SURETRAC

SUBARU

Construction of SURETRAC

SURETRAC is a new type of differential that mainly consists of two shaft hubs, two face cams, 19 cam followers, and a differential case.

The shapes of the two face cams are shown in the figure 1, and the protruding parts of the cams are called to as teeth. (The face cams function like the side gears in a conventional differential.)

The cam followers are sandwiched between the left and right face cams and are engaged with a spline built into the differential case. Differential operation and it's restriction in SURETRAC are made with the movement of the cam followers.

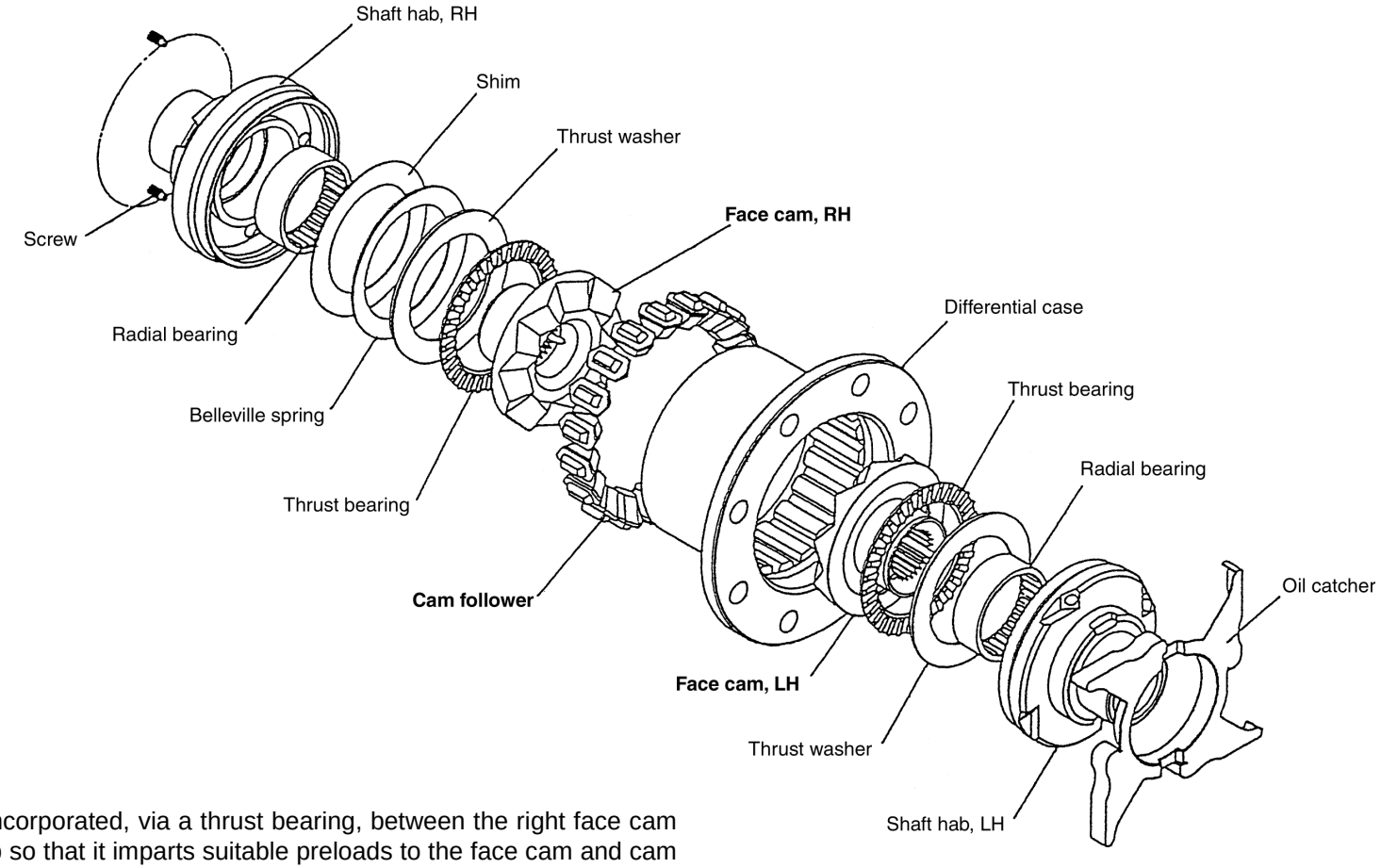


Fig. 1

A belleville spring is incorporated, via a thrust bearing, between the right face cam and the right shaft hub so that it imparts suitable preloads to the face cam and cam followers. An oil catcher is equipped outside the left shaft hub for lubrication.

SURETRAC Function Principle
Torque transmission route

Ring gear ---> differential case ---> cam followers ---> left and right face cams

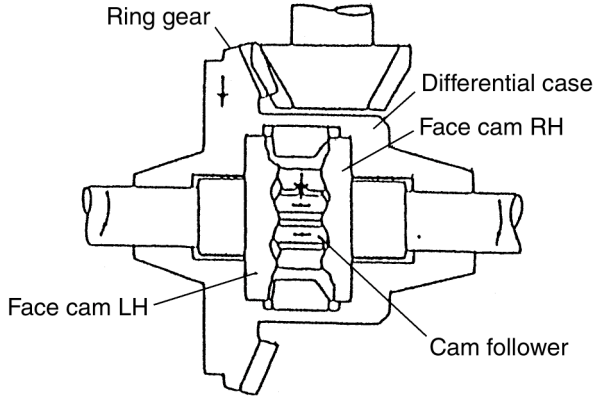


Fig. 2

Transmission of drive force when vehicle is driving straight ahead

When the vehicle is driving straight ahead, there is no difference in the rotation of the left and right wheels, so the two face cams rotate at the same speed. The drive force input to the ring gear is transmitted from the differential case to the cam follower. This transmitted drive force travels through the cam followers in contact with the left and right face cams (#1 and #3 in the case shown in the figure) to the left and right face cams, causing them to rotate.

NOTE
The number of teeth of the left and right face cams differs by one tooth. The reason for this is that, in order for the cam followers to transmit drive force to the face cams, the left and right face cams have to form wedge shapes, as shown in Figure 3. If the number of teeth were the same, all the hills and valleys of the teeth might in some cases arrange themselves opposite each other. The prerequisite wedge shape then would not be obtained, and the cam followers would slip down the helical surface of the face cams, zigzagging between the left and right face cams and making it impossible for drive force to be transmitted (see Figure 4). For this reason, the right face cam has 10 teeth and the left face cam has 9 teeth. If the number and angle of the teeth were the same, the force transmitted to the left and right sides would be the same and there would be no difference in rotational speed between the left and right sides. A slight difference between the left and right sides is created, therefore, by having a one-tooth difference on one side. Since this difference is slight and does not exert a marked effect, however, the torque transmitted to the left and right face cams is herein treated as equal for the sake of clarity.

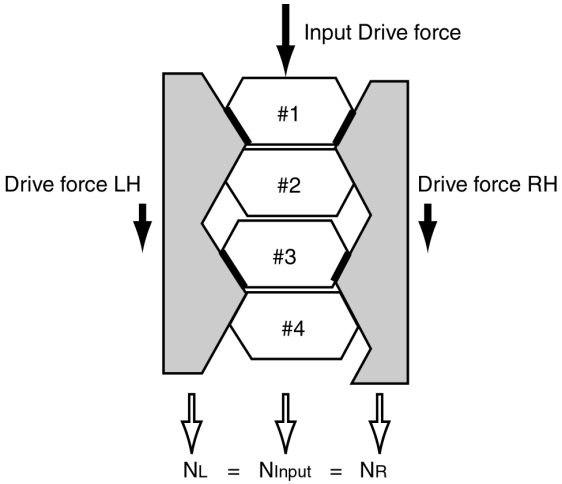


Fig. 3

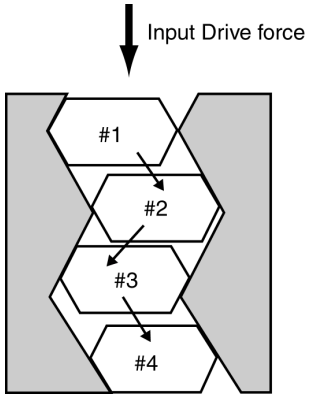


Fig. 4

Transmission of drive force when vehicle is turning

Let's compare the differential operation of the SURETRAC and a conventional differential. For this comparison, we'll consider what happens when a vehicle is making a right turn.

In the case of a conventional differential

During a right turn the left wheels turn faster than the right wheels. This difference in wheel rotational speed is absorbed by the rotation of the pinion gear. This occurs as follows.

The differential case is locked and the left wheels are made to rotate.

↓

Since the differential case is locked, the pinion gear rotates because it cannot revolve. This causes the right wheels to turn in the opposite direction.

↓

Here, if we make the rotation of the left wheels $+\alpha$, that of the right wheels, which is opposite, becomes $-\alpha$. If we make the rotation of the differential case N, therefore, the rotation of each part is expressed as follows.

Input rotation of differential case = N
Rotation of left wheels = $N + \alpha$
Rotation of right wheels = $N - \alpha$

↓

In the above, $+\alpha$ and $-\alpha$ can be considered the difference in rotational speed of the left and right wheels. Since $+\alpha$ and $-\alpha$ are produced by the rotation of the pinion gear, the difference in rotational speed ends up being absorbed by the pinion gear rotation.

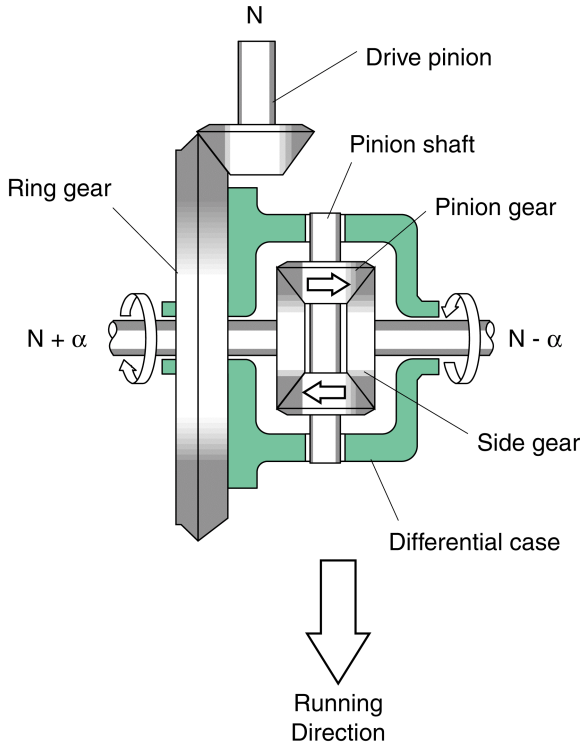


Fig. 5

In the case of the SURETRAC differential

Whereas the difference in rotation of the left and right wheels is absorbed by the pinion gear rotation in the conventional differential, in the SURETRAC differential it is absorbed by the left and right movement of the cam followers.

The differential case is locked and the left wheels are made to rotate.

↓

Since the differential case is locked, cam followers #2 and #4 move to the right along the inclined surfaces of the left face cam. [Figure 7-(1)]

↓

At this time, the right edges of cam followers #2 and #4 move along the inclined surfaces of the right face cam and push it up (causing the right face cam to turn in the opposite direction). [Figure 7-(1)]

↓

As the right face cam moves upward, cam followers #1 and #3 move to the left along the inclined surfaces of the right face cam. At the same time the left face cam moves downward, creating a space to the left of cam followers #1 and #3 that they can move into. [Figure 7-(2)]

↓

Here, if we make the rotation of the left wheels $+\alpha$, that of the right wheels, which is opposite, becomes $-\alpha$. If we make the rotation of the differential case N, therefore, the rotation of each part is expressed as follows. [Figure 7-(2)]

Input rotation of differential case = N
Rotation of left wheels = $N + \alpha$
Rotation of right wheels = $N - \alpha$

↓

From this it is evident that SURETRAC has the same differential function as a conventional differential, and the difference in rotational speed of the left and right wheels is absorbed by the left-right movement of the cam followers.

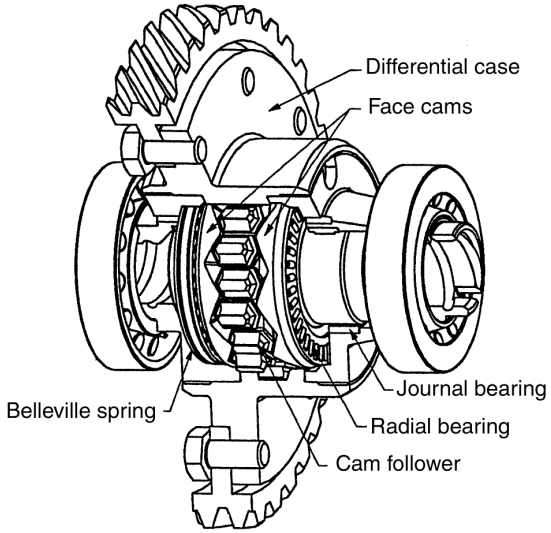


Fig. 6

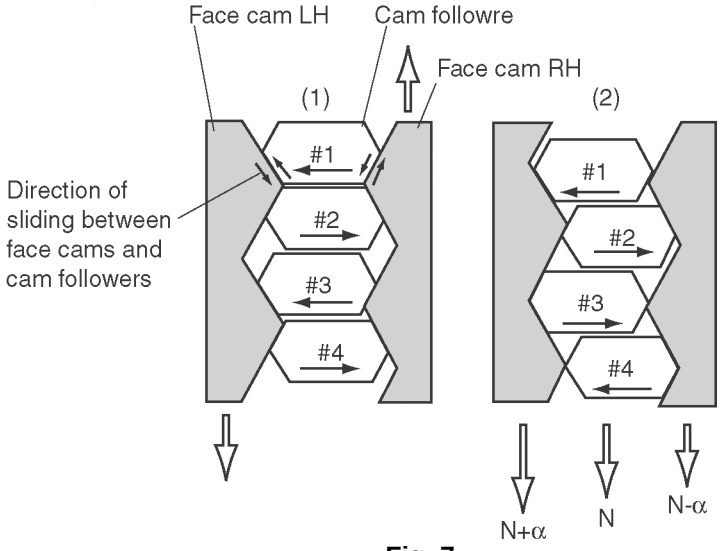


Fig. 7

SURETRAC LSD Function Principle

Let's consider the SURETRAC's limited slip differential (LSD) function principle. Here, we will consider a vehicle traveling on a low-friction road with only the left wheels turning.

Since the road is a low-friction road, the left wheels turn faster than the right wheels. The mechanisms inside the differential therefore move as described above to absorb this difference in rotational speed of the wheels. This movement creates friction (f_L, f_R) on the left and right face cams in the opposite direction of their movement. This results in a varying torque being transmitted to the left and right wheels as follows.

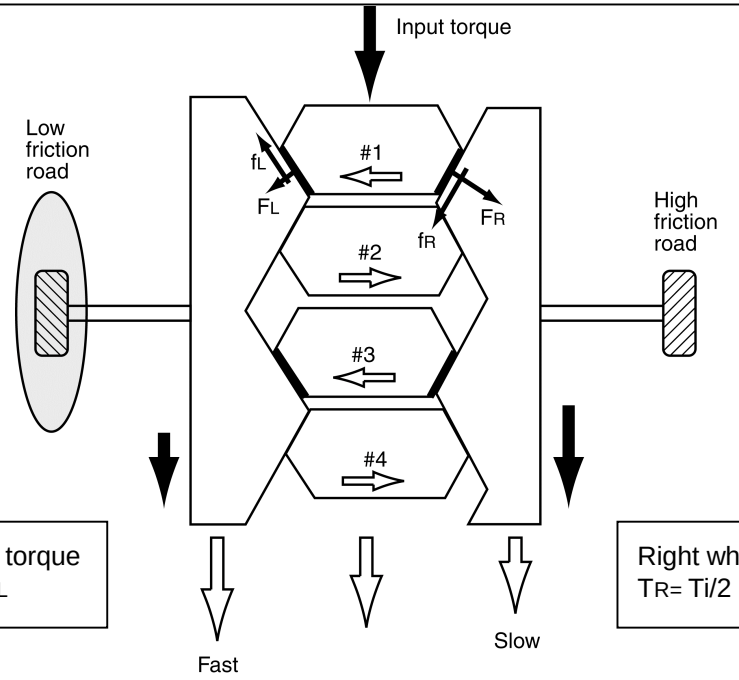
Input torque Ti is imparted to cam followers #1 and #3

Receiving a strong reaction force from the road, cam followers #1 and #3 move to the left along the inclined surfaces of the right face cam.

Left wheels

Cam followers #1 and #3 move to the left, so the left face cam is pushed down. (Cam followers #1 and #3 move along the inclined surfaces in the direction opposite to the rotation of the left face cam.)

Frictional force f_L is created between cam followers #1 and #3 and the left face cam, in the direction shown in the accompanying figure. Because this frictional force is negative, the left face cam torque is small.



Left wheel torque
$T_L = Ti/2 - f_L$

Right wheel torque
$T_R = Ti/2 + f_R$

Fig. 8

Right wheels

Cam followers #1 and #3 move along the right face cam in the direction of rotation.

Frictional force f_R is created between cam followers #1 and #3 and the right face cam, in the direction shown in the accompanying figure. Because this frictional force is positive, the right face cam torque is large.

Because of frictional forces f_L and f_R, the torque on the low-friction road side is small and that on the high-friction road side is large. In other words, SURETRAC has a restriction of differential operation.

The friction produced between the cam followers and face cams is proportional to the input torque, so the restriction of differential operation increases as the input torque increases. This means that SURETRAC is a torque-sensitive type limited slip differential.

Torque transmitted by a wedge shape

Let's see how torque is transmitted by a wedge shape both with and without the presence of friction.

When friction is not present

In this case there is no influence on input torque Ti, so torque is transmitted equally to the left and right sides as shown in the figure below.

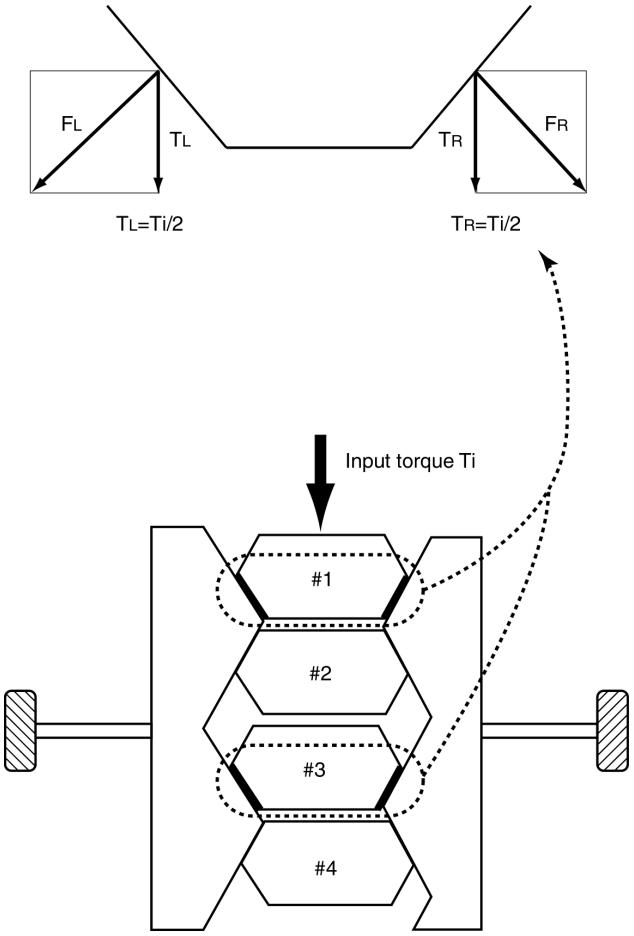


Fig. 9

When friction is present

In this case, when the left wheels are running on a low-friction road as described previously, a positive torque is transmitted to the right wheels (cam followers drag the right face cam by fR') and a negative torque to the left wheels (braking force work on the left face cam by fL'), in proportion to the frictional forces (fL' and fR').

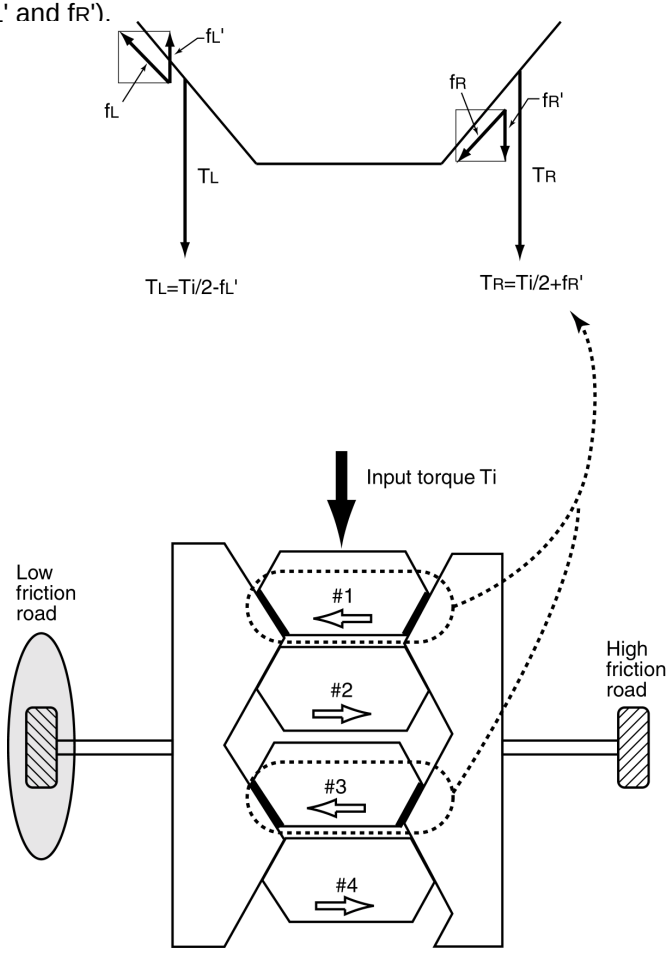
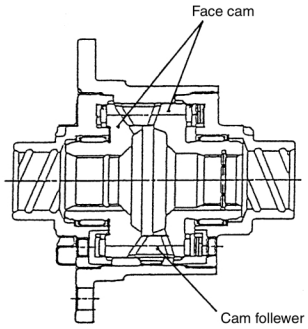
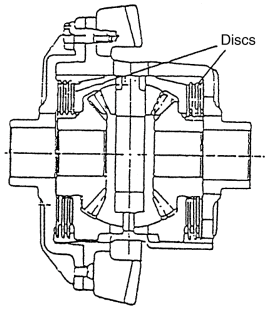
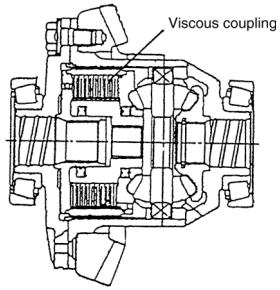


Fig. 10

Comparison of SURETRAC and Other LSDs

	SURETRAC	Multiple disc LSD	Viscous LSD
	 Fig.11	 Fig.12	 Fig.13
Type	Torque-sensitive type	Torque-sensitive type	Rotational speed differential-sensitive type
Construction	Construction is simple because cam followers and face cams control the differential operation and its restriction. (Consequently, it is possible to set in the same space with a differential without a limited-slip function.)	Construction is complex because the differential operation is made with pinion gears and side gears, while its restriction is controlled by a multiple-disc clutch.	Construction is complex because the differential operation is made with pinion gears and side gears, while its restriction is controlled by a viscous coupling.
Torque bias ratio *	The torque bias ratio is determined by the cam angle, so a wide range of ratios can be obtainable from 2:1 to 5:1.	The torque bias ratio is determined by the clutch plate total area (number and size of discs), so the ratio is less than 2.5:1.	The torque bias ratio is not constant because this type is sensitive to differences in rotational speed; it is determined by the viscosity of the silicon oil.
Effect of oil temperature	Less effect with oil temperature.	Less effect with oil temperature.	Largely affected by the silicon oil temperature.
Lubricating oil	GL-5	Special LSD oil	GL-5 + High-viscosity silicon oil (viscous coupling)
Acceleration response	Response is good because it is proportional to the input torque.	Response is good because it is proportional to the input torque.	Response is poor because it is proportional to the difference in rotational speed of the left and right wheels.

*The torque bias ratio is a value that indicates the ratio of drive force distributed to the left and right sides.
With a ratio of 3, for example, three times the drive force can be distributed to the low-friction road side (high rotational speed) than to the high-friction road side (low rotational speed).