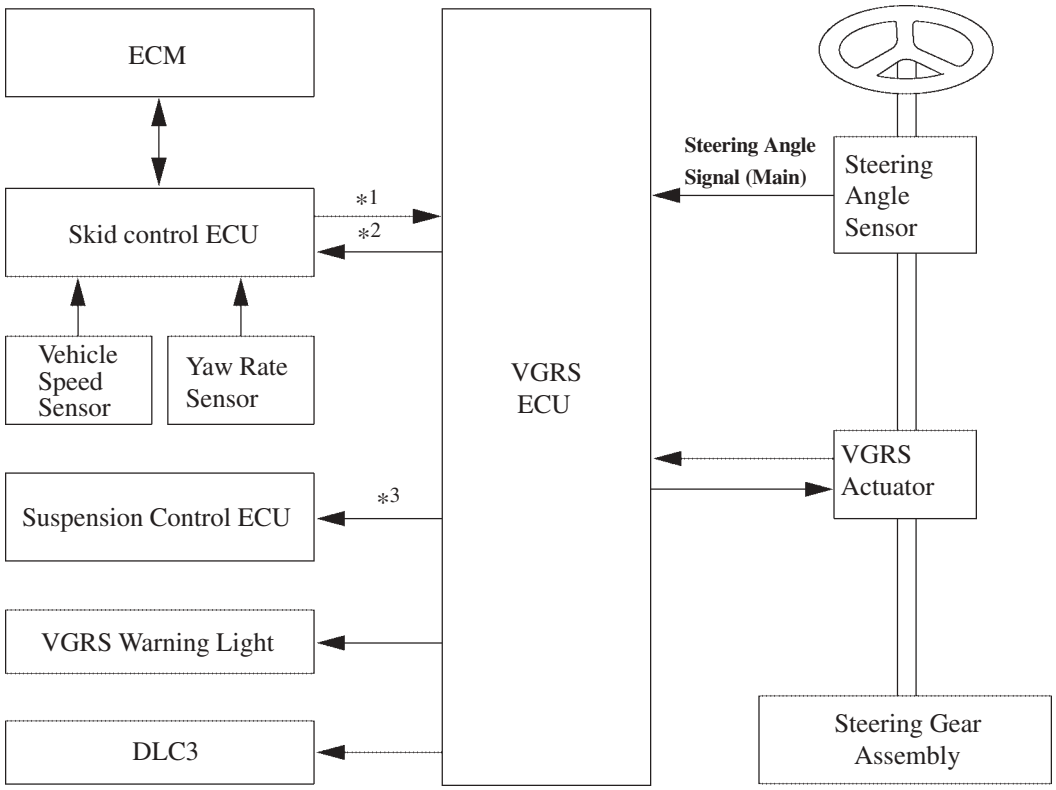
3. VGRS (Variable Gear Ratio Steering) System

General

- A VGRS (Variable Gear Ratio Steering) system, which variably controls the steering angle in accordance with the driving speed, has been adopted as optional equipment on the model for Europe.
- This system is controlled by the VGRS ECU, which operates the VGRS actuator that is mounted on the steering intermediate shaft. The operating angle of the actuator is thus added to the steering angle of the intermediate shaft in order to vary the turning angle of the front wheels in accordance with the vehicle speed.
- The VGRS ECU is equipped with a diagnosis function and a fail-safe function.

▶ System Diagram ◀



∗1: VGRS ECU Input Signal (Vehicle speed, Steering Angle (Sub), Steering Wheel Neutral Position)
∗2: VGRS ECU Output Signal (VGRS Actuator Operating Angle)
∗3: VGRS ECU Output Signal (Steering Wheel Steering Angle + VGRS Actuator Operating Angle)

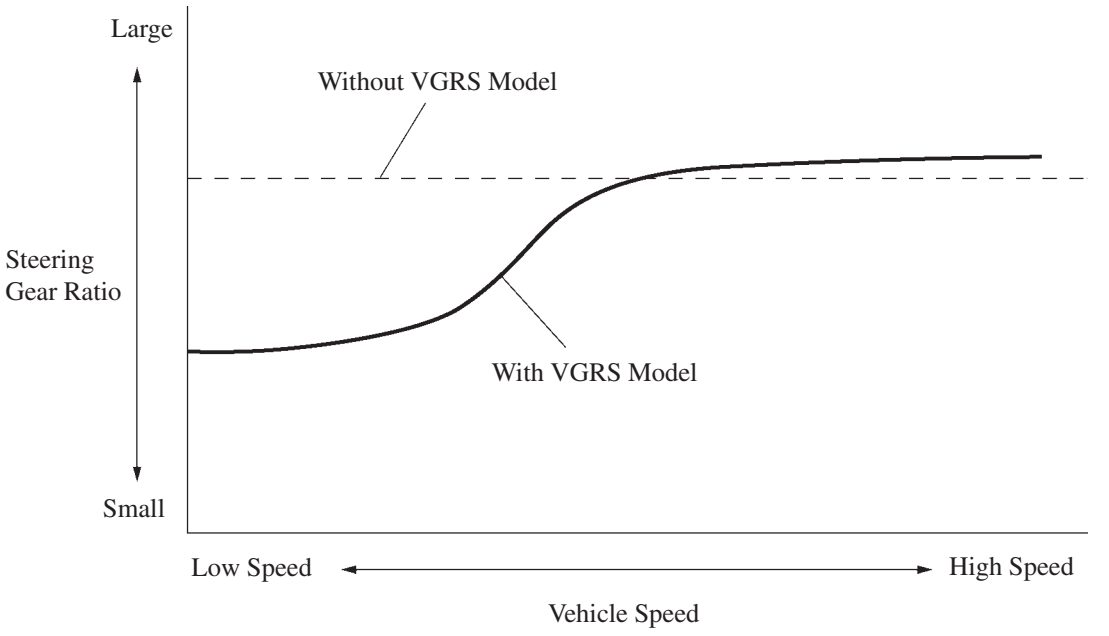
Outline of VGRS System

1) General

In the conventional steering system, the gear ratio is set primarily for the high-speed driving mode to prevent the vehicle from making over-sensitive movements in response to the driver's steering angle. For this reason, it requires a large the driver's steering angle while driving at low speeds.
In the VGRS system, the steering gear ratio can be changed at will. Thus, the VGRS ECU operates the VGRS actuator in order to constantly realize an optimal gear ratio in accordance with the driving conditions of the vehicle. Thus, it attains a high level of maneuverability and stability between the low- and the high-speed driving ranges.

- In the extremely low-speed range, which is used when the driver is attempting to park the vehicle, this system changes the steering gear into the smallest gear ratio in order to reduce the driver's steering angle.
- In the low- to medium-speed range, which is used when driving on city streets or on a winding road, this system changes the steering gear ratio to an optimal level in accordance with the vehicle speed. As a result, the vehicle responds with more agility and handles more easily.
- In the high-speed range, the steering gear ratio is set to the maximum level to prevent the vehicle from making over-sensitive movements in response to the driver's steering angle. Thus, this system ensures a stable vehicle response.
- If a vehicle that is driven straight ahead over a road surface with different friction coefficients brakes suddenly and causes the VSC to activate, the vehicle posture becomes disrupted, thus requiring the driver to operate the steering wheel. When this occurs, the steering gear ratio is rendered even smaller than that of the ordinary VGRS system in order to reduce the driver's steering angle.

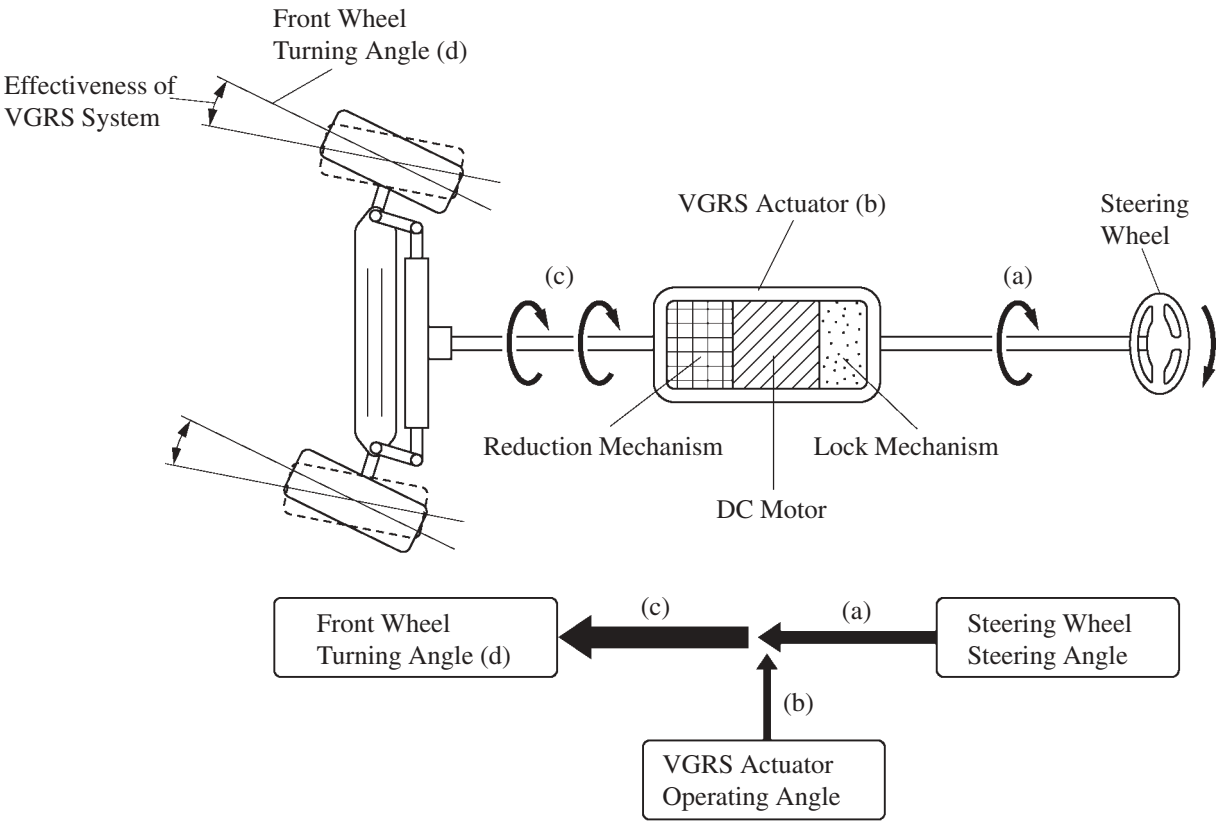
▶ Imaginary Diagram of Steering Gear Ratio ◀



230LX25

2) Main Function

- In accordance with the vehicle speed signals that are obtained from the skid control ECU, the VGRS ECU selects the driver's steering angle and direction (which are obtained from the steering angle sensor signals) and the actuator operating angle data (which is preset in the VGRS ECU in accordance with the vehicle speed). Based on these two pieces of information, the VGRS ECU controls the VGRS actuator in order to attain the proper actuator target operating angle.
- The VGRS actuator, which is mounted on the steering shaft, rotates constantly in unison with the shaft. The turning angle of the front wheels is the sum of the optimal operating angle of the VGRS actuator that the VGRS ECU has determined from the vehicle speed and the angle of the steering wheel that the driver has steered.
- As shown in the previously mentioned imaginary diagram, the VGRS actuator rotates in the direction that increases the turning angle of the front wheels in the low-speed range (in which a reduction in the steering wheel operating effort is desired) or in the medium-speed range (in which a more agile vehicle response is desired). In the high-speed range (in which an over-sensitive movement response of the vehicle is not desired), the VGRS actuator rotates in the direction to slightly decrease the turning angle of the front wheels.
  The VGRS actuator rotates only when the driver turns the steering wheel. Furthermore, when the VGRS actuator rotates in the negative direction, its rotation will not exceed the steering effort of the driver.
- This system contains a lock mechanism. When the VGRS ECU detects a system failure, it stops the operation of the actuator and locks it to prevent it from rotating. Thus, even if the system fails, the steering function of the conventional steering system is ensured. To protect the system, this lock mechanism activates even when the engine is stopped.



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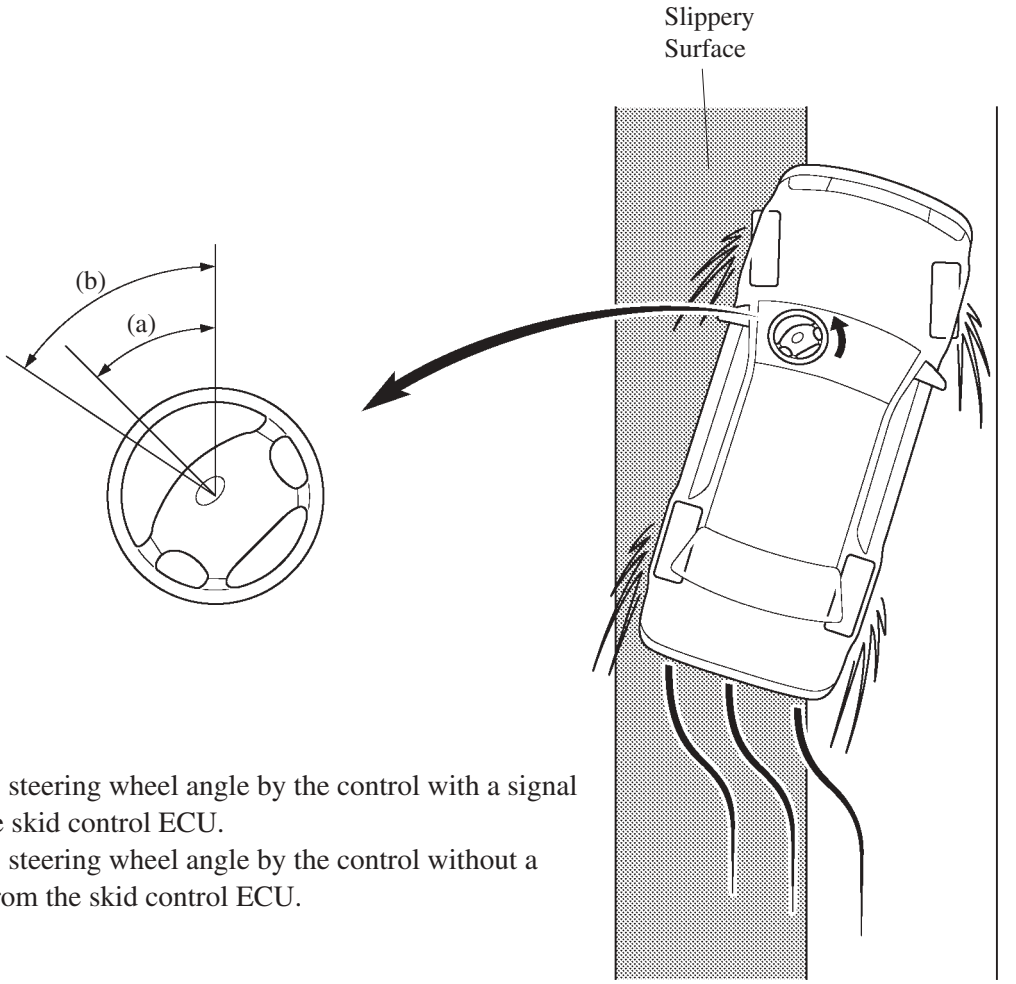
3) Control with a signal from the skid control ECU

If a vehicle that is driven straight ahead over a road surface with different friction coefficients brakes suddenly and causes the VSC to activate, the vehicle posture becomes disrupted, thus requiring the driver to operate the steering wheel. When this occurs, the skid control ECU transmits signals to the VGRS ECU. When the VGRS ECU receives these signals, it calculates the target operating angle for the VGRS actuator based on the driver's steering angle and direction (which are obtained from the steering angle sensor signals) and the vehicle speed signal (which is obtained from the skid control ECU). Then, the VGRS ECU operates the VGRS actuator to make the steering gear ratio smaller than that during usual VGRS system operation, thus reducing the driver's steering ability.



(a): Driver's steering wheel angle by the control with a signal from the skid control ECU.
(b): Driver's steering wheel angle by the control without a signal from the skid control ECU.

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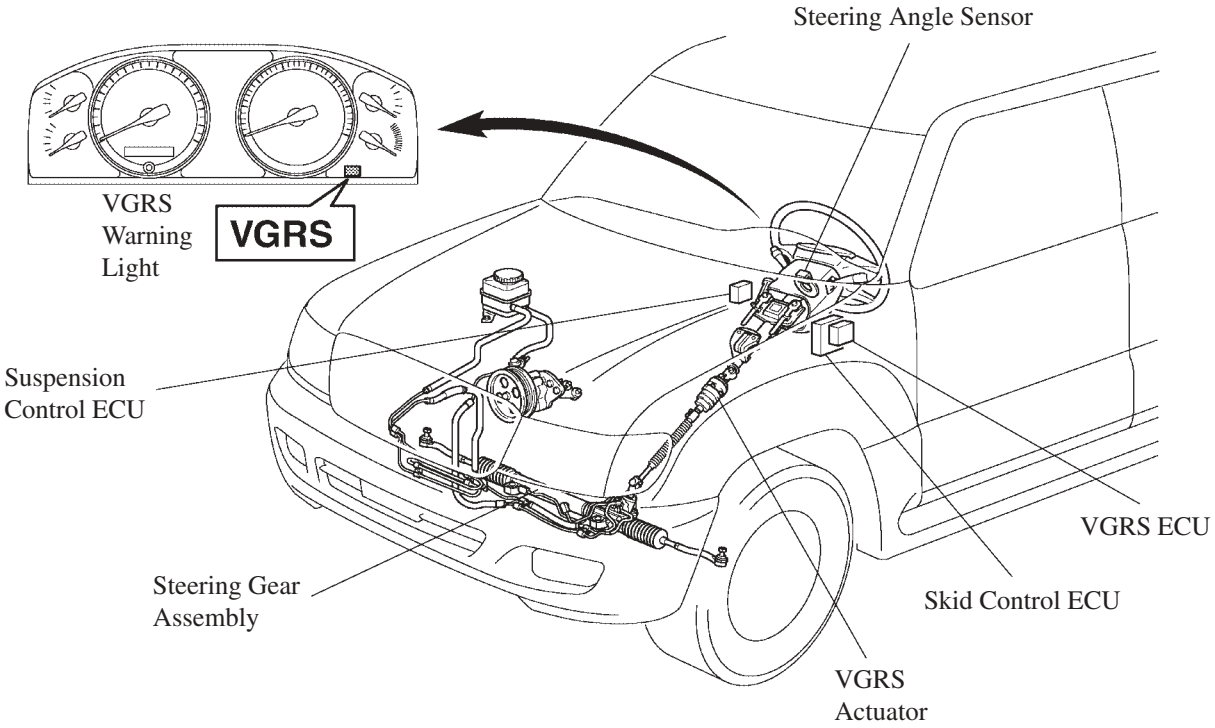
Layout of Main Components



Function of Main Components

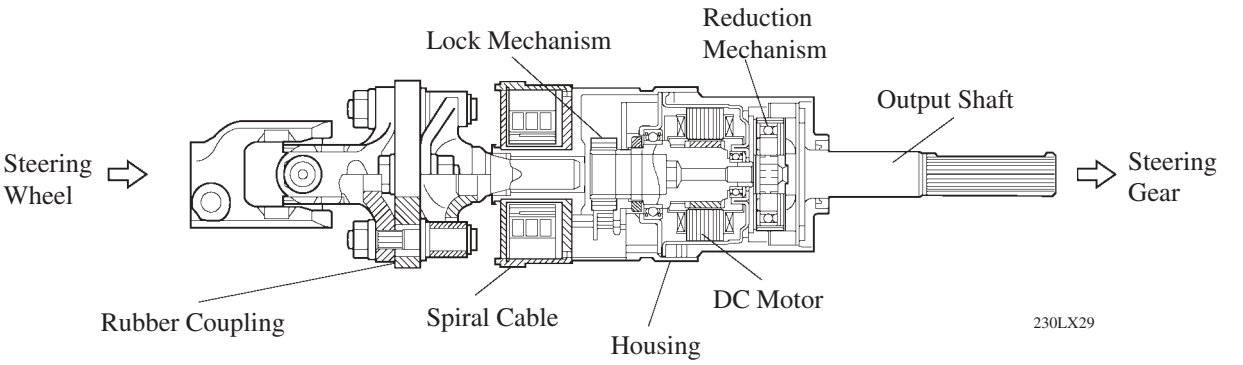
Components		Function
VGRS Actuator	DC Motor	Rotates to create the operating angle of the actuator.
	Reduction Mechanism	Uses a strain wave gear type reduction mechanism to reduce the rotation of the DC motor to the 1:50 ratio.
	Spiral Cable	Has practically the same construction as the spiral cable that is used for the driver's airbag of the SRS airbag system. It functions as the contact point for the wiring harness between the DC motor and the lock solenoid in the rotating actuator and the VGRS ECU.
	Lock Mechanism	Locks the motor shaft so that the DC motor will not rotate in case of a system failure or when the system is stopped due to the stopping of the engine.
VGRS ECU		Effects comprehensive control of the VGRS system. It primarily controls the following items: ● Operates the DC motor by calculating the operating angle of the actuator based on the signals from the steering angle sensor and the vehicle speed sensor. ● Controls the failsafe function and the diagnosis function.
Steering Angle Sensor		Detects the steering angle and direction of the steering wheel and transmits them to the VGRS ECU.
Skid Control ECU		Transmits the vehicle speed signal, steering neutral position information, and the engine speed signal to the VGRS ECU. Furthermore, it transmits the operating signal to enable this system to effect the control with a signal from the skid control ECU.
VGRS Warning Light		Illuminates to alert the driver if a failure occurs in the VGRS system.
Suspension Control ECU		Receives from the VGRS ECU the steered angle of the steering wheel (the sum of the steered angle of the steering wheel operated by the driver and the operating angle of the actuator), which is necessary for controlling the active height control suspension.

Construction and Operation of Main Components

1) VGRS Actuator

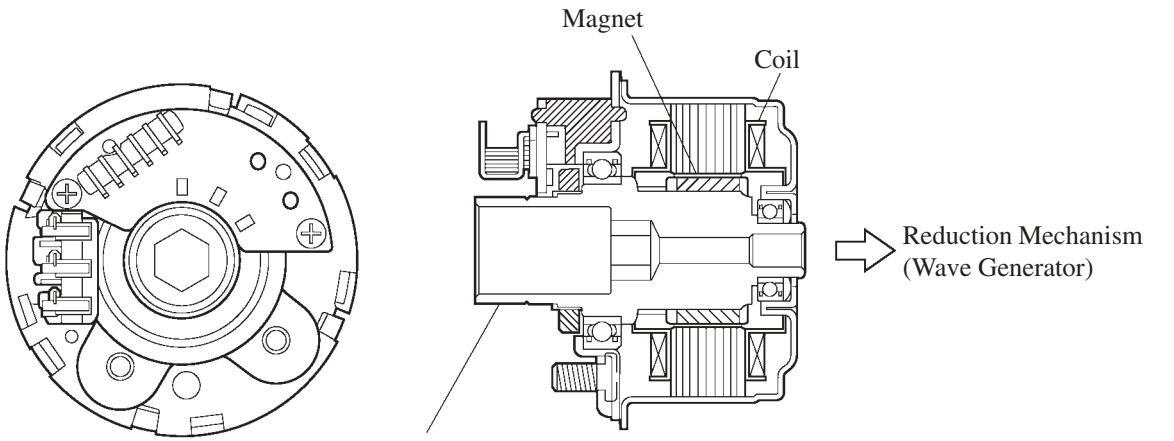
a. General

- The VGRS actuator mainly consists of a housing, DC motor, reduction mechanism, spiral cable, lock mechanism and output shaft.
- The VGRS actuator is integrated with the rubber coupling.



b. DC Motor

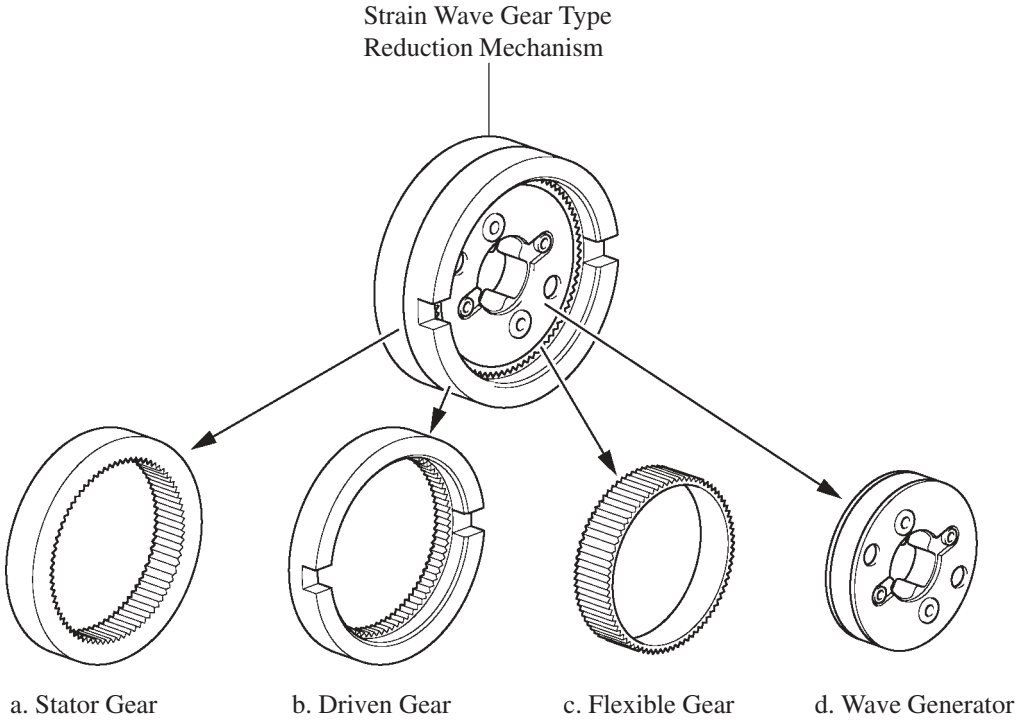
- A DC motor that is compact, has high power output, generates less noise, and is brushless, has been adopted. This DC motor is mounted on the housing.
- This DC motor mainly consists of a magnet, coil, and motor shaft. The motor shaft is coupled to the wave generator of the reduction mechanism in order to transmit the rotational movement of the motor to the reduction mechanism.
- This DC motor, which is controlled by the duty cycle signal from the VGRS ECU, rotates either clockwise or counterclockwise, depending on the steered direction of the steering wheel.
- This DC motor contains an rotational angle sensor. When the VGRS ECU receives the signals from this sensor, it calculates the operating angle of the VGRS actuator based on the rotational angle and the rotational direction of the DC motor.



c. Reduction Mechanism

i) General

- A strain wave gear type reduction mechanism is used.
- This reduction mechanism mainly consists of a driven gear, stator gear, flexible gear and wave generator.
- This reduction mechanism reduces the rotation to the 1:50 ratio.

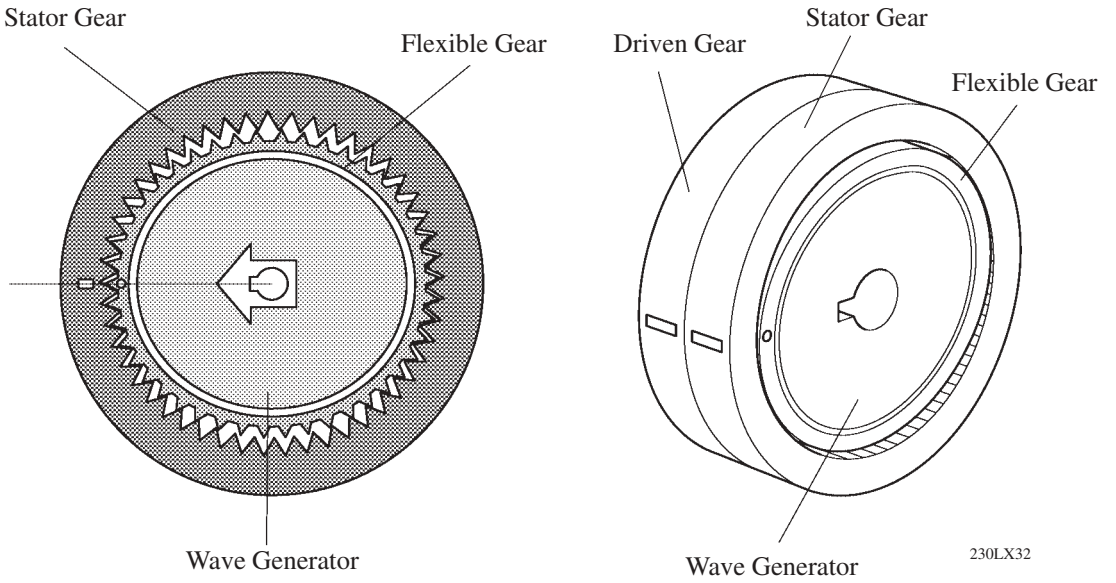


- The construction of the main components of the reduction mechanism is shown in the table below.

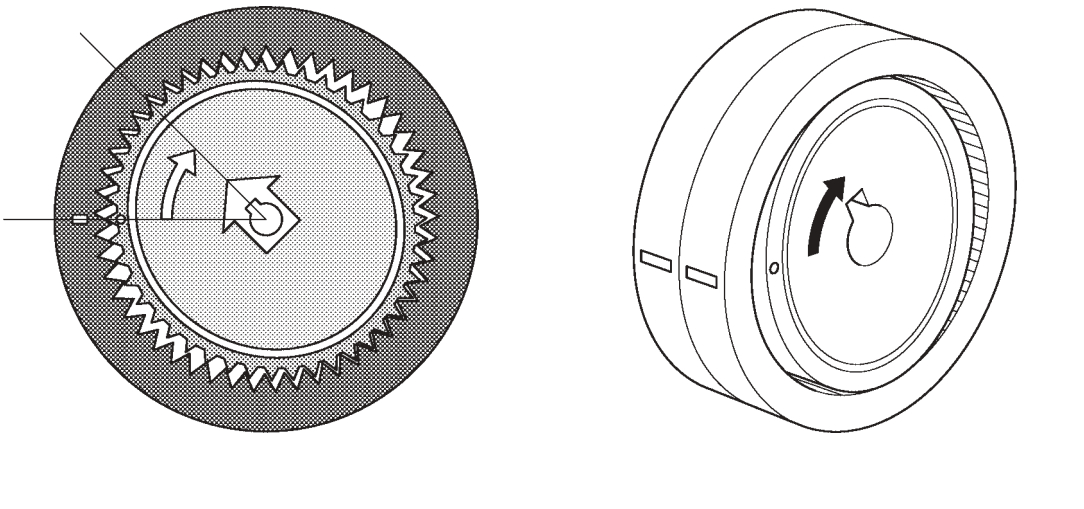
Item		Construction
a	Stator Gear	● Has a rigid body, a ring shape, and contains 102 teeth along the inner circumference. ● Positioned parallel with the driven gear. ● Coupled to the housing of the VGRS actuator.
b	Driven Gear (Output)	● Has a rigid body, a ring shape, and contains 100 teeth along the inner circumference. ● Positioned parallel with the stator gear. ● Coupled to the output shaft of the VGRS actuator.
c	Flexible Gear	● Has a flexible metal body that forms a belt shape and contains 100 teeth along the outer circumference. ● Located outside of the wave generator, and positioned in such a way that its gear teeth are meshed with the inside of both stator gear and driven gear.
d	Wave Generator (Input)	● Consists of an oval-shaped cam and a ball bearing that is fitted around the cam. ● Coupled to the motor shaft of the DC motor, and rotates inside the flexible gear while pushing the flexible gear against the stator gear and the driven gear.

ii) Operating Principle of Reduction Mechanism

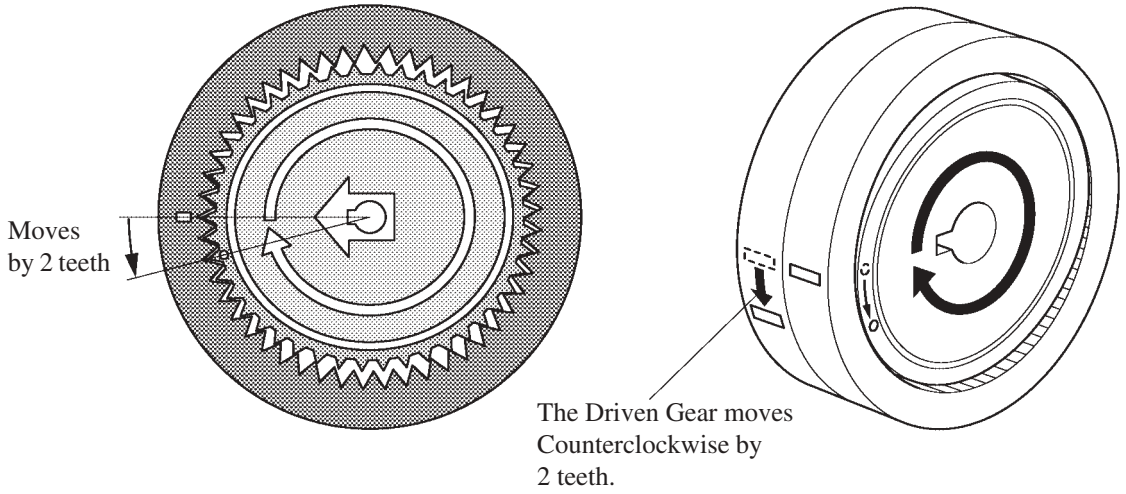
- The flexible gear is fitted inside the driven gear and the stator gear as illustrated. Furthermore, the wave generator is fitted inside the flexible gear.
  The flexible gear is flexed into an oval shape by the wave generator. The teeth at the long axis of the oval shape meshes with the teeth of the driven gear and stator gear, and the teeth at the short axis are disengaged.



- For example, if the wave generator (input) rotates clockwise while pushing the flexible gear, due to the rotational movement of the DC motor, the meshed area of the flexible gear and the driven gear and stator gear moves in sequence.

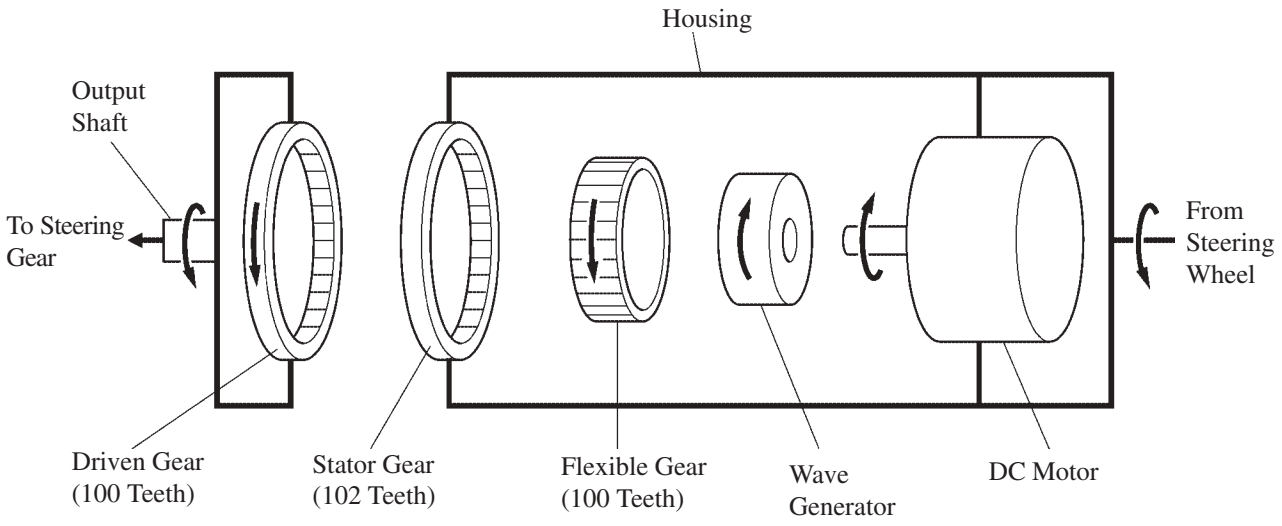


- When the wave generator makes one turn, the flexible gear moves counterclockwise by 2 teeth because the flexible gear has 2 fewer teeth than the stator gear. The driven gear and the flexible gear have the same number of teeth, so their rotational movements are identical. Therefore, the driven gear (output) moves by 2 teeth.



230LX34

- Due to the aforementioned principle, when the DC motor rotates clockwise, the rotational movement that is input by the wave generator (which is coupled to the motor shaft) outputs to the output shaft of the VGRS actuator (which is coupled to the driven gear). As a result, the output shaft rotates counterclockwise at the 1:50 gear ratio. This rotational angle is added to the actual steered angle of the steering wheel, thus changing the turning angle of the front wheels.



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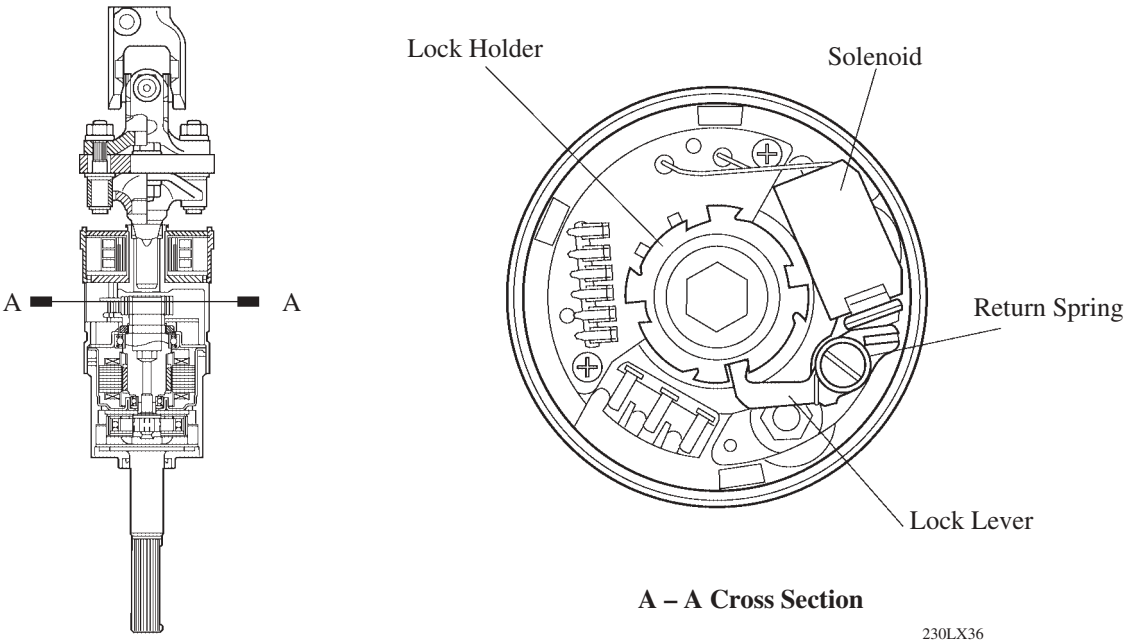
6

d. Lock Mechanism

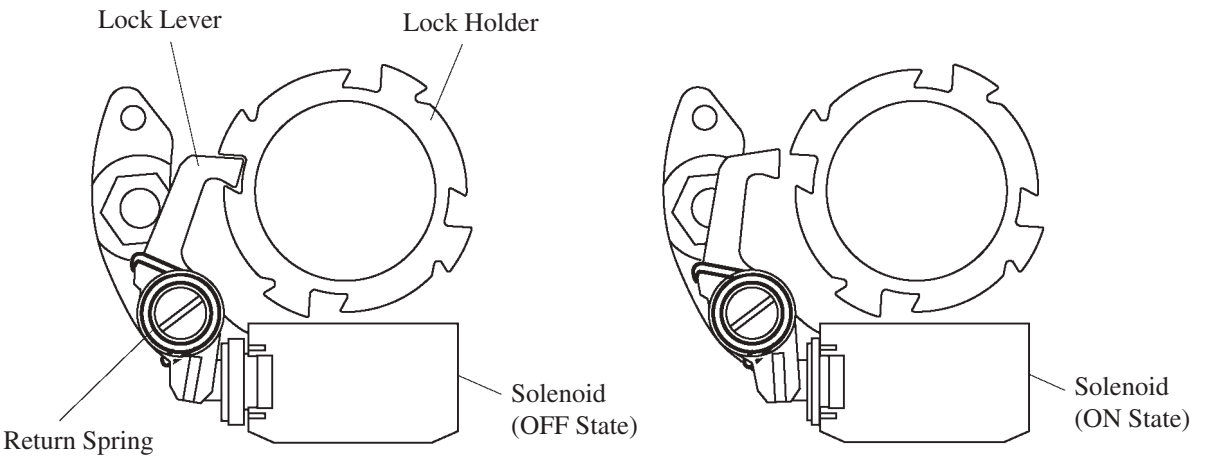
- This system contains a lock mechanism that mechanically locks the DC motor so that the motor will not rotate if a failure occurs or when the engine is not running. With this, the housing and the output shaft become united.
- The lock mechanism is mounted on the DC motor. It consists primarily of a lock holder that is secured to the motor shaft, a lock lever that is mounted on the housing, and a solenoid that operates the lock lever.



A – A Cross Section

230LX36

- When the lock mechanism is activated, the VGRS ECU turns OFF the current to the solenoid, and the return spring pushes the lock lever against the lock holder. Then, the lock lever meshes with the groove in the lock holder in order to mechanically lock the movement of the DC motor.
  When the lock is disengaged, the VGRS ECU turns ON the current to the solenoid, thus disengaging the lock lever and the lock holder and freeing the movement of the DC motor.



Lock State

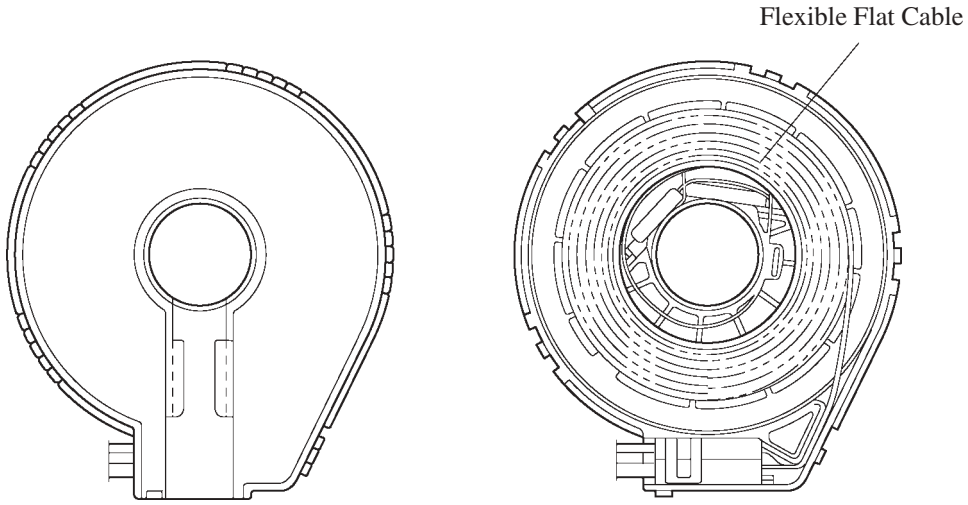
230LX37

Unlock State

230LX38

e. Spiral Cable

- The construction of the spiral cable is almost identical as that of the one used for the driver's airbag of the SRS airbag system. It functions as the contact point for the wiring harness between the DC motor and the lock solenoid in the rotating actuator and the VGRS ECU.
- This spiral cable is mounted above the housing.
- The spiral cable is an internal flexible flat cable with a dual winding construction, which consists of two systems: the power system and the signal system.
- The operating range of this spiral cable is 5.0 turns.



Cross Section 230LX39

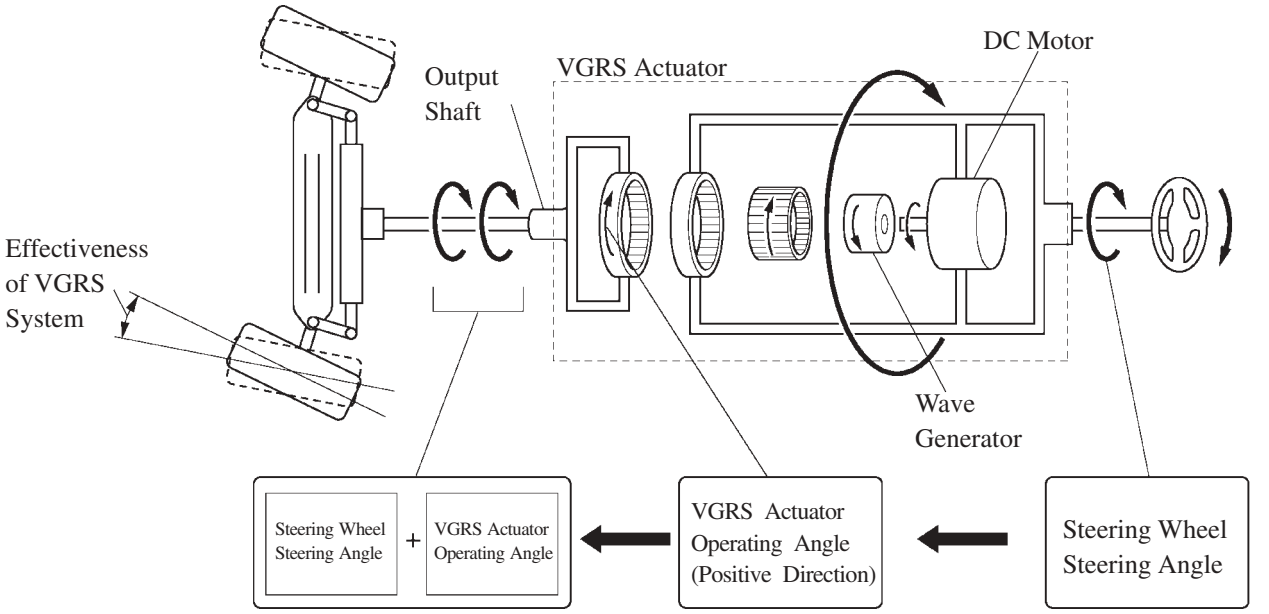
Service Tip

If the VGRS actuator must be removed from the vehicle and reinstalled or disconnect the steering linkage, it is necessary to verify the neutral position of the spiral cable for VGRS System and spiral cable for SRS Airbag System. For details, refer to the Land Cruiser Chasis and Body Repair Manual Supplement (Pub. No. RM970E).

2) Steering Torpue Transmission

a. Low and Middle Speed Range

This system rotates the VGRS actuator in the positive direction in the low-speed range (in which a reduction in the steering wheel operating effort is desired) or in the medium-speed range (in which a more agile vehicle response is desired).
For example, if the driver turns the steering wheel clockwise, the torque is transmitted as illustrated below.
In order to create the target operating angle for the actuator that has been determined by the VGRS ECU, the DC motor in the VGRS actuator rotates counterclockwise. Then, the rotational movement of the DC motor is input into the reduction mechanism by way of the wave generator. The rotational movement is reduced to a 1:50 gear ratio, and is output from the output shaft in the clockwise direction. This operating angle of the VGRS actuator is then added to the angle in which the steering wheel is steered by the driver. Thus, the intermediate shaft rotates more clockwise than the steered angle of the steering wheel by the amount of the operating angle of the VGRS actuator. As a result, the front wheels turn more to the right.



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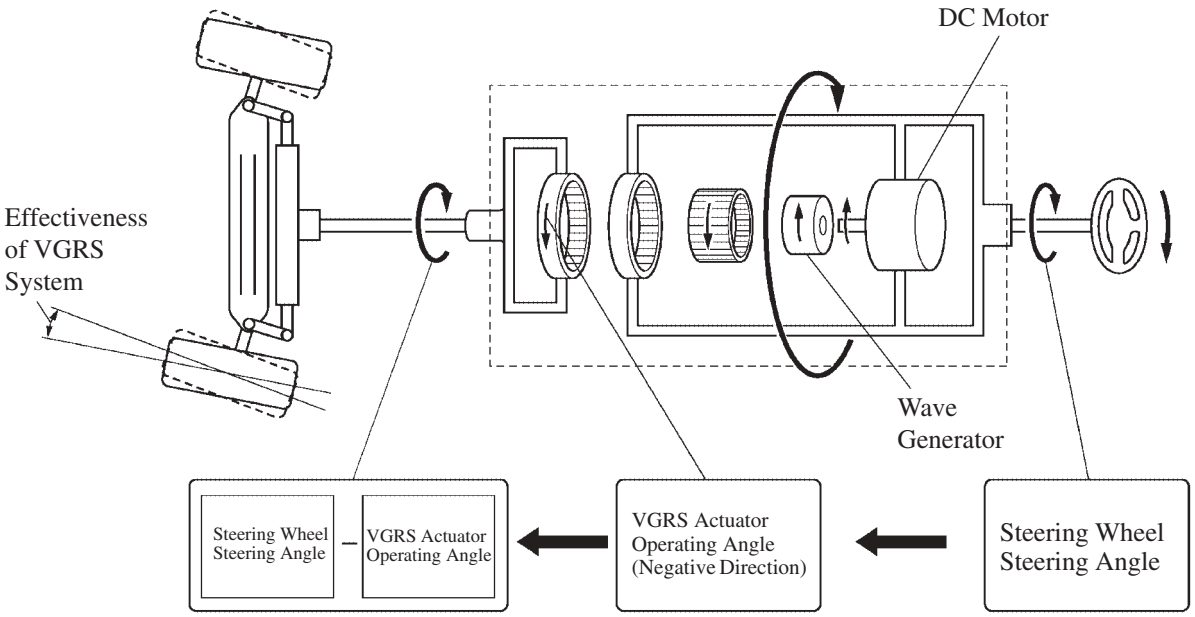
b. High Speed Range

In the high-speed range (in which an over-sensitive movement response of the vehicle is not desired), the VGRS actuator of this system rotates slightly in the negative direction.
For example, if the driver turns the steering wheel clockwise, the torque is transmitted as illustrated below.
In order to create the target operating angle for the actuator that has been determined by the VGRS ECU, the DC motor in the VGRS actuator rotates clockwise. Then, the rotational movement of the DC motor is input into the reduction mechanism by way of the wave generator. The rotational movement is reduced to a 1:50 gear ratio, and is output a little from the output shaft in the counterclockwise direction. This operating angle of the VGRS actuator is then subtracted from the angle in which the steering wheel is steered by the driver. Thus, the intermediate shaft rotates less clockwise than the steered angle of the steering wheel by the amount of the operating angle of the VGRS actuator. As a result, the front wheels turn less to the right.
When the VGRS actuator rotates in the negative direction, it will not rotate in excess of the driver's steering angle.



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3) VGRS ECU

a. General

- In accordance with the vehicle speed signals that are obtained from the skid control ECU, the VGRS ECU selects the driver's steering angle and direction (which are obtained from the steering angle sensor signals) and the actuator operating angle data (which is preset in the VGRS ECU in accordance with the vehicle speed). Based on these two pieces of information, the VGRS ECU controls the VGRS actuator in order to attain the proper actuator target operating angle.
- The VGRS ECU is located near the area where the brake pedal is mounted.
- The VGRS ECU stores in its memory the neutral position of the VGRS actuator that has been determined as desired. Thus, the VGRS ECU effects control by using this neutral position as a reference. Furthermore, the VGRS ECU constantly stores in its memory the operating angle of the VGRS actuator. These data that have been stored in memory will not be erased even if the battery terminals are disconnected.
- The VGRS ECU is equipped with a diagnosis function and a fail-safe function.

Service Tip

The VGRS ECU stores in its memory the neutral position of the VGRS actuator that has been determined as desired. If the VGRS ECU or the VGRS actuator must be replaced, it is necessary to correct the neutral position with respect to the operating angle of the VGRS actuator.
For details, refer to the Land Cruiser Chasis and Body Repair Manual Supplement (Pub. No. RM970E).

b. Diagnosis

- If the VGRS ECU detects a malfunction in the VGRS system, it will immediately stop the operation of the system, and illuminate the VGRS warning light that is provided in the combination meter in order to alert the driver.
  At the same time, the DTC (Diagnostic Trouble Code) are stored in memory.
  The DTC can be read by connecting the SST (09843-18040) between the Tc and CG terminals of DLC3 and observing the blinking of the VGRS warning light or by connecting a hand-held tester.
- The table below indicates the DTCs that are associated with this system. For details concerning the DTCs, see the Land Cruiser Chasis and Body Repair Manual Supplement (Pub. No. RM970E).

DTC No.	Detection Item	DTC No.	Detection Item
C1511/11	Steering Angle Sensor Malfunction	C1551/51	IG Power Source Voltage Malfunction
C1515/15	VGRS Actuator Neutral Position undone	C1552/52	DC Motor Power Source voltage Malfunction
C1516/16	VGRS Actuator Neutral Position undone	C1554/54	Power Source Relay Failure
C1521/21	VGRS Actuator Malfunction	C1555/55	Predriver Source Relay Failure
C1522/22	VGRS Actuator Malfunction	C1561/61	Lock Mechanism Malfunction
C1527/27	VGRS Actuator Malfunction	C1567/67	Lock Mechanism Insertion Malfunction
C1528/28	VGRS Actuator Malfunction	C1568/68	Lock Holder Deviation Detection
C1531/31	VGRS ECU Malfunction	C1569/69	Lock Mechanism Release Incomplete
C1532/32	VGRS ECU Malfunction	C1571	Vehicle Speed Sensor Malfunction (FLO)
C1533/33	VGRS ECU Malfunction	C1572	Vehicle Speed Sensor Malfunction (FRO)
C1541/41	Skid Control System Malfunction	C1575	Steering Angle Sensor Malfunction
C1549/49	Skid Control System Communication Malfunction	C1576	DC Motor Revolution Angle Sensor Malfunction

c. Fail-Safe

- If the VGRS ECU detects a malfunction in the VGRS system, it will take the actions indicated in the table below.
- The VGRS ECU has a built-in temperature sensor in order to effect failsafe control if it overheats. Furthermore, this ECU monitors any changes in the actuating voltage of the DC motor in order to detect the overheating of the motor.

Malfunction Item	Description of Control	VGRS Warning Light*1	DTC Memory Condition*2
Steering Angle Sensor Malfunction	Stops the control	○	○
DC Motor Malfunction	†	○	○
VGRS ECU Malfunction	†	○	○
DC Motor Circuit Malfunction	†	○	○
Lock Mechanism Circuit Malfunction	†	○	○
Vehicle Speed Signal Malfunction	†	○	○
Skid Control ECU Communication Signal Malfunction	†	○	○
DC Motor Overheat	First, the control is stopped; then, the control resumes after the system resumes its normal operation.	—	—
VGRS ECU Overheat	†	—	—
PIG Power Source Drop Voltage Malfunction	†	—	—
VGRS Actuator Malfunction*3	†	—	—

*1: ○ = VGRS Warning Light lights up
— = VGRS Warning Light does not light up.

*2: ○ = Memorize
— = None

*3: Specific Examples:
(1) When the steering is operated while the output of the power steering pump is unstable, immediately after starting a cold engine.
(2) If the driver attempts to operate the steering wheel further after it has been steered entirely to the rack end.