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(54) **MOTOR HEALTH MONITORING AND MEDICAL DEVICE INCORPORATING SAME**

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See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,631,847 A	1/1972	Hobbs, II
4,212,738 A	7/1980	Henne
4,270,532 A	6/1981	Franetzki et al.

(Continued)

FOREIGN PATENT DOCUMENTS

DE	4329229	3/1995
EP	0319268	11/1988

(Continued)

OTHER PUBLICATIONS

PCT Search Report (PCT/US02/03299), Oct. 31, 2002, Medtronic Minimed, Inc.

(Continued)

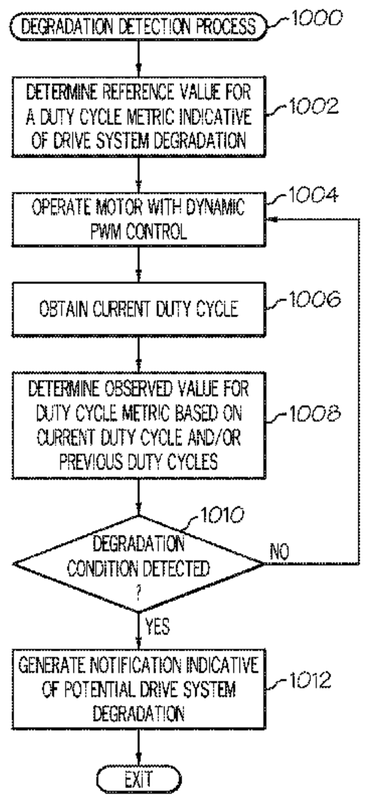
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(57) **ABSTRACT**

Apparatus are provided for motor control systems and related medical devices. In one embodiment, a control system includes a motor having a rotor, a modulation module coupled to the motor, and a control module coupled to the motor and the modulation module. The modulation module generates a modulated voltage that is applied to the motor, and the control module adjusts a duty cycle of the modulated voltage to achieve a commanded rotation of the rotor and detects a degradation condition based on the duty cycle.

20 Claims, 10 Drawing Sheets



(56) **References Cited**

U.S. PATENT DOCUMENTS

4,282,872	A	8/1981	Franetzki et al.
4,334,189	A	6/1982	Sato et al.
4,373,527	A	2/1983	Fischell
4,395,259	A	7/1983	Prestele et al.
4,433,072	A	2/1984	Pusineri et al.
4,443,218	A	4/1984	DeCant, Jr. et al.
4,494,950	A	1/1985	Fischell
4,542,532	A	9/1985	McQuilkin
4,550,731	A	11/1985	Batina et al.
4,559,037	A	12/1985	Franetzki et al.
4,562,751	A	1/1986	Nason et al.
4,671,288	A	6/1987	Gough
4,678,408	A	7/1987	Nason et al.
4,685,903	A	8/1987	Cable et al.
4,731,051	A	3/1988	Fischell
4,731,726	A	3/1988	Allen, III
4,781,798	A	11/1988	Gough
4,803,625	A	2/1989	Fu et al.
4,809,697	A	3/1989	Causey, III et al.
4,826,810	A	5/1989	Aoki
4,871,351	A	10/1989	Feingold
4,898,578	A	2/1990	Rubalcaba, Jr.
5,003,298	A	3/1991	Havel
5,011,468	A	4/1991	Lundquist et al.
5,019,974	A	5/1991	Beckers
5,050,612	A	9/1991	Matsumura
5,078,683	A	1/1992	Sancoff et al.
5,080,653	A	1/1992	Voss et al.
5,097,122	A	3/1992	Colman et al.
5,100,380	A	3/1992	Epstein et al.
5,101,814	A	4/1992	Palti
5,108,819	A	4/1992	Heller et al.
5,153,827	A	10/1992	Coutre et al.
5,165,407	A	11/1992	Wilson et al.
5,247,434	A	9/1993	Peterson et al.
5,262,035	A	11/1993	Gregg et al.
5,262,305	A	11/1993	Heller et al.
5,264,104	A	11/1993	Gregg et al.
5,264,105	A	11/1993	Gregg et al.
5,284,140	A	2/1994	Allen et al.
5,299,571	A	4/1994	Mastrototaro
5,307,263	A	4/1994	Brown
5,317,506	A	5/1994	Coutre et al.
5,320,725	A	6/1994	Gregg et al.
5,322,063	A	6/1994	Allen et al.
5,338,157	A	8/1994	Blomquist
5,339,821	A	8/1994	Fujimoto
5,341,291	A	8/1994	Roizen et al.
5,350,411	A	9/1994	Ryan et al.
5,356,786	A	10/1994	Heller et al.
5,357,427	A	10/1994	Langen et al.
5,368,562	A	11/1994	Blomquist et al.
5,370,622	A	12/1994	Livingston et al.
5,371,687	A	12/1994	Holmes, II et al.
5,376,070	A	12/1994	Purvis et al.
5,390,671	A	2/1995	Lord et al.
5,391,250	A	2/1995	Cheney, II et al.
5,403,700	A	4/1995	Heller et al.
5,411,647	A	5/1995	Johnson et al.
5,482,473	A	1/1996	Lord et al.
5,485,408	A	1/1996	Blomquist
5,497,772	A	3/1996	Schulman et al.
5,505,709	A	4/1996	Funderburk et al.
5,543,326	A	8/1996	Heller et al.
5,569,186	A	10/1996	Lord et al.
5,569,187	A	10/1996	Kaiser
5,573,506	A	11/1996	Vasko
5,582,593	A	12/1996	Hultman
5,586,553	A	12/1996	Halili et al.
5,593,390	A	1/1997	Castellano et al.
5,593,852	A	1/1997	Heller et al.
5,594,638	A	1/1997	Iliff
5,609,060	A	3/1997	Dent
5,626,144	A	5/1997	Tacklind et al.
5,630,710	A	5/1997	Tune et al.
5,643,212	A	7/1997	Coutre et al.
5,660,163	A	8/1997	Schulman et al.
5,660,176	A	8/1997	Iliff
5,665,065	A	9/1997	Colman et al.
5,665,222	A	9/1997	Heller et al.
5,685,844	A	11/1997	Marttila
5,687,734	A	11/1997	Dempsey et al.
5,704,366	A	1/1998	Tacklind et al.
5,735,887	A	4/1998	Barreras, Sr. et al.
5,750,926	A	5/1998	Schulman et al.
5,754,111	A	5/1998	Garcia
5,764,159	A	6/1998	Neftel
5,772,635	A	6/1998	Dastur et al.
5,779,665	A	7/1998	Mastrototaro et al.
5,788,669	A	8/1998	Peterson
5,791,344	A	8/1998	Schulman et al.
5,800,420	A	9/1998	Gross et al.
5,807,336	A	9/1998	Russo et al.
5,814,015	A	9/1998	Gargano et al.
5,822,715	A	10/1998	Worthington et al.
5,832,448	A	11/1998	Brown
5,840,020	A	11/1998	Heinonen et al.
5,861,018	A	1/1999	Feierbach et al.
5,868,669	A	2/1999	Iliff
5,871,465	A	2/1999	Vasko
5,879,163	A	3/1999	Brown et al.
5,885,245	A	3/1999	Lynch et al.
5,897,493	A	4/1999	Brown
5,899,855	A	5/1999	Brown
5,904,708	A	5/1999	Goedeke
5,913,310	A	6/1999	Brown
5,917,346	A	6/1999	Gord
5,918,603	A	7/1999	Brown
5,925,021	A	7/1999	Castellano et al.
5,933,136	A	8/1999	Brown
5,935,099	A	8/1999	Peterson et al.
5,940,801	A	8/1999	Brown
5,956,501	A	9/1999	Brown
5,960,403	A	9/1999	Brown
5,965,380	A	10/1999	Heller et al.
5,972,199	A	10/1999	Heller et al.
5,978,236	A	11/1999	Faberman et al.
5,997,476	A	12/1999	Brown
5,999,848	A	12/1999	Gord et al.
5,999,849	A	12/1999	Gord et al.
6,009,339	A	12/1999	Bentsen et al.
6,032,119	A	2/2000	Brown et al.
6,043,437	A	3/2000	Schulman et al.
6,081,736	A	6/2000	Colvin et al.
6,083,710	A	7/2000	Heller et al.
6,088,608	A	7/2000	Schulman et al.
6,101,478	A	8/2000	Brown
6,103,033	A	8/2000	Say et al.
6,119,028	A	9/2000	Schulman et al.
6,120,676	A	9/2000	Heller et al.
6,121,009	A	9/2000	Heller et al.
6,134,461	A	10/2000	Say et al.
6,143,164	A	11/2000	Heller et al.
6,162,611	A	12/2000	Heller et al.
6,175,752	B1	1/2001	Say et al.
6,183,412	B1	2/2001	Benkowski et al.
6,246,992	B1	6/2001	Brown
6,259,937	B1	7/2001	Schulman et al.
6,329,161	B1	12/2001	Heller et al.
6,408,330	B1	6/2002	DeLaHuerga
6,424,847	B1	7/2002	Mastrototaro et al.
6,472,122	B1	10/2002	Schulman et al.
6,484,045	B1	11/2002	Holker et al.
6,484,046	B1	11/2002	Say et al.
6,485,465	B2	11/2002	Moberg et al.
6,503,381	B1	1/2003	Gotoh et al.
6,514,718	B2	2/2003	Heller et al.
6,544,173	B2	4/2003	West et al.
6,553,263	B1	4/2003	Meadows et al.
6,554,798	B1	4/2003	Mann et al.
6,558,320	B1	5/2003	Causey, III et al.
6,558,351	B1	5/2003	Steil et al.
6,560,741	B1	5/2003	Gerety et al.
6,565,509	B1	5/2003	Say et al.

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,579,690	B1	6/2003	Bonnecaze et al.	
6,589,229	B1	7/2003	Connelly et al.	
6,591,125	B1	7/2003	Buse et al.	
6,592,745	B1	7/2003	Feldman et al.	
6,605,200	B1	8/2003	Mao et al.	
6,605,201	B1	8/2003	Mao et al.	
6,607,658	B1	8/2003	Heller et al.	
6,616,819	B1	9/2003	Liamos et al.	
6,618,934	B1	9/2003	Feldman et al.	
6,623,501	B2	9/2003	Heller et al.	
6,641,533	B2	11/2003	Causey, III et al.	
6,654,625	B1	11/2003	Say et al.	
6,659,980	B2	12/2003	Moberg et al.	
6,671,554	B2	12/2003	Gibson et al.	
6,676,816	B2	1/2004	Mao et al.	
6,689,265	B2	2/2004	Heller et al.	
6,728,576	B2	4/2004	Thompson et al.	
6,733,471	B1	5/2004	Ericson et al.	
6,740,072	B2	5/2004	Starkweather et al.	
6,746,582	B2	6/2004	Heller et al.	
6,747,556	B2	6/2004	Medema et al.	
6,749,740	B2	6/2004	Liamos et al.	
6,752,787	B1	6/2004	Causey, III et al.	
6,809,653	B1	10/2004	Mann et al.	
6,817,990	B2	11/2004	Yap et al.	
6,827,702	B2	12/2004	Lebel et al.	
6,881,551	B2	4/2005	Heller et al.	
6,892,085	B2	5/2005	McIvor et al.	
6,893,545	B2	5/2005	Gotoh et al.	
6,895,263	B2	5/2005	Shin et al.	
6,916,159	B2	7/2005	Rush et al.	
6,932,584	B2	8/2005	Gray et al.	
6,932,894	B2	8/2005	Mao et al.	
6,942,518	B2	9/2005	Liamos et al.	
7,018,361	B2	3/2006	Gillespie, Jr. et al.	
7,153,263	B2	12/2006	Carter et al.	
7,153,289	B2	12/2006	Vasko	
7,323,142	B2	1/2008	Pendo et al.	
7,396,330	B2	7/2008	Banet et al.	
7,621,893	B2	11/2009	Moberg et al.	
7,828,764	B2	11/2010	Moberg et al.	
7,905,868	B2	3/2011	Moberg et al.	
8,197,444	B1	6/2012	Bazargan et al.	
8,202,249	B2	6/2012	Lio et al.	
8,362,742	B2	1/2013	Kallmyer	
8,469,942	B2	6/2013	Kow et al.	
8,523,803	B1 *	9/2013	Favreau	A61M 5/142 604/67
8,539,812	B2	9/2013	Stringham et al.	
8,603,026	B2 *	12/2013	Favreau	A61M 5/172 604/67
8,603,027	B2 *	12/2013	Favreau	F04B 49/10 604/67
8,690,855	B2	4/2014	Alderete, Jr. et al.	
9,173,993	B2	11/2015	Yodfat et al.	
9,216,249	B2	12/2015	Smith et al.	
2001/0044731	A1	11/2001	Coffman et al.	
2002/0013518	A1	1/2002	West et al.	
2002/0055857	A1	5/2002	Mault et al.	
2002/0082665	A1	6/2002	Haller et al.	
2002/0137997	A1	9/2002	Mastrototaro et al.	
2002/0161288	A1	10/2002	Shin et al.	
2003/0060765	A1	3/2003	Campbell et al.	
2003/0078560	A1	4/2003	Miller et al.	
2003/0088166	A1	5/2003	Say et al.	
2003/0144581	A1	7/2003	Conn et al.	
2003/0152823	A1	8/2003	Heller	
2003/0176183	A1	9/2003	Drucker et al.	
2003/0188427	A1	10/2003	Say et al.	
2003/0199744	A1	10/2003	Buse et al.	
2003/0208113	A1	11/2003	Mault et al.	
2003/0220552	A1	11/2003	Reghabi et al.	
2004/0061232	A1	4/2004	Shah et al.	
2004/0061234	A1	4/2004	Shah et al.	
2004/0064133	A1	4/2004	Miller et al.	
2004/0064156	A1	4/2004	Shah et al.	
2004/0073095	A1	4/2004	Causey, III et al.	
2004/0074785	A1	4/2004	Holker et al.	
2004/0093167	A1	5/2004	Braig et al.	
2004/0097796	A1	5/2004	Berman et al.	
2004/0102683	A1	5/2004	Khanuja et al.	
2004/0111017	A1	6/2004	Say et al.	
2004/0122353	A1	6/2004	Shahmirian et al.	
2004/0167465	A1	8/2004	Mihai et al.	
2004/0263354	A1	12/2004	Mann et al.	
2005/0038331	A1	2/2005	Silaski et al.	
2005/0038680	A1	2/2005	McMahon et al.	
2005/0154271	A1	7/2005	Rasdal et al.	
2005/0192557	A1	9/2005	Brauker et al.	
2006/0229694	A1	10/2006	Schulman et al.	
2006/0238333	A1	10/2006	Welch et al.	
2006/0293571	A1	12/2006	Bao et al.	
2007/0088521	A1	4/2007	Shmueli et al.	
2007/0135866	A1	6/2007	Baker et al.	
2008/0154503	A1	6/2008	Wittenber et al.	
2008/0269687	A1	10/2008	Chong et al.	
2009/0081951	A1	3/2009	Erdmann et al.	
2009/0082635	A1	3/2009	Baldus et al.	
2011/0092894	A1	4/2011	McGill et al.	
2011/0233393	A1	9/2011	Hanson et al.	

FOREIGN PATENT DOCUMENTS

EP	0806738		11/1997
EP	0880936		12/1998
EP	1338295		8/2003
EP	1631036	A2	3/2006
GB	2218831		11/1989
WO	WO 96/20745		7/1996
WO	WO 96/36389		11/1996
WO	WO 96/37246	A1	11/1996
WO	WO 97/21456		6/1997
WO	WO 98/20439		5/1998
WO	WO 98/24358		6/1998
WO	WO 98/42407		10/1998
WO	WO 98/49659		11/1998
WO	WO 98/59487		12/1998
WO	WO 99/08183		2/1999
WO	WO 99/10801		3/1999
WO	WO 99/18532		4/1999
WO	WO 99/22236		5/1999
WO	WO 00/10628		3/2000
WO	WO 00/19887		4/2000
WO	WO 00/48112		8/2000
WO	WO 02/058537	A2	8/2002
WO	WO 03/001329		1/2003
WO	WO 03/094090		11/2003
WO	WO 2005/065538	A2	7/2005
WO	WO2009/102355	A2	8/2009

OTHER PUBLICATIONS

(Animas Corporation, 1999). Animas . . . bringing new life to insulin therapy.

Bode B W, et al. (1996). Reduction in Severe Hypoglycemia with Long-Term Continuous Subcutaneous Insulin Infusion in Type I Diabetes. Diabetes Care, vol. 19, No. 4, 324-327.

Boland E (1998). Teens Pumping it Up! Insulin Pump Therapy Guide for Adolescents. 2nd Edition.

Brackenridge B P (1992). Carbohydrate Gram Counting A Key to Accurate Mealtime Boluses in Intensive Diabetes Therapy. Practical Diabetology, vol. 11, No. 2, pp. 22-28.

Brackenridge, B P et al. (1995). Counting Carbohydrates How to Zero in on Good Control. MiniMed Technologies Inc.

Farkas-Hirsch R et al. (1994). Continuous Subcutaneous Insulin Infusion: A Review of the Past and Its Implementation for the Future. Diabetes Spectrum From Research to Practice, vol. 7, No. 2, pp. 80-84, 136-138.

Hirsch I B et al. (1990). Intensive Insulin Therapy for Treatment of Type I Diabetes. Diabetes Care, vol. 13, No. 12, pp. 1265-1283.

Kulkarni K et al. (1999). Carbohydrate Counting a Primer for Insulin Pump Users to Zero in on Good Control. MiniMed Inc.

(56) **References Cited**

OTHER PUBLICATIONS

Marcus A O et al. (1996). Insulin Pump Therapy Acceptable Alternative to Injection Therapy. Postgraduate Medicine, vol. 99, No. 3, pp. 125-142.
Reed J et al. (1996). Voice of the Diabetic, vol. 11, No. 3, pp. 1-38.
Skyler J S (1989). Continuous Subcutaneous Insulin Infusion [CSII] With External Devices: Current Status. Update in Drug Delivery Systems, Chapter 13, pp. 163-183. Futura Publishing Company.
Skyler J S et al. (1995). The Insulin Pump Therapy Book Insights from the Experts. MiniMed•Technologies.
Strowig S M (1993). Initiation and Management of Insulin Pump Therapy. The Diabetes Educator, vol. 19, No. 1, pp. 50-60.
Walsh J, et al. (1989). Pumping Insulin: The Art of Using an Insulin Pump. Published by MiniMed•Technologies.
(Intensive Diabetes Management, 1995). Insulin Infusion Pump Therapy. pp. 66-78.
Disetronic My Choice™ D-TRON™ Insulin Pump Reference Manual. (no date).
Disetronic H-TRON® plus Quick Start Manual. (no date).
Disetronic My Choice H-TRONplus Insulin Pump Reference Manual. (no date).
Disetronic H-TRON®plus Reference Manual. (no date).
(MiniMed, 1996). The MiniMed 506. 7 pages. Retrieved on Sep. 16, 2003 from the World Wide Web: http://web.archive.org/web/19961111054527/www.minimed.com/files/506_pic.htm.
(MiniMed, 1997). MiniMed 507 Specifications. 2 pages. Retrieved on Sep. 16, 2003 from the World Wide Web: http://web.archive.org/web/19970124234841/www.minimed.com/files/mmn075.htm.
(MiniMed, 1996). FAQ: The Practical Things . . . pp. 1-4. Retrieved on Sep. 16, 2003 from the World Wide Web: http://web.archive.org/web/19961111054546/www.minimed.com/files/faq_pract.htm.
(MiniMed, 1997). Wanted: a Few Good Belt Clips! 1 page. Retrieved on Sep. 16, 2003 from the World Wide Web: http://web.archive.org/web/19970124234559/www.minimed.com/files/mmn002.htm.
(MiniMed Technologies, 1994). MiniMed 506 Insulin Pump User's Guide.
(MiniMed Technologies, 1994). MiniMed™ Dosage Calculator Initial Meal Bolus Guidelines/MiniMed™ Dosage Calculator Initial Basal Rate Guidelines Percentage Method. 4 pages.
(MiniMed, 1996). MiniMed™ 507 Insulin Pump User's Guide.
(MiniMed, 1997). MiniMed™ 507 Insulin Pump User's Guide.
(MiniMed, 1998). MiniMed 507C Insulin Pump User's Guide.
(MiniMed International, 1998). MiniMed 507C Insulin Pump for those who appreciate the difference.
(MiniMed Inc., 1999). MiniMed 508 Flipchart Guide to Insulin Pump Therapy.
(MiniMed Inc., 1999). Insulin Pump Comparison/Pump Therapy Will Change Your Life.
(MiniMed, 2000). MiniMed® 508 User's Guide.
(MiniMed Inc., 2000). MiniMed® Now [I] Can Meal Bolus Calculator/MiniMed® Now [I] Can Correction Bolus Calculator.
(MiniMed Inc., 2000). Now [I] Can MiniMed Pump Therapy.
(MiniMed Inc., 2000). Now [I] Can MiniMed Diabetes Management.
(Medtronic MiniMed, 2002). The 508 Insulin Pump A Tradition of Excellence.
(Medtronic MiniMed, 2002). Medtronic MiniMed Meal Bolus Calculator and Correction Bolus Calculator. International Version.
Abel, P., et al., "Experience with an implantable glucose sensor as a prerequiste of an artificial beta cell," Biomed. Biochim. Acta 43 (1984) 5, pp. 577-584.
Bindra, Dilbir S., et al., "Design and in Vitro Studies of a Needle-Type Glucose Sensor for a Subcutaneous Monitoring," American Chemistry Society, 1991, 63, pp. 1692-1696.
Boguslavsky, Leonid, et al., "Applications of redox polymers in biosensors," Sold State Ionics 60, 1993, pp. 189-197.
Geise, Robert J., et al., "Electropolymerized 1,3-dianninobenzene for the construction of a 1,1'-dimethylferrocene mediated glucose biosensor," Analytica Chimica Acta, 281, 1993, pp. 467-473.
Gernet, S., et al., "A Planar Glucose Enzyme Electrode," Sensors and Actuators, 17, 1989, pp. 537-540.
Gernet, S., et al., "Fabrication and Characterization of a Planar Electromechanical Cell and its Application as a Glucose Sensor," Sensors and Actuators, 18, 1989, pp. 59-70.
Gorton, L., et al., "Amperometric Biosensors Based on an Apparent Direct Electron Transfer Between Electrodes and Immobilized Peroxiases," Analyst, Aug. 1991, vol. 117, pp. 1235-1241.
Gorton, L., et al., "Amperometric Glucose Sensors Based on Immobilized Glucose-Oxidizing Enymes and Chemically Modified Electrodes," Analytica Chimica Acta, 249, 1991, pp. 43-54.
Gough, D. A., et al., "Two-Dimensional Enzyme Electrode Sensor for Glucose," Analytical Chemistry, vol. 57, No. 5, 1985, pp. 2351-2357.
Gregg, Brian A., et al., "Cross-Linked Redox Gels Containing Glucose Oxidase for Amperometric Biosensor Applications," Analytical Chemistry, 62, pp. 258-263.
Gregg, Brian A., et al., "Redox Polymer Films Containing Enzymes. 1. A Redox-Conducting Epoxy Cement: Synthesis, Characterization, and Electrocatalytic Oxidation of Hydroquinone," The Journal of Physical Chemistry, vol. 95, No. 15, 1991, pp. 5970-5975.
Hashiguchi, Yasuhiro, MD, et al., "Development of a Miniaturized Glucose Monitoring System by Combining a Needle-Type Glucose Sensor With Microdialysis Sampling Method," Diabetes Care, vol. 17, No. 5, May 1994, pp. 387-389.
Heller, Adam, "Electrical Wiring of Redox Enzymes," Acc. Chem. Res., vol. 23, No. 5, May 1990, pp. 128-134.
Jobst, Gerhard, et al., "Thin-Film Microbiosensors for Glucose-Lactate Monitoring," Analytical Chemistry, vol. 68, No. 18, Sep. 15, 1996, pp. 3173-3179.
Johnson, K.W., et al., "In vivo evaluation of an electroenzymatic glucose sensor implanted in subcutaneous tissue," Biosensors & Bioelectronics, 7, 1992, pp. 709-714.
Jönsson, G., et al., "An Electromechanical Sensor for Hydrogen Peroxide Based on Peroxidase Adsorbed on a Spectrographic Graphite Electrode," Electroanalysis, 1989, pp. 465-468.
Kanapieniene, J. J., et al., "Miniature Glucose Biosensor with Extended Linearity," Sensors and Actuators, B. 10, 1992, pp. 37-40.
Kawamori, Ryuzo, et al., "Perfect Normalization of Excessive Glucagon Responses to Intraveneous Arginine in Human Diabetes Mellitus With the Artificial Beta-Cell," Diabetes vol. 29, Sep. 1980, pp. 762-765.
Kimura, J., et al., "An Immobilized Enzyme Membrane Fabrication Method," Biosensors 4, 1988, pp. 41-52.
Koudelka, M., et al., "In-vivo Behaviour of Hypodermically Implanted Microfabricated Glucose Sensors," Biosensors & Bioelectronics 6, 1991, pp. 31-36.
Koudelka, M., et al., "Planar Amperometric Enzyme-Based Glucose Microelectrode," Sensors & Actuators, 18, 1989, pp. 157-165.
Mastrototaro, John J., et al., "An electroenzymatic glucose sensor fabricated on a flexible substrate," Sensors & Actuators, B. 5, 1991, pp. 139-144.
Mastrototaro, John J., et al., "An Electroenzymatic Sensor Capable of 72 Hour Continuous Monitoring of Subcutaneous Glucose," 14th Annual International Diabetes Federation Congress, Washington D.C., Jun. 23-28, 1991.
McKean, Brian D., et al., "A Telemetry-Instrumentation System for Chronically Implanted Glucose and Oxygen Sensors," IEEE Transactions on Biomedical Engineering, Vo. 35, No. 7, Jul. 1988, pp. 526-532.
Monroe, D., "Novel Implantable Glucose Sensors," ACL, Dec. 1989, pp. 8-16.
Morff, Robert J., et al., "Microfabrication of Reproducible, Economical, Electroenzymatic Glucose Sensors," Annuaal International Conference of teh IEEE Engineering in Medicine and Biology Society, Vo. 12, No. 2, 1990, pp. 483-484.
Moussy, Francis, et al., "Performance of Subcutaneously Implanted Needle-Type Glucose Sensors Employing a Novel Trilayer Coating," Analytical Chemistry, vol. 65, No. 15, Aug. 1, 1993, pp. 2072-2077.
Nakamoto, S., et al., "A Lift-Off Method for Patterning Enzyme-Immobilized Membranes in Multi-Biosensors," Sensors and Actuators 13, 1988, pp. 165-172.
Nishida, Kenro, et al., "Clinical applications of teh wearable artifical endocrine pancreas with the newly designed needle-type glucose sensor," Elsevier Sciences B.V., 1994, pp. 353-358.

(56) **References Cited**

OTHER PUBLICATIONS

Nishida, Kenro, et al., "Development of a ferrocene-mediated needle-type glucose sensor covereed with newly designd biocompatible membrane, 2-methacryloyloxyethylphosphorylcholine-co-n-butyl nethacrylate," Medical Progress Through Technology, vol. 21, 1995, pp. 91-103.
Poitout, V., et al., "A glucose monitoring system for on line estimation oin man of blood glucose concentration using a miniaturized glucose sensor implanted in the subcutaneous tissue adn a wearable control unit," Diabetologia, vol. 36, 1991, pp. 658-663.
Reach, G., "A Method for Evaluating in vivo the Functional Characteristics of Glucose Sensors," Biosensors 2, 1986, pp. 211-220.
Shaw, G. W., et al., "In vitro testing of a simply constructed, highly stable glucose sensor suitable for implantation in diabetic patients," Biosensors & Bioelectronics 6, 1991, pp. 401-406.
Shichiri, M., "A Needle-Type Glucose Sensor—A Valuable Tool Not Only for a Self-Blood Glucose Monitoring but for a Wearable Artificial Pancreas," Life Support Systems Proceedings, XI Annual Meeting ESAO, Alpbach-Innsbruck, Austria, Sep. 1984, pp. 7-9.
Shichiri, Motoaki, et al., "An artificial endocrine pancreas—problems awaiting solution for long-term clinical applications of a glucose sensor," Frontiers Med. Biol. Engng., 1991, vol. 3, No. 4, pp. 283-292.
Shichiri, Motoaki, et al., "Closed-Loop Glycemic Control with a Wearable Artificial Endocrine Pancreas—Variations in Daily Insulin Requirements to Glycemic Response," Diabetes, vol. 33, Dec. 1984, pp. 1200-1202.
Shichiri, Motoaki, et al., "Glycaemic Control in a Pacreatectomized Dogs with a Wearable Artificial Endocrine Pancreas," Diabetologia, vol. 24, 1983, pp. 179-184.
Shichiri, M., et al., "In Vivo Characteristics of Needle-Type Glucose Sensor—Measurements of Subcutaneous Glucose Concentrations in Human Volunteers," Hormone and Metabolic Research, Supplement Series vol. No. 20, 1988, pp. 17-20.
Shichiri, M., et al., "Membrane design for extending the long-life of an implantable glucose sensor," Diab. Nutr. Metab., vol. 2, No. 4, 1989, pp. 309-313.
Shichiri, Motoaki, et al., "Normalization of the Paradoxic Secretion of Glucagon in Diabetes Who Were Controlled by the Artificial Beta Cell," Diabetes, vol. 28, Apr. 1979, pp. 272-275.
Shichiri, Motoaki, et al., "Telemetry Glucose Monitoring Device with Needle-Type Glucose Sensor: A useful Tool for Blood Glucose Monitoring in Diabetic Individuals," Diabetes Care, vol. 9, No. 3, May-Jun. 1986, pp. 298-301.
Shichiri, Motoaki, et al., "Wearable Artificial Endocrine Pancreas with Needle-Type Glucose Sensor," The Lancet, Nov. 20, 1982, pp. 1129-1131.
Shichiri, Motoaki, et al., "The Wearable Artificial Endocrine Pancreas with a Needle-Type Glucose Sensor: Perfect Glycemic Control in Ambulatory Diabetes," Acta Paediatr Jpn 1984, vol. 26, pp. 359-370.
Shinkai, Seiji, "Molecular Recognitiion of Mono- and Di-saccharides by Phenylboronic Acids in Solvent Extraction and as a Monolayer," J. Chem. Soc., Chem. Commun., 1991, pp. 1039-1041.
Shults, Mark C., "A Telemetry-Instrumentation System for Monitoring Multiple Subcutaneously Implanted Glucose Sensors," IEEE Transactions on Biomedical Engineering, vol. 41, No. 10, Oct. 1994, pp. 937-942.
Sternberg, Robert, et al., "Study and Development of Multilayer Needle-type Enzyme-based Glucose Microsensors," Biosensors, vol. 4, 1988, pp. 27-40.
Tamiya, E., et al., "Micro Glucose Sensors using Electron Mediators Immobilized on a Polypyrrole-Modified Electrode," Sensors and Actuators, vol. 18, 1989, pp. 297-307.
Tsukagoshi, Kazuhiko, et al., "Specific Complexation with Mono- and Disaccharides that can be Detected by Circular Dichroism," J. Org. Chem., vol. 56, 1991, pp. 4089-4091.
Urban, G., et al., "Miniaturized multi-enzyme biosensors integrated with pH sensors on flexible polymer carriers for in vivo applciations," Biosensors & Bioelectronics, vol. 7, 1992, pp. 733-739.
Ubran, G., et al., "Miniaturized thin-film biosensors using covalently immobilized glucose oxidase," Biosensors & Bioelectronics, vol. 6, 1991, pp. 555-562.
Velho, G., et al., "In vivo calibration of a subcutaneous glucose sensor for determination of subcutaneous glucose kinetics," Diab. Nutr. Metab., vol. 3, 1988, pp. 227-233.
Wang, Joseph, et al., "Needle-Type Dual Microsensor for the Simultaneous Monitoring of Glucose and Insulin," Analytical Chemistry, vol. 73, 2001, pp. 844-847.
Yamasaki, Yoshimitsu, et al., "Direct Measurement of Whole Blood Glucose by a Needle-Type Sensor," Clinics Chimica Acta, vol. 93, 1989, pp. 93-98.
Yokoyama, K., "Integrated Biosensor for Glucose and Galactose," Analytica Chimica Acta, vol. 218, 1989, pp. 137-142.

* cited by examiner

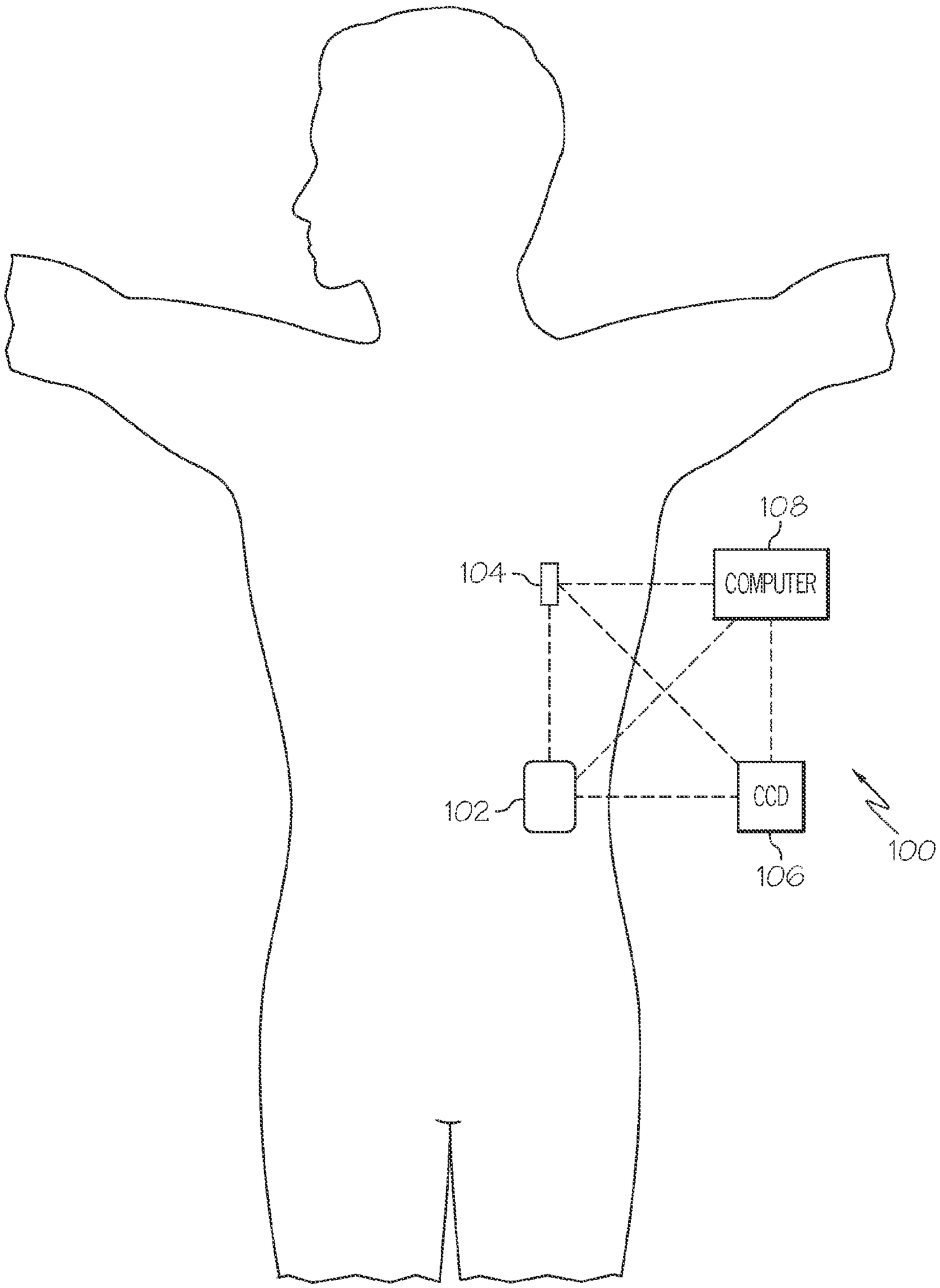


FIG. 1

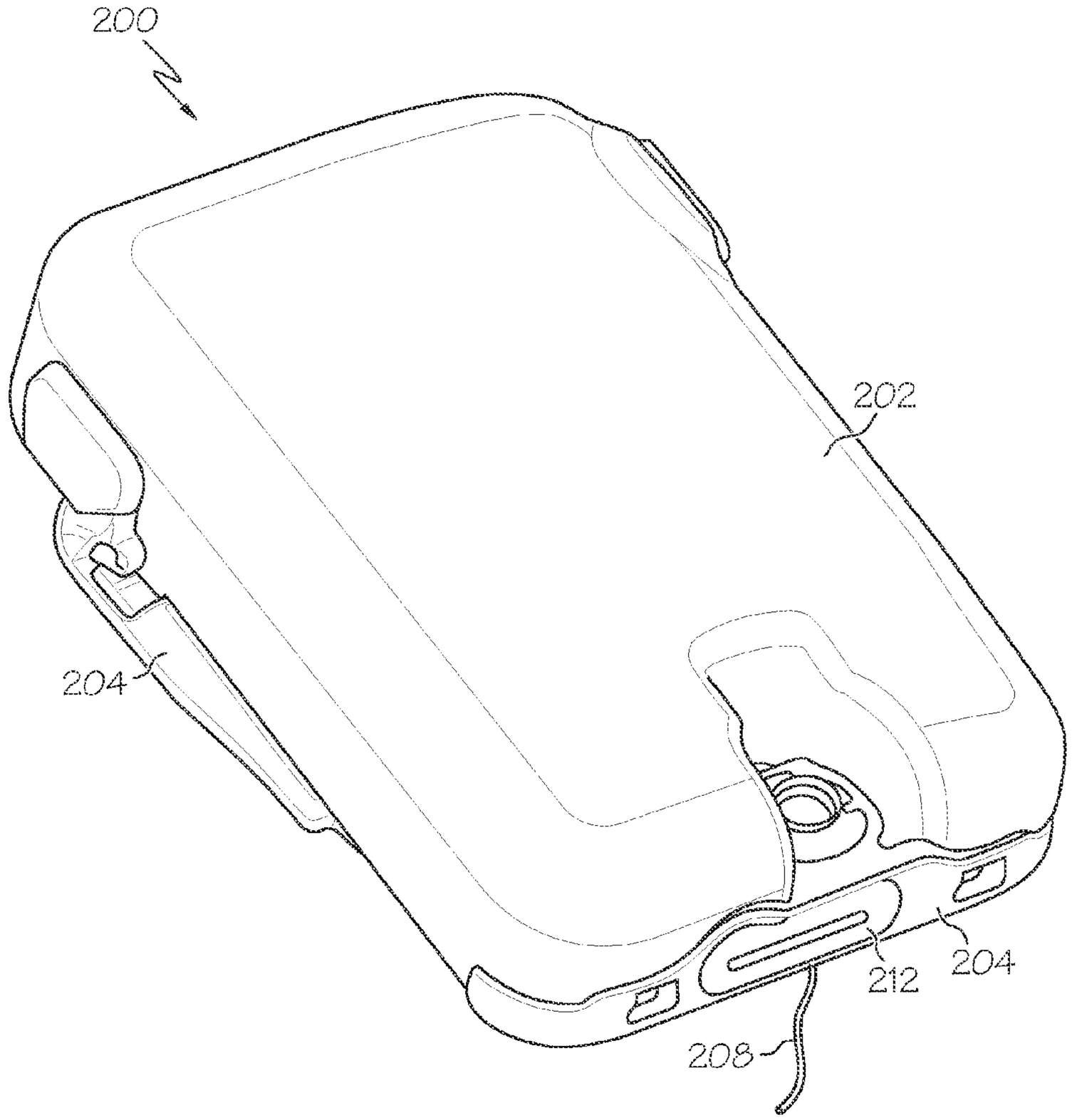


FIG. 2

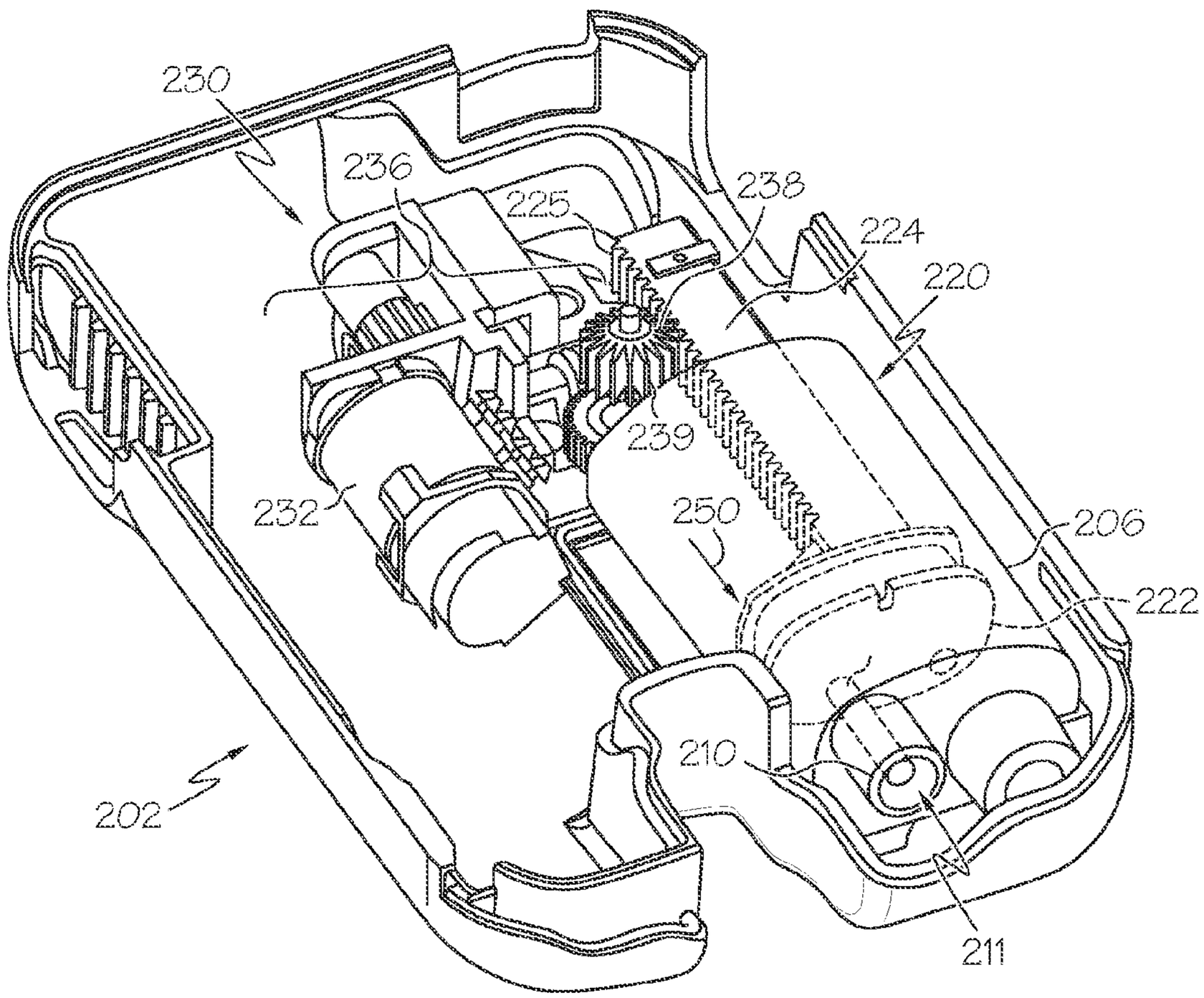


FIG. 3

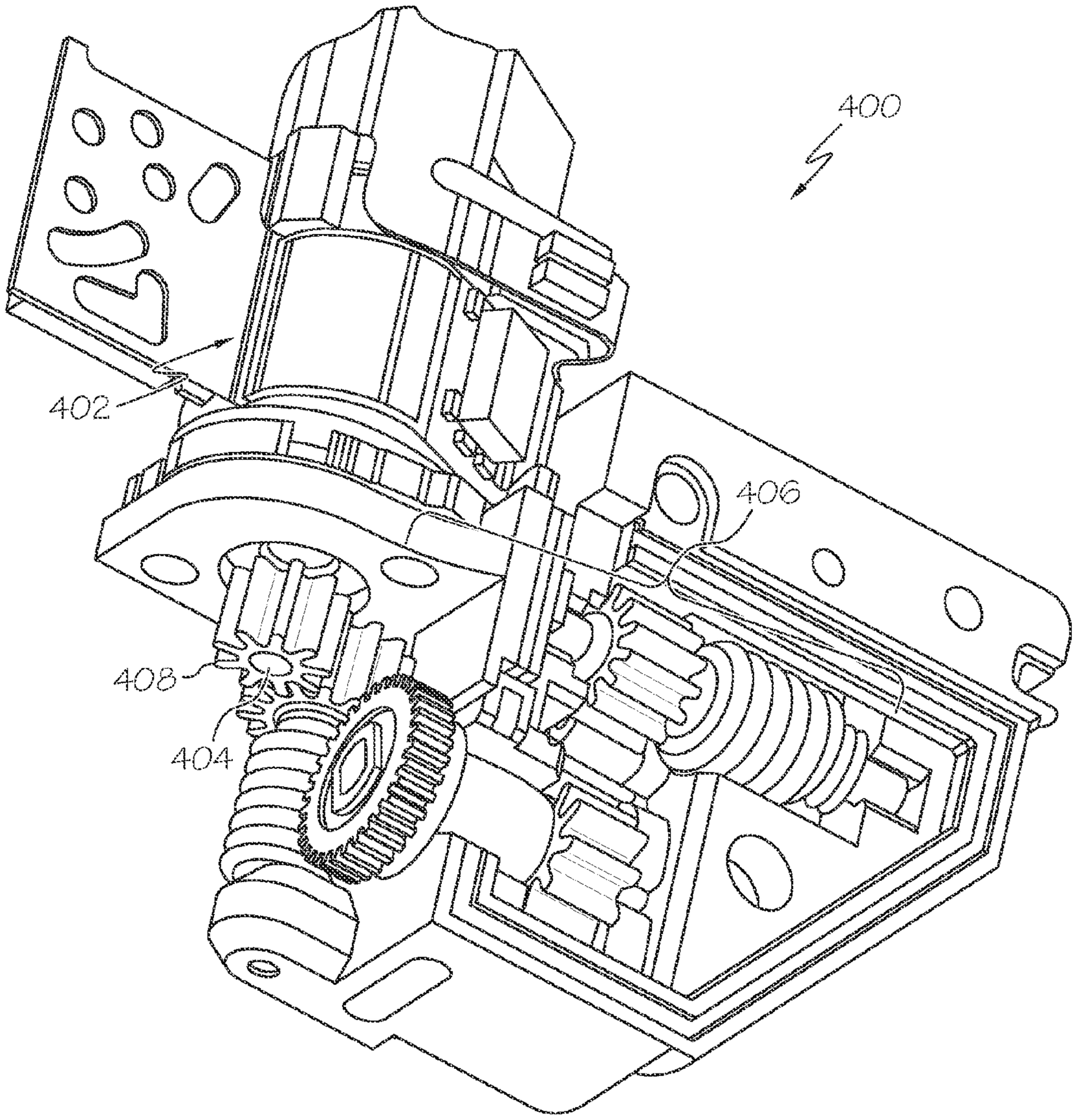


FIG. 4

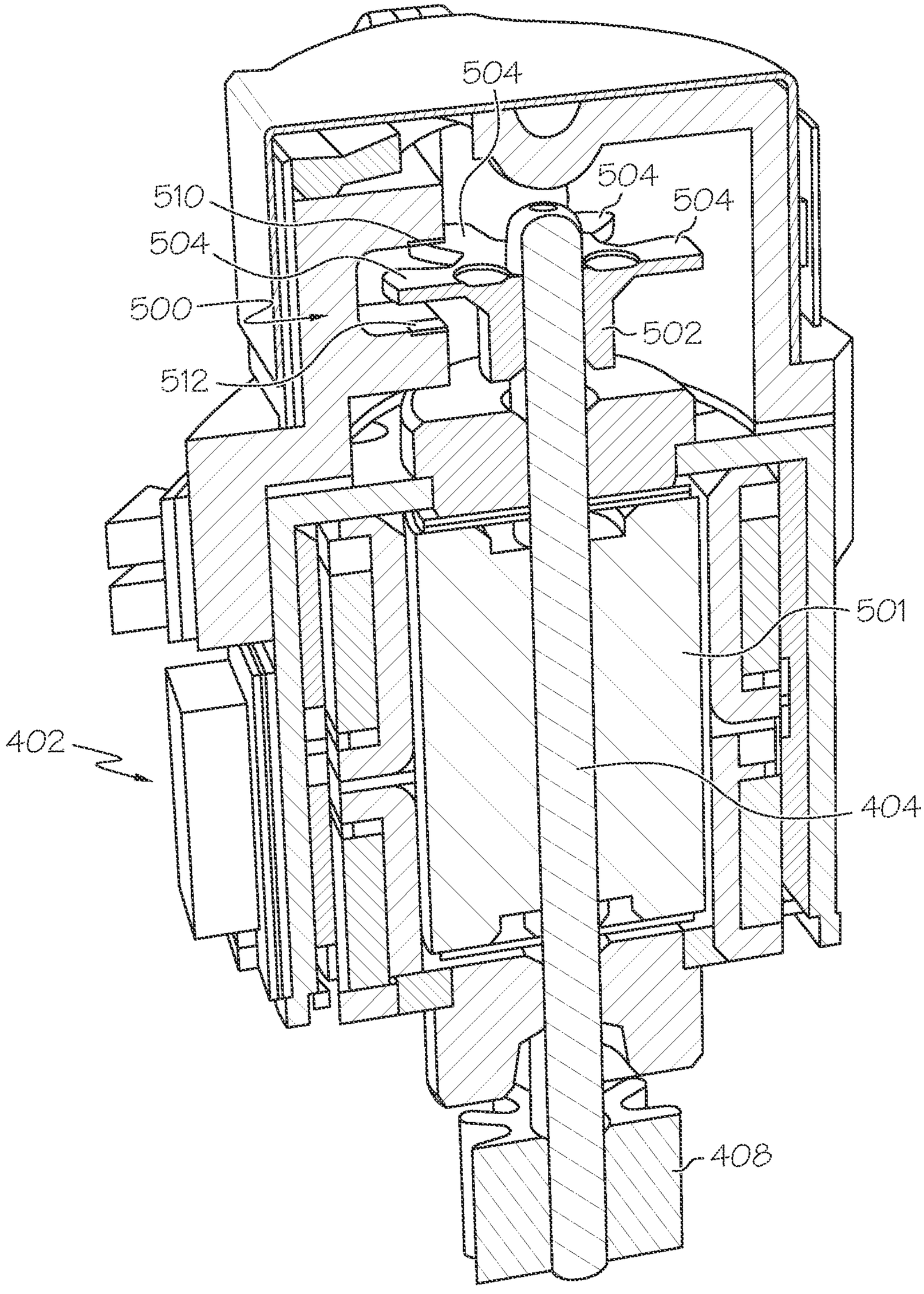


FIG. 5

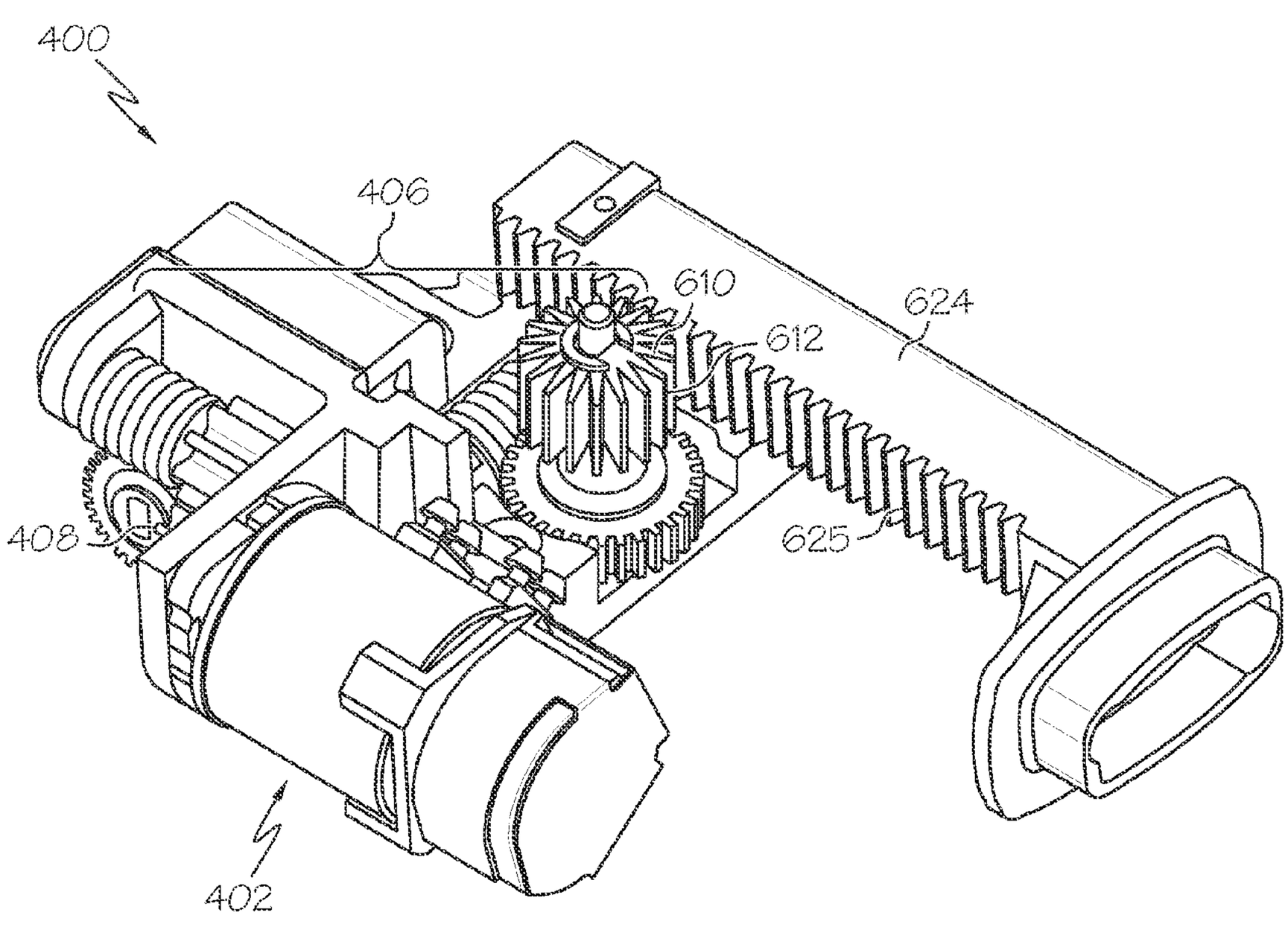


FIG. 6

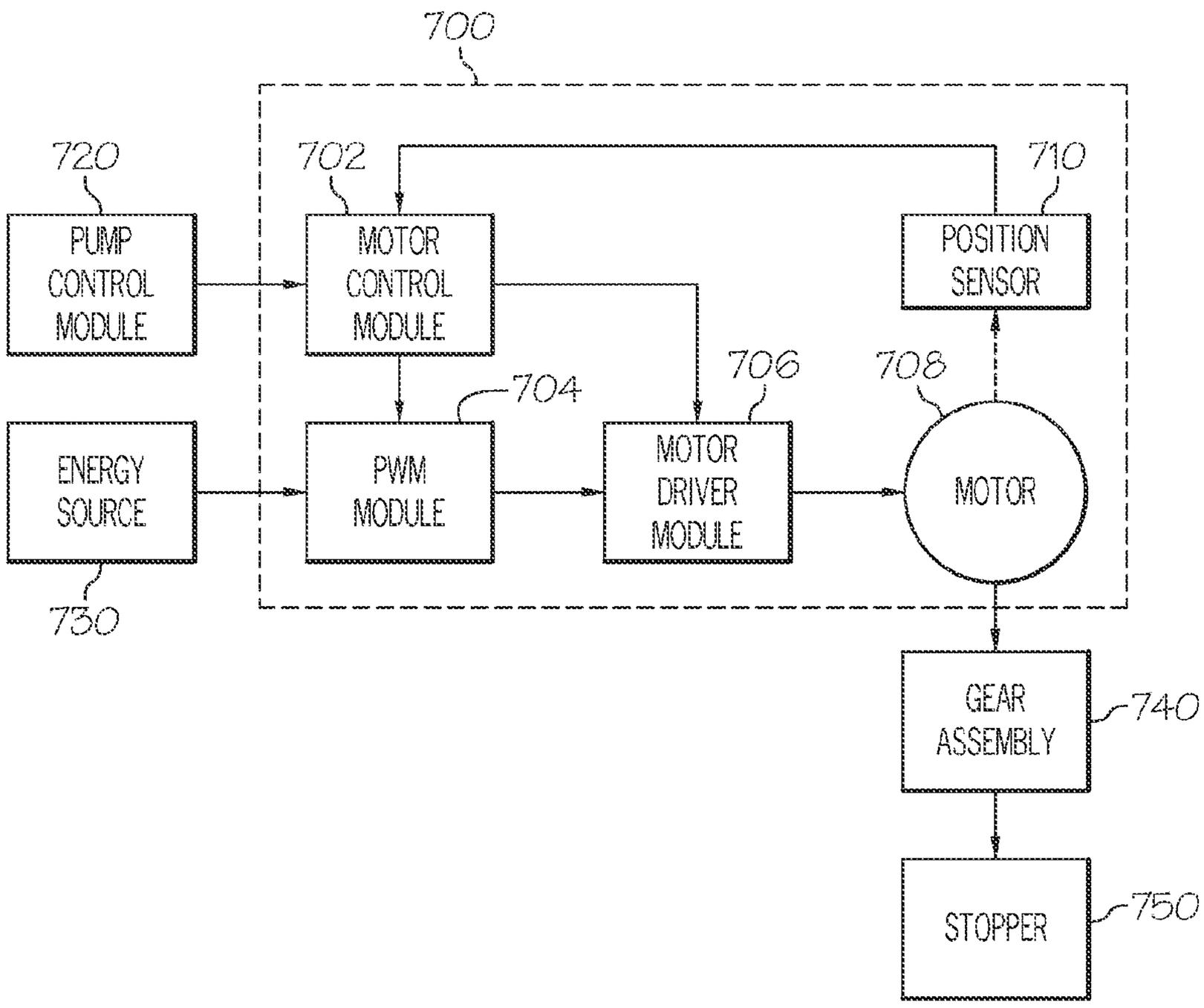

700
720
PUMP CONTROL MODULE
702
MOTOR CONTROL MODULE
710
POSITION SENSOR
704
706
708
ENERGY SOURCE
PWM MODULE
MOTOR DRIVER MODULE
MOTOR
730
GEAR ASSEMBLY
740
STOPPER
750

FIG. 7

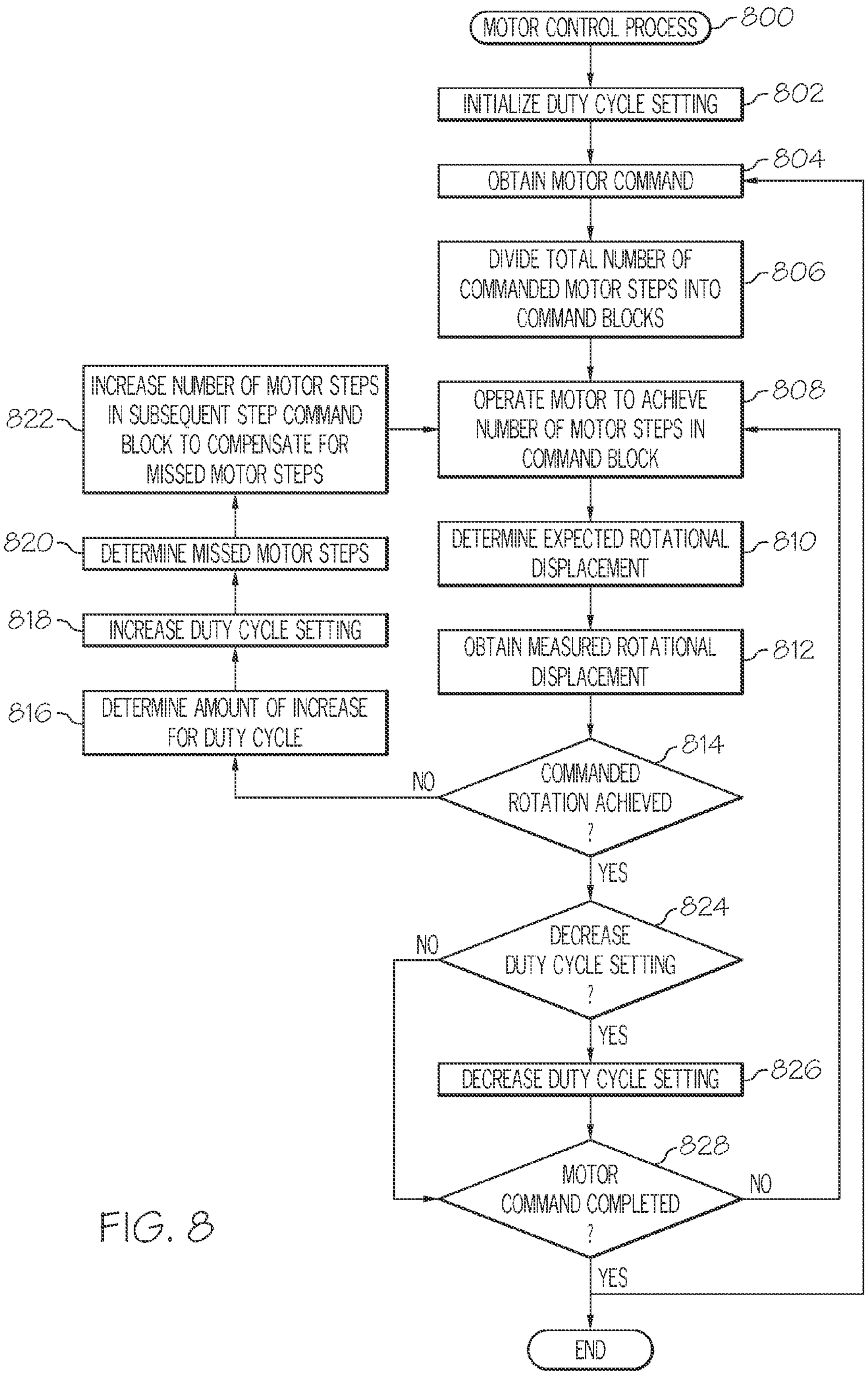

MOTOR CONTROL PROCESS
800
INITIALIZE DUTY CYCLE SETTING
802
OBTAIN MOTOR COMMAND
804
DIVIDE TOTAL NUMBER OF COMMANDED MOTOR STEPS INTO COMMAND BLOCKS
806
OPERATE MOTOR TO ACHIEVE NUMBER OF MOTOR STEPS IN COMMAND BLOCK
808
DETERMINE EXPECTED ROTATIONAL DISPLACEMENT
810
OBTAIN MEASURED ROTATIONAL DISPLACEMENT
812
COMMANDED ROTATION ACHIEVED ?
814
NO
YES
INCREASE NUMBER OF MOTOR STEPS IN SUBSEQUENT STEP COMMAND BLOCK TO COMPENSATE FOR MISSED MOTOR STEPS
822
DETERMINE MISSED MOTOR STEPS
820
INCREASE DUTY CYCLE SETTING
818
DETERMINE AMOUNT OF INCREASE FOR DUTY CYCLE
816
DECREASE DUTY CYCLE SETTING ?
824
NO
YES
DECREASE DUTY CYCLE SETTING
826
MOTOR COMMAND COMPLETED ?
828
NO
YES
END

FIG. 8

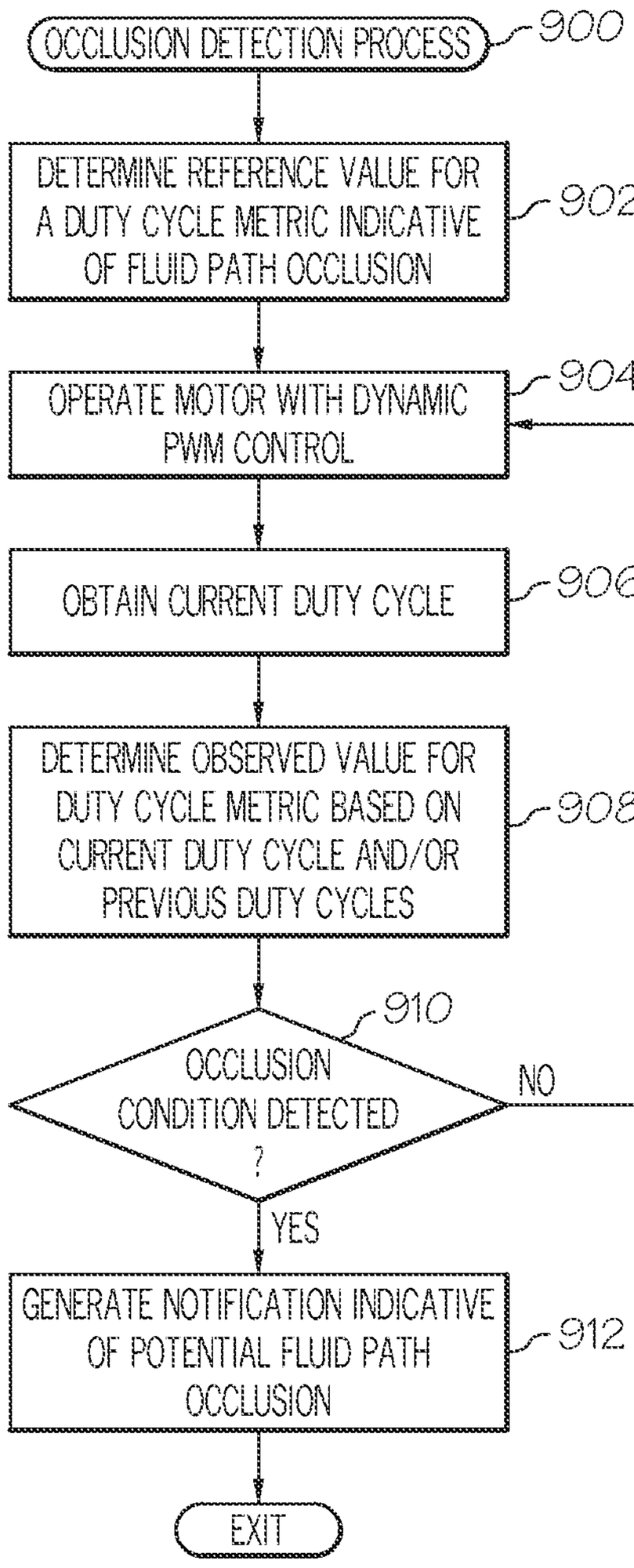

OCCLUSION DETECTION PROCESS
900
DETERMINE REFERENCE VALUE FOR A DUTY CYCLE METRIC INDICATIVE OF FLUID PATH OCCLUSION
902
OPERATE MOTOR WITH DYNAMIC PWM CONTROL
904
OBTAIN CURRENT DUTY CYCLE
906
DETERMINE OBSERVED VALUE FOR DUTY CYCLE METRIC BASED ON CURRENT DUTY CYCLE AND/OR PREVIOUS DUTY CYCLES
908
910
OCCLUSION CONDITION DETECTED ?
NO
YES
GENERATE NOTIFICATION INDICATIVE OF POTENTIAL FLUID PATH OCCLUSION
912
EXIT

FIG. 9

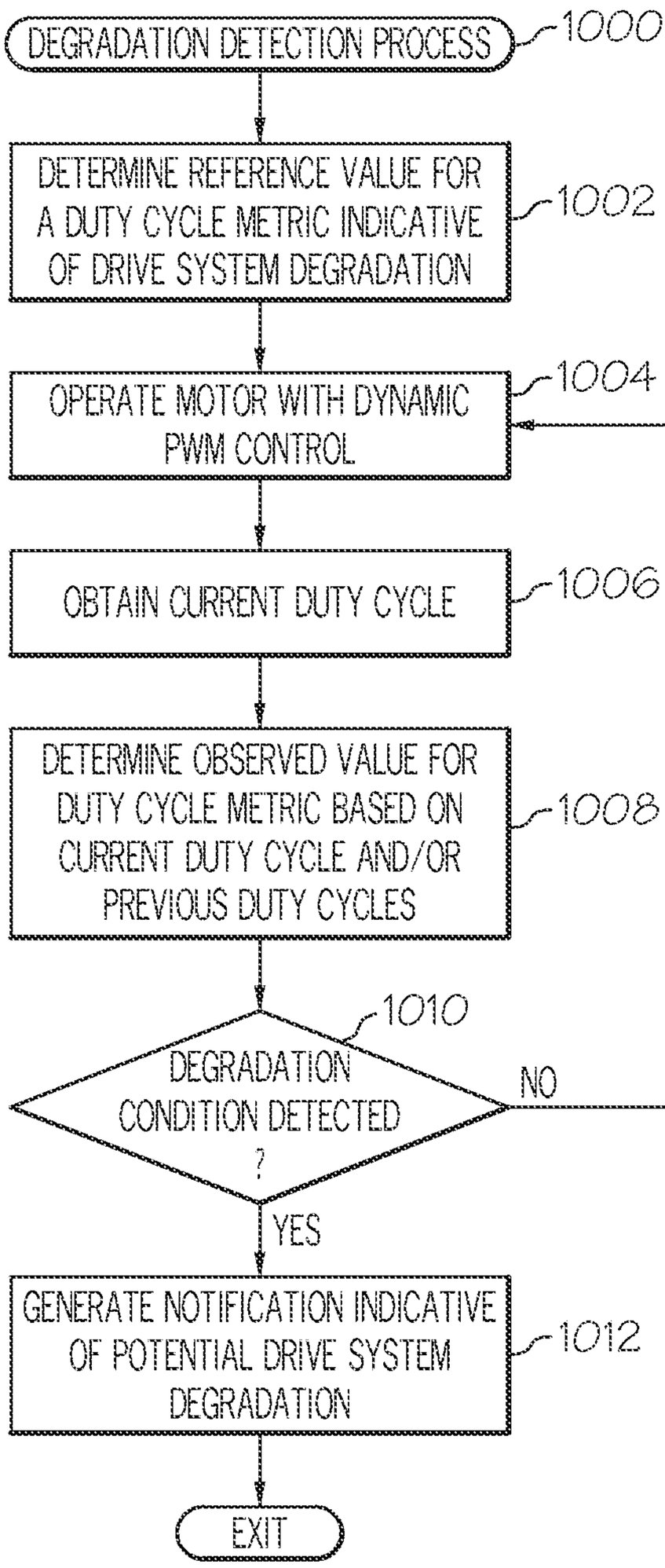

DEGRADATION DETECTION PROCESS
1000
DETERMINE REFERENCE VALUE FOR A DUTY CYCLE METRIC INDICATIVE OF DRIVE SYSTEM DEGRADATION
1002
OPERATE MOTOR WITH DYNAMIC PWM CONTROL
1004
OBTAIN CURRENT DUTY CYCLE
1006
DETERMINE OBSERVED VALUE FOR DUTY CYCLE METRIC BASED ON CURRENT DUTY CYCLE AND/OR PREVIOUS DUTY CYCLES
1008
DEGRADATION CONDITION DETECTED ?
1010
NO
YES
GENERATE NOTIFICATION INDICATIVE OF POTENTIAL DRIVE SYSTEM DEGRADATION
1012
EXIT

FIG. 10

MOTOR HEALTH MONITORING AND MEDICAL DEVICE INCORPORATING SAME

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation of U.S. patent application Ser. No. 13/425,190, filed Mar. 20, 2012. The subject matter described herein is also related to the subject matter described in U.S. patent application Ser. No. 13/425,174 and U.S. patent application Ser. No. 13/425,180, both filed Mar. 20, 2012.

TECHNICAL FIELD

Embodiments of the subject matter described herein relate generally to motor controls and related medical devices, and more particularly, embodiments of the subject matter relate to dynamic control of motors in fluid infusion devices using a modulated voltage.

BACKGROUND

Infusion pump devices and systems are relatively well-known in the medical arts, for use in delivering or dispensing an agent, such as insulin or another prescribed medication, to a patient. A typical infusion pump includes a pump drive system which typically includes a small motor and drive train components that convert rotational motor motion to a translational displacement of a stopper (or plunger) in a reservoir. The reservoir cooperates with tubing, a catheter and/or an infusion set to create a fluid path for carrying medication from the reservoir to the body of a user. Some fluid infusion devices also include a force sensor designed to detect and indicate a pump malfunction and/or non-delivery of the medication to the patient due to a fluid path occlusion.

Stepper motors may be used to displace the stopper by a precise amount, and thereby control the dosage administered to a user. Traditionally, a stepper motor is supplied with a direct current (DC) voltage to control and/or maintain position, and thus, the stepper motor continuously consumes power during use. Additionally, stepper motors are frequently controlled using an open-loop control scheme, where the voltage applied to the stepper motor is chosen to be large enough to ensure the stepper motor provides torque that meets or exceeds the likely maximum requirements of the system, thereby ensuring that the stepper motor achieves a number of commanded steps and obviating the need for feedback mechanisms to monitor the position. However, most infusion pump devices and other portable medical devices are battery powered, and accordingly, it is desirable to reduce the power consumption of the stepper motor and prolong battery life.

BRIEF SUMMARY

An embodiment of a motor control system is provided. The system includes a motor having a rotor, a modulation module coupled to the motor, and a control module coupled to the motor and the modulation module. The modulation module generates a modulated voltage that is applied to the motor, and the control module adjusts a duty cycle of the modulated voltage to achieve a commanded rotation of the rotor and detects a degradation condition based on the duty cycle.

Also provided is an embodiment of an infusion device. The infusion device includes a motor having a rotor and a shaft mechanically coupled to the rotor that is displaced to deliver fluid in response to rotation of the rotor. A modulation module is coupled to the motor and generates a modulated voltage that is applied to the motor. A control module is coupled to the modulation module to adjust a duty cycle of the modulated voltage to achieve a commanded rotation of the rotor and identify a degradation condition based on the duty cycle.

In another embodiment, a method for detecting degradation in a drive system is provided. The method involves applying a modulated voltage to a motor, adjusting a duty cycle of the modulated voltage to achieve a commanded rotation of a rotor of the motor, and identifying a degradation condition based on the duty cycle.

This summary is provided to introduce a selection of concepts in a simplified form that are further described below in the detailed description. This summary is not intended to identify key features or essential features of the claimed subject matter, nor is it intended to be used as an aid in determining the scope of the claimed subject matter.

BRIEF DESCRIPTION OF THE DRAWINGS

A more complete understanding of the subject matter may be derived by referring to the detailed description and claims when considered in conjunction with the following figures, wherein like reference numbers refer to similar elements throughout the figures.

FIG. **1** depicts an exemplary embodiment of an infusion system;

FIG. **2** is a perspective view of an embodiment of a fluid infusion device suitable for use in the infusion system of FIG. **1**;

FIG. **3** is a perspective view that depicts internal structure of the durable housing of the fluid infusion device shown in FIG. **2**;

FIG. **4** is a perspective view of an exemplary drive system suitable for use in the durable housing of the fluid infusion device of FIGS. **2-3**;

FIG. **5** is cross-sectional perspective view of the motor of motor drive system of FIG. **4** illustrating a sensor integrated therein;

FIG. **6** is a perspective view of the exemplary drive system of FIG. **4** illustrating the gear assembly engaged with a shaft;

FIG. **7** is a block diagram of an exemplary motor control system suitable for use in the fluid infusion device of FIGS. **2-3**;

FIG. **8** is a flow diagram of an exemplary motor control process suitable for use with the motor control system of FIG. **7**;

FIG. **9** is a flow diagram of an exemplary occlusion detection process suitable for use with the motor control system of FIG. **7** in connection with the motor control process of FIG. **8**; and

FIG. **10** is a flow diagram of an exemplary degradation detection process suitable for use with the motor control system of FIG. **7** in connection with the motor control process of FIG. **8**.

DETAILED DESCRIPTION

The following detailed description is merely illustrative in nature and is not intended to limit the embodiments of the subject matter or the application and uses of such embodiments. As used herein, the word "exemplary" means "serving as an example, instance, or illustration." Any implementation described herein as exemplary is not necessarily to be construed as preferred or advantageous over other implementations. Furthermore, there is no intention to be bound by any

expressed or implied theory presented in the preceding technical field, background, brief summary or the following detailed description.

Embodiments of the subject matter described herein generally relate to controlling the displacement (or rotational position) of a motor by dynamically adjusting the duty cycle of a modulated voltage, such as a pulse-width modulated voltage, that is applied the motor. In exemplary embodiments, a pulse-width modulated voltage is applied to the motor and the motor is operated to produce a commanded amount of rotation (or displacement). Based on the commanded amount of rotation, an expected displacement, either of the rotor or another element mechanically coupled to the rotor, that is expected to result from the commanded amount of rotation is determined and compared to a measured displacement obtained from a sensor after the motor is operated to produce the commanded amount of rotation. In response to a difference between the expected displacement and the measured displacement, the duty cycle of the pulse-width modulated voltage is increased and the motor is operated to compensate for the difference between the expected displacement and the measured displacement while a pulse-width modulated voltage having the increased duty cycle is applied.

In exemplary embodiments, the motor is a stepper motor or another direct current (DC) motor that is commanded to produce a particular number of motor steps, and the sensor is an incremental position sensor (e.g., a rotary encoder) that measures or otherwise detects incremental rotations of the rotor, wherein the expected displacement is the number of incremental rotations of the rotor that are expected to be detected by the incremental position sensor when the stepper motor achieves the commanded number of motor steps and the measured displacement is the actual measured number of incremental rotations identified via the incremental position sensor. However, it should be noted that the subject matter is not limited to stepper motors or incremental position sensors that detect motor rotation. For example, in some embodiments, the sensor may measure or otherwise detect the position or displacement of the shaft of a stopper (or plunger) that is mechanically coupled to the rotor of the motor, wherein the expected displacement is the displacement (or position) of the shaft (or stopper) that should result from the commanded amount of rotation of the rotor and the measured displacement (or position) is the actual measured displacement (or position) of the shaft via the sensor. As described in greater detail below, in exemplary embodiments, the duty cycle of the pulse-width modulated voltage is monitored during operation of the motor to detect an anomalous condition, such as an occlusion condition or a degradation condition, based on the duty cycle. In this regard, when changes in the duty cycle are indicative of an anomalous condition, a notification is generated to alert a user or a supervisory control system of the potential anomaly.

While the subject matter described herein can be implemented in any electronic device that includes a motor, exemplary embodiments described below are implemented in the form of medical devices, such as portable electronic medical devices. Although many different applications are possible, the following description focuses on a fluid infusion device (or infusion pump) as part of an infusion system deployment. For the sake of brevity, conventional techniques related to infusion system operation, insulin pump and/or infusion set operation, and other functional aspects of the systems (and the individual operating components of the systems) may not be described in detail here. Examples of infusion pumps may be of the type described in, but not limited to, U.S. Pat. Nos. 4,562,751; 4,685,903; 5,080,653; 5,505,709; 5,097,122; 6,485,465; 6,554,798; 6,558,320; 6,558,351; 6,641,533; 6,659,980; 6,752,787; 6,817,990; 6,932,584; and 7,621,893 which are herein incorporated by reference.

Turning now to FIG. **1**, in exemplary embodiments, an infusion system **100** includes, without limitation, a fluid infusion device (or infusion pump) **102**, a sensing arrangement **104**, a command control device (CCD) **106**, and a computer **108**. The components of an infusion system may be realized using different platforms, designs, and configurations, and the embodiment shown in FIG. **1** is not exhaustive or limiting. In practice, the infusion device **102** and the sensing arrangement **104** are secured at desired locations on the body of a user (or patient), as illustrated in FIG. **1**. In this regard, the locations at which the infusion device **102** and the sensing arrangement **104** are secured to the body of the user in FIG. **1** are provided only as a representative, non-limiting, example. The elements of the infusion system **100** may be similar to those described in U.S. patent application Ser. No. 13/049,803, assigned to the assignee of the present application, the subject matter of which is hereby incorporated by reference in its entirety.

In the illustrated embodiment of FIG. **1**, the infusion device **102** is designed as a portable medical device suitable for infusing a fluid, a liquid, a gel, or other agent into the body of a user. In exemplary embodiments, the infused fluid is insulin, although many other fluids may be administered through infusion such as, but not limited to, HIV drugs, drugs to treat pulmonary hypertension, iron chelation drugs, pain medications, anti-cancer treatments, medications, vitamins, hormones, or the like. In some embodiments, the fluid may include a nutritional supplement, a dye, a tracing medium, a saline medium, a hydration medium, or the like. The sensing arrangement **104** generally represents the components of the infusion system **100** configured to sense a condition of the user, and may include a sensor, a monitor, or the like, for providing data indicative of the condition that is sensed and/or monitored by the sensing arrangement. In this regard, the sensing arrangement **104** may include electronics and enzymes reactive to a biological condition, such as a blood glucose level, or the like, of the user, and provide data indicative of the blood glucose level to the infusion device **102**, the CCD **106** and/or the computer **108**. For example, the infusion device **102**, the CCD **106** and/or the computer **108** may include a display for presenting information or data to the user based on the sensor data received from the sensing arrangement **104**, such as, for example, a current glucose level of the user, a graph or chart of the user's glucose level versus time, device status indicators, alert messages, or the like. In other embodiments, the infusion device **102**, the CCD **106** and/or the computer **108** may include electronics and software that are configured to analyze sensor data and operate the infusion device **102** to deliver fluid to the body of the user based on the sensor data and/or preprogrammed delivery routines. Thus, in exemplary embodiments, one or more of the infusion device **102**, the sensing arrangement **104**, the CCD **106**, and/or the computer **108** includes a transmitter, a receiver, and/or other transceiver electronics that allow for communication with other components of the infusion system **100**, so that the sensing arrangement **104** may transmit sensor data or monitor data to one or more of the infusion device **102**, the CCD **106** and/or the computer **108**. In various embodiments, the sensing arrangement **104** may be secured to the body of the user or embedded in the body of the user at a location that is remote from the location at which the infusion device **102** is secured to the body of the user. In various other embodiments, the sensing arrangement **104** may be incorporated within the infusion device **102**. In other embodiments, the sensing

arrangement **104** may be separate and apart from the infusion device **102**, and may be, for example, part of the CCD **106**. In such embodiments, the sensing arrangement **104** may be configured to receive a biological sample, analyte, or the like, to measure a condition of the user.

As described above, in various embodiments, the CCD **106** and/or the computer **108** include electronics and other components configured to perform processing, delivery routine storage, and to control the infusion device **102** in a manner that is influenced by sensor data measured by and/or received from the sensing arrangement **104**. By including control functions in the CCD **106** and/or the computer **108**, the infusion device **102** may be made with more simplified electronics. However, in other embodiments, the infusion device **102** may include all control functions, and may operate without the CCD **106** and/or the computer **108**. In various embodiments, the CCD **106** may be a portable electronic device. In addition, in various embodiments, the infusion device **102** and/or the sensing arrangement **104** may be configured to transmit data to the CCD **106** and/or the computer **108** for display or processing of the data by the CCD **106** and/or the computer **108**.

In some embodiments, the CCD **106** and/or the computer **108** may provide information to the user that facilitates the user's subsequent use of the infusion device **102**. For example, the CCD **106** may provide information to the user to allow the user to determine the rate or dose of medication to be administered into the user's body. In other embodiments, the CCD **106** may provide information to the infusion device **102** to autonomously control the rate or dose of medication administered into the body of the user. In some embodiments, the sensing arrangement **104** may be integrated into the CCD **106**. Such embodiments may allow the user to monitor a condition by providing, for example, a sample of his or her blood to the sensing arrangement **104** to assess his or her condition. In some embodiments, the sensing arrangement **104** and the CCD **106** may be for determining glucose levels in the blood and/or body fluids of the user without the use of, or necessity of, a wire or cable connection between the infusion device **102** and the sensing arrangement **104** and/or the CCD **106**.

In some embodiments, the sensing arrangement **104** and/or the infusion device **102** may utilize a closed-loop system for delivering fluid to the user. Examples of sensing devices and/or infusion pumps utilizing closed-loop systems may be found at, but are not limited to, the following U.S. Pat. Nos. 6,088,608, 6,119,028, 6,589,229, 6,740,072, 6,827,702, and 7,323,142, all of which are incorporated herein by reference in their entirety. In such embodiments, the sensing arrangement **104** is configured to sense a condition of the user, such as, blood glucose level or the like. The infusion device **102** may be configured to deliver fluid in response to the condition sensed by the sensing arrangement **104**. In turn, the sensing arrangement **104** may continue to sense a new condition of the user, allowing the infusion device **102** to deliver fluid continuously in response to the new condition sensed by the sensing arrangement **104** indefinitely. In some embodiments, the sensing arrangement **104** and/or the infusion device **102** may be configured to utilize the closed-loop system only for a portion of the day, for example only when the user is asleep or awake.

Referring now to FIGS. **2-3**, in an exemplary embodiment, the infusion device **102** in the infusion system **100** of FIG. **1** is realized as fluid infusion device **200**. FIGS. **2-3** depict perspective views of the fluid infusion device **200**, which includes a durable housing **202** and a base plate **204**. While FIG. **2** depicts the durable housing **202** and the base plate **204** as being coupled together, in practice, the durable housing **202** and/or the base plate **204** may include features, structures, or elements to facilitate removable coupling (e.g., pawls, latches, rails, slots, keyways, buttons, or the like) and accommodate a removable/replaceable fluid reservoir **206**. As illustrated in FIG. **3**, in exemplary embodiments, the fluid reservoir **206** mates with, and is received by, the durable housing **202**. In alternate embodiments, the fluid reservoir **206** mates with, and is received by, the base plate **204**.

In exemplary embodiments, the base plate **204** is temporarily adhered to the skin of the user, as illustrated in FIG. **1** using, for example, an adhesive layer of material. After the base plate is affixed to the skin of the user, a suitably configured insertion device or apparatus may be used to insert a fluid delivery needle or cannula **208** into the body of the user. The cannula **208** functions as one part of the fluid delivery path associated with the fluid infusion device **200**. The durable housing **202** receives the fluid reservoir **206** and retains the fluid reservoir **206** in a substantially fixed position and orientation while the durable housing **202** and the base plate **204** are coupled. The durable housing **202** is configured to secure to the base plate **204** in a specified orientation to engage the fluid reservoir **206** with a reservoir port receptacle formed in the durable housing **202**. In particular embodiments, the fluid infusion device **200** includes certain features to orient, align, and position the durable housing **202** relative to the base plate **204** such that when the two components are coupled together, the fluid reservoir **206** is urged into the reservoir port receptacle to engage a sealing assembly and establish a fluid seal, as described in more detail below.

In exemplary embodiments, the fluid reservoir **206** includes a fluid delivery port **210** that cooperates with the reservoir port receptacle. The fluid delivery port **210** may include a pierceable septum if the fluid reservoir **206** is a prefilled unit. Alternatively, the fluid delivery port **210** may include a vented opening to accommodate filling of the fluid reservoir **206** by the patient, a doctor, a caregiver, or the like. The fluid delivery port **210** has an interior **211** defined therein that is shaped, sized, and otherwise configured to receive a sealing element when the fluid reservoir **206** is engaged with the reservoir port receptacle. The sealing element forms part of a sealing assembly for the fluid infusion device **200**. In this regard, the sealing assembly includes one or more sealing elements and/or fluid delivery needles configured to establish fluid communication from the interior of the reservoir **206** to the cannula **208** via the fluid delivery port **210** and a mounting cap **212**, and thereby establish a fluid delivery path from the reservoir **206** to the user via the cannula **208**.

As illustrated in FIG. **3**, the fluid reservoir **206** includes a reservoir barrel **220** that contains the fluid and a stopper **222** (or plunger) positioned to push fluid from inside the barrel **220** of the reservoir **206** along the fluid path through the cannula **208** to the user. The stopper **222** includes a shaft **224** having exposed teeth **225** that are configured to mechanically couple or otherwise engage the shaft **224** of the stopper **222** with a drive system **230** contained in the durable housing **202**. In exemplary embodiments, the drive system **230** includes a motor **232** having a rotor that is mechanically coupled to a gear assembly that translates rotation of the rotor of the motor **232** to translational displacement the stopper **222** in the direction **250** of the fluid delivery port **210**. In this regard, in exemplary embodiments, the rotor of the motor **232** is mechanically coupled to a rotary shaft, which, in turn, engages a gear assembly **236** that includes a pinion gear **238** having exposed teeth **239** configured to mate with or otherwise engage the teeth **225** of the shaft **224**. The rotary shaft translates rotation (or displacement) of the rotor of the motor **232** into a corresponding rotation (or displacement) of the

gear assembly **236** such that the exposed teeth **239** of the pinion gear **238** to apply force to the exposed teeth **225** of the shaft **224** of the stopper **222** in the direction **250** of the fluid delivery port **210** to thereby displace the stopper **222** in the direction **250** of the fluid delivery port **210** and dispense, expel, or otherwise deliver fluid from the barrel **220** of the reservoir **206** to the user via the fluid delivery path provided by the cannula **208**. In exemplary embodiments, the motor **232** is realized as a DC motor, such as a stepper motor or brushless DC motor capable of precisely controlling the amount of displacement of the stopper **222** during operation of the infusion device **200**, as described in greater detail below.

Referring now to FIGS. **4-6**, in accordance with one or more embodiments, the drive system **230** in the durable housing **202** of the fluid infusion device **200** is realized as drive system **400**. In this regard, FIG. **5** depicts a cross-sectional perspective view of the motor **402** of the drive system **400** and FIG. **6** depicts a perspective view of the drive system **400** engaged with a shaft **624**, such as the shaft **224** coupled to the stopper **222** of a reservoir **206** in the fluid infusion device **200**. Various aspects of the motor drive system **400** may be similar to those described in U.S. patent application Ser. No. 13/049,803. The illustrated drive system **400** includes a motor **402** (e.g., motor **232**) and a gear assembly **406** (e.g., gear assembly **236**). As described above, the drive system **400** includes a rotary shaft **404** that is mechanically coupled to the rotor **501** of the motor **402**. The rotary shaft **404** is mechanically coupled to a first gear **408** of the gear assembly **406**. In the illustrated embodiment, the first gear **408** is coaxial and/or concentric to and disposed about the rotary shaft **404**, and the first gear **408** is affixed to or otherwise integrated with the rotary shaft **404** such that the first gear **408** and the rotary shaft **404** rotate in unison. The gear assembly **406** includes a second gear **610** (e.g., pinion gear **238**) having teeth **612** that are configured to mate with the exposed teeth **625** on a shaft **624** (e.g., teeth **225** on the shaft **224** of the stopper **222**), such that rotation or displacement of the second gear **610** produces a corresponding linear displacement of the shaft **624**, as described above. In exemplary embodiments, the gear assembly **406** includes various additional gears and other drive train components (e.g., screws, cams, ratchets, jacks, pulleys, pawls, clamps, nuts, slides, bearings, levers, beams, stoppers, plungers, sliders, brackets, guides, bearings, supports, bellows, caps, diaphragms, bags, heaters, and the like) configured to mechanically couple the gears **408**, **610** so that rotation (or displacement) of the first gear **408** produces a corresponding rotation (or displacement) of the second gear **610**. Thus, during operation of the fluid infusion device **200**, when the motor **402** is operated to rotate the rotor **501** of the motor **402**, the rotary shaft **404** rotates in unison with the rotor **501** to cause a corresponding rotation of the first gear **408**, which, in turn, actuates the gears of the gear assembly **406** to produce a corresponding rotation or displacement of the second gear **610**, which, in turn, displaces the shaft **624** (e.g., shaft **224**) in a linear direction (e.g., direction **250**).

Referring to FIG. **5**, in an exemplary embodiment, a sensor **500** is configured to measure, sense, or otherwise detect rotation (or displacement) of the rotary shaft **404** and/or the rotor **501** of the motor **402**. In exemplary embodiments, the rotary shaft **404** includes a detectable feature that is measurable or otherwise detectable by the sensor **500**. In the illustrated embodiment, a rotary member (or wheel) **502** is provided on the rotary shaft **404** and includes a plurality of protruding features (or arms) **504** that are measurable or otherwise detectable by the sensor **500**. In the illustrated embodiment, the wheel **502** is coaxial and/or concentric to and disposed about the rotary shaft **404**, and the wheel **502** is affixed to or otherwise integrated with the rotary shaft **404** such that the wheel **502** and the rotary shaft **404** rotate in unison. In this manner, rotation (or displacement) of the wheel **502** corresponds to the displacement of the rotary shaft **404** and/or the rotor **501** of the motor **402**.

In exemplary embodiments, the sensor **500** is realized as an incremental position sensor configured to measure, sense, or otherwise detect incremental rotations of the rotary shaft **404** and/or the rotor **501** of the motor **402**. For example, in accordance with one or more embodiments, the sensor **500** is realized as a rotary encoder. In alternative embodiments, the sensor **500** may be realized using any other suitable sensor, such as (but not limited to) a magnetic sensor, optical sensor (or other light detector), tactile sensor, capacitive sensor, inductive sensor, and/or the like. In exemplary embodiments, the incremental position sensor **500** may be configured to count or otherwise sense incremental rotations of the motor **402** via the wheel **502**, for example, by counting each time a protruding feature **504** passes by the sensor **500**. In this regard, when the number of protruding features **504** equals or otherwise corresponds to the number of discrete motor steps of the stepper motor **402**, the incremental position sensor **500** counts or otherwise senses the number of motor steps traversed by the rotary shaft **404** and/or rotor of the motor **402**. In some embodiments, the sensor **500** includes an emitter **510** and a detector **512** disposed on opposite sides of the wheel **502** such that at least a portion of the protruding features **504** passes between the emitter **510** and the detector **512** as the wheel **502** rotates. In this regard, the sensor **500** may detect or otherwise count each instance when a protruding feature **504** interrupts a transmission from the emitter **510** to the detector **512**. Alternatively, the sensor **500** may detect or otherwise count each instance a transmission from the emitter **510** to the detector **512** is uninterrupted or otherwise completed (e.g., via gaps between protruding features **504**).

FIG. **7** depicts an exemplary embodiment of a motor control system **700** suitable for use in a fluid infusion device in an infusion system, such as infusion device **200** or infusion device **102** in the infusion system **100**. The illustrated motor control system **700** includes, without limitation, a motor control module **702**, a pulse-width modulation (PWM) module **704**, a motor driver module **706**, a motor **708** (e.g., motor **232**, **402**), and a position sensor **710** (e.g., sensor **500**). In exemplary embodiments, the motor control system **700** is suitably configured to operate the motor **708** to provide a desired amount of fluid to a user in response to a dosage command indicative of the desired amount of fluid to be delivered that is received from a pump control module **720**, as described in greater detail below. In this regard, the pump control module **720** generally represents the electronics and other components of the infusion system that process sensor data (e.g., from sensing arrangement **104**) pertaining to a condition of the user and control operation of the fluid infusion device according to a desired infusion delivery program in a manner that is influenced by sensor data measured by and/or received from the sensing arrangement **104** or otherwise dictated by the user. In practice, the features and/or functionality of the pump control module **720** may be implemented by control electronics located in the fluid infusion device **102**, **200**, the CCD **106** and/or the computer **108**. It should be understood that FIG. **7** is a simplified representation of the system **700** for purposes of explanation and is not intended to limit the subject matter described herein in any way. For example, in practice, the features and/or functionality of the motor control module **702** may implemented by or otherwise integrated into the pump control module **720**, or vice versa.

In the illustrated embodiment, the PWM module **704** generally represents the combination of circuitry, hardware and/or other electrical components configured to generate a pulse-width modulated voltage output applied to the motor **708** via the motor driver module **706**. In an exemplary embodiment, the PWM module **704** is coupled to an energy source **730**, such as a battery housed within the infusion device **200** (e.g., in the housing **202**), to receive a supply voltage. Based on a duty cycle setting for the PWM module **704**, the PWM module **704** generates or otherwise produces a pulse-width modulated voltage output that oscillates between the supply voltage provided by the energy source **730** and a ground (or reference) voltage over a time interval (e.g., the PWM period), wherein the pulse-width modulated voltage output is equal to the supply voltage for a percentage of the time interval corresponding to the duty cycle setting. For example, if the supply voltage provided by the energy source **730** is equal to five volts and the duty cycle setting is equal to 30%, then the pulse-width modulated voltage output generated by the PWM module **704** may be a square wave having a magnitude equal to five volts for 30% of the time interval and zero volts for the remaining 70% of the time interval. In this regard, the duty cycle setting corresponds to the width of a portion of the square wave (e.g., the portion corresponding the supply voltage), and accordingly, the duty cycle setting may alternatively be referred to herein as the PWM width setting. In an exemplary embodiment, the frequency of the pulse-width modulated voltage output (e.g., the inverse of the PWM period) is greater than the frequency of the motor driver module **706**, as described in greater detail below, and the frequency of the pulse-width modulated voltage output is typically greater than the electrical time constant of the motor coils. As described in greater detail below, in exemplary embodiments, the PWM module **704** is coupled to the motor control module **702** which is configured to adjust, modify, or otherwise control the duty cycle setting of the PWM module **704**.

In an exemplary embodiment, the motor **708** is a stepper motor or brushless DC motor having a toothed rotor and a number of sets of windings, wherein the number of teeth on the rotor along with the number of winding sets and the physical arrangement of the winding sets with respect to the rotor teeth provides a finite number of motor steps within a revolution of the rotor. In this regard, as used herein, a "motor step" or any variant thereof should be understood as referring to an incremental rotation of the rotor of the motor **708** that is dictated by the number of teeth of the rotor along with the number and/or arrangement of the winding sets. As described above, in an exemplary infusion pump embodiment, the rotor of the motor **708** is mechanically coupled to a gear assembly **740** (e.g., gear assembly **236**, **406**) that includes the gears or other drive train components of the infusion device, such that an incremental rotation of the rotor by one motor step produces a corresponding amount of displacement of a stopper **750** (e.g., stopper **222**) into a reservoir (e.g., reservoir **206**) to deliver fluid (e.g., insulin) to the body of a user.

The motor driver module **706** generally represents the combination of circuitry, hardware and/or other electrical components configured to sequentially apply a voltage provided at a supply voltage input of the motor driver module **706** to one or more sets of windings of the motor **708** in a particular order to produce a corresponding number of commanded motor steps of rotation by the motor **708**. In the illustrated embodiment, the supply voltage input of the motor driver module **706** is coupled to the output of the PWM module **704**, such that the motor driver module **706** provides the pulse-width modulated voltage from the PWM module **704** to the one or more sets of windings of the motor **708** in a particular order under control of the motor control module **702**. In this regard, in some embodiments, the motor driver module **706** is coupled to the motor control module **702** to receive a commanded number of motor steps from the motor control module **702**, wherein in response to the commanded number of motor steps, the motor driver module **706** sequentially applies the pulse-width modulated voltage from the PWM module **704** to the sets of windings of the motor **708** in the appropriate order to produce the commanded number of motor steps. In other embodiments, the motor control module **702** may operate the switches and/or other circuitry of the motor driver module **706** to produce the commanded number of motor steps. The frequency at which the motor driver module **706** is operated (e.g., the frequency at which the pulse-width modulated voltage is changed from being applied to one winding set to another winding set) is less than the frequency of the pulse-width modulated voltage output from the PWM module **704**, such that the pulse-width modulated voltage output oscillates between the supply voltage and the ground voltage multiple times over the time period (e.g., the inverse of the motor driver frequency) during which the pulse-width modulated voltage output is applied to a particular set of windings of the motor **708**.

In an exemplary embodiment, the position sensor **710** is realized as an incremental position sensor, such as a rotary encoder, that is configured to sense, measure, or otherwise detect an incremental rotation of the rotor of the motor **708**, in a similar manner as described above in the context of FIG. **5**. In exemplary embodiments, the resolution of the position sensor **710** is greater than or equal to the resolution of the motor **708**, that is, the number of discrete incremental rotations measurable by the position sensor **710** over one revolution of the rotor of the motor **708** (e.g., the number of detectable features **504**) is greater than or equal to the number of discrete motor steps over one revolution of the rotor of the motor **708**. The output of the position sensor **710** is coupled to the motor control module **702** to provide dynamic closed-loop PWM control of the motor **708**, as described in greater detail below.

Still referring to FIG. **7**, the motor control module **702** generally represents the hardware, software, firmware and/or combination thereof that is configured to receive or otherwise obtain a commanded dosage from the pump control module **720**, convert the commanded dosage to a commanded number of motor steps, and command, signal, or otherwise operate the motor driver module **706** to cause the motor **708** to produce the commanded number of motor steps. As described in greater detail below in the context of FIG. **8**, in exemplary embodiments, the motor control module **702** determines an expected number of incremental rotations of the motor **708** based on the commanded number of motor steps, obtains the measured number of incremental rotations of the rotor of the motor **708** from the position sensor **710**, and based on differences between the measured number and the expected number, modifies or otherwise adjusts the PWM width setting of the PWM module **704** to achieve the commanded number of motor steps. Depending on the embodiment, the motor control module **702** may be implemented or realized with a general purpose processor, a microprocessor, a controller, a microcontroller, a state machine, a content addressable memory, an application specific integrated circuit, a field programmable gate array, any suitable programmable logic device, discrete gate or transistor logic, discrete hardware components, or any combination thereof, designed to perform the functions described herein. Furthermore, the steps of a method or algorithm described in connection with the embodiments disclosed herein may be embodied directly in

hardware, in firmware, in a software module executed by the motor control module **702**, or in any practical combination thereof. In exemplary embodiments, the motor control module **702** includes or otherwise accesses a memory, including any sort of random access memory (RAM), read only memory (ROM), flash memory, registers, hard disks, removable disks, magnetic or optical mass storage, or any other short or long term storage media or other non-transitory computer-readable medium, which is capable of storing programming instructions for execution by the motor control module **702**. The computer-executable programming instructions, when read and executed by the motor control module **702**, cause the motor control module **702** to perform the tasks, operations, functions, and processes described in greater detail below.

FIG. **8** depicts an exemplary motor control process **800** suitable for implementation by a motor control system **700** to deliver fluid to a user using dynamic closed-loop PWM control. The various tasks performed in connection with the motor control process **800** may be performed by software, hardware, firmware, or any combination thereof. For illustrative purposes, the following description refers to elements mentioned above in connection with FIG. **7**. In practice, portions of the motor control process **800** may be performed by different elements of the motor control system **700**, such as, for example, the motor control module **702**, the PWM module **704**, the motor driver module **706**, the motor **708** and/or the position sensor **710**. It should be appreciated that the motor control process **800** may include any number of additional or alternative tasks, the tasks need not be performed in the illustrated order and/or the tasks may be performed concurrently, and/or the motor control process **800** may be incorporated into a more comprehensive procedure or process having additional functionality not described in detail herein. Moreover, one or more of the tasks shown and described in the context of FIG. **8** could be omitted from a practical embodiment of the motor control process **800** as long as the intended overall functionality remains intact.

Referring to FIG. **8**, and with continued reference to FIG. **7**, the motor control process **800** begins by determining an initial duty cycle setting and configuring the PWM module to implement that initial duty setting (task **802**). In an exemplary embodiment, the initial duty cycle setting is a minimum duty cycle capable of rotating the rotor of the motor **708** by one motor step. In this regard, in some embodiments, the motor control module **702** may calibrate or otherwise determine the initial duty cycle setting upon initialization of the infusion pump. For example, upon powering on the infusion pump and/or a reservoir being inserted into the infusion pump, the motor control module **702** may perform a calibration routine by initially setting the duty cycle setting of the PWM module **704** to a minimum value capable of being implemented by the PWM module **704**, signaling or otherwise commanding the motor driver module **706** to provide one motor step of rotation, and monitoring the output of the position sensor **710** to determine if the rotor of the motor **708** rotated by a motor step. If the motor **708** did not rotate by a motor step, the motor control module **702** incrementally increases the duty cycle setting of the PWM module **704**, repeats the steps of commanding the motor driver module **706** to provide one motor step of rotation and monitoring the output of the position sensor **710** until determining that the rotor of the motor **708** has rotated by a motor step. Once the motor **708** rotates by one motor step, the motor control module **702** maintains the duty cycle setting of the PWM module **704** at the duty cycle that resulted in a motor step of rotation. In other embodiments, the motor control system **700** may be pre-calibrated with an initial PWM width setting that is stored or otherwise maintained by the motor control module **702** for configuring the PWM module **704** upon initialization of the infusion pump and/or the motor control process **800**. For example, if the PWM module **704** has a minimum duty cycle setting (e.g., 20%), the motor control module **702** may default the duty cycle setting of the PWM module **704** to the minimum duty cycle capable of being implemented by the PWM module **704**.

After configuring the PWM module with an initial duty cycle setting, the motor control process **800** continues by receiving or otherwise obtaining a motor command corresponding to a desired displacement of a stopper or a desired amount of rotation to be provided by the motor (task **804**). For example, the pump control module **720** may determine or otherwise receive (e.g., from the CCD **106** and/or the computer **108**) a dose (or bolus) of fluid to be provided to the user based on a sensed condition of the user (e.g., a blood glucose level). In some embodiments, the pump control module **720** converts the amount of fluid to be provided to the user into a commanded displacement of the stopper **750**, converts the commanded displacement of the stopper **750** to a corresponding number of motor steps, and provides that commanded number of motor steps to the motor control module **702**. In other embodiments, the pump control module **720** provides the amount of fluid to be provided to the user to the motor control module **702**, wherein the motor control module **702** converts the commanded dosage into a corresponding number of commanded motor steps based on the amount of displacement of the stopper **750** corresponding to that amount of fluid.

In accordance with one or more embodiments, the motor control process **800** continues by dividing or otherwise converting the number of commanded motor steps into a number of step command blocks (task **806**). In this regard, in some embodiments, the step command blocks have a fixed number of steps, wherein when the number of commanded motor steps is greater than the fixed number of steps, the motor step command is broken up into smaller command blocks to decrease the response time when the motor **708** fails to achieve a commanded number of motor steps, as described in greater detail below. For example, if the total number of commanded motor steps corresponding to the desired dosage is equal to one hundred motor steps, the motor control module **702** may divide the commanded motor steps into ten different step command blocks of ten motor steps.

In an exemplary embodiment, the motor control process **800** continues by commanding or otherwise signaling the motor driver module to operate the motor in a manner intended to produce the commanded number of motor steps in a step command block with the current PWM width setting (task **808**). In this regard, the motor control module **702** signals, commands, instructs, or otherwise operates the motor driver module **706** to sequentially apply the pulse-width modulated voltage output of the PWM module **704** to the various sets of windings of the motor **708** in the appropriate order to cause rotor of the motor **708** rotate by the number of motor steps in the step command block. For example, the motor control module **702** may command the motor driver module **706** to implement ten motor steps, wherein in response, the motor driver module **706** changes which set of windings of the motor **708** that the pulse-width modulated voltage output of the PWM module **704** is applied to ten different times in an order or sequence intended to produce ten motor steps of rotation from the current position of the rotor. As described above, the motor driver module **706** applies the pulse-width modulated voltage output from the

PWM module **704** to a first set of windings of the motor **708** for a first time period substantially equal to the inverse of the motor driver module frequency to produce a first motor step of rotation from a current position of the rotor of the motor **708**, then applies the pulse-width modulated voltage output from the PWM module **704** to a second set of windings of the motor **708** for another time period substantially equal to the inverse of the motor driver module frequency to produce another motor step of rotation from the updated position of the rotor, and so on until reaching the commanded number of steps in the step command block.

In an exemplary embodiment, the motor control process **800** continues by calculating or otherwise determining an expected displacement of the rotor of the motor or another element mechanically coupled to the rotor (e.g., the stopper) after execution of the step command block based on the commanded number of motor steps in the step command block (task **810**). The expected displacement is the amount by which the rotor of the motor **708** is expected to have rotated when the commanded rotation is achieved. To put it another way, the expected displacement corresponds to the amount of displacement of the rotor of the motor **708** that is expected to be measured or detected by the position sensor **710** in response to the commanded rotation. For example, when the position sensor **710** is a rotary encoder or another incremental position sensor, the motor control module **702** calculates or otherwise determines a number of rotational increments that would be expected to be measured or otherwise detected by the position sensor **710** after execution of the step command block based on the number of motor steps in the step command block and the relationship between the resolution of the position sensor **710** with respect to the resolution of the motor **708**. In this regard, the expected number of measured rotational increments after execution of a step command block, n_E, is equal to

$$n_C \times \frac{r_P}{r_M},$$

where n_C is the number of motor steps in the step command block, r_P is the number of discrete rotational increments detectable by the position sensor **710** over a revolution of the rotor of the motor **708**, and r_M is the number of discrete motor steps (or discrete rotational increments) for the rotor of the motor **708** over one revolution. Thus, when the number of discrete rotational increments detectable by the position sensor **710** is equal to the number of possible motor steps over a revolution of the motor **708**, the expected number of measured rotational increments is equal to the commanded number of motor steps in the step command block.

Still referring to FIG. **8**, the motor control process **800** continues by obtaining a measured displacement of the rotor of the motor or another element mechanically coupled to the rotor (e.g., the stopper) after executing the step command block (task **812**). In this regard, after commanding the motor driver module **706**, the motor control module **702** waits for an amount of time required to implement the step command block before obtaining the position of the rotor of the motor **708** from the position sensor **710**. For example, the motor control module **702** may calculate the amount of time required by the motor driver module **706** to implement the step command block by multiplying the number of motor steps in the step command block by the inverse of the motor driver frequency (e.g., the amount of time a pulse-width modulated voltage is applied to produce an individual motor step). When the position sensor **710** is a rotary encoder or another incremental position sensor, the motor control module **702** obtains an initial position of the rotor of the motor **708** from the position sensor **710** (e.g., an initial encoder count) prior to commanding the motor driver module **706** to implement a step command block, obtains a subsequent position of the rotor of the motor **708** from the position sensor **710** (e.g., a subsequent encoder count) after commanding the motor driver module **706** to implement the step command block, and calculates or otherwise determines the measured number of rotational increments as a difference between positions obtained from the position sensor **710** (e.g., by subtracting the initial encoder count from the subsequent encoder count).

In exemplary embodiments, the motor control process **800** identifies or otherwise determines whether the motor has achieved the commanded amount of rotation (task **814**). In some embodiments, the motor control module **702** determines that the motor has failed to achieve the commanded amount of rotation when a difference between the expected displacement and the measured displacement exceeds a threshold value. The threshold value is indicative of the number of motor steps of rotation actually achieved by the motor **708** being less than the commanded number of motor steps in the step command block. For example, when the number of discrete rotational increments detectable by the position sensor **710** is equal to the number of possible motor steps over a revolution of the motor **708**, the threshold value may be equal to zero. Thus, in such an embodiment, when the expected number of measured rotational increments is greater than the measured number of rotational increments, the motor control module **702** identifies that the motor **708** did not achieve the commanded number of motor steps. In other embodiments where the resolution of the position sensor **710** is greater than the resolution of the stepper motor, the threshold value is chosen to be greater than zero to account for differences between the expected number and the measured number of rotational increments that could be attributable to noise, vibration, or other physical variations and/or misalignment between the position sensor **710** and the rotor teeth and/or positions of the windings sets of the motor **708**. For example, if the number of discrete rotational increments detectable by the position sensor **710** over a revolution of the motor **708** is equal to five times the number of motor steps over one revolution, the threshold value may be chosen to be equal to two, such that when the expected number of measured rotational increments is greater than the measured number of rotational increments by more than two, the motor control module **702** identifies that the motor **708** did not achieve the commanded number of motor steps.

In response to identifying that the motor did not achieve the commanded rotation, the motor control process **800** continues by calculating or otherwise determining an amount by which the duty cycle of the PWM module should be increased and increasing or otherwise adjusting the duty cycle setting for the PWM module (tasks **816**, **818**). In some embodiments, the motor control module **702** calculates an amount by which to increase the PWM width setting based on the difference between the expected displacement and the measured displacement of the motor **708**. For example, the motor control module **702** may increase the duty cycle setting of the PWM module **704** by a first amount if the difference between the expected displacement and the measured displacement of the motor **708** corresponds to one missed motor step, increase the duty cycle setting by a greater amount if the difference between the expected displacement and the measured displacement of the motor **708** corresponds to two missed motor steps, and so on. In this regard, the amount of increase to the

PWM width setting may correspond to the difference between the expected displacement and the measured displacement of the motor **708**. In other embodiments, the motor control module **702** may increase the duty cycle setting by a fixed amount (e.g., a fixed percentage or a percentage of the current duty cycle) regardless of the difference between the expected displacement and the measured displacement of the motor **708**. For example, the motor control module **702** may increase the duty cycle setting of the PWM module **704** by 5% each time the motor achieves a number of motor steps that was less than the commanded number of motor steps. After the motor control module **702** identifies or otherwise determines the amount by which to increase the PWM width setting for the PWM module **704**, the motor control module **702** determines an updated PWM width setting (e.g., a sum of the previous duty cycle and the amount of increase) for the PWM module **704** and configures the PWM module **704** to implement the updated PWM width setting. For example, if the initial PWM width setting corresponds to a 30% duty cycle and the motor control module **702** determines that the PWM width setting should be increased by 5% based on the difference between the expected number of measured rotational increments and the actual measured number of rotational increments, the motor control module **702** configures or otherwise instructs the PWM module **704** to implement a 35% duty cycle.

In an exemplary embodiment, the motor control process **800** determines the number of missed motor steps based on the measured displacement and modifies the number of motor steps in a subsequent step command block to compensate for the number of missed motor steps (tasks **820**, **822**). In accordance with one or more embodiments, the motor control module **702** adds a number of motor steps that corresponds to the difference between the expected displacement and the measured displacement to the commanded number of motor steps in the next step command block. In some embodiments, the motor control module **702** may calculate or otherwise determine the actual number of motor steps produced by the motor **708** based on the measured displacement of the rotor and determine the missed motor steps as the difference between the commanded number of motor steps and the actual number of motor steps. For example, when the position sensor **710** is a rotary encoder or another incremental position sensor, the motor control module **702** may convert the measured number of incremental rotations to a number of motor steps and subtract that number of motor steps from the commanded number of motor steps to obtain the missed motor steps. The measured number of incremental rotations may be converted motor steps by multiplying the measured number incremental rotations by

$$\frac{r_M}{r_P},$$

where r_P is the number of discrete rotational increments per revolution detectable by the position sensor **710** and r_M is the number of motor steps per revolution. Alternatively, the motor control module **702** may determine the missed motor steps by converting the difference between the expected number of measured incremental rotations and the actual measured number of incremental rotations to a number of motor steps (e.g., by multiplying the difference by

$$\frac{r_M}{r_P}).$$

After determining a modified step command block that compensates for missed motor steps, the motor control process **800** continues by commanding or otherwise signaling the motor driver module to operate the motor in a manner intended to produce the number of motor steps in the modified step command block with the updated PWM width setting (task **808**). For example, as described above, if the preceding step command block of ten motor steps resulted in two missed motor steps when executed at a PWM width setting of 30%, and the motor control module **702** determines that the PWM width setting should be increased to 35%, the motor control module **702** configures the PWM module **704** to implement a 35% duty cycle while commanding the motor driver module **706** to execute a step command block of twelve motor steps to compensate for the missed motor steps of the previous step command block. While the motor driver module **706** is implementing the modified step command block, the pulse-width modulated voltage oscillates between the supply voltage for 35% of the PWM period and the ground voltage for 65% of the PWM period, rather than oscillating between the supply voltage for 30% of the PWM period and the ground voltage for 70% of the PWM period as was done during the preceding step command block. As described above, the motor control module **702** determines an expected displacement of the rotor of the motor **708** after execution of the modified step command block, obtains a measured displacement of the rotor of the motor **708** after execution of the modified step command block, and determines whether the motor **708** achieved the commanded number of motor steps based on the measured displacement (tasks **810**, **812**, **814**). If the motor **708** did not achieve the number of motor steps commanded during the modified step command block with the updated PWM width setting, the motor control module **702** further increases the PWM width setting for the PWM module and modifies a subsequent step command block to compensate for the missed motor steps during the modified step command block (tasks **816**, **818**, **820**, **822**), as described above.

Still referring to FIG. **8**, in response to determining that the motor achieved the commanded amount of rotation (e.g., the commanded number of motor steps in a step command block), the motor control process **800** continues by determining whether the duty cycle for the PWM module should be decreased (task **824**). In this regard, the duty cycle setting is decreased after the duty cycle has remained unchanged (or constant) and achieved the commanded number of motor steps over a particular amount of time and/or achieved a particular number of commanded motor steps. In some embodiments, the motor control module **702** may store or otherwise maintain a timestamp corresponding to the most recent increase in the PWM width setting and determine that the PWM width setting should be decreased when more than a threshold amount of time has elapsed since the most recent increase in the PWM width setting. For example, the threshold amount of time may be twelve hours, wherein the motor control module **702** obtains a current time and determines the PWM width setting should be decreased when the current time is more than twelve hours after the most recent increase in the duty cycle implemented by the PWM module **704**. In other embodiments, the motor control module **702** may count or otherwise monitor a cumulative number of motor steps executed by the motor **708** since the most recent increase in the PWM width setting and determine that the PWM width

setting should be decreased when the cumulative number of motor steps executed by the motor **708** since the most recent increase in the duty cycle exceeds a threshold number of motor steps. For example, if the threshold number of motor steps is one thousand motor steps, the motor control module **702** determines the PWM width setting should be decreased when the motor **708** successfully completes one thousand motor steps with a constant duty cycle.

In response to determining the PWM width setting should be decreased, the motor control process **800** continues by decreasing the duty cycle setting for the PWM module (task **826**). In some embodiments, the motor control module **702** may decrease the PWM width setting of the PWM module **704** by a fixed amount (e.g., a fixed percentage or a certain percentage of the current duty cycle). In other embodiments, the motor control module **702** may store a previous duty cycle prior to increasing the duty cycle setting, wherein the motor control module **702** decreases the PWM width setting to that previous duty cycle. For example, if the PWM width setting was at a 30% duty cycle prior to increasing to 35%, and the motor **708** has achieved the commanded number of motor steps over a particular amount of time and/or achieved a particular number of commanded motor steps with the 35% duty cycle, the motor control module **702** may revert the PWM width setting of the PWM module **704** back to the 30% duty cycle for subsequent step command blocks.

In an exemplary embodiment, the motor control process **800** continues by determining whether the entire motor command has been completed (task **828**). In this regard, the motor control module **702** verifies or otherwise determines whether the rotor of the motor **708** has rotated by the total number of motor steps corresponding to the dose (or bolus) of fluid to be provided to the user. When the motor **708** has not achieved the total number of motor steps corresponding to the desired dosage, the motor control module **702** continues operating the PWM module **704** and the motor driver module **706** until the motor **708** achieves the desired number of motor steps. For example, if not all of the step command blocks corresponding to the motor command have been executed, the motor control module **702** commands or otherwise operates the motor driver module **706** in accordance with the next step command block (task **808**), as described above. Once the motor control module **702** determines that the motor **708** has achieved the desired number of motor steps to provide the desired dose of fluid to the user, in an exemplary embodiment, the motor control module **702** turns off the motor driver module **706** until receiving a subsequent motor command.

In response to a subsequent motor command from the pump control module **720** (task **804**), the motor control module **702** repeats the steps of operating the motor driver module **706** and dynamically increasing and/or decreasing the PWM width setting of the PWM module **704** based on whether or not the motor **708** achieves a commanded number of motor steps, as described above. The motor **708** consumes power from the energy source **730** only during the times when the pulse-width modulated voltage output of the PWM module **704** is equal to the supply voltage provided by the energy source **730**, and thus, by dynamically adjusting the PWM width setting, the power consumed by the motor **708** to achieve a desired number of motor steps may be reduced by keeping the duty cycle setting for the PWM module **704** relatively low and increasing the duty cycle on an as needed basis. As described in greater detail below, in exemplary embodiments, the motor control module **702** monitors the duty cycles provided by the PWM module **704** during operation of the motor control system **700** and detects or otherwise identifies anomalies in the motor control system **700** based on changes to the duty cycle provided by the PWM module **704** that are indicative of an anomalous condition, such as, for example, a degradation condition in the motor **708** and/or the gear assembly **740** or an occlusion condition in a fluid path from the fluid reservoir. In response to identifying an anomalous condition, the motor control module **702** generates a notification that is provided to the pump control module **720** or another supervisory system, which, in turns, notifies the user or initiates remedial action to address the potential anomaly.

FIG. **9** depicts an exemplary occlusion detection process **900** suitable for implementation by a motor control system **700** to detect an occlusion in a fluid path while delivering fluid to a user using closed-loop dynamic PWM control in accordance with the motor control process **800** of FIG. **8**. The various tasks performed in connection with the occlusion detection process **900** may be performed by software, hardware, firmware, or any combination thereof. For illustrative purposes, the following description refers to elements mentioned above in connection with FIG. **7**. In practice, portions of the occlusion detection process **900** may be performed by different elements of the motor control system **700**, such as, for example, the motor control module **702**. It should be appreciated that the occlusion detection process **900** may include any number of additional or alternative tasks, the tasks need not be performed in the illustrated order and/or the tasks may be performed concurrently, and/or the occlusion detection process **900** may be incorporated into a more comprehensive procedure or process having additional functionality not described in detail herein. Moreover, one or more of the tasks shown and described in the context of FIG. **9** could be omitted from a practical embodiment of the occlusion detection process **900** as long as the intended overall functionality remains intact.

In an exemplary embodiment, the occlusion detection process **900** characterizes the PWM width settings of the PWM module for an occlusion in the fluid path by determining a reference value for a duty cycle metric that is indicative of an occlusion in the fluid path (task **902**). In this regard, the reference value for the duty cycle metric is representative of the changes to the duty cycle setting of the PWM module **704** that are likely to be exhibited by the motor control system **700** in response to an occlusion in the fluid delivery path that slows, prevents, or otherwise degrades fluid delivery from the reservoir to a user's body while the motor **708** is operated in accordance with the motor control process **800**. In this regard, an occlusion in the fluid path increases the force opposing displacement of the stopper **750**, which, in turn, will increase the amount of torque required to rotate the rotor of the motor **708** by a motor step. Depending on the embodiment, the duty cycle metric may be a rate of change (or derivative) of the PWM width setting over a preceding time interval, a moving average of the PWM width setting over a preceding time interval, a sequence of PWM width settings over a preceding time interval, a threshold PWM width value, a matched filter applied to a sequence of PWM width settings over a preceding time interval, or some other metric representative of an occlusion in the fluid path while operating the motor **708** in accordance with the motor control process **800**.

In one embodiment, the reference value may be determined by creating or otherwise simulating an occlusion in the fluid path and operating the motor **708** in accordance with the motor control process **800** prior to providing the infusion pump to a user. For example, a component having a known occlusion (e.g., an occluded reservoir, needle, tubing, or the like) may be provided to the infusion pump to create a reference occlusion in the fluid path, and while the reference

occlusion exists, the pump control module **720** signals, instructs, or otherwise commands the motor control module **702** to perform a calibration routine by operating the motor **708** for a particular number of motor steps in accordance with the motor control process **800** and monitoring the PWM width settings. In accordance with one embodiment, the number of motor steps used for the calibration routine is greater than the amount of motor steps that are achievable with the reference occlusion in the fluid path. As described above in the context of FIG. **8**, the motor control module **702** operates the motor driver module **706** and increases the PWM width settings of the PWM module **704** based on the measured displacement of the motor **708**. For example, the motor control module **702** may operate the motor driver module **706** to produce a number of motor steps (e.g., ten motor steps) with the initial PWM width setting, wherein the resistance provided by the reference occlusion prevents the motor **708** and results in an increase in the PWM width setting. As described above, the motor control module **702** may calculate the amount of increase for the PWM width setting based on the difference between the expected displacement and the measured displacement of the motor **708**. Thus, when the reference occlusion substantially prevents displacement of the stopper **750** (and thereby prevents rotation of the rotor of the motor **708**), the PWM width settings determined by the motor control module **702** may increase at a rate (or by an amount) that is unlikely to occur during normal operation. In exemplary embodiments, the motor control module **702** monitors the PWM width settings determined during execution of the calibration routine and determines the reference value for a duty cycle metric that is indicative of an occlusion based on those PWM width settings (e.g., the amount of change in the PWM width settings during the time interval required to execute the calibration routine, the rate of change or derivative of the PWM width setting during the calibration routine, the sequence of PWM width settings or the sequence of increases to the PWM width settings during the calibration routine, a PWM width settings profile identified for the infusion device using a machine learning algorithm, or the like). After the calibration routine is completed, the reference occlusion is removed before the infusion device is provided to the user.

Still referring to FIG. **9**, in an exemplary embodiment, the occlusion detection process **900** continues by operating the motor using dynamic PWM control, obtaining the current PWM width setting for the PWM module, and determining an observed value for the duty cycle metric based on the current PWM width setting and/or previously obtained PWM width settings (tasks **904**, **906**, **908**). In this regard, the motor control module **702** obtains motor commands from the pump control module **720** and operates the motor **708** using dynamic PWM control in accordance with the motor control process **800** of FIG. **8**. In an exemplary embodiment, after each step command block executed by the motor driver module **706**, the motor control module **702** obtains the current PWM width setting for the PWM module **704** and calculates or otherwise determines an observed value for the duty cycle metric based on the current PWM width setting and/or previously obtained PWM width settings. For example, the motor control module **702** may determine the observed value as an amount of change or rate of change to the PWM width settings over a preceding time interval (e.g., over a preceding time interval equal to the time interval required to execute the calibration routine).

In an exemplary embodiment, the occlusion detection process **900** continues by identifying, detecting, or otherwise determining whether an occlusion condition exists based on the observed value for the duty cycle metric, and in response to detecting an occlusion condition, generating or otherwise providing a notification of the fluid path occlusion (tasks **910**, **912**). In accordance with one or more embodiments, the motor control module **702** compares the observed value for the duty cycle metric with the reference value indicative of a fluid path occlusion and detects or otherwise identifies an occlusion condition when the observed value meets or exceeds the reference value for the duty cycle metric. For example, if the duty cycle metric is an amount or rate of change to the PWM width setting, the motor control module **702** detects an occlusion condition when the amount or rate of change of the observed PWM width settings is greater than or equal to the amount or rate of change to the PWM width setting during the calibration routine. When the motor control module **702** detects an occlusion condition, the motor control module **702** provides a notification of the fluid path occlusion to the pump control module **720** or another supervisory system or module (e.g., the CCD **106** and/or the computer **108**). For example, the motor control module **702** may generate an interrupt signal that is handled by the pump control module **720**. In practice, the pump control module **720** and/or the infusion pump may perform other occlusion detection techniques (e.g., using force sensors or the like), wherein the pump control module **720** and/or the infusion pump may utilize the occlusion notification generated by the motor control module **702** to verify, confirm, or otherwise augment the other occlusion detection algorithms and/or techniques performed by the pump control module **720** and/or the infusion pump. In other embodiments, the pump control module **720** and/or the infusion pump may utilize the occlusion notification generated by the motor control module **702** as the sole indicia of a fluid path occlusion when anomalies exist with respect to the other occlusion detection algorithms and/or techniques supported by the infusion device (e.g., damage to other sensors normally relied on for detecting an occlusion). In the absence of a fluid path occlusion, the loop defined by tasks **904**, **906**, **908** and **910** repeats during operation of the motor **708** in accordance with the motor control process **800** to continuously monitor the PWM width settings of the PWM module **704** for an occlusion condition.

FIG. **10** depicts an exemplary degradation detection process **1000** suitable for implementation by a motor control system **700** to detect wear or degradation in a drive system while delivering fluid to a user using closed-loop dynamic PWM control in accordance with the motor control process **800** of FIG. **8**. The various tasks performed in connection with the degradation detection process **1000** may be performed by software, hardware, firmware, or any combination thereof. For illustrative purposes, the following description refers to elements mentioned above in connection with FIG. **7**. In practice, portions of the degradation detection process **1000** may be performed by different elements of the motor control system **700**, such as, for example, the motor control module **702**. It should be appreciated that the degradation detection process **1000** may include any number of additional or alternative tasks, the tasks need not be performed in the illustrated order and/or the tasks may be performed concurrently, and/or the degradation detection process **1000** may be incorporated into a more comprehensive procedure or process having additional functionality not described in detail herein. Moreover, one or more of the tasks shown and described in the context of FIG. **10** could be omitted from a practical embodiment of the degradation detection process **1000** as long as the intended overall functionality remains intact.

In an exemplary embodiment, the degradation detection process **1000** characterizes the drive system by determining a

reference value for a duty cycle metric based on the PWM width settings of the PWM module that is indicative of wear or degradation in the drive system (task **1002**). The reference value duty cycle metric is representative of the PWM width setting(s) that are likely to be exhibited by the motor control system **700** while the motor **708** is operated in accordance with the motor control process **800** when the motor **708** and/or the gear assembly **740** have experienced sufficient wear or degradation to the point that the motor **708** and/or the gear assembly **740** should be inspected for maintenance, repair and/or replacement. In this regard, reference value is indicates that the motor **708** and/or the gear assembly **740** should be inspected for maintenance, repair and/or replacement. For example, over time, frictional forces in the drive system may accumulate (e.g., due to lubricant wearing out, rust or other surface effects, damage to the motor and/or one or more of the gears, and the like) and increase the force that opposes displacement of the gear assembly **740**, the stopper **750** and/or the motor **708**, which, in turn, will increase the amount of torque required to rotate the rotor of the motor **708** by a motor step. Thus, the reference value may be a duty cycle that is unlikely to be exceeded (e.g., an 80% duty cycle setting) unless the motor **708** and/or gear assembly **740** has degraded. The duty cycle metric may be a threshold PWM width setting, an average PWM width setting, a sequence of PWM width settings, a matched filter applied to a sequence of PWM width settings over a preceding time interval, or some other metric capable of indicating degradation to the motor **708** and/or the gear assembly **740**. For example, the duty cycle metric may be a moving average of the PWM width settings of the PWM module **704** (e.g., an average of the PWM width settings over the previous 24 hours). In this regard, the reference value may be updated or otherwise determined dynamically during operation of the motor control system **700** and/or the infusion device. In some embodiments, the reference value may be the historical duty cycle average over the lifetime of the motor control system **700** and/or the infusion device. For example, the motor control module **702** may continuously obtain the PWM width settings of the PWM module **704** and recalculate the average PWM width setting over the lifetime of the motor control system **700** and/or the infusion pump (e.g., by averaging PWM width settings obtained after each step command block or each motor command), as described in greater detail below.

In an exemplary embodiment, the degradation detection process **1000** continues by operating the motor using dynamic PWM control, obtaining a current duty cycle setting for the PWM module, and determining an observed value for the duty cycle metric based on the current duty cycle setting and/or previously obtained duty cycle settings (tasks **1004**, **1006**, **1008**). As described above, the motor control module **702** obtains motor commands from the pump control module **720** and operates the motor **708** using dynamic PWM control in accordance with the motor control process **800** of FIG. **8**. In an exemplary embodiment, after each step command block (or alternatively, after each motor command) executed by the motor driver module **706**, the motor control module **702** obtains the current PWM width setting for the PWM module **704** and calculates or otherwise determines an observed value for the duty cycle metric based on the current PWM width setting and/or previously obtained PWM width settings. For example, the motor control module **702** may determine a moving average of the PWM width settings over a preceding time interval (e.g., the previous 24 hours) as the observed value for the duty cycle metric.

In an exemplary embodiment, the degradation detection process **1000** continues by identifying or otherwise determining whether the drive system is exhibiting degradation based on the observed value for the duty cycle metric, and in response to detecting a degradation condition, generating or otherwise providing a notification of the degradation condition (tasks **1010**, **1012**). The motor control module **702** identifies a degradation condition by comparing the observed value for the duty cycle metric with the reference value indicative of a degradation condition and detecting when the observed value meets or exceeds the reference value. For example, if the reference value is an 80% duty cycle, the motor control module **702** detects a degradation condition when the observed value (e.g., the current PWM width setting of the PWM module **704** or an average of the current and previous PWM width settings) exceeds 80%. Thus, when the duty cycle metric is a moving average of the PWM width settings over a preceding time interval (e.g., the previous 24 hours), the motor control module **702** identifies a degradation condition when the moving average of the PWM width setting exceeds the 80% duty cycle reference value. In some embodiments, the motor control module **702** identifies a degradation condition when the observed value exceeds the reference value by some threshold amount, such as a fixed amount (e.g., a fixed duty cycle percentage) or a fixed percentage of the reference value. In this regard, if the reference value is the average PWM width setting over the lifetime of the motor control system **700** and/or the infusion device, the motor control module **702** may identify a degradation condition when a moving average of the PWM width settings over a shorter time interval exceeds the reference value by more than a threshold percentage of the reference value. For example, if the average PWM width setting over the lifetime of the motor control system **700** corresponds to 50% duty cycle, the motor control module **702** may identify a degradation condition when an average of the PWM width settings over the preceding 24 hours exceeds the reference value by more than fifty percent of the reference value, that is, when the average of the PWM width settings over the preceding 24 hours exceeds a 75% duty cycle. Alternatively, the motor control module **702** may identify a degradation condition when an average of the PWM width settings over the preceding time interval exceeds the reference value by a fixed amount (e.g., a 20% difference in duty cycle).

When the motor control module **702** detects or otherwise identifies a degradation condition, the motor control module **702** provides a notification of the potential degradation to the pump control module **720** or another supervisory system or module. For example, the motor control module **702** may generate an interrupt signal that is handled by the pump control module **720** or another supervisory system, which, in turn, generates an audio and/or visual alert to the user that the drive system should be inspected. In the absence of a degradation condition, the loop defined by tasks **1004**, **1006**, **1008** and **1010** repeats during operation of the motor **708** in accordance with the motor control process **800** to continuously monitor the PWM width settings of the PWM module **704** for degradation in the drive system.

Referring to FIGS. **7-10**, in accordance with one or more embodiments, the motor control process **800**, the occlusion detection process **900**, and the degradation detection process **1000** are performed by the motor control system **700** concurrently. For example, as described above in the context of FIG. **8**, the motor control module **702** may receive motor commands from the pump control module **720** and operate the motor **708** via the PWM module **704** and the motor driver module **706** using closed-loop dynamic PWM control to vary or otherwise adjust the PWM width setting of the PWM module **704** (i.e., the duty cycle of the pulse-width modulated

voltage output of the PWM module **704**) to achieve the desired rotation of the motor **708**, and, in turn, achieve a desired dosage of fluid to the user by displacing the stopper **750** by the desired amount via the gear assembly **740**. While operating the motor **708** in accordance with the motor control process **800**, the motor control module **702** may obtain the current PWM width settings for the PWM module **704** and determine observed values for the duty cycle metrics used for detecting an occlusion condition or a degradation condition. In this regard, when the PWM width settings for the PWM module **704** rapidly increase or otherwise vary by a certain amount over a relative short period of time in a manner that is characteristic of an occlusion condition, the motor control module **702** detects the occlusion condition and generates a notification of the potential fluid path occlusion, as described above in the context of occlusion detection process **900**. In other situations, when the average PWM width settings for the PWM module **704** gradually increase over a longer period of time and exceed a reference value that is characteristic of a degradation condition, the motor control module **702** detects the degradation condition and generates a notification of the potential drive system degradation, as described above in the context of degradation detection process **1000**. In this regard, the motor control module **702** may operate the motor **708** using dynamic PWM control to reduce the amount of power consumed by the motor **708** while concurrently monitoring the PWM width settings to identify potential fluid path occlusions or drive system degradation that may impair operation of the infusion pump.

The foregoing description may refer to elements or nodes or features being "connected" or "coupled" together. As used herein, unless expressly stated otherwise, "coupled" means that one element/node/feature is directly or indirectly joined to (or directly or indirectly communicates with) another element/node/feature, and not necessarily mechanically. In addition, certain terminology may also be used in the herein for the purpose of reference only, and thus is not intended to be limiting. For example, terms such as "first", "second", and other such numerical terms referring to structures do not imply a sequence or order unless clearly indicated by the context.

While at least one exemplary embodiment has been presented in the foregoing detailed description, it should be appreciated that a vast number of variations exist. It should also be appreciated that the exemplary embodiment or embodiments described herein are not intended to limit the scope, applicability, or configuration of the claimed subject matter in any way. For example, the subject matter described herein is not limited to the infusion devices and related systems described herein. Moreover, the foregoing detailed description will provide those skilled in the art with a convenient road map for implementing the described embodiment or embodiments. It should be understood that various changes can be made in the function and arrangement of elements without departing from the scope defined by the claims, which includes known equivalents and foreseeable equivalents at the time of filing this patent application.

What is claimed is:

1. A system comprising:

a stepper motor having a rotor and sets of windings;

a sensor to detect incremental rotations of the rotor;

a modulation module to generate a modulated voltage oscillating between a first voltage and a second voltage, the modulated voltage being equal to the first voltage for a percentage of a time interval, the percentage corresponding to a duty cycle;

a motor driver module coupled between the modulation module and the stepper motor to apply the modulated voltage to one or more of the sets of windings; and

a control module coupled to the sensor, the modulation module, and the motor driver module to:

operate the motor driver module to sequentially apply the modulated voltage to the one or more of the sets of windings in a particular order to produce a commanded number of motor steps of rotation by the rotor;

obtain a measured number of the incremental rotations from the sensor after the stepper motor is operated to provide the commanded number of motor steps;

increase the duty cycle for the modulated voltage in response to a difference between an expected number of incremental rotations corresponding to the commanded number of motor steps and the measured number of the incremental rotations; and

detect a degradation condition based on the duty cycle.

2. An infusion device, comprising:

a motor having a rotor;

a shaft mechanically coupled to the rotor, the shaft being displaced to deliver fluid in response to rotation of the rotor;

a modulation module coupled to the motor, the modulation module generating a modulated voltage applied to the motor, the modulated voltage oscillating between a first voltage and a second voltage, the modulated voltage being equal to the first voltage for a percentage of a time interval, the percentage corresponding to a duty cycle; and

a control module coupled to the modulation module to adjust the duty cycle to achieve a commanded rotation of the rotor and identify a degradation condition based on the duty cycle.

3. The infusion device of claim **2**, further comprising a sensor to obtain a measured displacement that is influenced by rotation of the rotor, wherein the control module is coupled to the motor and the sensor to operate the motor to provide the commanded rotation of the rotor while the modulated voltage is applied to the motor and adjust the duty cycle for the modulated voltage in response to a difference between an expected displacement corresponding to the commanded rotation the measured displacement obtained after operating the motor to provide the commanded rotation.

4. The infusion device of claim **3**, wherein the control module converts a commanded dosage into a commanded displacement of the shaft, the commanded rotation corresponding to the commanded displacement of the shaft.

5. A system comprising:

a motor having a rotor;

a modulation module coupled to the motor, the modulation module generating a modulated voltage applied to the motor, the modulated voltage oscillating between a first voltage and a second voltage, the modulated voltage being equal to the first voltage for a percentage of a time interval, the percentage corresponding to a duty cycle; and

a control module coupled to the motor and the modulation module to adjust the duty cycle to achieve a commanded rotation of the rotor and detect a degradation condition based on the duty cycle.

6. The system of claim **1**, wherein the control module detects the degradation condition when the duty cycle gradually increases over a period of time.

7. The system of claim 1, wherein the first voltage comprises a supply voltage and the second voltage comprises a reference voltage.

8. The system of claim 1, the modulated voltage comprising a square wave, wherein the duty cycle corresponds to a width of a portion of the square wave.

9. The system of claim 1, wherein the control module detects the degradation condition when the duty cycle exceeds a reference value.

10. The system of claim 9, wherein the reference value is a duty cycle unlikely to be exceeded unless the motor has degraded.

11. The system of claim 9, wherein the reference value is a historical duty cycle average.

12. The system of claim 9, wherein the control module dynamically determines the reference value during operation of the system.

13. The system of claim 1, further comprising a motor driver module coupled between the modulation module and the motor to apply the modulated voltage to one or more sets of windings of the motor in a particular order to produce a corresponding number of commanded motor steps of rotation by the rotor, wherein the control module is coupled to the motor driver module to operate the motor driver module to provide the commanded rotation of the rotor while the modulated voltage is applied to the one or more sets of windings and increase the duty cycle for the modulated voltage in response to a difference between an expected displacement corresponding to the commanded rotation a measured displacement obtained after operating the motor driver module to provide the commanded rotation.

14. The system of claim 13, wherein a frequency at which the motor driver module is operated to apply the modulated voltage to the one or more sets of windings is less than a frequency of the modulated voltage.

15. The system of claim 14, wherein the frequency of the modulated voltage is greater than a time constant of the motor.

16. The system of claim 1, further comprising a sensor to obtain a measured displacement that is influenced by rotation of the rotor, wherein the control module is coupled to the sensor to increase the duty cycle in response to a difference between an expected displacement and the measured displacement, wherein the expected displacement is based on the commanded rotation of the rotor.

17. The system of claim 16, wherein:

the motor comprises a stepper motor;

the sensor comprises an incremental position sensor to detect incremental rotations of the rotor;

the measured displacement comprises a measured number of the incremental rotations after the motor is operated to provide the commanded rotation; and

the expected displacement comprises an expected number of the incremental rotations expected to be detected by the incremental position sensor after the motor is operated to provide the commanded rotation.

18. The system of claim 16, wherein the control module operates the motor to provide the commanded rotation of the rotor while the modulated voltage is applied to the motor and increases the duty cycle for the modulated voltage in response to the difference between the expected displacement and the measured displacement.

19. The system of claim 18, further comprising a shaft mechanically coupled to the rotor, wherein the commanded rotation corresponds to a commanded displacement of the shaft.

20. The system of claim 18, wherein the control module operates the motor to compensate for the difference between the measured displacement and the expected displacement while the modulated voltage having the increased duty cycle is applied to the motor.

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