The Mark Ortiz Automotive

CHASSIS NEWSLETTER

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WELCOME

Mark Ortiz Automotive is a chassis consulting service primarily serving oval track and road racers. This newsletter is a free service intended to benefit racers and enthusiasts by offering useful insights into chassis engineering and answers to questions. Readers may mail questions to: 155 Wankel Dr., Kannapolis, NC 28083-8200; submit questions by phone at 704-933-8876; or submit questions by e-mail to: markortiz@vnet.net. Readers are invited to subscribe to this newsletter by e-mail. Just e-mail me and request to be added to the list.

VIDEOS STILL AVAILABLE

I still have available videos of my lecture, "Minding Your Anti", presented March 2003 at UNC Charlotte. Price is $50.00, which includes shipping and handling worldwide. North Carolina residents please add 7½ % sales tax.

RAISING MY RATES

For the first time in three years, I have decided to raise my hourly rate for consulting. The new rate will be $50/hour, which is still reasonable compared to what other consultants have told me they ask. Retainer rates will likewise go up proportionately. A month will be $300; a year will be $1500. New rates take effect March 1.

DIFFERENTIATING DIFFERENTIALS

A 2200 lb., 300 bhp, rear-wheel-drive car is doing circuit racing on a short, twisty asphalt circuit with mostly right-hand turns. It runs the same rubber on all four wheels. Which of the following differential setups would be quickest around the track, giving good turn-in and good traction out of the corners?

1. *A spool type locked rear*
2. *A Positraction rear with 250 lb. preloading*
3. *A Detroit Locker rear*
4. *A Torsen rear*

All of these options have their adherents. One thing that complicates the picture is that the choice interrelates with setup and driving style.

Conventional wisdom is that spools are a bad idea for road courses. To get good steady-state cornering with a spool, the car needs to have tire stagger, or alternatively the power available and the nature of the track surface have to be conducive to powersliding. Tire stagger is generally an impossibility if the turns go both ways, although maybe if most of them go one way it is possible to accept poor behavior in the few that go the wrong way. If, as the questioner posits, the tires are truly identical all around, in circumference as well as all other properties, then we definitely don't have stagger.

Driven more or less normally, a car with a spool tends to understeer, or push. It does this much more in tight turns than in large-radius ones. We can free it up by putting lots of roll resistance in the rear suspension, but when it's right in the slow turns, it's too loose in the sweepers. One cure for this is to have a lot of aerodynamic downforce at the rear. Whether we can get that will depend on the bodywork rules.

There are situations where the locked-axle push is helpful. If we are trying to brake and turn at the same time, the car tends to oversteer. This limits how hard we can brake while turning. The car also will oversteer under power, if there is enough power applied, because the rear tires are using a lot of their available grip to make forward force and have less grip available for making lateral force. Again, if the car is tight to begin with, the driver can feed it more power before it goes power-loose.

This means that a spool can work on a road course if we have a driver who trail-brakes deep into the turns, and then gets on the power hard right away. In most of the slower turns, the car never sees steady-state cornering when driven this way. Mid-turn speed isn't necessarily best with this approach, but we get good entry and exit speed, and a late brake application point and an early power application point. Consequently, elapsed time, or average speed, on any straightaways before and after the turn improves.

Not surprisingly, the driver best known for making this work is the one who popularized trail-braking when most drivers were still completing their braking before turning: the late Mark Donohue. Donohue could win races on a road course with a spool, even in a car with huge tires and a massive rear wing, such as the Can-Am Porsche 917-30. Other drivers would get into cars set up to his liking, and not be able to do anything with them.

We might reasonably suppose that a driver could simply learn this, and adapt. Actually, drivers' abilities to do this vary considerably, and even those who can learn require practice to use a new technique well. Then again, we may have a driver who learned to drive this way, and has to learn a new style to do anything else. Not only do personal preferences differ on the question of trailbraking, so do driving schools.

To perform the best, a race driver needs to be able to drive the car without thinking, and focus his/her conscious mind on observation. This means that it's not easy to learn and unlearn new driving styles to adapt to different cars. For some talented individuals, it's merely difficult. For others, it's impossible. And for all drivers, just having to think about technique costs speed, all by itself. Therefore, when we set up a race car, we need to accommodate the driver, and not simply write off to stubbornness a driving style that doesn't suit our setup. If we have a driver who is in the habit of driving like Donohue, a spool may be worth considering. If not, that argues against the spool.

The spool is simpler and lighter than any alternative. Its simplicity is a plus for both cost and reliability, although a spool is generally harder on axles than any form of limited-slip.

For those unfamiliar with the Positraction, or Posi for short, it is a clutch pack style limited-slip, usually with a single clutch pack establishing friction between the right side gear and the carrier. The clutch pack is preloaded either by having a dish in one pair of discs so they act like Belleville washers, or by having coil springs bearing on the clutch pack. Added clutch loading is applied to the pack by the spreading force on the side gear when torque acts on the ring gear. At a given ring gear torque, this spreading force depends on the tooth profile and the diameter of the side gears. That makes the preload the only adjustment.

Preload is measured in lb.ft. of torque, rather than pounds – though it is common to say pounds for short in casual conversation. The procedure is to jack up one wheel, or jack up both rears and have a helper hold one, put the transmission in neutral, and measure the torque required to turn one wheel. This requires an adapter to allow a torque wrench to turn the wheel. For best accuracy, it's best to turn both wheels at once with the torque wrench first, to measure brake and bearing drag. Then you divide that value by two to find the drag for one wheel, and subtract that from your torque reading when turning just one wheel.

250 lb.ft. in this test is a lot. Typical values for stock road cars are more like 50. If the car is on racing slicks with a coefficient of friction of 1.3, and a rear wheel has a static load of 550 lb. and an effective radius of one foot, the tire's breakaway torque under static load is 715 lb.ft. For the inside tire in a corner, with a substantial portion of the traction circle being used for cornering, 250 lb.ft. could easily be enough to overpower the tire. And under power, we get more clutch pack loading. In such a situation, a heavily preloaded Posi can act a lot like a spool.

However, when the tires can overpower the clutch pack, the Posi acts tamer than a spool. Like a spool, but less severe. This will tend to save the axles to some extent, as well.

It might be worth mentioning the ZF style differential, which the questioner didn't list. The ZF and the Posi are both sometimes called Salisbury differentials, but they differ a bit. Like the Posi, the ZF has multi-disc clutches that can be preloaded and are loaded additionally by engine torque. The difference is that in a ZF, the clutch discs are outside the carrier, and the carrier is split into two halves at the pinion shafts. The pinion shafts have angled flats on them that bear against mating flats on the carrier halves. The angle of these flats can be varied, by installing different parts having different angles. This allows us to adjust the severity of the lockup under power. There are similar flats that spread the carrier halves under reverse torque (engine braking). The angles of the flats for power and decel can be varied independently, allowing the unit to lock more or less strongly on deceleration compared to acceleration.

The Torsen, or Gleason, is also two designs that have very similar properties. Both use worm gears in place of the spider and side gears of a conventional diff. The worm gears provide a very smooth, yet strong lockup under load, yet turn very freely with no load, provided they are not preloaded. Gleasons can be preloaded. One problem with preloaded Gleasons is that the preload is highly sensitive to gear wear.

If I were to make a general-purpose recommendation for road racing, it would be the Gleason. It has the ability to lock strongly, yet smoothly, with little or no preload. This makes it very driveable.

It does have some drawbacks. It is generally the costliest of all the types we're considering here, although not prohibitively so. The power and decel lockup are not separately tunable, as with the ZF. If the unit is not preloaded, it will not prevent one wheel from spinning if that wheel is very lightly loaded, or is airborne, or is on a very slippery surface.

The Detroit Locker is not really a differential in the sense that the Salisbury and Gleason are. That is, it has no gears at all, and there is no way it can be set up to split torque equally between the two output shafts, while letting their speeds vary, even at very low torques. The locker contains a center element consisting of a dog ring driven by the carrier, like the spider gears and pinions in a Salisbury or an open diff. This central dog ring has dogs on both sides. These mate with driven dog rings on either side, which drive the axle shafts.

The driving dog ring can float a bit side to side. It is held centered by two conical coil springs. When the driving dog ring is centered, it engages both driven dog rings, and we have a locked axle. If the driving dog ring moves to one side or the other, it moves more deeply into engagement with the driven dog ring it moves toward, and if it moves far enough it disengages from the other dog ring. We then have drive to only one wheel.

For a wheel to disengage, it has to overrun the carrier. For this reason, the locker is sometimes called a ratchet. This isn't really accurate, but the unit is somewhat similar to a pair of ratchets, each driving one wheel, in that it drives the slower wheel and lets the faster one overrun. It differs from a pair of ratchets in that only one wheel can overrun at a time. In decel, the slower wheel sees the engine braking. In a race car, this promotes very free turn-in. If the driver likes to finish braking and then turn, this can work well. If the driver likes to do heavy trail-braking, it may be a disadvantage.

When the driver gets on the power, the inner wheel drives, up to the point where it spins. As soon as the inside wheel reaches the speed of the outside wheel, the unit locks and drives both wheels. The lockup is not smooth at all. The dogs are either engaged, or they're not. The unit cannot slip. This requires the driver to develop a feel for when the unit is going to lock, and anticipate the change in car behavior at lockup. It also rewards decisive driving. That is, lockers are somewhat unpredictable if the driver is on and off the throttle trying to balance the car. It can be hard to predict whether the rear will be locked or unlocked when the power is reapplied after a brief lift. So the locker responds best to a driver who gets on the power and stays on it.

One peculiarity of the locker is that when backing up, it drives the faster wheel rather than the slower one. This means that we don't have drive to the wheel with traction if one wheel is off the ground or on very slick ice. Normally, this is of no concern in road racing, but it is something to consider for street or off-road use.

The locker develops less heat than a Salisbury or Torsen, since it has no slipping friction elements. The rear end can still get hot, due to the friction in the ring and pinion gears. And if it gets hot, the springs in the locker can lose their temper. This will cause erratic locker behavior. For this reason, it is customary in racing to replace the springs frequently.

Lockers are universal in NASCAR, because the rules require them. Salisburys and Torsens are prohibited. This rule originated with a prohibition against all limited-slips and spools. The inspection procedure was to test the rear end by turning one wheel with the transmission in neutral, as described above for testing a Posi. The wheel had to turn freely. Since a locker would pass this test, people started using them, and they were such an advantage over an open diff in a stock car that they became universal. NASCAR saw that the racing was better when the cars could put power down with both rear wheels, so they never prohibited lockers. Now, they are specifically written into the rules by name.