by the motor in turning the front vehicle wheels will be greater, thus resulting in a slight lagging of the motor and consequently a slight lagging in the follow-up movement of the valve casing **30**, resulting in a wider opening of the valve ports and consequently the establishment of greater differential pressures in the motor. These greater differential pressures, of course, will be duplicated in the diaphragm chambers **73** and **74**, and since the diaphragm **69** is mechanically connected to the steering wheel, it will be obvious that the greater the resistance encountered by the motor in turning the front wheels of the vehicle the greater will be the resistance which the operator will feel in turning the steering wheel. Thus the present device provides the steering wheel with "feel" which is accurately proportional to the resistance encountered by the motor in turning the front vehicle wheels.

The foregoing description applies, of course, to a reverse turning movement of the steering wheel, the valve **31** being moved to the left as viewed in Figure 4 to increase the degree of communication between the motor casing **23** and the source of vacuum while connecting the motor casing **24** to the atmosphere, through port **51**, groove **49** and atmospheric space **63**. This will result in the admisison of air into the motor casing **24** and consequent movement of the diaphragm **27** to the right as viewed in Figure 1. Under such conditions the lever **39** will have been turned in a counterclockwise direction and the motor **22** will turn the lever **16** in the same direction to effect a follow-up action of the valve mechanism, the steering forces being applied to the dirigible wheels of the vehicle, of course, through the drag link **15** or a corresponding steering connection. The reaction pressures in the diaphragm chambers **73** and **74** of course will be reversed but will function in the same manner as before to take up all mechanical play in the system and to afford accurate "feel" to the operator.

The manually operated portion of the mechanism is connected to the power operated portion only through the diaphragm **69** which, of course, is highly resilient. This arrangement prevents the transmission of road shocks to the steering wheel. Any tendency for the front wheels to swing through the encountering of an obstacle or hole in the highway will be transmitted through the drag link **15** to the levers **16** and thence to the valve casing **30** to move this casing in one direction or the other, thus immediately establishing or increasing differential pressures in the motor **22** to overcome the force tending to turn the front wheels of the vehicle. The establishment of such differential pressures in the motor will be duplicated in the chambers **73** and **74**, but the shock forces transmitted to the operator through the steering wheel will be very much reduced in extent because of the relatively small area of the diaphragm **69** with respect to the area of the diaphragm **27**, and the shock forces will be obviously transmitted solely through the medium of differential pressures in the chambers **73** and **74**, and thus will be cushioned.

It will be obvious that the apparatus functions to prevent the operator's having to constantly swing the steering wheel back and forth to maintain the vehicle in the desired line of travel, even when the vehicle is travelling in a straight line with the valve **31** in neutral position. When the valve is in such position there are no forces present tending to take up play between the parts, but upon any slight turning movement of the front vehicle wheels movement will be imparted to the motor casing **30** to move it with respect to the valve **31** to immediately establish whatever slight differential pressure is necessary to swing the front wheels back to a straight line position. Moreover, such operation results in immediate establishment of slight differential pressures in the chambers **73** and **74** to take up all play in the mechanical connections, thus stabilizing the operation of the valve mechanism.

The follow-up operation of the valve mechanism, as stated is such that the play between the lever arm **39** and lugs **18** is never taken up in the normal operation of the apparatus. However, in the event of a failure of power in the motor **22**, the motor will not cause operation of the lever **16** and under such conditions the lever arm **39** will swing until it engages one of the lugs **18**, whereupon a manual turning of the lever **16** can be effected. The response of the valve mechanism is so rapid and accurate that the play between the lever arm **39** and each lug **18** may be relatively slight. Emergency manual steering thus can be effected without much more play in the system than is present in most manual steering mechanisms in actual use.

From the foregoing it will be apparent that the present mechanism provides for an accurate follow-up of the motor **22** with respect to turning movement of the steering wheel. It is unnecessary to employ any friction means between the two valve units to tend to stabilize the operation of such units, the system being characterized by a total absence of any artificial resistances to turning movements of the front vehicle wheels. Without the use of friction or similar stabilizing means, the fluid reaction device very accurately stabilizes the operation of the apparatus and completely prevents any overrunning, creeping or "hunting" of the parts. In practice, therefore, it has been found that the front vehicle wheels very accurately remain in a position corresponding to the position of the steering wheel.

Moreover, it will be obvious that the normal jolts and jars to which a motor vehicle is subjected can, and do, tend to affect the positions of the valve elements of a vehicle steering mechanism. Thus, aside from any tendency of the front wheels of the vehicle to turn, a jolting of the vehicle frequently tends to move one of the valve elements. This would tend to cause a relative movement of the valve elements to effect at least limited energization of the steering motor, thus generating power to turn the front wheels, the direction of turning of such wheels depending upon the direction of relative movement of the valves.

Thus without any turning movement of the front wheels of the vehicle or any turning movement of the steering wheel imparted thereto by the operator a motor-energizing relative movement of the valves sometimes occurs. It is a particularly important feature of the present invention that it functions to prevent turning movement of the front wheels of the vehicle under such conditions. It will be noted that the area of the diaphragm **69** (Figures 4 and 5) is much smaller than the area of the diaphragm **27** (Figure 1), while the volumes of the diaphragm chambers **73** and **74** are relatively small compared with the volumes of the chambers formed in the ends of the motor **22**. Thus it will be apparent that upon any motor-energizing relative movement of the

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Fig. 4.

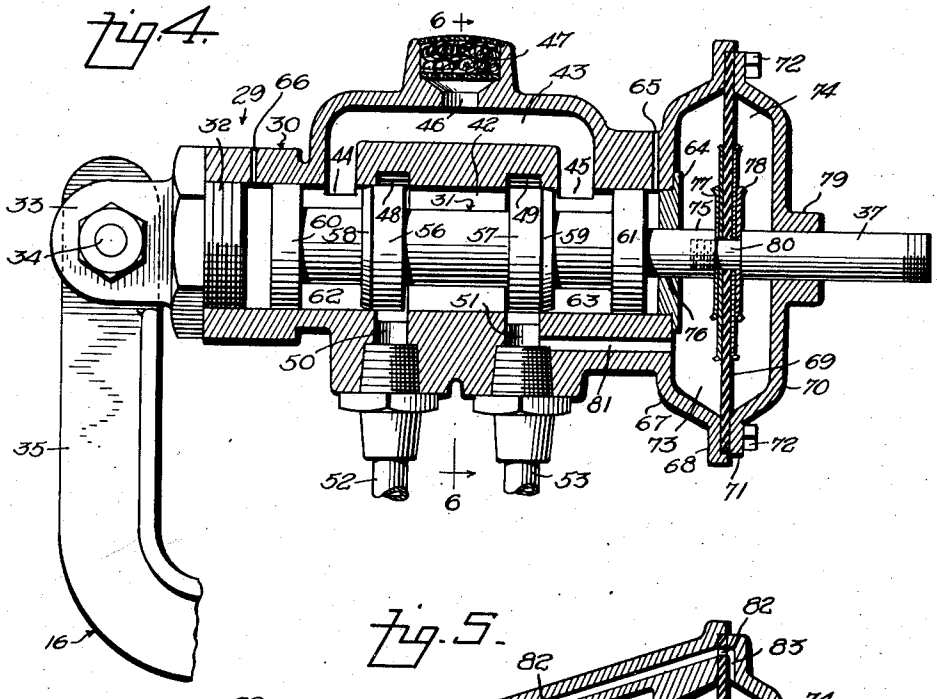


Fig. 5.

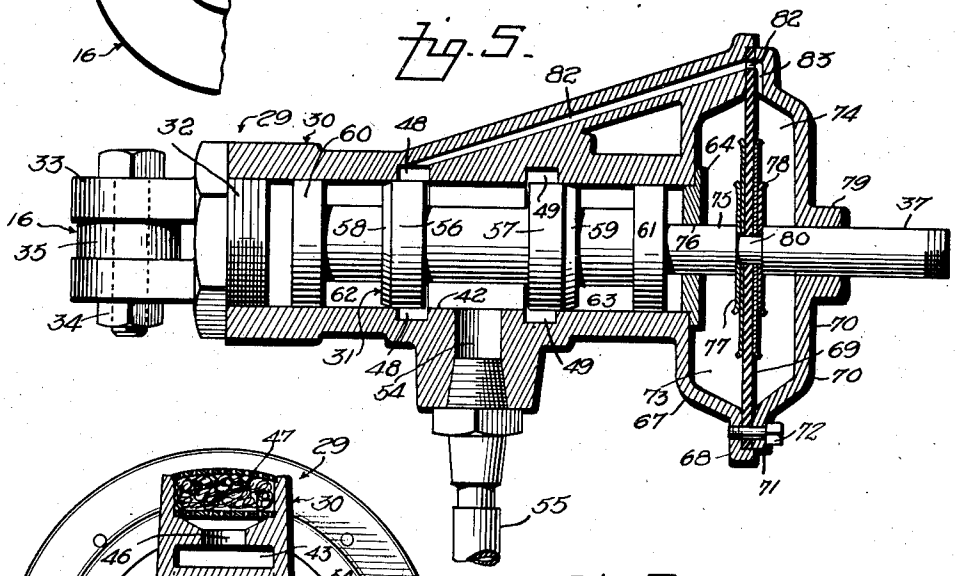
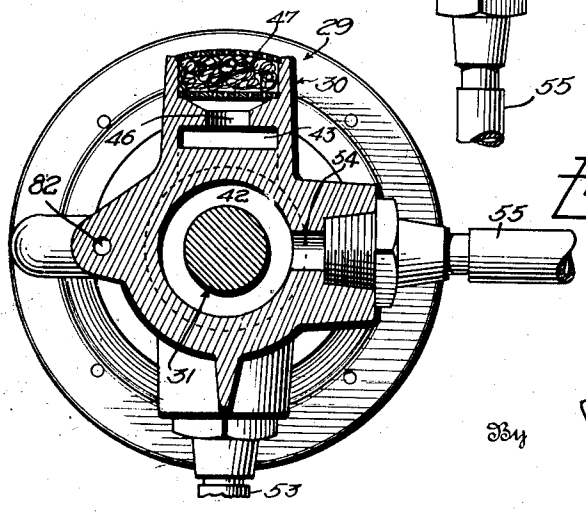


Fig. 6.



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2,313,704

POWER STEERING MECHANISM

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Application October 1, 1941, Serial No. 413,220

15 Claims. (Cl. 180—79.2)

This invention relates to power steering mechanisms.

Numerous attempts have been made to develop efficient power steering mechanisms for motor vehicles employing fluid pressure motors controlled by follow-up valve mechanisms operable by the steering wheel and by the action of the fluid pressure motor so that a given turning movement of the steering wheel will be followed by a proportional operation of the fluid pressure motor, the motor causing a follow-up action of the valve mechanism. These devices have been found to be operable but not commercially satisfactory and accordingly have never come into commercial use. There are several reasons for the unsatisfactory operation of prior mechanisms of this type. In the first place, it is impossible to connect the steering wheel to the manually operable element of the valve mechanism and to connect the motor to the follow-up element of the valve mechanism without introducing some lost motion into the mechanical connections. As a result, a given turning movement of the steering wheel does not accurately operate the steering motor to turn the front wheels of the vehicle at a given angle and hold them at such angle when the steering wheel is held stationary.

It will be apparent that with the slight lost motion in the mechanical connections referred to, due to the play therein, the manually operable element of the valve mechanism will be moved only approximately to the correct position, and while this position is sufficiently accurate the valve will not accurately remain in the position to which it is moved. The bouncing and vibratory forces transmitted to the valve mechanism by the moving vehicle will cause the manually operable valve to move back and forth within the limits of the play in its mechanical connections, thus energizing the motor to cause the front vehicle wheels to swing back and forth. If this operation does not occur, it almost always happens that the manually operable valve will gradually move to the limit of the play in the mechanical connections thereto, thus causing the motor to creep and result in the turning of the dirigible vehicle wheels to a greater extent than is intended.

Attempts have been made to overcome this fault in prior constructions by introducing some means such as frictional resistance to movement of the manually operable valve to provide for greater stability of this valve, which stability is wholly necessary in a practicable mechanism of this character. However, such means is not wholly satisfactory since the frictional resistance cannot be made too great and obviously will be constant, with the result that sudden jolts will move the manually operable valve against the resistance employed.

The second objection to prior mechanisms of this character is due to the fact that in the manual operation of the steering wheel the resistance to turning movement varies in accordance with the speed of the vehicle. When the vehicle is moving slowly much more effort is required to turn the steering wheel, and the average driver instinctively applies to the wheel the amount of force necessary to turn it under individual driving conditions. With prior mechanisms, even those including means for stabilizing the action of the manually operable valve, the operator does not have the same "feel" that he has in manual steering. Accordingly, when a vehicle is traveling relatively slowly and substantial effort normally is required to turn the steering wheel, such effort is not required with prior steering mechanisms and the result is that the operator will instinctively apply more force to the steering wheel than is necessary, thus frequently turning the steering wheel too rapidly or to too great an extent.

An important object of the present invention is to provide a power steering mechanism wherein the operation of the manually controlled valve is stabilized to a highly efficient degree, thus permitting the operator to turn the steering wheel to a given extent and then hold it stationary with the result that the front wheels of the vehicle will accurately turn to the same extent and still steadily hold their proper position without any back and forth turning movement or any creeping movement as has taken place with prior constructions.

A further object is to utilize differential pressures in the steering motor for affecting a pressure responsive element connected to the manually operable valve to oppose movement thereof in the direction in which the valve is being moved by the operator thus immediately taking up what play exists in the connections to the valve and perfectly stabilizing the valve in a given position with respect to the steering wheel.

A further object is to provide a mechanism of this type wherein the pressure responsive means connected to the manually operable valve provides in the steering wheel a degree of resistance to the turning movement thereof which is exactly proportional to the resistance encountered by the

motor in turning the front wheels of the vehicle in accordance with driving conditions, thus closely simulating conventional manual steering operations without the operator's having to exert as much force under any driving conditions as is true in manual steering.

A further object is to provide such a steering mechanism wherein shocks transmitted to the steering wheel by reason of the passage of the front wheels of the vehicle over bumps or holes in the road is so reduced as to be substantially negligible, the apparatus functioning at the same time to provide an extremely rapid increase in the energization of the motor or a reversal of the energization of the motor to take care of the tendency of the front wheels of the vehicle to alter their position, thus causing the vehicle to maintain a steady course without the operator's having to "fight" the steering wheel.

Other objects and advantages of the invention will become apparent during the course of the following description.

In the drawings I have shown one embodiment of the invention. In this drawing—

Figure 1 is a side elevation of the invention applied to the steering column and associated elements of a vehicle, the motor being shown in section and parts being broken away,

Figure 2 is a detail perspective view of the main lever of the apparatus,

Figure 3 is a detail sectional view on line 3—3 of Figure 1,

Figure 4 is an enlarged detail central vertical longitudinal sectional view through the valve mechanism,

Figure 5 is a similar view taken horizontally through the valve mechanism, and

Figure 6 is a transverse sectional view on line 6—6 of Figure 4.

Referring to Figure 1, the numeral 10 designates the steering column of a motor vehicle having a steering post 11 therein provided at its upper end with the usual steering wheel 12. The lower end of the steering column is provided with a housing 13 containing the usual reduction gearing means (not shown) for transmitting movement to a shaft 14, this shaft conventionally being directly mechanically connected to the drag link 15 or other element or elements by means of which steering movements are transmitted to the front wheels of the vehicle. In the present case a special lever indicated as a whole by the numeral 16 is employed and this lever will be described in detail below.

The lever is provided intermediate its ends with a hub 17 adapted to be mounted on the end of the shaft 14 and to turn freely thereon. The upper end of the lever 16 is provided with a pair of spaced lugs 18 for a purpose to be described. The lower end of the lever is pivotally connected as at 19 to the drag link or other steering connection 15. Between the shaft 14 and pivot 19, the lower end portion of the lever 16 is pivotally connected as at 20 to a rod 21 operable by a motor indicated as a whole by the numeral 22. This motor is energizable to power-operate the lever 16 as will become apparent. The motor 22 is preferably differential pressure operated and the source of pressure differential conveniently may be the intake manifold of the motor vehicle engine (not shown).

The motor 22 comprises a pair of preferably stamped casing sections 23 and 24, the latter of which is provided with a stud 25 adapted to be pivotally connected to any suitable stationary support (not shown) carried by any stationary part of the vehicle adjacent the motor. This pivotal connection obviously permits the motor to swing bodily to the extent necessary to permit the pivot 20 to turn about the axis of the shaft 14 upon rocking movement of the lever 16. The casing sections 23 and 24 are peripherally flanged as at 26 to be clamped against opposite faces of the peripheral portion of a diaphragm 27 and this diaphragm is secured to the rod 21. This rod is mounted to slide in a bearing 28 carried by the casing section 23.

The motor is controlled by a valve mechanism indicated as a whole by the numeral 29 and illustrated in detail in Figures 4, 5 and 6. The valve mechanism illustrated in the present case comprises a pair of units, namely, a casing indicated as a whole by the numeral 30 and a valve indicated as a whole by the numeral 31. One end of the valve casing is provided with a threaded plug 32 carrying ears 33 and a bolt 34 passes through these ears and through an arm 35 mounted between the ears. The arm 35 forms the end of an elongated arm 36 formed integral with the upper end of the lever 16. Therefore it will be apparent that this lever supports one end of the valve mechanism.

The valve 31 is provided with a stem 37 projecting from the end of the valve casing opposite the plug 32 and this stem is provided at its outer end with a yoke 38. A lever arm 39 has the hub 40 at its lower end surrounding the shaft 14 and keyed thereto as at 41, the lever arm being mounted between the lugs 18 and freely movable therebetween within reasonable limits. The upper end of the lever arm 39 is mounted in the yoke 38 and pivotally connected thereto as at 42. It will be apparent, therefore, that in the embodiment of the invention shown one end of the valve mechanism is supported by the lever 16 while its other end is supported by the upper end of the lever arm 39.

The valve casing 30 is provided with a cylindrical opening 42 therethrough in which the valve 31 is slidable. An air passage 43 is formed in the valve casing and is provided with ports 44 and 45 spaced from each other to be controlled by the valve 31 in a manner to be described. Air is admitted into the passage 43 through a port 46 preferably provided with a small air cleaner 47.

The bore 42 of the valve casing is provided with a pair of spaced annular grooves 48 and 49 communicating with ports 50 and 51 respectively, and these ports, in turn, communicate with opposite ends of the motor 22 through flexible hoses 52 and 53. Between the annular passages 48 and 49 (Figure 5), the valve casing is provided with a vacuum port 54 into which is tapped a pipe line 55 preferably connected to the intake manifold of the motor vehicle engine (not shown) as the source of partial vacuum.

The valve 31 is provided with a pair of spaced heads 56 and 57 having remote tapered ends 58 and 59 respectively. The space between the heads 56 and 57 obviously is in constant communication with the vacuum port 54 (Figure 5). The adjacent faces of the heads 56 and 57 are spaced apart a distance slightly greater than the distance between the inner limits of the grooves 48 and 49 and accordingly it will be apparent that when the valve is in the normal position shown in Figures 4 and 5, both ends of the motor 22 will be in limited communication with the source of vacuum, thus vacuum suspending the motor diaphragm 27.

Spaced from the respective heads 56 and 57, the valve is provided with end heads 60 and 61 providing spaces 62 and 63 in constant communication with the respective air ports 44 and 45. The end of the bore 42 is closed by a cap 64, for a purpose which will become apparent. The space between the head 61 and cap 64 is vented to the atmosphere as at 65, while the space between the head 60 and plug 32 is vented to the atmosphere as at 66. These vent openings obviously are provided to permit free movements of the heads 60 and 61 without creating any sub-atmospheric or super-atmospheric pressure in the ends of the valve casing.

The right hand end of the valve casing as viewed in Figure 4 is provided with an enlarged annular cupped portion 67 having a peripheral flange 68 against which is arranged a flexible diaphragm 69. A cupper cap 70 is provided with a peripheral flange 71 arranged against the opposite side of the diaphragm 69, and the flanges 68 and 71 and diaphragm 69 are secured together by bolts 72. The diaphragm 69 and elements 67 and 70 cooperate to form pressure chambers 73 and 74, for a purpose to be described.

The valve is provided with an axial projection 75 of circular cross-section projecting through a bearing opening 76 formed in the cap 64. It will be apparent that the cap 64 seals the chamber 73 from the space between the cap 64 and head 61, thus maintaining the proper pressure in the chamber 73. The end of the extension 75 seats against the outer of a pair of metal disks 77 arranged against the adjacent side of the diaphragm, similar disks 78 being arranged against the opposite side of the diaphragm. The stem 37 is slidable in a bearing 79 formed in the cap 70 and is provided with a reduced extension 80 projecting through the diaphragm and threaded into the extension 75. It will be apparent that the outermost disks 77 and 78 will be respectively engaged by the ends of the extension 75 and stem 37, thus effectively clamping the diaphragm with relation to the stem 37 and extension 75 and hence with respect to the valve 31.

Referring to Figure 4 it will be noted that the valve casing is provided with a passage 81 communicating between the port 51 and chamber 73. The valve casing is also provided with a passage 82 (Figure 5) communicating with the groove 48 and with the chamber 74 through a port 82 formed in the diaphragm 69 and through a groove 83 formed in the cap 70. The groove 48 communicates with the motor casing 23 (Figure 1) through the port 50 and pipe 52, and the passage 82 thus operates to duplicate in the chamber 74 any pressure which exists in the motor casing 23. Similarly, any pressure existing in the motor casing 24 will be duplicated in the chamber 73 through the passage 81.

The operation of the apparatus is as follows:

As previously stated, the lever 16 is mounted free on the shaft 14, while the lever arm 39 is fixed to the shaft 14. Upon turning movement of the steering wheel 12, therefore, the motion transmitting means within the casing 13 will turn the shaft 14 and with it the lever 39 and this lever is free to partake of movement within the limits defined by the lugs 18 without imparting any movement to the lever 16. Under all normal operating conditions, the play between the lever 39 and the lugs 18 will never be taken up, turning movement of the lever 39 resulting in a follow-up power operation of the lever 16.

Assuming that turning movement of the steering wheel 12 results in turning the lever arm 39 in a clockwise direction a viewed in Figure 1, the stem 37 (Figures 4 and 5) will be moved toward the right and will impart similar movement to the valve 31. In the normal position of the valve 31 as shown in Figures 4 and 5, both ports 50 and 51 will have been in constant restricted communication with the vacuum space between the heads 56 and 57, and accordingly air will have been exhausted from both ends of the motor 22 (Figure 1) to the same extent, pressures being balanced on opposite sides of the diaphragm 27.

Movement of the valve to the right as stated, therefore, will increase the degree of communication between the port 51 and the vacuum space between the valve heads 56 and 57, but this increased communication will not reduce pressure in the motor casing 24 (Figure 1), to which the pipe 53 leads from the port 51, the pressure in such casing having been normally reduced to that of the source. However, movement of the valve 31 to the right as viewed in Figure 4 will cause the head 56 to move to the right and relatively slight movement of the valve will cut off communication between the port 50 and the central vacuum space and will connect the port 50 to the air space 62, thus admitting air through pipe 52 into the motor casing 23 (Figure 1). This immediately establishes differential pressures on opposite sides of the diaphragm 27, the increase in pressure in the motor casing 23 resulting in movement of the diaphragm 27 and rod 21 to the left to impart similar movement to the lower end of the lever 16.

The operation referred to obviously turns the upper end of the lever 16 toward the right as viewed in Figure 1, or in a clockwise direction, which is the direction of turning movement imparted to the lever arm 39. Thus continued movement of the lever 39 will result in continuous movement of the lever 16 and play between the lever 39 and the right hand lug 18 (Figure 1) will not be taken up. When turning movement of the steering wheel 12 is arrested movement of the lever 39 obviously will stop, but it will be apparent that during movement of the valve 31 the valve casing 30 will have been moved by the lever arm 35, thus causing follow-up action of the valve casing with respect to the valve 31 and very slight additional movement of the valve casing after movement of the valve has been stopped will restore the normal position of the valve 31.

It will be apparent that as the normal relative positions of the valve elements is approached, the tapered face 58 will progressively restrict admission of air into the pipe 52 and admission of air will be immediately stopped as soon as the tapered face referred to has passed beyond the annular groove 48. This point and the point at which the right hand limit of the groove 48 passes the right hand limit of the head 57 as viewed in Figure 4 will be reached just prior to the neutral position of the valve elements and continued slight movement of the casing 30 takes place with restricted communication between the groove 48 and the vacuum space between the heads 56 and 57. Thus it will be apparent that the valve mechanism functions to cut off the admission of air into the pressure side of the motor 22 and to start to exhaust air from such side of the motor just before the neutral position of the valve is reached and the result is that pres-

sure in the end of the motor to which air previously has been admitted will be very suddenly dropped, thus eliminating the necessity for an overrunning of the neutral position of the valve in order to re-establish equal pressures in the motor. This operation tends to prevent any overrunning, creeping or "hunting" of the valve but is not in itself sufficient for this purpose. However, the means described below functions to assist the valve in providing a perfect operation in accordance with turning movement of the steering wheel.

It will be obvious that there necessarily will be some slight play in the mechanical connections between the steering wheel and the valve **31** and likewise there will be some slight play in the mechanical connections between the valve casing **30** and the connection of the drag link **15** with the front wheels of the vehicle. In prior steering mechanisms, this play has been sufficient to prevent stabilization of the valve with respect to the valve casing, these two units forming the two units of the follow-up valve mechanism. Assuming that the steering wheel has been operated to turn the vehicle wheels at a given angle, the normal jolting and vibration of the vehicle passing over irregularities in the road surface are sufficient to cause the two valve units to move freely relative to each other within the limits of the "play" in the mechanical connections referred to. With the steering wheel held in a given position, the movement of the parts referred to causes the front vehicle wheels to creep to a different angular position, or to swing back and forth to a fairly substantial extent. It is this inability of prior mechanisms to hold the front wheel steady in a position corresponding to the position of the steering wheel that has rendered such devices wholly impracticable, and the condition referred to is even more annoying when the vehicle is travelling in a straight line. Under such conditions the front wheels will swing back and forth to a sufficient extent to require that the driver swing the steering wheel back and forth to keep the vehicle in a straight line of travel.

The use of the reaction diaphragm **69** in the present mechanism provides a remarkable degree of accuracy and stability in operation and in practice it has been found that the vehicle can be kept on a given course of travel with almost perfect accuracy. When the valve **31** is moved to the right under the conditions previously discussed, the partial vacuum previously existing in the port **51**, pipe **53** and motor casing **24** will be maintained and this pressure is duplicated in the chamber **73** (Figure 4) through the passage **81**. Pressures in the motor casing **23** are duplicated in the chamber **74** (Figure 5) through the passage **82**, this passage communicating with the groove **48**, port **50**, pipe **52** and motor casing **23**. When the valve is in neutral position balanced sub-atmospheric pressures will exist in the chambers **73** and **74**, but upon movement of the valve to the right to admit air into the motor casing **23**, air likewise will be admitted through passage **82** into chamber **74**, thus setting up the pressure in the chamber **74** equal to that in the motor casing **23** and opposing movement of the valve **31** toward the right.

The immediate result of this operation is the generation of a differential fluid pressure reaction between the valve **31** and valve casing **29** and the force tending to move these elements in opposite directions immediately takes up all play in the mechanical connections effecting the two valve units. When the steering wheel is turned, therefore, a follow-up action of the valve is provided and when the operator turns the steering wheel to the desired extent, and then holds it stationary, the valve mechanism functions not to exactly return to neutral position but to a position in which it will maintain in the motor **22** the differential pressure necessary to hold the vehicle wheels against the force tending to return the wheels to a straight position. This tendency of the vehicle wheels, when the valve **31** is moved to the right, exerts a force at the pivot **34** (Figure 4) tending to move the valve casing **30** toward the left to hold the two valve units in such position as to maintain automatically whatever differential pressure is necessary in the motor to hold the front vehicle wheels in the desired position. Any tendency for too great a differential pressure to be established will cause a follow-up action of the valve casing tending to balance pressures in the motor, thus reducing the force applied in turning the front wheels and permitting them to remain in the proper position. Any tendency for the front wheels to swing in the opposite direction will tend to move the valve casing **30** toward the left to increase the differential pressures in the motor, thus preventing any turning movement of the wheels.

It will be obvious that the valve is prevented from floating back and forth due to the play in the mechanical connections, since the maintenance of differential pressures in the motor in the manner stated also results in maintenance of differential pressures in the chambers **73** and **74**. Accordingly it will be apparent that the fluid pressure reaction between the valve **31** and valve casing **30** will be maintained, thus preventing any play or lost motion in the mechanical connections from permitting the valve units to move with respect to each other. This reaction means therefore functions to stabilize the action of the valve mechanism and results in holding the front vehicle wheels very steadily in a position corresponding to turning movement of the steering wheel, which result has been impossible with prior power steering mechanisms.

The reaction mechanism referred to provides a second advantageous result. As is well known, the force required for turning the steering wheel of a motor vehicle progressively decreases as the vehicle speed progressively increases and the operator of the vehicle will instinctively apply to the steering wheel a greater turning force when the vehicle is travelling slowly than when it is travelling more rapidly. With the present mechanism the differential pressures in the motor **22** will be proportional to the force necessary for turning the front vehicle wheels and since the pressures in the chambers **73** and **74** (Figure 4) correspond to the pressures in the ends of the motor **22**, it necessarily follows that differential pressures in the two diaphragm chambers are proportional to the force necessary for turning the steering wheel.

In this connection it will be noted that when the vehicle is travelling at a relatively high speed under which conditions less force is required to turn the dirigible vehicle wheels, a slight movement of the valve **31** will establish sufficient differential pressures in the motor **22** to effect turning movement of the front wheels. When greater force is necessary to turn the front wheels of the vehicle, the resistance encountered

by the motor in turning the front vehicle wheels will be greater, thus resulting in a slight lagging of the motor and consequently a slight lagging in the follow-up movement of the valve casing **30**, resulting in a wider opening of the valve ports and consequently the establishment of greater differential pressures in the motor. These greater differential pressures, of course, will be duplicated in the diaphragm chambers **73** and **74**, and since the diaphragm **69** is mechanically connected to the steering wheel, it will be obvious that the greater the resistance encountered by the motor in turning the front wheels of the vehicle the greater will be the resistance which the operator will feel in turning the steering wheel. Thus the present device provides the steering wheel with "feel" which is accurately proportional to the resistance encountered by the motor in turning the front vehicle wheels.

The foregoing description applies, of course, to a reverse turning movement of the steering wheel, the valve **31** being moved to the left as viewed in Figure 4 to increase the degree of communication between the motor casing **23** and the source of vacuum while connecting the motor casing **24** to the atmosphere, through port **51**, groove **49** and atmospheric space **63**. This will result in the admisison of air into the motor casing **24** and consequent movement of the diaphragm **27** to the right as viewed in Figure 1. Under such conditions the lever **39** will have been turned in a counterclockwise direction and the motor **22** will turn the lever **16** in the same direction to effect a follow-up action of the valve mechanism, the steering forces being applied to the dirigible wheels of the vehicle, of course, through the drag link **15** or a corresponding steering connection. The reaction pressures in the diaphragm chambers **73** and **74** of course will be reversed but will function in the same manner as before to take up all mechanical play in the system and to afford accurate "feel" to the operator.

The manually operated portion of the mechanism is connected to the power operated portion only through the diaphragm **69** which, of course, is highly resilient. This arrangement prevents the transmission of road shocks to the steering wheel. Any tendency for the front wheels to swing through the encountering of an obstacle or hole in the highway will be transmitted through the drag link **15** to the levers **16** and thence to the valve casing **30** to move this casing in one direction or the other, thus immediately establishing or increasing differential pressures in the motor **22** to overcome the force tending to turn the front wheels of the vehicle. The establishment of such differential pressures in the motor will be duplicated in the chambers **73** and **74**, but the shock forces transmitted to the operator through the steering wheel will be very much reduced in extent because of the relatively small area of the diaphragm **69** with respect to the area of the diaphragm **27**, and the shock forces will be obviously transmitted solely through the medium of differential pressures in the chambers **73** and **74**, and thus will be cushioned.

It will be obvious that the apparatus functions to prevent the operator's having to constantly swing the steering wheel back and forth to maintain the vehicle in the desired line of travel, even when the vehicle is travelling in a straight line with the valve **31** in neutral position. When the valve is in such position there are no forces present tending to take up play between the parts, but upon any slight turning movement of the front vehicle wheels movement will be imparted to the motor casing **30** to move it with respect to the valve **31** to immediately establish whatever slight differential pressure is necessary to swing the front wheels back to a straight line position. Moreover, such operation results in immediate establishment of slight differential pressures in the chambers **73** and **74** to take up all play in the mechanical connections, thus stabilizing the operation of the valve mechanism.

The follow-up operation of the valve mechanism, as stated is such that the play between the lever arm **39** and lugs **18** is never taken up in the normal operation of the apparatus. However, in the event of a failure of power in the motor **22**, the motor will not cause operation of the lever **16** and under such conditions the lever arm **39** will swing until it engages one of the lugs **18**, whereupon a manual turning of the lever **16** can be effected. The response of the valve mechanism is so rapid and accurate that the play between the lever arm **39** and each lug **18** may be relatively slight. Emergency manual steering thus can be effected without much more play in the system than is present in most manual steering mechanisms in actual use.

From the foregoing it will be apparent that the present mechanism provides for an accurate follow-up of the motor **22** with respect to turning movement of the steering wheel. It is unnecessary to employ any friction means between the two valve units to tend to stabilize the operation of such units, the system being characterized by a total absence of any artificial resistances to turning movements of the front vehicle wheels. Without the use of friction or similar stabilizing means, the fluid reaction device very accurately stabilizes the operation of the apparatus and completely prevents any overrunning, creeping or "hunting" of the parts. In practice, therefore, it has been found that the front vehicle wheels very accurately remain in a position corresponding to the position of the steering wheel.

Moreover, it will be obvious that the normal jolts and jars to which a motor vehicle is subjected can, and do, tend to affect the positions of the valve elements of a vehicle steering mechanism. Thus, aside from any tendency of the front wheels of the vehicle to turn, a jolting of the vehicle frequently tends to move one of the valve elements. This would tend to cause a relative movement of the valve elements to effect at least limited energization of the steering motor, thus generating power to turn the front wheels, the direction of turning of such wheels depending upon the direction of relative movement of the valves.

Thus without any turning movement of the front wheels of the vehicle or any turning movement of the steering wheel imparted thereto by the operator a motor-energizing relative movement of the valves sometimes occurs. It is a particularly important feature of the present invention that it functions to prevent turning movement of the front wheels of the vehicle under such conditions. It will be noted that the area of the diaphragm **69** (Figures 4 and 5) is much smaller than the area of the diaphragm **27** (Figure 1), while the volumes of the diaphragm chambers **73** and **74** are relatively small compared with the volumes of the chambers formed in the ends of the motor **22**. Thus it will be apparent that upon any motor-energizing relative movement of the

valve elements 30 and 31, therefore, differential pressure will be instantly created on opposite sides of the diaphragm 69 and these pressures will urge the diaphragm 69 and the valve 31 in a direction opposite to its direction of displacement. Thus the valve 31 will be immediately moved back to its normal position before appreciable energization of the motor 22 can occur.

Thus the diaphragm 69 and its associated elements function to prevent an accidental or unintentional energization of the motor 22. Thus the jolting or jarring which displaces the valve elements from their normal or neutral positions will not result in a turning of the front wheels of the vehicle with the disadvantages and possible disastrous results which would follow such operation. It also will be apparent that prevention of any unintended operation is an inherent function of the apparatus and occurs without effecting movement of the steering wheel or requiring any action on the part of the operator. As a result, the present apparatus permits a vehicle to be driven in safety at relatively high vehicle speeds which is not possible in any other power steering mechanism of which I am aware.

It is to be understood that the form of my invention herewith shown and described is to be taken as a preferred example of the same and that various changes in the shape, size and arrangement of parts may be resorted to without departing from the spirit of the invention or the scope of the subjoined claims.

I claim:

1. A power steering mechanism for a motor vehicle having a steering wheel and a steering connection, comprising a motor connected to said steering connection, a follow-up control mechanism for said motor comprising a pair of relatively movable elements one of which is manually operable by the steering wheel and the other of which has mechanical connection with said steering connection, and means automatically operative upon a motor-energizing relative movement of said elements for generating a force tending to oppose such relative movement of said pair of elements.

2. A power steering mechanism for a motor vehicle having a steering wheel and a steering connection, comprising a motor connected to said steering connection, a follow-up control mechanism for said motor comprising a pair of relatively movable elements one of which is manually operable by the steering wheel and the other of which has mechanical connection with said steering connection, and means automatically operative upon a motor-energizing relative movement of said elements for applying opposite reactionary forces opposing such relative movement of said elements.

3. A power steering mechanism for a motor vehicle having a steering wheel and a steering connection, comprising a motor connected to said steering connection, a follow-up control mechanism for said motor comprising a pair of relatively movable elements one of which is manually operable by the steering wheel and the other of which has mechanical connection with said steering connection, and a differential fluid pressure operated device connected to said manually operable element and operative upon a motor-energizing relative movement of said elements to oppose such relative movement of said elements.

4. A power steering mechanism for a motor vehicle having a steering wheel and a steering connection, comprising a motor connected to said steering connection, a follow-up control mechanism for said motor comprising a pair of relatively movable elements one of which is manually operable by the steering wheel and the other of which has mechanical connection with said steering connection, and a differential fluid pressure operated device connected between the elements of said pair and energizable upon a motor-energizing relative movement of said elements to create opposing force reactions thereagainst which oppose such relative movement of said elements.

5. A power steering mechanism for a motor vehicle having a steering wheel and a steering connection, comprising a differential fluid pressure motor connected to said steering connection, a follow-up control valve mechanism for said motor comprising a pair of valve elements one operable by the steering wheel, and means subject to energization upon a motor-energizing relative movement of said valve elements for creating a force opposing such relative movement of said valve elements.

6. A power steering mechanism for a motor vehicle having a steering wheel and a steering connection, comprising a differential fluid pressure motor connected to said steering connection, a follow-up control valve mechanism for said motor comprising a pair of valve elements one operable by the steering wheel and the other in accordance with operation of said steering connection, and means subject to energization upon a motor energizing relative movement of said valve elements for creating a force opposing movement of said first named valve element, said means being connected to the other valve element for applying an opposite force thereto.

7. A power steering mechanism for a motor vehicle having a steering wheel and a steering connection, comprising a differential fluid pressure motor connected to said steering connection, a follow-up control valve mechanism for said motor comprising a pair of valve elements one operable by the steering wheel, and differential fluid pressure operated means subject to differential pressures occurring incident to a motor-energizing relative movement of said valve elements for opposing such relative movement of said valve elements.

8. A power steering mechanism for a motor vehicle having a steering wheel and a steering connection, comprising a differential fluid pressure motor connected to said steering connection, a follow-up control valve mechanism for said motor comprising a pair of valve elements one operable by the steering wheel and the other in accordance with operation of said steering connection, and differential fluid pressure operated means subject to control by said valve elements and operable upon a motor-energizing relative movement of said valve elements for opposing movement of said first named valve element in either direction, said means being connected to the other valve element for applying an opposite force thereto.

9. A power steering mechanism for a motor vehicle having a steering wheel and a steering connection, comprising a motor connected to said steering connection and having means for connecting it to a source of power, a control mechanism for said motor having a pair of elements one of which is a manually operable element, mechanical connections between said manually operable element and the steering wheel, and automatic means operable by power from the

same source upon a motor-energizing relative movement of said elements for opposing such relative movement of said elements.

10. A steering mechanism for a motor vehicle having a steering wheel and a steering connection, comprising a motor connected to said steering connection and having means for connecting it to a power source, a follow-up control mechanism for said motor having a pair of relatively movable elements one of which is a manually operable element, and means subject to operation by power from the same source as said motor and subject to control by said control mechanism upon a motor-energizing relative movement of said elements for opposing such relative movement.

11. A power steering mechanism for a motor vehicle having a steering wheel and a steering connection, comprising a differential fluid pressure motor connected to said steering connection and having means for connecting it to a source of pressure differential, a follow-up control valve mechanism for said motor comprising a pair of valve elements one of which is operable by the steering wheel, and means constructed and arranged to be energized upon a motor-energizing operation of said valve mechanism for creating an elastic force opposing such operation.

12. A power steering mechanism for a motor vehicle having a steering wheel and a steering connection, comprising a differential fluid pressure motor connected to said steering connection and having means for connecting it to a source of pressure differential, a follow-up control valve mechanism for said motor comprising a pair of valve elements one of which is operable by the steering wheel, and means subject to operation by pressure differential from said source under the control of said valve mechanism and operable upon a motor-energizing relative movement of said valve elements for opposing such relative movement.

13. A power steering mechanism for a motor vehicle having a steering wheel and a steering connection, comprising a differential fluid pressure motor connected to said steering connection and having means for connecting it to a source of pressure differential, a follow-up control valve mechanism for said motor comprising a pair of valve elements one of which is operable by the steering wheel and the other of which is mechanically connected to said steering connection, and means subject to operation by pressure differential from said source under the control of said valve mechanism for opposing any motor energizing movement of said first named valve element, said means being connected to the other valve element for applying an opposite force thereto.

14. A power steering mechanism for a motor vehicle having a steering wheel and a steering connection, comprising a differential fluid pressure motor connected to the steering connection, a follow-up control valve mechanism for said motor comprising a pair of valve elements one of which is mechanically connected to said steering connection and is provided with a passage connected to each end of said motor, and the other of which is operable by the steering wheel and movable to selectively connect said passages to the atmosphere and to a source of pressure differential, and a fluid pressure operated device comprising a diaphragm mechanically connected to said second named valve and having chambers on opposite sides thereof communicating respectively with said passages whereby said diaphragm will be subject to differential pressures upon a motor-energizing relative movement of said valve elements to oppose such relative movement.

15. A power steering mechanism for a motor vehicle having a steering wheel and a steering connection, comprising a differential fluid pressure motor connected to the steering connection, a follow-up control valve mechanism for said motor comprising a pair of valve elements one of which is mechanically connected to said steering connection and is provided with a passage connected to each end of said motor, and the other of which is operable by the steering wheel and movable to selectively connect said passages to the atmosphere and to a source of pressure differential, and a fluid pressure operated device comprising a diaphragm mechanically connected to said second named valve and having chambers on opposite sides thereof communicating respectively with said passages whereby said diaphragm will be subject to differential pressures upon a motor-energizing relative movement of said valve elements to oppose movement of said second named valve, said diaphragm being also connected to said first named valve element whereby differential pressures on opposite sides of said diaphragm create force reactions tending to move said valve elements in opposite directions.

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