18

Stagger and Stagger Torque

(*It's just not this simple!)*

Note: This is the one and only chapter in the dynamics section of the book which is **specific** to oval track racing.

Tire Stagger

Tire stagger is the difference in circumference between the right side and left side tire. If the right tire has a circumference of 86" and the left tire a circumference of 83 2", there is 2 2" or 3% stagger – (86/83.5 = 103%). Reverse stagger is when the left side tire is larger than the right side tire.

Locked Rear Ends (Exclusive to Live Axles)

As previously discussed, the torque reaction of the pinion trying to climb up the ring rear, solid rear axle, has a tendency to pick up the right side wheel in which case the right wheel will see less load. Pinion climbing forces would still exist with independent rear system, but there would be no axle housing to lift. "The right side wheel unloaded/spin is caused by the driveshaft torque being transferred to the housing (imagine the pinion welded to the housing: driveshaft torque would rotate the housing counter clockwise as seen from the rear). Pinion climbing the ring gear forces cause the nose of the housing to rise."[1]

If the differential is open, this often leads to the right rear tire spinning while the left rear is undriven. To prevent this from happening, race cars are equipped with some sort of torque sensing, torque adjustable, locking or locked differentials. In the case of many stock car series, the teams are required to run either a locking differential such as the Detroit Locker which locks the left and right wheels together as soon as torque is applied to the rear end or a spool which permanently locks the driving wheels together.

The locked rear differential solves one problem by locking both tires together; however, it creates another problem. When the rear end is locked, the driven wheels have to run in unison; this tends to keep the car headed in a straight line if both rear tires have the same circumference. It does not let the car turn freely into or out of the corner – the car pushes.

Stagger is used to help get the car through the corner without pushing; however, because stagger makes the car want to naturally run in a circle, a new problem surfaces while trying to run the car straight. With stagger, the car now wants to constantly turn left which means the front wheels need to be turned to the right in order to keep the car running straight. This dog tracking down the straights can create considerable front tire scrub, which, in turn, reduces top speed due to tire drag and may also cause the front tires to overheat. A small amount of straight line drag is also caused by the forces of the larger and smaller driven tires reacting against each other.

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[1] Bill Ball Senior GM engineer

Note: All staggers needs to be measured at the tire's loaded radius. As a tires load is increased its loaded radius is decreased.

The amount of stagger used determines the radius the car wants to run. The more stagger used, the tighter the radius will be. A narrower track width will also result in a tighter radius for the same amount of stagger. Additionally, when running on a banked track, less stagger is needed, because, as the banking is increased, the effective track is reduced – Figure 18-1 & 18-2.

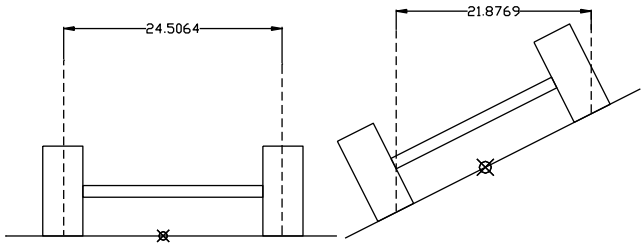


Figure 18-1 & 18-2

The **Tire Radius** calculator included with the Wan31A models provides a basis for adjusting stagger, but, remember, it is **only** a basis. There are a myriad of factors that affect how much stagger is needed. The correct amount of stagger for any particular radius is just that – one particular radius. Running up or down a lane requires a different stagger setting.

For most oval track series, the tire manufacture will only provide one or two stagger options; therefore, the teams need to change other parts of the set up, such as the percentage of cross weight, in order to compensate for less than optimum stagger

When using a locker or torque sensing differential, less stagger is needed because the differential is only locked during forward acceleration. Once the power is removed, the differential is unlocked and the drive wheels are no longer required to rotate in unison.

Stagger Torque

A simple example of the effects of stagger is to roll a coffee cup on its side. The cup will always turn in towards its smallest end. Its turn radius is determined by the relationship between the large and small ends. After rolling the cup and observing its turn radius, wrap a few lengths of masking tape around the small end. When the cup is rolled again, it will not have as tight a turn radius.

The forces that turn the coffee cup are the same as those forces created by live axle stagger in a race car. Considering that the left tire has a circumference of 83.5" and the right tire a circumference of 86", if both tires are rolled ten feet, the larger tire will need to revolve less in order to travel the same distance. If the tires are only slightly different in size; the smaller tire may only roll part of one revolution more than the larger tire, but, the fact remains that it will have a higher revolution rate than the larger tire in order to cover the same distance.

If the tires are rolled the same number of revolutions, the smaller tire will not cover as much distance - Figure 18-3. When this tire combination is run with a locked differential, the chassis will only run in a straight line if the left turning torque exerted by the real tires is overcome by turning the front tires to the right. In this case, even when coasting, at least one of the rear tires will be forced to run at a different speed than the ground speed. In other

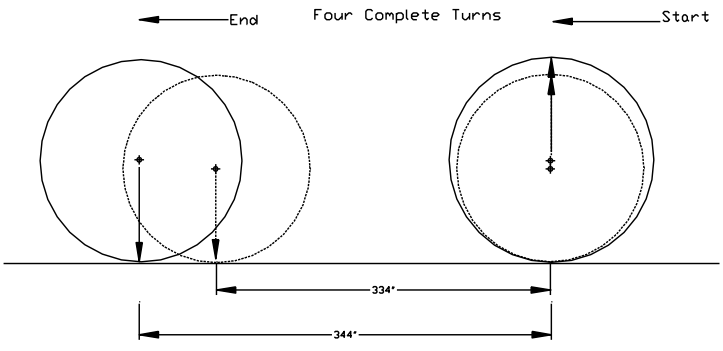


Figure 18-3

words, at least one of the tires will be shearing.

As previously discussed in the tire chapters, every tire has to have a small amount of shear in order to create either an accelerating or decelerating force. If the tire is operating with a shear angle of 7% and the car is traveling at 100 mph, the tire would be traveling at 107 mph.

Stagger and Straight Line Motion

If, while coasting with a locked differential the chassis is forced to run in a straight line, the smaller tire will be required to turn at a faster rate in order to run the same distance as the larger tire. However, if the tires are tied together and are forced to run at the same speed, it will result in the smaller tire having a tendency to pull back or drag while the larger tire will have a tendency to push ahead. These two opposite torques will cause the rear tires to steer the car to the left. This torque is called **stagger torque** - Figure 18-4.

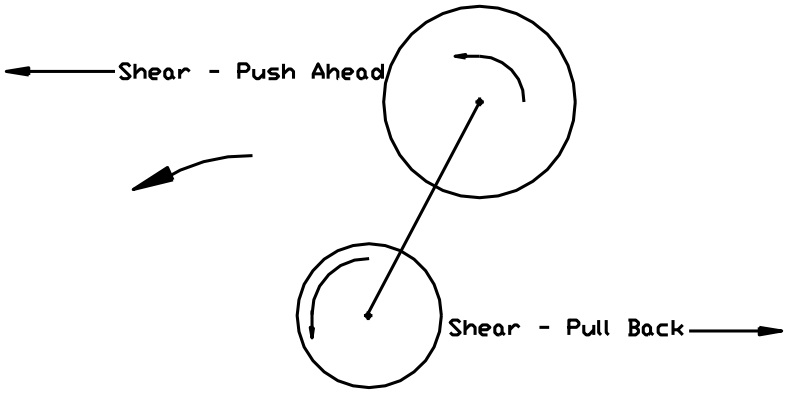


Figure 18-4

If both tires have the **same** vertical loading, they will both shear, but in opposite directions. The right tire will shear in the forward direction while the left tire will shear in the rearward direction. The amount each tire shears will be in proportion to its percentage of stagger provided they see equal normal loading. The percentage of shear between our example tires is 3%, which works out to be approximately 1.55% forward shear on the right rear and 1.45% rearward shear on the left rear. *It's not this simple*.

The shear percentage was found by:

- 3%/2 = 1.5% shear
- RR = 1.5* 103% = 1.55% shear
- LR = 1.5*97% = 1.46% shear

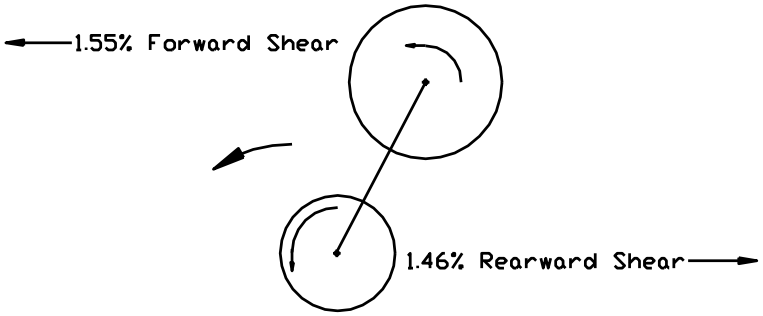


Figure 18-5

If engine torque is now added, the right side forward shear will begin to increase and the left side rearward shear will begin to decrease. As engine torque continues to increase, a point will be reached where the left tire will have no or little shear and will be pretty well free-wheeling while the right tire will be at 3% shear rate; in other words, the entire car is being accelerated by only one tire at just 3% shear rate – Figure 18-6.

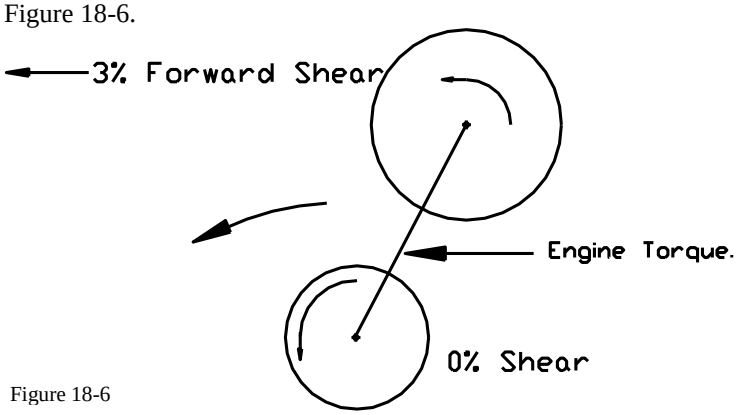


Figure 18-6

With an additional increase in engine torque, the right tire will move to its maximum coefficient of 7% shear while the left tire is still well below its maximum shear at 4% shear rate. If further engine torque is applied, the left tire will move to its peak 7% shear rate while the right side tire will be well over its peak coefficient of shear percentage- Figure 18-7.

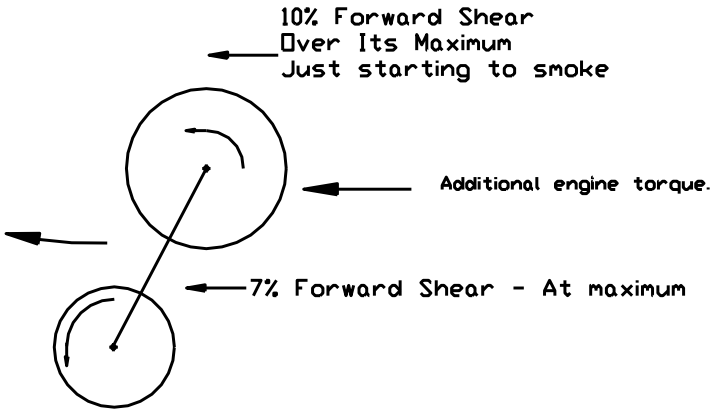


Figure 18-7

What all this really means is that under straight line acceleration, a driver will never be able to accelerate as quickly with rear stagger as without stagger. It takes a bit of time and thought to get around the fact that a tire can be driven in a forward direction while shearing in the rearward direction. If lateral and longitudinal weight transfer are also included, the calculations become somewhat more complex but only because these numbers are included with our percentages of shear rate and stagger.

Note: Remember the above examples were for a car moving in a **straight** line.

If the car is accelerating while also negotiating a left turn, things are somewhat different. If the radius of the turn matches the amount of stagger, there will be no stagger torque. Both tires will have the same amount of longitudinal acceleration shear rates and be quite similar to a car with a locked rear end and no stagger accelerating in a straight line. Of course, as the chassis is accelerating out of a corner, the corner radius will be constantly changing. Once again, longitudinal and lateral weight transfer needs to be included into our final calculations. Driver control plays a key role in keeping the rear tires at their peak

shear percentage. Once the rear tires break loose and begin to spin, it is incredibly difficult to regain the maximum amount of forward acceleration.

It is easy to see why a car that is set up for one radius, i.e. the bottom groove, will not work as well on the top groove with its larger radius. Obviously, the amount of stagger is going to be a compromise between what is needed for each cornering phase. Running less stagger not only increases the radius of the turn the car wants to naturally run, but also increases the cross weight if a stagger change is made and the preload is not rebalance. With the loaded radius of the RR tire at 13.65" and the loaded radius of the LR tire at 13.3", the resultant difference is 0.350". Depending upon the car and its set up, a radius change of 0.350" could represent a variation in cross weight of well over one percent.

Front Stagger

Because the two front tires are independent of each other, the only change will be to the chassis= cross weight, and, to a small degree, left bias braking torque. By using a larger circumference tire on the right front, the chassis is raised and cross weight is added. Front stagger is sometimes used to add wedge rather than changing preload. Every time the RF preload is changed, it will affect the front kinematics, including the steering geometry. Changing the RF or LF stagger rather than their preloads often has **less** effect on the chassis kinematics.

If the front brakes are both applying the same force, an effect somewhat the same as with a rear live axle torque sensing differential is produced, and, as a result, there will be a certain amount of left turning torque (LF tire smaller than the RF tire).

Racers are an Eclectic Bunch - Chris Sandvoss is an outstanding racecar fabricator turned Luthier (violin maker). After having one of his Cellos declared the **most outstanding** instrument at the 2004 VSA International Violin Making Competition, Chris has gone on to great riches. It doesn't hurt that his wife, Beth, is one of the world's foremost cello soloists. And here I thought race car engineering was rocket science.

