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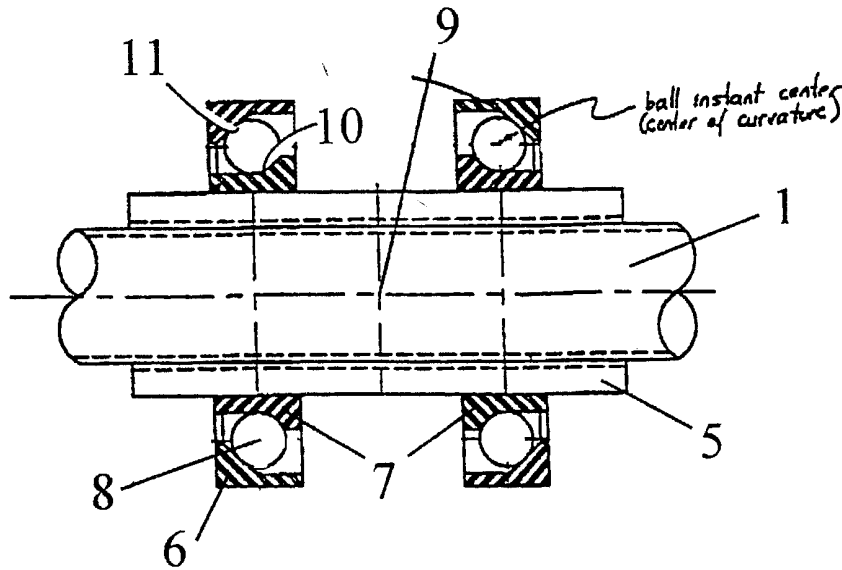
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(54) Title: VIRTUAL BALL JOINT



(57) Abstract: A virtual ball joint, comprising a pair of bearings (4) disposed about a center of curvature (9); each of the bearings comprising an inner race (7) and an outer race (6) supporting a plurality of balls (8) therebetween. The inner and outer races have angled surfaces (10 and 11) in contact with the balls (8), such that the outer angled surfaces (11) coincide with an imaginary sphere (13) centered about the center of curvature (9). A shaft (1) mounted in the bearings (4) may thus be rotated about the center of curvature as if mounted with a ball joint.



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VIRTUAL BALL JOINT

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is based upon, and claims the benefit of, United States Provisional Application Nos. 60/154,607, filed on September 17, 1999, and 60/159,822, filed on October 15, 1999, the disclosures of both of which are incorporated by reference herein in their entirety.

FIELD OF THE INVENTION

This disclosure relates to mechanical joints, particularly those used with sleeve-and-rack assemblies.

BACKGROUND OF THE INVENTION

It is known to provide power assist to a steering assembly by providing a sleeve surrounding and threadingly engaged with the rack such that rotation of the sleeve by a motor imparts force to the rack, thereby assisting the driver in steering the vehicle. However, providing such a sleeve causes the steering system to be overconstrained, thereby resulting in high friction and excessive wear and tear. Such systems as have actually been put into production show high friction and wear at the sleeve, indicating that the rack is not moving linearly along the axis of the sleeve,

thereby causing strain. This implies that prior art sleeve-and-rack systems are overconstrained. What is needed is a means to relieve the constraint.

BRIEF SUMMARY OF THE INVENTION

Disclosed is a “virtual ball joint” that comprises a pair of bearings, each having outer races with angled surfaces coinciding with a spherical surface, thereby allowing spherical motion of the inner and outer races relative to one another about a center of curvature. A shaft mounted in the bearings is thereby able to rotate about the center of curvature as though mounted with a ball joint. The device is particularly useful for mounting ball screw rack sleeves used in power assisted sleeve-and-rack steering assemblies. By so doing, two degrees of freedom are added to the power assist system, thereby transforming the sleeve-and-rack assembly from an overconstrained mechanical system to an underconstrained one. It is further disclosed that the load bearing capabilities of such a virtual ball joint are adequately preserved so long as the relative spherical motion of the bearing races is limited to no more than a fraction of a degree.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows a typical arrangement for assisted power steering.

Figures 2a and 2b show cross-sectional views of a virtual ball joint.

Figure 3 schematically shows the sphere defined by the angled surfaces in the races.

Figure 4 shows a stick figure and a schematic figure of a rack and pinion assembly equipped with a ball screw mechanism.

Figure 5 is a cross-sectional view of a virtual ball joint with the belleville springs.

DETAILED DESCRIPTION OF THE INVENTION

Referring to Figure 1, there is shown a power assisted rack 1 and pinion 3 mechanism. The pinion 3 connected to a steering wheel causes the rack 1 to

move from side to side as the steering wheel is turned in one direction or the other. The movement of the rack 1 is assisted by a sleeve 5 which is threadingly engaged with the rack 1 such that the rotation of the sleeve in one direction or the other will cause the rack to move back and forth and thereby turn a plurality of roadwheels linked to the rack. The sleeve 5 is rotatably mounted to the frame or chassis of the automobile by a pair of bearings 4. The sleeve will typically be driven by an electric motor that responds to a power steering assist system that will usually be responsive to torque sensors, mounted on the steering column or on the pinion 3, and thereby provide power assist to the driver of the vehicle. A preferred sleeve and power assist mechanism is a ball screw rack having a rolling key such as is described in U.S. Patent Application Serial No. _____, Attorney Docket No. H-204294, entitled BALL SCREW RACK ASSEMBLY, filed _____, the disclosures of which are incorporated by reference herein in their entirety and which in turn is based upon United States provisional patent application No. 60/154,682, filed September 17, 1999, the disclosures of which are also incorporated by reference herein in their entirety.

A major drawback with these systems is that there is significant wear and tear on the sleeve as result of the rack deviating from it's own assembly axis, due to bending and tolerances, when steering the vehicle. This places significant stress on the sleeve and, hence, the bearings. It has been discovered that this stress is completely relieved by permitting rotational motion of the sleeve about a point 9 located between the bearings 4.

Referring to Figures 2a and 2b, each bearing 4 comprises an inner race 7 and an outer race 6, between which are supported a plurality of balls 8. The inner race is provided with an inner angled surface 10 that opposes another outer angled surface 11 on the outer race 6.

Referring to Figures 2a, 2b, and 3, the angled outer surfaces 11 correspond to the surface of an imaginary outer sphere 13 that has a center of curvature 9. This is clearly seen in schematic form in Figure 3. The radius of curvature of the outer sphere is determined from the ball 8 circle diameter and the contact angle, α , formed between the ball 8 and the inner surface 10, such that it is equal to the half ball circle diameter multiplied by the arc-cosine of the contact angle,

α. This measurement also determines the distance between the bearings 4 and the center of curvature of the outer surface 11 to be exactly in the middle of the bearings 4 and on the axis of the rack 1.

Referring back to Figure 2a and 2b, it can be seen that the assembly behaves like a virtual ball joint, allowing the sleeve-and-rack to pivot about the center of curvature 9 in any direction, because the inner race 7 can spherically rotate relative to the outer race 6, albeit for relatively small movements. Nevertheless, small freedom of movement is all that is needed to relieve the stresses on the rack. It has been found that allowing too much movement reduces the load-bearing capacity of the bearing. Generally, the range of spherical movement of the inner race in relation to the outer race will be from about 0.1 to about 1 degree, preferably less than a degree, more preferably about 0.25 degrees. This allows sufficient freedom of movement to solve the constraint problem with sleeve-and-rack assemblies while providing acceptable load carrying capability.

Figure 2b shows the same mechanism of Figure 2a, but with the sleeve 5 rotated upward slightly about the center of curvature 9.

Referring to Figure 4, there is shown a stick diagram at the top and a mechanical schematic at the bottom of a typical sleeve-and-rack power assisted steering assembly. The sleeve in this case is a ballscrew. Mechanical kinematics requires that the degrees of freedom (d.o.f) of any mechanism must be equal to the number of inputs. For Figure 4, we have the following components:

<u>Link</u>	<u>Link</u>	<u>Joint Type</u>	<u>Constraint of d.o.f.</u>
Pinion	Housing	Revolute	5
Rack Bearing	Housing	Cylinder	4
Ballscrew Nut	Housing	Revolute	5
Ballscrew Nut	Ballscrew Screw	Screw	5
Rack Bearing	Rack	Cam+1 Axial	2+1
Pinion	Rack	Gear+1 Axial	2+1
Housing	Ground	Fixed	6

TOTAL

31

The degree of freedom of the entire mechanism may be calculated by:

$$\text{d.o.f.} = 6 * (\text{No. of Links}) + \text{sum}(\text{Constraint of Joint}) = 6 * 5 - 31 = -1 \quad (1)$$

The mechanism has a negative d.o.f., indicating that the system is overconstrained. The overconstraint problem is solved by removing two constraints from the link between the ballscrew nut and the housing, thereby converting the revolute joint type into a ball joint type as follows:

<u>Link</u>	<u>Link</u>	<u>Joint Type</u>	<u>Constraint of d.o.f.</u>
Pinion	Housing	Revolute	5
Rack Bearing	Housing	Cylinder	4
Ballscrew Nut	Housing	Ball	3
Ballscrew Nut	Ballscrew Screw	Screw	5
Rack Bearing	Rack	Cam+1 Axial	2+1
Pinion	Rack	Gear+1 Axial	2+1
Housing	Ground	Fixed	6
TOTAL			29

Inserting into equation 1, above, results in a positive calculated d.o.f. of 1, thereby indicating that the system is now underconstrained.

Referring to Figures 1 and 5, the initial accurate positioning of the sleeve 5 over the rack shaft 1 is necessary, but rather difficult to achieve with the bearings 4 placed in position. This adjustment is usually done by a threaded adjuster (not shown). Also, proper adjustment of the bearings 4 is frequently required to maintain the components in alignment and to reduce wear and tear. The excess wear and tear creates an audible noise when the load on the rack 1 increases, or the travel

direction of the sleeve 5 is reversed. Moreover, if the sleeve housing 20 is constructed of material other than steel, then it will be subjected to thermal expansion and contraction affecting the alignment of the bearings 4 and the sleeve 5.

Referring to Figure 5, an embodiment of the virtual ball joint that overcomes the above mentioned shortcomings of the prior art includes a plurality of belleville springs 18, preferably two, having a generally frustoconical shape with an inner periphery that is spaced axially from the plane of the outer periphery such that a force, applied axially against the belleville spring, causes the inner periphery to move toward the outer periphery and thereby place the belleville spring under compression. This movement of the frustoconical shaped spring steel element in an axial direction causes the belleville spring 18 to generate a reactive force proportional to the applied load, which reactive force is not uniform over the relatively small movement of a frustoconical spring. The reactive force and a high elasticity of belleville spring 18 return compensates for the developed misalignment caused by surface deterioration of the threaded sleeve 5 over the rack shaft 1, and eliminates the need for future component alignment. Each belleville spring 18 is preferably disposed within the sleeve housing 20 on opposite sides of the sleeve 5 with each belleville spring 18 having its concave surface facing the bearings 4 and the edges of the inner periphery are contacted with the outer races 6 of the bearing 4. The outer diameter of the outer periphery is sized to house the rack shaft 1 movably therethrough. Therefore, the bearings 4 and the sleeve 5 are continuously adjusted due to the reactive force from each belleville spring 18, and the increased load on the rack shaft 1 is countered by the reactive force from the belleville springs 18 keeping the rack shaft 1 in an aligned engagement with the sleeve 5.

While preferred embodiments have been shown and described, various modifications and substitutions may be made thereto without departing from the spirit and scope of the invention. Accordingly, it is to be understood that the present invention has been described by way of illustration only, and such illustrations and embodiments as have been disclosed herein are not to be construed as limiting to the claims.

CLAIMS

What is claimed is:

1. A virtual ball joint, comprising:
a plurality of bearings;
each of said bearings comprising an inner race and an outer race
supporting a plurality of balls therebetween; and
5 said inner race comprising inner angled surfaces and said outer race
comprising outer angled surfaces in contact with said balls, said angled outer surfaces
coinciding with an imaginary sphere centered about a center of curvature such that
said inner race is free to spherically rotate relative to said outer race.
2. The virtual ball joint recited in claim 1 further comprising a
plurality of belleville springs disposed within a sleeve housing and secured against
said outer race of each of said bearings wherein a rack shaft is slideably disposed
within an outer diameter of said belleville spring.
3. The virtual ball joint of claim 1 wherein said inner race is free
to spherically rotate no more than from about 0.1 degrees to about 1 degree relative to
said outer race.
4. The virtual ball joint of claim 3 wherein said inner race is free
to spherically rotate no more than about 0.25 degrees relative to said outer race.
5. The virtual ball joint of claim 2 wherein said inner race is free
to spherically rotate no more than from about 0.1 degrees to about 1 degree relative to
said outer race.

6. The virtual ball joint of claim 5 wherein said inner race is free to spherically rotate no more than about 0.25 degrees relative to said outer race.

7. A rack assembly, comprising:
a rack adapted to turn a plurality of roadwheels;
a sleeve, threadingly and rotationally engaged with said rack so as to move said rack in a manner effective in tuning said roadwheels when rotated; and
5 said sleeve mounted by a virtual ball joint, comprising:
a plurality of bearings;
each of said bearings comprising an inner race and an outer race supporting a plurality of balls therebetween; and
said inner race comprising inner angled surfaces and said outer race
10 comprising outer angled surfaces in contact with said balls, said angled outer surfaces coinciding with an imaginary sphere centered about a center of curvature such that said inner race is free to spherically rotate relative to said outer race.

8. The rack assembly recited in claim 7 further comprising a plurality of belleville springs disposed within a sleeve housing and secured against said outer race of each of said bearing wherein a rack shaft is slideably disposed within an outer diameter of said belleville spring.

9. The rack assembly of claim 7 wherein said sleeve comprises a ball screw.

10. The rack assembly of claim 7 wherein said sleeve is rotated by a power steering assist system.

11. The rack assembly of claim 8 wherein said sleeve comprises a ball screw.

12. The rack assembly of claim 8 wherein said sleeve is rotated by a power steering assist system.

13. The virtual ball joint of claim 7 wherein said inner race is free to spherically rotate no more than from about 0.1 degrees to about 1 degree relative to said outer race.

14. The virtual ball joint of claim 13 wherein said inner race is free to spherically rotate no more than about 0.25 degrees relative to said outer race.

15. The virtual ball joint of claim 8 wherein said inner race is free to spherically rotate no more than from about 0.1 degrees to about 1 degree relative to said outer race.

16. The virtual ball joint of claim 15 wherein said inner race is free to spherically rotate no more than about 0.25 degrees relative to said outer race.

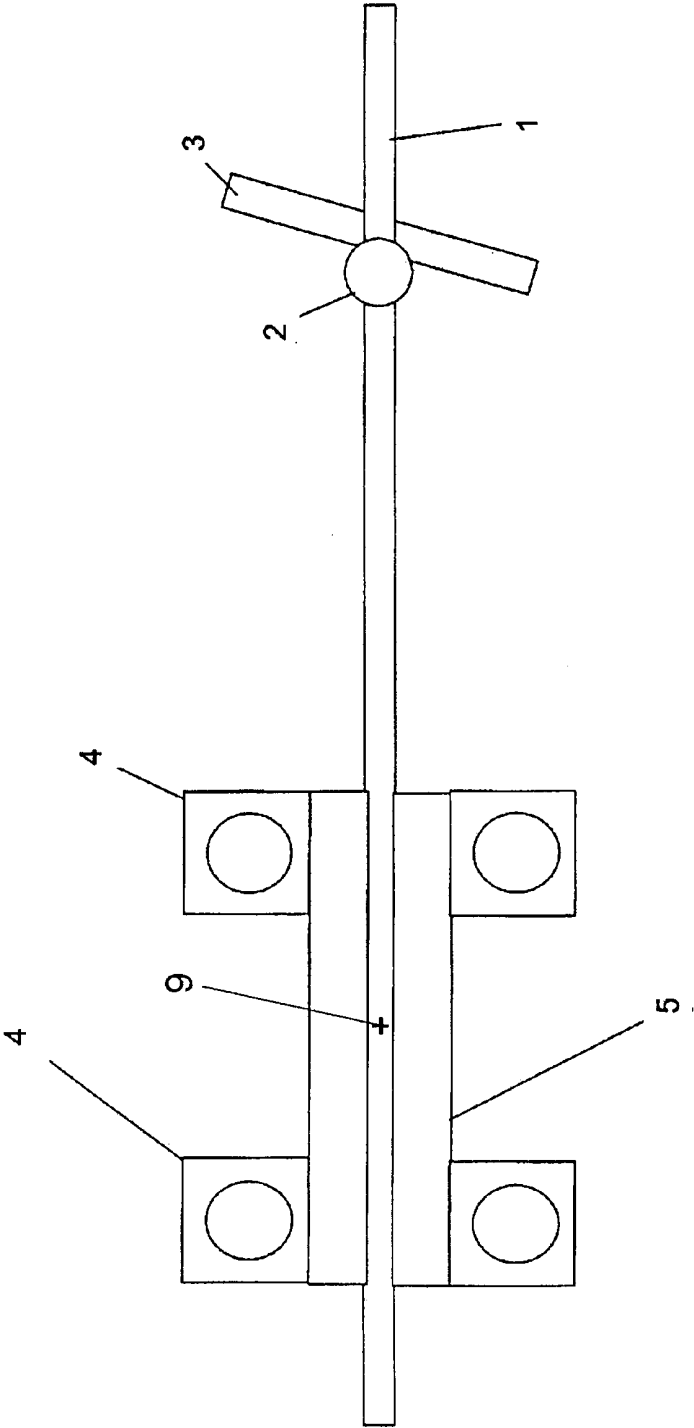


Figure 1

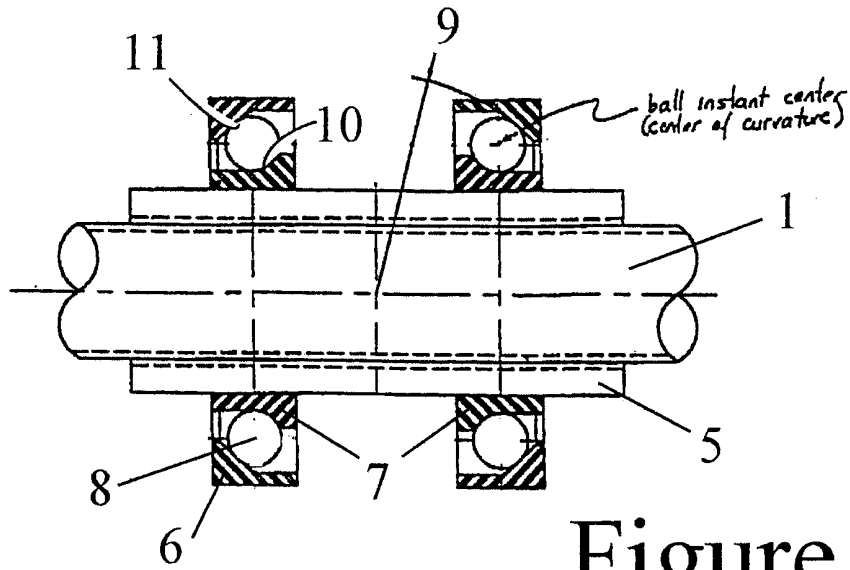


Figure 2a

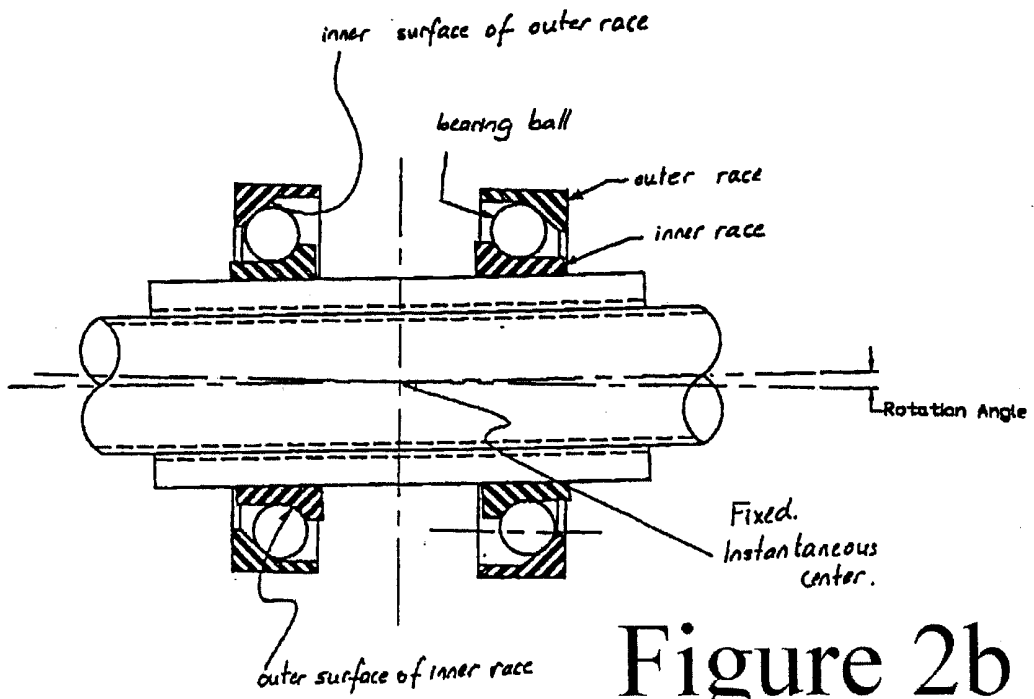


Figure 2b

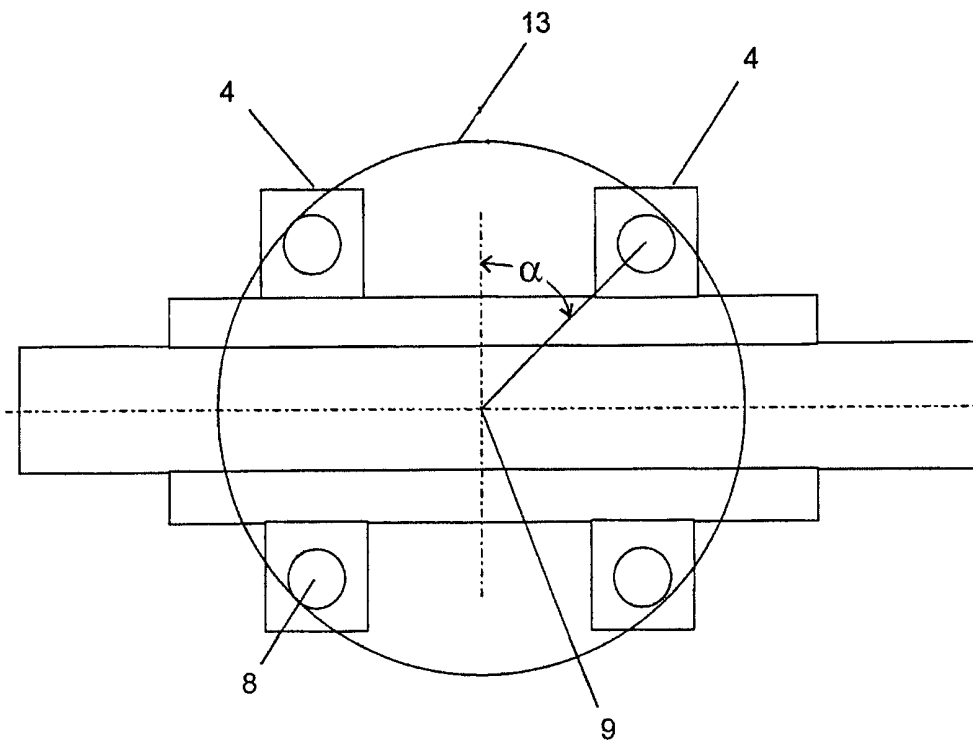


Figure 3

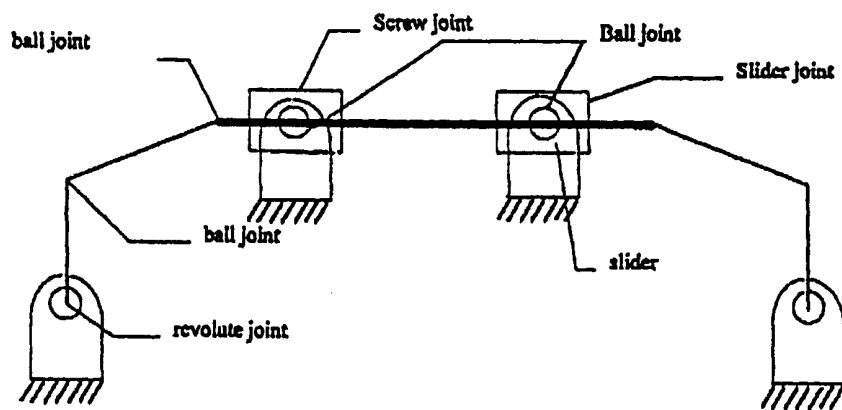
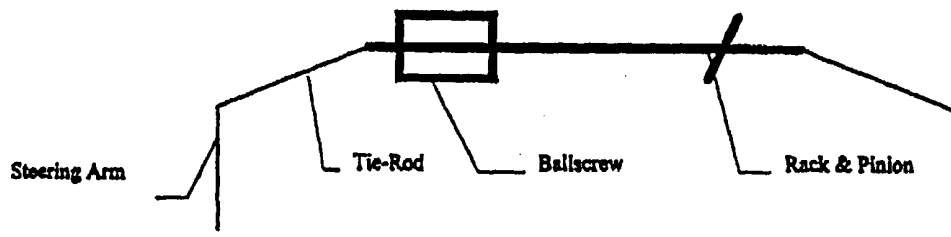
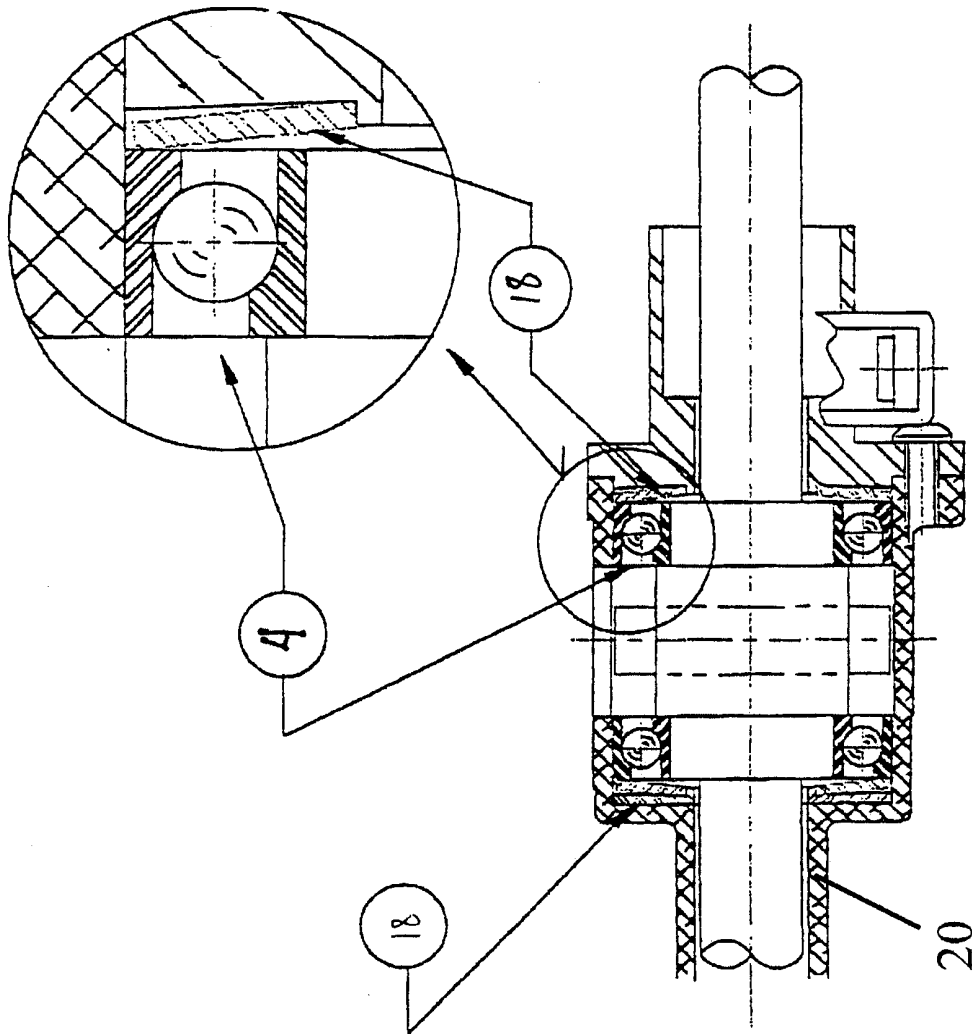


Figure 4

Figure 5



INTERNATIONAL SEARCH REPORT

International application No.
PCT/US00/25458

A. CLASSIFICATION OF SUBJECT MATTER				
IPC(7) : F16C 23/08 US CL : 384/496				
According to International Patent Classification (IPC) or to both national classification and IPC				
B. FIELDS SEARCHED				
Minimum documentation searched (classification system followed by classification symbols) U.S. : 384/496, 495, 497, 498, 504, 512, 513, 516, 517; 180/427, 428, 444; 74/388PS				
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched				
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)				
C. DOCUMENTS CONSIDERED TO BE RELEVANT				
Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.		
X	US 1,284,827 A (VORRABER) 12 November 1918 (12.11.18), column 1, lines 37-60.	1		
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Y		3, 4		
A	US 637,204 A (HEATH) 14 November 1899 (14.11.1899).	1-6		
A	US 1,321,417 A (CARLBORG et al) 11 November 1919 (11.11.1919).	1-6		
A	US 1,234,779 A (LJUNGBERG) 31 July 1917 (31.07.1917).	1-6		
<input type="checkbox"/> Further documents are listed in the continuation of Box C. <input type="checkbox"/> See patent family annex.				
<table style="width: 100%; border: none;"> <tr> <td style="width: 50%; border: none;"> * Special categories of cited documents: "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier application or patent published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed </td> <td style="width: 50%; border: none;"> "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family </td> </tr> </table>			* Special categories of cited documents: "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier application or patent published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family
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Date of the actual completion of the international search	Date of mailing of the international search report			
29 November 2000 (29.11.2000)	03 JAN 2001			
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703)305-3230	Authorized officer Thomas R. Hannon <i>Diana Brutt</i> Telephone No. (703) 308-2168			