THE MYSTERIES OF...

ACKERMAN AND TOE

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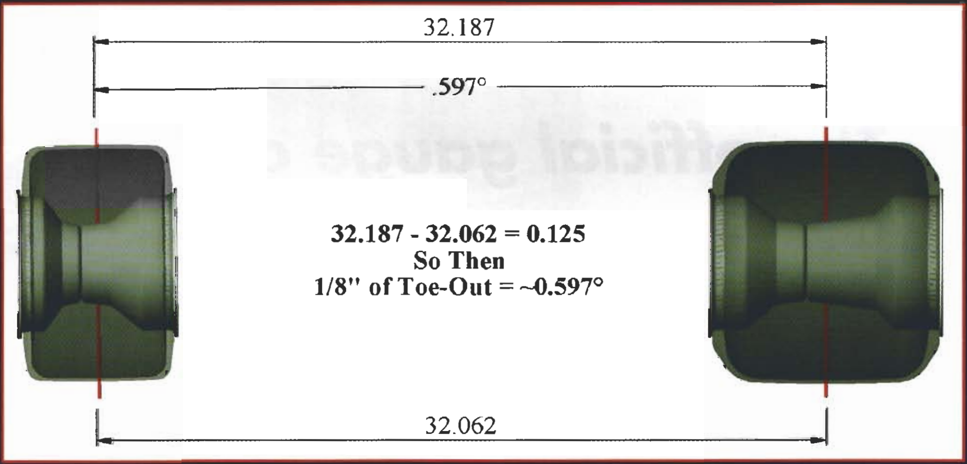
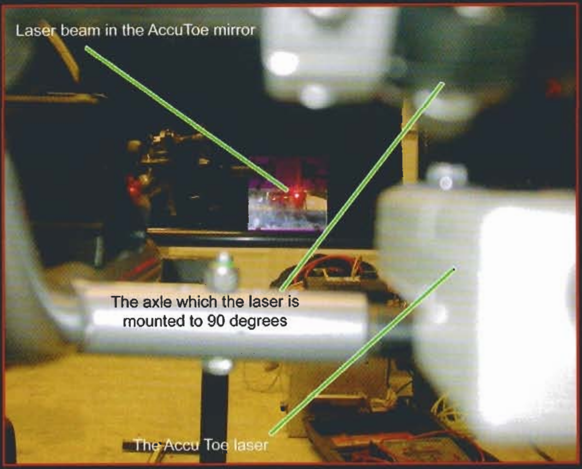
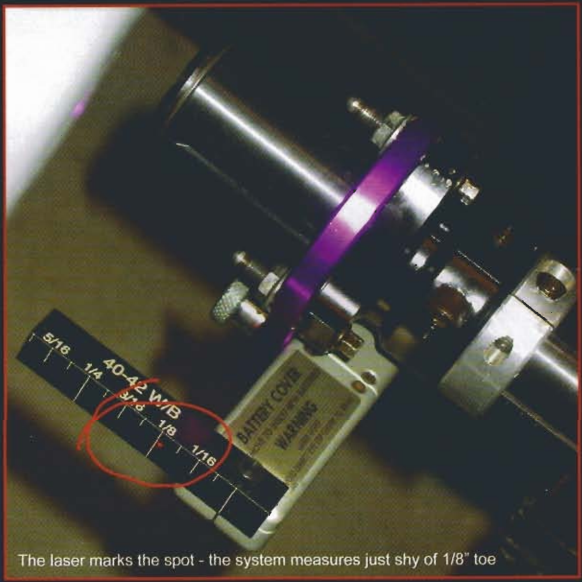
This month we're going to take an in-depth look at Ackermann and toe, what they are, what they do and what types of settings we typically run. We start our investigation by looking at what exactly Ackerman and toe are. Toe is the angular measurement between the tires and since on karts we have to run a solid rear axle we'll narrow this definition to the front tires only. If we say we have the toe "straight up" or "no toe" then the two tires are perfectly parallel or pointed in the same direction. If they point away from each other then we say we have "toe out" and if they point toward each other then we say we have "toe in". Even though the important bit is the angular difference between the tires it is difficult to measure this so we use linear measurements rather than angular ones. This is to say that we will measure the distance between the two tires at the front of the tire and get a measurement and then measure the distance between them at the back. Finally, we subtract the larger from the smaller to get the amount of toe (in or out) in inches. If the back measurement is larger the tires are toed in and if the front measurement is larger then the tires are toed out. Realize that when we take measurements in inches rather than angular measurements the distance away from the spindle becomes relevant in the measurement we get. What I mean by this is that on a kart the measurements are taken approximately 5-¼" in front of and behind the spindle axle. If we were to take a similar measurement on a car where the measurement is taken 14" in front of and behind the spindle axle then the same measurement will represent a different angle. For this reason, 1/8" of toe out on a kart represents a larger angular amount of toe out than 1/8" on a car. The moral of this example is to make sure you measure your toe the same way each time. Another option is to use aprcise measuring tool such as an Accutoe Pro which uses a laser and mirror to measure toe. It is more accurate and typically a faster method as well.



Now that we know what toe is, why do we run toe-in or toe out? On cars, toe is used to allow the wheels to point at the desired angle when the vehicle is traveling straight ahead and is necessary because of lost motion in steering systems and spring deflection. On karts, we don't have much spring deflection or lost motion so those tend not to be big reasons why we run toe. Most of the time we run toe to help the kart navigate the corner more efficiently, especially at corner entry. We do this because any losses we might incur from the tires being toed out are easily made up for by the gain in speed in the corner. So then, we run toe to help the kart turn and more specifically to help it turn down into the corner. In order to do this we tend to run toe-out. This toe out helps the LF bite a little harder in the first few feet of the corner to help get the karting rotating. After initial turn-in the LF unloads very quickly and toe tends not to make much difference but in those first few feet it can help a kart turn better. Similarly, it can help a kart turn a little better the last few feet of corner exit although the effect isn't as pronounced there as it is at corner entry.

If we're going to use toe, or specifically "toe out" to help the kart start turning at corner entry how much should we use? For the specific setting this depends mostly on the size of the track and the amount of turning power in the chassis, but before we get into the specifics let's look at what sets the practical limits. First, because of straightaway drag and the desire for enhanced corner entry turning power we don't typically run toe in. On tracks where we have plenty of turning power and wish to absolutely minimize drag on the straightaways we may choose to run the tires straight up or with a very small amount of toe out - 1/32" for example. This keeps the tires parallel on the straights for minimum drag but provides no additional turning power at corner entry due to the LF already being turned only slightly. If we are on a smaller or tighter track we may need a little more turning power at corner entry. Any slight losses on the straight will be easily made up for due to the cornering advantage so we may choose to run a bit more toe out, on the order of 1/16" or so. If we are on a really small or tight track where we need all the turning power we can get then we may choose to run 1/8" or even slightly more to help the kart rotate well. The practical limit on a kart seems to fall somewhere in the 3/16" range. So then, we've seen that toe out depends very much on the tightness of the track's corners along with the chassis' turning power and we use it to help the kart start rotating during the first few feet of corner entry.





The laser marks the spot - the system measures just shy of 1/8" toe

Now that we've looked at toe we'll begin our investigations on Ackermann. First, Ackermann is a geometric principle which arose during the days of the horse drawn carriage (it was developed around 1817 by Rudolph Ackermann). At that time the wheels had wooden hubs, spokes and rims, with metal rings around the wooden rims to add durability. As you might expect, these "tires" were quite inflexible. It was noticed that when cornering with this type of vehicle that one or both of the two tires were fighting each other with this "fighting" got worse the sharper the tires were turned. What Mr. Ackermann devised was a method to allow the inside tire to turn more so that its turning radius matched up with the tighter radius that the inside tire had to follow. If we think about this, we will notice that if our kart is taking a corner which measures 100 feet from the center of the corner to the centerline of the outside tire then on a kart which has a 30" front track width (the track width is the measurement from the centerline of one tire to the centerline of the other) the inside tire follows a radius which is ***not*** 100 feet but is rather 97 feet six inches. Because the corner radius of the LF is smaller it needs to turn slightly sharper to avoid scrubbing. So then, if we design our steering system as Mr. Ackermann describes, our LF will turn the additional amount necessary to navigate the corner without scrub. As you might imagine, with a solid tire such as those used on the early buggies this is quite necessary and had a noticeable effect. These days our tires are much more flexible and thus the use of Ackermann's principle needs to be modified somewhat.

Before we move on, let's look at some specific numbers for karts on typically-sized tracks. In the example above we used a 100-foot corner radius. While this may seem large, it is typical or even a bit small for a common 1/5-mile track. With this example, hypothetically, what falls out is that the amount of spindle rotation we would need to navigate the corner at slow speeds would be 1.92° at the LF and 1.90° at the RF. You will immediately notice the very slight amount of angular difference which results. This small difference is directly attributable to the large corner radius (100 feet is 1,200 inches) compared to the small track width of the kart (30 inches); the corner radius being 4,000% larger! Just for fun let's take the corner radius down to 50 ft. and see what the angular difference would need to be. Calculations indicate that we'd need a LF spindle rotation angle of 3.83° and a RF spindle rotation angle of 3.71°, still only 0.12°. We'd struggle to even measure a tenth of a degree of spindle rotation, much less feel it or measure it in laptimes.

You may have noticed that I used the words, "navigate the corner at slow speeds" above. In order to continue, it is necessary that we include slip angles in our discussion. You may recall in our investigation into why cut tires are faster printed in the June edition that tires operate at what is called a slip angle. You may remember that if we want the front of the kart to rotate at an angle of 2° we must input more than 2° of spindle rotation because the contact patch and the spindle are no longer at the same angle with the contact patch turning somewhat less than the spindle is rotated. In fact, we may have to rotate the spindle 4° or more to get the contact patch to rotate the 2° that we need it to in order to produce enough lateral force to turn the kart at 2°. What is happening here is that at slow speeds and low forces our rubber tires act very similarly to the old wooden tires but at high speeds and high cornering forces they do not because the rubber tire is much more flexible.

Now that we understand that our tires operate at slip angles how do we include them into our discussions on Ackermann? Okay, so we're in the corner navigating at high speeds and high forces and we've got our steering wheel turned about 8° which produces the 4° of spindle rotation (the typical ratio between steering wheel angle to spindle rotation is 2:1). We need to keep the front end of the kart turning at the 2° that it needs in order to navigate our 100-foot radius corner. If all of this is true then we still need that LF to turn slightly more than the RF right? No! There is one more thing we've got to remember: Once we get the kart turning and the weight moving around, the RF is loaded with nearly all of the weight on the front while the LF is loaded very lightly. Additionally, the LF is probably riding on a portion of the track which is slicker than that on which the RF is riding. The end result is that the RF is operating at the 2° of slip angle (4° of spindle rotation minus 2° of kart rotation) but due to the low loads on the LF it may only need to operate at 1° of slip. If this is the case then in order to minimize drag on the LF we would not need to turn it more than the RF but would, in fact, need to turn it less. How much less? We take the 4° of RF rotation, minus the 1° of slip angle difference plus the 0.02° of additional rotation the LF needs to turn to match its smaller corner radius and we get: 4° - 1° + 0.02° = 3.02°.

So then, in this example, in order to absolutely minimize the drag of the front tires we need for the LF to turn 0.98° *less* than the RF. In order to make this happen we need reverse Ackermann rather than the traditional Ackermann which most would expect. By the way, reverse Ackermann is when the inside tire turns less than the outside one rather than more. Now, before everyone goes out and adjusts their karts to have reverse Ackermann we need to understand a few things. First, both tires' slip angles are constantly changing throughout the corner so we'd never actually match it all up. Second, there is no one in karting who has the equipment to measure slip angles and on top of that they are constantly changing (literally from instant to instant). Finally, the amount of scrub which exists isn't huge. In the end I recommend leaving the Ackermann at the manufacturer's stock location and forgetting that it's adjustable; there just isn't enough speed there to worry about.

I imagine that some are thinking, "We can adjust toe but he's telling us to leave the Ackermann alone. Why is that since Ackermann is really only a dynamic toe adjustment?" The first reasons is that Ackermann geometry only changes the spindle rotation angles by very small amounts at the small steer angles at which a kart works. Our 0.02° of angular difference calculates out to about 0.0035 inches of toe out. The next thing is that in order to get the effects of Ackermann we've got to turn the steering wheel. At the point of turn-in we've only begun to turn the wheel so any Ackermann effect is even smaller than what we've looked at. Somewhere between turn-in and the apex where we've got the steering wheel cranked the most the LF is barely on the ground so it's not going to do much of anything.

I realize that our investigation into Ackermann has been a bit complex and littered with some math, but in order to understand what it is, how it works and what we need to do with it, we need to gain perspective on the actual numbers we're dealing with. Only when we do this can we get past the conventional wisdom which leads us to assume it's needed and very important to the true fact that it is so small that we'd never be able to feel it and even then what we'd actually need is opposite of what we'd expect.

To conclude, I hope that we have defined toe and presented what it does, why we run it and how we can adjust it and use it to help us make more speed on track and at the same time have demystified Ackermann.

Until next time…