Good morning! I’m Dale Starry. I represent Ingersoll-Rand in the construction industry and it is my honor and pleasure to share with you what I have learned about the science and technology for compaction of Hot Mix Asphalt. I started my career with the West Virginia State Road Commission more than 35 years ago. Educated as a Geologist, I also spent part of my early career working on civil engineering projects with American Electric Power. My compaction, paving and soil stabilization experience has been gained working with three different equipment manufacturers during the past thirty years.

**Compaction of HMA**

- Decreases permanent deformation
- Decreases moisture damage
- Decreases low temperature cracking
- Increases fatigue resistance and life
- Increases strength and stability
- Reduces aging and/or oxidation

“Compaction is the most important factor in the performance of an HMA pavement” as stated in the Hot-Mix Asphalt Paving Handbook 2000 section 18 on compaction.

In reality, we are really interested in accomplishing a number of objectives through the compaction process:

- Decreasing permanent deformation
- Decreasing moisture damage
- Decreasing low temperature cracking
- Increasing fatigue resistance and pavement life
- Increasing strength and stability
- Reducing aging and oxidation

Even an HMA mix that possesses every desirable mix characteristic will perform poorly under traffic if it has not been compacted to the proper level of density (air void content). Experience has showed that a well-compacted mix with marginal properties can outlast a poorly-compacted mix with correct design properties.
AVC / Density is paramount

To satisfy one of the major accountabilities in my 2005 PMP - Performance Management Plan, I travel around the country visiting paving projects where Blaw-Knox pavers and Ingersoll-Rand compactors are being operated. I also sometimes visit projects where competitive manufacturers' products are being used. I find that paving contractors are often frustrated by the difficulty to achieve target density on some projects. There continues to be much discussion about density specifications. From my perspective, it is more practical to compare field performance against a standard like ASTM D2041 Theoretical Maximum Specific Gravity and Density of Bituminous Paving Mixtures – the Rice test. In Virginia, for example, VDOT and contractors know if the density in place of a surface mix [SMA 9.5] is 165 pounds per square yard when compacted to 1½ inches thick, that an acceptable air void content has been reached. In Virginia, three different SMA 9.5 mixes are specified, each with varying PG binder stiffness to handle increasing traffic volumes.

Traditional 3 roller train

- Breakdown - 3-wheel or steel tandem static roller

I’m old enough to remember the ‘good old days’ when compaction was accomplished using the traditional three roller train. After the pavement panel was placed (and permitted to cool sufficiently to gain sufficient bearing capacity to support the weight of the breakdown roller without excessive mix displacement), a 3-wheel or tandem static roller did breakdown. This front roller’s objective was to reduce pavement air void content from 25% AVC (typical behind the highway class paver of the 1950s and 1960s) to something less than 10% AVC. With most 50-blow Marshall mixes this required a fully-ballasted roller making up to nine rolling passes.
Traditional 3 roller train

• Breakdown - 3-wheel or steel tandem static roller
• Intermediate - pneumatic roller

Following behind the breakdown roller in the three roller train was a pneumatic-tired compactor. Pneumatics with wheel loads from 2500 pounds to 6000 pounds per tire were used to reduce pavement permeability, and to increase density as well. This intermediate rolling phase, unfortunately, often left behind excessive rolling marks in the pavement surface that required subsequent rolling with a steel wheel roller.

Traditional 3 roller train

• Breakdown - 3-wheel or steel tandem static roller
• Intermediate - pneumatic roller
• Finish - steel tandem static roller

Finish rolling with a steel tandem static roller added little to the pavement’s density. Most Marshall mixes rolled with the conventional three-roller train ended up with air void contents of about 8%. As truck traffic volume and tire pressures increased, pavement frequentlyrutted at higher ambient temperatures or experienced cracking at colder temperatures.
Traditional 3 roller train

Problematic performance

There can be a problem with the three roller train. Due to the high compression load of the fully-ballasted front roller, it is sometimes necessary to permit the mix to cool for a period of time to increase its bearing capacity so the breakdown roller does not shove the mix. Also, there is evidence that static rolling has generally fallen short of achieving the high densities needed for contemporary mixes like FAA, SMA and Superpave. Since these mixes need to be rolled when their viscosity is low, lighter weight vibratory double drum rollers have been more successful reaching target air void contents for these mixes.

Many agencies continue to specify pneumatic compactors in the roller train. Manipulation continues to be an effective void reducing measure. Many of the projects I visit utilize ballasted nine-wheel pneumatic rollers while other contractors and agencies prefer units with fewer, but larger tires.

Regardless of the size and weight of the static compactors, however, achieving dramatic reduction in air void content is difficult (if not impossible) with today’s mixes using only static pressure as the compaction force. If air voids are excessive following rolling, compaction by traffic loads will occur, leading to rutting or other surface distresses and failures.

SMA/ Superpave roller train

• Breakdown - vibratory tandem roller (one or more)

Certainly, pavement failures led to the evolution of compaction from static pressure to the use of the forces of vibration to achieve greater reduction in pavement air void content and more uniform pavement density throughout the volume of the HMA surface. As mix designs evolved from Marshall or Hveem mixes to Superpave and Stone Matrix Asphalt, more powerful and effective compaction equipment became necessary.

SMA and Superpave mixes, particularly those with performance graded PG asphalt cements, fibers, lime as an anti-stripping agent, or polymer-modified binders make use of modern compaction technology imperative. It is essentially impossible to achieve specified air void content on today’s mixes using conventional static rollers.
Vibratory breakdown...

Therefore, breakdown rolling is most often accomplished using the vibratory tandem roller, with both drums vibrating for efficiency and productivity. Most rolling trains target achievement of at least 90% relative compaction from the breakdown roller. Since all current vibratory asphalt compactors feature variable drum amplitude, it is important that amplitude is selected on the basis of the stiffness and thickness of the pavement panel laid. In general, lower amplitude selections are appropriate for thinner lifts and higher amplitude selections are necessary to achieve proper compaction to depth for thicker lifts. The use of polymers in the mix typically necessitates selection of higher drum forces to achieve air void reduction.

SMA/ Superpave roller train

- Breakdown - vibratory tandem roller (one or more)
- Intermediate - oscillatory or vibratory tandem roller and/or pneumatic roller

The intermediate rolling phase is intended to further increase pavement density by from 2% to 5%, depending upon material conditions and the type of compaction equipment being used. Some agencies permit or specify a second vibratory compactor as the intermediate roller. Some states have a specification for a pneumatic roller with minimum weight, tire size and compression force. Many agencies leave it to the discretion of the contractor to select the equipment utilized to achieve specified air void content.
Intermediate rolling with a pneumatic compactor definitely changes the surface texture (and sometimes the surface profile) of the HMA pavement. Care needs to be exercised to keep the pneumatic tires hot so that they do not pick fines out of the mix. The use of special biodegradable release agents can sometimes help keep tires from having a pick-up problem. Roller manufacturers typically recommend against excessive use of water spray onto pneumatic tires during operation.

Once pick-up has occurred, the tire needs to be completely cleaned to remove the fines and asphalt cement. A liberal coating of release agent is then applied to prevent recurrence of the problem. Heat skirts around the compactor tires can also help to retain heat to reduce the tendency for tire pick-up.

One of the more interesting applications of technology for compaction equipment comes from a Japanese roller manufacturer, Sakai. They have developed a vibratory pneumatic roller. This unit has been tested around the US; results indicate that the forces of vibration increase the ability of this relatively light-weight pneumatic roller to manipulate the pavement surface (and shallow depth).

I have personally observed a unit in operation in North Carolina and spoken with the contractor about the machine’s performance. In the intermediate position, following a high-frequency vibratory roller, it was able to increase relative density by approximately 1.5 to 2 percent compared to a nine-wheel pneumatic roller. The unit's wide tires have stiff side walls to help transmit the forces of vibration into the pavement. Heat skirts help reduce the tendency for pick-up by the tires. [Pick-up continues to be the main operational difficulty with rubber-tire rollers on HMA applications.]

Utilizing two compaction forces with the same vehicle makes some sense, however, as time available for compaction can be optimized.
**SMA/ Superpave roller train**

- **Breakdown** - vibratory tandem roller (one or more)
- **Intermediate** - oscillatory or vibratory tandem roller and/or pneumatic roller
- **Finish** - oscillatory or vibratory tandem roller (static mode)

Where pneumatic compactors have been used, the finish rolling phase is important to remove any pavement surface depressions left by the rubber tires. There is a practical value to utilize a finish roller with relatively light weight (compression) so that it does not create additional rolling marks in the pavement surface. Most contractors permit the pavement to cool sufficiently to avoid this problem, however.

**Alternative roller train...**

Finish rolling is sometimes also used for final air void reduction to meet specifications. On rare occasions, oscillation or vibration may be engaged on the finish roller if pavement core temperature is high enough and ambient / environmental conditions permit. I have observed successful use of oscillatory technology as well as high frequency vibration to achieve additional void reduction during the finish rolling phase.
Why roller train changes?

- Need for higher pavement bearing capacity / rutting resistance
- Need for higher density at joints
- Need for more uniform density across pavement

The reasons why more powerful and productive compaction equipment is needed is very simple. Modern pavements need higher bearing capacity to resist the extremely high loads placed by heavily-loaded transport trucks with their high-pressure radial tires. Longitudinal (and transverse) joints require uniform compaction to low air void content to prevent subsequent separation and surface distress. In fact, the uniformity of pavement density across the panel is receiving much attention; wheel path rutting in the travel lane is no longer being tolerated by agencies or by motorists.

Science in compaction

- Nijboer factor - tendency to displace or shove hot mix
- Non-vibrating to vibrating (sprung to unsprung) mass relationship
- Rotary exciter energy
- Vibration frequency relationship to rolling speed with vibration

As indicated by the title of this presentation, there is ‘science’ involved during compaction of Hot Mix Asphalt. Agencies take the initiative to design pavement mixes that will provide many years of service life when properly processed, placed and compacted. Generally speaking, modern coarse-graded SMA and Superpave mixes are very stable and can support the weight of construction vehicles without excessive displacement or surface distress even at placement temperatures of 300 degrees Fahrenheit or hotter. Fine-graded mixes are not as stiff and require more attention during placement and compaction. As a consequence, the majority of dynamic compaction equipment being manufactured today exerts lower static pressure on the pavement surface to reduce tendency for mix displacement or shoving during rolling. The Dutch scientist LW Nijboer is generally credited with determining the tendency of a compactor drum to build up a bow wave ahead of it based on axle load, drum diameter and rolling width. Testing in Europe and in the United States by a number of roller manufacturers suggests that there is also a relationship between the non-vibrating mass and vibrating mass of the vibratory compactor that influences efficient compaction.
Nijboer value

• Static drum load
  ideally ~15 kg/cm²
  to avoid excessive mix displacement
due to plastic deformation

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<tr>
<th>Model</th>
<th>Nijboer Value</th>
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<td>BW161AD-4</td>
<td>19.4</td>
</tr>
<tr>
<td>CB-534D</td>
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The Nijboer Value for most breakdown or front rollers represents a comparatively low static drum load. Vibratory compaction equipment manufacturers typically target a static drum pressure of between 15 kilograms per square centimeter to 20 kilograms per square centimeter (between xx pounds per square inch and xx pounds per square inch). When mixes with lower bearing capacity are placed, the breakdown roller is able to begin rolling immediately behind the paver screed as long as shoving of the mix or lateral displacement do not occur. On stiffer mixes where displacement is not a concern, these lighter weight compactors are still able to achieve high reduction in void content due to their high dynamic drum forces.

Drum energy

• Product of amplitude, centrifugal force and vibration frequency

Drum energy is often a misunderstood force. By most roller manufacturer definitions, this dynamic force is a product of amplitude, centrifugal force and vibration frequency.

For the novice, amplitude is the calculated (or measured) value of drum motion. This motion can be more or less vertical, more or less horizontal or any resultant vector in between. It is generally agreed that amplitude influences the depth to which the dynamic drum forces are able to penetrate, especially true for vibratory compactors with more or less vertical drum amplitude. All highway class roller manufacturers design current double drum rollers to provide multiple amplitude selections for versatility of application. Many rollers have two amplitude selections for simple selection between thinner and thicker HMA panels. Other manufacturers have three or more selections of amplitude for enhanced versatility or for ‘fine-tuning’ of the roller’s performance during more difficult operating conditions.

Operation early season or late season, when laying over cold bases where time available for compaction is reduced, or when ambient conditions are marginal have proved to be applications where multiple selections of drum amplitude provide benefit. Today, Ingersoll Rand is unique in offering a complete line of intermediate and large double drum vibratory compactors with eight selections of drum amplitude.
The first vibratory rollers used on HMA compaction projects were manufactured by companies like Bros, Buffalo-Bomag, RayGo, Vibroplus, and Tamrock. These were single drum vibratory rollers with smooth rubber tires on the rear (driven) axle. Their vibration frequency was low by today's standards, on the order of 2000 vibrations per minute, just over 30 Hertz. These units evolved to possess higher vibration frequencies to as much as 2400 VPM (40 Hertz). With their heavy drums and lower efficiency vibration systems, they often damaged pavement surfaces during the rolling process and gained reputations for being difficult to apply with consistent compaction results.

The newest vibratory compactors have two vibrating drums; they provide much higher performance and productivity than their early counterparts. These vibratory rollers are manufactured by companies like Bomag, Caterpillar, Dynapac, Hamm, Ingersoll-Rand and Sakai. Their vibration frequency exceeds 4000 vibrations per minute, as high as 40 Hertz. With their wide but relatively light weight drums, they are able to achieve excellent air void reduction with reduced risk of damage to pavement surfaces during the rolling process. In the hands of trained operators, these double drum vibratory compactors have earned reputations for being easier to use with consistent compaction results.

We've noted the science involved in the compaction process. Now let's review some of the technologies that are state-of-the-art for compaction equipment used on HMA applications.

Obviously, most roller manufacturers have developed some level of automation of roller functions to make the operation of the roller more predictable and to yield more uniform compaction results (especially for less experienced roller operators). I'm referring to relatively simple automation like starting and stopping drum vibration and flow of drum wetting systems whenever the roller is in motion or comes to a stop.
Roller automation today

• Automatic start/stop of vibration

Another important vibratory roller automatic control function is start/stop of vibration. There is some risk of creating a ‘bump’ or depression in the HMA panel surface if a vibratory roller is permitted to vibrate without being in motion. By automating this control function, the roller helps its operator to avoid these pavement distresses. If the roller operator is relieved of the need to manually engage and disengage vibration, he or she can concentrate on rolling more efficiently and safely.

Roller automation today

Adjustable engagement

• Four speed selections
• On/off speeds:
  • ½ mph
  • 1 mph
  • 1½ mph
  • 2 mph

On some makes and models, the engagement and disengagement speed is preset from the factory. Other vibratory compactors permit the operator or foreman to select the speed at which vibration starts and stops. The selection can be made simply.

I am surprised how often roller operators choose to manually start and stop drum vibration, however. This summer I have visited a dozen or more paving projects where the front roller operators preferred using manual vibration control. When I asked why, the answer was often simply that they preferred to control the roller themselves. It makes me wonder if we compaction equipment manufacturers are making our machines too sophisticated for the real needs of those individuals who spend their days (or nights) in the seats.
Perhaps the most common mistake I see when I visit paving projects is breakdown roller operators rolling too fast. There is an industry-accepted rule-of-thumb that the vibratory roller needs to make between ten to fourteen drum impacts every longitudinal foot of pavement surface to achieve acceptable surface smoothness. Compactors with larger drums can roll faster than compactors with smaller diameter drums, due to the effect of drum circumference. So a ten-tonnes class double drum vibratory compactor with 4000 VPM frequency can roll at a speed as high as 400 feet per minute and impact the pavement surface ten times each longitudinal foot. This enables the front roller to keep up with a paver moving as fast as 80 feet per minute while making a five-pass breakdown rolling pattern.

Automatic start and stop of water spray for the drum wetting system is another relatively simple automation for the contemporary double drum vibratory roller. This is done, in part, to conserve water. There is another value for controlling water flow that I will share with you in a moment.
Automatic water spray

- Auto water on/off
- Automatic flow rate tied to speed
- Manual flow rate with rheostat or timer to vary flow

There are several different technologies available. Most roller manufacturers use a simple electronic timer to intermittently stop water flow through the distribution system. A few rollers have rheostats that vary the rate of flow of water through the spray system. At least one manufacturer offers an automatic flow control system that speeds up water spray as their roller speed increases and slows down water spray as the roller slows down. This technology has received a United States patent, number 6,827,524 (in which the speaker has the honor to share disclosure and award).

Critical roller function

- Drum wetting system must function for HMA compaction
- Drums must be kept wet or pick-up will occur

Remember that the drum wetting system is one of the more critical operating systems for the roller used for compaction of hot mix asphalt. Without water as a releasing agent, HMA sticks readily to steel drums. No one has yet perfected a drum material or permanent coating that prevents mix pickup, until this improvement is practically available, rollers will continue to need drum wetting systems for functionality.
Excessive water cools mat

There is a practical value for providing just enough water for drum wetting but not too much. Excessive water spray onto the drum surface rolls off onto the pavement surface and cools it. As this thermal image illustrates, there can be as much as 60 degrees Fahrenheit cooling of pavement surface temperature from drum wetting. Obviously, some of this temperature loss is regained through thermal conduction from the pavement core to the surface. This, however, has been proved to reduce TAC (Time Available for Compaction) and may lead to failure to achieve target air void content reduction as the mix prematurely cools below its workable viscosity.

Roller automation today

- Manual selection of amplitude based on laydown thickness

There are also some common machine functions that are not easily automated. One is the selection of drum amplitude to match the thickness and/or viscosity of the mix being compacted. As a general rule-of-thumb, thinner lifts are suited to compaction using low drum amplitudes and thicker lifts require higher drum amplitudes. There are external variables that can change this general practice such as mixes containing polymer-modified asphalt cements or anti-stripping agents like lime; additives like rubber also require generally require higher drum amplitude for effective compaction.
Roller automation today

- Manual selection of amplitude based on laydown thickness
- Manual discontinuance of vibration when target density achieved

Another manual function for nearly all vibratory compactors is stopping vibration once target density or air void content has been reached. There is abundant evidence that “over-rolling” is one of the primary causes of damage to the aggregate structure of HMA pavements. Knowing when to cease vibration is one of the keys to preventing such damage. Use of the nuclear density gauge or non-nuclear density measuring device can make this a science rather than an art. Regardless, it is important that excessive vibration is avoided during all phases of compaction.

Emerging roller automation

- Automatic control of dynamic forces of compaction to minimize pavement damage
- Automatic control of rollers to optimize compaction productivity

There are few rollers currently available that have “intelligent compaction systems” capable of automatically stopping drum vibration when a pre-selected material stiffness has been achieved. The Federal Highway Administration has been conducting (and continues to conduct) research to determine whether these systems are practical for the ‘typical’ paving contractor on the ‘typical’ paving project.

The interest in automatic compaction control has two major avenues. There is obviously interest in preventing damage to paving materials during their void content reduction. It is common knowledge that less durable aggregates can be fractured by modern vibratory compactors, especially when high drum forces are being used to effect void content reduction. The other area of interest is to optimize the productivity of the roller train. Getting target density optimally will reduce rolling time and increase the tonnage of pavement successfully placed and rolled each work session. This interests contractors and agencies alike.

The number of manufacturers offering automatic systems for vibratory compactors is presently limited to European suppliers. US manufacturers seem to be avoiding development of these systems pending verification of their practicality and cost effectiveness. I will not comment further except to note that these systems are expensive and that the cost to value proposition has yet to be conclusively proved.
Temperature measurement

- Roller-mounted sensors
  - infrared

We all realize that temperature of the HMA mix is one of the most important factors for successful placement and compaction. It is essentially impossible to reduce air void content for a mix that has cooled to the point of high viscosity. Therefore, many roller manufacturers mount an infrared temperature sensor onto some double drum vibratory models, especially those designed for breakdown rolling applications. These sensors ‘read’ the temperature of the surface of the pavement to give the roller operator an idea whether he or she is in the right mix viscosity range for effective air void content reduction. The front roller operator is the most obvious choice for this technology to provide benefit, since this roller has opportunity to have its rolling pattern adjusted to compensate for environmental or mix variables.

Once an SMA or Superpave mix has cooled below a surface temperature of about 250 degrees Fahrenheit it becomes very difficult to achieve target air void content without risk of damage to softer aggregates. Polymers and other additives to HMA mixes make the need for compaction at proper mix viscosity even more critical.

Effect of temperature

To help me emphasize how critical temperature is to the compaction process, let me cite a personal example. I have made three visits to a major paving contractors’ projects around Atlanta, Georgia this season to help overcome complaints about difficulties achieving compaction. In my carry bag I always take along an infrared temperature sensor and vibrating reed tachometer along with my boots, hard hat and safety vest.

One of the first checks I make, once paving begins, is of mix temperature - out of the truck into the material transfer vehicle; out of the MTV into the paver hopper; behind the paver screed; and at the breakdown and intermediate rollers. Each visit I discovered mix that was too cool for effective processing, leading to high air void contents (low densities). For example, for a PG64-22 with polymer-modified AC and lime (as anti-stripping agent) mix was being delivered to the MTV at 300 degrees Fahrenheit and was rarely hotter than 2280 degrees F behind the screed. Behind the breakdown roller the temperature was never above 250 degrees and was often cooler than 200 degrees before the intermediate pneumatic roller made its passes. Is there any wonder why this project was suffering from failure to achieve bonus for air void content?
The double drum vibratory compactor generally provides the best possible opportunity to reach target air void content on any project, whether day or night paving. Environmental factors always play a role in this success. Material variables are also of significant importance.

Working a thicker lift during the heat of a summer’s day generally permits longer TAC (Time Available for Compaction). Night-time paving projects will always shorten TAC, as will thinner layers.

Mixes also react differently based on ingredients. Neat asphalt cements as binders are typically more ‘workable’ than modified asphalts. Performance graded binders behave differently and often have narrower windows of opportunity for compaction to be achieved.

As pavement designs and mixes have evolved to provide superior bearing capacity and resistance to high temperature rutting and/or low temperature cracking, the dynamic energy of the compactor drum has required similar increase. Similarly, the need to breakdown at higher temperatures and still keep up with fast-moving pavers has uncovered the need for faster rollers. Since the limiting factor for rolling speed with the vibratory roller is vibration frequency and drum impact spacing, the need for faster VPM is obvious. Contemporary double drum vibratory compactors weighing nine to 11 tonnes now vibrate up to 70 Hertz (4200 vibrations per minute) frequency. As previously mentioned, this factor alone permits the roller train to maintain greater productivity to keep up with paver moving 70 feet per minute or more.
Since drum impact spacing is such an important variable, most vibratory roller manufacturers provide the roller operator with a tool to either control or monitor rolling speed with vibration. Simple gauges like shown here are provided with some equipment. Other rollers have switches or dials to select drum impact spacing. Some use a series of lights to alert the operator to rolling speed. Regardless of the technology provided, maintaining proper drum impact spacing helps assure contractors receive those incentives that agencies offer for superior smoothness of the finished pavement. These systems can also help contractors avoid any penalties that might be assessed for roughness, if their agency used disincentives rather than incentives for the pay factor.

The industry rule-of-thumb is to maintain between eight to fourteen drum impacts per foot of travel; for those of us who are metric system based, this is 26 to 46 impacts per meter of travel. The selection of spacing interval is dependent upon drum circumference and the contact surface of the drum during breakdown rolling. The larger the drum diameter, the fewer impacts are necessary to achieve smoothness. Conversely, the smaller the diameter of the compactor drum, the more closely impacts must be spaced to provide smooth surface finish.

The information shown on this image has been derived from practical field experience using a number of makes and models of compaction equipment during my more than thirty years working with vibratory double drum compactors.

- For optimum smoothness:
  - Drums to 35 inches in diameter select 14 impacts per foot
  - Drums 35 to 50 inches in diameter select 12 impacts per foot
  - Drums 50 to 55 inches in diameter select 10 impacts per foot
  - Drums over 55 inches in diameter select 8 impacts per foot
Rolling speed with vibration

\[
\frac{2500 \text{ vibrations/minute}}{10 \text{ impacts/ft}} = 250 \text{ fpm}
\]

\[
\frac{3000 \text{ vibrations/minute}}{10 \text{ impacts/ft}} = 300 \text{ fpm}
\]

\[
\frac{4000 \text{ vibrations/minute}}{10 \text{ impacts/ft}} = 400 \text{ fpm}
\]

These simple calculations show how to calculate the average rolling speed of the vibratory compactor during breakdown rolling. You can clearly see that higher vibration frequency plays a significant role in determining the ability of the roller to maintain pace with the paver.

Pavement smoothness

- Rolling speed (maintaining correct drum impact spacing for smoothness) faster for higher rolling productivity

Remember that pavement smoothness is directly influenced by how the vibratory compactor drum impacts are managed. Impacts too far apart will lead to surface roughness; surface roughness may lead to the agency penalizing the contractor for the project completed.

How smooth is smooth? That is a question better answered by the agency. However I can show you the corollary to smooth...
If your pavement ends up with this surface appearance, you know that drum impact spacing was excessively wide. Chances are this will lead to complaints from motorists as well as claims from transport companies for freight damage caused by roughness of the pavement. This type of work is simply unacceptable today!

Regardless of the size or type of roller being applied, it is important to optimize the productivity of the entire paving train. It makes little sense to have a paver operating at 25 percent efficiency because it must wait for the roller train to keep up with it. In general, there is a need to make multiple passes over the pavement surface for complete coverage. The relationship between roller drum width and panel width is a simple one to understand and optimize. In fact, it is for this reason alone that most roller manufacturers have at least three different rolling widths for highway class compactors. [These are 66 inches, 78 inches and 84 inches (1.7 meters, 2 meters and 2.1 meters).] This photo shows a double drum vibratory roller with 78 inches (2 meters) rolling width covering a 12 feet (3.65 meters) wide panel in two passes side-by-side. This represents the best coverage match possible on this panel, with minimum overlap between passes yet sufficient overlap of both supported edges. This was a “mill-and-fill” job.
Rolling patterns

Other panels may require different rolling techniques; panels of different widths may dictate other rolling widths. This photo shows a 15 feet (4.6 meters) wide paved panel with unsupported edges. This contractor chose a double drum vibratory roller with 66 inches (1.7 meters) rolling width making three side-by-side passes to cover the panel. Note that the operator correctly staggered the ends of each pass, with a slight arc at the end of the pass to prevent formation of a ‘bump’ in the surface as the roller moved forward to continue its rolling pattern.

Most stable SMA and Superpave mixes can support the weight of a roller at the unsupported edge without displacement of mix laterally. If lateral displacement occurs it is necessary to make the initial pass toward the paver off the edge by several inches (centimeters).

Keeping up with paver

For the paving contractor, the ability of the roller train to keep up with the paving train is fiscally and practically important. No foreman wants to be criticized at the end of the paving day for failing to achieve expected production.

Therefore, the practical element of speed for the compaction equipment is whether it is able to keep up with lay down rate. There is a simple relationship between paving speed and compactor speed. A paver needs to move forward at a consistent paving speed in order to lay the smoothest mat. For our example, let’s consider a paver moving 50 feet per minute, being fed by an MTV.

If the front roller needs two passes side-by-side to cover the laid panel, with two coverages over the panel to get density plus a make-up pass, it must be capable of average rolling speed with vibration of 250 feet per minute. See how we do the arithmetic?

Using a double drum vibratory compactor with vibration frequency of 3000 VPM (50 Hertz), making 12 drum impacts per foot of travel for smoothness, permits this compactor to roll with vibration at a speed of 250 feet per minute. This compactor is just able to keep up with the paving train. If the front roller frequency is more than 3000 VPM, for example 3600 VPM, we have margin for some operating inefficiency by the roller operator. For this reason alone, high frequency has become popular with paving contractors throughout the country.
In reality, there is another balance that needs to be maintained for a paving project to have optimum efficiency. There is a direct relationship between plant output and hauling capacity to laydown and compaction. West of the Mississippi it is relatively common to have greater tonnage processed per day than back east. Certainly the practice of placing mix onto grade and using a pick-up machine to feed the paver can lead to higher tonnage than possible when dumping from smaller end dumps directly into the paver hopper.

Regardless, contractors who recognize the balance between production and placement often achieve more incentives for work performed. This is a practical reason to pay attention to the details.

There is one new technology that shows promise to optimize vibratory compactor performance. Using a patented eight amplitude eccentric with a unique and proprietary control system, engineers have developed a “constant force” design that keeps drum energy high through the entire range of drum amplitudes. All earlier designs have drum energy that varies as amplitude is changed, with lower energy in lower amplitude selections and higher energy in higher amplitude. This can mean that as many passes are needed to densify thin lifts as thick lifts.

This new technology enables vibration frequency and drum amplitude to vary, inversely proportional. That is, with selection of lower drum amplitude, higher vibration frequency is achieved. As higher drum amplitude is selected, frequency automatically reduces so that radial load on the eccentric bearings is not excessive.
“Constant Force” advantages

• Delivers more drum energy into HMA material even for thin lifts in lower amplitude selections
• Reduces number of passes to reach density on thin lifts in lower amplitude selections
• Versatility to reach density when rolling at highest temperatures

Having more drum energy generally means that fewer passes are necessary to achieve density. In addition, this unique system permits target air void content to be reached even when mix temperature is lower than it should be during the breakdown rolling phase.

Paving contractors and agencies both receive benefit from greater compactor productivity. The public also benefits from shorter roadway closures for construction, and possibly shorter delays during actual construction.

Pavement Quality sensor

• TransTech patent
• Non-nuclear basis using ‘electricity’
• No certification or licensing required
• Correlates well to core density value

Another interesting technology that is proprietary (and patented) is installation of a non-nuclear ‘density’ measurement system onto a breakdown roller. Through arrangement with Trans-Tech Systems in New York, their proven PQI (Pavement Quality Indicator) is modified for installation on the roller. Since this system has no radioactive isotope encapsulated into the device there is no requirement for licensing or monitoring of technician exposure. A number of these systems have already been installed onto our current products and are providing good correlation of results with cores.
The sensor is deployed at the roller operator’s discretion with push of a switch. This actuates a procedure of stopping drum vibration, reducing drum wetting rate to minimum for the lead drum, slowing rolling speed to approximately twenty-five feet per minute and releasing of the tethering cable for the sensor head. The sensor makes contact with the pavement surface for approximately two seconds and is then retracted to its stowed position. All of this happens without additional input from the roller operator.

Once electrical measurements have been gathered, the relative “density” of the pavement is displayed on the screen of the control panel mounted to the left of the operator’s seat. After noting the density result the operator knows whether to continue rolling with vibration or to cease the breakdown rolling process and move to a fresh section of the pavement. Vibration needs to be manually re-engaged after the operator presses the test start/resume switch on the instrument panel.
I’ve shared with you some of my thoughts on the science and technology of compaction. Where this industry evolves is a matter of debate. Autonomous paving may become a reality for the future of this industry. There is certainly concern over safety of the work zone that could be improved if paving crews can be eliminated from the active work zone. It may not happen within my career or even within my life time. In the total scheme of things I’m a bit of a dinosaur really. Change is not always something I personally embrace.

Questions?

Thank you!

It has been my pleasure to spend this brief time with you this morning. I’d be pleased to answer any questions you might have about the material I have presented or any paving or compaction questions. Thank you again!