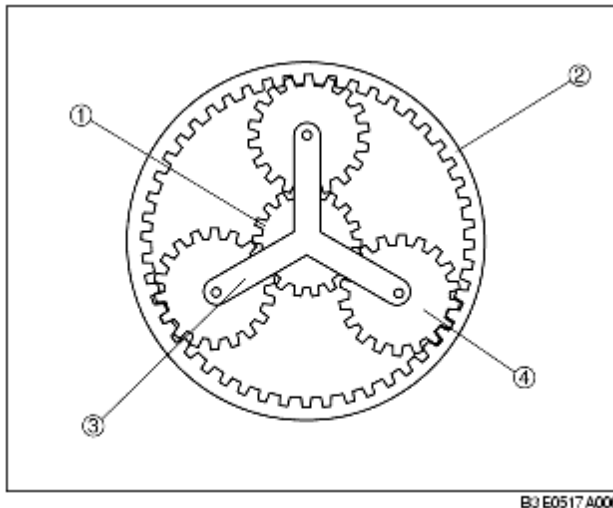


# PLANETARY GEAR OPERATION

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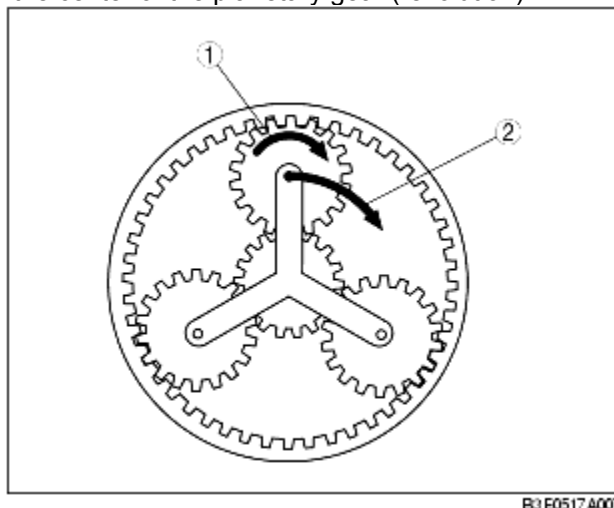
- The planetary gear works as a transaxle when the sun gear and the internal gear are engaged.
- The sun gear, installed inside of the pinion gears, and the internal gear, installed outside of the pinion gears, are engaged with their respective gears.

The sun gear and the internal gear rotate on the center of the planetary gear.



1	Sun gear
2	Internal gear
3	Planetary carrier
4	Pinion gear

- The pinion gears turn in the following two ways:
  - On their own centers (rotation)
  - On the center of the planetary gear (revolution)



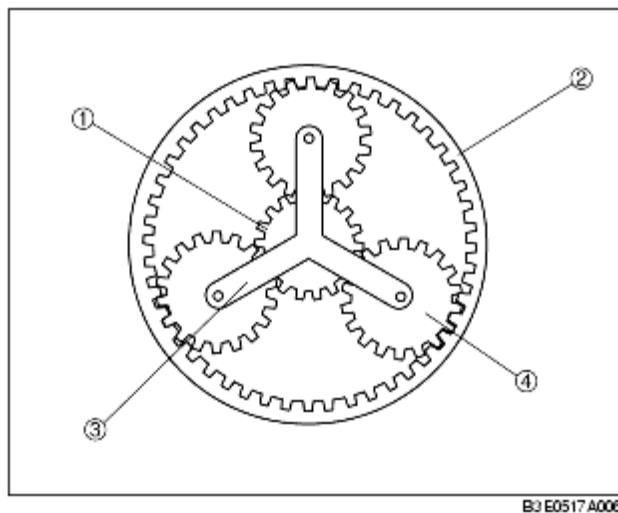
1	Rotation
2	Revolution

## Gear ratio of each range

• The relation between each element of the planetary gear set and the rotation speed is generally indicated in the formula below.

$$(Z_R + Z_S) N_C = Z_R N_R + Z_S N_S: \text{ formula (1)}$$

In this formula Z stands for the number of teeth, N stands for the rotation speed, and R, S, C stand for each gear element (refer to the table below).



1	Sun gear
2	Internal gear
3	Planetary carrier
4	Pinion gear

## Number of teeth and symbol of each gear

Planetary gear unit	Planetary gear element	Number of teeth	Unit identification symbol	
			Gear element	Unit
Front	Internal gear	89	R	F
	Planetary carrier (part of pinion gear)	20	C	F
	Sun gear	49	S	F
Rear	Internal gear	98	R	R
	Planetary carrier (part of pinion gear)	30	C	R
	Sun gear	37	S	R

## First gear

1	Front planetary gear
2	Sun gear $N_S$ (input)
3	Internal gear (fix)
4	Planetary carrier $N_C$ (output)
5	Pinion gear

### Gear rotation speed

Planetary gear unit	Front
Internal gear	0 (fix)
Planetary carrier	$N_C$ (output)
Sun gear	$N_S$ (input)

- Suppose gear ratio in first gear is  $i_1$ ,

$$i_1 = N_S / N_C$$

- From the result  $N_R = 0$  in formula (1), the relation between the gear ratio in first gear and the rotation speed of the planetary gear set is indicated in the formula below.

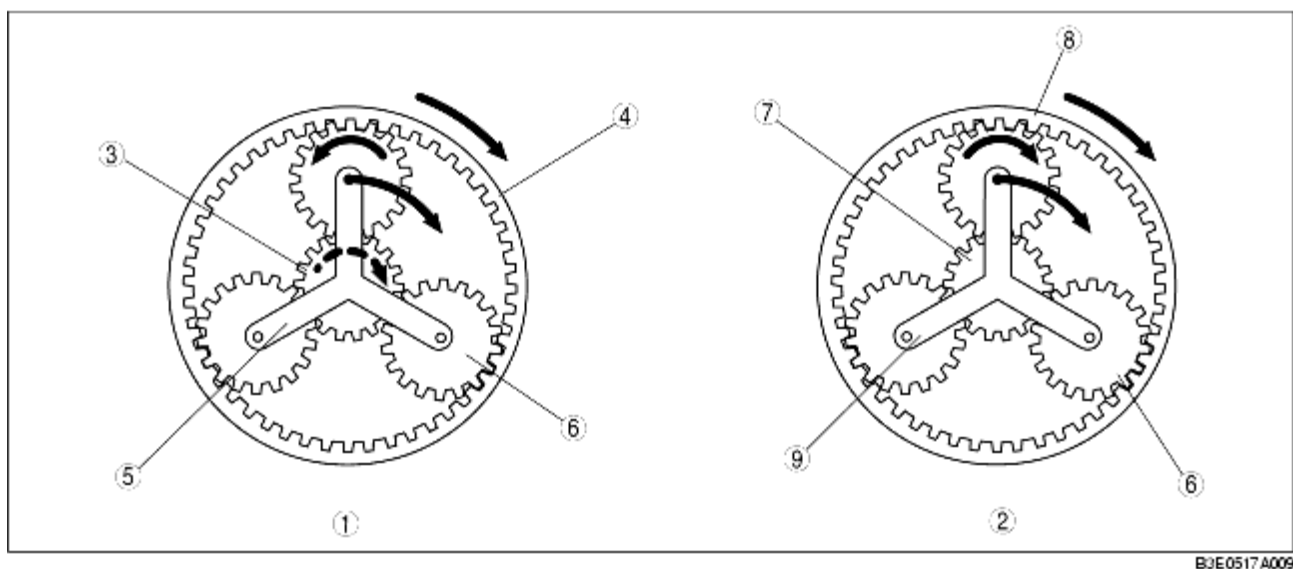
$$(Z_{RF} + Z_{SF}) N_C = Z_{SF} N_S$$

Therefore,

$$i_1 = N_S / N_C = (Z_{RF} + Z_{SF}) / Z_{SF} = (89 + 49) / 49 = 2.8163$$

As a result, the gear ratio in first gear is 2.816.

### Second gear



1	Front planetary gear
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2	Rear planetary gear
3	Sun gear $N_S$ (input)
4	Internal gear $N_R$
5	Planetary carrier $N_C$ (output)
6	Pinion gear
7	Sun gear $N_S$ (fix)
8	Internal gear $N_R$ (output)
9	Planetary carrier $N_C$

### Gear rotation speed

Planetary gear	Front	Rear
Internal gear	$N_R$	$N_R$ (output)
Planetary carrier	$N_C$ (output)	$N_C$
Sun gear	$N_S$ (input)	$N_S$ (fix)

### Note

- The front internal gear and the rear planetary carrier are integrated.
- The front planetary carrier and the rear internal gear rotate at the same speed.
- Suppose gear ratio in second gear is  $i_2$ ,

$$i_2 = N_S / N_R$$

- From formula (1), the relation between the gear ratio in second gear and the rotation speeds of the front and the rear planetary gear sets is indicated in formulas (2) and (3).

$$(Z_{RF} + Z_{SF}) N_R = Z_{RF} N_C + Z_{SF} N_S: (2) \text{ (Front planetary gear set)}$$

$$(Z_{RR} + Z_{SR}) N_C = Z_{RR} N_R + Z_{SR} N_S: (3) \text{ (Rear planetary gear set)}$$

- From the result  $N_S = 0$  in formula (3).

$$N_C = (Z_{RR} / (Z_{RR} + Z_{SR})) N_R: (4)$$

- Here we substitute formula (4) in formula (2).

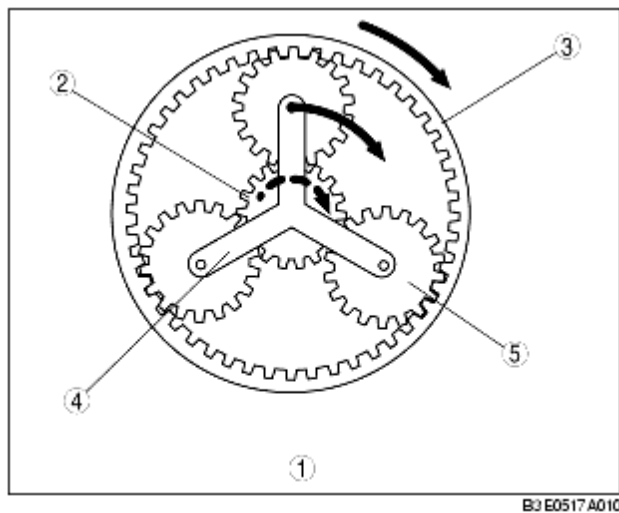
$$Z_{SR} N_S = (((Z_{RR} + Z_{SR}) (Z_{RF} + Z_{SF}) - Z_{RF} Z_{RR}) / (Z_{RR} + Z_{SR})) N_R$$

Therefore,

$$i_2 = N_S / N_R = (((Z_{RR} + Z_{SR}) (Z_{RF} + Z_{SF}) - Z_{RF} Z_{RR}) / (Z_{SF} (Z_{RR} + Z_{SR}))) N_R = ((98+37)(84+49) - 8998) / (49 (98+37)) = 1.4978$$

As a result, the gear ratio in second gear is 1.497.

### Third gear



1	Front planetary gear
2	Sun gear $N_S$ (input)
3	Internal gear $N_R$ (input)
4	Planetary carrier $N_C$ (output)
5	Pinion gear

### Gear rotation speed

Planetary gear	Front
Internal gear	$N_R$ (input)
Planetary carrier	$N_C$ (output)
Sun gear	$N_S$ (input)

- Here we have the result on  $N_R = N_S$ .
- Suppose gear ratio in third gear is  $i_3$ ,

$$i_3 = N_R / N_C$$

- From the result of  $N_R = N_S$  in formula (1), the relation between the gear ratio in third gear and the rotation speed of the front planetary gear set is indicated in the formula below.

$$(N_{RF} + Z_{SF}) N_C = (Z_{RF} + Z_{SF}) N_R$$

Therefore,

$$i_3 = N_R / N_C = (Z_{RF} + Z_{SF}) / (Z_{RF} + Z_{SF}) = (89 + 49) / (89 + 49) = 1.000$$

As a result, the gear ratio in third gear is 1.000.

### Fourth gear

1	Rear planetary gear
2	Sun gear (fix)
3	Internal gear $N_R$ (output)
4	Planetary carrier $N_C$ (input)
5	Pinion gear

### Gear rotation speed

Planetary gear	Rear
Internal gear	$N_R$ (output)
Planetary carrier	$N_C$ (input)
Sun gear	0 (fix)

- Suppose gear ratio in fourth gear is  $i_4$ ,

$$i_4 = N_C / N_R$$

- From the result of  $N_S = 0$  in formula (2), the relation between the gear ratio in fourth gear and the rotation speed of the rear planetary gear set is indicated in the formula below.

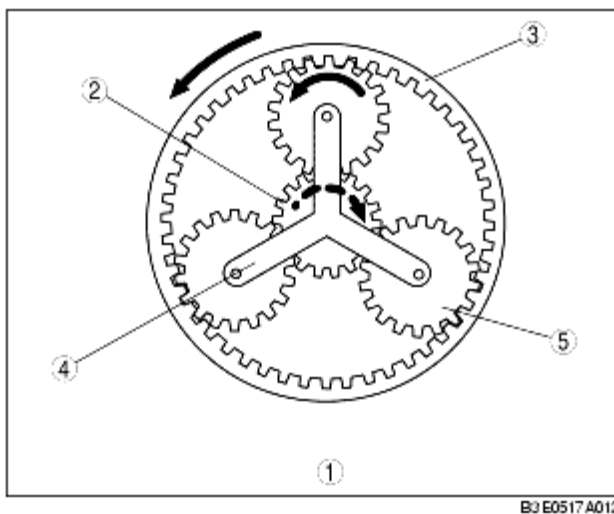
$$(Z_{RR} + Z_{SR}) N_C = Z_{RR} N_R$$

Therefore,

$$i_4 = N_C / N_R = Z_{RR} / (Z_{RR} + Z_{SR}) = 98 / (98 + 37) = 0.7259$$

As a result, the gear ratio in fourth gear is 0.725.

### Reverse



1	Rear planetary gear
2	Sun gear $N_S$ (input)

3	Internal gear $N_R$ (output)
4	Planetary carrier (fix)
5	Pinion gear

### Gear rotation speed

Planetary gear	Rear
Internal gear	$N_R$ (output)
Planetary carrier	0 (fix)
Sun gear	$N_S$ (input)

- Suppose gear ratio in reverse gear is  $i_{REV}$ ,

$$i_{REV} = N_S / N_R$$

- From the result of  $N_C = 0$  in formula (2), the relation between the gear ratio during reverse movement and the rotation speed of the planetary gear set is indicated in the formula below.

$$(Z_{RR} + Z_{SR}) 0 = Z_{RR} N_R + Z_{SR} N_S$$

Therefore,

$$i_{REV} = N_S / N_R = Z_{RR} / Z_{SR} = -98/37 = -2.6486$$

As a result, the gear ratio in reverse is 2.648.