

# **Future Direction of Automotive Testing of Tires and Wheels High Speed Uniformity and Flat Belt John K. Funcheon Kokusai, Inc.**

## **Executive Summary - Preface**

The balance of power in testing, specifying, and purchasing tires is beginning a gradual shift. Automobile manufacturers are picking up the pace and shifting power using new technologies for testing tire and wheels. New techniques, new tests, and eventually new requirements are heading towards the tire industry. Much of this new testing is originating from Japan, especially in the area of High Speed Uniformity and Flat Belt testing. The amount of information concerning tire construction, testing data and relationships to warranty is increasing at an astonishing pace. This paper will discuss the general trends in testing that are occurring at automobile manufacturers, the reasons for testing, the preliminary findings, and what may lie ahead for tire companies.

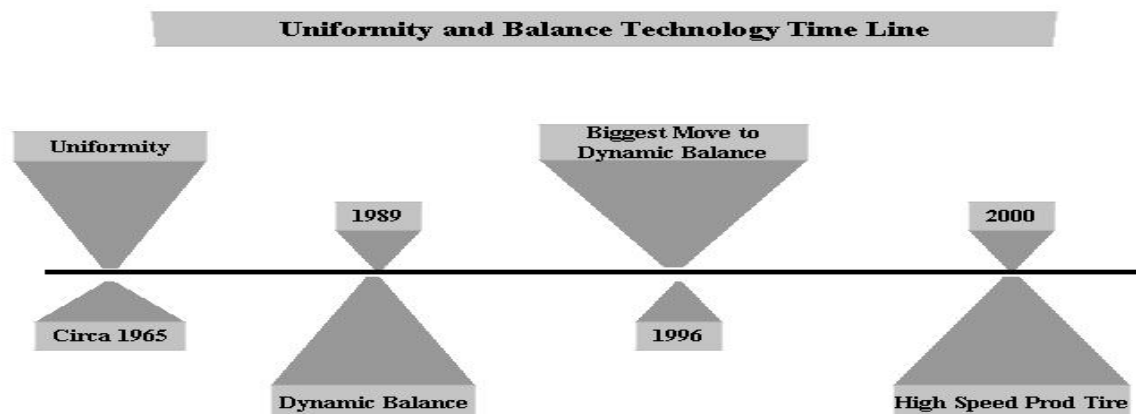
## **Background**

A large portion of vehicle vibration is generated at the contact point between the tire and the road. In addition to such conditions sometimes referred to as “shimmy, shake or flutter” vibration, other non-vibration factors, such as “steering pull” are of utmost concern. These forces are transmitted through the suspension system, the body of the car and to the driver and passengers. Vehicles react differently dependent upon their mass and their suspension systems. They also react differently at various speeds. What may not be a problem at 45 mph could be a big problem at 65 mph.

At speeds of up to 30-40 mph, the tire can act as a buffer in preventing these various vibrations from reaching passengers. Starting between 40 and 50 mph, the tire and wheel assembly (TWA) actually creates vibration. The vibrations are caused by imperfections in the tire, the wheel or in the process of assembling the tire and wheel together. Other than the assembly error, the TWA’s vibration is primarily caused by two phenomena; unbalance and force variation. Force variation is caused by irregularities in the construction of the tire that don’t allow a “uniform” rolling of the tire on the road. Overlapping or off-center belts, spaces between various subcomponents and variations in thickness are some of the factors. Force variation is detected by a process known as uniformity testing. Imbalance in the TWA can come from the tire, the wheel and the TWA. It is also caused by many of the same factors as force variation in addition to wheel imbalances and improper bead seating of the tire on the wheel. Various methods of detecting and correcting unbalance and uniformity have existed for decades.

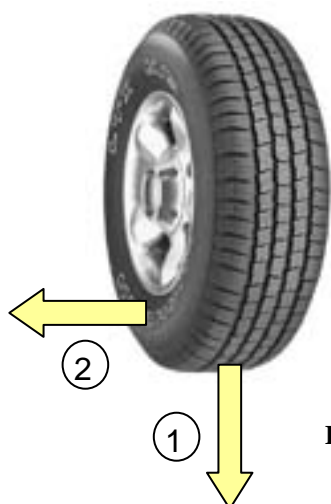
Current production testing on tires is mostly confined to dynamic balance and low speed uniformity. The only testing on the TWA is dynamic balance and in a few cases, low speed uniformity. Since every different vehicle has its own unique dynamics related to speed and vibration, ideally, testing on a tire or a TWA should mimic the actual conditions the TWA will be subjected to when mounted on a vehicle. Unbalance, force variation, load of the vehicle on the tire, and tire rotational speed are all very important variables. An effective testing machine needs to address all of these issues or some significant variables will go undetected – leading to higher warranty costs and loss of Customer satisfaction.

## History of Vibration Testing Product Development



### Tire Uniformity

Historically the automobile manufacturers have sent some specifications to the tire manufacturers based on their particular vehicles' dynamics. Radial Force Variation (RFV), Lateral Force Variation



**Radial Force: From the center of the tire moving out to the tread surface**

**Lateral Force: Across the tread surface**

- (1) Radial Force
- (2) Lateral Force

Figure 1

(LFV) (figure 1) and imbalance levels are required to be tested and only those tires below certain values can be shipped. These criteria, along with many others dealing with noise levels, road conditions, etc., are guidelines to which the tire manufacturers respond with specific tires that they feel best meet the specification given to them. Price, ability to produce to the specifications, scrap rates based on those specifications are all part of the formula of the negotiation for the final tire design chosen. Sometimes other factors of the tire

that are important to a particular vehicles' dynamics are often not part of the written specification. The automobile manufacturer might not even be aware of those tire aspects due to either a lack of testing or extensive knowledge about tires.

Due to the size of the major tire companies and their internal level of knowledge, they have considerable clout in tire specifications, despite the customer-supplier relationship that exists. Of course, the regular competitive pressures exist, but a definite imbalance of technical knowledge of the tire and its effects exists in general. Extensive testing by tire companies has taken place over many years. Much of this testing is considered top-secret and little information is shared. The automobile manufacturers by comparison have done very little extensive testing of the tires. This is not to say that no testing of the tires on the vehicles has taken place, just that independent testing of the tire or TWA by itself has varied greatly from company to company based on their internal programs and appropriate equipment to do such testing. The tests are usually very specific and of a low sample quantity.

Several hundred low speed uniformity testers had been installed and are still currently in production. The measurements taken and the functions of these low speed machines have, for all practical purposes, remained virtually unchanged. For the automotive manufacturer, retesting the TWA in production on the same or similar equipment that the tire was tested on at the same speeds is seen as redundant, costly, and unnecessary.

**Balancing**

In the not too distant past, quality control at tire companies was primarily reliant upon static balance testing. In the late 1980's the first production dynamic balancer for tires was put into production. The

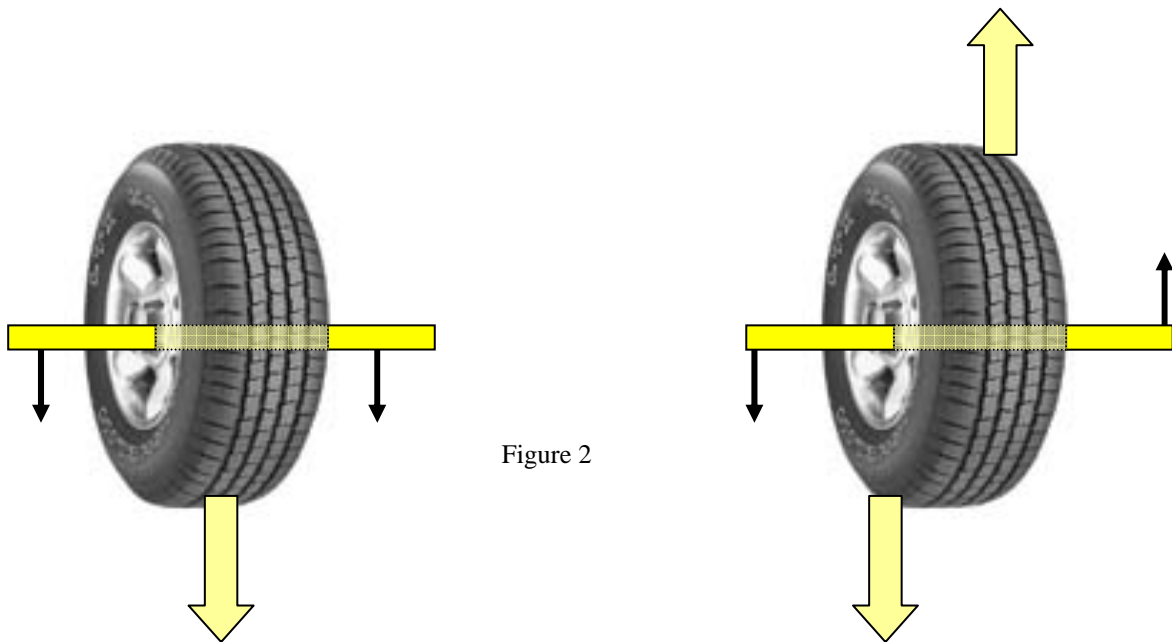


Figure 2

**Static Imbalance** – single direction force – axle wants to “shift” in one direction

**Couple Imbalance** – dual direction force – axle wants to “twist”

difference between static and couple balance is demonstrated in Figure 2. Dynamic balance is the addition of both static and couple balance. The most important difference is that static testers could not detect any couple imbalance. Later vibration testing showed that couple imbalance was a significant factor in vibration. The change to testing tires using dynamic balancers was a major industry shift beginning about 1990 with the largest adjustment taking place in 1996 and beyond. Even after many tire manufacturers changed from static balance to dynamic balance testing machines, many automobile manufacturers were still only measuring and correcting the final tire and wheel assembly for static unbalance. The static balancers were gradually replaced with dynamic balancers and today, very few static only TWA balancers exist.

### **Introduction of Production High Speed Uniformity Tester for Tires**

Low speed uniformity testers are only capable of measuring RFV and LFV at rotational speeds around 60rpm (60 rpm on a 29" outside diameter tire = 5 mph). Some other conditions, such as Plysteer and Conicity are derived from these measurements. Testing force variation at low speeds is similar to testing for static unbalance only. It just doesn't measure using the final conditions the TWA will see under actual road conditions. Laboratory machines have existed that could test RFV at high speeds, but no production machines did. In the year 2000, the first tire production machine was created that could measure dynamic balance, low speed uniformity and high speed uniformity all on one spindle. About twenty-three of these high speed machines have been installed at tire companies by mid 2004.

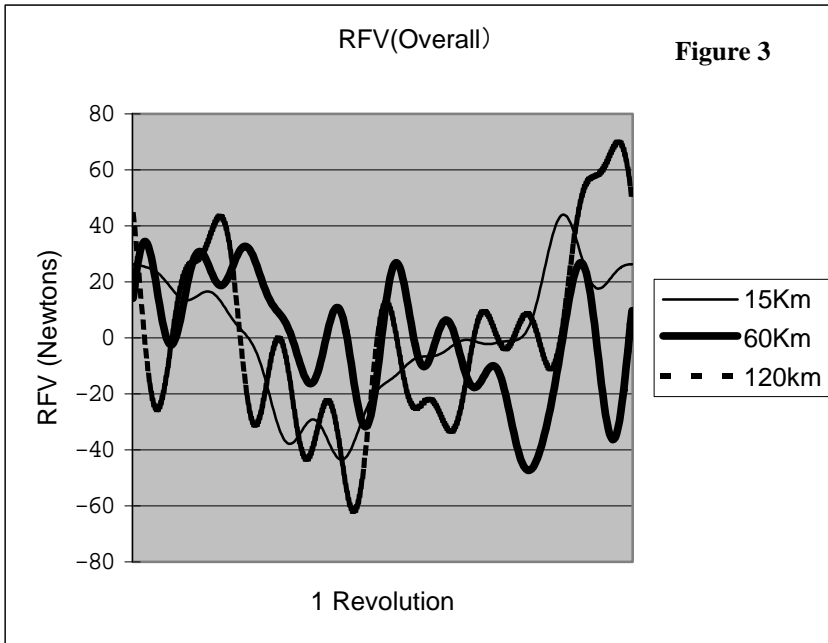
Automotive manufacturers rarely measure the TWA for force variation, although significant interest is picking up in this area. Historically, they have relied on the limits that they have set on the tire manufacturers. Some companies, such as Mercedes Benz, BMW and GM for their Corvette, started inspection of RFV (low speed) on the TWA in about 1993. A few Japanese automakers also started low speed uniformity testing of the TWA for their higher performance models a few years ago. The general feeling by those not choosing to test TWA uniformity was that not much value was added by performing the same tests as the tire had already been subjected to. Also, unlike balance testing, which the TWA can be corrected using weights, uniformity flaws on a TWA had no correction method.

## **The Changing Automotive Requirements For Tire and Wheel Testing**

### **Tire-Only Evaluation is NOT Enough**

For years automobile manufacturers have relied on their allowable limits of force variation and dynamic balance to the tire manufacturers to keep vibration to a minimum. All of these limits for RFV and LFV from the automotive manufactures are based on low speed test values. The tires are eventually mounted on wheels and then installed on vehicles that will be traveling at speeds many times exceeding 70 mph. The tire quality and characteristics has to be guaranteed against these actual running conditions. Moreover, once the tire has been mounted on the wheel, many times the RFV values increase. The combination of the assembly process errors plus the movement to testing tires at high speeds and the information available is changing the thinking at many top automotive companies.

Overall tire uniformity values are broken into harmonics, usually one through ten. Different harmonics have different affects on different vehicles. One harmonic may relate to a different kind of vibration or noise than another. Some harmonics are more affected by speed than others. Even the same model and size of tire may react differently at different speeds. This prevents the accurate estimation of speed effects from low speed testing. The following three figures demonstrate this point.



**Figure 3**

Figure 3 graphs the overall RFV of a single tire at three different speeds. The force is displayed on the y-axis. The three different curves are representative of one revolution of the tire. As can be seen from the graph, the RFV readings vary greatly dependent upon the speed at which the tire rotates.

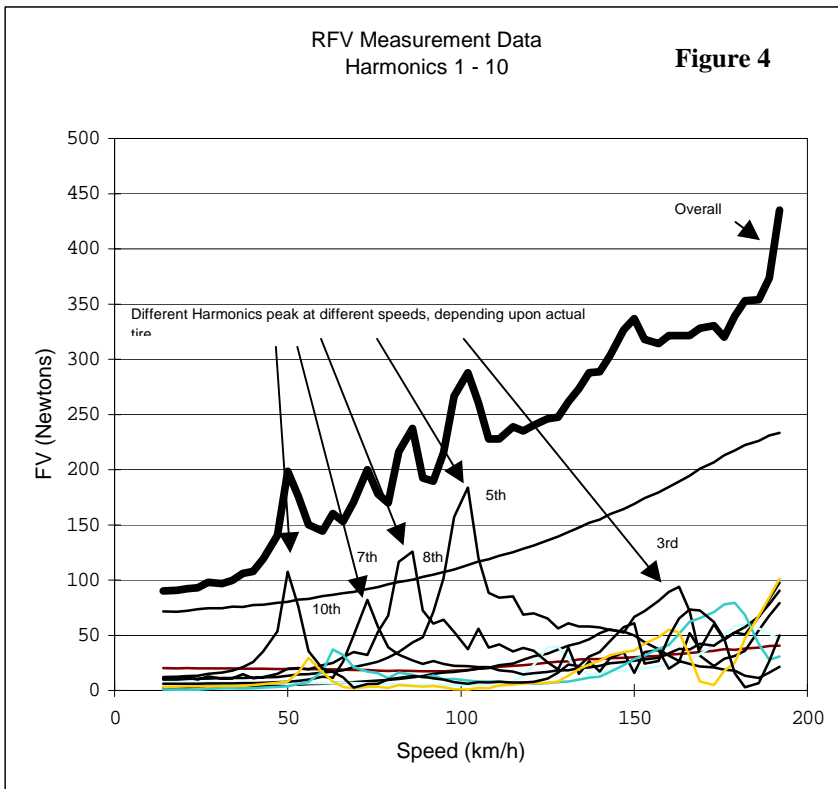


Figure 4 graphs the overall RFV reading for a single tire and also its first 10 harmonics. The y-axis is force. The x-axis is speed of the tire. The graph clearly shows that different harmonics peak at different speeds. For example, the 5<sup>th</sup> harmonic peaks at 100 kph whereas the 3<sup>rd</sup> harmonic doesn't peak until 160 kph

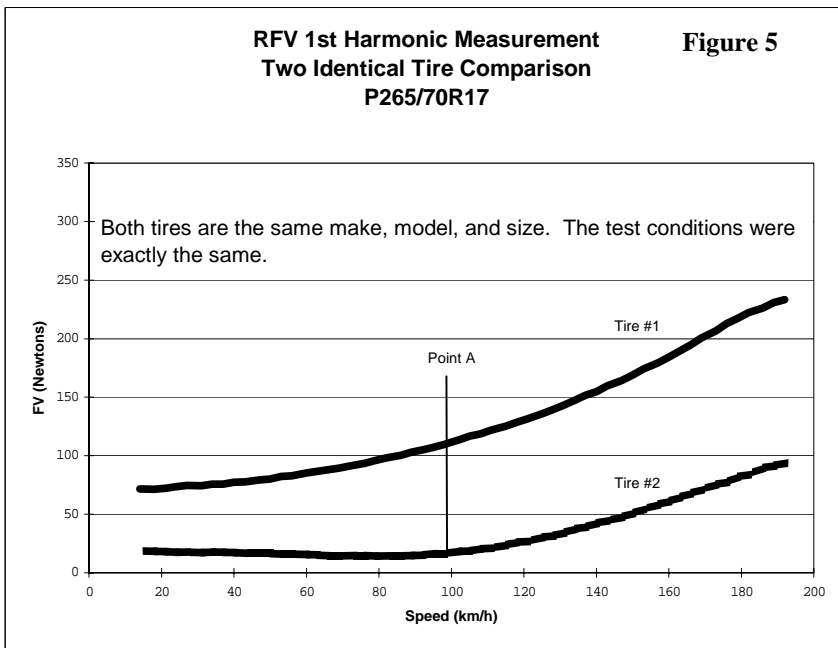


Figure 5 isolates only the 1st harmonic for two tires of identical make, model and size. Although the tires are identical, the graph demonstrates that at Point A, Tire #1's RFV 1<sup>st</sup> Harmonic (RFV1H) has increased by roughly 50% from 20kph to 100kph. Tire #2 has remained relatively constant over the same speed range.

This figure and the previous two show how unpredictable estimating RFV values from slow speeds can be.

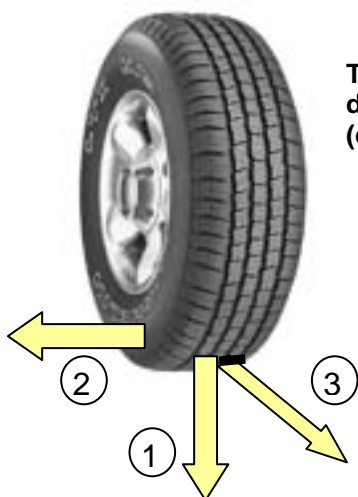
Due to RFV values increasing after assembly with the wheel and the influence of speed effects, not testing the TWA for force variation allows an unacceptable TWA to be processed through the system with only unbalance being checked and corrected. Automotive companies are starting to see these

issues and their effects due to some testing on high speed TWA laboratory machines and feedback from high speed production tire machines.

Since every vehicle's suspension system reacts differently at different speeds, the TWA or tire should be tested at the speed that the vehicle dynamics requires. There are generally one to two specific speeds that any vibrations in the TWA will have a significantly larger impact on the vehicle. Speed induced vibration below or even above this certain vehicle-matched speed may be of relatively low importance. All of these facts have put the automobile manufacturers on a new path of internal testing.

### **Tangential Force Variation – the “new” Factor**

To this point, the influence of Tangential Force Variation (TFV – figure 6.) hasn't been addressed.



**Tangential Force: In the direction of the tread (direction of the tire rotation).**

- (1) Radial
- (2) Lateral
- (3) Tangential

Figure 6

TFV begins to develop at about 37.5 mph (60 kph) and the full influence is felt at about 75 mph (120 kph). The known influences of TFV on any vehicle are a quickly evolving and ever increasingly interesting topic. Lab machines have existed that could also measure TFV, which requires high speed rotation with minimum speeds of 37 mph and as high as 70 mph. TFV is now being recognized as an important factor in vehicle ride quality. TFV cannot be measured on a low speed

uniformity machine and cannot be predicted from low speed uniformity measurements. TFV is a separate tire related phenomenon from RFV and LFV and as much of a difference as dynamic unbalance is to static unbalance. Many companies have been independently testing the effects of TFV on their vehicles. According to one study, even tires that are “qualified” based on today's low speed uniformity testing criteria have a TFV of between 5 and 15 kgf. If this TFV is overlapped with the influence of the remaining unbalance and/or RFV values at highway speed, unusually high vibration called “shake”, “shimmy”, “nibble” and “flutter” can be generated.

Since all vehicles' suspension systems have their own natural frequency, at some point the TWA vibration matches the resonance frequency of the vehicles suspension system. It has now entered into a phenomenon known as “critical speed”. When vibrations match in this range, the effect can increase by one to two hundred times the vibration of the TWA alone! Different vehicles have different natural frequencies. It is important to test the TWA at this speed to establish any remaining forces in the TWA as it will affect that particular vehicle (figure 7).

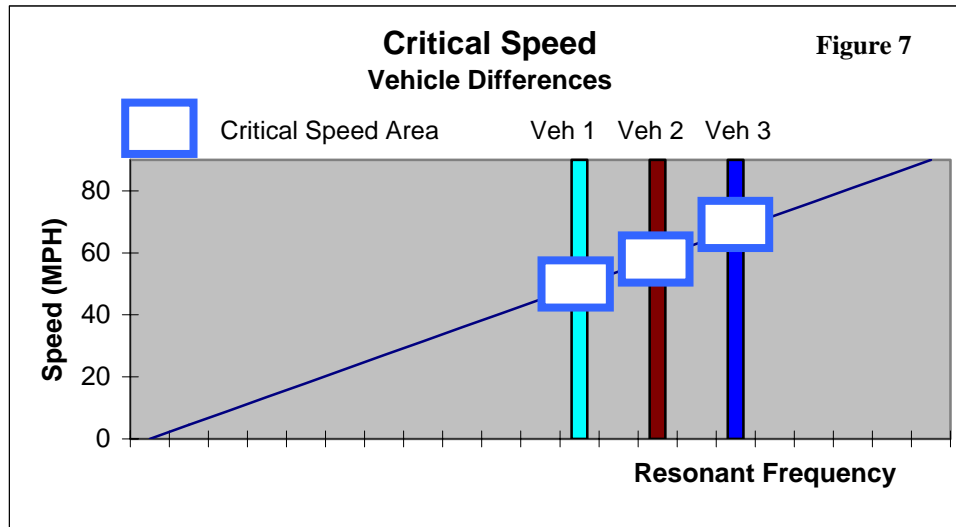
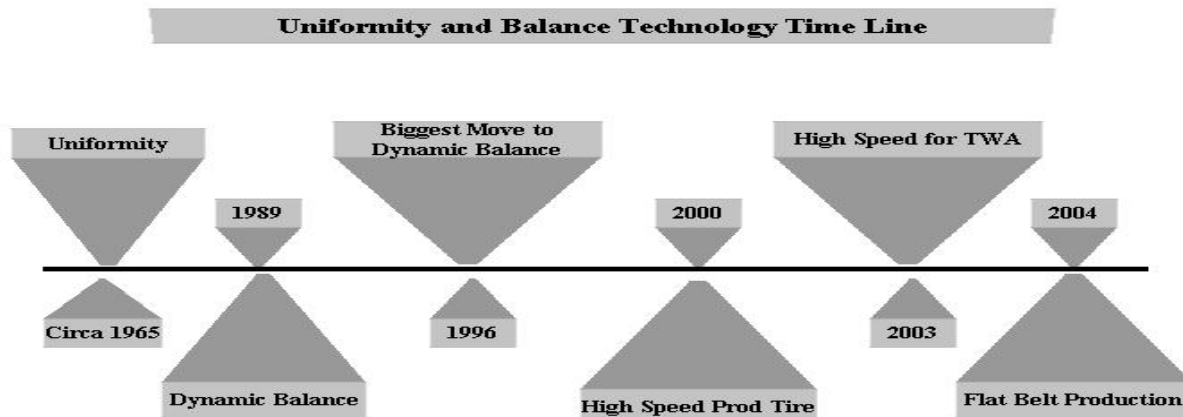


Figure 7 shows three different vehicles with differing natural frequencies based on their suspension system, weights, etc. As the rotation speeds increase, the frequency also increases. The vibrations of the TWA need to be the lowest for the particular speed that the vehicle requires.

All of the information presented on high speed testing and TFV explains some of the reasons why many vehicles experience TWA related vibrations even though the tire is inspected by low speed uniformity and the entire assembly is corrected for unbalance. Several other factors can have a major impact and are not being checked. Automotive manufacturers are seeing this, identifying the new found causes and taking action.



### High Speed Production Uniformity for TWA

Even automobile manufacturers that measure balance dynamically and uniformity at slow speeds have not been able to eliminate all of the shimmy vibration from their vehicles. These vibrations are reported to be 2-3% of warranty claims by J.D. Powers. In 2001, several Japanese automotive manufacturers recognized the need for high speed uniformity testing of TWA assemblies.

Unfortunately, no such machines existed. In March of 2003, the first production machine was purchased by a leading Japanese auto manufacturer and was delivered in October of 2003. Extensive testing is now underway. The change to high speed TWA testing in production is allowing for a wealth of information to be gathered. Prior to such information, automotive manufacturers' general knowledge of uniformity and tire construction compared to that of the tire manufacturers was relatively low. This has begun to change. This change is most directly coming from within Japanese automakers. These companies had previously purchased high speed laboratory machines capable of measuring many different phenomena including high speed conicity, high speed RFV, TFV, high speed lateral shift, self aligning torque and many other critical aspects of the tire. They are now purchasing production machines capable of the same measurements.

### **Two Plane Uniformity Capability**

Not only are there differences in measurement of variables at high speed and the ability to get TFV readings, but now uniformity values can be broken into two planes (figures 8-10). This is something never before measured even on laboratory machines. Like balancing, the old technology (static) could only measure imbalance in one plane, even though couple imbalance existed, it couldn't be measured. Uniformity has always been measured in one plane, similar to static unbalance. The new technology allows factors such as RFV and TFV to be measured in two planes. The differences are as great as dynamic unbalance is to static unbalance. The automotive company's investment in this technology has been increasing. But, more importantly, investment in production style machines, capable of measuring various attributes at high speed are also increasing. It is the advent of utilizing this technology within the production environment that will allow mass amounts of data to be gathered and compared with warranty figures.

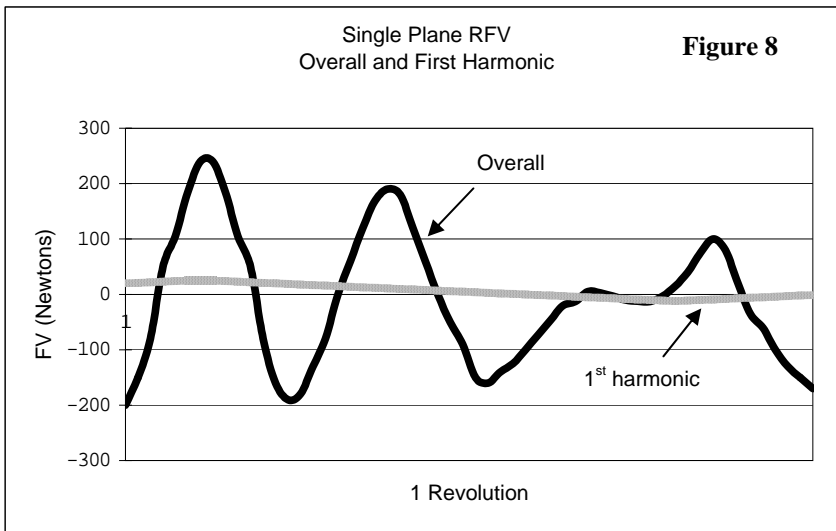
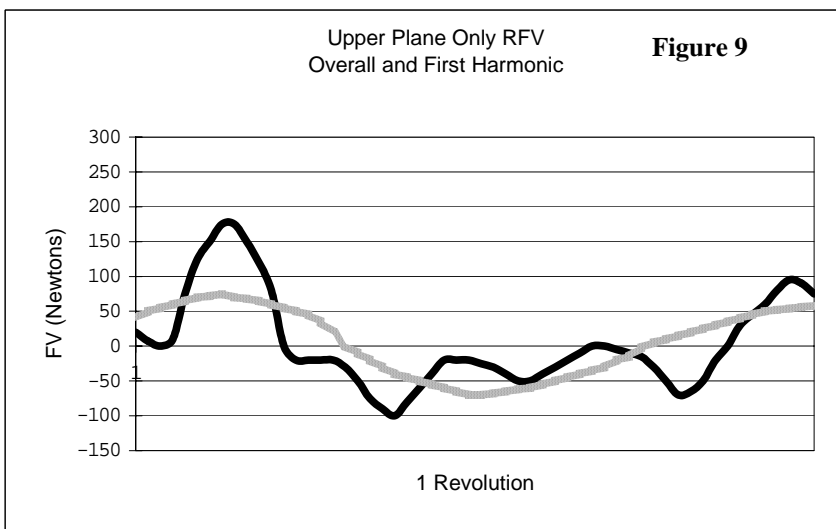
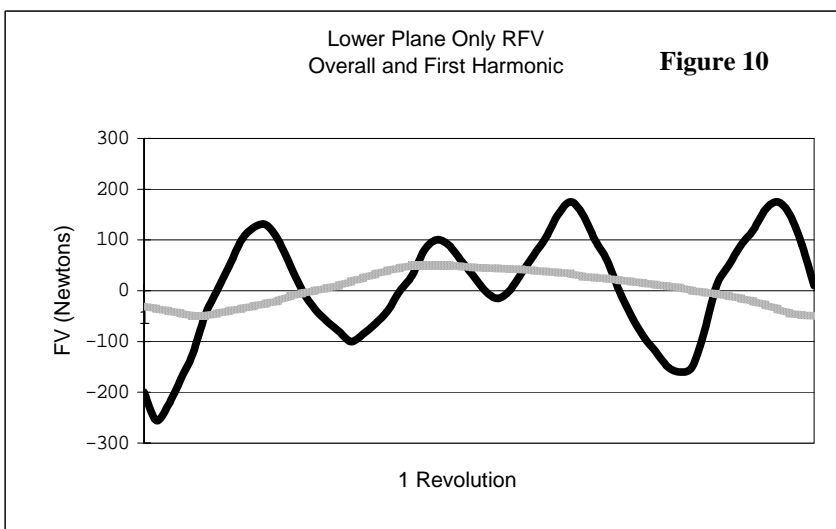


Figure 8 is the a typical RFV curve showing overall RFV and RFV1H. If the tire was to be judged on the 1<sup>st</sup> harmonic, this tire would be of little concern. However, when the RFV measurements are split into upper and lower planes (see figures 9 and 10) a much different result is seen.



When the RFV1H is split into upper and lower planes, it can be seen that the RFV1H values are actually much higher than what the typical test shows.

Because the 1<sup>st</sup> harmonics are roughly 180 degrees out of phase with each other, the single plane reading doesn't demonstrate this.



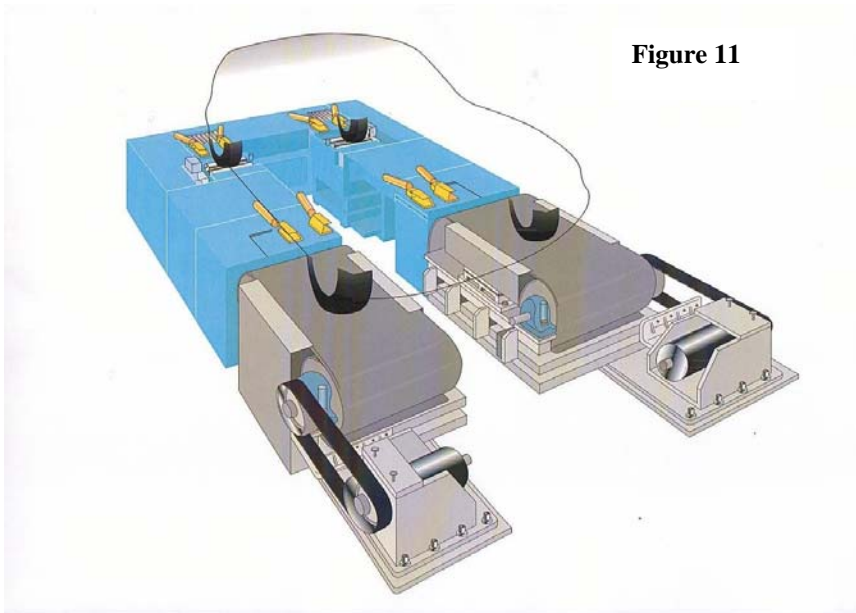
This is very much the same issue that once existed between static and dynamic balance. Referring back to figure 2, when a tire with 100% couple imbalance was measured on a static balancer, it would have graded a perfect tire. With dynamic balancers, this flaw was identified.

This new technology has created "dynamic uniformity" and will find flaws previously undetected.

Extensive testing and comparisons between production TWA and warranty costs are currently underway. No longer limited to lab machines that can only measure a small quantity of TWA, months and months of data can now be gathered from production equipment, tracked and compared to actual final consumer reports.

Even without this full production testing and data evaluation being completed, requirements for high speed testing, ranging from high speed RFV to TFV values have already been placed on several tire companies for specific platforms of automobiles. As the data comes in from these production machines, the number of requirements and limits will increase. The tire industry can expect heavy pressure from the automobile manufacturers for testing high speed RFV, TFV and various other factors that could not be measured previously. The change from static to dynamic balancing was driven from the automotive manufacturer and so will the use of this new technology.

### **Flat Belt Technology**



**Figure 11**

In addition to high speed uniformity using a standard round load wheel, movement has been made toward testing using flat belt technology. Flat belt testers have existed for laboratory use for many years. The shift, as with high speed uniformity, is in usage towards the production environment. Steering pull, lateral shift, high speed conicity, Residual Cornering Force (RCF), Residual Self Aligning Torque (RSAT) are a few issues that continue to plague warranty

results and customer satisfaction for several automotive customers. Steering pull is caused by two major factors – alignment and the influence of the tire. Tests have shown that roughly 60-70% of the average steering pull is caused by the tires. Tires that have passed all other tests, including even some high speed tests, continue to have problems with steering pull. Research from several companies has begun to identify the reasons as the difference in flatness of the road versus curvature of the load wheel on a standard uniformity machine. It is their conclusion that steering pull cannot adequately be measured on a traditional drum uniformity tester.

Like high speed uniformity machines entering the production environment, flat belt technology is leaving the laboratory and heading for production (figure 11). The running speeds of this equipment will be at vehicle service speeds and can mimic curves by changes in angles and pitch. Automotive

companies are beginning tests using this technology and firm plans are in place for several product lines to be 100% tested. Again, because of production testing, tremendous amounts of data will be gathered and compared with Customer satisfaction and warranty claims. All of this data analysis, and the requirement changes associated with it, will find its way back to the tire manufacturers. In addition to flat belt machines, shifts could also take place to remove drum style uniformity machines and replace them with flat belt technology.

### **Beyond the Automotive Manufacture's Assembly Plant**

These new technologies will not be confined to just the assembly plant. Just as almost all dealerships and retail tire suppliers have had low cost versions of balancers and even some uniformity, they have stayed away from extremely high technology areas. Some automotive manufactures are pursuing installation of this new technology into "super center" tire retail shops. Because of testing post shipment vehicles, even more information on relationships between high speed uniformity and flat belt testing will find it way back to the automotive manufacturer.

### **Summary**

The level of knowledge of tire construction and testing results weighs heavily in favor of the tire companies. The testing of high speed uniformity on TWA and also with Flat Belt testing in mass production will lead to greater knowledge within the automobile manufacturers. They won't be as reliant upon the expertise of the tire manufactures as they once were. One auto company has even gone a step further and will begin manufacturing their own limited number of tires! Tests of different tire construction, different speeds, different tests will yield a wealth of new information. Previously, each reduction in acceptable limits was accompanied by increased costs and therefore increased prices (or at least at the beginning of the negotiation) from the tire manufacturers. With limited knowledge, the automotive customer has been subjected to relying solely on market pressures to keep the tire prices down. With first hand knowledge of cause and effect (defect and warranty) and the tire manufacturing process, more power will be taken by them in these negotiations. The knowledge is a result of changes in technology availability and that this technology is being fully embraced by the automobile manufacturers first. Much of this testing is still in its infancy. The scope of all testing, its results, and the trickle-down effect that is coming towards tire manufacturers will more than a small trickle. It is a huge wave, looming.

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