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Development of Reduction Gears With Self-Locking Function

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Background

■ In response to global warming…

Keyword

⇨ Low fuel consumption　Electrification

■ Motor research is being conducted vigorously

- Motors are used not only in cars,
  but also in Construction machinery, machine tools, and aircraft
- Motors are used not only as a drive source for electric vehicles
  but also as actuators

Background

■ In situations where a motor is used as an actuator…

It has to maintain its position while being subjected to external forces

⇨ If the motor has a mechanism that mechanically locks,
the motor does not need to generate torque to maintain its position

→ Power consumption can be reduced

■ And, One of the methods to improve motor efficiency is…

To increase the rotational speed

⇨ Reduction gears with higher reduction ratios are required

Objective

mechanism that mechanically locks

In this study,

Gear system with a high reduction ratio and self-locking function were developed

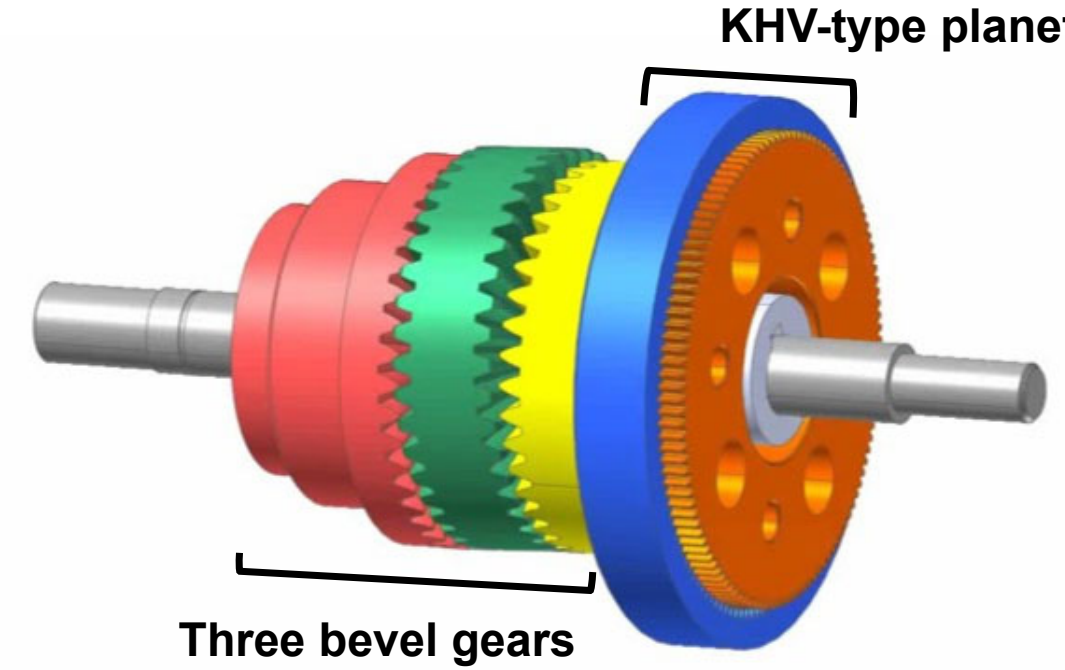
Reduction gears with higher reduction ratios

Developed gear system

Overview of the system

Developed reduction gears with self-locking function

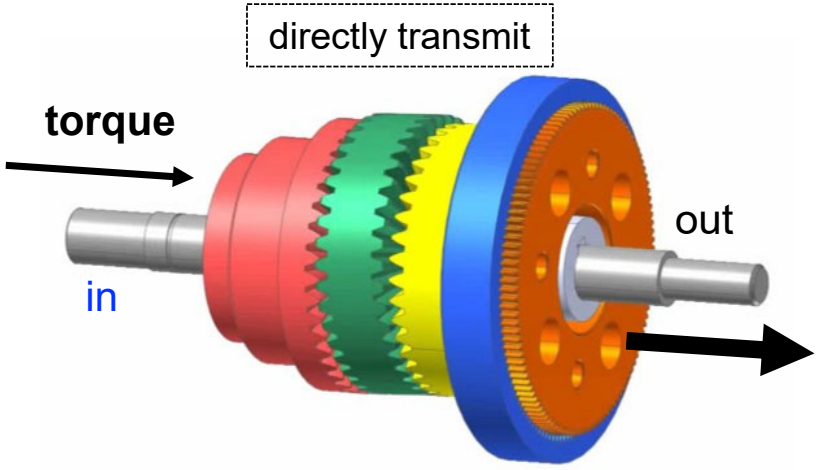
It primarily consists of KHV-type planetary gears and three bevel gears



Overview of the system

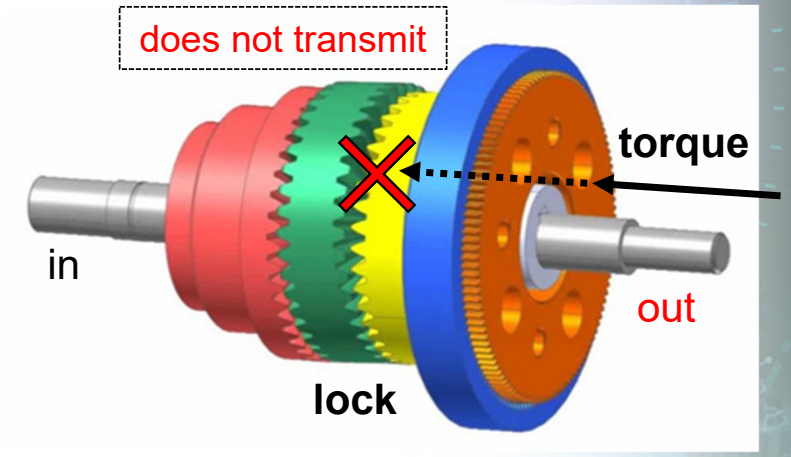
What is the self-lock function?

When torque is applied to the input shaft



Amplified torque
(due to the gearbox reduction)

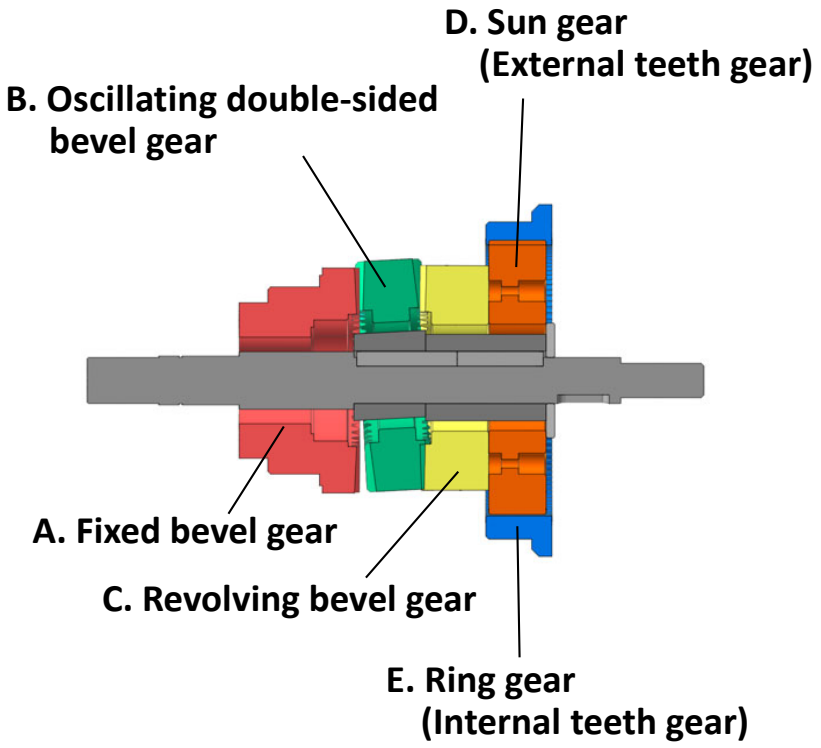
When torque is applied to the output shaft

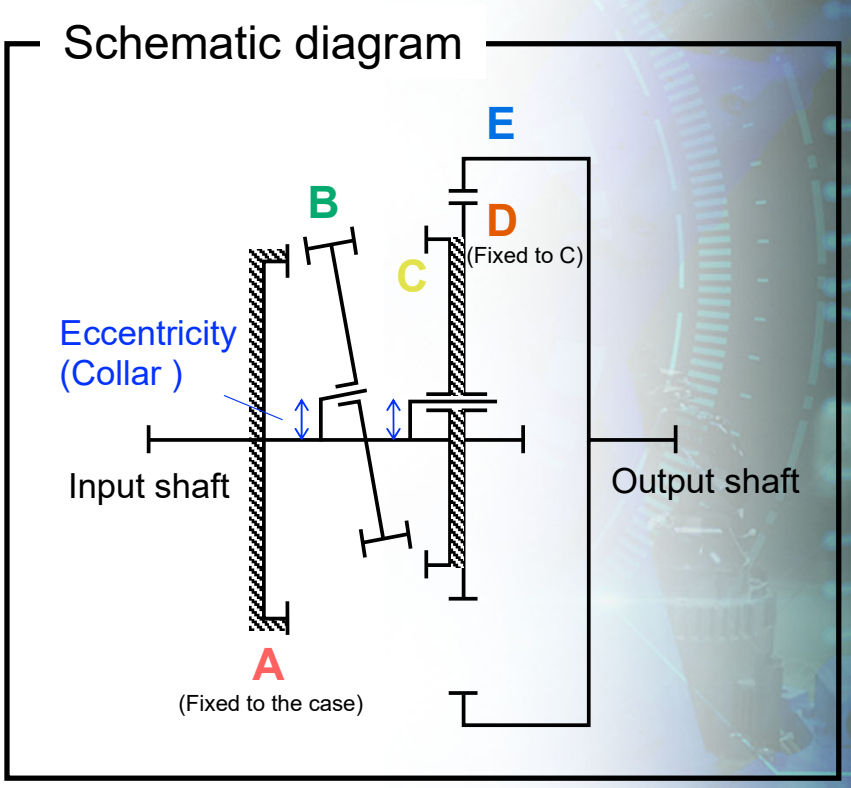


When torque is applied to the output shaft,
it does not transmit to the input shaft. (the gear system locks)

Structure

Overview

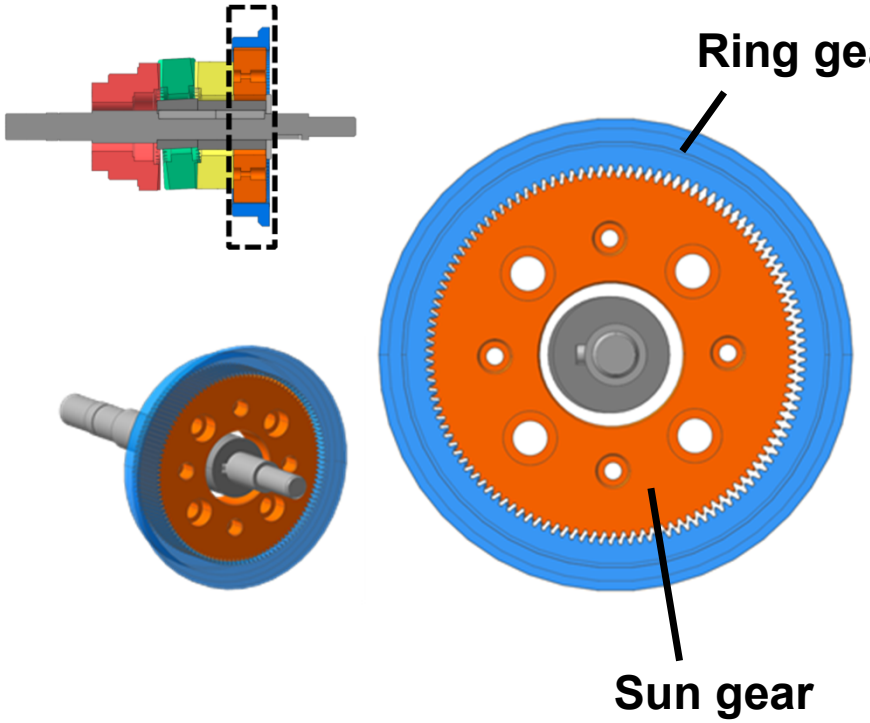




Structure

Reduction gears

KHV-type planetary gears is used for the developed gear system



Schematic diagram

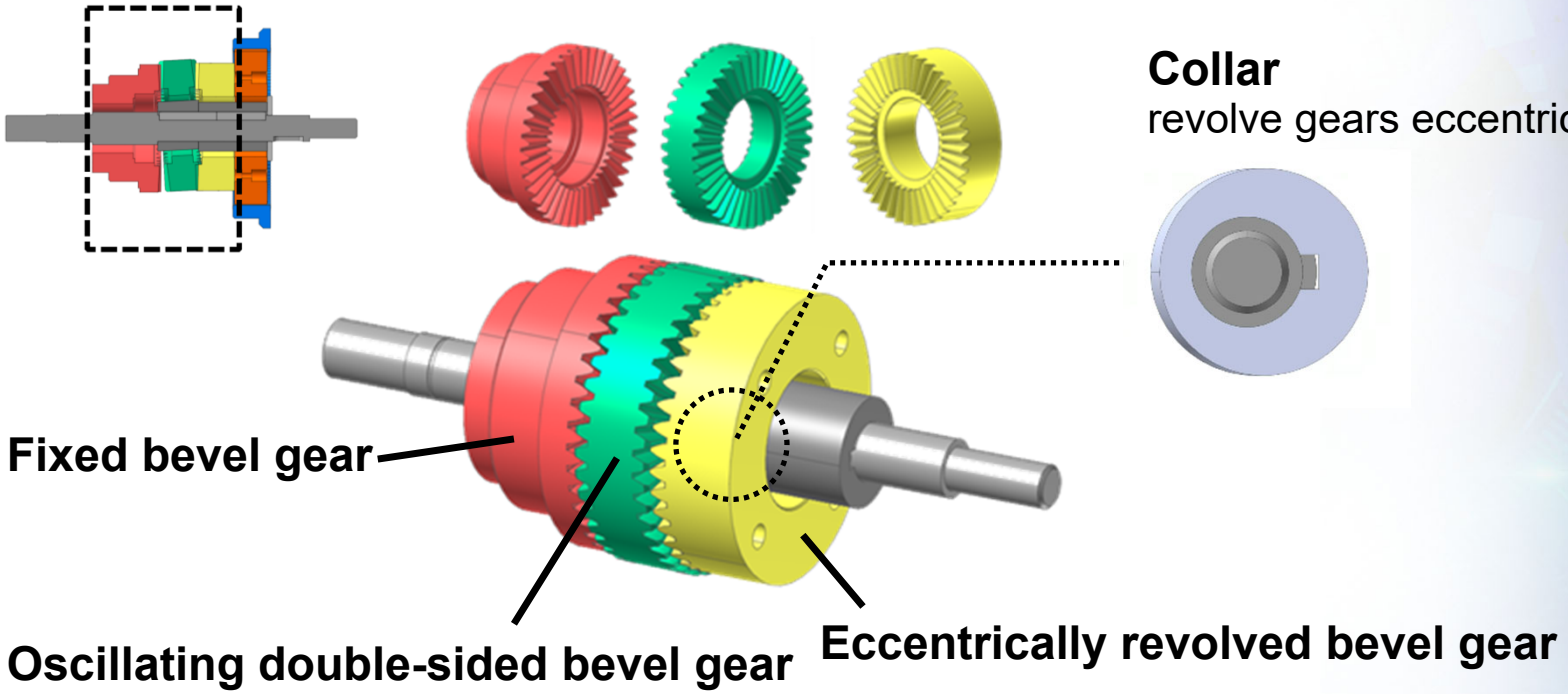
$$i = \frac{z_2}{z_2 - z_1}$$

z_1: number of teeth of the sun gear
z_2: number of teeth of the ring gear

Structure

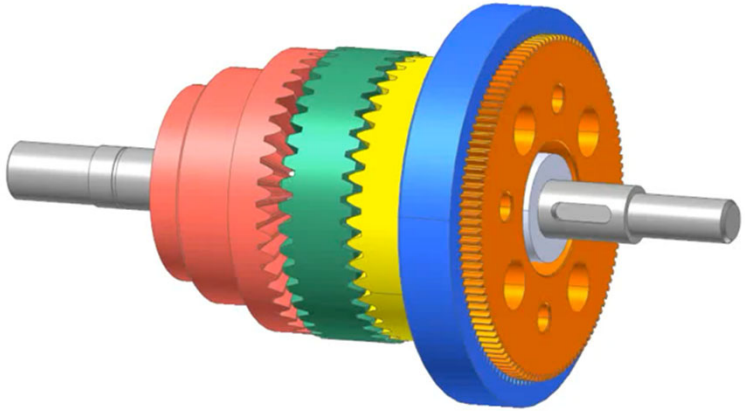
Eccentric mechanism

The eccentric mechanism of gear system consists 3 bevel gears



Motion

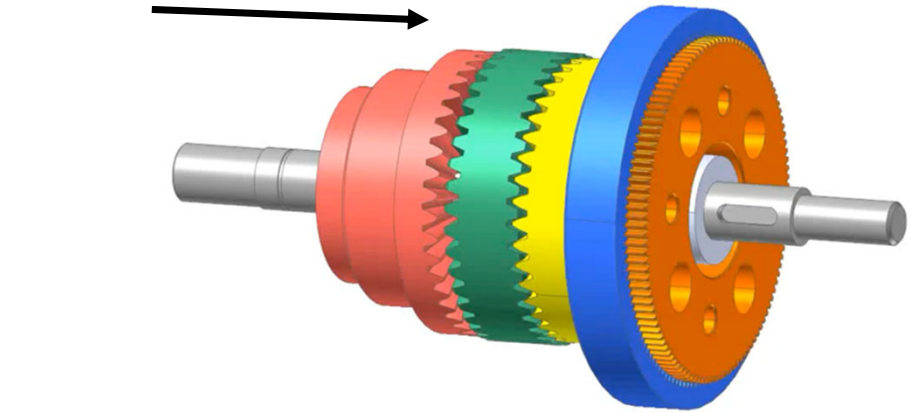
Power transmission path



Motion

■ Power transmission path

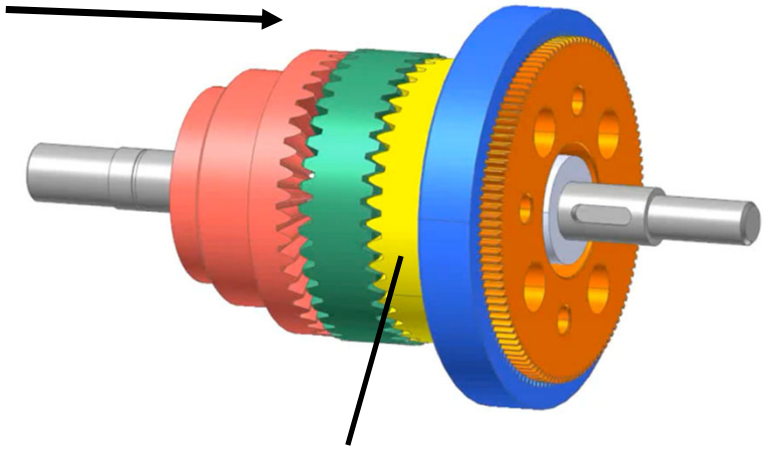
①Power input



Motion

■ Power transmission path

①Power input



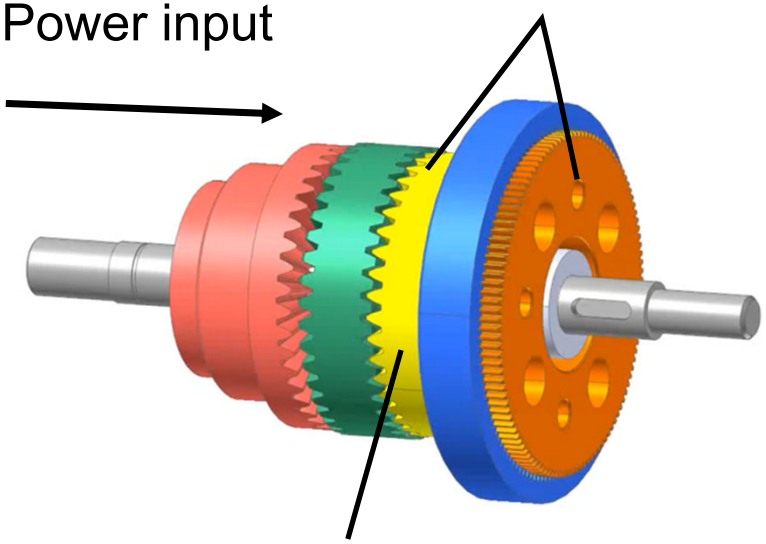
②Eccentrically revolved bevel gear
eccentrically rotates through the collar

Motion

■ Power transmission path

③Sun gear is fixed to
eccentrically revolved bevel gear

①Power input



②Eccentrically revolved bevel gear
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Motion

■ Power transmission path

③Sun gear is fixed to
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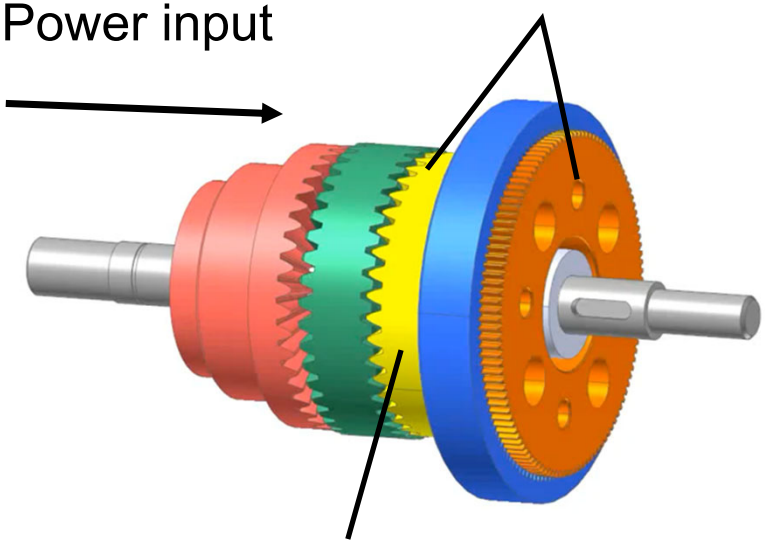
①Power input



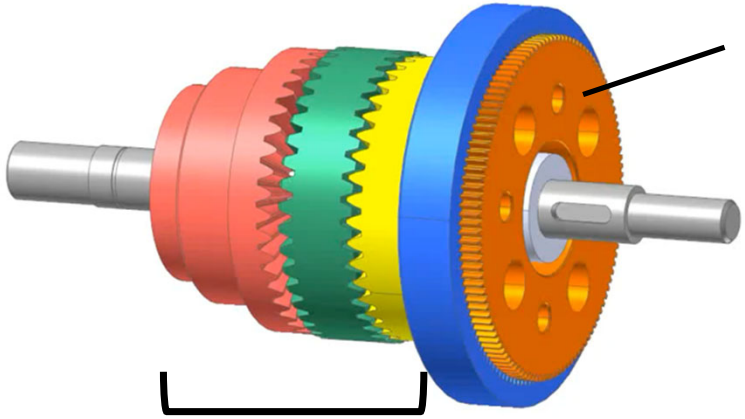
④Sun gear rotates ring gear
while eccentric

→ **Output speed is decelerated**

②Eccentrically revolved bevel gear
eccentrically rotates through the collar

Motion

■ Effect of eccentric mechanism



Eccentric mechanism

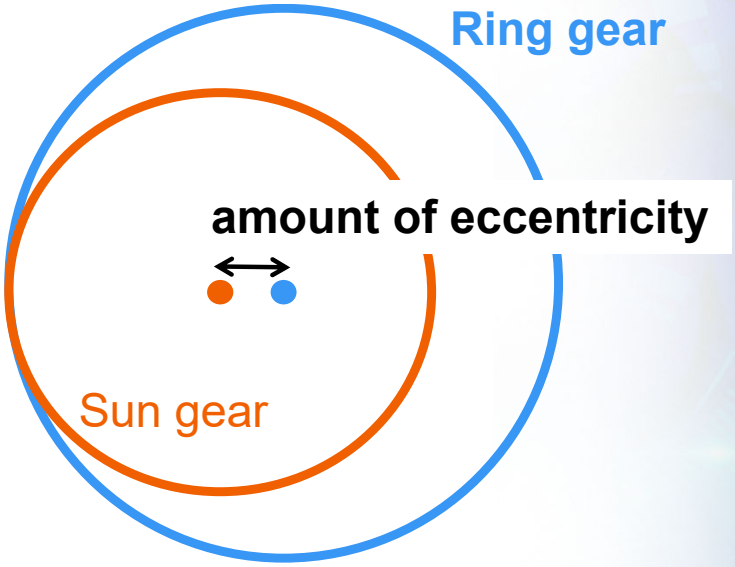
Sun gear holds its posture
(Eccentric mechanism holds it)

⇨ **Locks when torque is applied from output**

Locking performance

Torque Capacity

Torque capacity is determined by amount of eccentricity



Amount of eccentricity is small
→ Moment to rotate from the output shaft become small

3D multibody dynamics model

3D multibody dynamics

The performance of the proposed locking gear was analyzed and verified using three-dimensional (3D) multibody dynamics.

Multibody dynamics

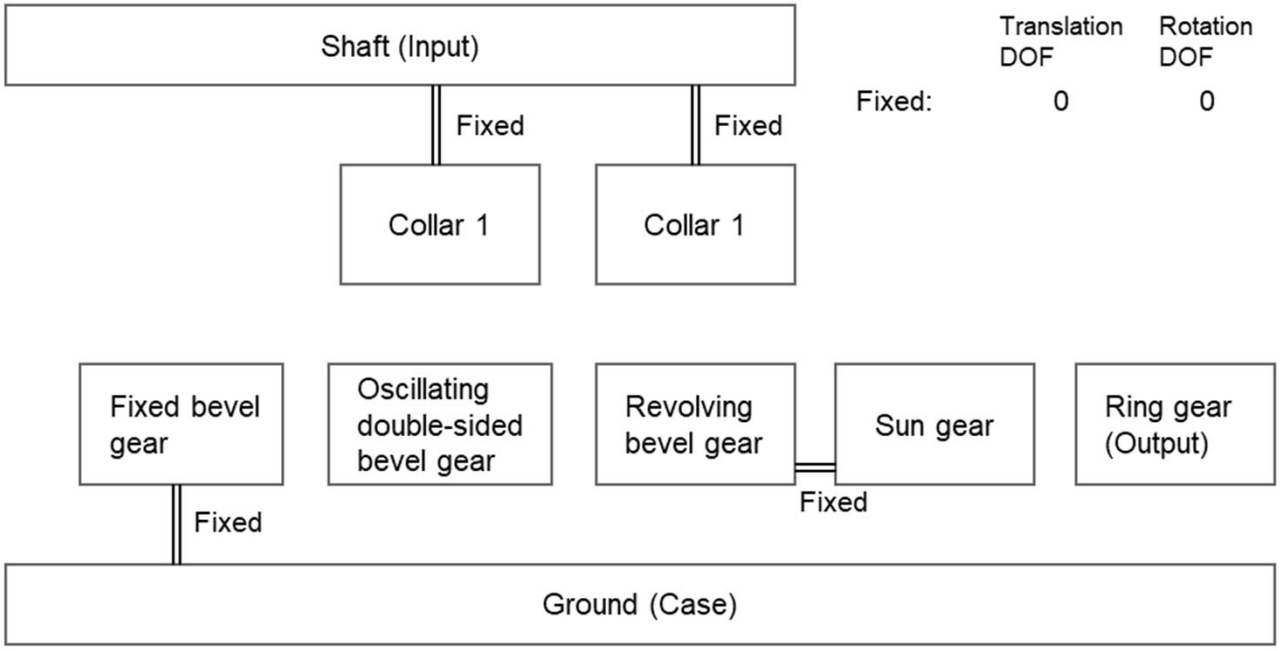
- ✓ Multibody dynamics can analyse of the motion of groups of interconnected bodies that have forces acting on them
- ✓ RecurDyn, a general-purpose multibody dynamics software, was used to develop the model.

RECURDYN

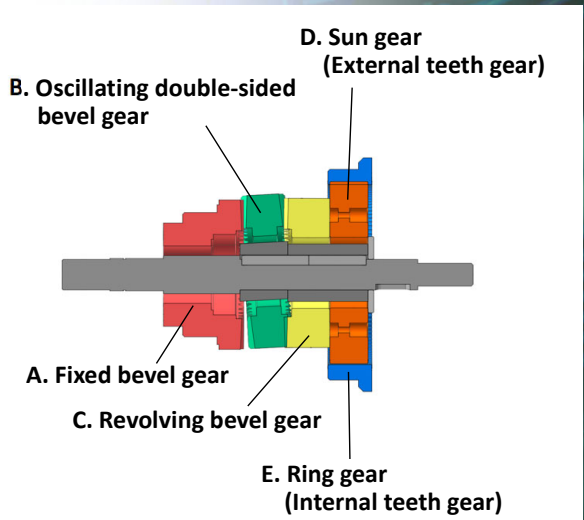
Analysis model

RECURDYN

Fixed constraints



	Translation DOF	Rotation DOF
Fixed:	0	0

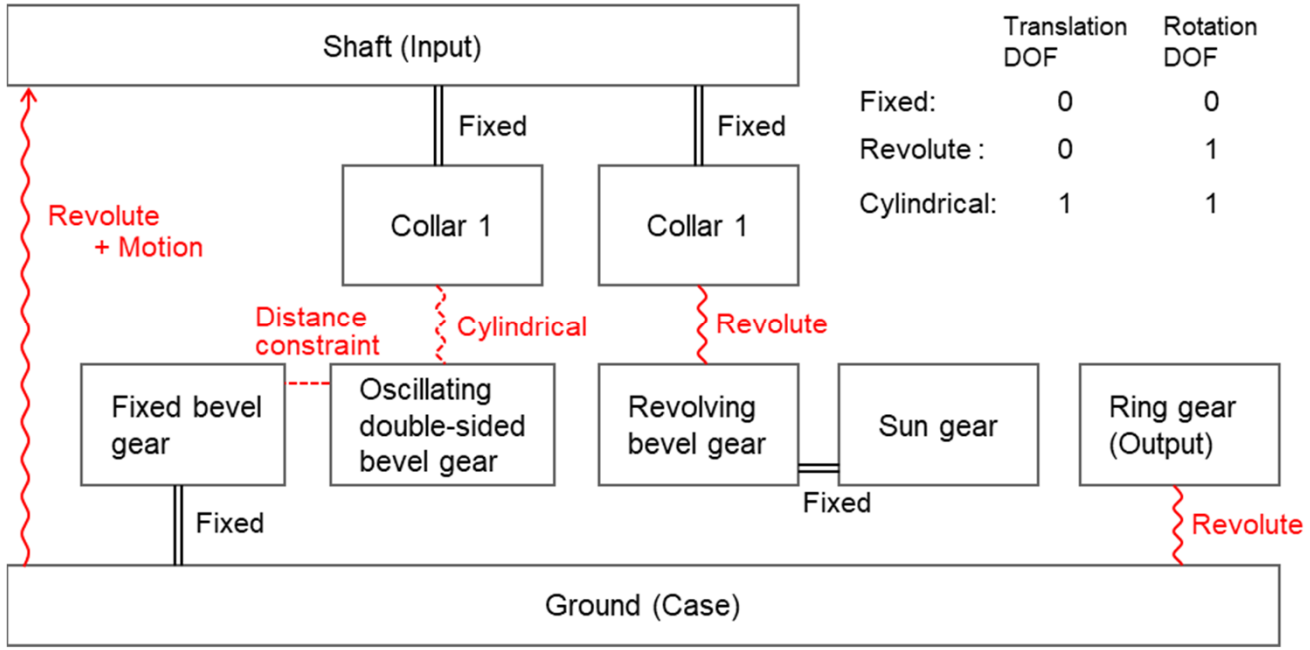


Analysis model

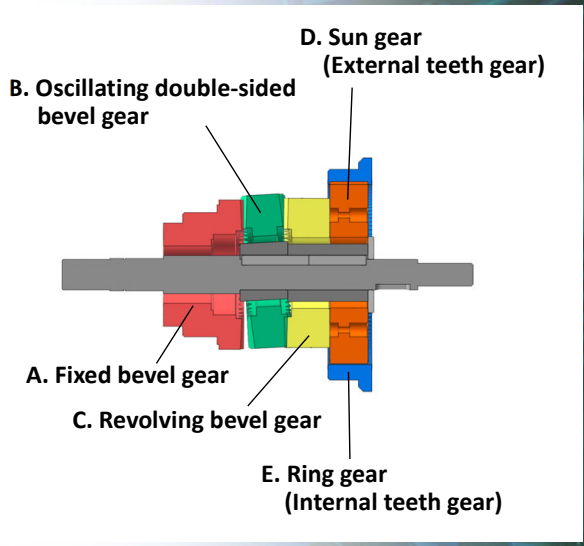
RECURDYN

■ Revolute, Cylindrical, Distance constraints

To reduce analysis load, bearings were modeled using these constraints



	Translation DOF	Rotation DOF
Fixed:	0	0
Revolute :	0	1
Cylindrical:	1	1

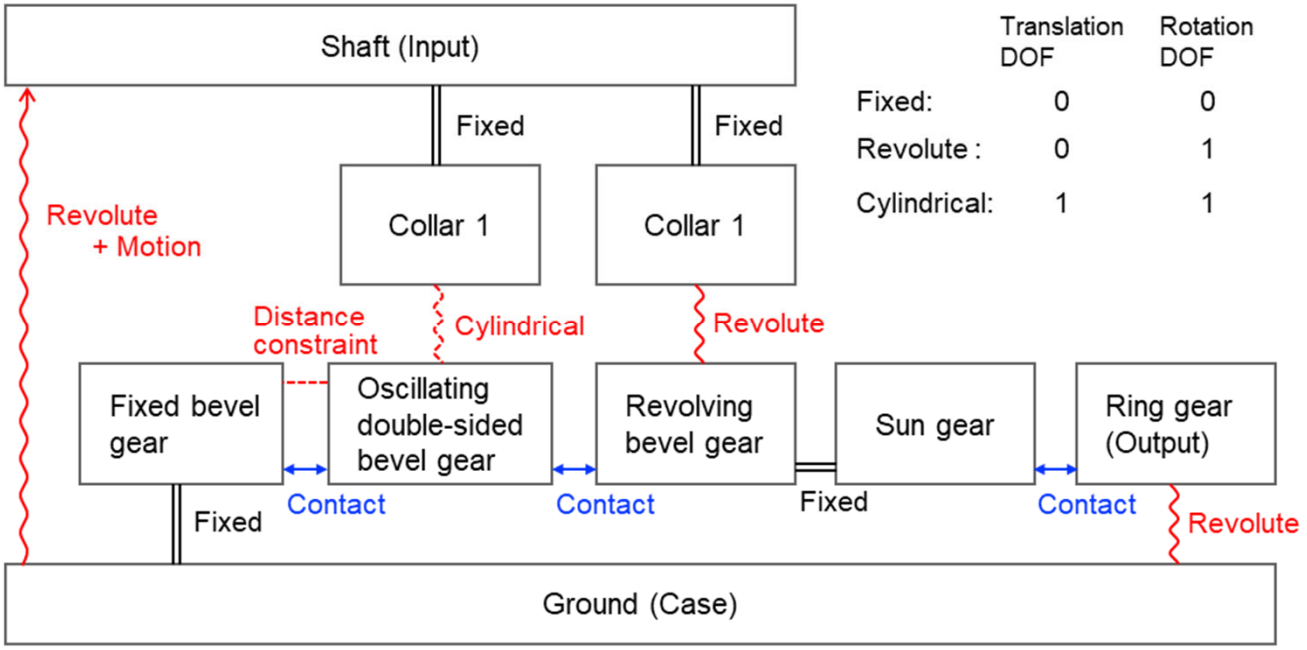


Analysis model

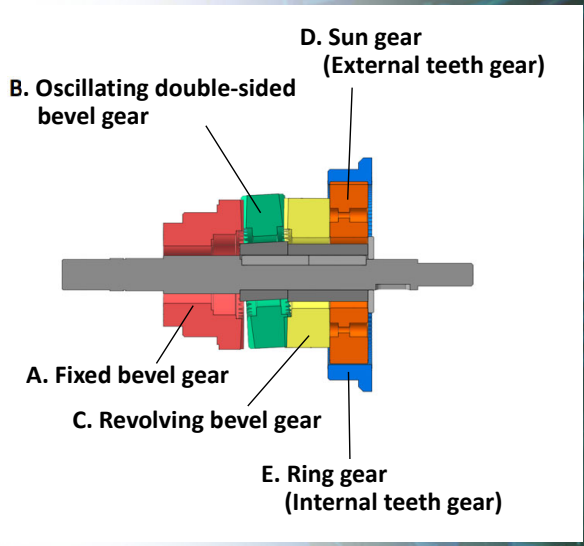
RECURDYN

Contact

The contact was calculated using the penalty method



	Translation DOF	Rotation DOF
Fixed:	0	0
Revolute :	0	1
Cylindrical:	1	1



Overview of the analysis

RECURDYN

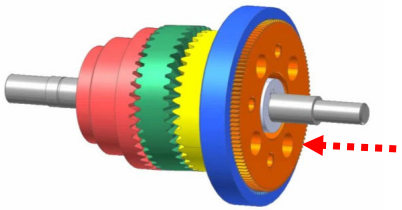
■ To clarify locking performance

The following calculation conditions were used in the analysis

0 ~ 2 sec

input : no rotation

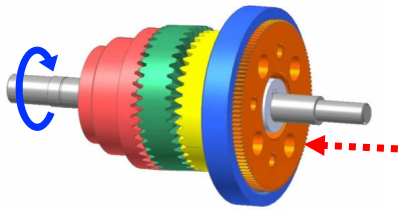
output : torque loaded



2 ~ 4 sec

input : rotation speed up to 300 rad/s

output : torque loaded

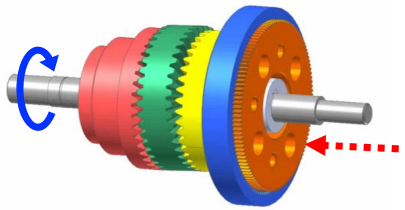


Unlock

4 ~ 6 sec

input : rotation speed is 300 rad/s

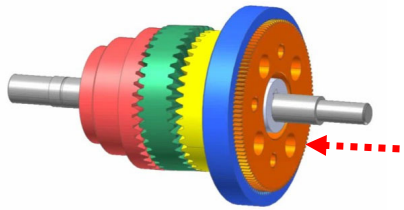
output : torque loaded



6 ~ 8 sec

input : no rotation

output : torque loaded

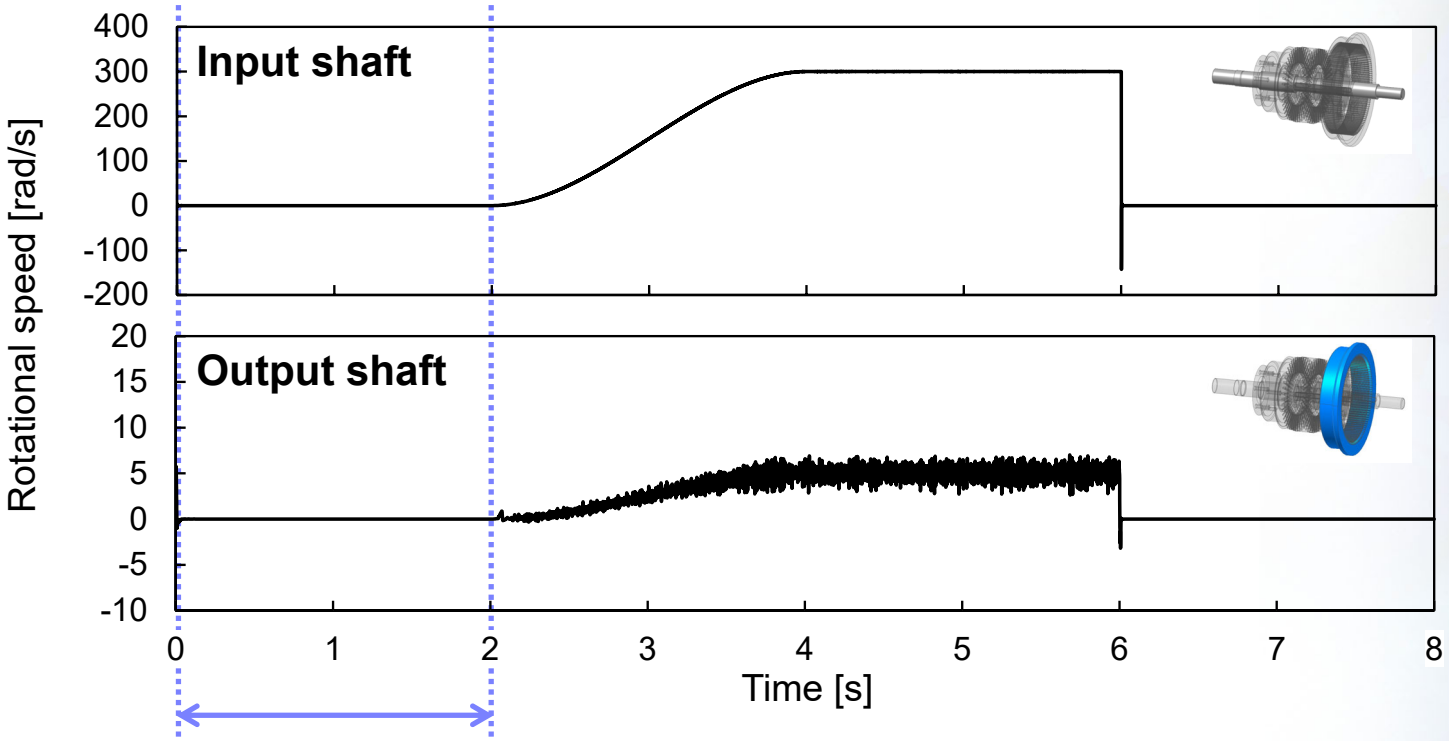


Lock

Analysis results

RECURDYN

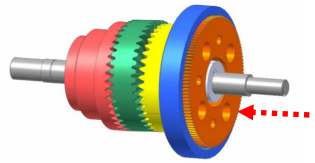
■ Rotation speeds of the input shaft & output shaft



0 ~ 2 sec

input : no rotation

output : torque loaded

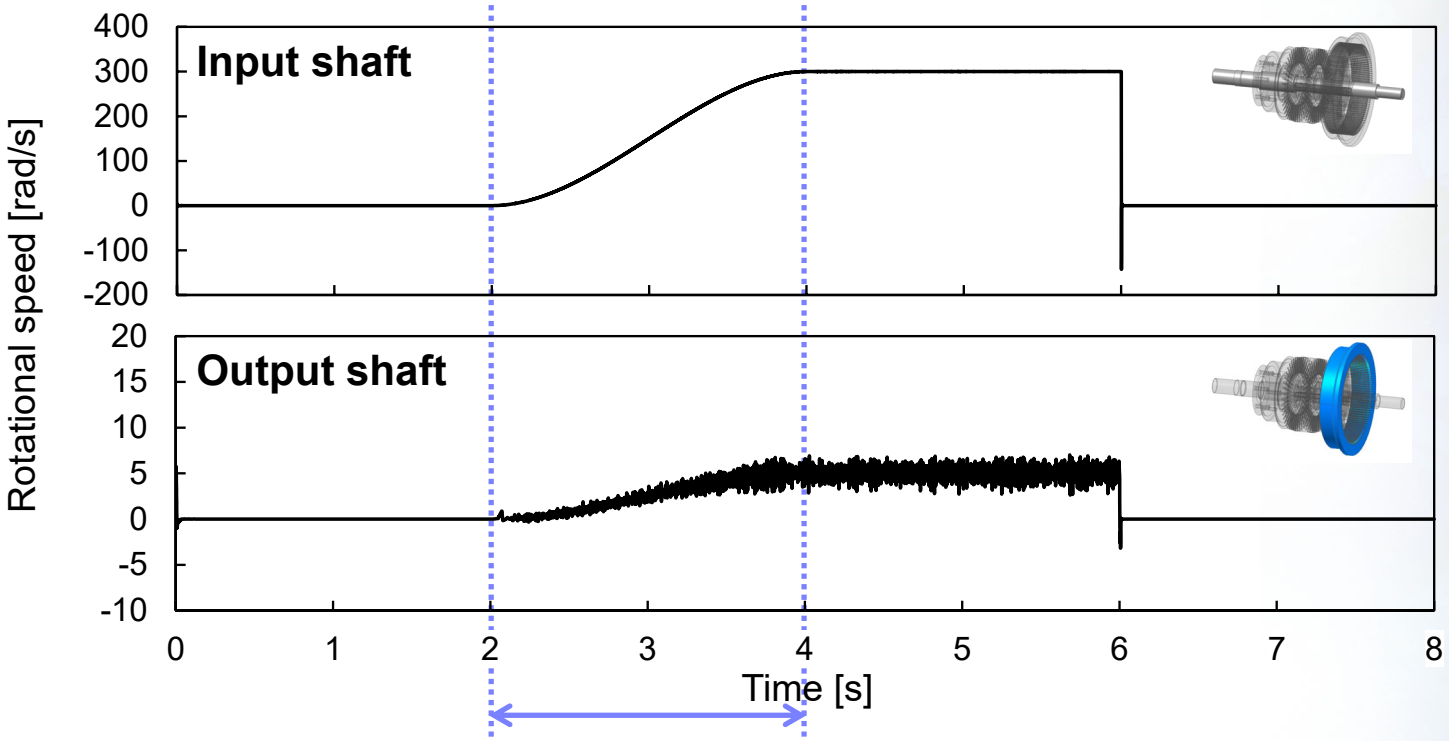


The rotation speed is 0 for both input and output because rotation is not transmitted from the output shaft (it was locked)

Analysis result

RECURDYN

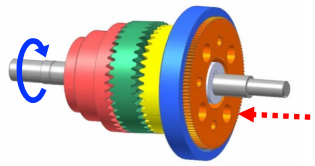
■ Rotation speeds of the input shaft & output shaft



2 ~ 4 sec

input : rotation speed up to 300 rad/s

output : torque loaded

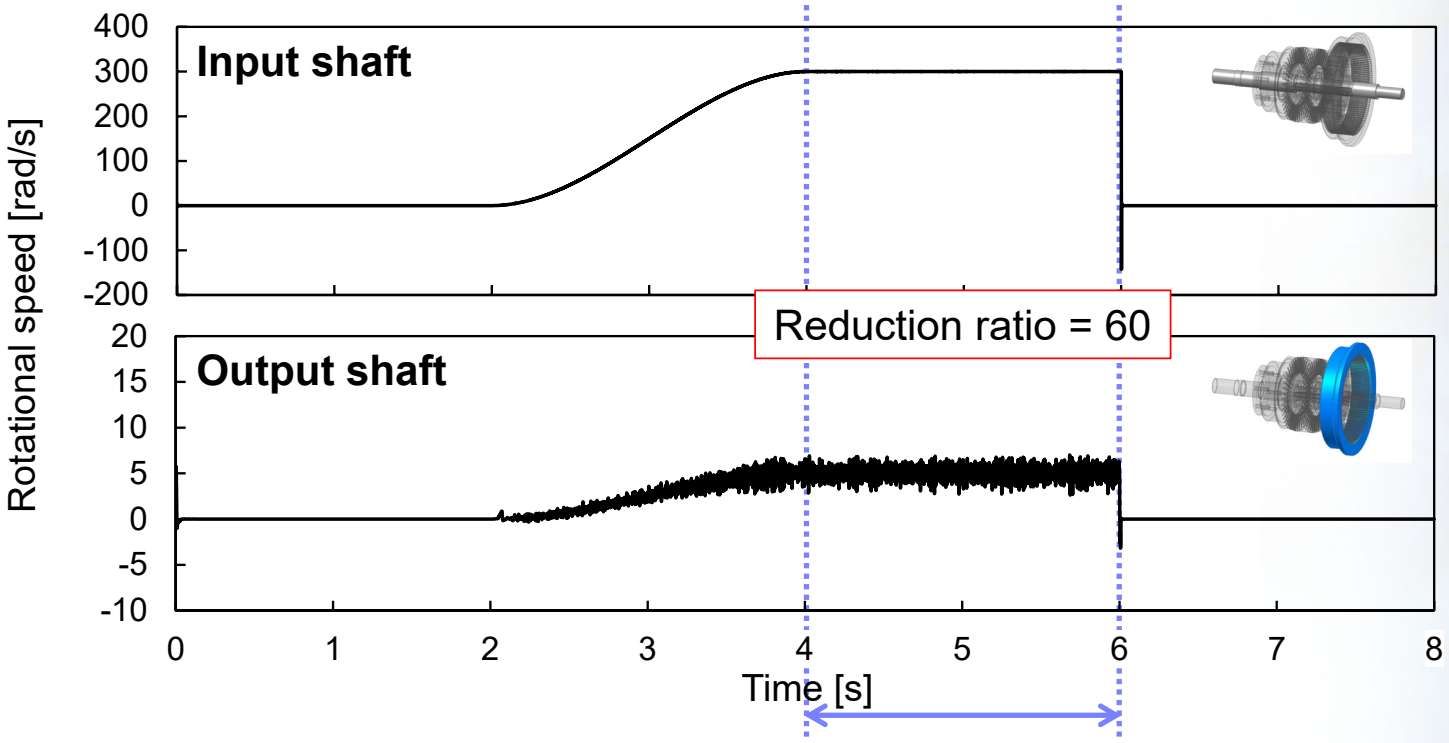


- The rotation decelerated by the reduction section was transmitted to the output
- Small vibrations were generated in output due to constraints and contact

Analysis result

RECURDYN

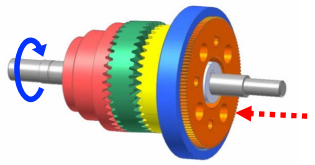
Rotation speeds of the input shaft & output shaft



4 ~ 6 sec

input : rotation speed is 300 rad/s

output : torque loaded



- The rotation decelerated by the reduction section was transmitted to the output
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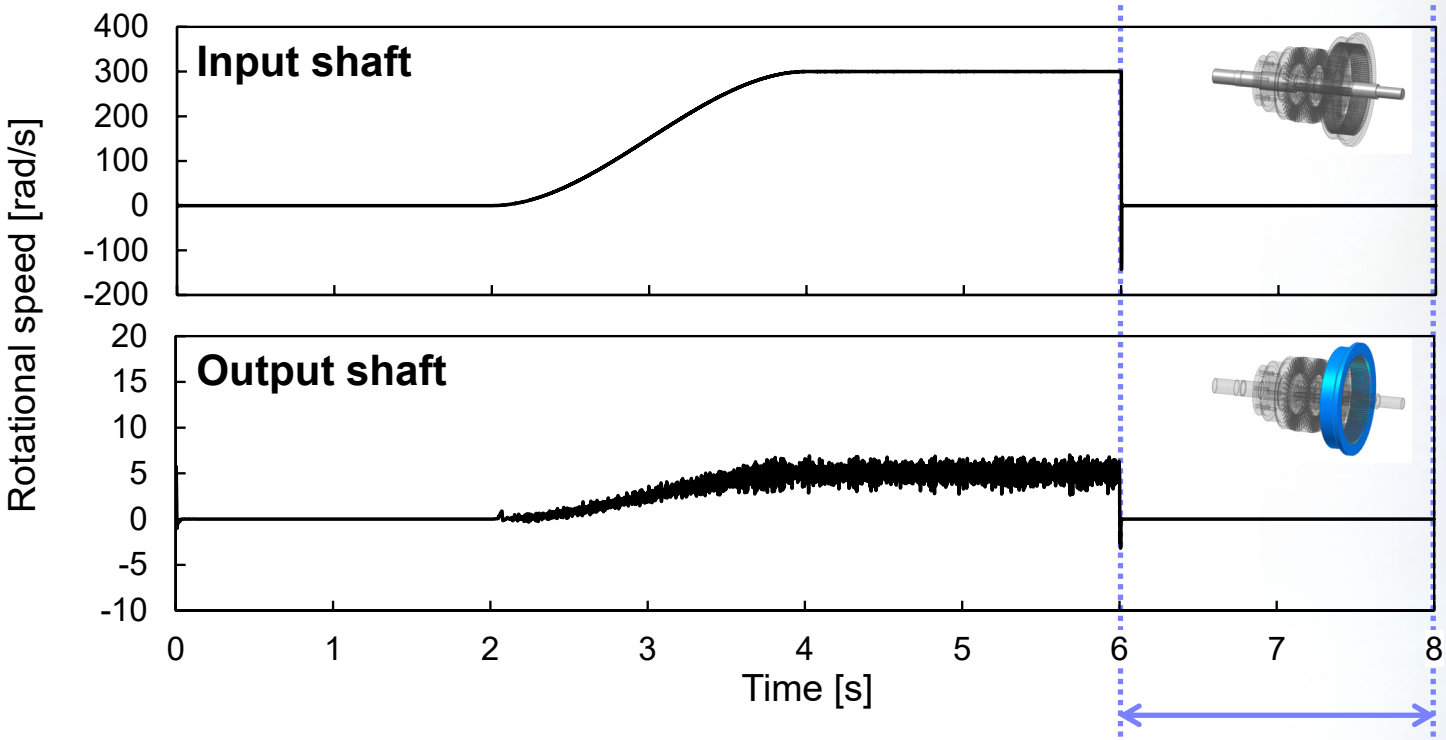
Analysis result

RECURDYN

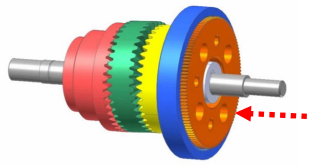
■ Rotation speeds of the input shaft & output shaft



6 ~ 8 sec

input : no rotation

output : torque loaded



The torque was applied only from the output shaft
→ it was locked again

Locking performance of the gear system has been confirmed

Shaft torque fluctuations

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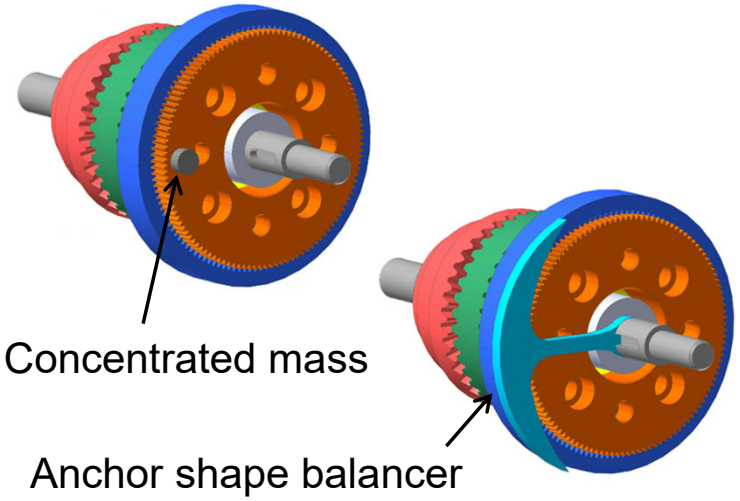
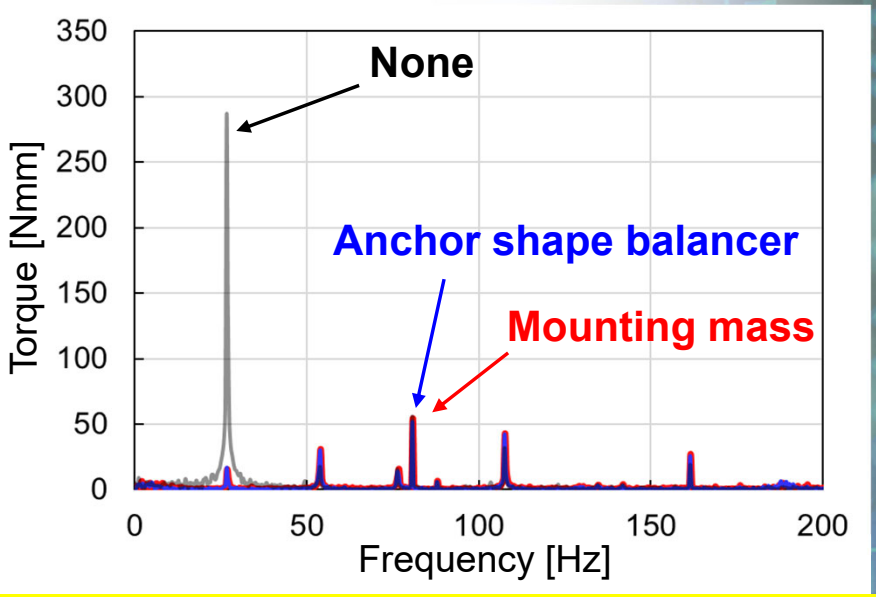
■ **The gear system has an eccentric mechanism**

→ **Shaft torque fluctuations occur in rotational order**

When a balancer is added to the sun gear…





By mounting mass, vibrations in primary rotation order can be reduced

Conclusion

Conclusion

- ✓ This study developed a gear system that has both a high reduction ratio and a self-locking function.
- ✓ When torque was applied to the input, power was transmitted to the output shaft through the reduction gear.
- ✓ When torque was applied from the output, it does not transmit to the input shaft. (the gear system locks)
- ✓ This study analyzed the operation and performance of the developed gear system using a multibody dynamics model.

*** This work was supported by JKA and its promotion funds from KEIRIN RACE**

Gear specifications of reduction section

Reduction ratio	60	
	Sun gear	Ring gear
Tooth form	Spur	Spur
Number of teeth	118	120
Module	0.8	0.8
Pressure angle	20°	20°

Gear specifications of locking section

	Fixed bevel gear	Oscillating double-sided bevel gear	Revolving bevel gear
Shaft angle	177°	180	177°
Number of teeth	40	40	40
Module	2	2	2
Pressure angle	20°	20°	20°

Parameters involved in the contact calculations

Stiffness coefficient [N/mm]	1.0×10^5
Damping coefficient [-]	10
Dynamic friction coefficient [-]	0.1