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(12) United States Patent

Nyikos et al.

(54) BEARINGLESS IMPLANTABLE BLOOD PUMP

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60/216 (2021.01); A61M 60/538 (2021.01); A61M 60/81 (2021.01); A61M 60/857 (2021.01)

(58) Field of Classification Search

CPC .. A61M 60/422; A61M 60/81; A61M 60/538; A61M 60/148; A61M 60/178; A61M 60/857; A61M 60/216

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(56) References Cited

U.S. PATENT DOCUMENTS

845,816 A 3/1907 Prindle 888,654 A 5/1908 Prindle 1,026,101 A 5/1912 Marsh (Continued)

FOREIGN PATENT DOCUMENTS

CN 300837668 10/2008 EP 150320 5/1990 (Continued)

OTHER PUBLICATIONS

Antaki et al., "PediaFlowTM Maglev Ventricular Assist Device: A Prescriptive Design Approach", Cardiovascular Engineering and Technology, vol. 1, No. 1, Mar. 2010, pp. 104-121.

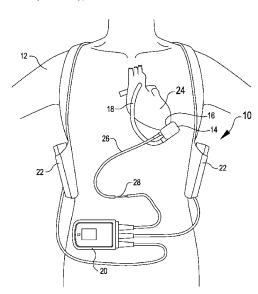
(Continued)

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(57) ABSTRACT

Implantable blood pumps and related methods employ a compact rotary motor. The compact rotary motor includes a stator and a rotor. The stator is disposed within a housing circumferentially about a dividing wall such that a blood flow conduit extends through the stator. The stator is disposed circumferentially around at least a portion of the rotor.

21 Claims, 7 Drawing Sheets

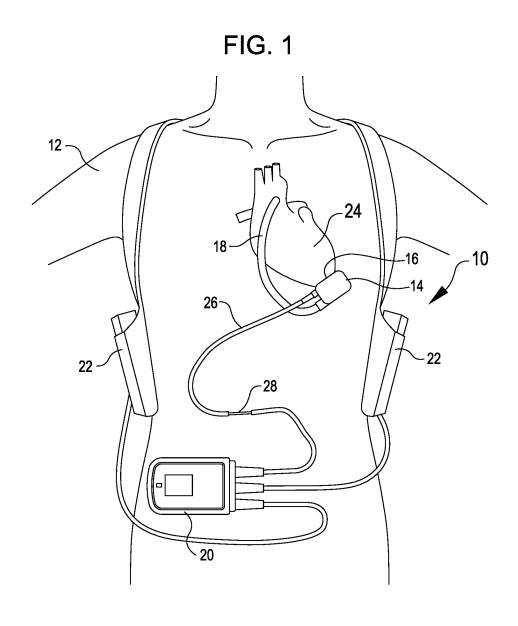


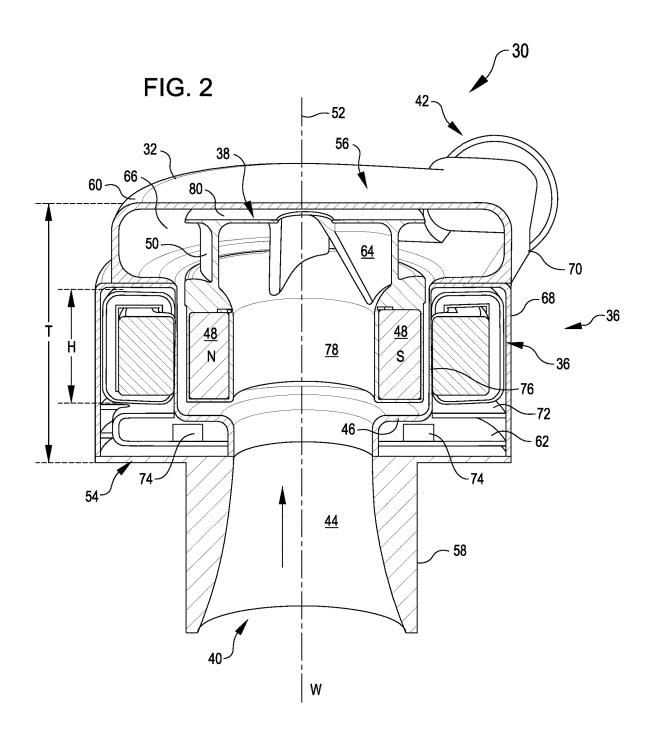
US 12,383,725 B2 Page 2

Color	(51)	Int. Cl. <i>A61M 60/81</i>		(2021.01)),618 5,862			Schoeb et al. Rau et al.
Color								10/2000	Schob
Company Comp		AUIM UW057		(2021.01)					
U.S. PATENT DOCUMENTS		_							
U.S. PATENT DOCUMENTS 6,234,772 BI 5,200 Mampler et al. 6,224,074,712 A 5,1956 Paul 2,747,712 A 5,1956 Paul 2,864,552 A 12,1958 Norman 3,005,117 A 10,1961 Bibenhold 3,005,340 A 12,1962 Beams 6,355,908 Bi 3,200 Schob et al. 3,021,01 A 2,1965 Beaker et al. 5,007,007,007,007,007,007,007,007,007,00	(56)]	Referen	ces Cited					
0,249,07 81 0,249,07 81 0,249,07 81 7,209 82 82,274,74512 A 91,938 Norman 0,236,455 B 7,209 B 2,274,74512 A 2,1945 Norman 0,236,661 B 10,200 Can		HS P	ATENT	DOCUMENTS					
2.147.430		0.5.1.	ALLINI	DOCOMENTS					
2.786.4352		2,128,988 A	9/1938	Russell					
2.608-1.527 A 1.01903 Sommold 6.301.648 B1 10.2001 Schobet et al.		2,747,512 A	5/1956	Paul					
3.005.417 A 1 1919 Beams									
3,122,101 A 21964 Baker et al. 6,393,766 B 3,000 Schoeb et al. 3,295,608 A 1,21965 Ivan 6,393,601,604 A 1,21965 Ivan 6,393,601,601 A 3,499,274 A 3,1970 Fergason 6,573,601 B 2,002,000 Carloit et al. 3,499,274 A 3,1970 Fergason 6,573,601 B 2,002,000 Carloit et al. 3,597,022 A 8,1971 Waldron 6,575,730 B 2 5,003 Carloit et al. 3,597,022 A 8,1971 Waldron 6,575,717 B 2 6,003 Carloit et al. 3,597,022 A 8,1971 Dorman et al. 6,589,030 B 2 7,003 Carloit et al. 3,601,815 A 10,1971 Fischell 6,605,032 B 2 8,003 Benamon et al. 3,601,815 A 10,1971 Fischell 6,605,032 B 2 8,003 Benamon et al. 6,589,030 B 2 7,003 Carloit et al. 3,601,815 A 10,1972 Raffery et al. 6,631,472 B 1 10,2003 Carloit et al. 3,601,815 A 3,1972 Raffery et al. 6,631,472 B 1 10,2003 Carloit et al. 3,601,813 A 3,1972 Raffery et al. 6,634,224 B 1 10,2003 Carloit et al. 4,002,376 A 4,1978 Welther et al. 6,646,173 B 1 11,003 Schob et al. 4,135,273 A 7,1980 Wilson 6,688,861 B 2,2004 Wampler 4,343,210 A 7,1982 Forster et al. 6,640,617 B 2 11,003 Schob et al. 4,213,207 A 7,1982 Forster et al. 6,707,200 B 2 3,2004 Carrolit et al. 4,405,286 A 9,1983 Bottler 6,901,390 Studer 6,901,390		, ,							
3,225,608 A 12/1965 Van 6,447,506 B2 5,2002 Schoels al. 3,499,274 A 3/1970 Fergason 6,547,530 B2 12/2002 Ozaki et al. 3,499,274 A 3/1970 Fergason 6,547,530 B2 12/2002 Ozaki et al. 5,595,507 B2 5,2003 Schoels 3,597,022 A 3/1971 Dorman et al. 6,595,507 B2 6,2003 Ozaki et al. 3,691,341 A 3/1971 Dorman et al. 6,695,032 B2 8,2003 Benkowski et al. 3,691,341 A 3/1971 Borten et al. 6,605,032 B2 8,2003 Benkowski et al. 3,691,341 A 3/1971 Fergason A 6,605,032 B2 8,2003 Benkowski et al. 6,605,034 B2 9,2003 Siess A 3,957,339 A 5/1976 Fergason A 6,602,644 B2 9,2003 Siess A 4,978 Benkowski et al. 6,602,644 B2 9,2003 Siess A 4,978 Benkowski et al. 6,640,617 B2 11,2003 Schob et al. 4,185,233 A 1/1978 Reich et al. 6,640,617 B2 11,2003 Schob et al. 4,185,233 A 1/1978 Benkowski et al. 6,644,378 B2 11,2004 Schob et al. 4,340,260 A 7/1980 Wilson 6,688,637 B2 2,2004 Wampfer A 4,408,237 A 5/1983 Baccson 6,817,836 B2 11,2004 Schob et al. 4,408,236 A 9/1983 Bankoson 6,817,836 B2 11,2004 Schob et al. 4,408,236 A 9/1983 Bankoson 6,817,836 B2 11,2004 Schob et al. 4,408,236 A 9/1983 Bankoson 6,817,836 B2 11,2004 Schob et al. 4,408,236 A 9/1983 Bankoson 6,817,836 B2 11,2004 Schob et al. 4,408,236 A 9/1983 Bankoson 6,911,595 B2 12,000 Schob 4,408,236 A 9/1983 Sharker et al. 6,941,595 B2 12,000 Sunke et al. 4,408,236 A 10/1988 Samber et al. 7,112,038 B1 12,000 Schob 4,408,408 A 10/1988 Samber et al. 7,112,038 B1 12,000 Schob 4,408,408 A 10/198 Schob et al. 7,112,038 B1 2,2000 Schob 4,408,408 A 10/198 Schob et al. 7,112,038 B1 2,2000 Schob 4,408,408 A 10/198 Schob et al. 7,112,038 B1 2,2000 Schob 4,408,408 A 10/198 Schob et al.		· · · · · · · · · · · · · · · · · · ·							
3,410,694 A 31970 Fergason 6,548,041 B2 102002 Ozaki cal. 3,499,274 A 31970 Fergason 6,547,530 B2 42003 Ozaki cal. 3,575,375 B2 42003 Ozaki cal. 6,599,507 B2 52003 Schoeb 6,599,507 B2 52004 Schoeb 6,599,507 B2 52004 Schoeb 6,599,507 B2 52004 Schoeb 6,599,507 B2 52004 Schoeb 6,5									
3,499,274 A 3,1910 Fergason									
3,597,022 A 8,1971 Waldron 6,397,670 R. 5,200,000 Schools 3,608,088 A 9,1971 Dorman et al. 6,559,030 B. 2,200,000 Czaki et al. 3,611,815 A 10/1971 Fischell 6,605,397,30 B. 2,200,000 Czaki et al. 3,611,815 A 10/1971 Fischell 6,605,397,30 B. 2,200,000 Czaki et al. 3,611,815 A 10/1971 Fischell 6,605,397,30 B. 2,200,000 Czaki et al. 3,613,398,913 A 2,1976 Isenberg et al. 6,624,474 B. 2,200,30 Schools et al. 4,082,376 A 4/1978 Wehde et al. 6,634,644 B. 2,200,40 Schools et al. 4,082,376 A 4/1978 Wehde et al. 6,644,677 B. 2,112,000 Schools et al. 4,135,253 A 1/1979 Reich et al. 6,644,677 B. 2,112,000 Schools et al. 4,082,376 A 4/1978 Wehde et al. 6,648,681 B. 2,2004 Wample 4,348,0260 A 7/1982 Forster et al. 6,648,681 B. 2,2004 Wample 4,348,0260 A 7/1982 Forster et al. 6,648,681 B. 2,2004 Wample 4,382,190 A 5/1983 Isaacson 6,871,836 B. 3,2004 Schools et al. 4,408,966 A 10,1983 Maruyama 6,949,066 B. 2,920,05 Beamson et al. 4,408,966 A 10,1983 Maruyama 7,070,398 B. 2,720,06 Olsen et al. 4,478,686 A 10,1983 Maruyama 7,070,398 B. 2,720,06 Olsen et al. 4,589,822 A 5,1986 Clausen et al. 7,118,071 B. 2,120,00 Work et al. 4,688,998 A 8,1987 Olsen et al. 7,180,714 B. 1,120,00 B. 1,120,00 Gauthier et al. 4,642,036 A 2,1987 Young 5,345,48 S. 1,2007 Urane et al. 4,776,102 A 8,1988 Bramm et al. 7,229,258 B. 2,62007 Wood et al. 4,776,102 A 8,1988 Bramm et al. 7,229,258 B. 2,2007 Wood et al. 4,776,102 A 8,1988 Bramm et al. 7,229,274 B. 2,200,28 Bramm et al. 7,229,274 B. 2,200,28 Bramm et al. 7,229,274 B. 2,200,28 Bramm et al. 7,229,274 B. 2,200,29 Masine et al. 7,338,571 B. 2,200,00 Masine et al. 7,338,571 B.					6,547	,530]	B2		
3,608,088 A 9/1971 Dorman et al. 3,611,815 A 10/1971 Fisschell 3,647,324 A 3/1972 Rafferty et al. 3,647,324 A 3/1972 Boden et al. 3,650,581 A 3/1972 Boden et al. 4,623,373 A 2/1976 Senberg et al. 4,623,373 A 2/1976 Rafferty et al. 4,082,376 A 4/1978 Welche et al. 4,082,376 A 7/1980 Wilson 4,135,273 A 1/1979 Reich et al. 4,082,376 A 7/1980 Wilson 4,340,260 A 7/1982 Forster et al. 4,340,260 A 7/1982 Forster et al. 4,382,199 A 5/1976 Senberg et al. 4,082,376 A 1978 Sudder 4,382,199 A 5/1983 Boden et al. 4,085,386 A 9/1983 Sudder 4,405,286 A 9/1983 Sudder 4,405,286 A 10/1984 Boden et al. 4,082,376 A 10/1984 Boden et al. 4,082,386 A 10/1985 Boden et al. 4,082,387 A 10/1985 Boden et al. 4,0									
3,611,815 A 3/1972 Rafferry et al. 6,669,032 B2 8/2003 Benkowski et al. 3,647,324 A 3/1972 Boden et al. 6,623,475 B1 9/2003 Ozaki 3,938,913 A 2/1976 Isenberg et al. 6,623,475 B1 10/2003 Schob et al. 3,938,913 A 2/1976 Isenberg et al. 6,624,641 B1 10/2003 Schob et al. 4,082,376 A 4/1978 Wehde et al. 6,640,617 B2 11/2003 Davis et al. 4,082,376 A 4/1978 Wehde et al. 6,640,617 B2 11/2003 Davis et al. 4,082,376 A 4/1978 Wehde et al. 6,640,617 B2 11/2003 Davis et al. 4,213,207 A 7/1989 Wilson 6,707,200 B2 3/2004 Carroll et al. 4,382,199 A 5/1993 Isaacson 6,817,386 B2 1/2004 Nose et al. 4,382,199 A 5/1993 Isaacson 6,817,386 B2 1/2004 Nose et al. 4,382,199 A 5/1993 Isaacson 6,817,386 B2 1/2006 Schob 4,408,286 A 9/1938 Studen et al. 6,949,066 B2 9/2005 Beamson et al. 4,408,286 A 9/1938 Marupama 7,707,398 B2 7/2006 Olsen et al. 4,408,386 A 9/1938 Marupama 7,707,398 B2 7/2006 Olsen et al. 4,408,386 A 9/1938 Carroll et al. 7,112,903 B1 9/2006 Schob 4,409,384 A 3/1938 Carroll et al. 7,112,903 B1 1/2006 Gauthier et al. 4,408,386 A 9/1938 Carroll et al. 7,138,776 B1 11/2006 Gauthier et al. 4,408,386 A 8/1937 Olsen et al. 7,138,776 B1 11/2006 Gauthier et al. 4,408,386 A 8/1937 Olsen et al. 7,138,776 B1 11/2006 Gauthier et al. 4,408,386 A 8/1937 Olsen et al. 7,138,776 B1 11/2006 Gauthier et al. 4,408,386 A 8/1937 Olsen et al. 7,138,776 B1 11/2006 Gauthier et al. 4,408,386 A 8/1937 Olsen et al. 7,138,776 B1 11/2006 Gauthier et al. 4,408,386 A 8/1937 Olsen et al. 7,138,776 B1 11/2006 Gauthier et al. 4,408,386 A 8/1937 Olsen et al. 7,138,776 B1 11/2006 Gauthier et al. 4,408,386 A 8/1937 Olsen et al. 7,138,776 B1 11/2006 Gauthier et al. 4,408,386 A 8/1937 Olsen et al. 7,138,776 B1 11/2006 Gauthier et al. 4,408,386 A 8/1938 Olsen et al. 7,138,776 B1 11/2006 Gauthier et al. 4,408,386 A 8/1938 Olsen et al. 7,138,776 B1 11/2006 Gauthier et al. 4,408,386 A 8/1938 Olsen et al. 7,138,776 B1 11/2006 Gauthier et al. 4,408,386 A 8/1938 Olsen et al. 7,138,776 B1 11/2006 Gauthier et al. 4,408,386 A 8/1938 Olsen et al. 7,138,776 B1 11/2006 Gaut									
3,650,581 A 3/1972 Boden et al. 6,623,475 B1 9,2003 Siess (3,938,913 A 3/1976 Boden et al. 6,626,644 B2 9,2003 Oznaki (3,937,389 A 5/1976 Rafferry et al. 6,636,644 B1 10,2003 Schob et al. 4,082,376 A 4/1978 Welch et al. 6,640,617 B2 11/2003 Schob et al. 4,185,253 A 1/1979 Reich et al. 6,640,617 B2 11/2003 Schob et al. 4,185,253 A 1/1979 Reich et al. 6,640,617 B2 11/2003 Schob et al. 4,185,253 A 1/1979 Reich et al. 6,640,617 B3 2 11/2003 Schob et al. 4,185,253 A 1/1979 Reich et al. 6,640,617 B3 2 11/2003 Schob et al. 4,185,253 A 1/1979 Reich et al. 6,640,617 B3 2 11/2003 Schob et al. 4,185,253 A 1/1979 Reich et al. 6,640,617 B3 2 12/2004 Vampler (3,194,194,194,194,194,194,194,194,194,194									
3.938.913 A 21976 Isenberg et al. 3022.044 B2 20200 OZAL 3.9375.38 A 51976 Rafferty et al. 6.640.647 B2 11/2003 Schob et al. 4.082.376 A 41978 Welde et al. 6.640.647 B2 11/2003 Davis et al. 4.135.253 A 11979 Reich et al. 6.640.647 B2 11/2003 Davis et al. 4.135.253 A 11979 Reich et al. 6.683.861 B2 22/004 Wampfer A.340,260 A 7/1982 Forster et al. 6.707.200 B2 3/2004 Carroll et al. 4.340,260 A 7/1983 Boden et al. 6.883.861 B2 22/004 Wampfer A.340,260 A 7/1983 Boden et al. 6.817.876 B2 11/2003 Schob et al. 4.05.286 A 9/1983 Boden et al. 6.949.066 B2 9/2005 Beamson et al. 4.05.286 A 9/1983 Butder 6.949.066 B2 9/2005 Beamson et al. 4.475.866 A 10/1984 Kambe et al. 7.070.308 B2 7/2006 Olsen et al. 4.475.866 A 10/1984 Kambe et al. 7.18,776 B3 11/2006 Gauthier et al. 4.507.048 A 3/1985 Belenger et al. 7.112.903 B1 12/2006 Gauthier et al. 4.642.036 A 2/1987 Young D.544.848 S 1/2007 Urano et al. 4.704.121 A 11/1987 Moise A.475.861 A 11/1988 Moise 7.229.248 B2 6/2007 Wood et al. 4.779.614 A 10/1988 Moise 7.229.248 B2 6/2007 Wood et al. 4.779.614 A 10/1988 Moise 7.229.248 B2 6/2007 Wood et al. 4.7878.31 A 11/1989 Eviser et al. 7.239.098 B2 7.2006 Nose et al. 4.7878.31 A 11/1989 Eviser et al. 7.239.098 B2 7.2007 Masino 4.4878.81 A 11/1989 Eviser et al. 7.239.098 B2 7.2007 Masino 4.4878.81 A 11/1989 Eviser et al. 7.239.098 B2 7.2007 Masino 4.4957.504 A 9/1990 Girault 7.497.116 B2 2.2009 Miyakoshi et al. 4.957.504 A 9/1990 Girault 7.497.116 B2 2.2009 Miyakoshi et al. 4.957.504 A 9/1990 Girault 7.497.116 B2 2.2009 Miyakoshi et al. 4.957.504 A 9/1990 Girault 7.497.116 B2 2.2009 Miyakoshi et al. 4.957.504 A 9/1990 Girault 7.497.116 B2 2.2009 Miyakoshi et al. 4.957.504 A 9/1990 Girault 7.497.116 B2 2.2009 Miyakoshi et al. 4.957.504 A 9/1990 Girault 7.497.116 B2 2.2009 Miyakoshi et al. 4.957.504 A 9/1990 Girault 7.497.116 B2 2.2001 Miyakoshi et al. 4.957.504 A 9/1990 Girault 7.497.116 B2 2.2001 Miyakoshi et al. 4.957.504 A 9/1990 Girault 7.497.116 B2 2.2001 Miyakoshi et al. 4.957.504 A 9/1990 Girault 7.497.106 B2 2.2001 Miyakoshi									
3.957,389 A 5/1976 Rafforty et al. 4.082,376 A 4/1978 Wehde et al. 4.135,253 A 1/1978 Wehde et al. 6.641,378 B2 11/2003 Schob et al. 4.213,307 A 7/1980 Wilson 6.688,861 B2 22004 Wampler 4.240,260 A 7/1982 Forster et al. 6.767,200 B2 3/2004 Carroll et al. 4.382,190 A 5/1983 Isaacson 6.711,948 B1 3/2004 Schob 6.381,380 B2 11/2004 Schob et al. 4.382,190 A 5/1983 Isaacson 6.817,836 B2 11/2004 Schob 6.249,066 B2 9/2005 Beamson et al. 4.408,966 A 10/1983 Marnyama 6.991,595 B2 1/2006 Burke et al. 4.475,666 A 10/1984 Kambe et al. 7.470,418 A 3/1985 Belenger et al. 7.470,418 A 3/1985 Belenger et al. 7.112,003 B1 1/2006 Gauthier et al. 4.507,048 A 3/1985 Belenger et al. 7.118,071 B2 1/22006 Gauthier et al. 4.588,982 A 5/1986 Clausen et al. 7.118,071 B2 1/22006 Muscer et al. 4.688,989 A 8/1987 Olsen et al. 7.160,242 B2 1/2007 Yanai 4.704,121 A 11/1987 Moise 7.229,278 B2 6/2007 Wood et al. 4.770,614 A 10/1988 Moise 7.229,478 B2 6/2007 Wood et al. 4.7876,649 A 10/1989 Lester et al. 7.239,98 B2 7/2007 Wood et al. 4.7876,640 A 10/1989 Lester et al. 7.239,98 B2 7/2007 Wood et al. 4.7876,440 A 10/1989 Bramm et al. 7.239,58 B2 7/2007 Wood et al. 4.7876,640 A 10/1989 Bramm et al. 7.239,58 B2 7/2007 Wood et al. 4.7876,704 A 9/1990 Girault 7.4971,16 B2 3/2009 Masino 7.7887,741 A 1/1992 Bramm et al. 7.597,741 B2 1/2007 Moset et al. 7.597,741 A 1/1992 Bramm et al. 7.597,741 B2 1/2007 Moset et a									
4,082,376 A 41979 Reich et al. 6,641,378 B2 11/2003 Davis et al. 4,1213,207 A 7/1980 Wilson 6,707,209 B2 3/2004 Carroll et al. 4,340,260 A 7/1982 Forster et al. 6,711,943 B1 3/2004 Schob 4,382,199 A 5/1983 Boden et al. 6,949,066 B2 9/2006 4,408,286 A 9/1983 Studer 6,949,066 B2 9/2006 Burke et al. 4,408,286 A 9/1983 Studer 6,991,959 B2 1/2006 Burke et al. 4,408,286 A 10/1984 Kambe et al. 7,070,398 B2 7/2006 Olsen et al. 4,507,048 A 3/1985 Belenger et al. 7,138,776 B1 1/2006 Schob 4,589,822 A 5/1986 Clausen et al. 7,138,776 B1 1/2006 Schob 4,589,822 A 5/1986 Clausen et al. 7,138,776 B1 1/2006 Schob 4,589,938 A 8/1987 Olsen et al. 7,138,776 B1 1/2006 Sudulier et al. 4,704,012 A 1/1987 Moise 7,229,258 B2 6/2007 Yanai 4,704,012 A 1/1988 Moise 7,229,258 B2 6/2007 Yanai 4,705,030 A 2/1988 Bramm et al. 7,239,098 B2 7/2007 Yanai 4,584,4707 A 7/1989 Letser et al. 7,338,521 B2 3/2008 Antaki et al. 4,587,6492 A 10/1999 Lester et al. 7,338,521 B2 3/2009 Miyakoshi et al. 4,937,544 A 7/1990 Bramm et al. 7,420,198 B1 2/2008 Antaki et al. 4,937,548 A 5/1990 Bramm et al. 7,511,748 B2 2/2007 Mossino 4,937,744 A 7/1990 Bramm et al. 7,511,748 B2 2/2007 Mossen et al. 4,937,744 A 7/1990 Bramm et al. 7,511,748 B2 2/2007 Mossen et al. 5,078,741 A 1/1992 Bramm et al. 7,693,588 B2 2/2010 Mendler 5,078,741 A 1/1992 Bramm et al. 7,693,588 B2 2/2010 Mendler 5,078,741 A 1/1992 Dorman 4,786,158 B2 2/2011 Miyakoshi et al. 5,078,741 A 1/1992 Dorman 4,786,158 B2 2/2011 Miyakoshi et al. 5,078,741 A 1/1992 Dorman 4,786,158 B2 2/2011 Miyakoshi et al. 5,078,741 A 1/1992 Dorman 4,786,158 B2 2/2011 Miyakoshi et al. 5,112,200 A 5/1992 Miyakoshi et al. 7,893,644 B2 2/2011 Miyakoshi et					,	,			
4,13,2,207 A 7,198 Wilson 6,688,861 B2 2,2004 Wampler 4,213,0,206 A 7,198 Wilson 6,707,200 B2 3,2004 Carroll et al. 4,340,266 A 7,198 Forster et al. 6,707,200 B2 3,2004 Nose et al. 4,382,773 A 8,198 Boden et al. 6,949,066 B2 9,2005 Beamson et al. 6,440,596 A 10,198 Maruyama 7,070,398 B2 7,2006 Olsen et al. 4,408,966 A 10,198 Maruyama 7,070,398 B2 7,2006 Olsen et al. 4,478,866 A 10,198 Maruyama 7,070,398 B2 7,2006 Olsen et al. 4,507,048 A 3,1985 Belenger et al. 7,118,776 B1 1,12006 Schob 4,507,048 A 3,1985 Belenger et al. 7,138,776 B1 1,12006 Schob 4,688,998 A 8,1987 Olsen et al. 7,150,711 B2 1,22006 Schob 4,688,998 A 8,1987 Olsen et al. 7,150,711 B2 1,22006 Schob 4,688,998 A 8,1987 Olsen et al. 7,150,711 B2 1,22007 Vanni 4,704,121 A 1,11987 Moise 7,229,258 B2 6,2007 Wood et al. 4,739,614 A 10,1988 Moise 7,229,288 B2 6,2007 Wood et al. 4,844,707 7,71989 Kletschka 7,229,474 B2 6,2007 Masino 4,847,6492 A 10,1989 Lester et al. 7,239,098 B2 7,2007 Masino 4,947,478 7,71990 Bramm et al. 7,497,116 B2 3,2009 Masino 4,947,478 7,71990 Bramm et al. 7,497,116 B2 3,2009 Masino 4,947,478 7,71990 Bramm et al. 7,497,116 B2 3,2009 Masino 4,947,478 7,71990 Bramm et al. 7,497,116 B2 3,2009 Mise et al. 5,008,256 A 3,1992 Smith 7,801,888 B2 2,2011 Morellor 5,008,256 A 3,1992 Smith 7,801,888 B2 2,2011 Morellor 5,008,256 A 3,1992 Smith 7,801,888 B2 2,2011 Morellor 5,112,009 A 5,1992 Smaron et al. 7,803,688 B2 2,2011 Morellor 5,112,009 A 5,1992 Smaron et al. 8,303,488 B2 2,2011 Morellor 5,112,009 A 5,1992 Smith 7,801,688 B2 2,2011 Morellor 5,112,009 A 5,1992 Smith 7,997,854 B2 2,2011 Morellor 5,112,009 A 5,1992 Smit									
4.21.207 A 71982 Forster et al. 6.711.943 B1 32004 Carroll et al. 4.349.260 A 71982 Forster et al. 6.711.943 B1 32004 Carroll et al. 4.382.199 A 51983 Boden et al. 6.711.943 B1 32004 Carroll et al. 4.382.199 A 51983 Boden et al. 6.949.066 B2 9.2005 Beamson et al. 4.405.286 A 91983 Bvder 6.991.595 B2 1/2006 Burke et al. 4.405.286 A 91983 Bvder 6.991.595 B2 1/2006 Burke et al. 7.112.903 B1 9.2006 Schob 4.475.866 A 101984 Kambe et al. 7.112.903 B1 9.2006 Schob 4.475.866 A 101984 Branger et al. 7.112.903 B1 9.2006 Schob 4.589.822 A 51986 Clausen et al. 7.112.903 B1 9.2006 Schob 4.589.822 A 51986 Clausen et al. 7.118.71 B1 11/200 Gunthier et al. 4.589.822 A 51986 Clausen et al. 7.150.711 B2 12.2006 Gunthier et al. 4.589.822 A 51986 Clausen et al. 7.150.711 B2 12.2006 Gunthier et al. 4.589.822 A 51986 Clausen et al. 7.150.711 B2 12.2006 Gunthier et al. 4.589.822 A 51986 Clausen et al. 7.150.711 B2 12.2006 Gunthier et al. 7.150.711 B2 12.2007 Vanai 4.703.032 A 81988 Bramm et al. 7.209.258 B2 10.2007 Vanai 4.703.032 A 81988 Bramm et al. 7.209.258 B2 10.2007 Vanai 4.703.032 A 81988 Bramm et al. 7.209.258 B2 10.2007 Vanai 4.775.041 A 101988 Moise 7.229.258 B2 10.2007 Masino 4.4576.492 A 101989 Lester et al. 7.338.521 B2 3.2008 Antaki et al. 4.929.158 A 51990 Gincult 7.462.019 B1 12.208 Allarie et al. 4.929.158 A 51990 Gincult 7.462.019 B1 12.208 Allarie et al. 4.929.158 A 51990 Gincult 7.462.019 B1 12.208 Miyakoshi et al. 4.937.758.74 A 91990 Chardack 7.578.788 B2 8.2009 Miyakoshi et al. 5.079.767 A 11992 Bramm et al. 7.699.588 B2 4.2010 Mendler 5.079.767 A 11992 Dorman 7.785.463 B2 12.0010 Mendler 5.055.005 A 31992 Smith 7.208.401 Allarie et al. 7.897.854 B2 12.0010 Mendler 5.127.797.87 A 11992 Dorman 4.1 Allarie et al. 7.897.854 B2 12.0010 Mendler 5.127.797.97 A 71992 Chardack 14. 7.896.274 B2 2.0011 Miyakoshi et al. 5.112.200 A 51992 Girault 7.796.271 B2 7.2011 Miyakoshi et al. 5.112.200 A 51992 Chardack 14.									
4,382,199 A 5,1983 saacson 6,711,794 B 2,2004 Nose et al.								3/2004	Carroll et al.
4,495,286 A 9/1983 Boden et al. 6,939,066 B2 9/2005 Bearnson et al. 4,405,866 A 10/1983 Maruyama 6,991,595 B2 1/2006 Olsen et al. 4,475,866 A 10/1984 Kambe et al. 7,112,903 B1 9/2006 Schob 14,475,866 A 10/1984 Kambe et al. 7,112,903 B1 9/2006 Schob 14,507,048 A 3/1985 Belenger et al. 7,112,903 B1 9/2006 Gauthier et al. 7,112,903 B1 9/2006 Gauthier et al. 7,112,903 B1 9/2006 Gauthier et al. 1,120,004 Gauthier et al. 1,120,004 Gauthier et al. 1,120,007 Gauth									
4,405,286									
4,408,906 A 101,984 Kamuyama 7,070,398 B2 7,2006 Colsen et al. 4,507,048 A 31,985 Belenger et al. 7,112,903 B1 11,2006 Cauthier et al. 4,507,048 A 31,985 Belenger et al. 7,138,776 B1 11,2006 Cauthier et al. 4,507,048 A 2,1987 Young 7,150,711 B2 12,2006 Chob 4,642,036 A 2,1987 Young 7,150,711 B2 12,2006 Chob 4,642,036 A 2,1987 Young 7,160,242 B2 1,2007 Urano et al. 4,704,121 A 11,1987 Moise 7,299,478 B2 1,2007 Yanai 4,703,032 A 8,1988 Bramm et al. 7,229,478 B2 6,2007 Yanai 4,779,614 A 101,988 Kletschka 7,284,956 B2 10,2007 Masino 4,876,492 A 101,989 Ester et al. 7,338,521 B2 3,2008 Antaki et al. 4,947,640 A 101,989 Ester et al. 7,338,521 B2 3,2008 Antaki et al. 4,924,748 A 7,1990 Bramm et al. 7,497,116 B2 3,2009 Miyakoshi et al. 4,937,504 A 9,1990 Chardack 7,518,782 B2 8,2009 Mise et al. 4,947,504 A 9,1991 Dorman A61M 60/824 7,578,782 B2 8,2009 Mise et al. 5,055,005 A 10/1991 Kletschka 7,699,588 B2 4/2010 Medvedev et al. 5,078,741 A 1/1992 Dorman 41,7636 7,654,5225 B2 1/2010 Medvedev et al. 5,098,256 A 3/1992 Smith 7,861,632 B2 1/2011 Miyakoshi et al. 5,112,200 A 5/1992 Girault 7,962,718 B2 2/2011 Miyakoshi et al. 5,112,200 A 5/1992 Smith 7,861,632 B2 2/2011 Miyakoshi et al. 5,112,200 A 5/1992 Smith 7,861,632 B2 2/2011 Miyakoshi et al. 5,112,200 A 5/1992 Girault 7,976,271 B2 2/2011 Morello Mendler 5,112,200 A 5/1992 Girault 7,976,271 B2 2/2011 Miyakoshi et al. 5,112,200 A 5/1992 Girault 7,976,271 B2 2/2011 Miyakoshi et al. 5,112,200 A 5/1992 Girault 7,976,271 B2 2/2011 Miyakoshi et al. 5,112,201 A 7,1992 Katsuta et al. 8,007,248 B2 2/2011 Miyakoshi et al. 5,112,2									
4,507,048 A 3/1985 Belenger et al. 4,507,048 A 3/1985 Belenger et al. 4,508,982 A 5/1986 Clausen et al. 4,642,036 A 2/1987 Young 1534,548 S 1/2007 Urano et al. 4,642,036 A 2/1987 Young 1534,548 S 1/2007 Urano et al. 4,763,032 A 8/1988 Bramm et al. 4,763,032 A 8/1988 Bramm et al. 4,779,164 A 10/1988 Moise 4,844,707 A 7/1989 Kletschka 4,878,431 A 11/1989 Ewing 4,878,831 A 11/1989 Ewing 4,929,158 A 5/1990 Girault 4,944,748 A 7/1990 Bramm et al. 4,946,748 A 9/1990 Chardack 4,977,740 A 9/1990 Chardack 5,055,005 A 10/1991 Kletschka 5,078,741 A 1/1992 Bramm et al. 5,098,256 A 3/1992 Smith 5,106,273 A 4/1992 Lemarquand et al. 5,112,200 A 5/1992 Smith 5,112,2									
4,589,822 A 5/1986 Clausen et al. 7,159,711 B 11/2006 Nusser et al.									
1,042,036 1,042,036 1,043,032 1,043,032 1,044,034,121 1,044,034,121 1,044,034,121 1,044,034,121 1,044,034,132 1,044,034,132 1,044,034,132 1,044,034,132 1,044,034,132 1,044,034,132 1,044,034,132 1,044,034,132 1,044,034,132 1,044,034,132 1,044,034,132 1,044,034,132 1,044,034,134 1,044,034,13									
4,088,998 A 8/198/ Olsen et al. 4,704,121 A 11/1987 Moise 4,763,032 A 8/1988 Bramm et al. 4,779,014 A 10/1988 Moise 4,876,492 A 10/1989 Elester et al. 4,876,492 A 10/1989 Elester et al. 4,876,492 A 10/1989 Elester et al. 4,929,158 A 5/1990 Girault 4,944,748 A 7/1990 Bramm et al. 4,947,748 A 7/1990 Bramm et al. 4,957,504 A 9/1990 Chardack 5,044,897 A 9/1990 Chardack 5,055,005 A 10/1991 Kletschka 5,079,467 A 1/1992 Bramm et al. 5,079,467 A 1/1992 Dorman 5,078,741 A 1/1992 Dorman 5,078,741 A 1/1992 Dorman 6,085,256 A 3/1992 Smith 5,106,273 A 4/1992 Lemarquand et al. 5,112,202 A 5/1992 Oshima et al. 5,112,203 A 1/1993 Elester et al. 5,112,204 A 1/1993 Eramm et al. 5,112,205 A 1/1994 Chardack 5,112,206 A 1/1995 Eramm et al. 5,126,612 A 6/1992 Girault 5,127,792 A 7/1992 Chardact et al. 5,127,793 A 1/1994 Chardact et al. 5,127,793 A 1/1994 Chardact et al. 5,127,793 A 1/1994 Chardact et al. 5,126,612 A 6/1993 Elester et al. 5,126,612 A 6/1994 Chardact et al. 5,127,793 A 1/1994 Chardact et al. 5,127,793 A 1/1994 Chardact et al. 5,127,794 A 1/1995 Chardact et al. 5,126,612 A 6/1994 Chardact et al. 5,127,794 A 1/1995 Chardact et al. 5,127,795 A 1/1994 Chardact et al. 5,127,795 A 1/1995 Chardact et al. 5,126,612 A 6/1994 Chardact et al. 5,127,794 A 1/1995 Chardact et al. 5,127,795 A 1/1995 Chardact et al. 5,127,238 A 1/1994 Chardact et al. 5,127,238 A 1/1995 Chardact et al. 5,127,238 A 1/1995 Chardact et al. 5,127,238 A 1/1994 Chardact et al. 5,127,208 A 1/1995 Chardact et al. 5,126,612 A 6/1995 Chardact et al. 5,127,238 A 1/1995 Chardact et al. 5,126,612 A 6/1995 Chardact et al. 5,127,238 A 1/1995 Chardact et al. 5,220,232 A 6/1993 Chardact et al. 5,									
4,763,032 A 8/1988 Bramm et al. 4,779,614 A 10/1988 Moise 7,239,078 B2 7/2007 Masino 4,876,492 A 10/1989 Letser et al. 4,876,492 A 10/1989 Letser et al. 4,876,492 A 10/1989 Lester et al. 4,876,492 A 10/1989 Lester et al. 7,338,521 B2 3/2008 Antaki et al. 4,929,158 A 5/1990 Girault 7,497,116 B2 3/2009 Miyakoshi et al. 4,944,748 A 7/1990 Bramm et al. 7,511,443 B2 3/2009 Miyakoshi et al. 7,511,443 B2 3/2009 Miles et al. 4,957,504 A 9/1990 Chardack 7,511,443 B2 3/2009 Miles et al. 7,511,777 B2 9/2009 LaRose Medvedev et al. 8,079,467 A 1/1992 Bramm et al. 7,699,588 B2 4/2010 LaRose et al. 7,699,588 B2 4/2010 Mendler 7,699,588 B2 4/2010 Mendler 7,893,644 B2 2/2011 Townsend et al. 7,811,200 A 5/1992 Smith 7,861,582 B2 1/2011 Miyakoshi et al. 7,811,200 A 5/1992 Isaacson et al. 7,811,200 A 5/1992 Oshima et al. 7,911,000 B2 2/2011 Townsend et al. 7,911,000 B2 2/2011 Townsend et al. 7,911,000 B2 2/2011 Miyakoshi et al. 7,911,000 B2 2/2011 Miyakoshi et al. 7,911,000 B2 2/2011 Miyakoshi et al. 7,911,000 B2 2/2011 Morello 7,911,000 B2 2/2011 Morello 7,911,000 B2 2/2011 Morello 7,911,000 B2 2/2011 Morello 7,912,000 B2 2/2011 Morello 7,913,877 A 3/1993 Kletschka 8,157,700 B2 4/2012 Marseille et al. 7,913,877 A 3/1993 Kletschka 8,157,700 B2 4/2012 Marseille et al. 7,913,877 A 3/1993 Kletschka 8,157,700 B2 4/2012 Marseille et al. 7,913,877 A 3/1993 Kletschka 8,157,700 B2 4/2012 Marseille et al. 7,913,877 A 3/1993 Kletschka 8,1998 Kapey H Fukuyama et al. 8,303,482 B2 1/2011 LaRose et al. 8,303,482 B2 1/2011 LaRose et al. 8,303,482 B2 1/2011 LaRose et al. 8,303,482 B2 1/2012 Jevenandam et al. 8,506,470 B2 4/2012 Marseille et al. 8,506,470 B2 4/2013 Dague et al. 8,506,470 B2 4/2014 Variet et al. 8,506,470 B2 4/2014 Variet et al. 8,506,470 B2 4/2014 Variet et al. 8,506,470									
4,779,614 A 10/1988 Moise 7,239,098 B2 7,2007 Masinno 4,844,707 A 7/1989 Kletschka 7,238,956 B2 10/2007 Mose et al. 4,8476,492 A 10/1989 Lester et al. 7,239,098 B2 7,2007 Masinno 4,876,492 A 10/1989 Lester et al. 7,233,098 B2 7,2007 Masinno 4,876,6492 A 10/1989 Lester et al. 7,233,095 B2 3/2008 Antaki et al. 11/1989 Ewing 7,338,521 B2 3/2008 Antaki et al. 12/2008 Allarie et al. 4,924,748 A 7/1990 Bramm et al. 7,462,019 B1 12/2008 Allarie et al. 3/2009 Miyakoshi et al. 5,044,897 A 9/1990 Chardack 7,578,782 B2 8/2009 Miles et al. 8/207,787,784 A 1/1992 Bramm et al. 7,591,777 B2 9/2009 LaRose 5,075,078,741 A 1/1992 Bramm et al. 7,699,586 B2 4/2010 Medvedev et al. 8/207,874,74 A 1/1992 Dorman 7,854,631 B2 12/2010 Medvedev et al. 5,079,467 A 1/1992 Dorman 7,854,631 B2 12/2010 Medvedev et al. 5,106,273 A 4/1992 Dorman 7,854,631 B2 12/2010 Townsendl et al. 5,112,200 A 5/1992 Saacson et al. 7,887,479 B2 2/2011 LaRose et al. 5,112,200 A 5/1992 Girault 7,861,582 B2 1/2011 Miyakoshi et al. 5,126,612 A 6/1992 Girault 7,951,062 B2 5/2011 Morello 5,126,612 A 6/1992 Girault 7,951,062 B2 5/2011 Morello 5,177,387 A 1/1993 Mcmichael et al. 8,007,254 B2 8/2011 LaRose et al. 5,159,219 A 10/1992 Chu et al. 8,007,254 B2 8/2011 LaRose et al. 5,159,219 A 10/1992 Chu et al. 8,233,174 B2 1/2012 Schima et al. 5,360,317 A 1/1993 Mcmichael et al. 8,333,48 B2 11/2012 Schima et al. 5,360,317 A 1/1994 Clausen et al. 8,333,174 B2 1/2012 Schima et al. 5,360,317 A 1/1995 Bramm et al. 8,333,174 B2 1/2012 Schima et al. 5,365,341,059 A 8/1994 Fukuyama et al. 8,233,174 B2 1/2012 Schima et al. 5,068,437 A 9/1998 Nakazeki et al. 8,556,509 B2 10/2013 Dolyard et al. 5,088,347 A 9/1998 Nakazeki et al. 8,556,509 B2 10/2013 Dolyard et al. 5,094,7703 A 9/1999 Nojiri et al. 8,652,024 B1 2/2014 Ayre et al. 5,947,703 A 9/1999 Nojiri et al. 8,658,733 B2 3/2014 LaRose et al. 1,094,703 A 9/1999 Nojiri et al. 8,658,733 B2 3/2014 LaRose et al. 1,094,703 A 9/1999 Nojiri et al. 8,658,733 B2 3/2014 LaRose et al. 1,094,703 A 9/1999 Nojiri et al. 8,658,733 B2 3/2014 LaR									
4,844,707 A 7/1989 Kletschka 7,234,956 B2 10/2007 Nose et al. 4,876,492 A 10/1989 Lester et al. 7,338,521 B2 3/2008 Antaki et al. 4,876,831 A 11/1989 Ewing 7,462,019 B1 12/2008 Allarie et al. 4,929,158 A 5/1990 Girault 7,497,116 B2 3/2009 Milse et al. 4,944,748 A 7/1990 Bramm et al. 7,511,443 B2 3/2009 Milse et al. 5,044,897 A 9/1990 Chardack 7,511,443 B2 3/2009 Milse et al. 5,044,897 A 9/1990 Dorman A61M 60/824 7,518,782 B2 8/2009 Milse et al. 5,055,005 A 10/1991 Kletschka 7,699,586 B2 4/2010 Medvedev et al. 5,078,741 A 1/1992 Bramm et al. 7,699,586 B2 4/2010 Medvedev et al. 5,078,741 A 1/1992 Dorman 7,854,631 B2 12/2010 Townsend et al. 5,098,256 A 3/1992 Smith 7,861,582 B2 1/2011 Milyakoshi et al. 5,106,273 A 4/1992 Lemarquand et al. 7,887,479 B2 2/2011 LaRose et al. 5,112,200 A 5/1992 Oshima et al. 7,854,648 B2 2/2011 Townsend et al. 5,12,202 A 5/1992 Oshima et al. 7,951,062 B2 5/2011 Morello 5,127,792 A 7/1992 Katsuta et al. 7,976,271 B2 7/2011 LaRose et al. 5,157,387 A 1/1993 Mcmichael et al. 8,007,254 B2 8/2011 LaRose et al. 5,177,387 A 1/1993 Mcmichael et al. 8,007,254 B2 8/2011 LaRose et al. 5,159,877 A 3/1993 Kletschka 8,157,720 B2 4/2012 Schima et al. 5,202,023 A 6/1993 Rigney, II et al. 8,303,482 B2 11/2012 Schima et al. 5,360,317 A 1/1995 Bramm et al. 8,333,174 B2 12/2012 Schima et al. 5,360,317 A 1/1995 Bramm et al. 8,333,174 B2 12/2012 Schima et al. 5,695,471 A 12/1997 Wampler 8,560,471 B2 8/2013 Horvath 5,508,347 A 3/1998 Roboth 8,506,471 B2 8/2013 Bolurque 5,507,83,346 A 10/1997 Bozeman, Jr. et al. 8,550,679 B2 10/2013 Bolyard et al. 5,888,242 A 3/1999 Nalazeki et al. 8,557,738 B2 12/2013 Bolyard et al. 5,983,31 A 7/1999 Prem 8,652,024 B1 2/2014 Ayre et al. 5,993,31 A 7/1999 Prem 8,652,024 B1 2/2014 Ayre et al. 5,947,703 A 9/1999 Nojir et al. 8,668,733 B2 3/2014 LaRose et al.									
4,878,831 A 10/1989 Lester et al. 4,878,831 A 10/1989 Ewing 7,462,019 B1 12/2008 Allarie et al. 4,929,158 A 5/1990 Girault 7,497,116 B2 3/2009 Miyakoshi et al. 4,944,748 A 7/1990 Bramm et al. 7,511,443 B2 3/2009 Miyakoshi et al. 7,571,462,019 B1 2/2008 Allarie et al. 7,571,116 B2 3/2009 Miyakoshi et al. 7,571,116 B2 3/2009 Miyakoshi et al. 7,571,471 B2 9/2009 Miles et al. 7,571,8782 B2 8/2009 Miles et al. 7,571,777 B2 9/2009 Miles et al. 7,591,777 B2 9/2009 Medvedev et al. 7,597,8741 A 1/1992 Bramm et al. 7,699,586 B2 4/2010 LaRose et al. 7,699,586 B2 4/2010 Medler 7,699,586 B2 4/2010 Medler 7,699,586 B2 4/2010 LaRose et al. 7,893,463 B2 1/2011 Townsendl et al. 7,861,582 B2 1/2011 Miyakoshi et al. 7,861,582 B2 1/2011 Morello 7,861,582 B2 1/2011 Morello 7,861,582 B2 1/2011 Morello 7,861,582 B2 1/2011 Morello 7,976,271 B2 7/2011 LaRose et al. 7,976,271 B2 7/2011 LaRose et al. 7,976,271 B2 7/2011 LaRose et al. 7,978,84 B2 8/2011 LaRose et al. 7,978,94 B2 8/2011 LaRose et al. 7,978,94 B2 8/2011 LaRose et al. 7,97		4,844,707 A							
4,3578,351 A 11/1989 EWing 7,462,019 B1 12/2008 Allarie et al. 4,924,748 A 7/1990 Bramm et al. 7,497,116 B2 3/2009 Townsend et al. 4,944,748 A 7/1990 Bramm et al. 7,511,443 B2 3/2009 Townsend et al. 5,044,897 A 9/1991 Dorman									
4,944,748 A 7/1990 Bramm et al. 7,511,443 B2 3/2009 Milyakoshi et al. 4,957,504 A 9/1990 Chardack 7,578,782 B2 8/2009 Miles et al. 7,578,782 B2 8/2009 Miles et al. 7,578,782 B2 8/2009 Miles et al. 1,000									
4,957,504 A 9/1990 Chardack 5,044,897 A * 9/1991 Dorman								3/2009	Miyakoshi et al.
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5,055,005 A 10/1991 Kletschka 7,695,586 B2 1/2010 Medvedev et al. 5,078,741 A 1/1992 Bramm et al. 7,699,586 B2 4/2010 LaRose et al. 5,079,467 A 1/1992 Dorman 7,854,631 B2 1/2010 Townsendl et al. 5,098,256 A 3/1992 Smith 7,861,582 B2 1/2011 Miyakoshi et al. 5,106,273 A 4/1992 Lemarquand et al. 7,861,582 B2 1/2011 LaRose et al. 5,112,200 A 5/1992 Isaacson et al. 7,887,479 B2 2/2011 LaRose et al. 5,112,202 A 5/1992 Oshima et al. 7,951,062 B2 5/2011 Morello 5,126,612 A 6/1992 Girault 7,976,271 B2 7/2011 LaRose et al. 5,159,219 A 10/1992 Chu et al. 8,007,254 B2 8/2011 LaRose et al. 5,173,387 A 1/1993 Memichael et al. 8,007,254 B2 8/2011 LaRose et al. 5,195,877 A 3/1993 Kletschka 8,152,493 B2 4/2012 LaRose et al. 5,341,059 A 8/1994 Fukuyama et al. 8,303,482 B2 11/2012 Schima et al. 5,360,317 A 11/1994 Clausen et al. 8,333,174 B2 12/2012 Jeevanandam et al. 5,360,317 A 11/1994 Clausen et al. 8,332,374 B2 12/2012 Jeevanandam et al. 5,360,317 A 11/1994 Bramm et al. 8,349,444 B2 5/2013 Marier et al. 5,695,471 A 12/1997 Wampler 8,560,471 B2 8/2013 LaRose et al. 8,506,470 B2 8/2013 Larose et al. 8,508,437 A 1/1998 Schob 8,517,699 B2 8/2013 Bourque 5,798,454 A 8/1998 Nakazeki et al. 8,581,690 B2 10/2013 Dague et al. 5,808,437 A 9/1998 Schob 8,517,699 B2 8/2013 Nauser et al. 8,588,242 A 8/1999 Nakazeki et al. 8,597,350 B2 12/2013 Dague et al. 5,988,314 A 7/1999 Prem 8,652,024 B1 2/2014 Vyee et al. 8,597,730 B2 1/2014 Vyea et al. 5,947,703 A 9/1999 Nojiri et al. 8,652,024 B1 2/2014 Vyea et al. 6,053,705 A 4/2000 Schob et al. 8,668,473 B2 3/2014 LaRose et al.		5,044,897 A *	9/1991						
5,078,741 A 1/1992 Bramm et al. 7,699,588 B2 4/2010 Mendler 5,079,467 A 1/1992 Dorman 7,699,588 B2 4/2010 Mendler 5,098,256 A 3/1992 Smith 7,854,631 B2 1/2011 Miyakoshi et al. 5,106,273 A 4/1992 Lemarquand et al. 7,887,479 B2 2/2011 Miyakoshi et al. 5,112,200 A 5/1992 Isaacson et al. 7,893,644 B2 2/2011 Townsend et al. 5,126,612 A 6/1992 Girault 7,951,062 B2 5/2011 Morello 5,127,792 A 7/1992 Katsuta et al. 7,997,854 B2 8/2011 LaRose et al. 5,173,387 A 1/1993 Mcmichael et al. 8,007,254 B2 8/2011 LaRose et al. 5,341,059 A 6/1993 Rigney, II et al. 8,303,482 B2 11/2012 Schima et al. 5,3470,208 A 1/1994 Fukuyama et al. 8,323,308 B2 2/2013 Maher et al.		5 0 5 5 0 0 5 A	10/1001		7,645	5,225	B2	1/2010	Medvedev et al.
5,079,467 A 1/1992 Dorman 7,854,631 B2 1/2/2010 Townsendl et al. 5,098,256 A 3/1992 Smith 7,854,631 B2 1/2/2010 Townsendl et al. 5,106,273 A 4/1992 Lemarquand et al. 7,881,631 B2 1/2011 Miyakoshi et al. 5,112,200 A 5/1992 Isaacson et al. 7,887,479 B2 2/2011 LaRose et al. 5,112,202 A 5/1992 Oshima et al. 7,951,062 B2 5/2011 Morello 5,126,612 A 6/1992 Girault 7,976,271 B2 7/2011 LaRose et al. 5,127,792 A 7/1992 Katsuta et al. 7,997,854 B2 8/2011 LaRose et al. 5,159,219 A 10/1992 Chu et al. 8,007,254 B2 8/2011 LaRose et al. 5,177,387 A 1/1993 Mcmichael et al. 8,152,493 B2 4/2012 LaRose et al. 5,195,877 A 3/1993 Kletschka 8,157,720 B2 4/2012 Marseille et al. 5,220,232 A 6/1993 Rigney, II et al. 8,303,482 B2 11/2012 Schima et al. 5,380,317 A 11/1994 Clausen et al. 8,323,174 B2 12/2012 Jeevanandam et al. </td <td></td> <td>· · · · · · · · · · · · · · · · · · ·</td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td>		· · · · · · · · · · · · · · · · · · ·							
5,098,256 A 3/1992 Smith 7,861,582 B2 1/2011 Miyakoshi et al. 5,106,273 A 4/1992 Lemarquand et al. 7,887,479 B2 2/2011 LaRose et al. 5,112,200 A 5/1992 Isaacson et al. 7,893,644 B2 2/2011 Townsend et al. 5,112,202 A 5/1992 Oshima et al. 7,951,062 B2 5/2011 Morello 5,126,612 A 6/1992 Girault 7,976,271 B2 7/2011 LaRose et al. 5,159,219 A 10/1992 Chu et al. 8,007,254 B2 8/2011 LaRose et al. 5,177,387 A 1/1993 Mcmichael et al. 8,152,493 B2 4/2012 LaRose et al. 5,195,877 A 3/1993 Kletschka 8,157,720 B2 4/2012 LaRose et al. 5,220,232 A 6/1993 Rigney, II et al. 8,303,482 B2 11/2012 Marseille et al. 5,360,317 A 11/1994 Fukuyama et al. 8,323,174 B2 12/2012 Jeevanandam et al. 5,470,208 A 11/1995 Bramm et al. 8,419,609 B2 4/2013 Laorse et al. 5,695,471 A 12/1997 Bozeman, Jr. et al. 8,506,470 B2 8/2013 Laorse et al. 5,798,346 A 1/1998 Schob 8,517,699 B2 8/2013 Bourque 5,798,454 A									
5,106,2/3 A 4/1992 Lemarquand et al. 7,887,479 B2 2/2011 LaRose et al. 5,112,202 A 5/1992 Oshima et al. 7,951,062 B2 5/2011 Morello 5,126,612 A 6/1992 Girault 7,976,271 B2 7/2011 LaRose et al. 5,127,792 A 7/1992 Katsuta et al. 7,997,854 B2 8/2011 LaRose et al. 5,159,219 A 10/1992 Chu et al. 8,007,254 B2 8/2011 LaRose et al. 5,177,387 A 1/1993 Mcmichael et al. 8,152,493 B2 4/2012 LaRose et al. 5,195,877 A 3/1993 Kletschka 8,157,720 B2 4/2012 LaRose et al. 5,241,059 A 8/1994 Fukuyama et al. 8,333,482 B2 11/2012 Schima et al. 5,341,059 A 8/1994 Fukuyama et al. 8,382,830 B2 2/2013 Maher et al. 5,340,317 A 11/1995 Bramm et al. 8,419,609 B2 4/2013 Larose et al.									
5,112,202 A 5/1992 Oshima et al. 7,951,062 B2 5/2011 Morello 5,126,612 A 6/1992 Girault 7,976,271 B2 7/2011 LaRose et al. 5,127,792 A 7/1992 Katsuta et al. 7,997,854 B2 8/2011 LaRose et al. 5,177,387 A 10/1992 Chu et al. 8,007,254 B2 8/2011 LaRose et al. 5,177,387 A 1/1993 Memichael et al. 8,157,720 B2 4/2012 LaRose et al. 5,195,877 A 3/1993 Kletschka 8,157,720 B2 4/2012 Marseille et al. 5,220,232 A 6/1993 Rigney, II et al. 8,303,482 B2 11/2012 Schima et al. 5,341,059 A 8/1994 Fukuyama et al. 8,333,482 B2 11/2012 Schima et al. 5,340,317 A 1/1995 Bramm et al. 8,323,174 B2 12/2013 Maher et al. 5,470,208 A<					7,887	7,479	B2	2/2011	LaRose et al.
5,126,612 A 6/1992 Girault 7,976,271 B2 7/2011 LaRose et al. 5,127,792 A 7/1992 Katsuta et al. 7,997,854 B2 8/2011 LaRose et al. 5,159,219 A 10/1992 Chu et al. 8,007,254 B2 8/2011 LaRose et al. 5,177,387 A 1/1993 Mcmichael et al. 8,152,493 B2 4/2012 LaRose et al. 5,195,877 A 3/1993 Kletschka 8,157,720 B2 4/2012 Marseille et al. 5,220,232 A 6/1993 Rigney, II et al. 8,303,482 B2 11/2012 Schima et al. 5,341,059 A 8/1994 Fukuyama et al. 8,332,174 B2 12/2012 Jeevanandam et al. 5,360,317 A 11/1995 Kletschka 8,449,609 B2 2/2013 Maher et al. 5,470,208 A 11/1995 Kletschka 8,449,444 B2 5/2013 Poirier 5,678,306 A </td <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td>									
5,127,792 A 7/1992 Katsuta et al. 7,997,854 B2 8/2011 LaRose et al. 5,159,219 A 10/1992 Chu et al. 8,007,254 B2 8/2011 LaRose et al. 5,177,387 A 1/1993 Mcmichael et al. 8,152,493 B2 4/2012 LaRose et al. 5,195,877 A 3/1993 Kletschka 8,157,720 B2 4/2012 Marseille et al. 5,220,232 A 6/1993 Rigney, II et al. 8,303,482 B2 11/2012 Schima et al. 5,341,059 A 8/1994 Fukuyama et al. 8,332,3174 B2 12/2012 Jeevanandam et al. 5,360,317 A 11/1994 Clausen et al. 8,382,830 B2 2/2013 Maher et al. 5,470,208 A 11/1995 Farmm et al. 8,419,609 B2 4/2013 Laorse et al. 5,678,306 A 10/1997 Bozeman, Jr. et al. 8,506,470 B2 8/2013 Bourque 5,708,346 A 1/1998 Schob 8,517,699 B2 8/2013 Bourque 5,798,454 A 8/1998 Nakazeki et al. 8,556,795 B2 10/2013 Bolyard et al. 5,808,437 A 9/1998 Schob 8,51,62,508 B2 10/2013 Dague et al. 5,917,297 A 6/1999 Gerster et al. 8,552,024 B1 2/2014 Vanai et al. 5,928,131 A 7/1999 Prem 8,652,024 B1 2/2014 Vanai et al.									
5,177,387 A 1/1993 Mcmichael et al. 8,152,493 B2 4/2012 LaRose et al. 5,195,877 A 3/1993 Kletschka 8,157,720 B2 4/2012 Marseille et al. 5,220,232 A 6/1993 Rigney, II et al. 8,303,482 B2 11/2012 Schima et al. 5,341,059 A 8/1994 Fukuyama et al. 8,323,174 B2 12/2012 Jeevanandam et al. 5,360,317 A 11/1994 Clausen et al. 8,382,830 B2 2/2013 Maher et al. 5,470,208 A 11/1995 Bramm et al. 8,419,609 B2 4/2013 Laorse et al. 5,678,306 A 10/1997 Bozeman, Jr. et al. 8,506,470 B2 8/2013 Doirier 5,708,346 A 1/1998 Schob 8,517,699 B2 8/2013 Bourque 5,798,454 A 8/1998 Nakazeki et al. 8,556,795 B2 10/2013 Dague et al. 5,808,437 A 9/1998 Nakazeki et al. 8,597,350 B2 11/2013									
5,195,877 A 3/1993 Kletschka 8,157,720 B2 4/2012 Marseille et al. 5,220,232 A 6/1993 Rigney, II et al. 8,303,482 B2 11/2012 Schima et al. 5,341,059 A 8/1994 Fukuyama et al. 8,303,482 B2 11/2012 Schima et al. 5,360,317 A 11/1994 Clausen et al. 8,382,830 B2 2/2013 Maher et al. 5,385,581 A 11/1995 Bramm et al. 8,419,609 B2 4/2013 Laorse et al. 5,470,208 A 11/1995 Kletschka 8,449,444 B2 5/2013 Poirier 5,678,306 A 10/1997 Bozeman, Jr. et al. 8,506,470 B2 8/2013 Bourque 5,708,346 A 1/1998 Schob 8,517,699 B2 8/2013 Bourque 5,798,454 A 8/1998 Nakazeki et al. 8,556,795 B2 10/2013 Bolyard et al. 5,808,437 A									
5,220,232 A 6/1993 Rigney, II et al. 8,303,482 B2 11/2012 Maher et al. 5,341,059 A 8/1994 Fukuyama et al. 8,333,482 B2 11/2012 Schima et al. 5,360,317 A 11/1994 Clausen et al. 8,382,830 B2 2/2013 Maher et al. 5,385,581 A 1/1995 Bramm et al. 8,419,609 B2 4/2013 Laorse et al. 5,470,208 A 11/1995 Kletschka 8,449,444 B2 5/2013 Poirier 5,678,306 A 10/1997 Bozeman, Jr. et al. 8,506,470 B2 8/2013 LaRose et al. 5,695,471 A 12/1997 Wampler 8,506,471 B2 8/2013 Bourque 5,708,346 A 1/1998 Schob 8,517,699 B2 8/2013 Horvath 5,798,454 A 8/1998 Nakazeki et al. 8,556,795 B2 10/2013 Bolyard et al. 5,808,437 A									
5,341,059 A 8/1994 Fukuyama et al. 8,323,174 B2 12/2012 Jeevanandam et al. 5,360,317 A 11/1994 Clausen et al. 8,382,830 B2 2/2013 Maher et al. 5,385,581 A 1/1995 Bramm et al. 8,419,609 B2 4/2013 Laorse et al. 5,470,208 A 11/1995 Kletschka 8,449,444 B2 5/2013 Poirier 5,678,306 A 10/1997 Bozeman, Jr. et al. 8,506,470 B2 8/2013 LaRose et al. 5,695,471 A 12/1997 Wampler 8,506,471 B2 8/2013 Bourque 5,708,346 A 1/1998 Schob 8,517,699 B2 8/2013 Horvath 5,798,454 A 8/1998 Nakazeki et al. 8,556,795 B2 10/2013 Bolyard et al. 5,808,437 A 9/1998 Schob 8,581,462 B2 11/2013 Nussbaumer 5,917,297 A 6/1999 Gerster et al. 8,597,350 B2 12/2013 Rudser et al. 5,947,703 A 9/1999 Nojiri et al. 8,657,733 B2 2/2014 Ayre et al. 6,053,705 A 4/2000 Schob et al. 8,668,473 B2 <td< td=""><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></td<>									
5,360,317 A 11/1994 Clausen et al. 8,382,830 B2 2/2013 Maher et al. 5,385,581 A 1/1995 Bramm et al. 8,419,609 B2 4/2013 Laorse et al. 5,470,208 A 11/1995 Kletschka 8,449,444 B2 5/2013 Poirier 5,678,306 A 10/1997 Bozeman, Jr. et al. 8,506,470 B2 8/2013 LaRose et al. 5,695,471 A 12/1997 Wampler 8,506,471 B2 8/2013 Bourque 5,708,346 A 1/1998 Schob 8,517,699 B2 8/2013 Horvath 5,798,454 A 8/1998 Nakazeki et al. 8,556,795 B2 10/2013 Bolyard et al. 5,808,437 A 9/1998 Schob 8,581,462 B2 11/2013 Nussbaumer 5,917,297 A 6/1999 Gerster et al. 8,597,350 B2 12/2013 Rudser et al. 5,928,131 A 7/1999 Prem 8,652,024 B1 2/2014 Yanai et al. 5,947,703 A 9/1999 Nojiri et al. 8,657,733 B2 2/2014 Ayre et al. 6,053,705 A 4/2000 Schob et al. 8,668,473 B2 3/2014 LaRose et al.									
5,470,208 A 11/1995 Kletschka 8,449,444 B2 5/2013 Poirier 5,678,306 A 10/1997 Bozeman, Jr. et al. 8,506,470 B2 8/2013 LaRose et al. 5,695,471 A 12/1997 Wampler 8,506,471 B2 8/2013 Bourque 5,708,346 A 1/1998 Schob 8,517,699 B2 8/2013 Bourque 5,725,357 A 3/1998 Nakazeki et al. 8,556,795 B2 10/2013 Bolyard et al. 5,808,437 A 9/1998 Schob 8,581,462 B2 10/2013 Dague et al. 5,888,242 A 3/1999 Antaki et al. 8,597,350 B2 11/2013 Nussbaumer 5,917,297 A 6/1999 Gerster et al. 8,597,350 B2 12/2013 Rudser et al. 5,928,131 A 7/1999 Prem 8,652,024 B1 2/2014 Yanai et al. 5,947,703 A 9/1999 Nojiri et al. 8,657,733 B2 2/2014 Ayre et al. 6,053,705 A 4/2000 Schob et al. 8,668,473 B2 3/2014 LaRose et al.									
5,678,306 A 10/1997 Bozeman, Jr. et al. 8,749,444 B2 3/2013 Foller 5,695,471 A 12/1997 Wampler 8,506,471 B2 8/2013 LaRose et al. 5,708,346 A 1/1998 Schob 8,517,699 B2 8/2013 Bourque 5,798,454 A 8/1998 Nakazeki et al. 8,556,795 B2 10/2013 Bolyard et al. 5,808,437 A 9/1998 Schob 8,562,508 B2 10/2013 Dague et al. 5,917,297 A 6/1999 Gerster et al. 8,597,350 B2 11/2013 Nussbaumer 5,928,131 A 7/1999 Prem 8,652,024 B1 2/2014 Yanai et al. 5,947,703 A 9/1999 Nojiri et al. 8,657,733 B2 2/2014 Ayre et al. 6,053,705 A 4/2000 Schob et al. 8,668,473 B2 3/2014 LaRose et al.									
5,695,471 A 12/1997 Wampler 8,506,471 B2 8/2013 Bourque 5,708,346 A 1/1998 Schob 8,517,699 B2 8/2013 Horvath 5,725,357 A 3/1998 Nakazeki et al. 8,556,795 B2 10/2013 Bolyard et al. 5,798,454 A 8/1998 Nakazeki et al. 8,562,508 B2 10/2013 Dague et al. 5,808,437 A 9/1998 Schob 8,581,462 B2 11/2013 Nussbaumer 5,917,297 A 6/1999 Gerster et al. 8,597,350 B2 12/2013 Rudser et al. 5,928,131 A 7/1999 Prem 8,652,024 B1 2/2014 Yanai et al. 5,947,703 A 9/1999 Nojiri et al. 8,657,733 B2 2/2014 Ayre et al. 6,053,705 A 4/2000 Schob et al. 8,668,473 B2 3/2014 LaRose et al.									
5,708,346 A 1/1998 Schob 5,725,357 A 3/1998 Nakazeki et al. 5,798,454 A 8/1998 Nakazeki et al. 5,808,437 A 9/1998 Schob 5,888,242 A 3/1999 Antaki et al. 5,917,297 A 6/1999 Gerster et al. 5,928,131 A 7/1999 Prem 8,652,024 B1 2/2013 Dague et al. 5,947,703 A 9/1999 Nojiri et al. 6,053,705 A 4/2000 Schob et al. 8,517,699 B2 8/2013 Horvath 10/2013 Dague et al. 11/2013 Nussbaumer 12/2014 Rudser et al. 8,657,733 B2 2/2014 Ayre et al. 8,657,733 B2 2/2014 Ayre et al.									
5,725,357 A 8/1998 Nakazeki et al. 8,556,795 B2 10/2013 Bolyard et al. 5,798,454 A 8/1998 Schob 8,562,508 B2 10/2013 Dague et al. 10/2013 Dague et al. 5,888,242 A 3/1999 Antaki et al. 8,581,462 B2 11/2013 Nussbaumer 5,917,297 A 6/1999 Gerster et al. 8,597,350 B2 12/2013 Rudser et al. 5,928,131 A 7/1999 Prem 8,652,024 B1 2/2014 Yanai et al. 5,947,703 A 9/1999 Nojiri et al. 8,657,733 B2 2/2014 Ayre et al. 6,053,705 A 4/2000 Schob et al. 8,668,473 B2 3/2014 LaRose et al.									-
5,808,437 A 9/1998 Schob 8,562,508 B2 10/2013 Dague et al. 5,888,242 A 3/1999 Antaki et al. 8,581,462 B2 11/2013 Nussbaumer 5,917,297 A 6/1999 Gerster et al. 8,597,350 B2 12/2013 Rudser et al. 5,928,131 A 7/1999 Prem 8,652,024 B1 2/2014 Yanai et al. 5,947,703 A 9/1999 Nojiri et al. 8,657,733 B2 2/2014 Ayre et al. 6,053,705 A 4/2000 Schob et al. 8,668,473 B2 3/2014 LaRose et al.					8,556	5,795	B2	10/2013	Bolyard et al.
5,888,242 A 3/1999 Antaki et al. 8,581,462 B2 11/2013 Nussbaumer 5,917,297 A 6/1999 Gerster et al. 8,597,350 B2 12/2013 Rudser et al. 5,928,131 A 7/1999 Prem 8,652,024 B1 2/2014 Yanai et al. 5,947,703 A 9/1999 Nojiri et al. 8,657,733 B2 2/2014 Ayre et al. 6,053,705 A 4/2000 Schob et al. 8,668,473 B2 3/2014 LaRose et al.									
5,928,131 A 7/1999 Prem 8,652,024 B1 2/2014 Yanai et al. 5,947,703 A 9/1999 Nojiri et al. 8,657,733 B2 2/2014 Ayre et al. 6,053,705 A 4/2000 Schob et al. 8,668,473 B2 3/2014 LaRose et al.		5,888,242 A	3/1999	Antaki et al.					
5,947,703 A 9/1999 Nojiri et al. 8,657,733 B2 2/2014 Ayre et al. 6,053,705 A 4/2000 Schob et al. 8,668,473 B2 3/2014 LaRose et al.									
6,053,705 A 4/2000 Schob et al. 8,668,473 B2 3/2014 LaRose et al.									
					8,764	1,621	B2	7/2014	Badstibner et al.

US 12,383,725 B2 Page 3

(56)	Referen	ces Cited	2014/0062239	A1*	3/2014	Schoeb	A61M 60/538 310/90.5
IIS P	PATENT	DOCUMENTS	2014/0100413	3 A1	4/2014	Casas et al.	310/90.3
0.5.1	2111111	Becoments	2014/019498			Vadala, Jr.	
8,852,072 B2	10/2014	White et al.	2014/0275723			Fritz, IV et al.	
		Reichenbach et al.	2014/0303426	5 A1	10/2014	Kerkhoffs et al.	
		LaRose et al.	2014/035793	7 A1	12/2014	Reyes et al.	
	11/2014	Fritz, IV et al.	2014/0364768			Hastie et al.	
		Dormanen et al.	2015/0051438		2/2015		
8,956,275 B2	2/2015	Bolyard et al.	2015/015103			Yaghdjian	
9,068,572 B2		Ozaki et al.	2015/0211542			Scheckel	
9,079,043 B2		Stark et al.	2015/027312:			Bourque	1.613.1.60/530
9,091,271 B2		Bourque	2015/0294550) A1*	10/2015	Kimball	
9,091,272 B2		Kim et al.	2016/022100		11/2016	61 1 4 1	340/636.1
9,265,870 B2		Reichenbach et al.	2016/0331883			Siebenhaar et al.	
9,382,908 B2		Ozaki et al.	2017/0119946			Mcchrystal et al. Bourque	
9,427,510 B2* 9,492,599 B2*		Siebenhaar A61M 60/178 Schimpf H05K 3/303	2017/024636: 2017/030214:			Holenstein et al.	
9,492,399 B2 9,675,741 B2		Bourque	2017/030214.	/ A1	10/2017	Holenstein et al.	
10,973,967 B2 *		Nyikos A61M 60/81	E	DEIG	NI DATE	NT DOCUMENT	re
2002/0105241 A1		Carroll et al.	Г	JKEIO	IN PAIE	NI DOCUMEN.	ıs
2003/0021683 A1		Capone et al.	EP	61	560	12/1990	
		Yamane et al.	EP EP)569 3251	6/1994	
2005/0004421 A1		Pacella et al.	EP		7374	8/2011	
2005/0025630 A1	2/2005	Ayre et al.	GB		1710	11/1977	
2005/0071001 A1	3/2005		JP	01253		10/1989	
2005/0135948 A1		Olsen et al.	JP	02016		1/1990	
2005/0147512 A1		Chen et al.	JP	03088	3996	4/1991	
2006/0122456 A1*	6/2006	LaRose A61M 60/237	JP	04148	3095	5/1992	
200=10100105 111		600/16		2000510)929	8/2000	
2007/0100196 A1*	5/2007	LaRose A61M 60/81		2002512		4/2002	
2000/00/4555	2/2000	600/16		2003093		4/2003	
2009/0064755 A1		Fleischli et al.		2011530		12/2011	
2009/0234447 A1		Larose et al.	WO		3974	10/1999	
2010/0130809 A1 2010/0150749 A1		Morello Horvath		2004098		11/2004	
2010/0150749 A1 2010/0152526 A1		Pacella et al.		2005032 2006131		4/2005 12/2006	
2010/0241223 A1		Lee et al.		2010013		2/2010	
		Iannello et al.		2010013		3/2010	
2011/0002794 A1		Haefliger et al.		2010036		4/2010	
2011/0031836 A1		Nussbaumer		2012028		3/2012	
2011/0054239 A1	3/2011	Sutton et al.					
2011/0071337 A1	3/2011			OTT	TED DIE	DI IO ITIONIO	
2011/0144413 A1*	6/2011	Foster A61M 60/226		OI.	HER PU	BLICATIONS	
		600/16	D 1 1		c - D	' T DI ID	N. D. CELL I
2011/0187217 A1		Nussbaumer		_		ing Less Blood Pun	•
2011/0237863 A1		Ricci et al.	International S	ymposiı	ım on Ma	gnetic Suspension T	echnology, Jul.
		Zafirelis et al.	1, 1996, pp. 26	55-274.			
2011/0313237 A1 2012/0035411 A1		Miyakoshi et al. LaRose et al.	Izraelev et al., '	'A Passi	vely-Susp	ended Tesla Pump	Left Ventricular
2012/0035411 A1*		Bourque A61M 60/515	Assist Device'	NIH	Public A	ccess, vol. 55, No	. 6, 2009, pp.
2012/0040514 A1	2/2012	600/16	556-561.			, ,	, , 11
2012/0059212 A1	3/2012	LaRose et al.		"Conce	nt of a 14	50 krpm Bearingles	s Slotless Disc
2012/0134832 A1	5/2012					Proceedings of the IE	
2012/0226097 A1		Smith et al.				onference (IEMDC 2	
2012/0245680 A1	9/2012	Masuzawa et al.	311-318.	. vo and	D11100 CO	morenee (initioe 2	.010), 2010, pp.
2012/0245681 A1		Casas et al.		Slotles	Regring!	ess Disk Drive for I	High-Sneed and
	10/2012					E Transactions on 1	
		Peters et al.				014, pp. 975-981.	industrial Elec-
2013/0164161 A1*	6/2013	Schob H02K 1/06				on of Slotless Bearing	less Motorowith
		417/420				International Pov	
		Eagle et al.	Conference, 20				to Licentines
		Kabir et al.	Comerence, 20	т ч , рр.	<i>∍14-</i> 301.		
		Pfeffer et al.	* aited by ar	omina			
2014/0030122 A1	1/2014	Ozaki et al.	* cited by ex	ammer			





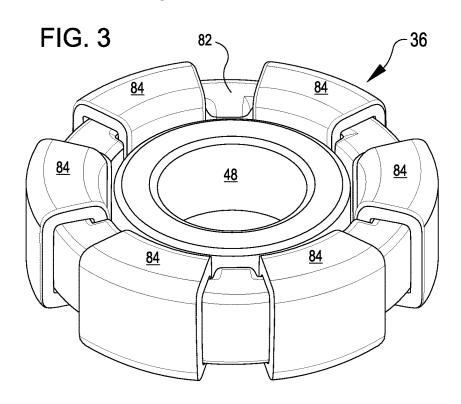
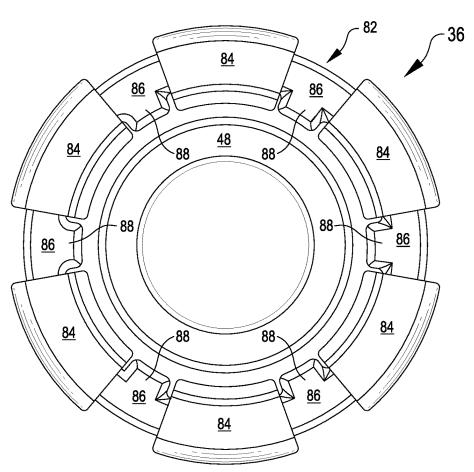
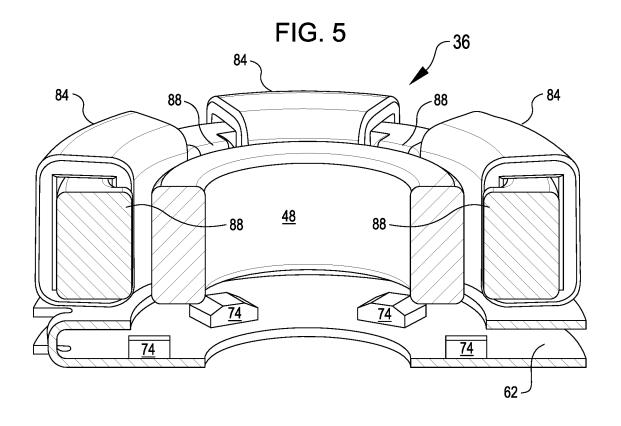
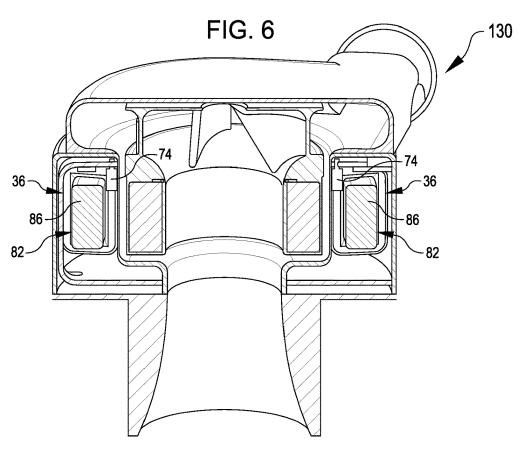
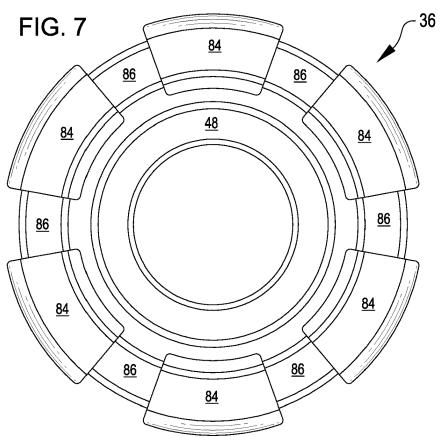


FIG. 4









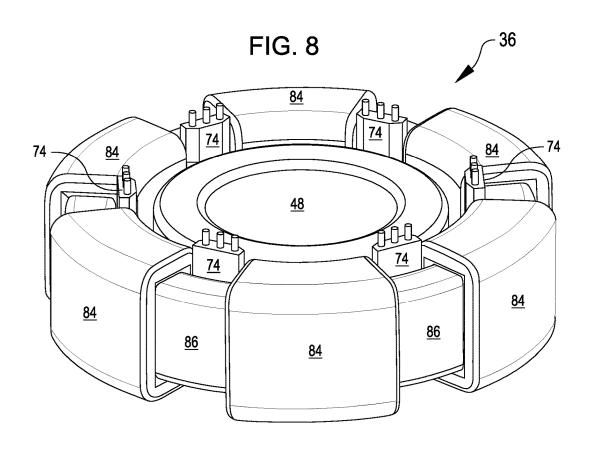
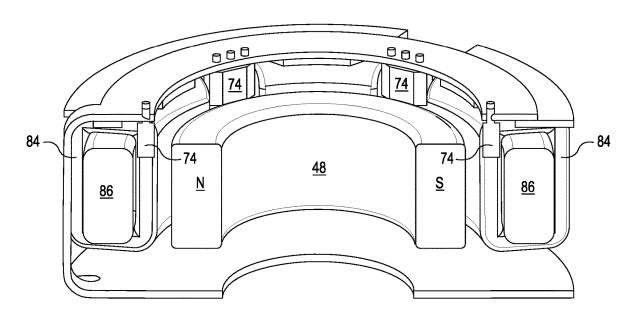


FIG. 9



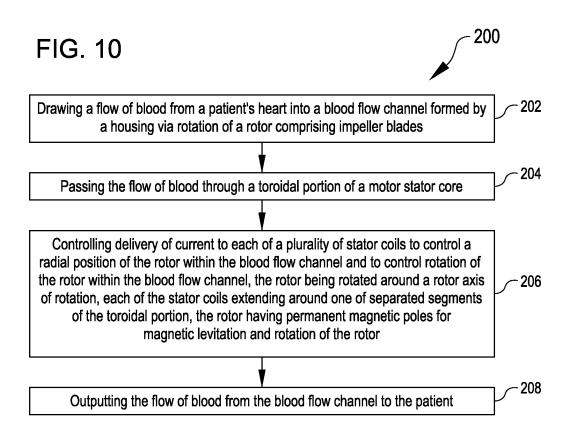
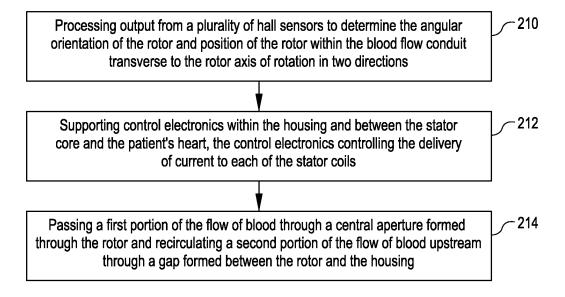


FIG. 11



BEARINGLESS IMPLANTABLE BLOOD PUMP

CROSS REFERENCE TO RELATED APPLICATIONS

The present application is a Continuation of U.S. patent application Ser. No. 16/204,015, now U.S. Pat. No. 10,973, 967, filed Nov. 29, 2018 (Allowed); which claims the benefit of U.S. application No. 62/615,708 filed Jan. 10, 2018, the full disclosures which are incorporated herein by reference in their entirety for all purposes.

BACKGROUND

Ventricular assist devices, known as VADs, often include an implantable blood pump and are used for both short-term (i.e., days, months) and long-term applications (i.e., years or a lifetime) where a patient's heart is incapable of providing adequate circulation, commonly referred to as heart failure or congestive heart failure. According to the American Heart Association, more than five million Americans are living with heart failure, with about 670,000 new cases diagnosed every year. People with heart failure often have shortness of breath and fatigue. Years of living with blocked arteries and/or high blood pressure can leave a heart too weak to pump enough blood to the body. As symptoms worsen, advanced heart failure develops.

A patient suffering from heart failure may use a VAD while awaiting a heart transplant or as a long term destination therapy. A patient may also use a VAD while recovering from heart surgery. Thus, a VAD can supplement a weak heart (i.e., partial support) or can effectively replace the natural heart's function.

BRIEF SUMMARY

The following presents a simplified summary of some embodiments of the invention in order to provide a basic understanding of the invention. This summary is not an 40 extensive overview of the invention. It is not intended to identify key/critical elements of the invention or to delineate the scope of the invention. Its sole purpose is to present some embodiments of the invention in a simplified form as a prelude to the more detailed description that is presented 45 later

In many embodiments, an implantable blood pump includes a rotary motor that includes a compact stator assembly. The compact size of the stator assembly is enabled by the stator assembly including a compact stator core, 50 which includes a toroidal portion, and stator coils. Each of the stator coils extend around a respective separated segment of the toroidal portion. In many embodiments, the stator does not extend beyond a disk-shaped volume having a compact thickness (e.g., less than 1.0 inches) in a direction 55 parallel to the axis of rotation of the rotary motor), thereby enabling the stator assembly to have a corresponding compact thickness parallel to the axis of rotation of the rotary motor. In some embodiments, the stator core includes separated stator teeth that extend inwardly from the toroidal 60 portion between adjacent pairs of the stator coils. In some embodiments, the rotary motor includes rotor position sensors (e.g., hall effect sensors). Each of the rotor position sensors can be disposed in or adjacent to a respective gap between adjacent pairs of the stator coils. The compact size 65 of the stator assembly parallel to the axis of rotation of the rotary motor enables the implantable blood pump to have a

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compact size parallel to the axis of rotation of the rotary motor, thereby requiring less space within the thoracic cavity.

Thus, in one aspect, a first implantable blood pump includes a housing and a rotary motor. The housing defines an inlet opening, an outlet opening, and a dividing wall within the housing defining a blood flow conduit. The blood flow conduit extends between the inlet opening and the outlet opening. The rotary motor includes a stator and a rotor. The stator includes a stator core and stator coils. The stator core includes a toroidal portion and stator teeth. Each of the stator teeth extend toward the rotor from the toroidal portion. Each of the stator teeth is separated from each of an adjacent two of the stator teeth by a respective adjacent intervening segment of the toroidal portion. Each of the stator coils extends around one of the intervening segments of the toroidal portion. The stator is disposed within the housing circumferentially about the dividing wall such that the blood flow conduit extends through the stator core. The stator core is disposed circumferentially around at least a portion of the rotor. The rotor has a rotor axis of rotation and includes a rotor magnet for driving the rotor. The stator teeth axially overlap the rotor magnet with respect to the rotor axis of rotation. In many embodiments, the stator does not extend beyond a disk-shaped volume having a compact thickness (e.g., less than 1.0 inches) in a direction parallel to the rotor axis of rotation.

In many embodiments, the first implantable blood pump is configured to pump blood from a heart ventricle to the aorta. In some embodiments, the outlet opening is oriented at an angle relative to the input opening. The inlet opening can be oriented to receive blood directly from a heart ventricle and the output opening oriented to output blood in a direction transverse to the orientation of the inlet opening so as to reduce the length of a blood flow cannula used to transfer the blood flow from the output opening to the aorta. The rotor can include centrifugal pump impeller blades.

In many embodiments of the first implantable blood pump, the rotor defines a rotor blood flow conduit that extends through the stator. For example, in many embodiments, the rotor defines a rotor blood flow conduit that extends through the rotor, thereby extending through the stator.

The rotor can have any suitable number of magnetic moments. In some embodiments, the rotor has only one magnetic moment.

In some embodiments, the first implantable blood pump includes one or more rotor position sensors that generate output indicative of the orientation of the rotor for use in electronic commutation of the rotary motor. In some embodiments, the output of the one or more rotor position sensors is indicative of the position of the rotor within the blood flow conduit transverse to the rotor axis of rotation (e.g., in two different directions transverse to the rotor axis of rotation). In some embodiments, the position of the rotor within the blood flow conduit transverse to the rotor axis of rotation is used to control operation of the stator to control magnetic levitation of the rotor within the blood flow conduit. In some embodiments, the one or more rotor position sensors includes hall effect sensors. In some embodiments, each of the hall effect sensors is disposed in or adjacent to a respective gap between an adjacent pair of the stator coils. In some embodiments, each of the hall effect sensors is disposed aligned with and above or below a respective gap between an adjacent pair of the stator coils.

In some embodiments, the first implantable blood pump includes control electronics disposed within the housing. In

such embodiments, the control electronics can be configured to control current passing through each of the stator coils to radially levitate the rotor and rotate the rotor within the blood flow conduit.

In many embodiments of the first implantable blood 5 pump, an axial position of the rotor along the blood flow conduit is restrained via passive magnetic interaction between the rotor and the stator such that the stator functions as a passive magnetic bearing that controls the axial position of the rotor parallel to the rotor axis of rotation. In such 10 embodiments, the first implantable blood pump can be configured without dedicated magnetic axial bearings that restrain the axial position of the rotor along the blood flow conduit.

In many embodiments of the first implantable blood 15 pump, the rotor is separated from the dividing wall so as to accommodate flow of blood around the rotor. For example, in some embodiments of the first implantable blood pump, a gap between the rotor and the dividing wall is between about 0.2 mm to about 2 mm with the rotor centered relative 20 to the stator core. A gap between the rotor and at least one of the stator teeth can be between about 0.3 mm to about 2.4 mm with the rotor centered relative to the stator core.

In another aspect, a second implantable blood pump includes a housing and a rotary motor. The housing defines 25 an inlet opening, an outlet opening, and a dividing wall defining a blood flow conduit extending from the inlet opening to the outlet opening. The rotary motor includes a stator, hall effect sensors, and a rotor. The stator includes a stator core and stator coils. The stator core includes a 30 toroidal portion. Each of the stator coils extends around one of separated segments of the toroidal portion. The stator is disposed within the housing circumferentially about the dividing wall such that the blood flow conduit extends through the stator core. The stator core is disposed circum- 35 ferentially around at least a portion of the rotor. Each of the hall effect sensors is disposed in a respective gap between an adjacent pair of the stator coils. The rotor has a rotor axis of rotation and includes a rotor magnet for driving the rotor. The stator core axially overlaps with the rotor magnet with 40 respect to the rotor axis of rotation. In many embodiments, the stator does not extend beyond a disk-shaped volume having a compact thickness (e.g., less than 1.0 inches) in a direction parallel to the rotor axis of rotation.

In many embodiments, the second implantable blood 45 pump is configured to pump blood from a heart ventricle to the aorta. In some embodiments, the outlet opening is oriented at an angle relative to the input opening. The inlet opening can be oriented to receive blood directly from a heart ventricle and the output opening oriented to output 50 blood in a direction transverse to the orientation of the inlet opening so as to reduce the length of a blood flow cannula used to transfer the blood flow from the output opening to the aorta. The rotor can include centrifugal pump impeller

In many embodiments of the second implantable blood pump, the rotor defines a rotor blood flow conduit that extends through the stator. For example, in many embodiments, the rotor defines a rotor blood flow conduit that extends through the rotor, thereby extending through the 60 the present invention, reference should be made to the

The rotor can have any suitable number of magnetic moments. In some embodiments, the rotor has only one magnetic moment.

In some embodiments, the second implantable blood 65 pump includes control electronics disposed within the housing. In such embodiments, the control electronics can be

configured to control current passing through each of the stator coils to radially levitate the rotor and rotate the rotor within the blood flow conduit.

In many embodiments of the second implantable blood pump, an axial position of the rotor along the blood flow conduit is restrained via passive magnetic interaction between the rotor and the stator. In such embodiments, the second implantable blood pump can be configured without dedicated magnetic axial bearings that restrain the axial position of the rotor along the blood flow conduit.

In many embodiments of the second implantable blood pump, the rotor is separated from the dividing wall so as to accommodate flow of blood around the rotor. For example, in some embodiments of the second implantable blood pump, a gap between the rotor and the dividing wall is between about 0.2 mm to about 2 mm with the rotor centered relative to the stator core. A gap between the rotor and at least one of the stator coils can be between about 0.3 mm to about 2.4 mm with the rotor centered relative to the stator

In another aspect, a method of assisting blood circulation in a patient is provided. The method includes drawing a flow of blood from a patient's heart into a blood flow channel formed by a housing via rotation of a rotor comprising impeller blades. The flow of blood is passed through a toroidal portion of a motor stator core. Delivery of current to each of a plurality of stator coils is controlled to control a radial position of the rotor within the blood flow channel and to control rotation of the rotor within the blood flow channel. The rotor is rotated around a rotor axis of rotation. Each of the stator coils extends around one of separated segments of the toroidal portion. The rotor has permanent magnetic poles for magnetic levitation and rotation of the rotor. The flow of blood is output from the blood flow channel to the patient.

In many embodiments, the method further includes processing output from a plurality of hall sensors to determine an orientation of the rotor. Each of the hall effect sensors can be disposed in a respective gap between an adjacent pair of the stator coils.

In many embodiments, the method further includes supporting control electronics within the housing and between the stator core and the patient's heart. The control electronics can control the delivery of current to each of the stator

In many embodiments, the method further includes flowing blood through and around the rotor. For example, the method can include (a) passing a first portion of the flow of blood through a central aperture formed through the rotor and (b) passing a second portion of the flow of blood through a gap formed between the rotor and the housing.

In many embodiments, the method further includes magnetically levitating the rotor within the blood flow channel. For example, the rotor can be levitated within the blood flow channel such that the rotor is separated from the housing by a gap between about 0.2 mm to about 2 mm. The rotor can be levitated within the blood flow channel such that the rotor is separated from at least one of the stator coils by a gap between about 0.3 mm to about 2.4 mm.

For a fuller understanding of the nature and advantages of ensuing detailed description and accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is an illustration of a mechanical circulatory support system implanted in a patient's body, in accordance with many embodiments.

FIG. 2 is a cross-sectional view illustration of an implantable blood pump that includes a compact rotary motor that includes a toroidal stator core with teeth, in accordance with some embodiments.

FIG. 3 is an isometric view illustration of the stator core 5 and a rotor component of the compact rotary motor of FIG. 2.

FIG. 4 is an axial view illustration of the stator core and a rotor component of the compact rotary motor of FIG. 2.

FIG. **5** is a cross-sectional view illustration of the stator ¹⁰ core, the rotor component, and rotor position sensors of the compact rotary motor of FIG. **2**.

FIG. **6** is a cross-sectional view illustration of an implantable blood pump that includes a compact rotary motor that includes a toroidal stator core without teeth, in accordance 15 with some embodiments.

FIG. 7 is an axial view illustration of the stator core and a rotor component of the compact rotary motor of FIG. 6.

FIG. **8** is an isometric view illustration of the stator core, the rotor component, and hall effect sensors of the compact ²⁰ rotary motor of FIG. **6**.

FIG. 9 is a cross-sectional view illustration of the stator core, the rotor component, and hall effect sensors of the compact rotary motor of FIG. 6.

FIG. 10 is a simplified schematic diagram illustration of ²⁵ a method of assisting blood circulation in a patient, in accordance with many embodiments.

FIG. 11 is a simplified schematic diagram illustration of additional acts that can be accomplished in the method of FIG. 10.

DETAILED DESCRIPTION

In the following description, various embodiments of the present invention will be described. For purposes of explanation, specific configurations and details are set forth in order to provide a thorough understanding of the embodiments. However, it will also be apparent to one skilled in the art that the present invention may be practiced without the specific details. Furthermore, well-known features may be 40 omitted or simplified in order not to obscure the embodiment being described.

Referring now to the drawings, in which like reference numerals represent like parts throughout the several views, FIG. 1 shows a mechanical circulatory support system 10 45 implanted in a patient's body 12. The mechanical circulatory support system 10 includes an implantable blood pump assembly 14, a ventricular cuff 16, an outflow cannula 18, an external system controller 20, and power sources 22. The implantable blood pump assembly 14 can include a VAD 50 that is attached to an apex of the left ventricle, as illustrated, or the right ventricle. A respective VAD can be attached to each of the ventricles of the heart 24. The VAD can include a centrifugal pump (as shown) that is capable of pumping the entire output delivered to the left ventricle from the pulmo- 55 nary circulation (i.e., up to 10 liters per minute). Related blood pumps applicable to the present invention are described in greater detail below and in U.S. Pat. Nos. 5,695,471, 6,071,093, 6,116,862, 6,186,665, 6,234,772, $6,264,635, \ 6,688,861, \ 7,699,586, \ 7,976,271, \ 7,976,271, \ 60$ 7,997,854, 8,007,254, 8,152,493, 8,419,609, 8,852,072, 8,652,024, 8,668,473, 8,864,643, 8,882,744, 9,068,572, 9,091,271, 9,265,870, and 9,382,908, all of which are incorporated herein by reference for all purposes in their entirety. The blood pump assembly 14 can be attached to the heart 24 65 via the ventricular cuff 16, which can be sewn to the heart 24 and coupled to the blood pump 14. The other end of the

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blood pump 14 connects to the ascending aorta (or the pulmonary artery when the VAD is coupled with the right ventricle of the heart) via the outflow cannula 18 so that the VAD effectively diverts blood from the weakened ventricle and propels it for circulation through the patient's vascular system.

FIG. 1 illustrates the mechanical circulatory support system 10 during battery 22 powered operation. A driveline 26 that exits through the patient's abdomen 28 connects the implanted blood pump assembly 14 to the external system controller 20, which monitors system 10 operation. Related controller systems applicable to the present invention are described in greater detail below and in U.S. Pat. Nos. $5,888,242,\ 6,991,595,\ 8,323,174,\ 8,449,444,\ 8,506,471,$ 8,597,350, and 8,657,733, EP 1812094, and U.S. Patent Publication Nos. 2005/0071001 and 2013/0314047, all of which are incorporated herein by reference for all purposes in their entirety. The system 10 can be powered by either one, two, or more batteries 22. It will be appreciated that although the system controller 20 and power source 22 are illustrated outside/external to the patient body, the driveline 26, the system controller 20 and/or the power source 22 can be partially or fully implantable within the patient, as separate components or integrated with the blood pump assembly 14. Examples of such modifications are further described in U.S. Pat. Nos. 8,562,508 and 9,079,043, all of which are incorporated herein by reference for all purposes in their entirety.

FIG. 2 is a cross-sectional view illustration of an implant-30 able blood pump assembly 30, in accordance with some embodiments. The blood pump assembly 30 can be used in place of the blood pump assembly 14 in the mechanical circulatory support system 10. The blood pump assembly 30 includes a housing 32 and a compact rotary motor 34. The compact rotary motor 34 includes a stator 36 and a rotor assembly 38. The housing 32 defines an inlet opening 40, an outlet opening 42, and a blood flow conduit 44 in fluid communication with the inlet opening 40 and the outlet opening 42. The housing 32 includes a dividing wall 46 that defines the blood flow conduit 44. The dividing wall 46 also partially defines a compartment in which the stator 36 is disposed and isolates the stator from blood flowing through the blood flow conduit 44. The rotor assembly 38 includes a rotor magnetic assembly 48 and an impeller blade assembly 50 attached to the rotor magnetic assembly 48. The rotor magnetic assembly 48 can include any suitable number of permanent magnets (e.g., 1 or more). In operation, the stator 36 generates magnetic fields that interact with the rotor magnetic assembly 48 to levitate the rotor magnetic assembly 48 radially within the blood flow conduit 44, rotate the rotor magnetic assembly 48 within the blood flow conduit 44 around a rotor axis of rotation 52, and react axial thrust applied to the rotor assembly 38 parallel to the rotor axis of rotation 52 during pumping of blood through the blood flow conduit 44 via rotation of the rotor assembly 38.

The housing 32 has a circular shape and is implanted in a patient's body with a first face 54 of the housing 32 facing the patient's heart 24 and a second face 56 of the housing 32 facing away from the heart 24. The housing 32 includes an inlet cannula 58 that couples with the ventricular cuff 16 and extends into a ventricle of the heart 24. The second face 56 of the housing 32 has a chamfered edge 60 to avoid irritating other tissue that may come into contact with the blood pump assembly 30, such as the patient's diaphragm. To construct the illustrated shape of the puck-shaped housing 32 in a compact form, the stator 36 and electronics 62 of the pump assembly 30 are positioned on the inflow side of the housing

32 toward first face 54, and the rotor assembly 38 is positioned along the second face 56. This positioning of the stator 36, electronics 62, and the rotor assembly 38 permits the edge 60 to be chamfered along the contour of the impeller blade assembly 50.

The blood flow conduit 44 extends from the inlet opening 40 of the inlet cannula 58 through the stator 36 to the outlet opening 42. The rotor assembly 38 is positioned within the blood flow conduit 44. The stator 36 is disposed circumferentially around the rotor magnetic assembly 48. The stator 10 36 is also positioned relative to the rotor assembly 38 such that, in use, blood flows within the blood flow conduit 44 through the stator 36 and the rotor magnetic assembly 48 before reaching the impeller blade assembly 50. In some embodiments, the rotor magnetic assembly 48 has a perma- 15 nent magnetic north pole (N) and a permanent magnetic south pole (S) for combined active and passive magnetic levitation of the rotor magnetic assembly 48 and for rotation of the rotor assembly 38. In some embodiments, the rotor magnetic assembly 48 has more than one pair of magnetic 20 poles (e.g., 2, 3, 4, 5, or more). The impeller blade assembly 50 includes impeller blades 64. The impeller blades 64 are located within a volute 66 of the blood flow conduit 44 such that the impeller blades 64 are located proximate to the second face 56 of the housing 32.

The puck-shaped housing 32 further includes a peripheral wall 68 that extends between the first face 54 and a removable cap 70. As illustrated, the peripheral wall 68 is formed as a hollow circular cylinder having a width (W) between opposing portions of the peripheral wall 68. The housing 32 30 also has a thickness (T) between the first face 54 and the second face 56 that is less than the width (W). The thickness (T) is from about 0.5 inches to about 1.5 inches, and the width (W) is from about 1 inch to about 4 inches. For example, the width (W) can be approximately 2 inches, and 35 the thickness (T) can be approximately 1 inch.

The peripheral wall **68** encloses an internal compartment **72** that surrounds the dividing wall **46** and the blood flow conduit **44**, with the stator **36** and the electronics **62** disposed in the internal compartment **72** about the dividing wall **46**. 40 The removable cap **70** includes the second face **56**, the chamfered edge **60**, and defines the outlet opening **42**. The cap **70** has an inner surface that defines the volute **66** that is in fluid communication with the outlet opening **42**.

Within the internal compartment 72, the electronics 62 are 45 positioned adjacent to the first face 54 and the stator 36 is positioned adjacent to the electronics 62 on an opposite side of the electronics 62 from the first face 54. The electronics 62 can include one or more circuit boards and various components carried on the circuit boards to control the 50 operation of the blood pump assembly 30 (e.g., magnetic levitation and/or drive of the rotor assembly 38) by controlling currents applied to the stator 36. The housing 32 is configured to receive the electronics 62 within the internal compartment 72 generally parallel to the first face 54 for 55 efficient use of the space within the internal compartment 72. The electronics 62 also extend radially-inward towards the dividing wall 46 and radially-outward towards the peripheral wall 68. For example, the internal compartment 72 is generally sized no larger than necessary to accommodate the 60 stator 36 and the electronics 62, and space for heat dissipation, material expansion, potting materials, and/or other elements used in installing the stator 36 and the electronics 62. Thus, the external shape of the housing 32 proximate the first face 54 generally fits the shape of the electronics 62 65 closely to provide external dimensions that are not much greater than the dimensions of the electronics 62. In the

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illustrated embodiment, the electronics 62 include Hall effect sensors 74 that generate output indicative of the angular orientation of the rotor magnetic assembly 48 and the transverse position of the rotor magnetic assembly 48 transverse to the rotor axis of rotation 52 in two directions. The output from the Hall effect sensors 74 is used by the electronics 62 to control operation of the stator 36 to levitate and rotate the rotor assembly 38.

The rotor assembly 38 is arranged within the housing 32 such that the rotor magnetic assembly 48 is located upstream of the impeller blade assembly 50. The rotor magnetic assembly 48 is disposed within the blood flow conduit 44 proximate the stator 36. The rotor magnetic assembly 48 and the dividing wall 44 form a gap 76 between the rotor magnetic assembly 48 and the dividing wall 44 when the rotor magnetic assembly 48 is centered within the blood flow conduit 44. In many embodiments, the gap 76 is from about 0.2 millimeters to about 2 millimeters. In some embodiments, the gap 76 is approximately 1 millimeter. The north permanent magnetic pole N and the south permanent magnetic pole S of the rotor magnetic assembly 48 provide a permanent magnetic attractive force between the rotor magnetic assembly 48 and the stator 36 that acts as a passive axial force that tends to maintain the rotor magnetic assem-25 bly 48 generally axially aligned with the stator 36 relative to the rotor axis of rotation 52 thereby resisting movement of the rotor magnetic assembly 48 towards the first face 54 or towards the second face 56.

As blood flows through the blood flow conduit 44, blood flows through a central aperture 78 formed through the rotor magnetic assembly 48. Blood also flows through the gap 76 between the rotor magnetic assembly 48 and the dividing wall 46 and through a gap 80 between the impeller blade assembly 50 and the inner surface of the cap 70. The gaps 76 and 80 are large enough to allow adequate blood flow to limit clot formation that may occur if the blood is allowed to become stagnant. The gaps 76 and 80 are also large enough to limit shear forces on the blood cells such that the blood is not damaged when flowing through the blood pump assembly 30. As a result of the size of the gaps 76 and 80 limiting shear forces on the blood cells, the gaps 76 and 80 are too large to provide a meaningful hydrodynamic suspension effect. That is to say, the blood does not act as a bearing within the gaps 76 and 80, and the rotor magnetic assembly 48 is only magnetically-levitated.

Because the rotor assembly 38 is radially suspended by active control of the stator 36, and because the rotor assembly 38 is axially suspended by passive interaction between the stator 36 and the rotor magnetic assembly 48, no rotor levitation components other than the stator 36 and related components used to control operation of the stator 36 are needed (e.g., proximate the second face 56) to levitate the rotor assembly 38 transverse to the rotor axis of rotation 52 and to control the position of the rotor assembly 38 parallel to the rotor axis of rotation 52. By levitating the rotor assembly 38 via the stator 36, the cap 70 can be contoured to the shape of the impeller blade assembly 50 and the volute **66.** Additionally, levitating the rotor assembly **38** via the stator 36 eliminates the need for electrical connectors extending from the compartment 72 to the cap 70, which allows the cap 70 to be easily installed and/or removed and eliminates potential sources of pump failure.

FIG. 3 and FIG. 4 show the stator 36 and the rotor magnetic assembly 48. The stator 36 includes an integral stator core 82 and stator coils 84. The integral stator core 82 includes a toroidal portion 86 and stator teeth 88. Each of the stator teeth 88 extends toward the rotor magnetic assembly

48 from the toroidal portion 86. Each of the stator teeth 88 is separated from each of an adjacent two of the stator teeth 88 by a respective adjacent intervening segment of the toroidal portion 86. Each of the stator coils 84 extends around one of the intervening segments of the toroidal 5 portion 86. The stator 36 is disposed within the housing 32 circumferentially around the dividing wall 46 such that the blood flow conduit 44 extends through the stator core 82. The stator core 82 is disposed circumferentially around the rotor magnetic assembly 48. In many embodiments, the stator 36 does not extend beyond a disk-shaped volume having a compact thickness (e.g., (H) shown in FIG. 2 less than 1.0 inches) in a direction parallel to the rotor axis of rotation 52.

FIG. 5 is a cross-sectional view illustration of the stator 15 36, the rotor magnetic assembly 48, and the electronics 62. In the illustrated embodiment, the electronics 62 include Hall-effect sensors 74, each of which is disposed adjacent to a respective one of the stator teeth 88. By positioning the Hall-effect sensors 74 aligned with the stator teeth 88, the 20 signals generated by the Hall-effect sensors 74 can be processed to track the orientation of the rotor magnetic assembly 48 relative to the stator teeth 88 without adjusting for an orientation difference between the Hall-effect sensors 74 and the stator teeth 88.

FIG. 6 is a cross-sectional view illustration of an implantable blood pump assembly 130, in accordance with some embodiments. The blood pump assembly 130 can be used in place of the blood pump assembly 14 in the mechanical circulatory support system 10. The blood pump assembly 30 130 is configured similar to the blood pump assembly 30 except for differences with respect to the stator core 82 and the location of the Hall-effect sensors 74 as described herein. Accordingly, components of the blood pump assembly 130 that are the same or similar to the components of the blood 35 pump assembly 30 are identified using the same or similar reference identifiers in the drawing figures. As illustrated in FIG. 6 and FIG. 7, the stator core 82 of the blood pump assembly 130 includes the toroidal portion 86 and does not include the stator teeth 88 of the stator core 82 of the blood 40 pump assembly 30. As illustrated in FIG. 6, FIG. 8, and FIG. 9, each of the Hall-effect sensors 74 in the blood pump assembly 130 is located in a respective gap between adjacent stator coils 86 that corresponds to a space that is occupied by a respective stator tooth 88 in the blood pump assembly 30. 45

FIG. 10 is a simplified schematic diagram illustration of a method 200 of assisting blood circulation in a patient, in accordance with many embodiments. Any suitable blood pump assembly, such as the blood pump assemblies 14, 30, 130 described herein, can be used to practice the method 50 200

The method 200 includes drawing a flow of blood from a patient's heart into a blood flow channel formed by a housing via rotation of a rotor comprising impeller blades (act 202). For example, with reference to FIG. 2, the rotor 55 assembly 38 can be levitated and rotated via application of drive currents to the stator 36, thereby drawing blood from the patient's ventricle into the inlet cannula 58 and pumping the blood through the blood flow conduit 44.

The method **200** includes passing the flow of blood 60 through a toroidal portion of a motor stator core (act **204**). For example, with reference to FIG. **2** and FIG. **4**, the flow of blood passes through the toroidal portion **86** of the motor stator core **82** as the blood flows through the blood flow conduit **44**.

The method 200 includes controlling delivery of current to each of a plurality of stator coils to control a radial

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position of the rotor within the blood flow channel and to control rotation of the rotor within the blood flow channel, the rotor being rotated around a rotor axis of rotation, each of the stator coils extending around one of separated segments of the toroidal portion, the rotor having permanent magnetic poles for magnetic levitation and rotation of the rotor (act 206). For example, with reference to FIG. 2 through FIG. 4, delivery of current to each of the stator coils 84 is controlled (e.g., via the electronics 62) to control a radial position of the rotor magnetic assembly 48 within the blood flow conduit 44 (i.e., transverse to the rotor axis of rotation 52) and to control rotation of the rotor magnetic assembly 48 within the blood flow conduit 44. The rotor magnetic assembly 48 is rotated around the rotor axis of rotation 52. Each of the stator coils 84 extends around one of separated segments of the toroidal portion 86. The rotor magnetic assembly 48 has permanent magnetic poles for magnetic levitation and rotation of the rotor magnetic assembly 48.

The method 200 includes outputting the flow of blood from the blood flow channel to the patient (act 208). For example, referring to FIG. 2, the blood flowing through the blood flow conduit 44 is output via the outlet opening 42 and to the ascending aorta via the outflow cannula 18.

FIG. 11 is a simplified schematic diagram illustration of additional acts that can be accomplished in the method 200. For example, the method 200 can further include processing output from a plurality of Hall-effect sensors to determine the angular orientation of the rotor and the position of the rotor transverse to the rotor axis of rotation in two directions (act 210). Each of the Hall-effect sensors can be aligned with a respective gap between an adjacent pair of the stator coils (e.g., above the respective gap, below the respective gap, in the respective gap). For example, referring to FIG. 6, FIG. 8, and FIG. 9, output from the Hall-effect sensors 74 is processed (e.g., via the electronics 62) to determine the orientation of the rotor magnetic assembly 48 for use in controlling supply of current to each of the stator coils 84 to control levitation and rotation of the rotor magnetic assembly 48. In the blood pump assembly 130, each of the Hall-effect sensors 74 is disposed in a respective gap between an adjacent pair of the stator coils 84.

Method 200 can further include supporting control electronics within the housing and between the stator core and the patient's heart, the control electronics controlling the delivery of current to each of the stator coils (act 212). For example, referring to FIG. 2, the electronics 62 are supported within the housing 32 and control delivery of current to each of the stator coils 84.

Method 200 can further include passing a first portion of the flow of blood through a central aperture formed through the rotor and passing a second portion of the flow of blood through a gap formed between the rotor and the housing (act 214). For example, referring to FIG. 2, a first portion of the blood flowing through the blood flow conduit 44 passes through a central aperture formed through the rotor magnetic assembly 48 and a second portion of the blood flowing through the blood flow conduit 44 recirculates back upstream through the gaps 76, 80 formed between the rotor assembly 38 and the housing 32.

Other variations are within the spirit of the present invention. Thus, while the invention is susceptible to various modifications and alternative constructions, certain illustrated embodiments thereof are shown in the drawings and have been described above in detail. It should be understood, however, that there is no intention to limit the invention to the specific form or forms disclosed, but on the contrary, the

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intention is to cover all modifications, alternative constructions, and equivalents falling within the spirit and scope of the invention, as defined in the appended claims.

The use of the terms "a" and "an" and "the" and similar referents in the context of describing the invention (espe-5 cially in the context of the following claims) are to be construed to cover both the singular and the plural, unless otherwise indicated herein or clearly contradicted by context. The terms "comprising," "having," "including," and "containing" are to be construed as open-ended terms (i.e., 10 meaning "including, but not limited to,") unless otherwise noted. The term "connected" is to be construed as partly or wholly contained within, attached to, or joined together, even if there is something intervening. Recitation of ranges of values herein are merely intended to serve as a shorthand 15 method of referring individually to each separate value falling within the range, unless otherwise indicated herein, and each separate value is incorporated into the specification as if it were individually recited herein. All methods described herein can be performed in any suitable order 20 unless otherwise indicated herein or otherwise clearly contradicted by context. The use of any and all examples, or exemplary language (e.g., "such as") provided herein, is intended merely to better illuminate embodiments of the invention and does not pose a limitation on the scope of the 25 rotor has only one magnetic moment. invention unless otherwise claimed. No language in the specification should be construed as indicating any nonclaimed element as essential to the practice of the invention.

Preferred embodiments of this invention are described herein, including the best mode known to the inventors for 30 carrying out the invention. Variations of those preferred embodiments may become apparent to those of ordinary skill in the art upon reading the foregoing description. The inventors expect skilled artisans to employ such variations as appropriate, and the inventors intend for the invention to 35 be practiced otherwise than as specifically described herein. Accordingly, this invention includes all modifications and equivalents of the subject matter recited in the claims appended hereto as permitted by applicable law. Moreover, possible variations thereof is encompassed by the invention unless otherwise indicated herein or otherwise clearly contradicted by context.

All references, including publications, patent applications, and patents, cited herein are hereby incorporated by 45 reference to the same extent as if each reference were individually and specifically indicated to be incorporated by reference and were set forth in its entirety herein.

What is claimed is:

- 1. An implantable blood pump comprising:
- a housing defining an inlet opening, an outlet opening, and a dividing wall within the housing defining a blood flow passage that extends between the inlet opening and the outlet opening;
- a rotary motor including a stator and a rotor; wherein the 55 stator comprises a stator core and stator coils, wherein the stator core has a toroidally-shaped external surface that extends circumferentially and continuously around an axis of rotation of the rotor, wherein each of the stator coils is wound around and encloses a respective 60 circumferentially extending segment of the toroidallyshaped external surface, wherein each of the stator coils is separated from each of two adjacent instances of the stator coils by an intervening gap that corresponds to a respective exposed circumferentially extending segment of the toroidally-shaped external surface, wherein the stator is disposed within the housing circumferen-

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tially about the dividing wall such that the blood flow passage extends through the stator core, wherein the stator core is disposed circumferentially around at least a portion of the rotor, wherein the rotor includes a rotor magnet for driving the rotor, and wherein the stator core overlaps the rotor magnet with respect to the axis of rotation of the rotor; and

- control electronics disposed within the housing and configured to control current passing through each of the stator coils to radially levitate the rotor and rotate the rotor within the blood flow passage.
- 2. The implantable blood pump of claim 1, wherein the outlet opening is oriented at an angle relative to the inlet
- 3. The implantable blood pump of claim 1, wherein the rotor comprises centrifugal pump impeller blades.
- 4. The implantable blood pump of claim 3, wherein the rotor defines a rotor blood flow passage extending through
- 5. The implantable blood pump of claim 1, wherein the rotor defines a rotor blood flow passage extending through
- 6. The implantable blood pump of claim 1, wherein the
- 7. The implantable blood pump of claim 1, wherein an axial position of the rotor along the blood flow passage is restrained via passive magnetic interaction between the rotor and the stator.
- 8. The implantable blood pump of claim 1, wherein the rotor and the dividing wall are separated by a distance in a range from 0.2 mm to 2 mm with the rotor centered relative to the stator core.
- 9. The implantable blood pump of claim 1, wherein the rotor and at least one of the stator coils are separated by a distance in a range from 0.3 mm to 2.4 mm with the rotor centered relative to the stator core.
- 10. The implantable blood pump of claim 1, further comprising hall effect sensors for monitoring an orientation any combination of the above-described elements in all 40 and one or more positions of the rotor relative to the stator.
 - 11. A ventricular assist device comprising:
 - a housing defining an inlet opening, an outlet opening, and a dividing wall within the housing defining a blood flow passage that extends between the inlet opening and the outlet opening;
 - a rotary motor including a stator and a rotor; wherein the stator is operable to rotate the rotor around a rotor around a rotor axis of rotation, wherein the stator comprises a stator core and stator coils, wherein the stator core has a toroidally-shaped external surface that extends circumferentially and continuously around the rotor axis of rotation, wherein each of the stator coils is wound around and encloses a respective circumferentially extending segment of the toroidally-shaped external surface, wherein each of the stator coils is separated from each of two adjacent instances of the stator coils by an intervening gap that corresponds to a respective exposed circumferentially extending segment of the toroidally-shaped external surface, wherein the stator does not extend beyond a disk-shaped volume having a thickness in a direction parallel to the rotor axis of rotation of less than 1.0 inches, wherein the stator is disposed within the housing circumferentially about the dividing wall such that the blood flow passage extends through the stator core, wherein the stator core is disposed circumferentially around at least a portion of the rotor, wherein the rotor includes a rotor magnet for

- driving the rotor, and wherein the stator core axially overlaps the rotor magnet with respect to the rotor axis of rotation; and
- control electronics disposed within the housing and configured to control current supplied to the stator to radially levitate the rotor and rotate the rotor within the blood flow passage.
- 12. The ventricular assist device of claim 11, wherein: a housing comprising an inlet cannula and a first side face from which the inlet cannula extends;
- the inlet cannula is configured to couple with a ventricular cuff attached to a heart and extend into a ventricle of the heart; and
- the housing extends by a maximum distance of 1.5 inches from the first side face in a direction away from the inlet cannula.
- 13. The ventricular assist device of claim 11, wherein the outlet opening is oriented at an angle relative to the inlet opening.
- 14. The ventricular assist device of claim 11, wherein the rotor comprises centrifugal pump impeller blades.
- 15. The ventricular assist device of claim 14, wherein the rotor defines a rotor blood flow passage extending through the rotor

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- 16. The ventricular assist device of claim 11, wherein the rotor defines a rotor blood flow passage extending through the rotor.
- 17. The ventricular assist device of claim 11, wherein the rotor has only one magnetic moment.
- 18. The ventricular assist device of claim 11, wherein an axial position of the rotor along the blood flow passage is restrained via passive magnetic interaction between the rotor and the stator.
- 19. The ventricular assist device of claim 11, wherein the rotor and the dividing wall are separated by a distance in a range from 0.2 mm to 2 mm with the rotor centered relative to the stator core.
- 20. The ventricular assist device of claim 11, wherein the rotor and the stator are separated by a distance in a range from 0.3 mm to 2.4 mm with the rotor centered relative to the stator core.
- 21. The ventricular assist device of claim 11, further comprising hall effect sensors for monitoring an orientation and one or more positions of the rotor relative to the stator.

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