LIMITED-SLIP DIFFERENTIAL AS A WINTER DRIVING TRACTION AID

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The conventional differential divides the driving force equally to both rear wheels. The total driving force is limited by the wheel that has the least amount of traction. Therefore, if one wheel is on ice, snow, or mud, it will spin, and the driving force is lost. Limited-slip differentials direct more of the driving force to the wheel with better traction, thus improving the mobility of the vehicle. Limited-slip differentials and studded tires are complementary to one another. Studded tires increase the amount of traction available, and limited-slip differentials enable vehicles to use more of the traction that is available. The performance of the limited-slip differential is generally independent of the driver. It does its job automatically so that no special action is required except reasonable care not to abuse it.

•A CONVENTIONAL automotive differential allows the driving wheels to rotate at different speeds while dividing the driving torque equally between them. This function is ordinarily desirable and satisfactory. However, the total driving torque can be no more than double the torque at the wheel having the least traction. When traction conditions are not the same for both driving wheels, a portion of the available traction cannot be used.

Under certain common driving conditions, the conventional differential imposes serious limitations on mobility. If one wheel is on ice, snow, or mud, the wheel will spin, and the driving force is lost. The potential total traction of the vehicle is seriously reduced because of the equal torque balance of the differential. The wheel that is on the more slippery surface can develop only a small amount of torque and will not allow the other wheel to utilize its more favorable traction. The maximum driving force is limited to twice the traction force of the slipping wheel.

OPERATION

The limited-slip differential was conceived to improve motor vehicle mobility in situations where the traction conditions are not the same for both driving wheels. More driving force is directed to the wheel having the better traction to improve the ability of the vehicle to pull out of mud or snow. Even though one driving wheel may be on a low friction surface, the other wheel can develop additional torque before wheel spin will occur.

In a typical friction-type limited-slip differential, the added traction is achieved by use of clutch assemblies mounted between the side gears and the differential case. These clutches resist differential motion and tend to hold the side gear stationary relative to the differential case. Because of this resisting clutch torque, the differential will not differentiate until external torques exceed the capacity of the clutch, at which time the clutch will begin to slip.

The clutch application force comes from both a preload spring or spring pack and side-gear separation loads. Because the separation load of the gear teeth is a function of torque, the clutch capacity is also a function of torque. If no preload mechanism were used and the unit had to depend solely on side-gear separation loads for clutch application force, it would provide very little advantage over the conventional differen-

tial when one wheel is on wet ice. However, the preloading device provides clutch application force even when one driving wheel of the vehicle is off the ground.

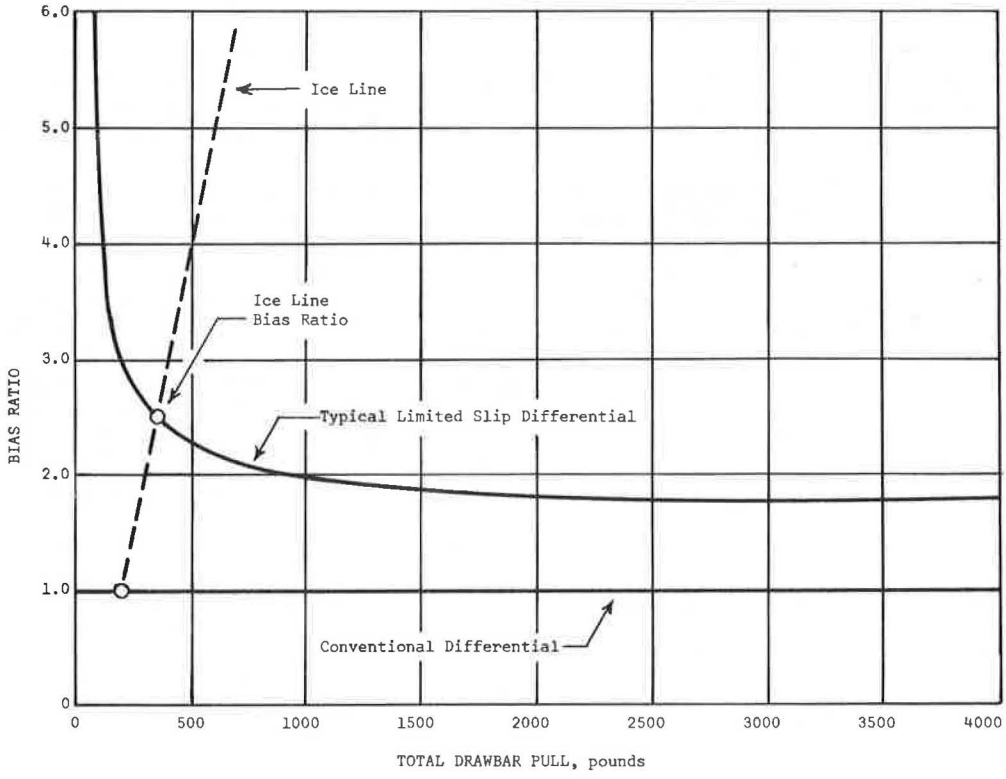
EFFECTIVENESS

The performance of a limited-slip differential is generally evaluated in terms of the ratio of the torque that can be developed by the high traction wheel to that that is developed by the low traction wheel (1). This ratio is called the "bias ratio" and is expressed as follows: Bias ratio = static wheel torque/slipping wheel torque. The slipping wheel has the unfavorable traction condition such as ice, snow, or mud, whereas the static wheel has the better traction condition and therefore the greater torque capability.

The bias ratio is a rating of the maximum effectiveness of a differential in improving the traction capability of the vehicle. It is measured at the point at which the unit begins to differentiate, that is, when the clutch begins to slip and the low traction wheel starts to spin. A larger bias ratio indicates greater traction capability of the vehicle, whereas a smaller ratio indicates lesser traction capability. The conventional differential has a bias ratio of one, and it is always constant. The limited-slip differential has a bias ratio greater than one, and it varies with the torque output.

Figure 1 shows a typical bias ratio curve. Normally, the most severe operating condition occurs when one wheel is on wet ice. This is represented by one point on the bias curve and is generally used to compare the effectiveness of two similar units. This point is designated as the "ice line bias ratio." The ice line is the broken line in the figure, and it represents a skid number of 10 for the slipping wheel. This results in a slipping wheel torque of about 100 ft-lb for an average-weight car having a drive axle weight of approximately 2,000 lb. The ice line bias ratio is 2.5 for the particular curve

Figure 1. Bias ratio curve for limited-slip and conventional differentials.



shown, and the vehicle produces a total drawbar pull of approximately 350 lb (100 lb from the low traction wheel plus 250 lb from the higher traction wheel).

The shape of the bias ratio curve can be changed by changing either the clutch capacity or the spring preload force. Increasing the clutch capacity results in an increased bias ratio throughout the complete torque range, whereas a reduction in clutch capacity lowers the curve across the total range (1). Similarly, the bias ratio can be increased by added spring preload. Because the total clutch application load is the sum of the spring preload and the side-gear separation load, an increase of the spring force is more effective at the lower torque levels.

At first, one might expect that the bias ratio should be as high as possible to maximize traction capabilities. This, however, is not practical. The design of the limited-slip differential must be optimized to satisfy traction requirements and yet result in a satisfactory operating vehicle during all maneuvers.

If the bias ratio is too high, the differential assembly will overly resist differentiation and will lock up when making a turn. If it does not slip while going around a turn, the vehicle will shudder because of the difference in distance traveled by the inside and outside wheels. The vibration is caused by scrubbing of the tires on the pavement, which, in turn, causes the complete drive line to go into a resonant vibration. The shudder is more pronounced during a hard acceleration. It also is more severe when the pavement is slightly damp, reducing the torque level at which the tires will slip. Obviously, for overall satisfaction, the bias ratio must be tuned to match the overall requirements of the vehicle.

Although numerous variations in the design of a limited-slip differential can be made to alter certain characteristics under specific conditions, each change also introduces new limitations along with the improvements. It becomes apparent, therefore, that the characteristics designed into a unit must be a compromise to best satisfy all expected driving conditions.

ADVANTAGES

The primary performance goal of a limited-slip differential is to improve the traction of the vehicle during adverse traction conditions. The advantage offered on ice- and snow-covered roads is fairly obvious. It also provides improved mobility for motor vehicle operators who encounter adverse conditions when they leave the hard-surfaced roads to travel into camping areas or other off-road locations. For boat owners, it frequently affords that little bit of extra traction needed to pull a trailer from a boat launching point.

The driver of a high-performance vehicle is at a distinct disadvantage when trying to utilize the maximum capability of his vehicle if it is not equipped with a torque biasing differential. The effect of the limited-slip differential can be seen at the drag strip where on acceleration both rear wheels leave an even strip of rubber. Generally, a car with a conventional axle and a stock suspension will have the right rear wheel smoking while the left is barely moving. A similar condition occurs during hard acceleration on sweeping turns, when the centrifugal force tends to unload the inner driving wheel.

Another benefit derived from a limited-slip differential is a reduction in shock loading to the drive line due to an airborne wheel returning to the ground, as experienced on a bumpy road surface. With a conventional axle, the wheel in the air tends to accelerate and induces a shock load on the drive train on returning to the road surface. A limited-slip differential tends to restrict the acceleration and dampens the impact on return, thus reducing the shock load.

It is significant that limited-slip differentials and studded tires both provide improved overall traction capabilities for the vehicle on which they are installed, but neither can replace the other. Studded tires increase the amount of traction available on snow- or ice-covered surfaces, whereas limited-slip differentials enable vehicles to utilize more of the traction that is available regardless of surface condition. It follows, therefore, that a limited-slip differential and studded tires used together offer greater improvement in vehicular mobility than either one used separately.

LIMITATIONS

Although the manufacturers of limited-slip differentials attempt to optimize their designs, they are compromises, and certain inherent limitations must be recognized.

Certain caution must be exercised when accelerating with both rear wheels on a very slippery surface. If too much throttle is applied, particularly when cornering, lateral stability will be lost, and the rear of the car will go into a slide. This occurs when both wheels spin together without differentiation (i.e., the clutch capacity exceeds the road's ability to induce differentiation).

Under other road surface conditions, the differential may not have enough capacity to develop the traction required to move a vehicle. If one wheel should start to spin independently of the other, the capability of the unit has been exceeded. Any further spinning will only result in possible permanent damage to the unit.

Other precautions that are not related to the operation of the vehicle on slippery roads must also be observed.

A vehicle equipped with a limited-slip differential should never be run in gear with only one driving wheel jacked up. If the unit is operating properly, the vehicle will run off the jack.

Dynamic balancing of rear wheels while still on the car should be avoided. Independent spinning of one wheel can ruin the friction device.

Car washes that clean the tires by inducing independent spinning of the wheels should be avoided for the same reason.

The lubricant used in limited-slip differentials is a most crucial item. It must maintain an acceptable ratio between the static and dynamic coefficients of friction within the clutch to prevent noise. Only the lubricant specified by the manufacturer should be used when adding to or refilling the rear-axle sump.

DEMAND

In spite of the particular traction advantages offered by the limited-slip differential, it has steadily declined in popularity as a factory-installed option on domestic passenger cars over the past 5 years. The percentage of domestic passenger car production and the number of units equipped with limited-slip differentials for each of 5 model years (2) are as follows:

Factor	1968	1969	1970	1971	1972
Percentage of car production	10.8	9.2	8.3	5.5	4.4
Number of units	874,895	758,527	656,537	416,381	392,936

The downward trend in owner demand for limited-slip differentials on new automobiles may be partly due to the special cautions that must be observed. However, the decline in their use has occurred concurrently with an increase in use of studded tires. This leads to speculation that new car purchasers may have elected to forgo the special advantages of the limited-slip differential in favor of studded tires, perhaps not realizing that the two are complementary rather than being substitutes for one another.

Inasmuch as several states have taken action to outlaw use of studded tires or are seriously considering such action, it would seem appropriate that a renewed demand for limited-slip differentials should appear. Even though a driver must observe a few special precautions in the operation and care of his vehicle equipped with a limited-slip differential, the improved traction capabilities outweigh any operational inconveniences.

REFERENCES

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