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STEERING DEVICE

Abstract

A steering system includes a shaft that rotates in conjunction with steering of a steering wheel, a ball screw mechanism that converts rotation of the shaft into rotation of an output shaft, and a speed reducer that applies torque to the shaft. The ball screw mechanism includes a first housing, a ball screw shaft, and first and second bearings that support the ball screw shaft. The speed reducer includes a second housing and a third bearing that supports the shaft. An outside diameter of the shaft is set so that a third center line passing through a center of a cross section of the third bearing is positioned on a radially outer side of a first center line passing through a center of a cross section of the first bearing or a second center line passing through a center of a cross section of the second bearing.

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Background/Summary

TECHNICAL FIELD

[0001] The present disclosure relates to a steering system.

BACKGROUND ART

[0002] Hitherto, so-called cab-over vehicles such as freight vehicles in which a driver's seat is located forward of a front wheel axle often use an axle suspension in which right and left wheels are connected by an axle. The vehicles including the axle suspension often use a ball screw steering gearbox. The steering gearbox is mounted on, for example, a vehicle body frame.

[0003] An electric power steering system of Patent Document 1 includes a motor and a ball screw steering gearbox. The steering gearbox converts a rotational motion of a steering shaft into rotation of an output shaft that rotates in conjunction with steered wheels. The direction of the steered wheels is changed in conjunction with the rotation of the output shaft. The torque of the motor is transmitted to a ball screw shaft of the steering gearbox via a worm reducer. This assists steering of a steering wheel.

[0004] The steering shaft includes an input shaft, an output shaft, and a torsion bar. The input shaft and the output shaft are connected to each other via the torsion bar. Steering torque applied to the steering wheel is transmitted to the output shaft via the input shaft and the torsion bar. The torsion bar is twisted in response to the steering torque. The end of the output shaft opposite to the input shaft is connected to the end of the ball screw shaft.

RELATED ART DOCUMENTS

Patent Documents

[0005] Patent Document 1: Chinese Patent Application Publication No. 111284556

SUMMARY OF THE INVENTION

Problem to be Solved by the Invention

[0006] The electric power steering system of Patent Document 1 has the following concern. That is, the output shaft and the ball screw shaft are coupled to each other by serration coupling. The serration coupling is a method of coupling a rotation shaft to a component having a fitting portion to which the rotation shaft is fitted. Serrated teeth provided on the outer circumferential surface of the rotation shaft and serrated grooves provided on the inner circumferential surface of the fitting portion are fitted together to restrict relative rotation between the rotation shaft and the component.

[0007] In the electric power steering system of Patent Document 1, serrated teeth extending in an axial direction are provided on the outer circumferential surface of the end of the output shaft coupled to the ball screw shaft. The end of the ball screw shaft to which the output shaft is coupled includes a fitting portion. Serrated grooves extending in the axial direction are provided on the inner circumferential surface of the fitting portion. The serrated teeth and the serrated grooves are fitted together by press-fitting the end of the output shaft to the fitting portion.

[0008] However, there is a slight amount of backlash between the end of the output shaft and the fitting portion of the ball screw shaft in a rotation direction or a radial direction thereof. Along with long-term use of the electric power steering system, the amount of backlash between the end of the output shaft and the fitting portion of the ball screw shaft may gradually increase. In this case, there is a concern that the output shaft may tilt due to the backlash between the end of the output shaft

and the fitting portion of the ball screw shaft.
Means for Solving the Problem
[0009] A steering system according to one embodiment of the present disclosure includes a shaft configured to rotate in conjunction with steering of a steering wheel of a vehicle, a ball screw mechanism configured to convert rotation of the shaft into rotation of an output shaft configured to operate in conjunction with a steered wheel, and a speed reducer configured to apply torque to the shaft. The ball screw mechanism includes a first housing, a ball screw shaft housed inside the first housing, the ball screw shaft including a first end and a second end, and being connected to the shaft to be rotatable together by intermeshing coupling between the first end and the shaft, a first bearing that supports the first end of the ball screw shaft so that the ball screw shaft is rotatable relative to the first housing, and a second bearing that supports the second end of the ball screw shaft so that the ball screw shaft is rotatable relative to the first housing. The speed reducer includes a second housing that is connected to the first housing in an axial direction and into which the shaft is inserted in the axial direction, and a third bearing that supports the shaft so that the shaft is rotatable relative to the second housing. A line passing through a center of a cross section obtained by cutting the first bearing in the axial direction and parallel to a central axis of the shaft is a first center line. A line passing through a center of a cross section obtained by cutting the second bearing in the axial direction and parallel to the central axis of the shaft is a second center line. A line passing through a center of a cross section obtained by cutting the third bearing in the axial direction and parallel to the central axis of the shaft is a third center line. An outside diameter of the shaft is set so that the third center line is positioned on an outer side of the first center line or the second center line in a radial direction about the central axis of the shaft.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
[0010] FIG. **1** is a schematic diagram of a steering system according to one embodiment.
[0011] FIG. **2** is a sectional view of a steering gearbox in FIG. **1**.
[0012] FIG. **3**A is a sectional view showing a first comparative example of an output shaft in FIG. **2**.
[0013] FIG. **3**B is a sectional view showing a second comparative example of the output shaft in FIG. **2**.
[0014] FIG. **4**A is a sectional view showing tilt in the first comparative example of the output shaft in FIG. **2**.
[0015] FIG. **4**B is a sectional view showing tilt in the second comparative example of the output shaft in FIG. **2**.
MODES FOR CARRYING OUT THE INVENTION
[0016] A steering system according to one embodiment will be described. The steering system is, for example, an electric power steering system.
Overall Configuration
[0017] As shown in FIG. **1**, a steering system **20** is mounted on, for example, a cab-over vehicle **10**. The vehicle **10** includes an axle suspension **11**. The suspension **11** supports a front axle **12**. Steered wheels **13** that are front wheels are connected to both ends of the front axle **12**. The suspension **11** includes a leaf spring **14**. As an example, the leaf spring **14** is positioned above the front axle **12**. The leaf spring **14** extends in a front-rear direction of the vehicle. Both ends of the leaf spring **14** are attached to a vehicle body frame **16** via support members **15** such as shackles.
[0018] The steering system **20** includes a steering shaft **21**, a steering gearbox **22**, a motor **23**, a torque sensor **24**, and a speed reducer **25**. The steering shaft **21** and the steering gearbox **22** constitute a steering mechanism of the vehicle **10**. A first end of the steering shaft **21** is connected

to a steering wheel **26**. A second end of the steering shaft **21** is connected to the steering gearbox **22** via the torque sensor **24** and the speed reducer **25**. The motor **23** is connected to the steering gearbox **22** via the speed reducer **25**. The steering gearbox **22** is, for example, of an RBS type (recirculating ball screw type).

[0019] The steering gearbox **22** is connected to the steered wheels **13** via a link mechanism **30**. The link mechanism **30** includes a pitman arm **31**, a drag link **32**, and a tie rod **33**. The base end of the pitman arm **31** is connected to the side of the steering gearbox **22**. The pitman arm **31** is swingable about its base end in the front-rear direction of the vehicle. A first end of the drag link **32** is rotatably connected to the distal end of the pitman arm **31**. A second end of the drag link **32** is rotatably connected to a knuckle arm **34** of the right steered wheel **13**. Both ends of the tie rod **33** are connected to the right and left steered wheels **13** via tie rod arms **35**.

[0020] The rotation of the steering wheel **26** is transmitted to the steering gearbox **22** via the steering shaft **21**. The steering gearbox **22** converts a rotational motion of the steering shaft **21** into a swinging motion of the pitman arm **31**. The swinging motion of the pitman arm **31** drives the drag link **32** in the front-rear direction of the vehicle. The knuckle arm **34** swings in conjunction with the drag link **32**, thereby turning the steered wheels **13**.

[0021] The motor **23** generates torque in the same direction as the steering direction of the steering wheel **26** in response to steering torque detected by the torque sensor **24**. The torque of the motor **23** is transmitted to the steering shaft **21** via the speed reducer **25**. That is, the speed reducer **25** is configured to apply torque to the steering shaft **21**. The torque in the same direction as the steering direction is applied to the steering shaft **21**, thereby assisting the steering of the steering wheel **26**.

Configuration of Steering Gearbox **22**

[0022] As shown in FIG. **2**, the steering gearbox **22** includes a first housing **40**. A ball screw shaft **41**, a ball screw nut **42**, a plurality of balls **43**, a sector shaft **44**, and a sector gear **45** are provided inside the first housing **40**.

[0023] When the steering gearbox **22** is mounted on the vehicle **10**, the ball screw shaft **41** is maintained in a posture in which it extends in the vertical direction with respect to the vehicle **10**. The ball screw shaft **41** is supported via a first bearing **46** and a second bearing **47** to be rotatable relative to the first housing **40**. The first bearing **46** and the second bearing **47** are, for example, the same products.

[0024] The first bearing **46** supports a first end of the ball screw shaft **41**. The first end is an end of the ball screw shaft **41** oriented upward of the vehicle **10** when the steering gearbox **22** is mounted on the vehicle **10**. The first end of the ball screw shaft **41** is connected to the steering shaft **21** via the torque sensor **24**.

[0025] The second bearing **47** supports a second end of the ball screw shaft **41**. The second end is an end of the ball screw shaft **41** opposite to the first end. That is, the second end is an end of the ball screw shaft **41** oriented downward of the vehicle **10** when the steering gearbox **22** is mounted on the vehicle **10**. The second end faces an end wall of the first housing **40**.

[0026] The ball screw shaft **41** has a first groove **41**A. The first groove **41**A is a helical groove provided on the outer circumferential surface of the ball screw shaft **41**. A threaded portion is formed by providing the first groove **41**A. The ball screw shaft **41** has a connection hole **41**B at the first end. The connection hole **41**B extends in an axial direction. A plurality of serration grooves extending in the axial direction is provided on the inner circumferential surface of the connection hole **41**B. The serration grooves are disposed at equal intervals in a circumferential direction of the connection hole **41**B. The serration groove has, for example, a triangular shape as viewed in the axial direction. The ball screw nut **42** has a tubular shape and has a second groove **42**A.

[0027] The second groove **42**A is a helical groove provided on the inner circumferential surface of the ball screw nut **42**. The second groove **42**A faces the first groove **41**A in a radial direction. The ball screw nut **42** engages with the ball screw shaft **41** via the plurality of balls **43**. A helical space surrounded by the first groove **41**A and the second groove **42**A functions as a rolling path along which the balls **43** roll. The ball screw shaft **41**, the ball screw nut **42**, and the balls **43** constitute a ball screw mechanism **48**.

[0028] The ball screw nut **42** includes a plurality of rack teeth **42**B. The rack teeth **42**B are provided on the outer circumferential surface of the ball screw nut **42**. The rack teeth **42**B are arranged in an axial direction of the ball screw nut **42**.

[0029] The sector shaft **44** extends in a direction orthogonal to the axis of the ball screw nut **42** (direction orthogonal to the drawing sheet of FIG. **2**). The sector shaft **44** is supported via a bearing that is not shown to be rotatable relative to the first housing **40**. The sector shaft **44** has an outer end exposed to the outside through the first housing **40**. The base end of the pitman arm **31** is fixed to the outer end of the sector shaft **44**. The sector shaft **44** is an output shaft of the steering gearbox **22** and operates in conjunction with the steered wheels **13**.

[0030] The sector gear **45** is provided to the sector shaft **44** to be rotatable together. The sector gear **45** is a gear having a sector shape and has a plurality of teeth **45**A. The teeth **45**A of the sector gear **45** mesh with the rack teeth **42**B of the ball screw nut **42**.

[0031] The rotation of the steering wheel **26** is transmitted to the ball screw shaft **41** via the steering shaft **21** and the torque sensor **24**. As the ball screw shaft **41** rotates, the ball screw nut **42** moves in the axial direction relative to the ball screw shaft **41**. Therefore, the sector gear **45** swings about the sector shaft **44**. When the sector shaft **44** rotates as the sector gear **45** swings, the pitman arm **31** swings about the sector shaft **44**.

Configuration of Torque Sensor **24**

[0032] As shown in FIG. **2**, the torque sensor **24** includes an input shaft **24**A, an output shaft **24**B, a torsion bar **24**C, and a detector **24**D. The input shaft **24**A and the output shaft **24**B are connected to each other via the torsion bar **24**C. The input shaft **24**A and the output shaft **24**B are each a hollow cylinder.

[0033] A first end of the input shaft **24**A is connected to the steering shaft **21**. A second end of the input shaft **24**A is inserted into a first end of the output shaft **24**B. The input shaft **24**A is kept out of contact with the output shaft **24**B. A plain bearing **24**E is interposed between the outer circumferential surface of the input shaft **24**A and the inner circumferential surface of the output shaft **24**B. The input shaft **24**A and the output shaft **24**B can rotate relative to each other via the plain bearing **24**E.

[0034] A second end of the output shaft **24**B is fitted to the connection hole **41**B through an end wall of the first housing **40**. A plurality of serration teeth extending in the axial direction is provided on the outer circumferential surface of the second end of the output shaft **24**B. The serration teeth are disposed at equal intervals in the circumferential direction. The serration tooth has, for example, a triangular shape as viewed in the axial direction. The serration teeth of the output shaft **24**B and the serration grooves of the connection hole **41**B are fitted together. Serration coupling between the output shaft **24**B and the ball screw shaft **41** restricts relative rotation between the output shaft **24**B and the ball screw shaft **41**. The output shaft **24**B is rotatable together with the ball screw shaft **41**.

[0035] Although the coupling structure using so-called triangular tooth serrations has been exemplified, any structure may be used as long as it is intermeshing coupling between an inner member with external teeth and an outer member with internal teeth, and it may also be square splines or involute splines.

[0036] The second end of the output shaft **24**B is an end of the output shaft **24**B positioned opposite to a bearing attachment portion **24**B**1** across a worm wheel attachment portion **24**B**2**. The second end of the output shaft **24**B is indirectly supported by the first bearing **46** via a peripheral wall of the connection hole **41**B while being fitted to the connection hole **41**B in the axial direction.

[0037] The output shaft **24**B includes the bearing attachment portion **24**B**1** and the worm wheel attachment portion **24**B**2**. The bearing attachment portion **24**B**1** and the worm wheel attachment portion **24**B**2** are positioned between the first end and the second end of the output shaft **24**B. The outside diameter of the bearing attachment portion **24**B**1** is larger than the outside diameters of the other portions of the output shaft **24**B except for the worm wheel attachment portion **24**B**2**. The outside diameter of the worm wheel attachment portion **24**B**2** is slightly larger than the outside diameter of the bearing attachment portion **24**B**1**.

[0038] The bearing attachment portion **24**B**1** and the worm wheel attachment portion **24**B**2** are adjacent to each other in the axial direction. The bearing attachment portion **24**B**1** is positioned opposite to the ball screw shaft **41** across the worm wheel attachment portion **24**B**2**. The bearing attachment portion **24**B**1** is a portion of the output shaft **24**B positioned above the worm wheel attachment portion **24**B**2** when the steering gearbox **22** is mounted on the vehicle **10**. The worm wheel attachment portion **24**B**2** is a portion of the output shaft **24**B positioned below the bearing attachment portion **24**B**1** when the steering gearbox **22** is mounted on the vehicle **10**.

[0039] The torsion bar **24**C is inserted into the input shaft **24**A and the output shaft **24**B. A first end of the torsion bar **24**C is fixed to the inner circumferential surface of the first end of the input shaft **24**A. A second end of the torsion bar **24**C is fixed to the inner circumferential surface of the second end of the output shaft **24**B. A clearance is present between the inner circumferential surface of the output shaft **24**B and the outer circumferential surface of a portion of the torsion bar **24**C between the first end and the second end.

[0040] Steering torque applied to the steering wheel **26** is transmitted to the input shaft **24**A via the steering shaft **21**. Therefore, the input shaft **24**A rotates. The rotation of the input shaft **24**A is transmitted to the output shaft **24**B via the torsion bar **24**C. Therefore, the output shaft **24**B rotates. The output shaft **24**B corresponds to a shaft that rotates in conjunction with the steering of the steering wheel **26**. The torsion bar **24**C is twisted in response to the steering torque.

[0041] The detector **24**D is provided, for example, to surround the outer circumferential surface of the input shaft **24**A. The detector **24**D detects steering torque based on the amount of twist of the torsion bar **24**C.

Configuration of Speed Reducer **25**

[0042] As shown in FIG. **2**, the speed reducer **25** includes a second housing **50**. The second housing **50** is connected to the first housing **40** of the steering gearbox **22**. The second housing **50** is connected to a portion of the first housing **40** that is closer to the first bearing **46** than to the second bearing **47** in the axial direction.

[0043] The first housing **40** includes a tubular connection portion **40**A extending in the axial direction. The connection portion **40**A is provided at the end of the first housing **40** oriented upward of the vehicle **10** when the steering gearbox **22** is mounted on the vehicle **10**. The connection portion **40**A is closer to the first bearing **46** than to the second bearing **47** in the axial direction.

[0044] The second housing **50** has a tubular shape and includes an end wall at a first end in the axial direction. The first end is an end of the second housing **50** oriented upward of the vehicle **10** when the steering gearbox **22** is mounted on the vehicle **10**. The end wall has a first opening **50**A. The input shaft **24**A and the output shaft **24**B extend through the first opening **50**A in the axial direction in a non-contact state. The second housing **50** has a second opening **50**B at a second end opposite to the first end. The second end is an end of the second housing **50** oriented downward of the vehicle **10** when the steering gearbox **22** is mounted on the vehicle **10**.

[0045] The connection portion **40**A of the first housing **40** and the second opening **50**B of the second housing **50** are fitted together in the axial direction. Specifically, the inner circumferential surface of the second opening **50**B is fitted to the outer circumferential surface of the connection portion **40**A. There is no step between the outer circumferential surface of the first housing **40** and the outer circumferential surface of the second housing **50**. The inside of the first housing **40** and the inside of the second housing **50** communicate with each other.

[0046] The motor **23** is attached to the outside of the second housing **50**. An output shaft **23**A of the motor **23** extends, for example, in a direction orthogonal to the axis of the ball screw shaft **41** and parallel to the axis of the sector shaft **44**. The output shaft **23**A extends through the second housing **50** and is inserted into the second housing **50**.

[0047] A worm wheel **51** and a worm **52** are housed inside the second housing **50**. The output shaft **24**B extends through the second housing **50** in the axial direction. The output shaft **24**B is supported via a third bearing **53** to be rotatable relative to the inner circumferential surface of the first opening **50**A of the second housing **50**. The third bearing **53** is attached to the outer circumferential surface of the bearing attachment portion **24**B**1** of the output shaft **24**B. The third bearing **53** is, for example, a ball bearing. The fitting between an inner ring of the third bearing **53** and the outer circumferential surface of the bearing attachment portion **24**B**1** is clearance fit. That is, the bore diameter of the inner ring of the third bearing **53** is slightly larger than the outside diameter of the bearing attachment portion **24**B**1**. The fitting between an outer ring of the third bearing **53** and the inner circumferential surface of the first opening **50**A is clearance fit. That is, the outside diameter of the outer ring of the third bearing **53** is slightly smaller than the bore diameter of the first opening **50**A.

[0048] The worm wheel **51** has a tubular shape and is attached to the outer circumferential surface of the worm wheel attachment portion **24**B**2** of the output shaft **24**B. The worm wheel **51** is rotatable together with the output shaft **24**B. The first end face of the worm wheel **51** and the third bearing **53** are spaced away from each other in the axial direction. The second end face of the worm wheel **51** and the connection portion **40**A of the first housing **40** are spaced away from each other in the axial direction. The second end face is an end face of the worm wheel **51** opposite to the first end face. The second end face of the worm wheel **51** has a recess **51**A. The recess **51**A has, for example, a truncated cone shape. The recess **51**A is a region including the center of the second end face as viewed in the axial direction, and is provided in a region from the center of the second end face to the vicinity of the root. The recess **51**A is open opposite to the bearing attachment portion **24**B**1** across the worm wheel attachment portion **24**B**2**. A portion of the connection portion **40**A of the first housing **40** is inserted into the recess **51**A.

[0049] The worm **52** is connected to the output shaft **23**A of the motor **23** to be rotatable together. The axis of the output shaft **23**A and the axis of the worm **52** coincide with each other. The worm **52** meshes with the worm wheel **51**. The shaft angle between the worm **52** and the worm wheel **51** is, for example, 90°.

[0050] The torque of the motor **23** is transmitted to the ball screw shaft **41** via the speed reducer **25**. The torque in the same direction as the steering direction of the steering wheel **26** is applied to the ball screw shaft **41**, thereby assisting the steering of the steering wheel **26**.

Suppression of Tilt of Output Shaft **24**B

[0051] As described above, the output shaft **24**B and the ball screw shaft **41** are coupled to each other in the axial direction via the serration teeth and the serration grooves. In this case, there is a slight amount of backlash between the output shaft **24**B and the ball screw shaft **41** in a rotation direction or a radial direction thereof due to the structure. Further, the fitting between the outer ring of the third bearing **53** and the first opening **50**A is clearance fit. Therefore, there is a concern that the output shaft **24**B may tilt about a fulcrum that is the connection point to the ball screw shaft **41** depending on the clearance between the outer circumferential surface of the outer ring of the third bearing **53** and the inner circumferential surface of the first opening **50**A.

[0052] In the present embodiment, the following configuration is adopted to suppress the tilt of the output shaft **24**B.

[0053] As shown in FIG. **2**, a line passing through the center of a cross section obtained by cutting the first bearing **46** in the axial direction and parallel to a central axis O of the output shaft **24**B is a first center line O**1**. A line passing through the center of a cross section obtained by cutting the second bearing **47** in the axial direction and parallel to the central axis O of the output shaft **24**B is a second center line O**2**. A line passing through the center of a cross section obtained by cutting the third bearing **53** in the axial direction and parallel to the central axis O of the output shaft **24**B is a third center line O**3**. An outside diameter φ**1** of the bearing attachment portion **24**B**1** of the output shaft **24**B is set so that the third center line O**3** is positioned on an outer side of the first center line O**1** in the radial direction about the central axis O of the output shaft **24**B. In other words, the outside diameter φ**1** of the bearing attachment portion **24**B**1** of the output shaft **24**B is set so that a radial distance from the central axis O of the output shaft **24**B to the third center line O**3** is larger than a radial distance from the central axis O of the output shaft **24**B to the first center line O**1**. In the following description, a “radially outer side” and a “radially inner side” mean an outer side and an inner side in the radial direction about the central axis O of the output shaft **24**B, respectively.

[0054] With this configuration, the tilt of the output shaft **24**B can be suppressed compared to, for example, the case where the outside diameter φ**1** of the bearing attachment portion **24**B**1** of the output shaft **24**B is set so that the third center line O**3** is positioned on the radially inner side of the first center line O**1**. This is because the tilt amount of the output shaft **24**B decreases as the outside diameter φ**1** of the bearing attachment portion **24**B**1** increases.

[0055] Although all the first bearing **46**, the second bearing **47**, and the third bearing **53** are ball bearings, the third bearing **53** has a smaller ball diameter than the other bearings **46**, **47**. Thus, the bore diameter of the third bearing **53** can be increased, and the outside diameter φ**1** of the bearing attachment portion **24**B**1** can further be increased.

[0056] The third center line O**3** is positioned on the radially outer side of the second center line O**2**. The first bearing **46** and the second bearing **47** are the same products and are positioned coaxially. Therefore, the second center line O**2** coincides with the first center line O**1**. Thus, when the third center line O**3** is positioned on the radially outer side of the first center line O**1**, the third center line O**3** is naturally positioned on the radially outer side of the second center line O**2**.

[0057] The outside diameter φ**1** of the bearing attachment portion **24**B**1** is larger than an outside diameter **42** of the ball screw shaft **41**. The outside diameter φ**2** is an outside diameter of a portion of the ball screw shaft **41** other than the portions supported by the first bearing **46** and the second bearing **47**.

Relationship between Outside Diameter and Tilt of Output Shaft **24**B

[0058] A first comparative example of the output shaft **24**B shown in FIG. **3**A and a second comparative example of the output shaft **24**B shown in FIG. **3**B will be considered.

[0059] As shown in FIG. **3**A, in the first comparative example, the outside diameter φ**1** of the bearing attachment portion **24**B**1** is set to a first outside diameter φ**11**. It is assumed that there is an imaginary wall WL that faces a first end face of the third bearing **53** in the axial direction. The first end face is an end face of the third bearing **53** opposite to the worm wheel attachment portion **24**B**2**, and is oriented upward of the vehicle **10** when the steering gearbox **22** is mounted on the vehicle **10**.

[0060] The first end face of the third bearing **53** and the imaginary wall WL are spaced away from each other in the axial direction by a distance Y**1**. The central axis O of the output shaft **24**B and the outer circumferential surface of the outer ring of the third bearing **53** are spaced away from each other in the radial direction by a distance X**1**. The output shaft **24**B can maximally tilt up to a position where a corner P**1** of the outer ring of the third bearing **53** comes into contact with the imaginary wall WL. The corner P**1** is a corner formed by the first end face of the third bearing **53** and the outer circumferential surface of the outer ring of the third bearing **53**. The tilt amount of the output shaft **24**B is equal to the tilt amount of the first end face of the third bearing **53**. Therefore, a tilt amount θ**1** in the first comparative example of the output shaft **24**B is represented by the following expression (1).

[00001] $$1 = \tan^{-1}(Y1 / X1) \quad (1)$$

As shown in FIG. **3**B, in the second comparative example, the outside diameter φ**1** of the bearing attachment portion **24**B**1** is set to a second outside diameter φ**12**. The second outside diameter φ**12** is larger than the first outside diameter φ**11**. Similarly to the first comparative example, it is assumed that there is an imaginary wall WL that faces the first end face of the third bearing 53 in the axial direction. Similarly to the first comparative example, the first end face of the third bearing 53 and the imaginary wall WL are spaced away from each other in the axial direction by the distance Y1. The central axis O of the output shaft 24B and the outer circumferential surface of the outer ring of the third bearing 53 are spaced away from each other in the radial direction by a distance X2. The distance X2 is larger than the distance X1 in the first comparative example. A tilt amount θ2 of the output shaft 24B in the second comparative example is represented by the following expression (2).

[00002] $2 = \tan^{-1}(Y1/X2)$ (2)

As described above, the distance X2 in the second comparative example of the output shaft 24B is larger than the distance X1 in the first comparative example of the output shaft 24B. Therefore, as shown in FIGS. 4A and 4B, the tilt amount θ2 in the second comparative example of the output shaft 24B is smaller than the tilt amount θ1 in the first comparative example of the output shaft 24B.

[0061] Thus, when the clearance distance between the outer circumferential surface of the outer ring of the third bearing 53 and the inner circumferential surface of the first opening 50A is the same, the tilt amount of the output shaft 24B decreases as the outside diameter φ1 of the bearing attachment portion 24B1 increases.

Effects of Embodiment

[0062] The present embodiment has the following effects. [0063] (1) The outside diameter of the output shaft 24B is set so that the third center line O3 passing through the center of the cross section obtained by cutting the third bearing 53 in the axial direction is positioned on the radially outer side of the first center line O1 passing through the center of the cross section obtained by cutting the first bearing 46 in the axial direction. The outside diameter is the outside diameter φ1 of the bearing attachment portion 24B1. In this way, the tilt of the output shaft 24B can be suppressed compared to, for example, the case where the outside diameter φ1 of the bearing attachment portion 24B1 is set so that the third center line O3 is positioned on the radially inner side of the first center line O1. This is because the tilt amount of the output shaft 24B decreases as the outside diameter φ1 of the bearing attachment portion 24B1 increases. The first center line O1 is a reference for setting the outside diameter φ1 of the bearing attachment portion 24B1. [0064] (2) The outside diameter φ1 of the bearing attachment portion 24B1 when the first center line O1 is positioned on the radially outer side of the second center line O2 is larger than, for example, the outside diameter φ1 of the bearing attachment portion 24B1 when the first center line O1 is positioned on the radially inner side of the second center line O2. A bearing having a larger bore diameter as the outside diameter φ1 of the bearing attachment portion 24B1 increases is used as the third bearing 53. As the bore diameter of the third bearing 53 increases, the number of balls in the third bearing 53 increases. As the number of balls increases, the load on each ball decreases. Therefore, the useful life of the third bearing 53 can be secured. [0065] (3) The output shaft 24B is supported via the single third bearing 53 to be rotatable relative to the inner circumferential surface of the second housing 50. That is, the output shaft 24B only needs to be provided with the single bearing attachment portion 24B1. Therefore, the axial length of the output shaft 24B can be reduced compared to, for example, the case where the output shaft 24B is supported by two bearings spaced away from each other in the axial direction. Thus, it is possible to reduce the axial length of the speed reducer 25 and furthermore the total axial length of the speed reducer 25 and the steering gearbox 22.

[0066] In the case where the output shaft 24B is supported by two bearings, the output shaft 24B needs to be provided with two bearing attachment portions 24B1 spaced away from each other in the axial direction. Therefore, the axial length of the output shaft 24B increases. Thus, the axial length of the speed reducer 25 and furthermore the total axial length of the speed reducer 25 and the steering gearbox **22** may increase. [0067] (4) The bearing attachment portion **24**B**1** is positioned opposite to the ball screw shaft **41** across the worm wheel attachment portion **24**B**2**. The ball screw shaft **41** has the connection hole **41**B extending in the axial direction at the first end. The end of the output shaft **24**B positioned opposite to the bearing attachment portion **24**B**1** across the worm wheel attachment portion **24**B**2** is indirectly supported by the first bearing **46** via the peripheral wall of the connection hole **41**B while being fitted to the connection hole **41**B in the axial direction. Therefore, the output shaft **24**B can stably be supported by the third bearing **53** and the first bearing **46**. [0068] (5) The first housing **40** and the second housing **50** are fitted together in the axial direction to have an overlapping portion in a direction orthogonal to the axial direction. Therefore, it is possible to reduce the total axial length of the speed reducer **25** and the steering gearbox **22** compared to the case where the first housing **40** and the second housing **50** are connected, for example, by abutting against each other in the axial direction. [0069] (6) The second end face of the worm wheel **51** has the recess **51**A. A portion of the first housing **40** is inserted into the recess **51**A in the axial direction. The portion of the first housing **40** is a portion of the connection portion **40**A. Therefore, it is possible to reduce the total axial length of the speed reducer **25** and the steering gearbox **22** compared to the case where the second end face of the worm wheel **51** is, for example, a flat face without the recess **51**A. [0070] (7) With the above configurations (5), (6), the axial distance between the first bearing **46** and the third bearing **53** can further be reduced. Further, the first bearing **46** can be positioned in correspondence with the axial position of the second end of the output shaft **24**B. [0071] (8) Since the total axial length of the speed reducer **25** and the steering gearbox **22** is further reduced, the speed reducer **25** and the steering gearbox **22** can easily be mounted on the vehicle.

Other Embodiments

[0072] The present embodiment may be modified as follows. [0073] The fitting relationship between the first housing **40** and the second housing **50** may be reversed. That is, the outer circumferential surface of the second housing **50** may be fitted to the inner circumferential surface of the first housing **40** in the axial direction. Even in this way, the first housing **40** and the second housing **50** are fitted together in the axial direction to have an overlapping portion in a direction orthogonal to the axis. [0074] The first center line O**1** need not be positioned on the radially outer side of the third center line O**3**. In the case where the first bearing **46** and the second bearing **47** are not the same products, there is a possibility that the third center line O**3** and the second center line O**2** do not coincide with each other. For example, the third center line O**3** may be positioned on the radially outer side or the radially inner side of the second center line O**2**. Even in this case, it is appropriate to set the outside diameter φ**1** of the bearing attachment portion **24**B**1** so that the first center line O**1** is positioned on the radially outer side of the second center line O**2**.

[0075] In the case where the third center line O**3** is positioned on the radially outer side of the second center line O**2**, the outside diameter φ**1** of the bearing attachment portion **24**B**1** may be set so that the first center line O**1** is positioned on the radially outer side of the third center line O**3**. By setting the outside diameter φ of the bearing attachment portion **24**B**1** to a larger value, it is possible to further suppress the tilt of the output shaft **24**B. The third center line O**3** may be used as a reference for setting the outside diameter φ**1** of the bearing attachment portion **24**B**1**. [0076] The first housing and the second housing need not be fitted together in the axial direction to have an overlapping portion in a direction orthogonal to the axial direction. For example, the first housing **40** and the second housing **50** may be connected to each other by abutting against each other in the axial direction. [0077] A portion of the first housing **40** need not be inserted into the recess **51**A of the worm wheel **51** in the axial direction. In this case, a configuration in which the recess **51**A is omitted may be adopted as that of the worm wheel **51**. The second end face of the worm wheel **51** is provided, for example, as a flat face. [0078] The axial position of the first bearing **46** and the axial position of the second end of the output shaft **42**B need not correspond to each other. In this case, the output shaft **24**B may be supported by two bearings spaced away from each other in the axial direction. The first bearing **46** may support the ball screw shaft **41** at a position offset in the axial direction from the second end of the output shaft **42**B. [0079] The outside diameter of the bearing attachment portion **24**B**1** and the outside diameter of the worm wheel attachment portion **24**B**2** may be the same. Further, the outside diameter of the output shaft **24**B may be constant over its entire length. Even in this case, the outside diameter of the output shaft **24**B is set so that the first center line O**1** is positioned on the radially outer side of the second center line O**2**. Thus, it is possible to suppress the tilt of the output shaft **24**B. [0080] The position of the torque sensor **24** may be changed as appropriate. For example, the torque sensor **24** may be provided midway along the steering shaft **21**. In this case, a configuration including a shaft similar to the output shaft **24**B may be adopted as that of the speed reducer **25**. The steering shaft **21** is connected to the ball screw shaft **41** via the shaft. The shaft rotates in conjunction with the steering of the steering wheel **26**.

Claims

1. A steering system comprising: a shaft configured to rotate in conjunction with steering of a steering wheel of a vehicle; a ball screw mechanism configured to convert rotation of the shaft into rotation of an output shaft configured to operate in conjunction with a steered wheel; and a speed reducer configured to apply torque to the shaft, wherein the ball screw mechanism includes: a first housing; a ball screw shaft housed inside the first housing, the ball screw shaft including a first end and a second end, and being connected to the shaft to be rotatable together by intermeshing coupling between the first end and the shaft; a first bearing that supports the first end of the ball screw shaft so that the ball screw shaft is rotatable relative to the first housing; and a second bearing that supports the second end of the ball screw shaft so that the ball screw shaft is rotatable relative to the first housing, the speed reducer includes a second housing that is connected to the first housing in an axial direction and into which the shaft is inserted in the axial direction, and a third bearing that supports the shaft so that the shaft is rotatable relative to the second housing, a line passing through a center of a cross section obtained by cutting the first bearing in the axial direction and parallel to a central axis of the shaft is a first center line, a line passing through a center of a cross section obtained by cutting the second bearing in the axial direction and parallel to the central axis of the shaft is a second center line, a line passing through a center of a cross section obtained by cutting the third bearing in the axial direction and parallel to the central axis of the shaft is a third center line, and an outside diameter of the shaft is set so that the third center line is positioned on an outer side of the first center line or the second center line in a radial direction about the central axis of the shaft.
2. The steering system according to claim 1, wherein the speed reducer includes, inside the second housing, a worm wheel attached to an outer circumferential surface of the shaft, and a worm meshing with the worm wheel, the shaft includes a bearing attachment portion to which the third bearing is attached, and a worm wheel attachment portion that is adjacent to the bearing attachment portion in the axial direction and to which the worm wheel is attached, and an outside diameter of the bearing attachment portion is set so that the third center line is positioned on the outer side of the first center line or the second center line in the radial direction about the central axis of the shaft.
3. The steering system according to claim 2, wherein the bearing attachment portion is positioned opposite to the ball screw shaft across the worm wheel attachment portion, the ball screw shaft has a connection hole extending in the axial direction at the first end, and an end of the shaft positioned opposite to the bearing attachment portion across the worm wheel attachment portion is indirectly supported by the first bearing via a peripheral wall of the connection hole while being fitted to the connection hole in the axial direction.
4. The steering system according to claim 3, wherein the worm wheel has a recess that is open opposite to the bearing attachment portion across the worm wheel attachment portion, and a portion

of the first housing is inserted into the recess in the axial direction.

5. The steering system according to claim 1, wherein the first housing and the second housing are fitted together in the axial direction to have an overlapping portion in a direction orthogonal to the axial direction.

6. The steering system according to claim 1, further comprising a torque sensor configured to detect steering torque applied to the steering wheel, wherein the torque sensor includes an input shaft to which the steering torque is transmitted, an output shaft provided to be rotatable relative to the input shaft, and a torsion bar connecting the input shaft and the output shaft, and the shaft is the output shaft.