ABSTRACT: A multicycle self-balancing gear pump incorporates a variable staging valve for changing the amount of discharge flow of the pump. The pump employs seven gears with six gear meshes at pumping states and the variable staging valve controls both discharge and bypass porting of the pump. In one embodiment the staging valve is a rotary valve having a pair of valving members for controlling the discharge portion and a pair of valve members for controlling bypass porting. Another construction employs a linearly operated staging valve for controlling porting of the liquid flow.
MULTICYCLE SELF-BALANCING GEAR PUMP

BACKGROUND OF THE INVENTION

1. Field of the Invention
This invention relates to pump apparatus, and more particularly to gear pump apparatus having a plurality of pumping stages and adjustable valving for controlling liquid flow through the pump.

2. Description of the Prior Art
Gear pumps are well known in the art and have found particularly advantageous application as fuel pumps. Included in this art is a type of gear pump in which a plurality of gears of even number form an endless annular train in which each gear is meshed with a pair of adjacent gears. In designing such gear pumps, it is difficult to accurately determine, and therefore reduce, the gear tooth load of the driving one of these gears. For example, in an eight-gear train in which the teeth of the eighth gear are engaged with the teeth of the first or driving gear, it is difficult to ascertain whether the eighth gear is being driven directly by the first gear or via the second through seventh gears. Extremely good tolerances would then be required to determine if the eighth gear were actually driven by the first gear or the seventh gear. Also, since the eighth gear is driven by the seventh gear, there is a built-in leakage path between the gear teeth of the eighth gear and the first gear. This is also true for any gear in such a gear cluster. Accordingly, it is readily apparent that accurate determination and reduction of gear tooth load, high- and low-pressure values and bearing loading in the design of such apparatus is difficult. These problems are further aggravated in gear pumps which are required to provide a variable delivery.

It is therefore highly desirable to provide, and a primary objection of the present invention to provide, a variable delivery gear pump which is free of the above inherent problems.

SUMMARY OF THE INVENTION
According to the invention, a variable delivery, multicycle, self-balancing gear pump is provided with the gears in an open-ended cluster arrangement having an odd number of gears and an even number of intermediate gear meshes. A gear pump constructed in accordance with the gear configuration of the present invention and employing seven gears can be realized at a reduced size when compared to that of a similarly rated conventional two-gear pump. The gear tip velocity is a critical and sometimes limiting factor in the design of gear pumps; therefore, since the cluster pump design reduces the individual gear size, the pump speed may be increased from, say 7,800 to 13,200 r.p.m. and still maintain the same gear tip velocity as found in the conventional pump. A gear pump constructed in accordance with the present invention has the further advantages of less weight and less volume.

The gear loads resulting from the hydraulic pressure and gear meshes of adjacent gears provides forces on the intermediate gear or gears which nearly balance and produce a low resultant force. The load is the greatest on the outboard gear due to the hydraulic unbalance around the periphery of the gear, however, the resultant force may be accurately determined during pump design and maintained within a reasonable and acceptable value.

The discharge flow of a pump constructed in accordance with the present invention may be varied by staging various gear meshes. According to one embodiment of the invention, the discharge flow may be varied by a rotary staging valve which opens and closes axial inlet and discharge ports. This rotary valve includes a plurality of valve members which simultaneously either open discharge valving members and close bypass valving members, or close the discharge valving members and open the bypass valving members. Rotation of the valve is provided remotely from an engine control which supplies a rotational input to the valve to add or delete a pump stage in accordance with changes in engine flow requirements.

According to another embodiment of the invention, the variable discharge flow of the pump is provided by a linearly displacable valve in which the valve ports and flow passageways are selectively controlled to carry either bypass flow or discharge flow at the command of a mechanical movement from the engine control, or by a transduced signal, such as a pressure signal.

A further advantage of a gear pump constructed in accordance with the principles of the present invention resides in the amount of fuel temperature rise across a cluster gear pump having a staging valve as compared to a conventional gear pump. Since the staging valve allows all but one stage to bypass and operate without any pressure rise, the temperature rise at low flow is that for a single stage pump which has, in the case of seven gears, one-sixth the capacity of the conventional pump. This reduction in energy loss and high fuel turndown ratios results in a lower fuel temperature rise across the pump.

BRIEF DESCRIPTION OF THE DRAWINGS
Other objects, and features of the invention, its organization, construction and operation, will be best understood from the following detailed description taken in conjunction with the accompanying drawings, in which:

FIG. 1 is a sectional elevation view of a cluster gear pump according to an embodiment of the invention, the gear pump employing a rotary staging valve having a plurality of valve members;

FIG. 2 is a sectional view of the gear pump illustrated in FIG. 1 taken generally along the line II—II of FIG. 1;

FIG. 3 is a sectional view of the gear pump illustrated in FIG. 1 taken generally along the line III—III of FIG. 1;

FIG. 4 is a sectional view of a gear pump according to a second embodiment of the invention looking generally at a section of the pump similar to that of FIG. 2 and particularly illustrating a linearly displacable staging valve; and

FIG. 5 is a sectional view of the gear pump illustrated in FIG. 4 particularly illustrating the flow passages between the gear stages and the staging valve in a section immediately adjacent the area of the gears shown in FIG. 4.

DESCRIPTION OF THE PREFERRED EMBODIMENTS
Referring first to FIGS. 1, 2 and 3, a multistage self-balancing gear pump is illustrated at 10 as comprising a pump housing 11 including an inner housing section 12 and an outer housing section 13, generally spaced apart from the section 12 but fluid sealed thereto. A booster housing section 15 is secured to the pump housing 14 by means of a plurality of machine screws 16 which extend through aligned apertures 17, 18 and 19 of the pump elements 15, 14 and 14, respectively.

The inner housing section 12 has formed therein a plurality of cylindrical cavities or chambers 20a—20g arranged in an arcuate disposition about the longitudinal axis of the inner section 12. Each of the chambers 20a—20g intersects adjacent similar chambers in fluid passageways 26—31. Each of the chambers receives therein a rotatably mounted gear 32—38 the teeth of which mesh in the respective fluid passageways 26—31 to provide the pumping function upon rotation of the gears.

The central intermediate gear 35 of the gear train 32—38 is drivenly engaged with a rotatable drive shaft 39 for imparting rotatory motion to each of the gears 32—38. A fluid inlet passageway 40 is provided for receiving fluid from a fluid supply and delivering the fluid to the booster pump housing 15 wherein it is received in a chamber 41 and directed to a rotating impeller 42 having a plurality of impeller blades 43 and 44. The impeller 42 is secured to the end 45 of the rotating shaft 39. The impeller includes a sleeve 46 having a central bore for receiving the shaft end 45, the sleeve 46 being rotatably held by bearings 47 and 47a in the housing elements 15 and 14, respectively. The sleeve 46 includes a threaded end portion 48 which receives a nut 48a for securing the impeller 42 in the booster pump assembly.

Rotation of the impeller 42 by the drive shaft 39 propels the fluid to a chamber 49 having an outlet opening 50 through
which the fluid is delivered to a chamber 53 of the inner housing section 12 by way of an opening 51 in plate 14 and inlet opening 52 in housing section 12. Fluid to be pumped has therefore been provided to the inner housing section 12 of the gear pump from the inlet passageway 40 to the chamber 53 by way of a booster pump.

Referring specifically to FIGS. 2 and 3, fluid delivery to the pumping stages is provided by way of a passageway 54 in the inner pump housing section 12 in communication with the chamber 53 and in communication with a generally flat annular chamber 55 via a communicating cylindrical chamber 55a extending between the drive shaft 39 and the hollow portion of gear 35.

A plurality of fluid passageways extend between the chamber 55 and the pumping stages to provide fluid inlet and bypass flow for the pump. A plurality of fluid inlet chambers 56-61 are provided in a generally axial direction between the chamber 55 and the individual pumping stages. Each of these passageways has one end in communication with a passageway formed at the intersection of a pair of gear receiving chambers and another end which is ported into the main inlet chamber 55. For example, the fluid inlet chamber 56 includes a port 56a for permitting fluid delivery to the other end 55 of the passageway which communicates with the generally radial passageway 26 at the low pressure inner running side of the gear mesh provided by gears 32 and 33 which are disposed in chambers 20a and 20b, respectively. Each of the passageways 56-61 therefore provides fluid delivery to the low-pressure areas of their respective pumping stages, that is at the inner running sides of the gear meshes thereof.

At the outer running sides of the gear meshes, that is at the high-pressure portions of the pumping stages, fluid is directed for delivery to the exterior of the pump. For example, at the outer running side of the gear mesh of gears 37 and 38 the fluid under a high pressure is discharged by way of a port 62a to an outlet or discharge chamber 68 which is in communication with the pump outlet 81.

The discharge port 62b is one of a plurality, in this case 3, of such ports 62a, 63b and 64b are also in fluid communication with the chamber 55 by way of a corresponding plurality of passageways 62a, 63a and 64a which terminate at respective ports 62a (covered in FIG. 3), 63a and 64a. The high pressure portions of the radially extending passageways 26, 28 and 30 are also placed in communication with the chamber 55 by way of a plurality of passageways 65, 66 and 67a. Each of these passageways terminate at respective ports 65a, 66a and 67a in chamber 55 at one end thereof and in the corresponding high pressure areas 65b, 66b and 67b at the other ends thereof, the passageways extending generally axially of the pump.

Fluid communication between the discharge ports 62b, 63b and 64b with the chamber 68, and thus with the exterior of the pump, is controlled by movement of a rotary valve 70 having a valve member 71 positioned between housing sections 12 and 13 and including a window 69 therein for covering and uncovering the ports upon rotation of the rotary valve 70 about the peripheral surface 86 of the inner pump housing section 12. The window 69 is positionable to sequentially uncover and cover the ports 62a, 63b and 64b to vary the amount of fluid discharged to chamber 68.

The valve member 71 of the valve 70 is connected for mutual rotation with a valve member 78. The inner pump housing section 12 includes a central bore 77 having a sleeve 75 therein for rotatably receiving the valve member 78. The valve member 78 is of generally tubular construction and includes a central bore 77 which is in communication with the fluid outlet 81 of the pump by way of a passageway 80 in the outer housing section 13.

A plurality of passageways 65, 66 and 67 are provided generally axially of the pump in the inner pump housing section 12 in communication at one end thereof by means of valve ports 65a, 66a and 67a with the chamber 55. A bypassing of fluid is provided through these passageways to the chamber 55 by selective rotation of the tubular valving member 78 to position the window 79 thereof away from ports 65b, 66b and 67b which communicate through openings 72, 73 and 74, respectively, with the fluid passageway 77 for discharging fluid to the outlet 81. Rotation of the valve 70 may effect an uncovering of these fluid channels at the window 79 to provide a discharge path, while covering of these channels provides bypass of the fluid to the chamber 55 by way of the fluid passageways 65, 66 and 67.

Selective rotation of the valve 70 is attained through the provision of a plurality of teeth 88 on the periphery thereof for engagement with teeth 90 of a motor driven adjustment gear 89.

The fluid provided to the pump at passageway 40 has therefore been subjected to the boosting action of the impeller 42 and the pumping action of the gears 32-38 to provide the fluid at the outlet 81. Selective rotational positioning of the valve 70 by means of the gear 89 positions the windows 69 and 79 to selectively cover and uncover discharge ports 62b, 63b, 64b, 65b, 66b and 67b.

In addition, the selective positioning of the valve 70 also provides for covering and uncovering of the aforementioned valve ports 56a-67a which closes off the respective axial passageways to insulate passage of the fluid from the high pressure areas to the discharge passageways rather than back to the chamber 55.

Referring now to FIGS. 4 and 5, there is illustrated generally at 100 a multistage gear pump which is somewhat similar to the gear pump discussed above but which includes a linearly operated staging valve rather than rotary staging valve.

The pump 100 comprises a housing 101 including a plurality of gear-receiving chambers 102-108 of generally cylindrical form and disposed in an arcuate pattern similar to that of the pump 10. Adjacent ones of chambers 102-108 intersect in the area of radially extending passageways 109-114 and have individually disposed therein gears 115-121 which form a serially connected gear train of which gear 118 is the intermediate driven gear, gear 118 being rotatably driven by a shaft 122.

Extending somewhat axially of the pump are a plurality of fluid passageways 123-128 which are placed in selective communication with a fluid supply through a passageway 129 and a passageway 130 by means of a staging valve 131.

Passageways 123-128 each include an axial portion, such as portion 127a, which is in communication with another axial portion, such as 127c, through an intermediate portion, such as 127b, to further communicate with an annular valve portion, such as 127d, formed in the housing 101 in the path of the staging valve 131. The axial portions 123c, 128c are aligned with corresponding annular grooves 123d-128d and may operate as either inlet or discharge passageways, 123c and 128c always being discharge passageways.

The staging valve 131 includes a hollow tubular member 132 having a plunger 133 slidably disposed therein and connected to a linearly operable shaft 134. The plunger 133 is fluid sealed to the interior wall of the tubular member 132 by means of an O-ring. Tubular member 132 includes a plurality of ports 135-139 adjacent the grooves 123d-127d for permitting fluid flow from passageway 130 to enter corresponding passageways, such as 127c, which are to the left of the plunger 133. The passageways to the left of the plunger 133 therefore supply a fluid input to the pump while passageways to the right-hand side of plunger 133 are effective as discharge passageways to the chamber 123c which surrounds the plunger shaft 134.

Chamber 123d serves as the discharge passageway and is in communication with a relief valve by way of a passageway 140 in a housing section 141 which provides the discharge pressure against a valve member 142. The valve member 142 is justly biased by a spring 143 and threaded adjustment 144 to provide a selective relief pressure. The relief valve does not affect staging of the pump, but serves to provide a pressure release to channel fluid by means of fluid passageway 145 back to the fluid inlet of the pump.
Staging of the pump 100 may be accomplished by a mechanical movement of the rod 134 by an engine control, or by a pressure signal.

Generally then there has been provided a multistage gear pump with selective staging of the pump in one embodiment by a rotary valve, and in another embodiment by a linearly operated valve. The gear pump includes a plurality of gears connected in a serially innermeshed cluster with the intermediate gear of the cluster being driven to in turn drive the remaining gears. The gears are disposed in individual intersecting cylindrically shaped cavities into which fluid is ported from a booster pump stage to the gear pumping stages. Selective rotational positioning of the rotary valve allows a predetermined amount of fluid discharge from the pump and a predetermined amount of fluid bypass from high-pressure to low-pressure portions of the pumping stages by way of a fluid inlet chamber which serves as a common fluid feed to all pumping stages. In the case of a linear staging valve all discharge flow from the pump is ported through the staging valve and a linearly operated piston is selectively positioned to control which portion of a plurality of fluid passageways are serving as inlet passageways and which portion are serving as discharge passageways.

Many changes and modifications may be made in the invention by one skilled in the art without departing from the true spirit and scope of the invention and should be included in the appended claims.

What I claim is:

1. A multistage gear pump comprising:
   a pump housing including means forming a plurality of cylindrically shaped parallel intersecting chambers arranged in an arcuate disposition;
   a plurality of gears meshed to form a serial gear train with the gears thereof disposed in and rotatably mounted in individual ones of said chambers;
   a drive shaft rotatably mounted in said housing and drivingly connected to an intermediate gear of said gear train for rotating adjacent gears in opposite directions, the rotation of said gears effecting low pressure in portions of said chambers at the intersection of said chambers adjacent the running sides of the meshes of said gears and high pressure in portions of said chambers at the intersections of said chambers adjacent the outrunning sides of the meshes of said gears;
   a plurality of fluid delivery passageways in said pump housing communicating with said low-pressure portions of said chambers;
   a plurality of fluid discharge passageways in said pump housing with said high-pressure portions of said chambers;
   staging valve means operable to alter the number of said delivery and discharge passageways in communication with said plurality chambers;
   a main fluid delivery passageway; and
   a fluid delivery chamber in communication with said main fluid delivery passageway and with said plurality of delivery passageways,
   said staging valve means including a delivery valve operable to alter the number of said plurality of fluid delivery passageways in communication with said fluid delivery chamber.

2. A gear pump according to claim 1, comprising a plurality of bypass passageways in communication with said fluid delivery chamber and with said high-pressure portions of said plurality of chambers, said staging valve means including a bypass valve operable to alter the number of said bypass passageways in communication with said delivery chamber.

3. A gear pump according to claim 2, wherein said staging valve means includes a discharge valve operable to alter the number of discharge passageways in communication with said plurality of chambers.

4. A multistage gear pump comprising:
   a pump housing including means forming a plurality of cylindrically shaped parallel intersecting chambers arranged in an arcuate disposition;
   a plurality of gears meshed to form a serial gear train with the gears thereof disposed in an rotatably mounted in individual ones of said chambers;
   a drive shaft rotatably mounted in said housing and drivingly connected to an intermediate gear of said gear train for rotating adjacent gears in opposite directions, the rotation of said gears effecting low pressure in portions of said chambers at the intersection of said chambers adjacent the running sides of the meshes of said gears and high pressure in portions of said chambers at the intersections of said chambers adjacent the outrunning sides of the meshes of said gears;
   a plurality of fluid delivery passageways in said pump housing communicating with said low-pressure portions of said chambers;
   staging valve means operable to alter the number of said delivery and discharge passageways in communication with said plurality chambers;
   a main fluid delivery passageway; and
   a fluid delivery chamber in communication with said main fluid delivery passageway and with said plurality of fluid delivery passageways,
   each of said plurality of fluid delivery passageways including a delivery port opening into said fluid delivery chamber, and
   said staging valve means including a delivery valve disposed in said delivery chamber and slidably operable to cover and uncover said delivery ports.

5. A multistage gear pump comprising:
   a pump housing including means forming a plurality of cylindrically shaped parallel intersecting chambers arranged in an arcuate disposition;
   a plurality of gears meshed to form a serial gear train with the gears thereof disposed in and rotatably mounted in individual ones of said chambers;
   a drive shaft rotatably mounted in said housing and drivingly connected to an intermediate gear of said gear train for rotating adjacent gears in opposite directions, the rotation of said gears effecting low pressure in portions of said chambers at the intersection of said chambers adjacent the running sides of the meshes of said gears and high pressure in portions of said chambers at the intersections of said chambers adjacent the outrunning sides of the meshes of said gears;
   a plurality of fluid delivery passageways in said pump housing communicating with said high-pressure portions of said chambers including
   a main fluid delivery passageway,
   a fluid inlet chamber in communication with said main fluid delivery passageway, and
   a plurality of individual fluid delivery passageways extending between said fluid inlet chamber and separate ones of said low-pressure portions of said chambers;
   means for discharging fluid from said high-pressure portions of said chambers including
   a main fluid discharge passageway, and
   a plurality of individual fluid discharge passageways extending between said fluid inlet chamber and separate ones of said high-pressure portions of said chambers;
   staging valve means operable to alter the number of said individual delivery and discharge passageways in communication with said chambers including
   first valve means interposed between said main delivery passageway and said individual delivery passageway, and
   second valve means interposed between said individual discharge passageways and said main discharge passageway.

6. A multistage gear pump comprising:
   a pump housing including
a generally cylindrical inner pump housing section, a cup-shaped outer pump housing section spaced apart from said inner housing section, and means forming a plurality of cylindrically shaped parallel intersecting pumping chambers in said inner housing section in an arcuate disposition with their axes parallel to the axis of said inner housing section;
a plurality of gears meshed to form a gear train, each of said gears being disposed in a separate one of said pumping chambers and rotatably mounted in said inner housing section;
a drive shaft connected to an intermediate gear of said gear train for rotating adjacent gears in opposite directions to effect low-pressure portions in said pumping chambers adjacent the inner running sides of the gear meshes and high-pressure portions adjacent the outer running sides of the gear meshes;
a plurality of fluid delivery passageways in said inner housing section individually communicating with said low-pressure portions of said pumping chambers and having ports at one end of the inner housing section;
a plurality of discharge passageways in said inner housing section individually communicating with said high-pressure portions of said pumping chambers and having ports at the peripheral surface of said inner housing section; and
a cup-shaped rotatable valve disposed in the space between said inner and outer pump housing sections operable to vary the number of said delivery and discharge passageways in communication with said pumping chambers, said valve including a first valve member for opening and closing the ports of said delivery passageways, and a second valve member for opening and closing the ports of said discharge passageways.

7. A gear pump according to claim 6, wherein said cup-shaped rotatable valve comprises a cylindrical portion embracing the periphery of said inner housing section and having means forming a window therein for communication with the ports of said discharge passageways, and an annular portion covering the end of said inner housing section having the ports of said delivery passageways therein, said annular portion including window therein for communication with the ports of said delivery passageways.

8. A gear pump according to claim 7, comprising a main delivery passageway in said inner pump housing section, means forming an inlet chamber in communication with said main delivery passageway including the ported end of said inner housing section and a shaped surface of said annular portion of said valve spaced from the ported end.

9. A gear pump comprising:
a generally cylindrical inner housing section having an annular end and a cylindrical peripheral surface, an axial bore in said inner housing section, means forming a plurality of cylindrically shaped parallel intersecting pumping chambers in said inner housing section in arcuate disposition with their axes parallel to the axial bore, and an outer housing section having a cylindrical wall spaced from the peripheral surface of said inner housing section and an end wall spaced from the annular end of said inner housing section;
a plurality of gears each of which is rotatably mounted in separate ones of said pumping chambers, adjacent gears being meshed to form a gear train;
a drive shaft connected to an intermediate gear of said gear train for rotating adjacent gears in opposite directions to effect low-pressure chamber portions adjacent the inner running sides of the gear meshes and high-pressure chamber portions adjacent the outer running sides of the gear meshes;
means forming a fluid inlet chamber including said annular end of said inner housing section and said end wall of said outer housing section;
a first fluid delivery passageway in said inner housing section in communication with said inlet chamber; a plurality of second fluid delivery passageways individually extending between said annular end and said low-pressure chamber portions; means forming a first fluid discharge chamber including said peripheral surface of said inner housing section and said cylindrical wall of said outer housing section; a first fluid discharge passageway extending between said first fluid discharge chamber and the exterior of the pump; a plurality of second fluid discharge passageways individually extending between some of said high-pressure chamber portions and said peripheral surface of said inner housing section; a plurality of third fluid discharge passageways individually extending between others of said high-pressure chamber portions and the axial bore of said inner housing section; a plurality of fluid bypass passageways extending between said high-pressure chamber portions and said annular end of said inner housing section, each of said second fluid delivery passageways and said fluid bypass passageways having ports at said annular end for communication with said inlet chamber; each of said second and third discharge passageways having ports at the respective peripheral surface and axial bore; a rotary valve disposed in the space between said housing sections and in the axial bore including first valve means positionable about said peripheral surface to open and close the ports of said second fluid discharge passageways, second valve means positionable along said annular end to open and close the ports of second fluid delivery and fluid bypass passageways, and third valve means positionable within the axial bore to open and close the ports of said third discharge passageways, said third valve means including a fourth fluid discharge passageway; and a fifth fluid discharge passageway extending between said fourth fluid discharge passageway and said first fluid discharge passageway.

10. The gear pump according to claim 9, wherein the ports of said second fluid delivery passageways and said bypass passageways are arranged in arcuate disposition, and said second valve means includes arcuate surfaces associated with the ports.

11. A multistage gear pump comprising:
a pump housing;
means forming a plurality of cylindrical parallel intersecting pumping chambers in said housing;
a plurality of gears serially meshed to form a gear train and individually rotatably mounted within said chambers; means for rotating the gears of said gear train; a fluid delivery chamber formed in said housing; means for providing a fluid flow to said delivery chamber; a plurality of first passageways connecting said delivery chamber to said pumping chambers; means forming a discharge passageway in said housing; a plurality of second passageways connecting said pumping chambers to said discharge passageway; a plurality of third passageways further connecting said second passageways with said delivery chamber; and staging valve means disposed within said housing and including a first valve means operable to control the fluid coupling between said second passageways and said discharge passageway, and second valve means operable to control the fluid coupling by way of said first and third passageways between said pump chambers and said delivery chamber.
12. A multistage gear pump according to claim 11, wherein said first and second valve means include an integrally formed structure and are therefore concurrently operable.