



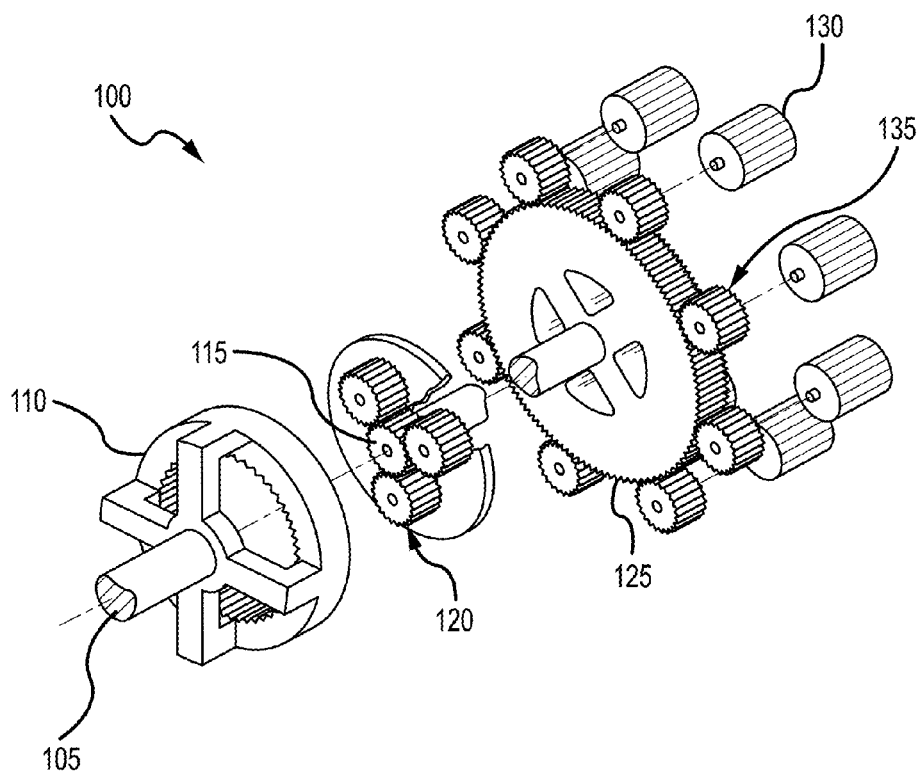
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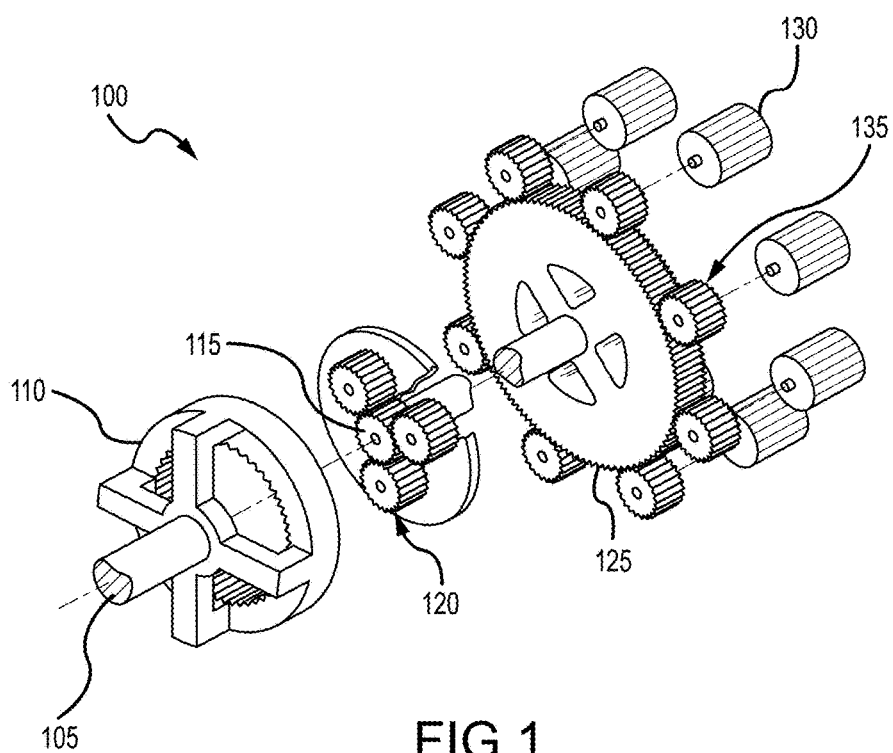
(19) **United States**(12) **Patent Application Publication**
Oehring et al.(10) **Pub. No.: US 2019/0249754 A1**(43) **Pub. Date: Aug. 15, 2019**(54) **MULTI-PLUNGER PUMPS AND
ASSOCIATED DRIVE SYSTEMS**(52) **U.S. Cl.**CPC **F16H 3/52** (2013.01); **F16H 2200/2007**
(2013.01); **F04B 17/03** (2013.01); **F04B 23/04**
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(57)

ABSTRACT(73) Assignee: **U.S. Well Services, Inc.**, Houston, TX
(US)(21) Appl. No.: **16/210,807**(22) Filed: **Dec. 5, 2018****Related U.S. Application Data**(60) Provisional application No. 62/594,912, filed on Dec.
5, 2017.**Publication Classification**(51) **Int. Cl.****F16H 3/52** (2006.01)
F04B 23/04 (2006.01)
F04B 17/03 (2006.01)

A hydraulic fracturing system for fracturing a subterranean formation is described according to various embodiments. In an embodiment, the system can include a multi-plunger hydraulic fracturing pump fluidly connected to a well associated with the subterranean formation, the multi-plunger pump configured to pump fluid into a wellbore associated with the well at a high pressure so that the fluid passes from the wellbore into the subterranean formation and fractures the subterranean formation. In an embodiment, a plurality of motors can be positioned to power the multi-plunger pump, and a planetary gear train can have a plurality of pinion gears in rotational contact with each of the plurality of motors. In an embodiment, a gear ratio of the planetary gear train and a speed at which the plurality of motors operates can be selected so as to limit a maximum pump speed associated with the multi-plunger pump.





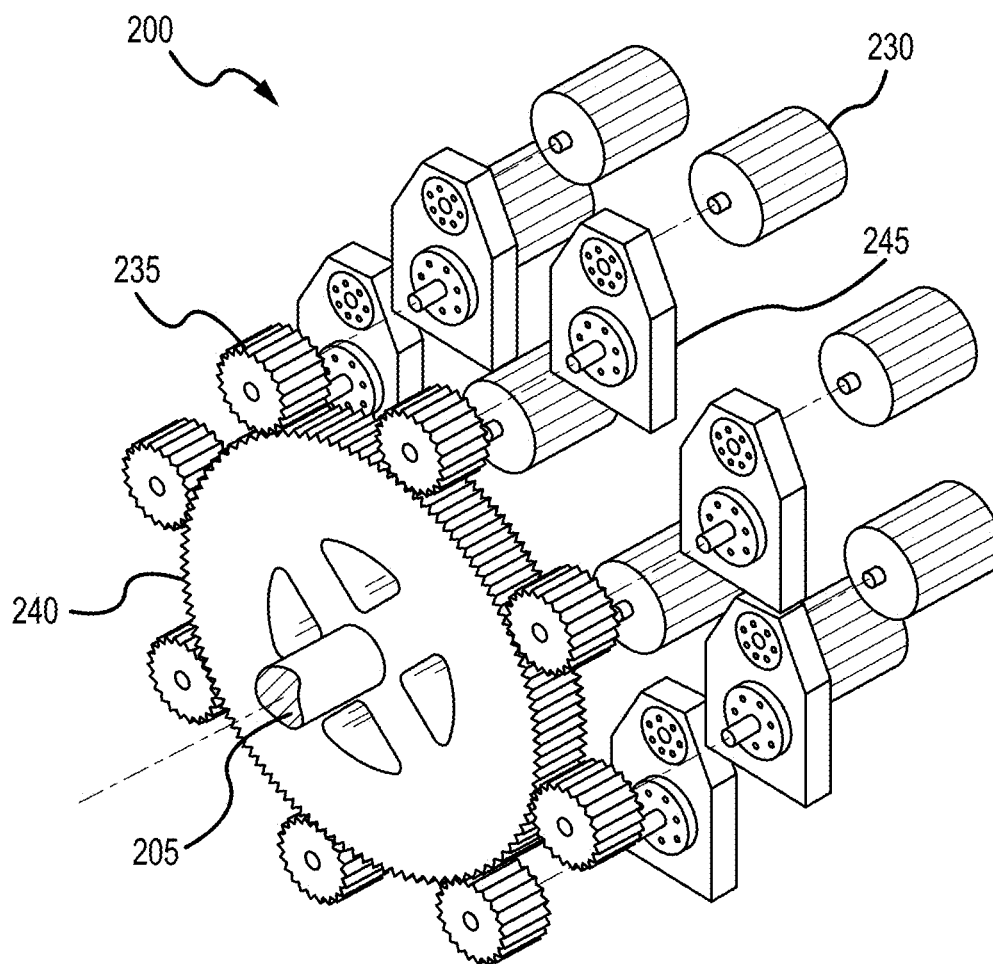


FIG.2

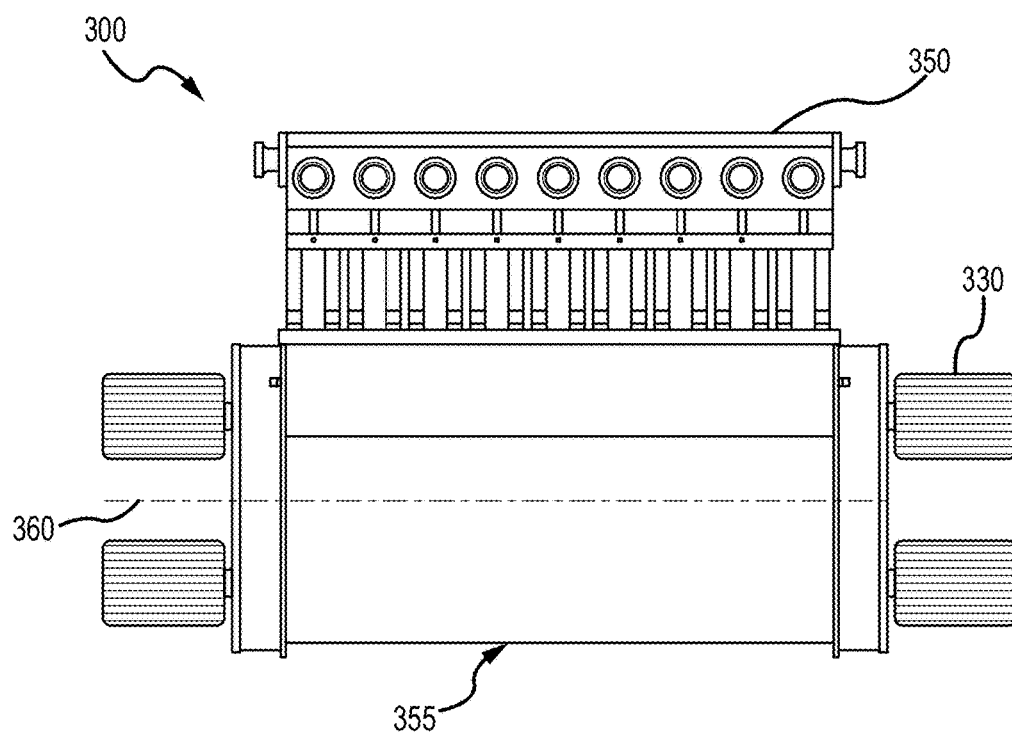


FIG.3

Plunger Critical Speed Calculations

Plunger Critical Speed = 32 in/sec (based on 120-gpm crankshaft speed on 8" stroke pump)
 Plunger Maximum Speed = 40 in/sec (based on 120-gpm crankshaft speed on 8" stroke pump)

Pump Stroke (in.)	Volume per rev. (BBL)				Crankshaft rpm		Discharge Rates (BPM) at Critical Speed				Discharge Rates (BPM) at Maximum Speed			
	Triplex	Quint	9 Plunger	13 Plunger	Critical	Maximum	Triplex	Quint	9 Plunger	13 Plunger	Triplex	Quint	9 Plunger	13 Plunger
2.75" Bore	8	0.01665	0.02448	0.04492	0.06367	120.00	120.00							
	9	0.01655	0.02455	0.04492	0.06367	108.67	133.33							
	10	0.01645	0.02462	0.04492	0.06367	96.00	120.00	3.76	2.94	5.29	7.84	2.20	3.67	6.61
	11	0.01635	0.02469	0.04492	0.06367	87.27	109.09							
	12	0.01625	0.02476	0.04492	0.06367	80.00	100.00							
3.0" Bore	8	0.01749	0.02614	0.05346	0.07577	120.00	120.00							
	9	0.01767	0.02579	0.04901	0.06524	108.67	133.33							
	10	0.01786	0.02543	0.04457	0.05471	96.00	120.00	2.10	3.30	5.29	8.09	2.62	4.37	7.87
	11	0.01804	0.02507	0.04013	0.04419	87.27	109.09							
	12	0.01823	0.02471	0.03569	0.03366	80.00	100.00							
3.25" Bore	8	0.02051	0.03420	0.06155	0.08593	120.00	120.00							
	9	0.02070	0.03385	0.05710	0.07540	108.67	133.33							
	10	0.02089	0.03350	0.05265	0.06487	96.00	120.00	1.46	4.10	7.89	10.67	3.08	5.13	8.13
	11	0.02108	0.03314	0.04820	0.05434	87.27	109.09							
	12	0.02127	0.03279	0.04375	0.04381	80.00	100.00							
3.5" Bore	8	0.02380	0.03967	0.07140	0.10313	120.00	120.00							
	9	0.02400	0.03932	0.06695	0.09260	108.67	133.33							
	10	0.02420	0.03897	0.06250	0.08207	96.00	120.00	2.56	4.76	8.87	12.38	3.57	5.95	10.71
	11	0.02440	0.03862	0.05805	0.07154	87.27	109.09							
	12	0.02460	0.03827	0.05360	0.06101	80.00	100.00							
4.0" Bore	8	0.03109	0.05181	0.09326	0.13470	120.00	120.00							
	9	0.03130	0.05146	0.08881	0.12417	108.67	133.33							
	10	0.03151	0.05111	0.08436	0.11364	96.00	120.00	3.73	6.22	11.19	16.38	4.66	7.77	13.95
	11	0.03172	0.05076	0.07991	0.10311	87.27	109.09							
	12	0.03193	0.05041	0.07546	0.09258	80.00	100.00							
4.5" Bore	8	0.04428	0.07377	0.13275	0.19580	120.00	120.00							
	9	0.04450	0.07342	0.12830	0.18527	108.67	133.33							
	10	0.04472	0.07307	0.12385	0.17474	96.00	120.00	4.71	7.87	14.16	20.46	6.90	9.84	17.70
	11	0.04494	0.07272	0.11940	0.16421	87.27	109.09							
	12	0.04516	0.07237	0.11495	0.15368	80.00	100.00							
5.0" Bore	8	0.06071	0.10119	0.18234	0.26308	120.00	120.00							
	9	0.06094	0.10084	0.17789	0.25255	108.67	133.33							
	10	0.06116	0.10049	0.17344	0.24202	96.00	120.00	5.83	9.37	17.49	25.26	7.29	11.14	21.86
	11	0.06138	0.10014	0.16899	0.23149	87.27	109.09							
	12	0.06160	0.09979	0.16454	0.22096	80.00	100.00							

FIG. 4

Transmission									
CAT TH55-E90 Reverser									
1st Gear	4.07								
2nd Gear	3.43								
3rd Gear	2.53								
4th Gear	2.11								
5th Gear	1.85								
6th Gear	1.55								
7th Gear	1.44								
8th Gear	1.46								
9th Gear	1.50								

Pto. Speed									
Pto. Speed									
1st Gear	5.00/rev								
2nd Gear	5.00/rev								
3rd Gear	5.00/rev								
4th Gear	5.00/rev								
5th Gear	5.00/rev								
6th Gear	5.00/rev								
7th Gear	5.00/rev								
8th Gear	5.00/rev								
9th Gear	5.00/rev								

CAT TH55-E90 Transmission - Quint Pumps																			
		Engine rpm	Pump Crank rpm	Pump RPM	Engine rpm	Pump Crank rpm	Pump RPM	Engine rpm	Pump Crank rpm	Pump RPM	Engine rpm	Pump Crank rpm	Pump RPM	Engine rpm	Pump Crank rpm	Pump RPM	Engine rpm	Pump Crank rpm	Pump RPM
4.0" Fluid End	1st Gear	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
		1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
		1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
		1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
		1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
		1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
		1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
		1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
		1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
		1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
4.5" Fluid End	1st Gear	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
		1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
		1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
		1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
		1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
		1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
		1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
		1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
		1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
		1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
5.0" Fluid End	1st Gear	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
		1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
		1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
		1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
		1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
		1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
		1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
		1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
		1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
		1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500

FIG. 5

Transmission			Frax Pump		
Allison 9800 Ratios			Fluid End	Triplex BBL/Rev	
1st Gear	8.75		4.57	0.159177	
2nd Gear	2.64		4.57	0.039133	
3rd Gear	2.25				
4th Gear	1.77				
5th Gear	1.38				
6th Gear	1.29				
7th Gear	1.00				

Allison 9800 Transmission, Triplex Pumps

Allison 9800 Transmission	Triplex 4.57"	Engine rpm	Pump Crank rpm	Pump BPM	Triplex 4.57"	Engine rpm	Pump Crank rpm	Pump BPM	Triplex 4.57"	Engine rpm	Pump Crank rpm	Pump BPM	Triplex 4.57"	Engine rpm	Pump Crank rpm	Pump BPM
		1st Gear				2nd Gear				3rd Gear				4th Gear		
		1500	1500	1500		1500	1500	1500		1500	1500	1500		1500	1500	1500
		1550	1550	1550		1550	1550	1550		1550	1550	1550		1550	1550	1550
		1600	1600	1600		1600	1600	1600		1600	1600	1600		1600	1600	1600
		1650	1650	1650		1650	1650	1650		1650	1650	1650		1650	1650	1650
		1700	1700	1700		1700	1700	1700		1700	1700	1700		1700	1700	1700
		1750	1750	1750		1750	1750	1750		1750	1750	1750		1750	1750	1750
		1800	1800	1800		1800	1800	1800		1800	1800	1800		1800	1800	1800
		1850	1850	1850		1850	1850	1850		1850	1850	1850		1850	1850	1850
		1900	1900	1900		1900	1900	1900		1900	1900	1900		1900	1900	1900
		1950	1950	1950		1950	1950	1950		1950	1950	1950		1950	1950	1950

FIG. 6

Transmission Allison 9800 Ratio	
1st Gear	3.75
2nd Gear	1.89
3rd Gear	1.29
4th Gear	1.17
5th Gear	1.13
6th Gear	1.17
7th Gear	1.00

Frac Pump	
Fluid End Bore	981.749
4.5"	0.00345
5.0"	0.00385

Allison 9800 Transmission, Quint Pumps

	Allison 9800 Transmission					Allison 9800 Transmission					Allison 9800 Transmission					Allison 9800 Transmission				
	Engine rpm	Pump Crank rpm	Pump BPM	Ratio		Engine rpm	Pump Crank rpm	Pump BPM	Ratio		Engine rpm	Pump Crank rpm	Pump BPM	Ratio		Engine rpm	Pump Crank rpm	Pump BPM	Ratio	
Allison 9800 Transmission	1st Gear	1500	633	6.33	2nd Gear	1500	633	6.33	3rd Gear	1500	633	6.33	4th Gear	1500	633	6.33	5th Gear	1500	633	6.33
		1750	733	7.33		1750	733	7.33		1750	733	7.33		1750	733	7.33		1750	733	7.33
		1900	790	7.90		1900	790	7.90		1900	790	7.90		1900	790	7.90		1900	790	7.90
		2050	847	8.47		2050	847	8.47		2050	847	8.47		2050	847	8.47		2050	847	8.47
		2200	904	9.04		2200	904	9.04		2200	904	9.04		2200	904	9.04		2200	904	9.04
	1st Gear	2350	961	9.61	2nd Gear	2350	961	9.61	3rd Gear	2350	961	9.61	4th Gear	2350	961	9.61	5th Gear	2350	961	9.61
		2500	1018	10.18		2500	1018	10.18		2500	1018	10.18		2500	1018	10.18		2500	1018	10.18
		2650	1075	10.75		2650	1075	10.75		2650	1075	10.75		2650	1075	10.75		2650	1075	10.75
		2800	1132	11.32		2800	1132	11.32		2800	1132	11.32		2800	1132	11.32		2800	1132	11.32
		2950	1189	11.89		2950	1189	11.89		2950	1189	11.89		2950	1189	11.89		2950	1189	11.89
Allison 9800 Transmission	1st Gear	1500	633	6.33	2nd Gear	1500	633	6.33	3rd Gear	1500	633	6.33	4th Gear	1500	633	6.33	5th Gear	1500	633	6.33
		1750	733	7.33		1750	733	7.33		1750	733	7.33		1750	733	7.33		1750	733	7.33
		1900	790	7.90		1900	790	7.90		1900	790	7.90		1900	790	7.90		1900	790	7.90
		2050	847	8.47		2050	847	8.47		2050	847	8.47		2050	847	8.47		2050	847	8.47
		2200	904	9.04		2200	904	9.04		2200	904	9.04		2200	904	9.04		2200	904	9.04
	1st Gear	2350	961	9.61	2nd Gear	2350	961	9.61	3rd Gear	2350	961	9.61	4th Gear	2350	961	9.61	5th Gear	2350	961	9.61
		2500	1018	10.18		2500	1018	10.18		2500	1018	10.18		2500	1018	10.18		2500	1018	10.18
		2650	1075	10.75		2650	1075	10.75		2650	1075	10.75		2650	1075	10.75		2650	1075	10.75
		2800	1132	11.32		2800	1132	11.32		2800	1132	11.32		2800	1132	11.32		2800	1132	11.32
		2950	1189	11.89		2950	1189	11.89		2950	1189	11.89		2950	1189	11.89		2950	1189	11.89

FIG. 7

Transmission	
CVT	Class-17.5 Speed
2nd Gear	0.55
3rd Gear	0.50
5th Gear	0.22
6th Gear	0.14
7th Gear	0.15
8th Gear	0.10
9th Gear	0.09

Spec Pump	
Field End	Triplex
Size	301/rev
4.0"	0.00107
4.5"	0.00095
5.0"	0.00086

CAT TH55-E70 Transmission, Triplex Pumps

[illegible]

FIG. 8

Hot Pump	
Flow Rate	Cost
Flow	Cost/ton
4.7	5.00/50
4.5	5.00/45
4.0	5.00/30

[illegible]

FIG. 9

Transmission TA90-8501 Ratios	
1st Gear	4.37
2nd Gear	3.57
3rd Gear	2.85
4th Gear	2.41
5th Gear	1.92
6th Gear	1.54
7th Gear	1.25
8th Gear	1.00
9th Gear	0.80

Rac Pump Fluid End Quint	
Rate	68L/min
4.0"	0.00537
4.5"	0.00548
5.0"	0.00559

Twin Disc TA90-8501 Transmission - Quint Pumps																					
4.0" Fluid End	1st Gear	Engine rpm	Pump Crank rpm	Pump BPM	2nd Gear	Engine rpm	Pump Crank rpm	Pump BPM	3rd Gear	Engine rpm	Pump Crank rpm	Pump BPM	4th Gear	Engine rpm	Pump Crank rpm	Pump BPM	5th Gear	Engine rpm	Pump Crank rpm	Pump BPM	
		1500	65.8	2.75		1550	66.3	2.67		1600	67.8	2.68		1650	68.0	2.66		1700	68.3	2.65	1750
		1550	64.6	2.82		1580	66.3	2.53		1574	67.6	2.42		1550	68.2	2.23		1550	67.1	2.57	
		1600	66.3	2.91		1610	70.5	2.65		1600	68.4	2.57		1600	69.4	2.40		1600	68.2	2.66	
		1650	68.1	3.00		1680	72.8	2.76		1656	69.1	2.71		1650	69.8	2.57		1650	68.5	2.69	
		1700	69.9	3.09		1720	75.0	2.87		1700	69.9	2.85		1700	71.0	2.78		1700	69.3	2.80	
		1750	61.6	3.18		1780	77.2	2.99		1750	69.7	2.89		1750	71.4	2.61		1750	69.3	2.91	
		1800	63.4	3.28		1810	79.4	3.10		1800	69.4	2.94		1800	71.6	2.67		1800	69.7	2.92	
		1850	65.1	3.37		1880	81.6	3.21		1850	70.7	2.98		1850	72.8	2.74		1850	69.7	2.94	
		1900	66.9	3.46		1900	83.8	3.32		1900	70.9	3.03		1900	74.1	2.81		1900	69.8	2.95	
		1950	68.7	3.55		1950	86.0	3.43		1950	71.7	3.06		1950	75.4	2.88		1950	69.7	2.96	
4.5" Fluid End	1st Gear	1500	67.8	3.36	2nd Gear	1500	68.3	3.27	3rd Gear	1500	69.8	3.28	4th Gear	1500	70.0	3.26	5th Gear	1500	70.2	3.24	
		1550	64.6	3.57		1550	68.3	3.13		1550	70.2	3.07		1550	70.2	3.07					
		1600	66.3	3.66		1600	70.5	3.24		1600	71.1	3.21		1600	70.4	3.04					
		1650	68.1	3.75		1650	72.8	3.35		1650	73.0	3.27		1650	71.8	3.10					
		1700	69.9	3.84		1700	75.0	3.46		1700	75.0	3.33		1700	73.0	3.17					
			1750	61.6	3.93		1780	77.2	3.57		1750	73.4	3.28		1750	73.4	3.28		1750	71.4	3.20
			1800	63.4	4.02		1810	79.4	3.68		1800	73.4	3.33		1800	73.8	3.34		1800	71.8	3.26
			1850	65.1	4.11		1880	81.6	3.79		1850	73.8	3.39		1850	74.8	3.40		1850	72.8	3.32
			1900	66.9	4.20		1900	83.8	3.90		1900	74.0	3.44		1900	75.8	3.46		1900	73.0	3.38
			1950	68.7	4.29		1950	86.0	4.01		1950	74.7	3.48		1950	77.4	3.50		1950	73.3	3.40
5.0" Fluid End	1st Gear	1500	69.8	3.96	2nd Gear	1500	70.3	3.87	3rd Gear	1500	71.8	3.88	4th Gear	1500	72.0	3.86	5th Gear	1500	72.2	3.84	
		1550	64.6	4.17		1550	70.3	3.73		1550	72.2	3.79		1550	72.2	3.79					
		1600	66.3	4.26		1600	72.5	3.84		1600	73.0	3.89		1600	72.4	3.80					
		1650	68.1	4.35		1650	74.8	3.95		1650	74.0	3.98		1650	73.8	3.91					
		1700	69.9	4.44		1700	77.0	4.06		1700	76.0	4.01		1700	74.0	4.08					
			1750	61.6	4.53		1780	79.2	4.17		1750	76.4	4.12		1750	76.4	4.12		1750	74.4	4.13
			1800	63.4	4.62		1810	81.4	4.28		1800	76.4	4.17		1800	76.8	4.18		1800	74.8	4.14
			1850	65.1	4.71		1880	83.6	4.39		1850	76.8	4.22		1850	77.8	4.23		1850	75.8	4.19
			1900	66.9	4.80		1900	85.8	4.50		1900	77.0	4.26		1900	78.8	4.26		1900	76.0	4.22
			1950	68.7	4.89		1950	88.0	4.61		1950	77.7	4.28		1950	80.0	4.28		1950	76.3	4.24

FIG. 10

MULTI-PLUNGER PUMPS AND ASSOCIATED DRIVE SYSTEMS

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to and the benefit of U.S. Provisional Patent Application No. 62/594,912, filed Dec. 5, 2017, the full disclosure of which is hereby incorporated by reference herein for all purposes.

BACKGROUND

1. Technical Field

[0002] This disclosure relates generally to drive systems for reciprocating plunger-style pumps used in hydraulic fracturing operations, and more particularly to multi-plunger hydraulic fracturing pumps and associated drive systems.

2. Background

[0003] With advancements in technology over the past few decades, the ability to reach unconventional sources of hydrocarbons has tremendously increased. Horizontal drilling and hydraulic fracturing are two such ways that new developments in technology have led to hydrocarbon production from previously unreachable shale formations. Hydraulic fracturing (fracking) operations typically require powering numerous components in order to recover oil and gas resources from the ground. For example, hydraulic fracturing usually includes pumps that inject fracking fluid down the wellbore, blenders that mix proppant into the fluid, cranes, wireline units, and many other components that all must perform different functions to carry out fracking operations.

[0004] Hydraulic fracturing operations commonly use diesel-powered pumps to transmit fluid media down the well bore, the transmissions for the diesel-powered pumps often having seven speeds or more. When one or more pumps go offline during operation, for example due to system failure or for scheduled maintenance, the speed of the remaining operating pumps is increased accordingly. However, many of the top gears in these diesel transmissions provide speeds that are above the critical speed for the associated plunger pumps. Thus, compensating for the downed pump or pumps by up-shifting operation of the remaining pumps to these higher gears, above the critical speed for the pumps, can result in damage to the pumps. There is a need for hydraulic fracturing pumps that are capable of operation at or below the critical speed, without sacrificing pump rate, efficiency, and efficacy.

SUMMARY

[0005] One of the most common transmissions utilized in hydraulic fracturing pump applications is a nine-speed transmission, often driven by a diesel-powered engine. When this transmission is in fifth gear and the engine is running at 1700 rotations per minute (rpm), for example, the critical speed of 120 rpm on an associated 8-inch stroke pump is reached. Therefore, running the pump with the transmission operating in any of gears six through nine, above the critical speed reached at gear five, could cause pump cavitation and damage accumulation to the fluid end of the pump.

[0006] It has historically been believed that pump cavitation is caused by air entering the pump. Through testing and

data-gathering, however, Applicants have observed that pump cavitation and damage are caused by the formation of vacuum bubbles as a result of fluid being accelerated too fast through the pump. A heightened speed of operation creates low pressure within the pumps, creating vacuum bubbles. As the pump plungers retract, the vacuum bubbles implode, causing damage (cavitation) to the pump and engine systems. Although the risks of operating the pumps at too great of speeds may be known, concerns about lowered pump rates and lost efficiency resulting from maintaining slower transmission speeds commonly lead to disregard of the risks as an unavoidable consequence of maintaining pump efficiency.

[0007] In seeking to avoid such pump damage, Applicants have observed that, by operating transmissions such that pumps are maintained at or below critical pump speeds, such formation of vacuum bubbles and resulting pump cavitation and damage may be avoided. Further still, Applicants have observed that use of electric- or hydraulic-powered pumps may allow for better control of pump speeds at or below the critical speed due to the smaller increments between gear speeds as compared to those of pumps driven by diesel-powered engines.

[0008] Operation below critical pump speeds has previously been avoided as being considered inefficient and ineffective for pump usage in fracking, as slower pump speeds are historically believed to be directly tied to pump rates. Applicant has observed, however, that the introduction of multiple electric- or hydraulic-powered motors driving planetary gear trains can provide effective and efficient pumping power, thereby maintaining a consistent pump rate for fluid transfer, while also sustaining a pumping speed at or below the critical speed for the plungers. For example, Applicant discovered that varying pump bore sizes and stroke lengths, as well as number of plungers, allowed for operation at slower pump speeds while maintaining or increasing fluid pump rates. Applicant also discovered, through testing and analysis, that certain bore size, stroke length, and plunger number combinations provided maximum pump rate efficiency at a usable and economically effective overall pump size.

[0009] The present disclosure is directed to hydraulic fracturing system for fracturing a subterranean formation, according to various embodiments. In an embodiment, the hydraulic fracturing system can include a multi-plunger hydraulic fracturing pump fluidly connected to a well associated with the subterranean formation, and the multi-plunger pump can be configured to pump fluid into a wellbore associated with the well at a high pressure so that the fluid passes from the wellbore into the subterranean formation and fractures the subterranean formation. In an embodiment, the system can further include a plurality of motors positioned to power the multi-plunger pump, and a planetary gear train having a plurality of input pinion gears in rotational contact with each of the plurality of motors. In an embodiment, a gear ratio of the planetary gear train and a speed at which the plurality of motors operates can be selected so as to limit a maximum pump speed associated with the multi-plunger pump.

[0010] In an embodiment, the system can include a plurality of speed reduction gearboxes positioned between the plurality of input pinion gears and the plurality of motors so as to achieve a desired pump rate.

[0011] In an embodiment, the plurality of motors can include one of a plurality of electric motors or a plurality of hydraulic motors.

[0012] In an embodiment, the maximum pump speed can correlate to a critical plunger speed associated with each of the plurality of hydraulic pumps.

[0013] In an embodiment, the maximum pump speed can be 5% or less over a critical plunger speed associated with each of the plurality of hydraulic pumps.

[0014] In an embodiment, the plurality of hydraulic pumps includes an odd number of plungers greater than or equal to five plungers.

[0015] In an embodiment, a stroke length of each of the plungers associated with the plurality of hydraulic pumps can be selected to inversely relate to a pump speed associated with the plurality of hydraulic pumps so as to achieve a predetermined flow rate.

[0016] In an embodiment, the system can include a variable frequency drive (VFD) connected to the plurality of motors to control the speed of the plurality of motors. The VFD can be positioned to accelerate or decelerate pump rotational speeds associated with each of the plurality of hydraulic pumps, according to an embodiment.

[0017] In an embodiment, the VFD can include a plurality of VFDs and the plurality of VFDs can be configured to share a load required to power the plurality of hydraulic pumps.

[0018] In an embodiment, the plurality of VFDs can be configured to automatically shut off in the event of an overpressure event with respect to the plurality of hydraulic pumps.

[0019] The present disclosure is also related to a hydraulic fracturing system for fracturing a subterranean formation, according to an embodiment. In an embodiment, the system can include a multi-plunger hydraulic fracturing pump fluidly connected to a well associated with the subterranean formation, and the multi-plunger pump can be configured to pump fluid into a wellbore associated with the well at a high pressure so that the fluid passes from the wellbore into the subterranean formation and fractures the subterranean formation. In an embodiment, a plurality of motors can be positioned to power the multi-plunger pump. The system can further include a variable frequency drive connected to the plurality of motors to control the speeds of the plurality of electric motors, according to an embodiment. In an embodiment, the system can include a planetary gear train having a plurality of input pinion gears in rotational contact with each of the plurality of motors. In an embodiment, a gear ratio of the planetary gear train and a speed at which the plurality of motors operates can be selected so as to limit a maximum pump speed associated with the multi-plunger pump.

[0020] The present disclosure is also directed to a method for pumping fluid into a wellbore associated with a subterranean formation. In an embodiment, the method can include fluidly connecting a multi-plunger hydraulic fracturing pump to a well associated with the subterranean formation such that the multi-plunger pump pumps fluid into the wellbore at a high pressure so that fluid passes from the wellbore into the subterranean formation and fractures the subterranean formation. In an embodiment, the method can include powering the multi-plunger pump with a plurality of motors. In an embodiment, the method can further include providing a planetary gear train having a plurality of input

pinion gears in rotational contact with each of the plurality of motors so as to translate power from the plurality of motors into a desired pump rate of the multi-plunger pump.

[0021] Other aspects and features of the present disclosure will become apparent to those of ordinary skill in the art after reading the detailed description herein and the accompanying figures.

BRIEF DESCRIPTION OF DRAWINGS

[0022] Some of the features and benefits of the present invention having been stated, others will become apparent as the description proceeds when taken in conjunction with the accompanying drawings, in which:

[0023] FIG. 1 is an exploded schematic example of a planetary gear train having multiple input pinions for direct connection to an electric motor, according to an embodiment.

[0024] FIG. 2 is an exploded schematic example of a planetary gear train having a speed reduction gearbox mounting for connection to an electric motor, according to an embodiment.

[0025] FIG. 3 is a schematic example of a multi-plunger pump having nine plungers and four electric motors mounted for driving the multi-plunger pump, according to an embodiment.

[0026] FIG. 4 is a table showing calculations of plunger pump critical speeds according to embodiments of the present technology.

[0027] FIG. 5 is a table showing data related to certain pumps and transmissions in an example application, meant to highlight certain embodiments of the present technology.

[0028] FIGS. 6-10 are tables showing additional data related to certain pumps and transmissions in further example applications, meant to further highlight embodiments of the present technology.

[0029] While the invention will be described in connection with the preferred embodiments, it will be understood that the included description is not intended to limit the invention to the described preferred embodiments. On the contrary, the description is intended to cover all alternatives, modifications, and equivalents, as may be included within the spirit and scope of the invention as defined by the appended claims.

DETAILED DESCRIPTION OF INVENTION

[0030] The method and system of the present disclosure will now be described more fully hereinafter with reference to the accompanying drawings in which embodiments are shown. The method and system of the present disclosure may be in many different forms and should not be construed as limited to the illustrated embodiments set forth herein; rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey its scope to those skilled in the art. Like numbers refer to like elements throughout.

[0031] It is to be further understood that the scope of the present disclosure is not limited to the exact details of construction, operation, exact materials, or embodiments shown and described, as modifications and equivalents will be apparent to one skilled in the art. In the drawings and specification, there have been disclosed illustrative embodi-

ments and, although specific terms are employed, they are used in a generic and descriptive sense only and not for the purpose of limitation.

[0032] Described herein is an example of a method and system for providing reciprocating, plunger-style pumps as part of a multi-plunger system for use in hydraulic fracturing operations. Also described are various drive systems for use with the described reciprocating, plunger-style pumps. In various embodiments, the pumps and drive systems may be utilized by conventionally powered (i.e., diesel engine-driven) hydraulic fracturing pumping systems, or in other embodiments by hydraulically powered or electrically powered hydraulic fracturing pumping systems.

[0033] Multi-plunger hydraulic fracturing pumps, though known in the art, are typically limited to either triplex (three plungers) or quintuplex (five plungers) arrangements. Common hydraulic fracturing pumps often utilize 8-inch, 10-inch, and 11-inch stroke triplex and quintuplex hydraulic fracturing pumps. Hydraulic fracturing pumps are commonly driven by an engine (usually a 2500 horsepower (HP) diesel engine) and a multiple speed transmission, usually having seven speeds or more. However, many of the top gears, depending on the manufacturer and gear ratios, provide speeds that are above the critical speed of a plunger pump. FIG. 4 details calculations of such plunger critical speeds.

[0034] For example, one of the most common transmissions utilized in hydraulic fracturing pump applications is the Caterpillar model TH55-E90, which is a 9-speed transmission. As shown in FIG. 5, when this transmission is in 5th gear and the engine is operating at 1700 rpm, the critical speed of 120 rpm on an 8-inch stroke pump is reached. Therefore, running the pump with the transmission in any of gears 6 through 9 could cause pump cavitation and damage accumulation to the fluid end.

[0035] Similarly, the common hydraulic fracturing application transmissions known in the art may exhibit the same issues in higher gears, as shown below in FIGS. 6-10. For example, as shown in FIG. 6 and FIG. 7, the critical plunger speed is reached in the 3rd gear, such that use of gears 4-7 may cause cavitation and damage accumulation. Similarly, as shown in FIG. 8 and FIG. 9, the critical plunger speed is reached in the 4th gear, such that use of gears 5-7 may cause cavitation and damage accumulation. In FIG. 10, the critical plunger speed is reached in the 4th gear, such that use of gears 5-9 may result in cavitation and damage accumulation.

[0036] Use of the multi-plunger hydraulic fracturing pumps according to the present disclosure may eliminate the need for a diesel engine and transmission. As shown above, diesel engines and transmissions often include multiple gears that accelerate the plunger speed above critical operating speeds. This elimination of the typical engine and transmission from hydraulic fracturing pump units may enable the pumps to be driven by multiple electric motors, according to some embodiments, or multiple hydraulic motors according to other embodiments. These electric or hydraulic motors may have fewer gears such that operation in gears that increase the plunger speeds above their critical speeds can be avoided. By using multiple motors, whether hydraulic or electric, to drive a single pump, pump rates can be increased without exceeding critical plunger speeds.

[0037] Use of electric or hydraulic motors, rather than diesel motors, may also make maintenance, repair, and replacement of the electric motors safer and faster than

single or double electric motor-driven pumps. This configuration may prevent the fracturing pumps from being run at speeds higher than the critical plunger speed, which may help to minimize pump cavitation and damage accumulation, thus greatly extending the usable life of the pump fluid ends. For example, as discussed in more detail below, the system could be designed to allow only a slight overspeed of the pumps beyond the identified critical pump speed as a safety margin in the event that one of the fleet's pumps were taken offline for repairs or maintenance, and an additional rate of the remaining online pumps were required to complete the stage being pumped.

[0038] In the multiple electric motor-driven embodiment of the present disclosure, the electric motors may directly drive the pump, and the gear ratios of the planetary drive along with the electric motor-rated speeds may be chosen to limit the maximum pump speed, so as to not exceed the plunger critical speed. However, the gear ratios and electric motor-rated speeds may also be chosen to allow only a slight percentage of overspeed (higher than critical plunger speed) as a safe margin to enable a fleet of operating pumps to achieve a desired pump rate, for example when one pump is taken off line, as is often the case in hydraulic fracturing. For example, the gear ratios and electric motor-rated speeds may be chosen to operate 5% or less above the critical plunger speed according to some examples; 10% or less above the critical plunger speed according to some examples; or any other acceptable range as will be readily understood by one having ordinary skill in the art. Repairs or maintenance are generally performed as quickly as possible so that the offline pump is available by the next sequential fracturing stage. This same logic could be applied to the hydraulic motor driven system or the system that utilizes speed reduction gearboxes driving a single ring gear.

[0039] By the present disclosure, multi-plunger hydraulic fracturing pumps utilizing higher multiples of plungers, such as 7, 9, 11, 13, etc. (septenplex, novenplex, undenplex, tredenplex, etc.), are described. In some embodiments, more than 13 plungers may be utilized, as will be readily understood by one having ordinary skill in the art. In some embodiments, odd numbers of plungers may be chosen so that the pump flow ripple magnitude is minimized. For example, in multi-plunger hydraulic fracturing pumps having higher numbers of plungers, the plunger ripple frequency may be increased, thereby reducing the amount of time between ripples, which may provide a smoother pressure performance for the pumps.

[0040] In some embodiments, longer stroke lengths of the plunger pumps may be utilized to reduce plunger speed. For example, a 10-inch stroke pump of a given plunger size may be run at a slower speed than an 8-inch stroke pump of the same plunger size, in order to accomplish the same flow rate. Slowing the plunger down may also decrease the possibility of pump cavitation. For example, when triplex and quintuplex pumps, as are known in the art, are operated at higher rates, conditions for cavitation to occur are measurably higher. According to an embodiment, a critical pump speed may be 120 rpm of the pump crankshaft. With this pump speed, on the currently used 8-inch stroke pumps, the rotational speed translates to an average linear speed of the plungers at a velocity of 32 inches per second. At higher speeds, with every stroke of the plungers, fluid is accelerated into and out of the pump fluid end, creating a likelihood of low pressure regions within the fluid end that approach or

dip below vapor pressure values for the fluid, thereby causing cavitation, and ultimately damage accumulation, to occur. The use of longer stroke plungers accordingly contributes critically to longer fluid end life.

[0041] Various drive systems for powering multi-plunger hydraulic fracturing pumps are contemplated. According to an embodiment, multiple electric motors may be utilized to power the multi-plunger hydraulic fracturing pump. The number of motors utilized may be selected based on the output hydraulic horsepower for which the pump is designed, in some examples. In other examples, the number of motors could be determined on an “n plus 1” basis, in which “n” number of motors would be adequate to provide enough input power according to the output hydraulic horsepower for which the pump is designed, and one (“1”) additional motor would be included to allow for a single motor failure or maintenance situation. In such a situation, the failed motor (or motor purposefully removed for maintenance) could be disconnected from the electrical circuit and allowed to freewheel, while the remaining operational motors would still provide adequate power for the pump, according to an embodiment.

[0042] In the example illustrated in FIG. 1, an exploded schematic view shows an embodiment of a planetary gear train **100** in which the multiple input pinion gears **135** are directly connected to the electric motors **130**. According to the illustrated embodiment, both ends of the pump crankshaft **105** may be powered with an identical planetary gear train **120** and electric motors **130** to enable the motors **130** to be sized small enough to simplify motor removal and installation as compared to a larger single electric motor, or a double electric motor drive system.

[0043] In the illustrated embodiment of FIG. 1, eight electric motors **130** may correspond to and drive eight input pinion gears **135** associated with a single main planetary gear **125**. The main planetary gear **125** may in turn drive the sun gear **115** positioned central to three planetary gears **120**. The final drive gear **110** may have internal gear teeth positioned to catch the external gear teeth of the three planetary gears **120**, which may cause rotation of the pump crankshaft **105**. In this way, a plurality of electric motors **130** may provide power to a pump crankshaft **105**, which may in turn drive a multi-plunger pump, for example as illustrated in FIG. 3 and discussed in greater detail below.

[0044] In another embodiment, multiple hydraulic motors may be utilized to power a multi-plunger hydraulic fracturing pump, in which a planetary gear train system **100** similar to that illustrated in FIG. 1 could also be utilized. In an example, a planetary gear train system may be utilized on one or both ends of the pump crankshaft to allow for smaller hydraulic motors to be utilized.

[0045] According to an alternate embodiment, for example as illustrated in FIG. 2, a plurality of electric motors or hydraulic motors **230** each may be mounted to a plurality of speed reduction gearboxes **245**. FIG. 2 illustrates an exploded schematic example of a planetary gear train **200** having a plurality of speed reduction gearbox **245** mountings for connection to a plurality of electric motors **230**, according to an embodiment. The speed reduction gearboxes **245** may, in turn, power a single ring gear **240** to turn the pump crankshaft **205** at the proper rpm needed to drive the multi-plunger pumps at the desired pump rate. In some examples, this configuration may not require use of a multi-planetary gear train system as described above and

illustrated in FIG. 1, for example. For example, as illustrated in the embodiment of FIG. 2, the plurality of electric motors **230** may drive the main planetary gear in the form of a ring gear **240** through speed reduction gearboxes **245**, and the ring gear **240** may directly turn the pump crankshaft **205**. In such an example additional planetary gears **120**, as illustrated in the embodiment of FIG. 1, for example, may not be included.

[0046] In an embodiment utilizing multiple electric motors, the fleet of fracturing pumps may be powered by multiple electric motors, and overall electric power may be generated by one or more diesel or gas turbines. When the pumps are being brought online to pump fluids into the well, the power may be switched via appropriate switchgear to the electric motors.

[0047] In some embodiments, the speed of the motors may be controlled by one or more variable frequency drives (VFD), which may accelerate or decelerate the pump rotational speeds using an S curve. The pump operator may select the various pump speeds via a human-machine interface (HMI) according to some embodiments, for example from inside a data van, or from a “suitcase,” which is a portable, standalone HMI. The HMI or suitcase may allow on/off control of the pumps as well as speed control of the pumps, to allow the pumps to run at speeds from zero crankshaft rpm up to the maximum speed, which would correlate with the plunger critical speed.

[0048] According to an embodiment, one of the VFDs may be designated as the master VFD, and the remaining VFDs may be designed to share the load required to power the pump under all load conditions. In the case of an overpressure event, the hydraulic fracturing controls may automatically turn the VFD off using the on/off signal for rapid shutdown, instead of using the rpm command, which uses an S curve to control the acceleration and/or deceleration. A manual emergency shutdown may also be included, which uses an HMI (such as a push button or other HMI, which may be electronic and/or manual) to shut off the VFD using the on/off function. This manual emergency shutdown feature may be configured to shut down all VFDs simultaneously, thereby shutting down the entire site. The emergency shutdown may also be configured to stop the VFD on the blender discharge pumps, and may or may not be tied into the electrical microgrid to open breakers, thereby stopping the flow and/or generation of electricity and/or gas compression.

[0049] The HMI may be designed to allow only a slight percentage of overspeed (higher than critical plunger speed) as a safe margin to enable a fleet of operating pumps to achieve a desired pump rate when one pump is taken offline, for example, as is often the case in hydraulic fracturing. Repairs or maintenance are generally performed as quickly as possible so that the offline pump is available by the next sequential fracturing stage. This same logic could be applied to the hydraulic motor driven system or the system that utilizes speed reduction gearboxes driving a single ring gear.

[0050] FIG. 3 illustrates a schematic example of a multi-plunger pump **300** with four electric motors mounted to the pump for driving the multi-plunger pump, according to an embodiment. In the illustrated embodiment, the multi-plunger pump **300** may include nine plungers positioned at the multi-plunger fluid end **350** of the multi-plunger pump **300**. In other embodiments, various other numbers of plung-

ers may be included, as will be readily understood by one having ordinary skill in the art.

[0051] A crankshaft centerline **360** may bisect the multi-plunger pump **300** between the multi-plunger fluid end **350** and the pump power end **355**. Two electric motors **330** may be positioned on opposing sides of the multi-plunger pump **300**, across the crankshaft centerline **360**. The four total electric motors **330** may drive the crankshaft associated with the nine plungers, as described above with respect to FIGS. **1** and **2**. For example, in some embodiments the four electric motors **330** may drive the crankshaft via one or more planetary gear trains. In some embodiments, a plurality of speed reduction gearboxes may be positioned between the electric motors **330** and the one or more planetary gear trains so as to control the rotational speed of the one or more planetary gear trains and, ultimately, the pump rate of the plungers.

[0052] The present invention described herein, therefore, is well adapted to carry out the objects and attain the ends and advantages mentioned, as well as others inherent therein. While a presently preferred embodiment of the invention has been given for purposes of disclosure, numerous changes exist in the details of procedures for accomplishing the desired results. These and other similar modifications will readily suggest themselves to those skilled in the art, and are intended to be encompassed within the spirit of the present invention disclosed herein and the scope of the appended claims.

What is claimed is:

1. A hydraulic fracturing system for fracturing a subterranean formation comprising:

a multi-plunger hydraulic fracturing pump fluidly connected to a well associated with the subterranean formation, the multi-plunger pump configured to pump fluid into a wellbore associated with the well at a high pressure so that the fluid passes from the wellbore into the subterranean formation and fractures the subterranean formation;

a plurality of motors positioned to power the multi-plunger pump; and

a planetary gear train having a plurality of input pinion gears in rotational contact with each of the plurality of motors,

wherein a gear ratio of the planetary gear train and a speed at which the plurality of motors operates are selected so as to limit a maximum pump speed associated with the multi-plunger pump.

2. The system of claim **1**, the system further comprising a plurality of speed reduction gearboxes positioned between the plurality of input pinion gears and the plurality of motors so as to achieve a desired pump rate.

3. The system of claim **1**, wherein the plurality of motors comprises one of a plurality of electric motors or a plurality of hydraulic motors.

4. The system of claim **1**, wherein the maximum pump speed correlates to a critical plunger speed associated with each of the plurality of hydraulic pumps.

5. The system of claim **1**, wherein the maximum pump speed is 5% or less over a critical plunger speed associated with each of the plurality of hydraulic pumps.

6. The system of claim **1**, wherein the plurality of hydraulic pumps comprises an odd number of plungers greater than or equal to five plungers.

7. The system of claim **6**, wherein a stroke length of each of the plungers associated with the plurality of hydraulic pumps is selected to inversely relate to a pump speed associated with the plurality of hydraulic pumps so as to achieve a predetermined flow rate.

8. The system of claim **1**, further comprising:

a variable frequency drive (VFD) connected to the plurality of motors to control the speed of the plurality of motors, wherein the VFD is positioned to accelerate or decelerate pump rotational speeds associated with each of the plurality of hydraulic pumps.

9. The system of claim **8**, wherein the VFD comprises a plurality of VFDs and wherein the plurality of VFDs are configured to share a load required to power the plurality of hydraulic pumps.

10. The system of claim **9**, wherein the plurality of VFDs are configured to automatically shut off in the event of an overpressure event with respect to the plurality of hydraulic pumps.

11. A hydraulic fracturing system for fracturing a subterranean formation comprising:

a multi-plunger hydraulic fracturing pump fluidly connected to a well associated with the subterranean formation, the multi-plunger pump configured to pump fluid into a wellbore associated with the well at a high pressure so that the fluid passes from the wellbore into the subterranean formation and fractures the subterranean formation;

a plurality of motors positioned to power the multi-plunger pump;

a variable frequency drive connected to the plurality of motors to control the speeds of the plurality of electric motors; and

a planetary gear train having a plurality of input pinion gears in rotational contact with each of the plurality of motors,

wherein a gear ratio of the planetary gear train and a speed at which the plurality of motors operates are selected so as to limit a maximum pump speed associated with the multi-plunger pump.

12. The system of claim **11**, the system further comprising a plurality of speed reduction gearboxes positioned between the plurality of input pinion gears and the plurality of motors so as to achieve a desired pump rate.

13. The system of claim **11**, wherein the plurality of motors comprises one of a plurality of electric motors or a plurality of hydraulic motors.

14. The system of claim **11**, wherein the maximum pump speed correlates to a critical plunger speed associated with each of the plurality of hydraulic pumps.

15. A method for pumping fluid into a wellbore associated with a subterranean formation, the method comprising:

fluidly connecting a multi-plunger hydraulic fracturing pump to a well associated with the subterranean formation such that the multi-plunger pump pumps fluid into the wellbore at a high pressure so that fluid passes from the wellbore into the subterranean formation and fractures the subterranean formation;

powering the multi-plunger pump with a plurality of motors;

providing a planetary gear train having a plurality of input pinion gears in rotational contact with each of the

plurality of motors so as to translate power from the plurality of motors into a desired pump rate of the multi-plunger pump.

16. The method of claim **15**, further comprising:

positioning a plurality of speed reduction gearboxes between the plurality of input pinion gears and the plurality of motors so as to achieve the desired pump rate.

17. The method of claim **15**, wherein the plurality of motors comprises one of a plurality of electric motors or a plurality of hydraulic motors.

18. The method of claim **15**, wherein the maximum pump speed correlates to a critical plunger speed associated with each of the plurality of hydraulic pumps.

19. The method of claim **15**, further comprising:

connecting a variable frequency drive (VFD) to the plurality of motors so as to control the speed of the plurality of motors, wherein the VFD is positioned to accelerate or decelerate pump rotational speeds associated with each of the plurality of hydraulic pumps.

20. The method of claim **19**, the method further comprising:

detecting an overpressure event with respect to the plurality of hydraulic pumps; and
automatically shutting off the plurality of VFDs.

* * * * *