicles are more sensitive to static imbalance forces than couple forces.



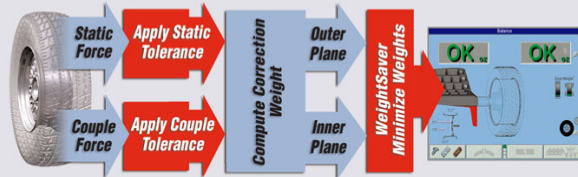
Figures “C”

Traditional Balancing Method Deficiencies



- Same tolerance is applied to both static and couple imbalance conditions
- Applies the tolerance to correction weight
- Results in the application of unnecessarily high amounts of correction weight
- Technicians waste time on repeated check spins

SmartWeight™ Balancing Technology



- Evaluates static and couple forces independently
- Applies separate tolerances to each force
- Computes corrections weights based on force reduction, not correction weight
- Minimizes the amount of weight required
- Reduces check spins

Figure “D”

Example of Individual Dynamic Wheel Balancer Weight Savings

Weight Savings						
	<-14"	15"->17"	18"->20"	21"->23"	24"->26"	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					

Large Assemblies

Normal Assemblies

Non-SmartWeight

Weights Blind 0.30oz

SmartWeight™

Shake Force Limit 0.58oz

Shimmy Force Limit 0.30oz

1.50oz

0.75oz

WeightSaver™ 75 %

Residual Goal

Spins @ above settings 1233

Exit

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, weight incremental size and mass of the assembly. The static and couple forces are incorrectly assumed to be equally affected by the same incremental weight size. This function of conventional dynamic balancing is unnecessary to maintain superior TWA ride quality expectations.

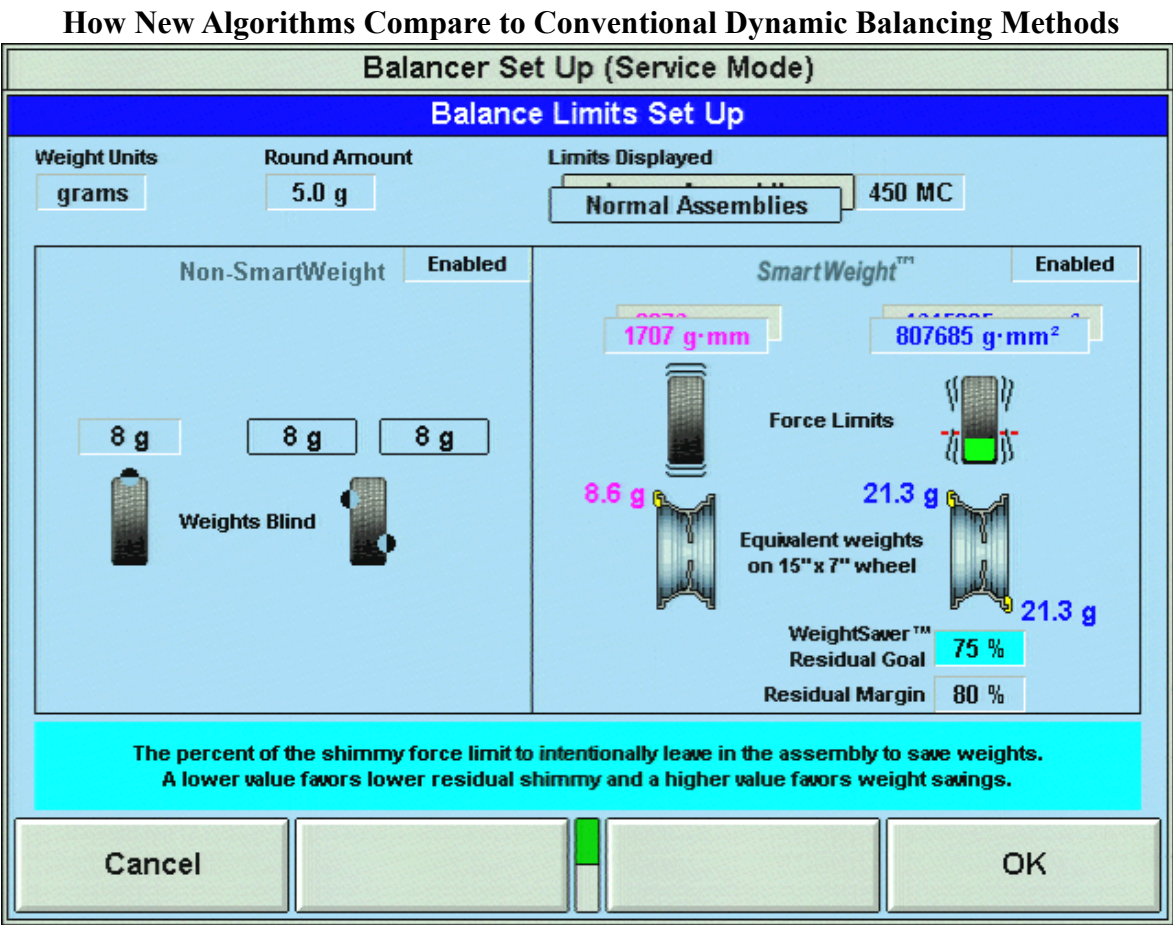
New dynamic balancing algorithms (SmartWeight®) do not use similar fixed weight increments for elimination of static and couple forces. This allows the cancellation of absolute static force yet evaluates couple unbalance independently with the appropriate tolerance which is below the threshold of the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

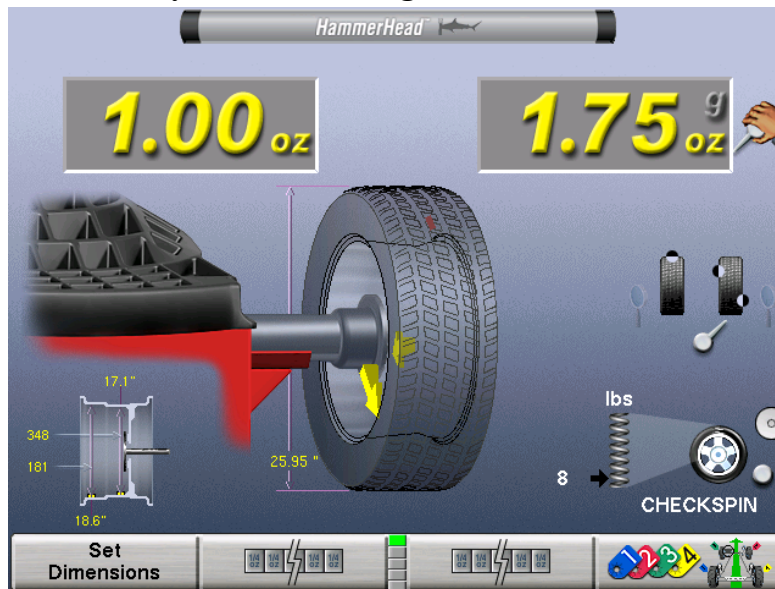
The optimized correction spin of new dynamic balancing algorithms seek to eliminate the static unbalance to the smallest weight amount available and then intentionally leave a residual amount of couple correction weight which is below the threshold for the vehicle to vibrate. This translates to the significant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

Figure “E”



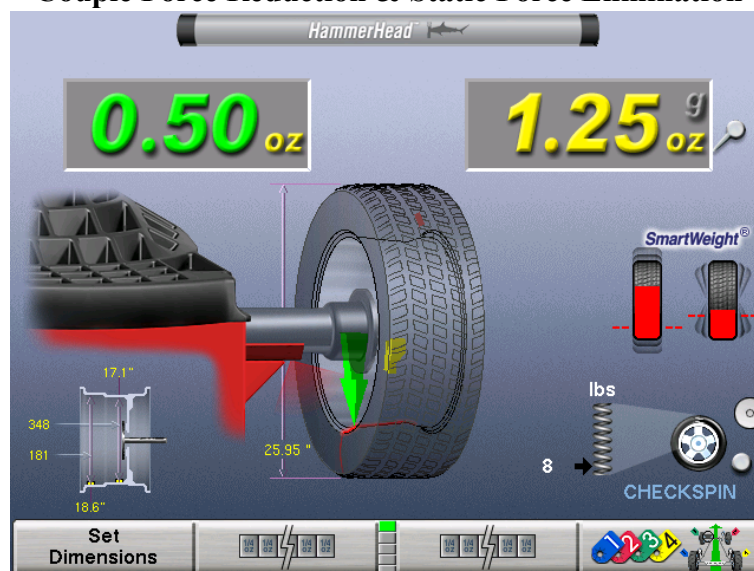
Conventional dynamic balancing (Non-SmartWeight) using the fixed weight increments and fixed weight blinding of residual unbalance is tracked on every wheel balance and compared to the results of the balanced wheel with the new method. Weight savings can be exactly quantified.

A Wheel Balanced With a Traditional Dynamic Balancing Two Plane Mode



Conventional dynamic balancing using fixed weight incremental sizes and fixed weight blinding regardless of location chosen will display large amount of couple weight that do not create a couple force large enough to create a vehicle vibration.

The Same Wheel Balanced with New Dynamic Balancing Couple Force Reduction & Static Force Elimination



Significant weight savings is seen on the same wheel.