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| (54) INTERRUPTED PARTICLE SOURCE | 2,615,129 A | 10/1952 | Mcmillan | H05H 13/02
313/62 |
| (71) Applicant: Mevion Medical Systems, Inc. ,
Littleton, MA (US) | 2,659,000 A
3,175,131 A
3,432,721 A | 11/1953
3/1965
3/1969 | Salisbury
Burleigh et al.
Naydan et al. | |
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Gerrit Townsend Zwart , Durham, NH (US) | 3,582,650 A
3,679,899 A
3,689,847 A
3,757,118 A
3,868,522 A | 6/1971
7/1972
9/1972
9/1973
2/1975 | Avery
Dimeff
Verster
Hodge et al.
Bigham et al. | |
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(56) **References Cited**

U.S. PATENT DOCUMENTS

- 2,280,606 A 4/1942 Roberts
2,492,324 A 12/1949 Salisbury

FOREIGN PATENT DOCUMENTS

- CA 2629333 5/2007
CN 1537657 A 10/2004
(Continued)

OTHER PUBLICATIONS

Angert, N (GSI, Darmstadt), CAS—CERN Accelerator School : 5th
General Accelerator Physics Course, Jyväskylä, Finland, Sep. 7-18,
1992, pp. 619-642 (CERN-1994-001).

(Continued)

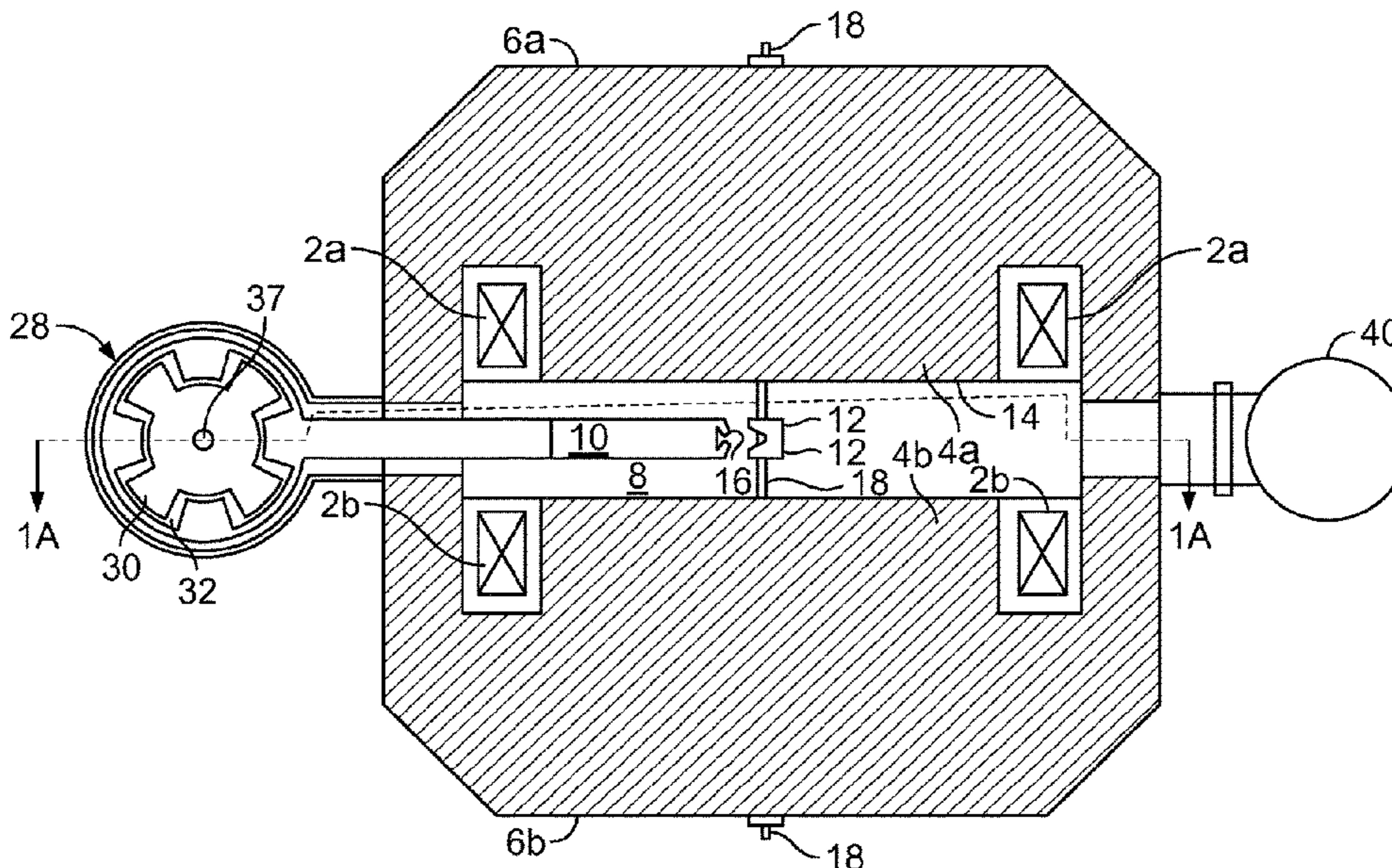
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(57) **ABSTRACT**

A synchrocyclotron includes magnetic structures to provide a magnetic field to a cavity, a particle source to provide a plasma column to the cavity, where the particle source has a housing to hold the plasma column, and where the housing is interrupted at an acceleration region to expose the plasma column, and a voltage source to provide a radio frequency (RF) voltage to the cavity to accelerate particles from the plasma column at the acceleration region.

62 Claims, 9 Drawing Sheets



(56)

References Cited

U.S. PATENT DOCUMENTS

3,886,367 A	5/1975	Castle, Jr.	5,039,867 A	8/1991	Nishihara et al.
3,925,676 A	12/1975	Bigham et al.	5,046,078 A	9/1991	Hernandez et al.
2,958,327 A	5/1976	Marancik et al.	5,072,123 A	12/1991	Johnsen
3,955,089 A	5/1976	McIntyre et al.	5,111,042 A	5/1992	Sullivan et al.
3,958,327 A	5/1976	Marancik et al.	5,111,173 A	5/1992	Matsuda et al.
3,992,625 A	11/1976	Schmidt et al.	5,117,194 A	5/1992	Nakanishi et al.
4,038,622 A	7/1977	Purcell	5,117,212 A	5/1992	Yamamoto et al.
4,047,068 A	9/1977	Ress et al.	5,117,829 A	6/1992	Miller et al.
4,112,306 A	9/1978	Nunan	5,148,032 A	9/1992	Hernandez
4,129,784 A	12/1978	Tschunt et al.	5,166,531 A	11/1992	Huntzinger
4,139,777 A	2/1979	Rautenbach	5,189,687 A	2/1993	Bova et al.
4,197,510 A	4/1980	Szu	5,240,218 A	8/1993	Dye
4,220,866 A	9/1980	Symmons et al.	5,260,579 A	11/1993	Yasuda et al.
4,230,129 A	10/1980	LeVeen	5,260,581 A	11/1993	Lesyna et al.
4,256,966 A	3/1981	Heinz	5,278,533 A	1/1994	Kawaguchi
4,293,772 A	10/1981	Stieber	5,285,166 A	2/1994	Hiramoto et al.
4,336,505 A	6/1982	Meyer	5,317,164 A	5/1994	Kurokawa
4,342,060 A	7/1982	Gibson	5,336,891 A	8/1994	Crewe
4,345,210 A	8/1982	Tran	5,341,104 A	8/1994	Anton et al.
4,353,033 A	10/1982	Karasawa	5,349,198 A	9/1994	Takanaka
4,425,506 A	1/1984	Brown et al.	5,365,742 A	11/1994	Boffito et al.
4,490,616 A	12/1984	Cipollina et al.	5,374,913 A	12/1994	Pissantezky et al.
4,507,614 A	3/1985	Prono et al.	5,382,914 A	1/1995	Hamm et al.
4,507,616 A	3/1985	Blosser et al.	5,401,973 A	3/1995	McKeown et al.
4,589,126 A	5/1986	Augustsson et al.	5,405,235 A	4/1995	Lebre et al.
4,598,208 A	7/1986	Brunelli et al.	5,434,420 A	7/1995	McKeown et al.
4,628,523 A	12/1986	Heflin	5,440,133 A	8/1995	Moyers et al.
4,633,125 A	12/1986	Blosser et al.	5,451,794 A	9/1995	McKeown et al.
4,641,057 A	2/1987	Blosser et al.	5,461,773 A	10/1995	Kawaguchi
4,641,104 A	2/1987	Blosser et al.	5,463,291 A	10/1995	Carroll et al.
4,651,007 A	3/1987	Perusek et al.	5,464,411 A	11/1995	Schulte et al.
4,680,565 A	7/1987	Jahnke	5,492,922 A	2/1996	Palkowitz
4,705,955 A	11/1987	Mileikowsky	5,511,549 A	4/1996	Legg et al.
4,710,722 A	12/1987	Jahnke	5,521,469 A	5/1996	Laisne
4,726,046 A	2/1988	Nunan	5,538,942 A	7/1996	Koyama et al.
4,727,293 A *	2/1988	Asmussen H01J 27/16 118/723 MA	5,549,616 A	8/1996	Schulte et al.
4,734,653 A	3/1988	Jahnke	5,561,697 A	10/1996	Takafuji et al.
4,736,173 A	4/1988	Basil, Jr. et al.	5,585,642 A	12/1996	Britton et al.
4,737,727 A	4/1988	Yamada et al.	5,633,747 A	5/1997	Nikoonahad
4,739,173 A	4/1988	Blosser et al.	5,635,721 A	6/1997	Bardi et al.
4,745,367 A	5/1988	Dustmann et al.	5,668,371 A	9/1997	Deasy et al.
4,754,147 A	6/1988	Maughan et al.	5,672,878 A	9/1997	Yao
4,763,483 A	8/1988	Olsen	5,691,679 A	11/1997	Ackermann et al.
4,767,930 A	8/1988	Stieber et al.	5,726,448 A	3/1998	Smith et al.
4,769,623 A	9/1988	Marsing et al.	5,727,554 A	3/1998	Kalend et al.
4,771,208 A	9/1988	Jongen et al.	5,730,745 A	3/1998	Schulte et al.
4,783,634 A	11/1988	Yamamoto et al.	5,751,781 A	5/1998	Brown et al.
4,808,941 A	2/1989	Marsing	5,778,047 A	7/1998	Mansfield et al.
4,812,658 A	3/1989	Koehler	5,783,914 A	7/1998	Hiramoto et al.
4,843,333 A	6/1989	Marsing et al.	5,784,431 A	7/1998	Kalend et al.
4,845,371 A	7/1989	Stieber	5,797,924 A	8/1998	Schulte et al.
4,865,284 A	9/1989	Gosis et al.	5,811,944 A	9/1998	Sampayan et al.
4,868,843 A	9/1989	Nunan	5,818,058 A	10/1998	Nakanishi et al.
4,868,844 A	9/1989	Nunan	5,821,705 A	10/1998	Caporaso et al.
4,870,287 A	9/1989	Cole et al.	5,825,845 A	10/1998	Blair et al.
4,880,985 A	11/1989	Jones	5,841,237 A	11/1998	Alton
4,894,541 A	1/1990	Ono	5,846,043 A	12/1998	Spath
4,902,993 A	2/1990	Krevet	5,851,182 A	12/1998	Sahadevan
4,904,949 A	2/1990	Wilson	5,866,912 A	2/1999	Slater et al.
4,905,267 A	2/1990	Miller et al.	5,874,811 A	2/1999	Finlan et al.
4,917,344 A	4/1990	Prechter et al.	5,895,926 A	4/1999	Britton et al.
4,931,698 A	6/1990	Yoshida	5,920,601 A	7/1999	Nigg et al.
4,943,781 A	7/1990	Wilson et al.	5,929,458 A	7/1999	Nemezawa et al.
4,945,478 A	7/1990	Merickel et al.	5,963,615 A	10/1999	Egley et al.
4,968,915 A	11/1990	Wilson et al.	5,993,373 A	11/1999	Nonaka et al.
4,987,309 A	1/1991	Klasen et al.	6,008,499 A	12/1999	Hiramoto et al.
4,996,496 A	2/1991	Kitamura et al.	6,034,377 A	3/2000	Pu
5,006,759 A	4/1991	Krispel	6,057,655 A	5/2000	Jongen
5,010,562 A	4/1991	Hernandez et al.	6,061,426 A	5/2000	Linders et al.
5,012,111 A	4/1991	Ueda	6,064,807 A	5/2000	Arai et al.
5,017,789 A	5/1991	Young et al.	6,066,851 A	5/2000	Madono et al.
5,017,882 A	5/1991	Finlan	6,080,992 A	6/2000	Nonaka et al.
5,036,290 A	7/1991	Sonobe et al.	6,087,670 A	7/2000	Hiramoto et al.
5,039,057 A	8/1991	Prechter et al.	6,094,760 A	8/2000	Nonaka et al.
			6,118,848 A	9/2000	Reiffel
			6,140,021 A	10/2000	Nakasuji et al.
			6,144,875 A	11/2000	Schweikard et al.
			6,158,708 A	12/2000	Egley et al.
			6,207,952 B1	3/2001	Kan et al.

(56)

References Cited

U.S. PATENT DOCUMENTS

6,219,403 B1	4/2001	Nishihara	6,979,832 B2	12/2005	Yanagisawa et al.
6,222,905 B1	4/2001	Yoda et al.	6,984,835 B2	1/2006	Harada
6,241,671 B1	6/2001	Ritter et al.	6,992,312 B2	1/2006	Yanagisawa et al.
6,246,066 B1	6/2001	Yuehu	6,993,112 B2	1/2006	Hesse
6,256,591 B1	7/2001	Yoda et al.	7,008,105 B2	3/2006	Amann et al.
6,265,837 B1	7/2001	Akiyama et al.	7,011,447 B2	3/2006	Moyers
6,268,610 B1	7/2001	Pu	7,012,267 B2	3/2006	Moriyama et al.
6,278,239 B1	8/2001	Caporaso et al.	7,014,361 B1	3/2006	Ein-Gal
6,279,579 B1	8/2001	Riaziat et al.	7,026,636 B2	4/2006	Yanagisawa et al.
6,307,914 B1	10/2001	Kunieda et al.	7,041,479 B2	5/2006	Swartz et al.
6,316,776 B1	11/2001	Hiramoto et al.	7,045,781 B2	5/2006	Adamec et al.
6,366,021 B1	4/2002	Meddaugh et al.	7,049,613 B2	5/2006	Yanagisawa et al.
6,368,678 B1 *	4/2002	Bluck	7,053,389 B2	5/2006	Yanagisawa et al.
		C23C 16/26	7,054,801 B2	5/2006	Sakamoto et al.
		118/723 E	7,060,997 B2	6/2006	Norimine et al.
6,369,585 B2	4/2002	Yao	7,071,479 B2	7/2006	Yanagisawa et al.
6,380,545 B1	4/2002	Yan	7,073,508 B2	7/2006	Moyers
6,407,505 B1	6/2002	Bertsche	7,081,619 B2	7/2006	Bashkirov et al.
6,417,634 B1	7/2002	Bergstrom	7,084,410 B2	8/2006	Belousov et al.
6,433,336 B1	8/2002	Jongen et al.	7,091,478 B2	8/2006	Haberer
6,433,349 B2	8/2002	Akiyama et al.	7,102,144 B2	9/2006	Matsuda et al.
6,433,494 B1	8/2002	Kulish et al.	7,122,811 B2	10/2006	Matsuda et al.
6,441,569 B1	8/2002	Janzow	7,122,966 B2	10/2006	Norling et al.
6,443,349 B1	9/2002	Van Der Burg	7,122,978 B2	10/2006	Nakanishi et al.
6,465,957 B1	10/2002	Whitham et al.	7,135,678 B2	11/2006	Wang et al.
6,472,834 B2	10/2002	Hiramoto et al.	7,138,771 B2	11/2006	Bechthold et al.
6,476,403 B1	11/2002	Dolinskii et al.	7,154,107 B2	12/2006	Yanagisawa et al.
6,492,922 B1	12/2002	New	7,154,108 B2	12/2006	Tadokoro et al.
6,493,424 B2	12/2002	Whitham	7,154,991 B2	12/2006	Earnst et al.
6,498,444 B1	12/2002	Hanna et al.	7,162,005 B2	1/2007	Bjorkholm
6,501,981 B1	12/2002	Schweikard et al.	7,173,264 B2	2/2007	Moriyama et al.
6,519,316 B1	2/2003	Collins	7,173,265 B2	2/2007	Miller et al.
6,593,696 B2	7/2003	Ding et al.	7,173,385 B2	2/2007	Caporaso et al.
6,594,336 B2	7/2003	Nishizawa et al.	7,186,991 B2	3/2007	Kato et al.
6,600,164 B1	7/2003	Badura et al.	7,193,227 B2	3/2007	Hiramoto et al.
6,617,598 B1	9/2003	Matsuda	7,199,382 B2	4/2007	Rigney et al.
6,621,889 B1	9/2003	Mostafavi	7,208,748 B2	4/2007	Sliski et al.
6,627,875 B2 *	9/2003	Afeyan	7,212,608 B2	5/2007	Nagamine et al.
		G01N 30/72	7,212,609 B2	5/2007	Nagamine et al.
		250/282	7,221,733 B1	5/2007	Takai et al.
6,639,234 B1	10/2003	Badura et al.	7,227,161 B2	6/2007	Matsuda et al.
6,646,383 B2	11/2003	Bertsche et al.	7,247,869 B2	7/2007	Tadokoro et al.
6,670,618 B1	12/2003	Hartmann et al.	7,257,191 B2	8/2007	Sommer
6,683,318 B1	1/2004	Haberer et al.	7,259,529 B2	8/2007	Tanaka
6,683,426 B1	1/2004	Kleeven	7,262,424 B2	8/2007	Moriyama et al.
6,693,283 B2	2/2004	Eickhoff et al.	7,274,018 B2	9/2007	Adamec et al.
6,710,362 B2	3/2004	Kraft et al.	7,280,633 B2	10/2007	Cheng et al.
6,713,773 B1	3/2004	Lyons et al.	7,295,649 B2	11/2007	Johnsen
6,713,976 B1	3/2004	Zumoto et al.	7,297,967 B2	11/2007	Yanagisawa et al.
6,717,162 B1	4/2004	Jongen	7,301,162 B2	11/2007	Matsuda et al.
6,736,831 B1	5/2004	Hartmann et al.	7,307,264 B2	12/2007	Brusasco et al.
6,745,072 B1	6/2004	Badura et al.	7,318,805 B2	1/2008	Schweikard et al.
6,769,806 B2	8/2004	Moyers	7,319,231 B2	1/2008	Moriyama et al.
6,774,383 B2	8/2004	Norimine et al.	7,319,336 B2	1/2008	Baur et al.
6,777,689 B2	8/2004	Nelson	7,331,713 B2	2/2008	Moyers
6,777,700 B2	8/2004	Yanagisawa et al.	7,332,880 B2	2/2008	Ina et al.
6,780,149 B1	8/2004	Schulte	7,345,291 B2	3/2008	Kats
6,799,068 B1	9/2004	Hartmann et al.	7,345,292 B2	3/2008	Moriyama et al.
6,800,866 B2	10/2004	Amemiya et al.	7,348,557 B2	3/2008	Armit
6,803,585 B2	10/2004	Glukhoy et al.	7,348,579 B2	3/2008	Pedroni
6,803,591 B2	10/2004	Muramatsu et al.	7,351,988 B2	4/2008	Naumann et al.
6,814,694 B1	11/2004	Pedroni	7,355,189 B2	4/2008	Yanagisawa et al.
6,822,244 B2	11/2004	Belousov et al.	7,361,607 B2 *	4/2008	Yamaguchi
6,853,142 B2	2/2005	Chistyakov			H01L 21/02057
6,853,703 B2	2/2005	Svatos et al.	7,368,740 B2	5/2008	216/58
6,864,770 B2	3/2005	Nemoto et al.	7,372,053 B2	5/2008	Belousov et al.
6,865,254 B2	3/2005	Nafstadius	7,378,672 B2	5/2008	Yamashita et al.
6,873,123 B2	3/2005	Marchand et al.	7,381,979 B2	6/2008	Harada
6,891,177 B1	5/2005	Kraft et al.	7,397,054 B2	7/2008	Yamashita et al.
6,891,924 B1	5/2005	Yoda et al.	7,397,901 B1	7/2008	Natori et al.
6,894,300 B2	5/2005	Reimoser et al.	7,398,309 B2	7/2008	Johnsen
6,897,451 B2	5/2005	Kaercher et al.	7,402,822 B2	7/2008	Baumann et al.
6,914,396 B1	7/2005	Symons et al.	7,402,823 B2	7/2008	Guertin et al.
6,936,832 B2	8/2005	Norimine et al.	7,402,824 B2	7/2008	Guertin et al.
6,953,943 B2	10/2005	Yanagisawa et al.	7,402,963 B2	7/2008	Sliski
6,965,116 B1	11/2005	Wagner et al.	7,405,407 B2	7/2008	Hiramoto et al.
6,969,194 B1	11/2005	Nafstadius	7,425,717 B2	9/2008	Matsuda et al.
			7,432,516 B2	10/2008	Peggs et al.
			7,439,528 B2	10/2008	Nishiuchi et al.

(56)

References Cited

U.S. PATENT DOCUMENTS

7,446,328 B2	11/2008	Rigney et al.	7,786,451 B2	8/2010	Ward et al.
7,446,490 B2	11/2008	Jongen et al.	7,786,452 B2	8/2010	Ward et al.
7,449,701 B2	11/2008	Fujimaki et al.	7,789,560 B2	9/2010	Moyers
7,453,076 B2	11/2008	Welch et al.	7,791,051 B2	9/2010	Belousov et al.
7,465,944 B2	12/2008	Ueno et al.	7,796,731 B2	9/2010	Nord et al.
7,466,085 B2	12/2008	Nutt	7,801,269 B2	9/2010	Cravens et al.
7,468,506 B2	12/2008	Rogers et al.	7,801,270 B2	9/2010	Nord et al.
7,473,913 B2	1/2009	Hermann et al.	7,801,988 B2	9/2010	Baumann et al.
7,476,867 B2	1/2009	Fritsch et al.	7,807,982 B2	10/2010	Nishiuchi et al.
7,476,883 B2	1/2009	Nutt	7,809,107 B2	10/2010	Nord et al.
7,482,606 B2	1/2009	Groezinger et al.	7,812,319 B2	10/2010	Diehl et al.
7,492,556 B2	2/2009	Atkins et al.	7,812,326 B2	10/2010	Groezinger et al.
7,507,975 B2	3/2009	Mohr	7,816,657 B2	10/2010	Hansmann et al.
7,525,104 B2	4/2009	Harada	7,817,778 B2	10/2010	Nord et al.
7,541,905 B2	6/2009	Antaya	7,817,836 B2	10/2010	Chao et al.
7,547,901 B2	6/2009	Guertin et al.	7,834,334 B2	11/2010	Groezinger et al.
7,554,096 B2	6/2009	Ward et al.	7,834,336 B2	11/2010	Boeh et al.
7,554,097 B2	6/2009	Ward et al.	7,835,494 B2	11/2010	Nord et al.
7,555,103 B2	6/2009	Johnsen	7,835,502 B2	11/2010	Spence et al.
7,557,358 B2	7/2009	Ward et al.	7,839,972 B2	11/2010	Ruchala et al.
7,557,359 B2	7/2009	Ward et al.	7,839,973 B2	11/2010	Nord et al.
7,557,360 B2	7/2009	Ward et al.	7,848,488 B2	12/2010	Mansfield
7,557,361 B2	7/2009	Ward et al.	7,857,756 B2	12/2010	Warren et al.
7,560,715 B2	7/2009	Pedroni	7,860,216 B2	12/2010	Jongen et al.
7,560,717 B2	7/2009	Matsuda et al.	7,860,550 B2	12/2010	Saracen et al.
7,567,694 B2	7/2009	Lu et al.	7,868,301 B2	1/2011	Diehl
7,574,251 B2	8/2009	Lu et al.	7,875,861 B2	1/2011	Huttenberger et al.
7,576,499 B2	8/2009	Caporaso et al.	7,875,868 B2	1/2011	Moriyama et al.
7,579,603 B2	8/2009	Birgy et al.	7,881,431 B2	2/2011	Aoi et al.
7,579,610 B2	8/2009	Groezinger et al.	7,894,574 B1	2/2011	Nord et al.
7,582,866 B2	9/2009	Furuhashi et al.	7,906,769 B2	3/2011	Blasche et al.
7,582,885 B2	9/2009	Katagiri et al.	7,914,734 B2	3/2011	Livingston
7,582,886 B2	9/2009	Trbojevic	7,919,765 B2	4/2011	Timmer
7,586,112 B2	9/2009	Chiba et al.	7,920,040 B2	4/2011	Antaya et al.
7,598,497 B2	10/2009	Yamamoto et al.	7,920,675 B2	4/2011	Lomax et al.
7,609,009 B2	10/2009	Tanaka et al.	7,928,415 B2	4/2011	Bert et al.
7,609,809 B2	10/2009	Kapatoes et al.	7,934,869 B2	5/2011	Ivanov et al.
7,609,811 B1	10/2009	Siljamaki et al.	7,940,881 B2	5/2011	Jongen et al.
7,615,942 B2	11/2009	Sanders et al.	7,943,913 B2	5/2011	Balakin
7,626,347 B2	12/2009	Sliski	7,947,969 B2	5/2011	Pu
7,629,598 B2	12/2009	Harada	7,949,096 B2	5/2011	Cheng et al.
7,639,853 B2	12/2009	Olivera et al.	7,950,587 B2	5/2011	Henson et al.
7,639,854 B2	12/2009	Schnarr et al.	7,960,710 B2	6/2011	Kruip et al.
7,643,661 B2	1/2010	Ruchala et al.	7,961,844 B2	6/2011	Takeda et al.
7,656,258 B1	2/2010	Antaya et al. H01F 6/00 313/62	7,977,648 B2	7/2011	Westerly et al.
7,659,521 B2	2/2010	Pedroni	7,977,656 B2	7/2011	Fujimaki et al.
7,659,528 B2	2/2010	Uematsu	7,982,198 B2	7/2011	Nishiuchi et al.
7,668,291 B2	2/2010	Nord et al.	7,982,416 B2	7/2011	Tanaka et al.
7,672,429 B2	3/2010	Urano et al.	7,984,715 B2	7/2011	Moyers
7,679,073 B2	3/2010	Urano et al.	7,986,768 B2	7/2011	Nord et al.
7,682,078 B2	3/2010	Rietzel	7,987,053 B2	7/2011	Schaffner
7,692,166 B2	4/2010	Muraki et al.	7,989,785 B2	8/2011	Emhofer et al.
7,692,168 B2	4/2010	Moriyama et al.	7,990,524 B2	8/2011	Jureller et al.
7,696,499 B2	4/2010	Miller et al.	7,997,553 B2	8/2011	Sloan et al.
7,696,847 B2	4/2010	Antaya	8,002,466 B2	8/2011	Von Neubeck et al.
7,701,677 B2	4/2010	Schultz et al.	8,003,964 B2	8/2011	Stark et al.
7,709,818 B2	5/2010	Matsuda et al.	8,009,803 B2	8/2011	Nord et al.
7,710,051 B2	5/2010	Caporaso et al.	8,009,804 B2	8/2011	Siljamaki et al.
7,718,982 B2	5/2010	Sliski	8,039,822 B2	10/2011	Rietzel
7,728,311 B2	6/2010	Gall	8,041,006 B2	10/2011	Boyden et al.
7,746,978 B2	6/2010	Cheng et al.	8,044,364 B2	10/2011	Yamamoto
7,755,305 B2	7/2010	Umezawa et al.	8,049,187 B2	11/2011	Tachikawa
7,759,642 B2	7/2010	Nir	8,053,508 B2	11/2011	Korkut et al.
7,763,867 B2	7/2010	Birgy et al.	8,053,739 B2	11/2011	Rietzel
7,767,988 B2	8/2010	Kaiser et al.	8,053,745 B2	11/2011	Moore
7,770,231 B2	8/2010	Prater et al.	8,053,746 B2	11/2011	Timmer et al.
7,772,577 B2	8/2010	Saito et al.	8,067,748 B2	11/2011	Balakin
7,773,723 B2	8/2010	Nord et al.	8,069,675 B2	12/2011	Radovinsky et al.
7,773,788 B2	8/2010	Lu et al.	8,071,966 B2	12/2011	Kaiser et al.
7,778,488 B2	8/2010	Nord et al.	8,080,801 B2	12/2011	Safai
7,783,010 B2	8/2010	Clayton	8,085,899 B2	12/2011	Nord et al.
7,784,127 B2	8/2010	Kuro et al.	8,089,054 B2	1/2012	Balakin
7,786,442 B2 *	8/2010	Norling H05H 13/00 250/363.03	8,093,564 B2	1/2012	Balakin
			8,093,568 B2	1/2012	Mackie et al.
			8,111,125 B2	2/2012	Antaya et al.
			8,129,699 B2	3/2012	Balakin
			8,144,832 B2	3/2012	Balakin
			8,173,981 B2	5/2012	Trbojevic
			8,188,688 B2	5/2012	Balakin

(56)

References Cited

U.S. PATENT DOCUMENTS

8,198,607 B2 6/2012 Balakin
 8,222,613 B2 7/2012 Tajiri et al.
 8,227,768 B2 7/2012 Smick et al.
 8,232,536 B2 7/2012 Harada
 8,288,742 B2 10/2012 Balakin
 8,291,717 B2 10/2012 Radovinsky et al.
 8,294,127 B2 10/2012 Tachibana
 8,304,725 B2 11/2012 Komuro et al.
 8,304,750 B2 11/2012 Preikszas et al.
 8,309,941 B2 11/2012 Balakin
 8,330,132 B2 12/2012 Guertin et al.
 8,334,520 B2 12/2012 Otaka et al.
 8,335,397 B2 12/2012 Takane et al.
 8,344,340 B2 1/2013 Gall
 8,350,214 B2 1/2013 Otaki et al.
 8,368,038 B2 2/2013 Balakin
 8,368,043 B2 2/2013 Havelange et al.
 8,373,143 B2 2/2013 Balakin
 8,373,145 B2 2/2013 Balakin
 8,378,299 B2 2/2013 Frosien
 8,378,321 B2 2/2013 Balakin
 8,382,943 B2 2/2013 Clark
 8,389,949 B2 3/2013 Harada et al.
 8,399,866 B2 3/2013 Balakin
 8,405,042 B2 3/2013 Honda et al.
 8,405,056 B2 3/2013 Amaldi et al.
 8,415,643 B2 4/2013 Balakin
 8,416,918 B2 4/2013 Nord et al.
 8,421,041 B2 4/2013 Balakin
 8,426,833 B2 4/2013 Trbojevic
 8,436,323 B2 5/2013 Iseki et al.
 8,440,987 B2 5/2013 Stephani et al.
 8,445,872 B2 5/2013 Behrens et al.
 8,466,441 B2 6/2013 Iwata et al.
 8,472,583 B2 6/2013 Star-Lack et al.
 8,483,357 B2 7/2013 Siljamaki et al.
 8,487,278 B2 7/2013 Balakin
 8,552,406 B2 10/2013 Phaneuf et al.
 8,552,408 B2 10/2013 Hanawa et al.
 8,569,717 B2 10/2013 Balakin
 8,581,215 B2 11/2013 Balakin
 8,581,523 B2 11/2013 Gall et al.
 8,653,314 B2 2/2014 Pelati et al.
 8,653,473 B2 2/2014 Yajima
 8,952,634 B2* 2/2015 Sliski H05H 13/02
 315/502

2002/0172317 A1 11/2002 Maksimchuk et al.
 2003/0048080 A1 3/2003 Amemiya et al.
 2003/0125622 A1 7/2003 Schweikard et al.
 2003/0136924 A1 7/2003 Kraft et al.
 2003/0152197 A1 8/2003 Moyers
 2003/0163015 A1 8/2003 Yanagisawa et al.
 2003/0183779 A1 10/2003 Norimine et al.
 2003/0234369 A1 12/2003 Glukhoy
 2004/0000650 A1 1/2004 Yanagisawa et al.
 2004/0017888 A1 1/2004 Seppi et al.
 2004/0056212 A1 3/2004 Yanagisawa et al.
 2004/0061077 A1 4/2004 Muramatsu et al.
 2004/0061078 A1 4/2004 Muramatsu et al.
 2004/0085023 A1 5/2004 Chistyakov
 2004/0098445 A1 5/2004 Baumann et al.
 2004/0111134 A1 6/2004 Muramatsu et al.
 2004/0118081 A1 6/2004 Reimoser et al.
 2004/0149934 A1 8/2004 Yanagisawa et al.
 2004/0159795 A1 8/2004 Kaercher et al.
 2004/0173763 A1 9/2004 Moriyama et al.
 2004/0174958 A1 9/2004 Moriyama et al.
 2004/0183033 A1 9/2004 Moriyama et al.
 2004/0183035 A1 9/2004 Yanagisawa et al.
 2004/0200982 A1 10/2004 Moriyama et al.
 2004/0200983 A1 10/2004 Fujimaki et al.
 2004/0213381 A1 10/2004 Harada
 2004/0227104 A1 11/2004 Matsuda et al.
 2004/0232356 A1 11/2004 Norimine et al.
 2004/0240626 A1 12/2004 Moyers

2005/0058245 A1 3/2005 Ein-Gal
 2005/0089141 A1 4/2005 Brown
 2005/0161618 A1 7/2005 Pedroni
 2005/0184686 A1 8/2005 Caporaso et al.
 2005/0228255 A1 10/2005 Saracen et al.
 2005/0234327 A1 10/2005 Saracen et al.
 2005/0247890 A1 11/2005 Norimine et al.
 2006/0017015 A1 1/2006 Sliski et al.
 2006/0067468 A1 3/2006 Rietzel
 2006/0126792 A1 6/2006 Li
 2006/0145088 A1 7/2006 Ma
 2006/0175991 A1 8/2006 Fujisawa
 2006/0284562 A1 12/2006 Hruby et al.
 2007/0001128 A1 1/2007 Sliski et al.
 2007/0013273 A1 1/2007 Albert et al.
 2007/0014654 A1 1/2007 Haverfield et al.
 2007/0023699 A1 2/2007 Yamashita et al.
 2007/0029510 A1 2/2007 Hermann et al.
 2007/0051904 A1 3/2007 Kaiser et al.
 2007/0061937 A1 3/2007 Curle
 2007/0092812 A1 4/2007 Caporaso et al.
 2007/0145916 A1 6/2007 Caporaso et al.
 2007/0171015 A1 7/2007 Antaya
 2007/0181519 A1 8/2007 Khoshnevis
 2007/0284548 A1 12/2007 Kaiser et al.
 2008/0093567 A1 4/2008 Gall
 2008/0218102 A1 9/2008 Sliski
 2009/0096179 A1 4/2009 Stark et al.
 2009/0140671 A1 6/2009 O'Neal, III et al.
 2009/0140672 A1 6/2009 Gall et al.
 2009/0200483 A1 8/2009 Gall et al.
 2010/0045213 A1 2/2010 Sliski
 2010/0230617 A1 9/2010 Gall
 2010/0308235 A1 12/2010 Sliski
 2011/0299919 A1 12/2011 Stark
 2013/0053616 A1 2/2013 Gall
 2013/0127375 A1 5/2013 Sliski
 2013/0131424 A1 5/2013 Sliski
 2013/0237425 A1 9/2013 Leigh et al.
 2014/0097920 A1 4/2014 Goldie et al.

FOREIGN PATENT DOCUMENTS

CN 1816243 A 8/2006
 CN 101932361 12/2010
 CN 101933405 12/2010
 CN 101933405 A 12/2010
 CN 101933406 12/2010
 CN 101061759 5/2011
 CN ZL200880125918.1 7/2013
 CN 103347363 A 10/2013
 DE 27 53 397 6/1978
 DE 31 48 100 6/1983
 DE 35 30 446 8/1984
 DE 41 01 094 C1 5/1992
 DE 4411171 10/1995
 EP 0194728 9/1986
 EP 0194728 A1 9/1986
 EP 0 277 521 8/1988
 EP 0 208 163 B1 1/1989
 EP 0 222 786 7/1990
 EP 0 221 987 1/1991
 EP 0499253 8/1992
 EP 0499253 A2 8/1992
 EP 0 306 966 4/1995
 EP 0 388 123 5/1995
 EP 0 465 597 5/1997
 EP 0 864 337 9/1998
 EP 0 776 595 12/1998
 EP 1 069 809 1/2001
 EP 1 153 398 A1 4/2001
 EP 1 294 445 3/2003
 EP 1 348 465 10/2003
 EP 1 358 908 11/2003
 EP 1 371 390 12/2003
 EP 1 402 923 3/2004
 EP 0 911 064 6/2004
 EP 1 430 932 6/2004
 EP 1 454 654 9/2004

(56)

References Cited

FOREIGN PATENT DOCUMENTS			
EP	1 454 655	A2	9/2004
EP	1 454 656		9/2004
EP	1 454 657		9/2004
EP	1 477 206		11/2004
EP	1 605 742	A1	12/2005
EP	1 738 798		1/2007
EP	1826778		8/2007
EP	1826778	A2	8/2007
EP	1949404		7/2008
EP	2183753		7/2008
EP	2394498		2/2010
EP	2227295		9/2010
EP	2232961		9/2010
EP	2232962		9/2010
EP	2227295		5/2011
EP	2363170		9/2011
EP	2363171		9/2011
EP	1672670		2/2014
FR	2 560 421		8/1985
FR	2911843		8/2008
FR	2911843	A1	8/2008
GB	957342		5/1964
GB	2015821	A	9/1979
GB	2 361 523		10/2001
JP	43-23267		10/1968
JP	47-0028762		8/1972
JP	S47-028762		8/1972
JP	48-108098		12/1973
JP	U48-108098		12/1973
JP	61-80800		4/1986
JP	61-225798		10/1986
JP	A61-225798		10/1986
JP	62-150804		7/1987
JP	62-186500		8/1987
JP	63-149344		6/1988
JP	63-218200		9/1988
JP	63-226899		9/1988
JP	1-276797		11/1989
JP	4-94198		3/1992
JP	04-128717		4/1992
JP	04-129768		4/1992
JP	04-273409		9/1992
JP	04-337300		11/1992
JP	05-341352		12/1993
JP	06-233831		8/1994
JP	06233831		8/1994
JP	06233831	A	8/1994
JP	06-036893		10/1994
JP	07-260939		10/1995
JP	2007-260939	A	10/1995
JP	07260939		10/1995
JP	08-173890		7/1996
JP	08-264298		10/1996
JP	09-162585		6/1997
JP	10-071213		3/1998
JP	11-47287		2/1999
JP	11-102800		4/1999
JP	11-243295		9/1999
JP	2000-243309		9/2000
JP	2000-294399		10/2000
JP	2001-6900		1/2001
JP	2001-129103		5/2001
JP	2002-164686		6/2002
JP	2003-504628		2/2003
JP	A2003-504628		2/2003
JP	2004-031115		1/2004
JP	2004-031115	A	1/2004
JP	2006-032282		2/2006
JP	2009-515671		4/2009
JP	S48-108098		3/2010
JP	2010-536130		11/2010
JP	2011-505191		2/2011
JP	2011-505670		2/2011
JP	2011-507151		3/2011
JP	5046928		7/2012

JP	5607536		9/2014
JP	5607536	B2	10/2014
SU	300137		11/1969
SU	569 635		8/1977
TW	200930160		7/2009
TW	200934682		8/2009
TW	200939908		9/2009
TW	200940120		10/2009
WO	WO 86/07229		12/1986
WO	WO90/12413		10/1990
WO	WO 92/03028		2/1992
WO	WO 93/02536		2/1993
WO	WO 98/17342		4/1998
WO	WO99/39385		8/1999
WO	WO 00/40064		7/2000
WO	WO 00/49624		8/2000
WO	WO 01/05199		1/2001
WO	WO 01/26569		4/2001
WO	WO 02/07817		1/2002
WO	WO 03/039212		5/2003
WO	WO 03/092812		11/2003
WO	WO 2004/026401		4/2004
WO	WO 2004/101070		11/2004
WO	WO 2006/012467		2/2006
WO	2007/061937		5/2007
WO	WO2007/061937		5/2007
WO	WO2007/084701		7/2007
WO	WO2007/130164		11/2007
WO	WO2007/145906		12/2007
WO	WO-2007145906	A2	12/2007
WO	WO2008/030911		3/2008
WO	WO 2008/081480		10/2008
WO	WO 2009/048745		4/2009
WO	WO2009-070173		6/2009
WO	WO2009/070588		6/2009
WO	WO2009-070588		6/2009
WO	WO2009-073480		6/2009
WO	WO 2009/048745		11/2009

OTHER PUBLICATIONS

First Office Action (Chinese Translation) for CN 201310240538.5, 4 pages dated May 20, 2015.

First Office Action (English Translation) for CN 201310240538.5, 6 pages dated May 20, 2015.

Second Office Action (Chinese Translation) for CN 201310240538.5, 5 pages dated Dec. 4, 2015.

Examination Report for CA 2706,952, 5 pages dated Mar. 23, 2015.

Communication pursuant to Article 71(3) EPC FOR EP 08855024.9, 35 pages dated Sep. 19, 2016.

Communication pursuant to Article 94(3) EPC for EP 08855024.9, 6 pages dated Jul. 9, 2015.

Communication pursuant to Article 94(3) EPC for EP 08855024.9, 7 pages dated Apr. 6, 2016.

U.S. Provisional application No. 60/850,565, filed on Oct. 10, 2006, including copy of application as filed, transaction history from Pair (PTO website).

U.S. Provisional application No. 60/991,454, filed on Nov. 30, 2007, including copy of application as filed, transaction history from Pair (PTO website).

Written Opinion for PCT/US2007/001628, dated Feb. 18, 2008 (11 pages).

Cosgrove et al., "Microdosimetric Studies on the Orsay Proton Synchrocyclotron at 73 and 200 MeV," Radiation Protection Dosimetry, 1997, 70(1-4):493-496.

Coupland, High-field (5 T) pulsed superconducting dipole magnet, Proceedings of the Institution of Electrical Engineers, Jul. 1974, 121(7):771-778.

Coutrakon et al. Proton Synchrotrons for Cancer Therapy, Application of Accelerators in Research and Industry- Sixteenth International Conf., American Institute of Physics, Nov. 1-5, 2000, vol. 576, pp. 861-864.

Coutrakon et al., a prototype beam delivery system for the proton medical accelerator at Loma Linda, Medical Physics, Nov/Dec 1991, 18(6):1093-1099.

(56)

References Cited

OTHER PUBLICATIONS

- Cuttone, Applications of a Particle Accelerators in Medical Physics, Istituto Nazionale di Fisica Nucleare-Laboratori Nazionali del Sud, V.S. Sofia, 44 Catania, Italy, Jan. 2010, 17 pages.
- Cuttone, G., "Applications of a Particle Accelerators in Medical Physics," Istituto Nazionale di Fisica Nucleare-Laboratori Nazionali del Sud, V.S. Sofia, 44 Catania, Italy (17 pp.). No. date.
- Dahl P, Superconducting Magnet System, American Institute of Physics, AIP Conference Proceedings, 1987-1988, 2: 1329-1376.
- Dialog Search, Jan. 31, 2005, 17 pages.
- Dugan et al., Tevatron Status IEEE, Particle Accelerator Conference, Accelerator Science & Technology, 1989, pp. 426-430.
- Eickhoff et al., the Proposed Accelerator Facility for Light Ion Cancer Therapy in Heidelberg, Proceedings of the 1999 Particle Accelerator Conference, New York, 1999, pp. 2513-2515.
- Enchevich et al., Minimizing Phase Losses in the 680 MeV Synchrocyclotron by Correcting the Accelerating Voltage Amplitude, Atomnava Energiva, 1969, 26:(3):315-316.
- Endo et al., Compact Proton and Carbon Ion Synchrotrons for Radiation Therapy, Proceedings of EPAC 2002, Paris France, 2002, pp. 2733-2735.
- European Communication from corresponding European application No. 11165422.4 dated Sep. 2, 2011 (5 pages).
- European Communication from corresponding European application No. 11165423.2 dated Sep. 2, 2011 (5 pages).
- European Communication from European application No. 06838033.6 dated Apr. 20, 2010 (7 pages).
- European Communication from European application No. 07868958.5, dated Nov. 26, 2010 (50 pages).
- European Patent Office communication from European application No. 08855024.9, dated Jul. 30, 2010 (2 pages).
- European Patent Office communication from European application No. 07868958.5, dated Jul. 16, 2010 (2 pages).
- European Patent Office communication from European application No. 08856764.9, dated Jul. 30, 2010 (2 pages).
- European Search Report from corresponding European application No. 11165422.4 dated Aug. 8, 2011 (118 pages).
- European Search Report from corresponding European application No. 11165423.2 dated Aug. 8, 2011 (118 pages).
- File History of U.S. Pat. No. 8,581,523 (downloaded from Pair Mar. 21, 2017).
- File History of U.S. Pat. No. 8,970,137 (downloaded from Pair Mar. 21, 2017).
- Flanz et al., "Operation of a Cyclotron Based Proton Therapy Facility", Massachusetts General Hospital, Boston, Ma 02114, pp. 1-4, retrieved from Internet in 2009.
- Flanz et al., Large Medical Gantries, Particle Accelerator Conference, Massachusetts General Hospital, 1995, pp. 1-5.
- Flanz et al., the Northeast Proton Therapy Center at Massachusetts General Hospital, Fifth Workshop on Heavy Charge Particles in Biology and Medicine, Gsi, Darmstadt, Aug. 1995, 11 pp.
- Flanz et al., Treating Patients with the NPTC Accelerator Based Proton Treatment Facility, Proceedings of the 2003 Particle Accelerator Conference, 2003, pp. 690-693.
- Flanz, et al., "Scanning Beam Technologies", PTCOG 2008, 28 pages.
- Flood and Frazier, The Wide-Band Driven RF System for the Berkeley 88-Inch Cyclotron, American Institute of Physics, Conference Proceedings, No. 9, 1972, 459-466.
- Foster and Kashikhin, Superconducting Superferric Dipole Magnet with Cold Iron Core for the VLHC, IEEE Transactions on Applied Superconductivity, Mar. 2002, 12(1):111-115.
- Friesel et al., Design and Construction Progress on the IUCF Midwest Proton Radiation Institute, Proceedings of EPAC 2002, 2002, pp. 2736-2738.
- Fukumoto et al., A Proton Therapy Facility Plan Cyclotrons and their Applications, Proceedings of the 13th International Conference, Vancouver, Canada, Jul. 6-10, 1992, pp. 258-261.
- Fukumoto, Cyclotron Versus Synchrotron for Proton Beam Therapy, KEK Prepr., No. 95-122, Oct. 1995, pp. 533-536.
- Gordon, et. al., Design Study for a Compact 200 MeV Cyclotron, AIP Conference Proceedings Sixth International Cyclotron Conference, No. 9, pp. 78-86 (1972).
- Gordon, M. M., Extraction Studies for a 250 MeV Superconducting Synchrocyclotron, Proceedings of the 1987 IEEE Particle Accelerator Conference: Accelerator Engineering and Technology, pp. 1255-1257 (1987).
- Goto et al., Progress on the Sector Magnets for the Riken SRC, American Institute of Physics, 714 CP600, Cyclotrons and Their Applications 2001, Sixteenth International Conference, 2001, pp. 319-323.
- Graffman et al., Acta Radial. Therapy Phys. Biol. 1970, 9, 1 (1970).
- Graffman et al., Design Studies for a 200 MeV Proton Clinic for Radiotherapy, AIP Conference Proceedings: Cyclotrons—1972, 1972, No. 9, pp. 603-615.
- Graffman, et. al. Proton radiotherapy with the Uppsala cyclotron. Experience and plans Strahlentherapie, 1985, 161(12):764-770.
- Hede, Research Groups Promoting Proton Therapy Lite, Journal of the National Cancer Institute, Dec. 6, 2006, 98(23):1682-1684.
- Heinz, Superconducting Pulsed Magnetic Systems for High-Energy Synchrotrons, Proceedings of the Fourth International Cryogenic Engineering Conference, May 24-26, 1972, pp. 55-63.
- Hentschel et al., Plans for the German National Neutron Therapy Centre with a Hospital-Based 70 MeV Proton Cyclotron at University Hospital Essen/Germany, Cyclotrons and their Applications, Proceedings of the Fifteenth International Conference on Cyclotrons and their Applications, Caen, Franco, Jun. 14-19, 1998, pp. 21-23.
- Hepburn et al., Superconducting Cyclotron Neutron Source for Therapy, International Journal of Radiation Oncology Biology Physics, vol. 3 complete, 1977, pp. 387-391.
- Hirabayashi, Development of Superconducting Magnets for Beam Lines and Accelerator at KEK, IEEE Transaction on Magnetics, Jan. 1981, Mag-17(1):728-731.
- International Search Report and Written Opinion for PCT application No. PCT/US2008/084695 dated Jan. 26, 2009 (15 pages).
- International Search Report and Written Opinion from corresponding PCT application No. PCT/US2008/084695 dated Jan. 26, 2009 (13 pages).
- Ishibashi and McInturff, Stress Analysis of Superconducting 1 OT Magnets for Synchrotron, Proceedings of the Ninth International Cryogenic Engineering Conference, May 11-14, 1982, pp. 513-516.
- Ishibashi and McInturff, Winding Design Study of Superconducting 10 T Dipoles for a Synchrotron, IEEE Transactions on Magnetics, May 1983, Mag-19(3):1364-1367.
- Jahnke et al., First Superconducting Prototype Magnets for a Compact Synchrotron Radiation Source in Operation, IEEE Transactions on Magnetics, Mar. 1988, 24(2):1230-1232.
- Japanese Office action with English translation from corresponding Japanese application No. 2010- 536130 dated Jun. 4, 2013 (8 pages).
- Japanese Office Action with English translation from corresponding Japanese application No. 2010- 536130 dated Feb. 10, 2014 (9 pages).
- Jones and Dershem, Synchrotron Radiation from Proton in a 20 TEV, 10 TESLA Superconducting Super Collider Proceedings of the 12th International Conference on High-Energy Accelerator, Aug. 11-16, 1983, pp. 138-140.
- Jones and Mills, The South African National Accelerator Centre: Particle Therapy and Isotope Production Programmes, Radiation Physics and Chemistry, Apr.- Jun. 1998, 51 (4-6):571578.
- Jones et al., Status Report of the NAC Particle Therapy Programme, Strahlentherapie and Onkologie, vol. 175, Suppl. II, Jun. 1999, pp. 30-32.
- Jones, Present Status and Future Trends of Heavy Particle Radiotherapy, Cyclotrons and their Applications 1998, Proceedings of the Fifteenth International Conference on Cyclotrons and their Applications, Jun. 14-19, 1998, pp. 13-20.
- Jones, Progress with the 200 MeV Cyclotron Facility at the National Accelerator Centre, Commission of the European Communities Radiation Protection Proceedings, Fifth Symposium on Neutron Dosimetry, Sep. 17-21, 1984, vol. II, pp. 989-998.

(56)

References Cited

OTHER PUBLICATIONS

- Jongen et al., Development of a Low-cost Compact Cyclotron System for Proton Therapy, National Institute of Radiol. Sci, 1991, No. 81, DD. 189-200.
- Jongen et al., Progress report on the IBA-SHI small cyclotron for cancer therapy Nuclear Instruments and Methods in Physics Research, Section B, vol. 79, issue 1-4, 1993, pp. 885-889.
- Jongen et al., the proton therapy system for MGH's NPTC: equipment description and progress report, Bulletin du Cancer/Radiotherapie, Proceedings of the meeting of the European Heavy Particle Therapy Group, 1996, 83(Suppl. 1):219-222.
- Jongen et al., The proton therapy system for the NPTC: Equipment Description and progress report, Nuclear Instruments and methods in physics research, 1996, Section B, 113(1): 522-525.
- Kanai et al., Three-dimensional Beam Scanning for Proton Therapy, Nuclear Instruments and Methods in Physic Research, Sep. 1, 1983, The Netherlands, 214(23):491-496.
- Karlin et al., Medical Radiology (Moscow), 1983, 28, 13.
- Karlin et al., The State and Prospects in the Development of the Medical Proton Tract on the Synchrocyclotron in Gatchina, Med. Radial., Moscow, 28(3):28-32 (Mar. 1983)(German with English Abstract on end of page 32).
- Kats and Druzhinin, Comparison of Methods for Irradiation Prone Patients, Atomic Energy, Feb. 2003, 94(2): 120-123.
- Kats and Onosovskii, A Planar Magneto-optical System for the Irradiation of a Lying Patient with a Proton Beam from Various Directions, Instruments and Experimental Techniques, 1996, 39(1):127-131.
- Kats and Onosovskii, A Simple, Compact, Flat System for the Irradiation of a Lying Patient with a Proton Beam from Different Directions, Instruments and Experimental Techniques, 1996, 39(1):132-134.
- Khoroshkov et al., Moscow Hospital-Based Proton Therapy Facility Design, Am. Journal Clinical Oncology: CCT, Apr. 1994, 17(2):109-114.
- Kim and Blosser, Optimized Magnet for a 250 MeV Proton Radiotherapy Cyclotron, Cyclotrons and Their Applications 2001, May 2001, Sixteenth International Conference, pp. 345-347.
- Kim and Yun, A Light-Ion Superconducting Cyclotron System for Multi-Disciplinary Users, Journal of the Korean Physical Society, Sep. 2003, 43(3):325-331.
- Kim et al., Construction of 8T Magnet Test Stand for Cyclotron Studies, IEEE Transactions on Applied Superconductivity, Mar. 1993, 3(1):266-268.
- Kim et al., Design Study of a Superconducting Cyclotron for Heavy Ion Therapy, Cyclotrons and Their Applications 2001, Sixteenth International Conference, May 13-17 2001, pp. 324-326.
- Kim et al., Trim Coil System for the Riken Cyclotron Ring Cyclotron, Proceedings of the 1997 Particle Accelerator Conference, IEEE, Dec. 1981, vol. 3, pp. 214-235 or 3422-3424, 1998.
- Kim, An Eight Tesla Superconducting Magnet for Cyclotron Studies, Ph.D. Dissertation, Michigan State University, Department of Physics and Astronomy, 1994, 138 pages.
- Kishida and Yano, Beam Transport System for the RIKEN SSC (II), Scientific Papers of the Institute of Physical and Chemical Research, Dec. 1981, 75(4):214-235.
- Kleeven, W., Injection and extraction for cyclotrons, Proceedings of the Specialised CERN Accelerator School on Small Accelerators, pp. 271-286 (2006).
- Koehler et al., Range Modulators for Protons and Heavy Ions, Nuclear Instruments and Methods, 1975, vol. 131, pp. 437-440.
- Koehler, A.M., et al., Range Modulators for Protons and Heavy Ions, Nuclear Instruments and Methods, vol. 131, DD. 437-440 (1975).
- Koto and Tsujii, Future of Particle Therapy, Japanese Journal of Cancer Clinics, 2001, 47(1):95-98 [Lang.: Japanese], English abstract (<http://scielinks.j12/jeast/article/200206/000020020601A05I1453.nhn>).
- Kraft et al., Hadrontherapy in Oncology, U. Amaldi and Larsson, editors Elsevier Science, 1994, 161 pages.
- Krevet et al., Design of a Strongly Curved Superconducting Bending Magnet for a Compact Synchrotron Light Source, Advances in Cryogenic Engineering, 1988, vol. 33, pp. 25-32.
- Krevet, et al., "Design of a Strongly Curved Superconducting Bending Magnet for a Compact Synchrotron Light Source", Advances in Cryogenic Engineering, vol. 33, pp. 25-32 (Dec. 3, 1988).
- Laisne et al., "The Orsay 200 MeV Synchrocyclotron," IEEE Transactions on Nuclear Science, Apr. 1979, NS-26(2):1919-1922.
- Larsson et al., Nature, 1958, 182:1222.
- Larsson, Biomedical Program for the Converted 200-MeV Synchrocyclotron at the Gustaf Werner Institute, Radiation Research, 1985, 104:S310-S318.
- Lawrence et al., Heavy particles in acromegaly and Cushing's Disease, in Endocrine and Norendocrine Hormone Producing Tumors (Year Book Medical Chicago, 1973, pp. 29-61.
- Lawrence et al., Successful Treatment of Acromegaly: Metabolic and Clinical Studies in 145 Patients, the Journal of Clinical Endocrinology and Metabolism, Aug. 1970, 31(2), 21 pages.
- Lawrence et al., Treatment of Pituitary Tumors, (Excerpta medica, Amsterdam/American Elsevier, New York, 1973, pp. 253-262.
- Lawrence, Cancer, 1957, 10:795.
- Lecroy et al., Viewing Probe for High Voltage Pulses, Review of Scientific Instruments USA, Dec. 1960, 31(12):1354.
- Lin et al., "Principles and 10 Year Experience of the Beam Monitor System at the PSI Scanned Proton Therapy Facility", Center for Proton Radiation Therapy, Paul Scherrer Institute, CH-5232, Villigen PSI, Switzerland, 2007, 21 pages.
- Linfoot et al., Acromegaly, in Hormonal Proteins and Peptides, edited by C.H. Li, 1975, pp. 191-246.
- Literature Keyword Search, Jan. 24, 2005, 98 pages.
- Literature Search, Jan. 26, 2005, 37 pages.
- Mandrillon, High Energy Medical Accelerators, EPAC 90, 2nd European Particle Accelerator Conference, Jun. 12-16, 1990, 2:54-58.
- Marchand et al., "1EA Proton Pencil Beam Scanning: an Innovative Solution for Cancer Treatment," Proceedings of EPAC 2000, Vienna, Austria, 3 pages.
- Marti et al., High Intensity Operation of a Superconducting Cyclotron, Proceedings of the 4th International Conference, Cyclotrons and Their Applications, Oct. 1995, pp. 45-48 (Oct. 1995).
- Martin, Operational Experience with Superconducting Synchrotron Magnets Proceedings of the 1987 IEEE Particle Accelerator Conference, Mar. 16-19, 1987, vol. 3 of 3: 1379-1382.
- Meote et al., ETOILE Hadrontherapy Project, Review of Design Studies Proceedings of EPAC 2002, 2002, pp. 2745-2747.
- Miyamoto et al., Development of the Proton Therapy System, The Hitachi Hyoron, 79(10):775775-779 (1997) [Lang: Japanese], English abstract (http://www.hitachi.com/rev/1998/revfeb98/rev4_706.htm).
- Montelius et al., The Narrow Proton Beam Therapy Unit at the Svedberg Laboratory in Uppsala, ACTA Oncologica, 1991, 30:739-745.
- Moser et al., Nonlinear Beam Optics with Real Fields in Compact Storage Rings, Nuclear Instruments & Methods in Physics Research/Section B, B30, Feb. 1988, No. 1, pp. 105-109.
- Moyers et al., "A Continuously Variable Thickness Scatterer for Proton Beams Using Self-compensating Dual Linear Wedges" Lorna Linda University Medical Center, Dept. Of Radiation Medicine, Lorna Linda, Ca, Nov. 2, 1992, 21 pp.
- National Cancer Institute Funding (Senate-September 21, 1992) (www.tbomas.loc.gov/cgi-bin/quer/v/z?r102:S21SE2-71212na2es).
- Nicholson, Applications of Proton Beam Therapy, Journal of the American Society of Radiologic Technologists, May/June. 1996, 67(5): 439-441.
- Nolen et al., the Integrated Cryogenic—Superconducting Beam Transport System Planned for MSU, Proceedings of the 12th International Conference on High-Energy Accelerators, Aug. 1983, pp. 549-551.
- Non Final Office Action from U.S. Appl. No. 11/948,359 dated Aug. 20, 2010 (12 pages).
- Non Final Office Action from U.S. Appl. No. 12/275,103 dated Feb. 1, 2011 (6 pages).

(56)

References Cited

OTHER PUBLICATIONS

Non Final Office Action from U.S. Appl. No. 12/618,297 dated May 13, 2011 (44 pages).

Norimine et al., a Design of a Rotating Gantry with Easy Steering for Proton Therapy, Proceedings of EPAC 2002, 2002, pp. 2751-2753.

Office action from U.S. Appl. No. 11/948,359, dated Aug. 20, 2010 (12 pages).

Office action with English translation dated Feb. 10, 2014 from corresponding Japanese application No. 2010-536130 (5 pages).

Okumura et al., Overview and Future Prospect of Proton Radiotherapy, Japanese Journal of Cancer Clinics, 1997, 43(2):209-214 [Lang: Japanese].

Okumura et al., Proton Radiotherapy Japanese Journal of Cancer and Chemotherapy, 1993, 10. 20(14):2149-2155[Lang.: Japanese]. Outstanding from Search Reports, Accelerator of Polarized Portons at Fermilab, 2005, 20 pages.

Palmer and Tollestrup, Superconducting Magnet Technology for Accelerators, Annual Review of Nuclear and Particle Science, 1984, vol. 34, pp. 247-284.

Pardo, J. et al., Simulation of the performance of the Cnao facility's Beam Delivery System, PTCOG 46, Zibo, China, 17 pages (2007). Patent Assignee and Keyword Searches for Synchrocyclotron, Jan. 25, 2005, 78 pages.

Pavlovic, Beam-optics study of the gantry beam delivery system for light-ion cancer therapy, Nuclear Instruments and Methods in Physics Research, Section A, Nov. 1997, 399(2):439-454(16).

Pedroni and Enge, Beam optics design of compact gantry for proton therapy Medical & Biological Engineering & Computing, May 1995, 33(3):271-277.

Pedroni and Jermann, Sgsm: Bulletin Mar. 2002 Proscan Project, Progress Report on the Proscan.

Pedroni et al., A Novel Gantry for Proton Therapy at the Paul Scherrer Institute, Cyclotrons and Their Applications 2001: Sixteenth International Conference. Aip Conference Proceedings, 2001, 600:13-17.

Pedroni et al., the 200-MeV proton therapy project at the Paul Scherrer Institute: Conceptual design and practical realization, Medical Physics, Jan. 1995, 22(1):37-53.

Pedroni, "Status of Proton Therapy: results and future trends," Paul Scherrer Institute, Division of Radiation Medicine, 1994, 5 pages.

Pedroni, Accelerators for Charged Particle Therapy: Performance Criteria from the User Point of View, Cyclotrons and their Applications, Proceedings of the 13th International Conference, Jul. 6-10, 1992, pp. 226-233.

Pedroni, Latest Developments in Proton Therapy Proceedings of Epac 2000, pp. 240-244, 2000.

Potts et al., MPWP6-Therapy Iii: Treatment Aids and Techniques Medical Physics, Sep/Oct 1988, 15(5):798.

Pourrahimi et al., Powder Metallurgy Processed Nb₃Sn(Ta) Wire for High Field NMR magnets, IEEE Transactions on Applied Superconductivity, Jun. 1995, 5(2):1603-1606.

Prieels et al., The IBA State-of-the-Art Proton Therapy System, Performances and Recent Results, Application of Accelerators in Research and industry—Sixteenth Int'l Conj, American Institute of Physics, Nov 1-5, 2000, 576:857-860.

Rabin et al., Compact Designs for Comprehensive Proton Beam Clinical Facilities, Nuclear Instruments & Methods in Physics Research, Apr. 1989, Section B, vol. 40-41, Part II, pp. 1335-1339.

Renner et al., "Preliminary Results of a Raster Scanning Beam Delivery System", IEEE, 1989, 3 pages.

Research & Development Magazine, Proton Therapy Center Nearing Completion, Aug. 1999, 41(9):2 pages (www.rdmag.com).

Resmini Design Characteristics of the K=800 Superconducting Cyclotron at M.S.U., Cyclotron Laboratory, Michigan State University, East Lansing, Michigan 48824, IEEE Transaction on Nuclear Science, vol. NS-26, No. 2, Apr. 1979, 8 pages.

Response to Non Final Office Action dated Feb. 1, 2011 in U.S. Appl. No. 12/275,103 filed May 2, 2011 (13 pages).

Response to Office Action dated Aug. 20, 2010 in U.S. Appl. No. 11/948,359 filed Feb. 22, 2011 (17 pages).

Response with English translation to Japanese Office action dated Feb. 10, 2014 from corresponding Japanese application No. 2010-536130, filed May 8, 2014 (15 pages).

Revised Patent Keyword Search, Jan. 25, 2005, 86 pages.

Rifuggiato et, al., Status Report of the LNS Superconducting Cyclotron Nukleonika, 2003, 48:SI31-SI34, Supplement 2.

Rode, Tevatron Cryogenic System, Proceedings of the 12th International Conference on Highenergy Accelerators, Fermilab, Aug. 11-16, 1983, pp. 529-535.

Salzburger et al., "Superconducting Synchrotron Magnets Supraleitende Synchrotronmagnete," Siemens A.G., Erlangen (West Germany). Abteilung Technische Physik, Report No. BMFT-FB-T-75-25, Oct. 1975, p. 147, Journal Announcement: GRA17619; STAR1415, Subm-Sponsored by Bundesmin. Fuer Forsch. U. Technol. In German; English Summary.

Salzburger et al., Superconducting Synchrotron Magnets Supraleitende Synchrotronmagnete, NTiS, 155 pages (Oct. 1975).

Schillo et al., Compact Superconducting 250 MeV Proton Cyclotron for the PSI Proscan Proton Therapy Project, Cyclotrons and Their Applications 2001, Sixteenth International Conference, 2001, pp. 37-39.

Schneider et al., Nevis Synchrocyclotron Conversion Program—RF System, IEEE Transactions on Nuclear Science USA, Jun. 1969, ns. 16(3): 430-433.

Schreuder et al., The Non-orthogonal Fixed Beam Arrangement for the Second Proton Therapy Facility at the National Accelerator Centre, Application of Accelerators in Research and Industry, American Institute of Physics, Proceedings of the Fifteenth International Conference, Nov 1998, Part Two, pp. 963-966.

Schreuder, Recent Developments in Superconducting Cyclotrons, Proceedings of the 1995 Particle Accelerator Conference, May 1-5, 1995, vol. 1, pp. 317-321.

Schubert and Blosser, Conceptual Design of a High Field Ultra-Compact Cyclotron for Nuclear Physics Research, Proceedings of the 1997 Particle Accelerator Conference, May 12-16, 1997, vol. 1, 3 pages 1060-1062.

Schubert, Extending the Feasibility Boundary of the Isochronous Cyclotron, Dissertation submitted to Michigan State University, 1997, Abstract <http://adsabs.harvard.edu/abs/1998PhDT...147S>.

Shelaev et al., Design Features of a Model Superconducting Synchrotron of JINR, Proceedings of the 12th International Conference on High-energy Accelerators, Aug. 11-16, 1983, pp. 416-418.

Shintomi et. Al, Technology and Materials for the Superconducting Super Collider (SSC) Project, [Lang.: Japanese], The Iron and Steel Institute of Japan 00211575, 78(8): 1305-1313, 1992, <http://ci.nii.ac.jp/naid/I I 0001493249/en/>.

Sisterson, Clinical use of proton and ion beams from a world-wide perspective, Nuclear Instruments and Methods in Physics Research, Section B, 1989, 40-41:1350-1353.

Sisterson, World Wide Proton Therapy Experience in 1997, The American Institute of Physics, Applications of Accelerators in Research and Industry, Proceedings of the Fifteenth International Conference, Part Two, Nov 1998, pp. 959-962.

Slater et al., Developing a Clinical Proton Accelerator Facility: Consortium-Assisted Technology Transfer, Conference Record of the 1991 IEEE Particle Accelerator Conference: Accelerator Science and Technology, vol. I, May 6-9, 1991, pp. 532-536.

Slater et al., Development of a Hospital-Based Proton Beam Treatment Center, International Journal of Radiation Oncology J Biolog J Physics, Apr. 1988, 14(4):761-775.

Smith et al., the Northeast Proton Therapy Center at Massachusetts General Hospital Journal of Brachytherapy International, Jan. 1997, pp. 137-139.

Snyder and Marti, Central region design studies for a proposed 250 MeV proton cyclotron, Nuclear Instruments and Methods in Physics Research, Section A, 1995, vol. 355, pp. 618-623.

Soga, Progress of Particle Therapy in Japan, Application of Accelerators in Research and Industry, American Institute of Physics, Sixteenth International Conference, Nov. 2000, pp. 869-872.

(56)

References Cited

OTHER PUBLICATIONS

Spiller et al., The GSI Synchrotron Facility Proposal for Acceleration of High Intensity Ion and Proton Beams Proceedings of the 2003 Particle Accelerator Conference, May 12-16, 2003, vol. 1, pp. 589-591.

Stanford et al., "Method of Temperature Control in Microwave Ferroelectric Measurements," Sperry Microwave Electronics Company, Clearwater, Florida, Sep. 19, 1960, 1 page.

Superconducting Cyclotron Contract awarded by Paul Scherrer Institute (PSI), Villigen, Switzerland, http://www.accel.de/News/superconducting_cyclotron_contract.htm, Jan. 2009, 1 page.

Tadashi et al., "Large superconducting super collider (SSC) in the planning and materials technology," 1992, 78(8):1305-1313, the Iron and Steel Institute of Japan 00211575.

Tadashi et al., Large superconducting super collider (SSC) in the planning and materials technology, 78(8):1305-1313, The Iron and Steel Institute of Japan 00211575, Aug. 1992.

Takada, Conceptual Design of a Proton Rotating Gantry for Cancer Therapy, Japanese Journal of Medical Physics, 1995, 15(4):270-284.

Takayama et al., Compact Cyclotron for Proton Therapy, Proceedings of the 81st Symposium on Accelerator Science and Technology, Japan, Nov. 25-27, 1991, pp. 380-382.

Teng, The Fermilab Tevatron, Coral Gables 1981, Proceedings, Gauge Theories, Massive Neutrinos, and Proton Decay, 1981, pp. 43-62.

The Davis 76-Inch Isochronous Cyclotron, Beam On: Crocker Nuclear Laboratory, University of California, 2009, 1 page.

The Journal of Practical Pharmacy, 1995, 46(1):97-103 [Japanese]. The K100 Neutron-therapy Cyclotron, National Superconducting Cyclotron Laboratory at Michigan State University (NSCL), retrieved from: <http://www.nsl.msui.edu/tech/accelerators/kl00>, Feb. 2005, 1 page.

The K250 Proton therapy Cyclotron, National Superconducting Cyclotron Laboratory at Michigan State University (NSCL), retrieved from: <http://www.nsl.msui.edu/tech/accelerators/k.250.html>, Feb. 2005, 2 pages.

The K250 Proton-therapy Cyclotron Photo Illustration, National Superconducting Cyclotron Laboratory at Michigan State University (NSCL), retrieved from: <http://www.nsl.msui.edu/media/image/experimental-equipment-technology/250.html>, Feb. 2005, 1 page.

Timmer, "The ACCEL Single Room Proton Therapy Facility" ACCEL Instruments GmbH, PTCOG 45, Oct. 2006, Houston, Texas, 18 pages.

Tobias et al., Cancer Research, 1958, 18, 121 (1958).

Tom, The Use of Compact Cyclotrons for Producing Fast Neutrons for Therapy in a Rotatable Isocentric Gantry, IEEE Transaction on Nuclear Science, Apr. 1979, 26(2):2294-2298.

Toyoda, Proton Therapy System, Sumitomo Heavy Industries, Ltd., 2000, 5 pages.

Trinks et al., The Tritron: A Superconducting Separated-Orbit Cyclotron, Nuclear Instruments and Methods in Physics Research, Section A, 1986, vol. 244, pp. 273-282.

Tsuji, The Future and Progress of Proton Beam Radiotherapy, Journal of Japanese Society for Therapeutic Radiology and Oncology, 1994, 6(2):63-76.

UC Davis School of Medicine, Unlikely Partners Turn Military Defense into Cancer Offense, Current Issue Summer 2008, Sacramento, California, pp. 1-2.

Umegaki et al., Development of an Advanced Proton Beam Therapy System for Cancer Treatment Hitachi Hyoron, 2003, 85(9):605-608 [Lang.: Japanese], English abstract, http://www.hitachi.com/ICSFiles/afiedfile/2004/06/01/r2003_04_I_04.pdf or http://www.hitachi.com/rev/archive/2003/2005649_12606.html (full text) [Hitachi, 52(4), Dec. 2003].

Umezawa et al., Beam Commissioning of the new Proton Therapy System for University of Tsukuba, Proceedings of the 2001 Particle Accelerator Conference, vol. 1, Jun. 18-22, 2001, pp. 648-650.

van Steenberg, Superconducting Synchrotron Development at Bnl, Proceedings of the 8th International Conference on High-Energy Accelerators CERN 1971, 1971, pp. 196-198.

van Steenberg, the CMS, a Cold Magnet Synchrotron to Upgrade the Proton Energy Range of the BNL Facility, IEEE Transactions on Nuclear Science, Jun. 1971, 18(3):694-698.

Vandeplassche et al., 235 MeV Cyclotron for Mgh's Northeast Proton Therapy Center (NPTC): Present Status, EPAC 96, Fifth European Particle Accelerator Conference, vol. 3, Jun. 10-14, 1996, pp. 2650-2652.

Vorobiev et al., Concepts of a Compact Achromatic Proton Gantry with a Wide Scanning Field, Nuclear Instruments and Methods in Physics Research, Section A., 1998, 406(2):307-310.

Vrenken et al., A Design of a Compact Gantry for Proton Therapy with 2D-Scanning, Nuclear Instruments and Methods in Physics Research, Section A, 1999, 426(2):618-624.

Welton, R. F., RF-Plasma Coupling Schemes for the SNS Ion Source, AIP Conference Proceedings, vol. 694, Jan. 1, 2003 (Jan. 1, 2003), pp. 431-438, XP055119965.

Wikipedia, Cyclotron <http://en.wikipedia.org/wiki/Cyclotron> (originally visited Oct. 6, 2005, revisited Jan. 28, 2009), 7 pages.

Wikipedia, Synchrotron <http://en.wikipedia.org/wiki/Synchrotron> (originally visited Oct. 6, 2005, revisited Jan. 28, 2009), 7 pages.

Wu, Conceptual Design and Orbit Dynamics in a 250 MeV Superconducting Synchrocyclotron, Ph.D. Dissertation, Michigan State University, Department of Physics and Astronomy, 1990, 172 pp.

Yamaya a, T., et al.: A Small Cold Cathode Heavy Ion Source for a Compact Cyclotron, Nuclear Instruments and Methods in Physics Research, vol. 226, 1 Jan. 1984 (1984-0101), pp. 219-222, XP055119506.

York et al., Present Status and Future Possibilities at NSCL-MSU, EPAC 94, Fourth European Particle Accelerator Conference, pp. 554-556, Jun. 1994.

York et al., the NSCL Coupled Cyclotron Project—Overview and Status, Proceedings of the Fifteenth International Conference on Cyclotrons and their Applications, Jun. 1998, pp. 687-691.

Yudelev et al., Hospital Based Superconducting Cyclotron for Neutron Therapy: Medical Physics Perspective, Cyclotrons and their applications 2001, 16th International Conference. American Institute of Physics Conference Proceedings, vol. 600, May 13-17, 2001, pp. 4043.

Zherbin et al., Proton Beam Therapy at the Leningrad Synchrocyclotron (Clinicological Aspects and Therapeutic Results), Aug. 1987, 32(8):17-22, (German with English abstract on pp. 21-22).

Livingston, M. S., et al. "A Capillary Ion Source for the Cyclotron" *Review Science Instruments*, vol. 10:63, pp. 63-67, (Feb. 1939).

English Translation of Notification of Reasons for Rejection in counterpart Japanese Application No. 2010-536130 dated Jun. 4, 2013.

Response to Office Action with English translation issued in corresponding Japanese Application No. 2010-536130, filed on Nov. 26, 2013 (24 pages).

Office action with English translation issued Feb. 10, 2014 from corresponding Japanese application No. 2010-536130 (5 pages).

Office action and response history of U.S. Appl. No. 11/601,056 to Mar. 24, 2009.

U.S. Appl. No. 60/738,404, filed Nov. 18, 2005.

U.S. Appl. No. 11/948,359, filed Nov. 30, 2007.

PCT application No. PCT/US2006/44853, filed on Nov. 17, 2006, with Publication No. WO/2007/061937.

U.S. Appl. No. 10/949,734, filed Sep. 24, 2004, Patent No. 7,208,748, issued on Apr. 24, 2007.

U.S. Appl. No. 11/724,055, filed Mar. 14, 2007.

U.S. Appl. No. 11/371,622, filed Mar. 9, 2006.

U.S. Appl. No. 60/590,088, filed Jul. 21, 2004.

U.S. Appl. No. 11/187,633, filed Jul. 21, 2005.

PCT application No. PCT/US2005/25942 filed on Jul. 21, 2005, with Publication No. WO/2006/012452.

U.S. Appl. No. 11/463,403, filed Aug. 9, 2006.

U.S. Appl. No. 11/517,490, filed Sep. 7, 2006.

U.S. Appl. No. 11/624,769, filed Jan. 19, 2007.

(56)

References Cited

OTHER PUBLICATIONS

- PCT application No. PCT/US2007/01506 filed on Jan. 19, 2007, with Publication No. WO/2007/084701.
- PCT application No. PCT/US2007/01628 filed on Jan. 19, 2007, with Publication No. WO/2007/130164.
- PCT application No. PCT/US2007/77693 filed on Sep. 6, 2007 with Publication No. WO/2007/77693.
- U.S. Appl. No. 11/870,961, filed Oct. 11, 2007.
- PCT application No. PCT/US2008/077513, filed on Sep. 24, 2008.
- PCT application No. PCT/US2008/084695 filed on Nov. 25, 2008.
- PCT application No. PCT/US2008/084699 filed on Nov. 25, 2008.
- U.S. Appl. No. 60/991,454, filed Nov. 30, 2007.
- U.S. Appl. No. 12/275,103, filed Nov. 20, 2008.
- PCT application No. PCT/US2007/086109 filed on Nov. 30, 2007.
- U.S. Appl. No. 60/850,565, filed Oct. 10, 2006.
- PCT International Search report and Written Opinion of PCT application No. PCT/US2006/044853, mailed Oct. 5, 2007 (12 pages).
- PCT International Preliminary Report on Patentability of corresponding PCT application No. PCT/US2006/044853, mailed May 29, 2008 (8 pages).
- International Search Report dated Aug. 26, 2008 in PCT application No. PCT/US2007/086109 (6 pages).
- Written Opinion dated Aug. 26, 2008 in PCT application No. PCT/US2007/086109 (6 pages).
- International Search Report and Written Opinion for PCT application No. PCT/US2008/084699 mailed Feb. 4, 2009 (11 pages).
- International Search Report and Written Opinion for PCT application No. PCT/US2007/001506 mailed Jul. 5, 2007, Publication No. W02007/084701, Published Jul. 26, 2007 (14 pages).
- International Preliminary Report on Patentability for PCT application No. PCT/US2007/001506 mailed Jul. 5, 2007 (15 pages).
- International Search Report for PCT/US2007/001628 mailed Feb. 18, 2008 (4 pages).
- Written Opinion for PCT/US2007/001628, mailed Feb. 18, 2008 (11 pages).
- International Preliminary Report on Patentability for PCT/US2007/001628, mailed Apr. 22, 2008 (15 pages).
- Abrosimov, N.K., et al. Proc. Academy Science, USSR 5, 84 (1985).
- Abrosimov, N.K., et al. "1000MeV Proton Beam Therapy facility at Petersburg Nuclear Physics Institute Synchrocyclotron", Medical Radiology (Moscow) 32, 10 (1987) revised in Journal of Physics, Conference Series 41, pp. 424-432, Institute of Physics Publishing Limited, 2006.
- Adachi, T., et. al. "A 150MeV FFAG Synchrotron with "Return-Yoke Free" Magnet" *Proceedings of the 2001 Particle Accelerator Conference*, Chicago (2001).
- Ageyev, A. I., et. al. "The IHEP Accelerating and Storage Complex (UNK) Status Report" *11th International Conference on High-Energy Accelerators*, pp. 60-70 (Jul. 7-11, 1980).
- Agosteo, S., et. al. "Maze Design of a gantry room for proton therapy" *Nuclear Instruments & Methods in Physics Research*, Section A, 382, pp. 573-582 (1996).
- Allardyce, B. W., et al., "Performance and Prospects of the Reconstructed CERN 600 MeV Synchrocyclotron" *IEEE Transactions on Nuclear Science USA ns-24:(3)*, pp. 1631-1633 (Jun. 1977).
- Alexeev, V. P., et. al. "R4 Design of Superconducting Magnets for Proton Synchrotrons" *Proceedings of the Fifth International Cryogenic Engineering Conference*, pp. 531-533 (1974).
- Amaldi, U. "Overview of the world landscape of Hadrontherapy and the projects of the TERA foundation" *Physica Medica, An International journal Devoted to the Applications of Physics to Medicine and Biology*, vol. XIV, Supplement 1 (Jul. 1998), *6th Workshop on Heavy Charged Particles in Biology and Medicine*, Instituto Scientifico Europeo (ISE), Baveno, pp. 76-85 (Sep. 29-Oct. 1, 1997).
- Amaldi, U., et. al. "The Italian project for a hadrontherapy centre" *Nuclear Instruments and Methods in Physics Research A*, 360, pp. 297-301 (1995).
- "An Accelerated Collaboration Meets with Beaming Success", Lawrence Livermore National Laboratory, Apr. 12, 2006, S&TR, Livermore, California, pp. 1-3. <http://www.llnl.gov/str/April06/Caporaso.html>.
- Anferov, V., et. al. "The Indiana University Midwest Proton Radiation Institute" *Proceedings of the 2001 Particle Accelerator Conference*, Chicago, pp. 645-647 (2001).
- Anferov, V., et. al. "Status of the Midwest Proton Radiotherapy Institute", *Proceedings of the 2003 Particle Accelerator Conference*, pp. 699-701 (2003).
- Appun, J. "Various problems of magnet fabrication for high-energy accelerators" *Journal for All Engineers Interested in the Nuclear Field*, pp. 10-16 (1967) [Lang.: German], English bibliographic information (http://www.osti.gov/energycitations/product.biblio.jsp?osti_id=4442292).
- Arduini, G., et. al. "Physical specifications of clinical proton beams from a synchrotron" *Med. Phys.* 23 (6), pp. 939-951 (Jun. 1996).
- Beeckman, W., et. al. "Preliminary design of a reduced cost proton therapy facility using a compact, high field isochronous cyclotron" *Nuclear Instruments and Methods in Physics Research B56/57*, pp. 1201-1204 (1991).
- Bellomo, G., et al., "The Superconducting Cyclotron Program at Michigan State University" *Bulletin of the American Physical Society*, vol. 25, No. 7, pp. 767 (Sep. 1980).
- Benedikt, M. and Carli, C. "Matching to Gantries for Medical Synchrotrons" *IEEE Proceedings of the 1997 Particle Accelerator Conference*, pp. 1379-1381 (1997).
- Bieth, C., et. al. "A Very Compact Protontherapy Facility Based on an Extensive Use of High Temperature Superconductors (HTS)" *Cyclotrons and their Applications 1998, Proceedings of the Fifteenth International Conference on Cyclotrons and their Applications*, Caen, pp. 669-672 (Jun. 14-19, 1998).
- Bigham, C.B. "Magnetic Trim Rods for Superconducting Cyclotrons," *Nuclear Instruments and Methods* (North-Holland Publishing Co.) 141 (1975), pp. 223-228.
- Blackmore, E. W., et. al. "Operation of the Triumf Proton Therapy Facility" *IEEE Proceedings of the 1997 Particle Accelerator Conference*, vol. 3, pp. 3831-3833 (May 12-16, 1997).
- Bloch, C. "The Midwest Proton Therapy Center" *Application of Accelerators in Research and Industry, Proceedings of the Fourteenth Int'l. Conf.*, Part Two, pp. 1253-1255 (Nov. 1996).
- Blosser, H., et. al. "A Compact Superconducting Cyclotron for the Production of High Intensity Protons" *Proceedings of the 1997 Particle Accelerator Conference*, vol. 1, pp. 1054-1056 (May 12-16, 1997).
- Blosser, H., et al., "Advances in Superconducting Cyclotrons at Michigan State University", *Proceedings of the 11th International Conference on Cyclotrons and their Applications*, pp. 157-167 (Oct. 1986), Tokyo.
- Blosser, H., "Application of Superconductivity in Cyclotron Construction", *Ninth International Conference on Cyclotrons and their Applications*, pp. 147-157 (Sep. 1981).
- Blosser, H. "Applications of Superconducting Cyclotrons" *Twelfth International Conference on Cyclotrons and Their Applications*, pp. 137-144 (May 8-12, 1989).
- Blosser, H., et al., "Characteristics of a 400 (Q2/A) MeV Superconducting Heavy-Ion Cyclotron", *Bulletin of the American Physical Society*, p. 1026 (Oct. 1974).
- Blosser, H. G. "Compact Superconducting Synchrocyclotron Systems for Proton Therapy" *Nuclear Instruments & Methods in Physics Research*, Section B40-41, Part II, pp. 1326-1330 (Apr. 1989).
- Blosser, H.G., "Future Cyclotrons" *AIP, The Sixth International Cyclotron Conference*, pp. 16-32 (1972).
- Blosser, H., et. al. "Medical Accelerator Projects at Michigan State Univ." *IEEE Proceedings of the 1989 Particle Accelerator Conference*, vol. 2, pp. 742-746 (Mar. 20-23, 1989).
- Blosser, H.G., "Medical Cyclotrons", *Physics Today*, Special Issue Physical Review Centenary, pp. 70-73 (Oct. 1993).
- Blosser, H., et al, National Superconducting Cyclotron Laboratory, Michigan State University, Report MSUCL-760, Nov. 2013.

(56)

References Cited

OTHER PUBLICATIONS

- Blosser, H., et al., "Preliminary Design Study Exploring Building Features Required for a Proton Therapy Facility for the Ontario Cancer Institute", MSUCL-760a (Mar. 1991).
- Blosser, H., Present and Future Superconducting Cyclotrons, *Bulletin of the American Physical Society*, vol. 32, No. 2, p. 171 (Feb. 1987), Particle Accelerator Conference, Washington, D.C. 1987.
- Blosser, H., et al., "Problems and Accomplishments of Superconducting Cyclotrons", Proceedings of the 14th International Conference, Cyclotrons and Their Applications, pp. 674-684 (Oct. 1995).
- Blosser, H.G., "Program on the Coupled Superconducting Cyclotron Project", *Bulletin of the American Physical Society*, vol. 26, No. 4, p. 558 (Apr. 1981).
- Blosser, H., et al., "Superconducting Cyclotron for Medical Application", *IEEE Transactions on Magnetics*, vol. 25, No. 2, pp. 1746-1754 (Mar. 1989).
- Blosser, H.G., et al., "Superconducting Cyclotrons", Seventh International Conference on Cyclotrons and their Applications, pp. 584-594 (Aug. 19-22, 1975).
- Blosser, H.G., "Superconducting Cyclotrons at Michigan State University", *Nuclear Instruments & Methods in Physics Research*, vol. B 24/25, part II, pp. 752-756 (1987).
- Blosser, H. G. "Synchrocyclotron Improvement Programs" *IEEE Transactions on Nuclear Science USA*, vol. 16, No. 3, Part I, pp. 405-414 (Jun. 1969).
- Blosser, H.G., "The Michigan State University Superconducting Cyclotron Program", *Nuclear Science*, vol. NS-26, No. 2, pp. 2040-2047 (Apr. 1979).
- Botha, A. H., et. al. "A New Multidisciplinary Separated-Sector Cyclotron Facility" *IEEE Transactions on Nuclear Science*, vol. NS-24, No. 3, pp. 1118-1120 (1977).
- Chichili, D.R., et al., "Fabrication of Nb₃Sn Shell-Type Coils with Pre-Preg Ceramic Insulation," American Institute of Physics Conference Proceedings, AIP USA, No. 711, (XP-002436709, ISSN: 0094-243X), 2004, pp. 450-457.
- Chong, C.Y., et al., *Radiology Clinic North American* 7, 3319 (1969).
- Chu, et. al. "Instrumentation for Treatment of Cancer Using Proton and Light-ion Beams" *Review of Scientific Instruments*, 64 (8), pp. 2055-2122 (Aug. 1993).
- Cole, et. al. "Design and Application of a Proton Therapy Accelerator", Fermi National Accelerator Laboratory, IEEE, 1985.
- Conradie, et. al. "Proposed New Facilities for Proton Therapy at iThemba Labs" Proceedings of EPAC, pp. 560-562 (2002).
- C/E Source of Ions for Use in Sychro-Cyclotrons Search, Jan. 31, 2005, 9 pages.
- Source Search Cites of U.S. and Foreign Patents/Published applications in the name of Mitsubishi Denki Kabushiki Kaisha and Containing the Keywords (Proton and Synchrocyclotron), 8 pages, Apr. 1957.
- Coupland, . "High-field (5 T) pulsed superconducting dipole magnet" Proceedings of the Institution of Electrical Engineers, vol. 121, No. 7, pp. 771-778 (Jul. 1974).
- Coutrakon, et. al. "A prototype beam delivery system for the proton medical accelerator at Loma Linda" *Medical Physics*, vol. 18(6), pp. 1093-1099 (Nov./Dec. 1991).
- Coutrakon, G et al. "Proton Synchrotrons for Cancer Therapy" Application of Accelerators in Research and Industry—Sixteenth International Conf., American Institute of Physics, vol. 576, pp. 861-864 (Nov. 1-5, 2000).
- "CPAC Highlights Its Proton Therapy Program at ESTRO Annual Meeting", TomoTherapy Incorporated, Sep. 18, 2008, Madison, Wisconsin, pp. 1-2.
- Dialog Search, Jan. 31, 2005 (18 pages).
- "Indiana's mega-million proton therapy cancer center welcomes its first patients" [online] Press release, Health & Medicine Week, 2004, retrieved from NewsRx.com, Mar. 1, 2004, pp. 119-120.
- Ishibashi, K. and McInturff, A., "Stress Analysis of Superconducting 10T Magnets for Synchrotron", Proceedings of the Ninth International Cryogenic Engineering Conference, pp. 513-516 (May 11-14, 1982).
- Ishibashi, K. and McInturff, A. "Winding Design Study of Superconducting 10 T Dipoles for a Synchrotron" *IEEE Transactions on Magnetics*, vol. MAG-19, No. 3, pp. 1364-1367 (May 1983).
- Jahnke, A., et. al. "First Superconducting Prototype Magnets for a Compact Synchrotron Radiation Source in Operation" *IEEE Transactions on Magnetics*, vol. 24, No. 2 (Mar. 1988), pp. 1230-1232.
- Jones, D.T.L. "Progress with the 200 MeV Cyclotron Facility at the National Accelerator Centre" *Commission of the European Communities Radiation Protection Proceedings, Fifth Symposium on Neutron Dosimetry*, vol. II, pp. 989-998 (Sep. 17-21, 1984).
- Jones, D. T. L. "Present Status and Future Trends of Heavy Particle Radiotherapy" *Cyclotrons and their Applications 1998, Proceedings of the Fifteenth International Conference on Cyclotrons and their Applications*, pp. 13-20 (Jun. 14-19, 1998).
- Jones, and Dershem . "Synchrotron Radiation from Proton in a 20 TEV, 10 TESLA Superconducting Super Collider" *Proceedings of the 12th International Conference on High-Energy Accelerators*, pp. 138-140 (Aug. 11-16, 1983).
- Jones, D. T. L. and Mills, S. J. "The South African National Accelerator Centre: Particle Therapy and Isotope Production Programmes" *Radiation Physics and Chemistry*, vol. 51, Nos. 4-6, pp. 571-578 (Apr.-Jun. 1998).
- Jones, D. T. L., et. al. "Status Report of the NAC Particle Therapy Programme" *Stralenterapie und Onkologie*, vol. 175, Suppl. II, pp. 30-32 (Jun. 1999).
- Jongen, Y., et. al. "Progress report on the IBA-SHI small cyclotron for cancer therapy" *Nuclear Instruments and Methods in Physics Research, Section B*, vol. 79, issue 1-4, pp. 885-889 (1993).
- Jongen, Y., et. al. "The proton therapy system for MGH's NPTC: equipment description and progress report" *Bulletin du Cancer/Radiotherapie, Proceedings of the meeting of the European Heavy Particle Therapy Group*, vol. 83, Suppl. 1, pp. 219-222 (1996).
- Jongen, Y., et. al. "Development of a Low-cost Compact Cyclotron System for Proton Therapy" *National Institute of Radiol. Sci.*, No. 81, pp. 189-200 (1991).
- Jongen, Y. et. al. "The proton therapy system for the NPTC: equipment description and progress report" *Nuclear Instruments and methods in Physics Research, Section B*, vol. 113, No. 1, pp. 522-525 (1996).
- Kanai, et al., "Three-dimensional Beam Scanning for Proton Therapy," *Nuclear Instruments and Methods in Physic Research*, Sep. 1, 1983, The Netherlands, vol. 214, No. 23, pp. 491-496.
- Karlin, D.L., et al., "Medical Radiology" (Moscow) 28, 13 (1983).
- Karlin, D.L., et al., "The State and Prospects in the Development of the Medical Proton Tract on the Synchrocyclotron in Gatchina", *Med. Radiol.*, Moscow, vol. 28(3), pp. 28-32 (Mar. 1983)(German with English Abstract on end of p. 32).
- Kats, M.M. and Druzhinin, B.L. "Comparison of Methods for Irradiation Prone Patients" *Atomic Energy*, vol. 94, No. 2, pp. 120-123 (Feb. 2003).
- Kats, M. M. and Onosovskii, K. K. "A Planar Magneto-optical System for the Irradiation of a Lying Patient with a Proton Beam from Various Directions" *Instruments and Experimental Techniques*, vol. 39, No. 1, pp. 127-131 (1996).
- Kats, M. M. and Onosovskii, K. K. "A Simple, Compact, Flat System for the Irradiation of a Lying Patient with a Proton Beam from Different Directions" *Instruments and Experimental Techniques*, vol. 39, No. 1, pp. 132-134 (1996).
- Koehler, A.M., et al., "Range Modulators for Protons and Heavy Ions," *Nuclear Instruments and Methods*, vol. 131, pp. 437-440 (1975).
- Khoroshkov, V. S., et. al. "Moscow Hospital-Based Proton Therapy Facility Design" *Am. Journal Clinical Oncology: CCT*, vol. 17, No. 2, pp. 109-114 (Apr. 1994).
- Kim, J. and Yun, C. "A Light-Ion Superconducting Cyclotron System for Multi-Disciplinary Users" *Journal of the Korean Physical Society*, vol. 43, No. 3, pp. 325-331 (Sep. 2003).

(56)

References Cited

OTHER PUBLICATIONS

- Kim, J.W., "An Eight Tesla Superconducting Magnet for Cyclotron Studies," Ph.D. Dissertation, Michigan State University, Department of Physics and Astronomy (1994).
- Kim, J., et al., "Construction of 8T Magnet Test Stand for Cyclotron Studies", *IEEE Transactions on Applied Superconductivity*, vol. 3, No. 1, pp. 266-268 (Mar. 1993).
- Kim, J., et al., "Design Study of a Superconducting Cyclotron for Heavy Ion Therapy", *Cyclotrons and Their Applications 2001, Sixteenth International Conference*, pp. 324-326 (May 13-17, 2001).
- Kim, J. and Blosser, H., "Optimized Magnet for a 250 MeV Proton Radiotherapy Cyclotron", *Cyclotrons and Their Applications 2001, Sixteenth International Conference*, pp. 345-347 (May 2001).
- Kim, J.W., et al., "Trim Coil System for the Riken Cyclotron Ring Cyclotron", *Proceedings of the 1997 Particle Accelerator Conference, IEEE*, vol. 3, pp. 214-235 (Dec. 1981). OR 3422-3424, 1998).
- Kishida, N. and Yano, Y. "Beam Transport System for the Riken SSC (II)" *Scientific Papers of the Institute of Physical and Chemical Research*, vol. 75, No. 4, pp. 214-235 (Dec. 1981).
- Koto, M. and Tsujii, H. "Future of Particle Therapy" *Japanese Journal of Cancer Clinics*, vol. 47, No. 1, pp. 95-98 (2001) [Lang.: Japanese], English abstract (<http://sciencelinks.jp/j-east/article/200206/000020020601A0511453.php>).
- Kraft, G. et al., "Hadrontherapy in Oncology", U. Amaldi and Larrsson, editors Elsevier Science, 1994.
- Krevet, et al, "Design of a Strongly Curved Superconducting Bending Magnet for a Compact Synchrotron Light Source", *Advances in Cryogenic Engineering*, vol. 33, pp. 25-32, 2013.
- Larsson, B. "Biomedical Program for the Converted 200-MeV Synchrocyclotron at the Gustaf Werner Institute" *Radiation Research*, 104, pp. S310-S318 (1985).
- Larsson, B., et al., *Nature* 182, 1222 (1958).
- Lawrence, J.H., *Cancer* 10, 795 (1957).
- Lawrence, J.H., et al., "Heavy particles in acromegaly and Cushing's Disease," in *Endocrine and Norendocrine Hormone Producing Tumors* (Year Book Medical Chicago, 1973), pp. 29-61.
- Lawrence, J.H., et al., "Successful Treatment of Acromegaly: Metabolic and Clinical Studies in 145 Patients", *The Journal of Clinical Endocrinology and Metabolism*, vol. 31, No. 2, Aug. 1970.
- Lawrence, J.H., et al., *Treatment of Pituitary Tumors*, (Excerpta medica, Amsterdam/American Elsevier, New York, 1973), pp. 253-262.
- Lecroy, W., et al., "Viewing Probe for High Voltage Pulses", *Review of Scientific Instruments USA* 31(12), p. 1354 (Dec. 1960).
- Linfoot, J.A., et al., "Acromegaly," in *Hormonal Proteins and Peptides*, edited by C.H. Li, (1975), pp. 191-246.
- Literature Author and Keyword Search, Feb. 14, 2005 (44 pages).
- Literature Author and Keyword Searches (Synchrotron), Jan. 25, 2005 (78 pages).
- Literature Keyword Search, Jan. 24, 2005 (96 pages).
- Literature Search, Jan. 26, 2005 (36 pages).
- Literature Search and Keyword Search for Synchrocyclotron, Jan. 25, 2005 (68 pages).
- Literature Search by Company Name/Component Source, Jan. 24, 2005 (111 pages).
- "LLNL, UC Davis Team Up to Fight Cancer", Lawrence Livermore National Laboratory, Apr. 28, 2006, SF-06-04-02, Livermore, California, pp. 1-4.
- Mandrillon, P. "High Energy Medical Accelerators" *EPAC 90, 2nd European Particle Accelerator Conference*, vol. 2, (Jun. 12-16, 1990), pp. 54-58.
- Marti, F., et al., "High Intensity Operation of a Superconducting Cyclotron", *Proceedings of the 14th International Conference, Cyclotrons and Their Applications*, pp. 45-48 (Oct. 1995).
- Martin, P. "Operational Experience with Superconducting Synchrotron Magnets" *Proceedings of the 1987 IEEE Particle Accelerator Conference*, vol. 3 of 3, pp. 1379-1382 (Mar. 16-19, 1987).
- Meot, F., et al. "ETOILE Hadrontherapy Project, Review of Design Studies" *Proceedings of EPAC 2002*, pp. 2745-2747 (2002).
- Miyamoto, S., et. al. "Development of the Proton Therapy System" *The Hitachi Hyoron*, vol. 79, 10, pp. 775-779 (1997) [Lang: Japanese], English abstract (<http://www.hitachi.com/rev/1998/revfeb98/rev4706.htm>).
- Montelius, A., et. al. "The Narrow Proton Beam Therapy Unit at the Svedberg Laboratory in Uppsala" *ACTA Oncologica*, vol. 30, pp. 739-745 (1991).
- Moser, H.O., et al., "Nonlinear Beam Optics with Real Fields in Compact Storage Rings", *Nuclear Instruments & Methods in Physics Research/Section B*, B30, Feb. 1988, No. 1, pp. 105-109.
- National Cancer Institute Funding (Senate—Sep. 21, 1992) (www.thomas.loc.gov/cgi-bin/query/z?r102:S21SE2-712 (2 pages)).
- Nicholson, J. "Applications of Proton Beam Therapy" *Journal of the American Society of Radiologic Technologists*, vol. 67, No. 5, pp. 439-441 (May/Jun. 1996).
- Nolen, J.A., et al., "The Integrated Cryogenic—Superconducting Beam Transport System Planned for MSU", *Proceedings of the 12th International Conference on High-Energy Accelerators*, pp. 549-551 (Aug. 1983).
- Norimine, T., et. al. "A Design of a Rotating Gantry with Easy Steering for Proton Therapy" *Proceedings of EPAC 2002*, pp. 2751-2753 (2002).
- Okumura, T., et. al. "Overview and Future Prospect of Proton Radiotherapy" *Japanese Journal of Cancer Clinics*, vol. 43, No. 2, pp. 209-214 (1997) [Lang.: Japanese].
- Okumura, T., et. al. "Proton Radiotherapy" *Japanese Journal of Cancer and Chemotherapy*, 10. 20, No. 14, pp. 2149-2155 (1993) [Lang.: Japanese].
- Outstanding from Search Reports, "Accelerator of Polarized Portons at Fermilab," 20 pages, 2005.
- Palmer, R. and Tollestrup, A. V. "Superconducting Magnet Technology for Accelerators" *Annual Review of Nuclear and Particle Science*, vol. 34, pp. 247-284 (1984).
- Patent Assignee and Keyword Searches for Synchrocyclotron, Jan. 25, 2005 (77 pages).
- "Patent Assignee Search Paul Scherrer Institute," Library Services at Fish & Richardson P.C., Mar. 20, 2007 (40 pages).
- "Patent Prior Art Search for 'Proton Therapy System'," Library Services at Fish & Richardson P.C., Mar. 20, 2007 (46 pages).
- Pavlovic, M. "Beam-optics study of the gantry beam delivery system for light-ion cancer therapy" *Nuclear Instruments and Methods in Physics Research*, Section A, vol. 399, No. 2, pp. 439-454(16) (Nov. 1997).
- Pedroni, E. "Accelerators for Charged Particle Therapy: Performance Criteria from the User Point of View" *Cyclotrons and their Applications, Proceedings of the 13th International Conference*, pp. 226-233 (Jul. 6-10, 1992).
- Pedroni, E. "Latest Developments in Proton Therapy" *Proceedings of EPAC 2000*, pp. 240-244 (2000).
- Pedroni, E., et. al. "The 200-MeV proton therapy project at the Paul Scherrer Institute: Conceptual design and practical realization" *Medical Physics*, vol. 22, No. 1, pp. 37-53 (Jan. 1995).
- Pedroni, E., et. al. "A Novel Gantry for Proton Therapy at the Paul Scherrer Institute" *Cyclotrons and Their Applications 2001: Sixteenth International Conference. AIP Conference Proceedings*, vol. 600, pp. 13-17 (2001).
- Pedroni, E. and Enge, H. "Beam optics design of compact gantry for proton therapy" *Medical & Biological Engineering & Computing*, vol. 33, No. 3, pp. 271-277 (May 1995).
- Pedroni, E. and Jermann, M. "SGSMP: Bulletin Mar. 2002 PROSCANProject, Progress Report on the Proscan Project of PSI" [online] retrieved from www.sgsmp.ch/protA23.htm, (5 pages) Mar. 2002.
- Potts, R., et. al. "MPWP6-Therapy III: Treatment Aids and Techniques" *Medical Physics*, vol. 15, No. 5, p. 798 (Sep./Oct. 1988).
- Pourrahimi, S. et al., "Powder Metallurgy Processed Nb3Sn(Ta) Wire for High Field NMR magnets," *IEEE Transactions on Applied Superconductivity*, vol. 5, No. 2, (Jun. 1995), pp. 1603-1606.
- Prieels, D., et. al. "The IBA State-of-the-Art Proton Therapy System, Performances and Recent Results" *Application of Accelerators in Research and industry—Sixteenth Int'l. Conf., American Institute of Physics*, vol. 576, pp. 857-860 (Nov. 1-5, 2000).

(56)

References Cited

OTHER PUBLICATIONS

- Rabin, M. S. Z., et. al. "Compact Designs for Comprehensive Proton Beam Clinical Facilities" *Nuclear Instruments & Methods in Physics Research*, Section B, vol. 40-41, Part II, pp. 1335-1339 (Apr. 1989).
- Research & Development Magazine, "Proton Therapy Center Nearing Completion", vol. 41, No. 9, Aug. 1999 (2 pages)(www.rdmag.com).
- RetroSearch "Berkeley 88-Inch Cyclotron 'RF' or 'Frequency Control'," Jan. 21, 2005 (36 pages).
- RetroSearch "Berkeley 88-Inch Cyclotron," Jan. 24, 2005 (170 pages).
- RetroSearch "Bernard Gottschalk, Cyclotron, Beams, Compensated Upstream Modulator, Compensated Scatter," Jan. 21, 2005 (20 pages).
- RetroSearch "Cyclotron with 'RF' or 'Frequency Control'," Jan. 21, 2005 (49 pages).
- RetroSearch Gottschalk, Bernard, Harvard Cyclotron Wheel, Jan. 21, 2005 (20 pages).
- RetroSearch "Loma Linda University, Beam Compensation Foil Wedge," Jan. 21, 2005 (15 pages).
- RetroSearch "Loma Linda University Beam Compensation," Jan. 21, 2005 (60 pages).
- Revised Patent Keyword Search, Jan. 25, 2005 (88 pages).
- Rifuggiato, D., et. al. "Status Report of the LNS Superconducting Cyclotron" *Nukleonika*, vol. 48, pp. S131-S134 (Supplement 2, 2003).
- Rode, C. H. "Tevatron Cryogenic System" *Proceedings of the 12th International Conference on High-energy Accelerators, Fermilab*, pp. 529-535 (Aug. 11-16, 1983).
- Schillo, M., et. al. "Compact Superconducting 250 MeV Proton Cyclotron for the PSI Proscan Proton Therapy Project" *Cyclotrons and Their Applications 2001, Sixteenth International Conference*, pp. 37-39 (2001).
- Schneider et al., "Superconducting Cyclotrons," *IEEE Transactions on Magnetics*, vol. MAG-11, No. 2, Mar. 1975, New York, pp. 443-446.
- Schneider, R., et al., "Nevis Synchrocyclotron Conversion Program—RF System," *IEEE Transactions on Nuclear Science USA ns 16(3)* pp. 430-433 (Jun. 1969).
- Schreuder, H.W. "Recent Developments in Superconducting Cyclotrons" *Proceedings of the 1995 Particle Accelerator Conference*, vol. 1, pp. 317-321 (May 1-5, 1995).
- Schreuder, A. N., et. al. "The Non-orthogonal Fixed Beam Arrangement for the Second Proton Therapy Facility at the National Accelerator Centre" *Application of Accelerators in Research and Industry, American Institute of Physics, Proceedings of the Fifteenth International Conference*, Part Two, pp. 963-966 (Nov. 1998).
- Schubert, J. R. "Extending the Feasibility Boundary of the Isochronous Cyclotron" Dissertation submitted to Michigan State University, 1997, Abstract <http://adsabs.harvard.edu/abs/1998PhDT.....147S>.
- Schubert, J. and Blosser, H. "Conceptual Design of a High Field Ultra-Compact Cyclotron for Nuclear Physics Research" *Proceedings of the 1997 Particle Accelerator Conference*, vol. 1, pp. 1060-1062 (May 12-16, 1997).
- Shelaev, I. A., et. al. "Design Features of a Model Superconducting Synchrotron of JINR" *Proceedings of the 12th International Conference on High-energy Accelerators*, pp. 416-418 (Aug. 11-16, 1983).
- Shintomi, T., et. al. "Technology and Materials for the Superconducting Super Collider (SSC) Project" [Lang.: Japanese], *The Iron and Steel Institute of Japan 00211575*, vol. 78, No. 8 (19920801), pp. 1305-1313, <http://ci.nii.ac.jp/naid/110001493249/en/>, 1992.
- Sisterson, J. M. "World Wide Proton Therapy Experience in 1997" *The American Institute of Physics, Applications of Accelerators in Research and Industry, Proceedings of the Fifteenth International Conference*, Part Two, pp. 959-962 (Nov. 1998).
- Sisterson, J. M. "Clinical Use of Proton and Ion Beams From a World-Wide Perspective" *Nuclear Instruments and Methods in Physics Research*, Section B, vols. 40-41, pp. 1350-1353 (1989).
- Slater, J. M., et. al. "Development of a Hospital-Based Proton Beam Treatment Center" *International Journal of Radiation Oncology Biology Physics*, vol. 14, No. 4, pp. 761-775 (Apr. 1988).
- Slater, J. M., et. al. "Developing a Clinical Proton Accelerator Facility: Consortium-Assisted Technology Transfer" *Conference Record of the 1991 IEEE Particle Accelerator Conference: Accelerator Science and Technology*, vol. 1, pp. 532-536 (May 6-9, 1991).
- Smith, A., et. al. "The Northeast Proton Therapy Center at Massachusetts General Hospital" *Journal of Brachytherapy International*, pp. 137-139 (Jan. 1997).
- Snyder, S. L. and Marti, F. "Central region design studies for a proposed 250 MeV proton cyclotron" *Nuclear Instruments and Methods in Physics Research*, Section A, vol. 355, pp. 618-623 (1995).
- Soga, F. "Progress of Particle Therapy in Japan" *Application of Accelerators in Research and Industry, American Institute of Physics, Sixteenth International Conference*, pp. 869-872 (Nov. 2000).
- Spiller, P., et. al. "The GSI Synchrotron Facility Proposal for Acceleration of High Intensity Ion and Proton Beams" *Proceedings of the 2003 Particle Accelerator Conference*, vol. 1, pp. 589-591 (May 12-16, 2003).
- Stanford, A.L., et al., "Method of Temperature Control in Microwave Ferroelectric Measurements," Sperry Microwave Electronics Company, Clearwater, Florida, Sep. 19, 196 (1 page), 2013.
- Superconducting Cyclotron Contract awarded by Paul Scherrer Institute (PSI), Villigen, Switzerland, http://www.accel.de/News/superconducting_cyclotron_contract.html Feb. 3, 2005.
- Tadashi, I., et al., "Large superconducting super collider (SSC) in the planning and materials technology", vol. 78, No. 8 (Aug. 1, 1992), pp. 1305-1313, *The Iron and Steel Institute of Japan 00211575*.
- Takada, Yoshihisa Tsukumba, "A review of rotating gantries for heavy charged particle therapy," Symposium of Research Center for Charged Particle Therapy on Fundamental development of the charged particle therapy, Chiba (Japan), Nov. 13-14, 2001.
- Takada, Y. "Conceptual Design of a Proton Rotating Gantry for Cancer Therapy" *Japanese Journal of Medical Physics*, vol. 15, No. 4, pp. 270-284 (1995).
- Takayama, T., et al., "Compact Cyclotron for Proton Therapy," *Proceedings of the 8th Symposium on Accelerator Science and Technology*, Japan (Nov. 25-27, 1991) pp. 380-382.
- Teng, L. C. "The Fermilab Tevatron" *Coral Gables 1981, Proceedings, Gauge Theories, Massive Neutrinos, and Proton Decay*, pp. 43-62 (1981).
- "The Davis 76-Inch Isochronous Cyclotron", Beam On: Crocker Nuclear Laboratory, University of California, 2013.
- The Journal of Practical Pharmacy, vol. 46, No. 1, 1995, pp. 97-103. [Japanese].
- "The K100 Neutron-therapy Cyclotron," National Superconducting Cyclotron Laboratory at Michigan State University (NSCL), retrieved from: <http://www.nsl.msu.edu/tech/accelerators/k100>, Feb. 2005.
- "The K250 Proton therapy Cyclotron," National Superconducting Cyclotron Laboratory at Michigan State University (NSCL), retrieved from: <http://www.nsl.msu.edu/tech/accelerators/k250.html>, Feb. 2005.
- "The K250 Proton-therapy Cyclotron Photo Illustration," National Superconducting Cyclotron Laboratory at Michigan State University (NSCL), retrieved from: <http://www.nsl.msu.edu/media/image/experimental-equipment-technology/250.html>, Feb. 2005.
- Tobias, C.A., et al., *Cancer Research* 18, 121 (1958).
- Tom, J. L. "The Use of Compact Cyclotrons for Producing Fast Neutrons for Therapy in a Rotatable Isocentric Gantry" *IEEE Transaction on Nuclear Science*, vol. 26, No. 2, pp. 2294-2298 (Apr. 1979).
- Toyoda, E., "Proton Therapy System", Sumitomo Heavy Industries, Ltd., 2013.
- Trinks, U., et. al. "The Tritron: A Superconducting Separated-Orbit Cyclotron" *Nuclear Instruments and Methods in Physics Research*, Section A, vol. 244, pp. 273-282 (1986).

(56)

References Cited

OTHER PUBLICATIONS

- Tsuji, H., "Cancer Therapy by Proton Beam: Latest State and Future Prospects", *Isotope News*, No. 459, pp. 2-7 (1992).
- Tsuji, H. "The Future and Progress of Proton Beam Radiotherapy" *Journal of Japanese Society for Therapeutic Radiology and Oncology*, vol. 6, No. 2, pp. 63-76 (1994).
- UC Davis School of Medicine, "Unlikely Partners Turn Military Defense into Cancer Offense", Current Issue Summer 2008, Sacramento, California, pp. 1-2.
- Umegaki, K., et. al. "Development of an Advanced Proton Beam Therapy System for Cancer Treatment" *Hitachi Hyoron*, vol. 85, No. 9, pp. 605-608 (2003) [Lang.: Japanese], English abstract, http://www.hitachi.com/ICSFiles/afiedfile/2004/06/01/r2003_04_104.pdf or http://www.hitachi.com/rev/archive/2003/2005649_12606.html (full text) [Hitachi, vol. 52, No. 4 Dec. 2003].
- Umezawa, M., et. al. "Beam Commissioning of the new Proton Therapy System for University of Tsukuba" *Proceedings of the 2001 Particle Accelerator Conference*, vol. 1, pp. 648-650 (Jun. 18-22, 2001).
- van Steenbergen, A. "The CMS, a Cold Magnet Synchrotron to Upgrade the Proton Energy Range of the BNL Facility" *IEEE Transactions on Nuclear Science*, vol. 18, Issue 3, pp. 694-698 (Jun. 1971).
- van Steenbergen, A. "Superconducting Synchrotron Development at BNL" *Proceedings of the 8th International Conference on High-Energy Accelerators CERN 1971*, pp. 196-198 (1971).
- Vandeplassche, D., et. al. "235 MeV Cyclotron for MGH's Northeast Proton Therapy Center (NPTC): Present Status" EPAC 96, *Fifth European Partical Accelerator Conference*, vol. 3, pp. 2650-2652 (Jun. 10-14, 1996).
- Vorobiev, L.G., et al., "Concepts of a Compact Achromatic Proton Gantry with a Wide Scanning Field", *Nuclear Instruments and Methods in Physics Research, Section A.*, vol. 406, No. 2, pp. 307-310 (1998).
- Vrenken, H., et. al. "A Design of a Compact Gantry for Proton Therapy with 2D-Scanning" *Nuclear Instruments and Methods in Physics Research, Section A*, vol. 426, No. 2, pp. 618-624 (1999).
- Wikipedia, "Cyclotron" <http://en.wikipedia.org/wiki/Cyclotron> (originally visited Oct. 6, 2005, revisited Jan. 28, 2009)(7 pages).
- Wikipedia, "Synchrotron" <http://en.wikipedia.org/wiki/Synchrotron> (originally visited Oct. 6, 2005, revisited Jan. 28, 2009)(7pages).
- Worldwide Patent Assignee Search, Jan. 24, 2005 (224 pages).
- Worldwide Patent Keyword Search, Jan. 24, 2005 (94 pages).
- Wu, X., "Conceptual Design and Orbit Dynamics in a 250 MeV Superconducting Synchrocyclotron," Ph.D. Dissertation, Michigan State University, Department of Physics and Astronomy (1990).
- York, R.C., et al., "Present Status and Future Possibilities at NSCL-MSU", EPAC 94, Fourth European Particle Accelerator Conference, pp. 554-556 (Jun. 1994).
- York, R.C., et al., "The NSCL Coupled Cyclotron Project—Overview and Status", *Proceedings of the Fifteenth International Conference on Cyclotrons and their Applications*, pp. 687-691 (Jun. 1998).
- Yudelev, M., et. al. "Hospital Based Superconducting Cyclotron for Neutron Therapy: Medical Physics Perspective" *Cyclotrons and their applications 2001, 16th International Conference. American Institute of Physics Conference Proceedings*, vol. 600, pp. 40-43 (May 13-17, 2001) http://www.osti.gov/energycitations/product.biblio.jsp?osti_id=20468164 <http://adsabs.harvard.edu/abs/2001AIPC..600..40Y> <http://scitation.aip.org/getabs/servlet/GetabsServlet?prog=normal&id=APCP-CS00060000001000040000001&idtype=cvips&gifs=yes>.
- Zherbin, E. A., et al., "Proton Beam Therapy at the Leningrad Synchrocyclotron (Clinicmethodological Aspects and Therapeutic Results)", pp. 17-22, Aug. 1987, vol. 32(8)(German with English abstract on pp. 21-22).
- 18th Japan Conference on Radiation and Radioisotopes [Japanese], Nov. 25-27, 1987, 9 pages.
- "510(k) Summary: Ion Beam Applications S.A.", FDA, Apr. 13, 2001.
- "510(k) Summary: Optivus Proton Beam Therapy System", Jul. 21, 2000, 5 pages.
- U.S. Appl. No. 11/601,056, filed Nov. 17, 2006.
- Flanz, et al., "Operation of a Cyclotron Based Proton Therapy Facility", Massachusetts General Hospital, Boston, MA 02114, pp. 1-4, 2013.
- Resmini, F., "Design Characteristics of the K=800 Superconducting Cyclotron at M.S.U.", Cyclotron Laboratory, Michigan State University, East Lansing, Michigan 48824, IEEE Transaction on Nuclear Science, vol. NS-26, No. 2, Apr. 1979 (8 pages).
- European Search Report from application No. EP 06838033.6 (PCT/US2006/044853) mailed May 11, 2009 (69 pages).
- European Patent Office communication for application No. 06838033.6, patent No. 1949404, mailed Aug. 5, 2009 (1 page).
- Invitation to Pay Additional Fees and, where applicable, Protest Fees with partial search report for application No. PCT/US2008/077513 mailed Jul. 3, 2009 (62 pages).
- Office action and response history of U.S. Appl. No. 11/601,056 to Aug. 24, 2009.
- International Search Report and Written Opinion mailed Oct. 1, 2009 in PCT application No. PCT/US2008/077513 (73 pages).
- International Preliminary Report on Patentability from PCT application No. PCT/US2008/084695, mailed Jun. 10, 2010 (10 pages).
- International Preliminary Report on Patentability from PCT application No. PCT/US2008/084699, mailed Jun. 10, 2010 (8 pages).
- International Preliminary Report on Patentability from PCT application No. PCT/US2007/086109, mailed Jun. 10, 2010 (7 pages).
- European Patent Office communication from European application No. 07868958.5, mailed Jul. 16, 2010 (2 pages).
- Voluntary amendment filed Apr. 18, 2011 in corresponding Chinese application No. CN200780102281.X, including English translation of claim amendments (10 pages).
- Non Final Office Action from U.S. Appl. No. 12/618,297 mailed May 13, 2011 (44 pages).
- Response to Office Action issued Aug. 20, 2010 in U.S. Appl. No. 11/948,359, filed Feb. 22, 2011 (17 pages).
- Non Final Office Action from U.S. Appl. No. 11/948,359 mailed Aug. 20, 2010 (12 pages).
- Non Final Office Action from U.S. Appl. No. 12/275,103 mailed Feb. 1, 2011 (6 pages).
- Response to Non Final Office Action issued Feb. 1, 2011 in U.S. Appl. No. 12/275,103, filed May 2, 2011 (13 pages).
- European Search Report from corresponding European application No. 11165422.4 mailed Aug. 8, 2011 (118 pages).
- European Search Report from corresponding European application No. 11165423.2 mailed Aug. 8, 2011 (118 pages).
- European Communication from corresponding European application No. 11165422.4 mailed Sep. 2, 2011 (5 pages).
- European Communication from corresponding European application No. 11165423.2 mailed Sep. 2, 2011 (5 pages).
- Chinese Office action from Chinese application No. 200680051421.0 issued Aug. 22, 2011 (4 pages).
- Chinese Office action from Chinese application No. 200680051421.0 issued Mar. 21, 2011 (6 pages).
- Chinese Office action from Chinese application No. 200680051421.0 issued Dec. 25, 2009 (8 pages).
- Canadian Office action from Canadian application No. 2,629,333 issued May 11, 2011 (2 pages).
- Canadian Office action from Canadian application No. 2,629,333 issued Aug. 30, 2010 (5 pages).
- European Communication from European application No. 06838033.6 mailed Apr. 20, 2010 (7 pages).
- European Patent Office communication from European application No. 08855024.9, mailed Jul. 30, 2010 (2 pages).
- European Patent Office communication from European application No. 08856764.9, mailed Jul. 30, 2010 (2 pages).
- Chinese Office action from Chinese application No. 200880125918.1, mailed Sep. 15, 2011 (111 pages).
- Chinese Office action from Chinese application No. 200880125832.9, mailed Sep. 22, 2011 (11 pages).
- Response to Chinese Office action of Jan. 25, 2010 in Chinese application No. 200680051421.0, filed Jun. 24, 2010 (34 pages).

(56)

References Cited

OTHER PUBLICATIONS

Office action from U.S. Appl. No. 11/948,359, mailed Aug. 20, 2010 (12 pages).

Response to European Communication of Apr. 20, 2010, from European application No. 06838033.6, filed Nov. 2, 2010 (13 pages).

European Communication from European application No. 07868958.5, mailed Nov. 26, 2010 (50 pages).

Response to European Communication of Jul. 16, 2010 in European application No. 07868958.5 filed Aug. 26, 2010 (9 pages).

Response to European Communication of Nov. 26, 2010 in European application No. 07868958.5, filed Mar. 28, 2011 (9 pages).

Schubert and Blosser, "Progress Toward an Experiment to Study the Effect of RF Grounding in an Internal Ion Source on Axial Oscillations of the Beam in a Cyclotron", National Superconducting Cyclotron Laboratory, Michigan State University, Report MSUCL-760, CP600, Cyclotrons and Their Applications 2001, Sixteenth International Conference, 2001 pp. 274-276.

Cuttone, G., "Applications of a Particle Accelerators in Medical Physics" Istituto Nazionale di Fisica Nucleare-Laboratori Nazionali del Sud, V.S. Sofia, 44 Catania, Italy, Jan. 2010 (17 pages).

Source Search Cites of U.S. and Foreign Patents/Published applications in the name of Mitsubishi Denki Kabushiki Kaisha and Containing the Keywords (Proton and Synchrocyclotron), Jan. 2005, 8 pages.

Flanz, et al., "Operation of a Cyclotron Based Proton Therapy Facility", Massachusetts General Hospital, Boston, MA, 2010, pp. 1-4.

Krevet, et al., "Design of a Strongly Curved Superconducting Bending Magnet for a Compact Synchrotron Light Source", *Advances in Cryogenic Engineering*, vol. 33, pp. 25-32, 1988.

Stanford, A.L., et al., "Method of Temperature Control in Microwave Ferroelectric Measurements," Sperry Microwave Electronics Company, Clearwater, Florida, Sep. 19, 1960 (1 page).

Tadashi, I., et al., "Large superconducting super collider (SSC) in the planning and materials technology", vol. 78, No. 8 (Aug. 1992), pp. 1305-1313, The Iron and Steel Institute of Japan 00211575.

"The Davis 76-Inch Isochronous Cyclotron", *Beam On: Crocker Nuclear Laboratory*, University of California, Feb. 9, 2009 (1 page).

Badano et al., *Proton-Ion Medical Machine Study (PIMMS) Part I*, PIMMS, Jan. 1999, 238 pages.

"Beam Delivery and Properties" *Journal of the ICRU*, vol. 7 No. 2, 2007, 20 pages.

Peggs et al. "A Survey of Hadron Therapy Accelerator Technologies" *Particle Accelerator Conference*, Jun. 25-29, 2007, 7 pages.

Pedroni et al., "Latest Developments in Proton Therapy" *Proceedings of EPAC*, Vienna Austria, 2000, 5 pages.

Collins, et al., "The Indiana University Proton Therapy System", *Proceedings of EPAC 2006*, Edinburgh, Scotland, 3 pages.

Paganetti et al., "Proton Beam Radiotherapy—The State of the Art" Springer Verlag, Heidelberg, ISBN 3-540-00321-5, Oct. 2005, 36 pages.

Pedroni, "Status of Proton Therapy: results and future trends" Paul Scherrer Institute, Division of Radiation Medicine, 5 pages, 2013.

Kimstrand, "Beam Modelling for Treatment Planning of Scanned Proton Beams" *Digital Comprehensive Summaries of Uppsala dissertations from the Faculty of Medicine 330*, Uppsala Universitet, 2008, 58 pages.

Marchand et al., "IBA Proton Pencil Beam Scanning: an Innovative Solution for Cancer Treatment", *Proceedings of EPAC 2000*, Vienna, Austria, 3 pages.

Alonso, "Magnetically Scanned Ion Beams for Radiation Therapy" *Accelerator & Fusion Research Division*, Lawrence Berkeley Laboratory, Berkeley, CA, Oct. 1988, 13 pages.

Moyers et al., "A Continuously Variable Thickness Scatterer for Proton Beams Using Self-compensating Dual Linear Wedges" Loma Linda University Medical Center, Dept. of Radiation Medicine, Loma Linda, CA, Nov. 2, 1992, 21 pages.

Chu et al., "Performance Specifications for Proton Medical Facility", Lawrence Berkeley Laboratory, University of California, Mar. 1993, 128 pages.

Chu, "Instrumentation in Medical Systems" *Accelerator and Fusion Research Division*, Lawrence Berkeley Laboratory, University of California, Berkeley, CA, May 1995, 9 pages.

Tilly et al., "Development and verification of the pulsed scanned proton beam at The Svedberg Laboratory in Uppsala", *Phys. Med. Biol.* 52, 2007, pp. 2741-2754.

Bimbot, "First Studies of the External Beam from the Orsay S.C. 200 MeV" *Institut de Physique Nucleaire*, BP 1, Orsay, France, IEEE, 1979, pp. 1923-1926.

Cosgrove et al., "Microdosimetric Studies on the Orsay Proton Synchrocyclotron at 73 and 200 MeV", *Radiation Protection Dosimetry*, vol. 70, Nos. 1-4, pp. 493-496, 1997.

Laisne et al., "The Orsay 200 MeV Synchrocyclotron" *IEEE Transactions on Nuclear Science*, vol. NS-26, No. 2, Apr. 1979, pp. 1919-1922.

Lin et al., "Principles and 10 year experience of the beam monitor system at the psi scanned proton therapy facility" *Center for Proton Radiation Therapy*, Paul Scherrer Institute, Switzerland, 21 pages, 2013.

Chinese Office Action for Chinese application 200880125918.1 mailed Sep. 15, 2011 (15 pages).

Response to Chinese Office Action mailed Sep. 15, 2011 in Chinese application 200880125918.1, filed Mar. 29, 2012 (26 pages).

Chinese Office Action for Chinese application 200880125918.1 mailed May 30, 2012 (10 pages).

Response to Chinese Office Action mailed May 30, 2012 in Chinese application 200880125918.1, filed Aug. 14, 2012 (19 pages).

Chinese Office Action for Chinese application 200880125918.1 mailed Dec. 7, 2012 (10 pages).

Japanese Office action with English translation from corresponding Japanese application No. 2010-536130 issued Jun. 4, 2013 (8 pages).

Timmer, Jan, "The ACCEL Single Room Proton Therapy Facility" *ACCEL Instruments GmbH*, PTCOG 45, Oct. 7-11, 2006, Houston, Texas (18 pages).

Renner, T.R., et al., "Preliminary Results of a Raster Scanning Beam Delivery System", *IEEE*, 1989 (3 pages).

Pardo, J., et al., "Simulation of the Performance of the CNAO facility's Beam Delivery System", *PTCOG 46*, Zibo, China, May 21, 2007 (17 pages).

"Single Room Proton Therapy Facility", *ACCEL*, Oct. 2006 (1 page).

Flanz, J, et al., "Scanning Beam Technologies", *PTCOG 2008* (28 pages).

Lin, S., et al., "Principles and 10 Year Experience of the Beam Monitor System at the PSI Scanned Proton Therapy Facility", *Center for Proton Radiation Therapy*, Paul Scherrer Institute, CH-5232 Villigen PSI, Switzerland, 2007 (21 pages).

Tilly, et al., "Development and verification of the pulsed scanned proton beam at The Svedberg Laboratory in Uppsala", *Physics in Medicine and Biology*, *Phys. Med. Biol.* 52, pp. 2741-2754, 2007.

Response with English translation to Japanese Office action mailed Feb. 10, 2014 from corresponding Japanese application No. 2010-536130, filed May 8, 2014 (15 pages).

Japanese Office Action with English translation from corresponding Japanese application No. 2010-536130 issued on Feb. 10, 2014 (9 pages).

International Search Report and Written Opinion from corresponding PCT application No. PCT/US2008/084695 mailed on Jan. 26, 2009 (13 pages).

European Search Report from corresponding European application 08855024.9 dated Jun. 6, 2014 (5 pages).

European Communication from corresponding European application 08855024.9 dated Jul. 29, 2014 (10 pages).

Kleeven, W., "Injection and Extraction for Cyclotrons", *Ion Beam Applications (IBA)*, *Proceedings of the Specialised CERN Accelerator School on Small Accelerators*, Oct. 26, 2006, pp. 271-296, XP055119328, Geneva, Switzerland, Retrieved from the Internet: URL:<http://cds.cern.ch/record/1005057/files/p271.pdf>, [retrieved on May 21, 2014].

(56)

References Cited

OTHER PUBLICATIONS

YamayaA, T., et al.: "A Small Cold Cathode Heavy Ion Source for a Compact Cyclotron", Nuclear Instruments and Methods in Physics Research, vol. 226, Jan. 1, 1984, pp. 219-222, XP055119506.

Welton, R. F., "RF-Plasma Coupling Schemes for the SNS Ion Source", AIP Conference Proceedings, vol. 694, Jan. 1, 2003, pp. 431-438, XP055119965.

Taiwanese Office Action with English translation from corresponding Taiwanese application 097144549 dated Sep. 4, 2014 (20 pages).

* cited by examiner

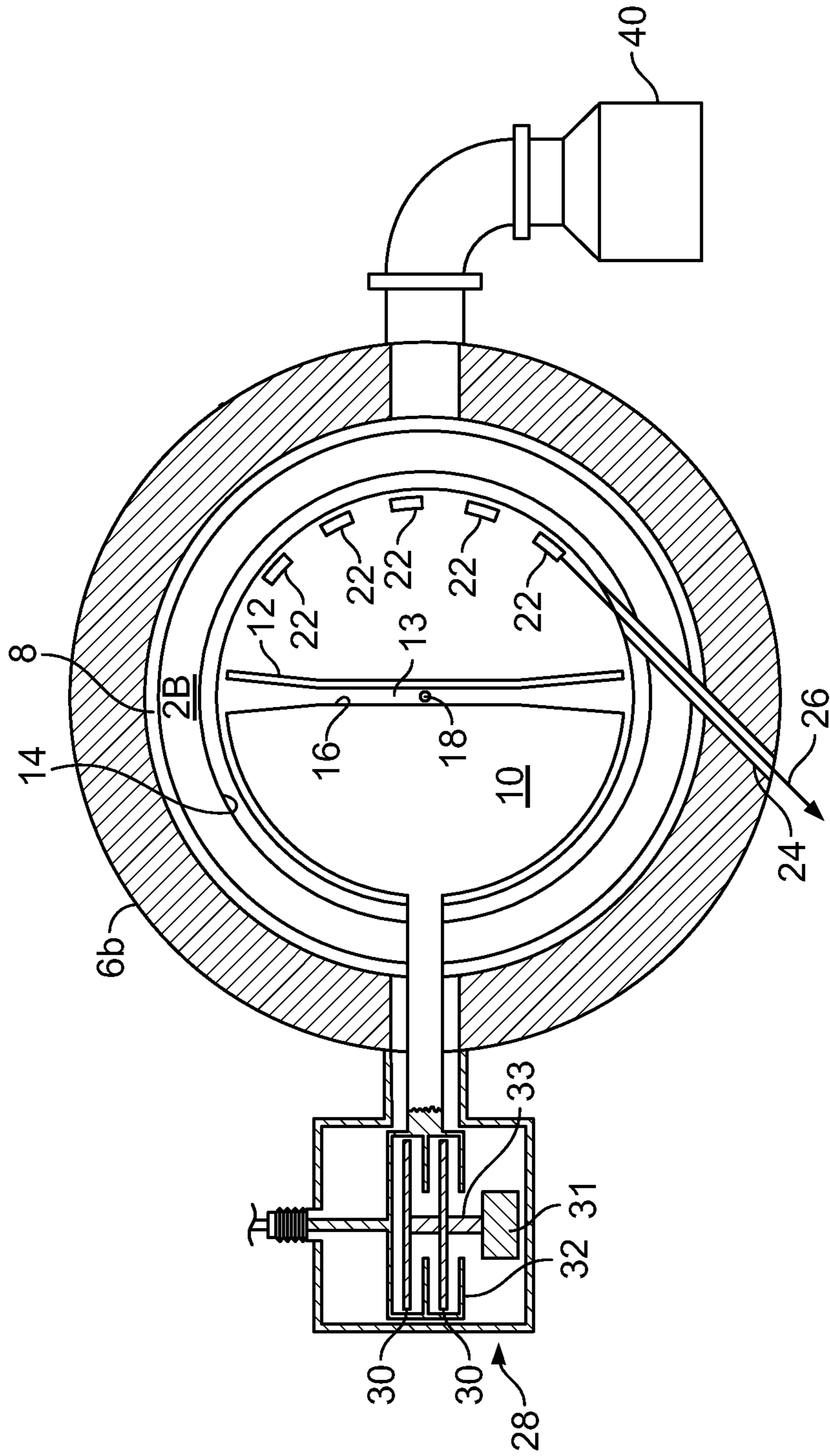


FIG. 1A

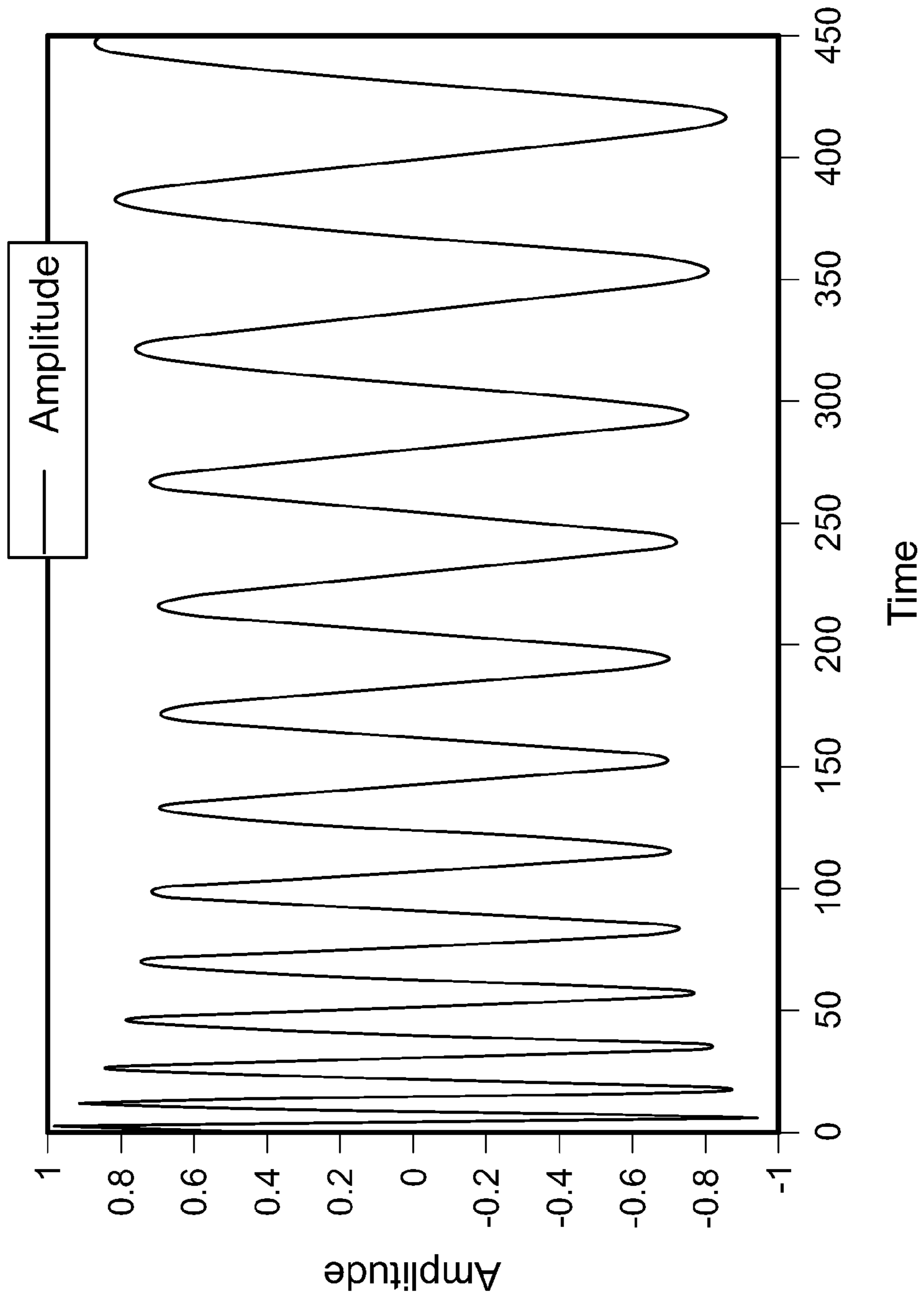


FIG. 2

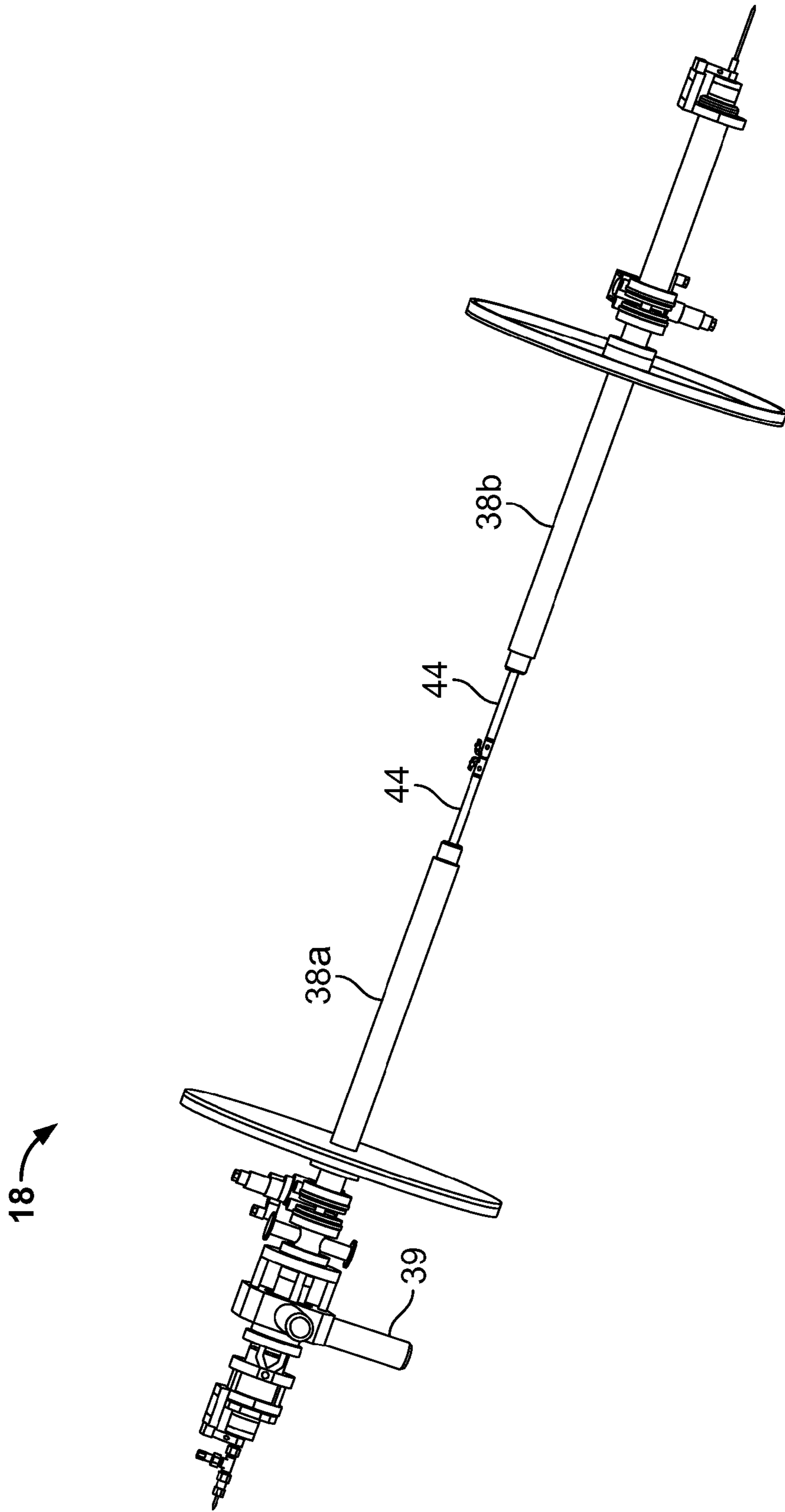


FIG. 3A

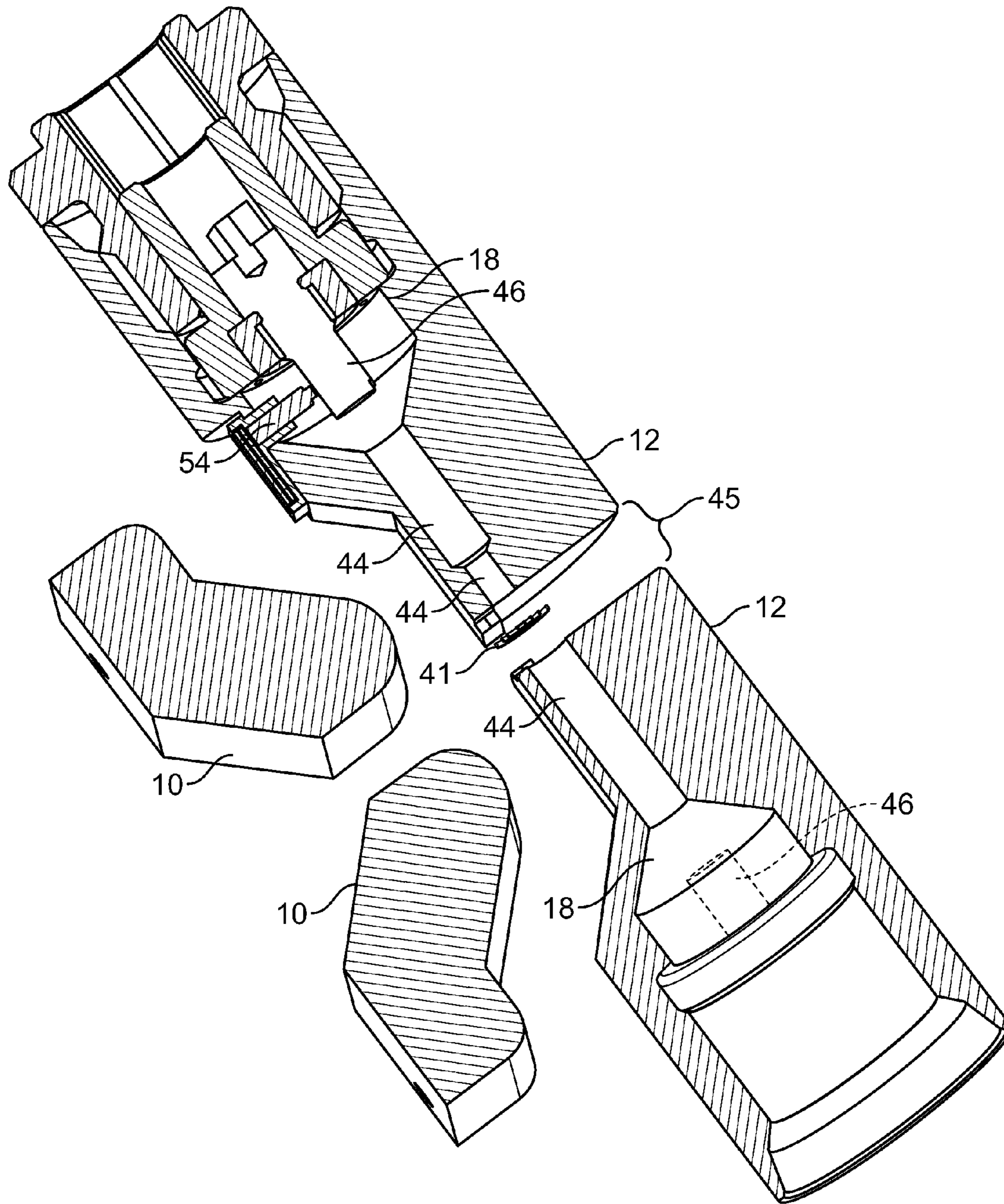


FIG. 3B

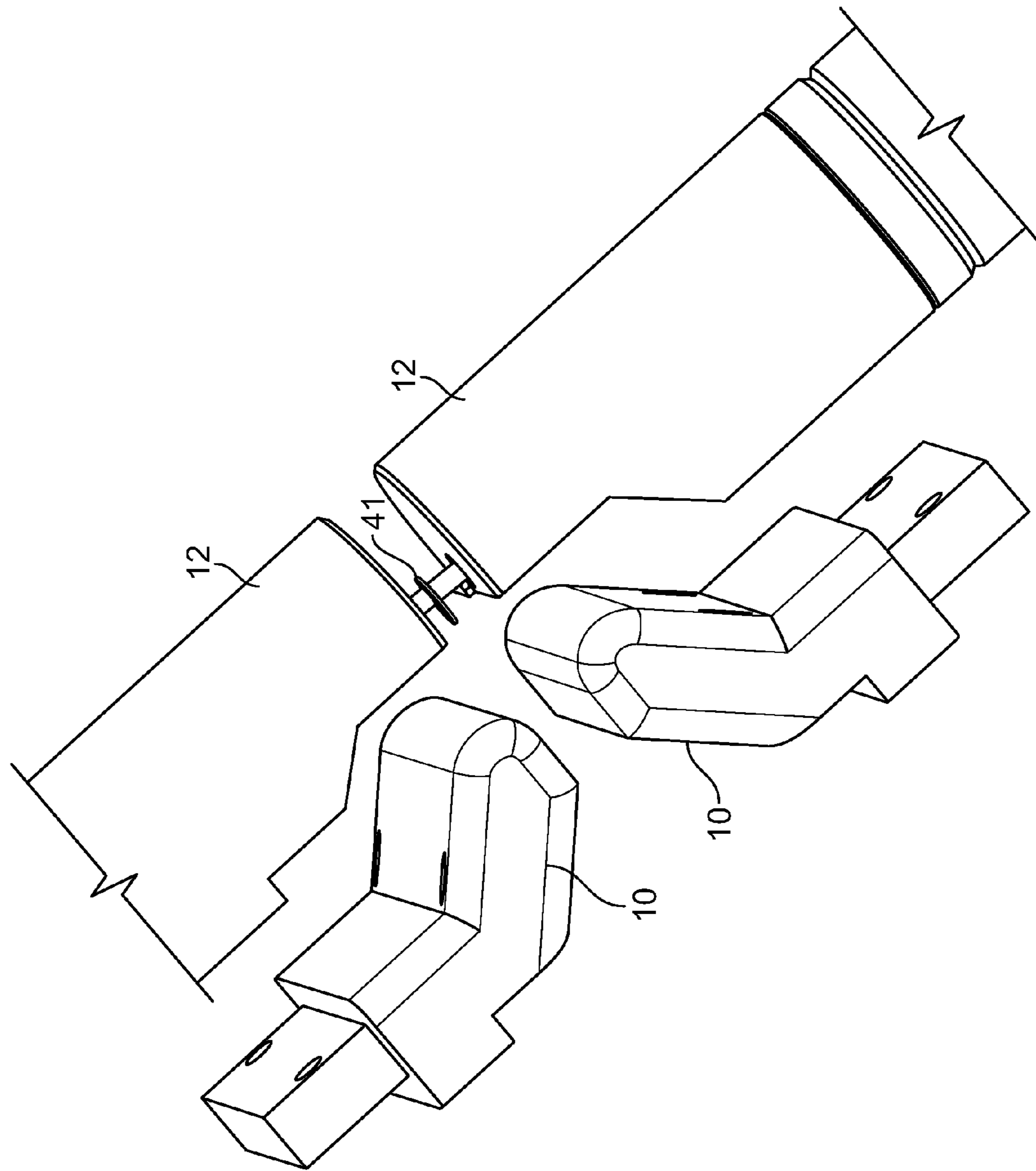


FIG. 4

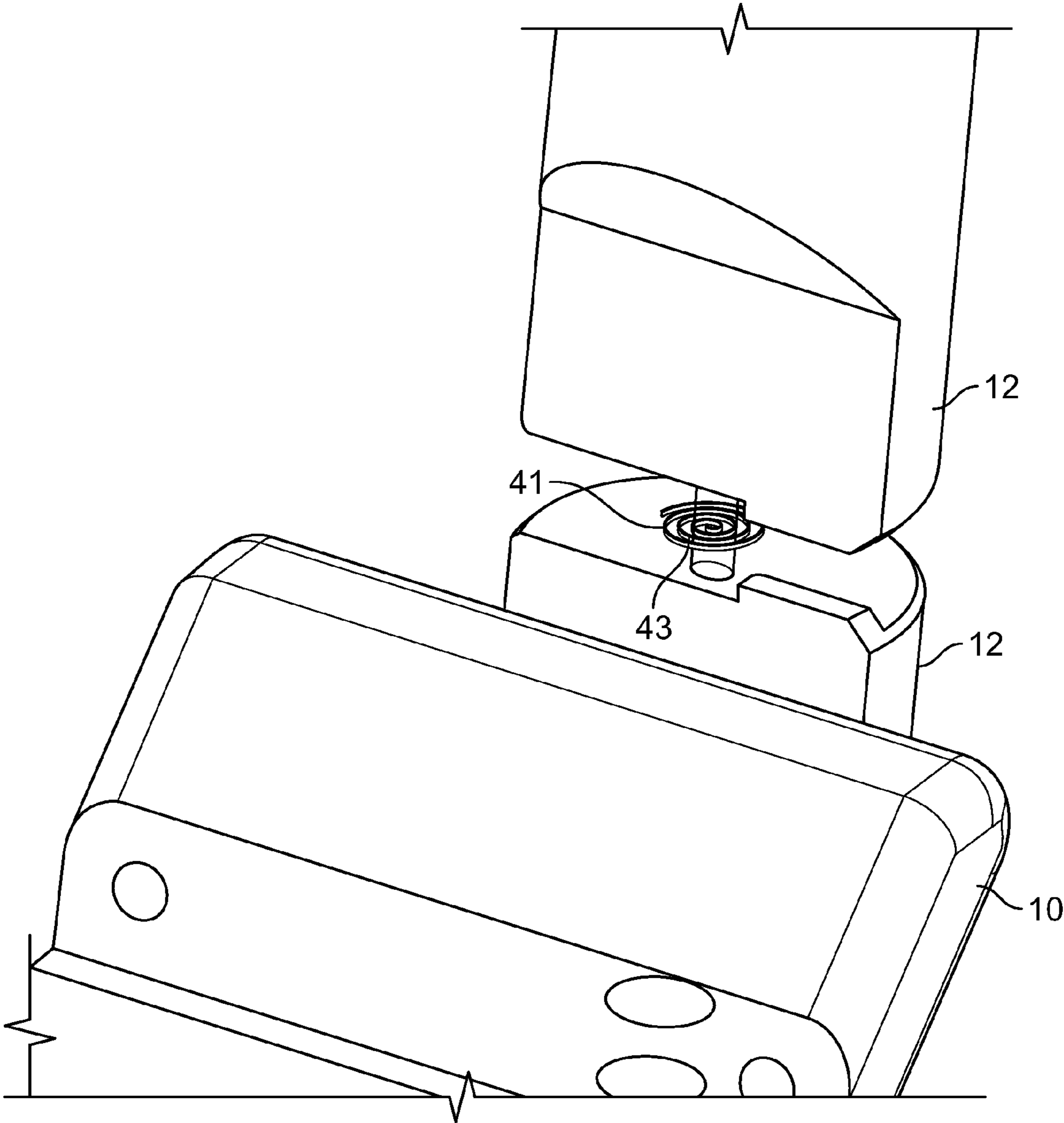


FIG. 5

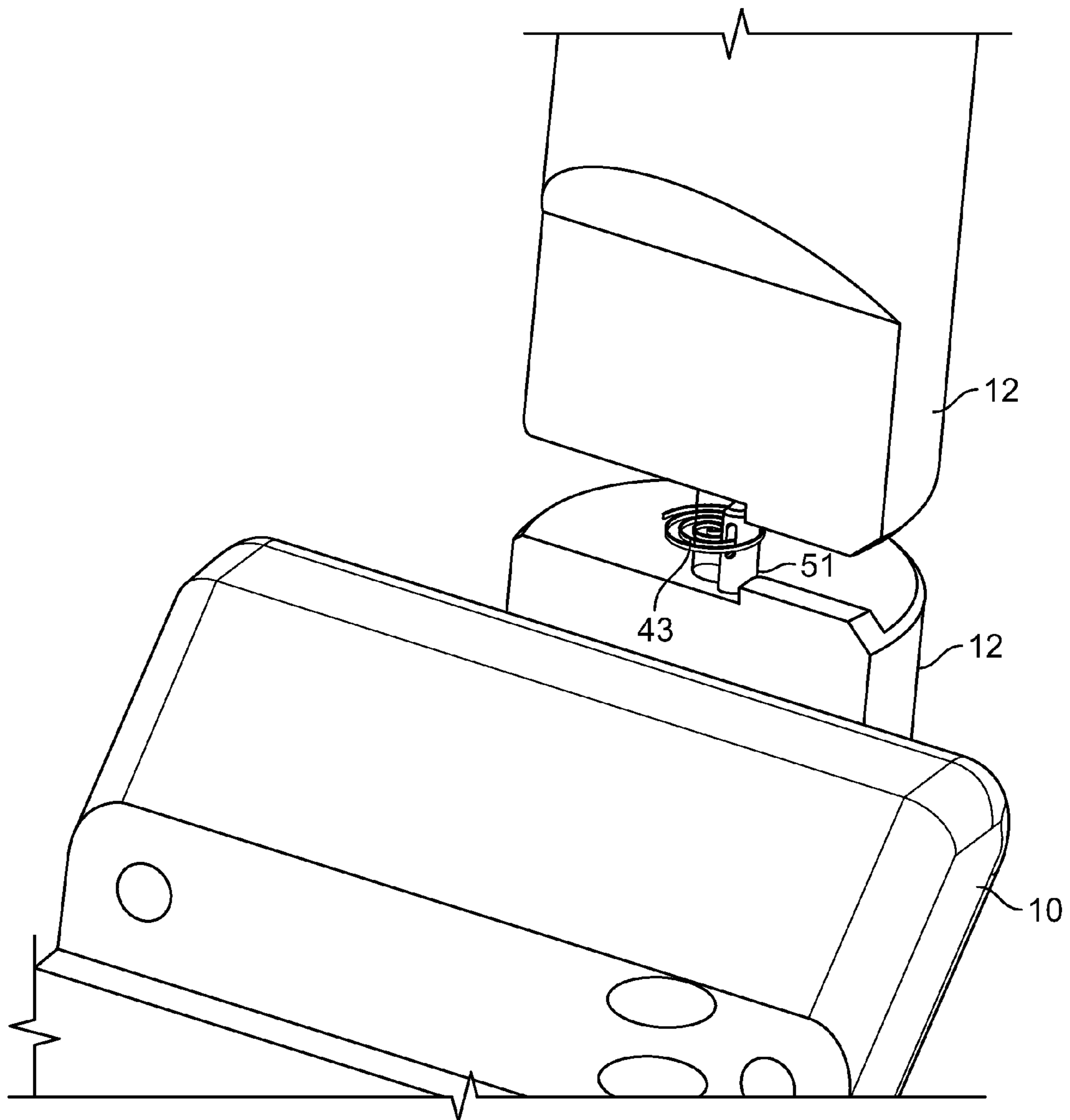


FIG. 6

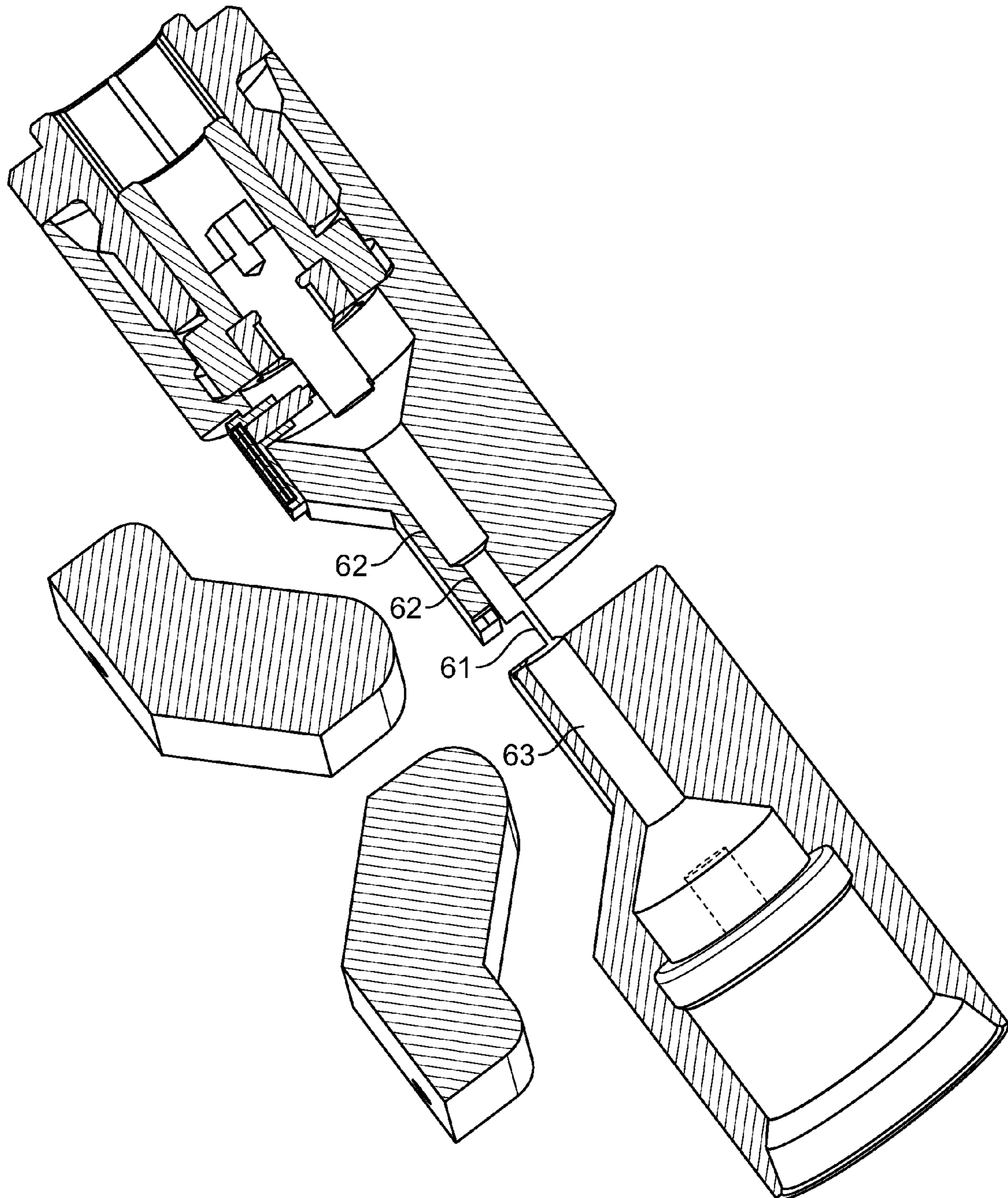


FIG. 7

INTERRUPTED PARTICLE SOURCE

Matter enclosed in heavy brackets [] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue; a claim printed with strikethrough indicates that the claim was canceled, disclaimed, or held invalid by a prior post-patent action or proceeding.

CROSS-REFERENCE TO RELATED APPLICATION

This [patent] application *a reissue application of U.S. application Ser. No. 14/075,261 filed on Nov. 8, 2013 now U.S. Pat. No. 8,970,137, which is a continuation of U.S. application Ser. No. 11/948,662, which was filed on Nov. 30, 2007 [and which is scheduled to issue as] now U.S. Pat. No. 8,581,523 [on Nov. 12, 2013]. The contents of U.S. application Ser. No. 11/948,662 are incorporated herein by reference.*

TECHNICAL FIELD

This patent application describes a particle accelerator having a particle source that is interrupted at an acceleration region.

BACKGROUND

In order to accelerate charged particles to high energies, many types of particle accelerators have been developed. One type of particle accelerator is a cyclotron. A cyclotron accelerates charged particles in an axial magnetic field by applying an alternating voltage to one or more dees in a vacuum chamber. The name dee is descriptive of the shape of the electrodes in early cyclotrons, although they may not resemble the letter D in some cyclotrons. The spiral path produced by the accelerating particles is perpendicular to the magnetic field. As the particles spiral out, an accelerating electric field is applied at the gap between the dees. The radio frequency (RF) voltage creates an alternating electric field across the gap between the dees. The RF voltage, and thus the field, is synchronized to the orbital period of the charged particles in the magnetic field so that the particles are accelerated by the radio frequency waveform as they repeatedly cross the gap. The energy of the particles increases to an energy level greatly in excess of the peak voltage of the applied RF voltage. As the charged particles accelerate, their masses grow due to relativistic effects. Consequently, the acceleration of the particles varies the phase match at the gap.

Two types of cyclotrons presently employed, an isochronous cyclotron and a synchrocyclotron, overcome the challenge of increase in relativistic mass of the accelerated particles in different ways. The isochronous cyclotron uses a constant frequency of the voltage with a magnetic field that increases with radius to maintain proper acceleration. The synchrocyclotron uses a decreasing magnetic field with increasing radius to provide axial focusing and varies the frequency of the accelerating voltage to match the mass increase caused by the relativistic velocity of the charged particles.

SUMMARY

In general, this patent application describes a synchrocyclotron comprising magnetic structures to provide a mag-

netic field to a cavity, and a particle source to provide a plasma column to the cavity. The particle source has a housing to hold the plasma column. The housing is interrupted at an acceleration region to expose the plasma column. A voltage source is configured to provide a radio frequency (RF) voltage to the cavity to accelerate particles from the plasma column at the acceleration region. The synchrocyclotron described above may include one or more of the following features, either alone or in combination.

The magnetic field may be above 2 Tesla (T), and the particles may accelerate from the plasma column outwardly in spirals with radii that progressively increase. The housing may comprise two portions that are completely separated at the acceleration region to expose the plasma column. The voltage source may comprise a first dee that is electrically connected to an alternating voltage and a second dee that is electrically connected to ground. At least part of the particle source may pass through the second dee. The synchrocyclotron may comprise a stop in the acceleration region. The stop may be for blocking acceleration of at least some of the particles from the plasma column. The stop may be substantially orthogonal to the acceleration region and may be configured to block certain phases of particles from the plasma column.

The synchrocyclotron may comprise cathodes for use in generating the plasma column. The cathodes may be operable to pulse a voltage to ionize gas to generate the plasma column. The cathodes may be configured to pulse at voltages between about 1 kV to about 4 kV. The cathodes need not be heated by an external heat source. The synchrocyclotron may comprise a circuit to couple voltage from the RF voltage to the at least one of the cathodes. The circuit may comprise a capacitive circuit.

The magnetic structures may comprise magnetic yokes. The voltage source may comprise a first dee that is electrically connected to an alternating voltage and a second dee that is electrically connected to ground. The first dee and the second dee may form a tunable resonant circuit. The cavity to which the magnetic field is applied may comprise a resonant cavity containing the tunable resonant circuit.

In general, this patent application also describes a particle accelerator comprising a tube containing a gas, a first cathode adjacent to a first end of the tube, and a second cathode adjacent to a second end of the tube. The first and second cathodes are for applying voltage to the tube to form a plasma column from the gas. Particles are available to be drawn from the plasma column for acceleration. A circuit is configured to couple energy from an external radio frequency (RF) field to at least one of the cathodes. The particle accelerator described above may include one or more of the following features, either alone or in combination.

The tube may be interrupted at an acceleration region at which the particles are drawn from the plasma column. The first cathode and the second cathode need not be heated by an external source. The first cathode may be on a different side of the acceleration region than the second cathode.

The particle accelerator may comprise a voltage source to provide the RF field. The RF field may be for accelerating the particles from the plasma column at the acceleration region. The energy may comprise a portion of the RF field provided by the voltage source. The circuit may comprise a capacitor to couple energy from the external field to at least one of the first cathode and the second cathode.

The tube may comprise a first portion and a second portion that are completely separated at a point of interruption at the acceleration region. The particle accelerator may

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comprise a stop at the acceleration region. The stop may be used to block at least one phase of the particles from further acceleration.

The particle accelerator may comprise a voltage source to provide the RF field to the plasma column. The RF field may be for accelerating the particles from the plasma column at the acceleration region. The RF field may comprise a voltage that is less than 15 kV. Magnetic yokes may be used to provide a magnetic field that crosses the acceleration region. The magnetic field may be greater than about 2 Tesla (T).

In general, this patent application also describes a particle accelerator comprising a Penning ion gauge (PIG) source comprising a first tube portion and a second tube portion that are at least partially separated at an acceleration region. The first tube portion and the second tube portion are for holding a plasma column that extends across the acceleration region. A voltage source is used to provide a voltage at the acceleration region. The voltage is for accelerating particles out of the plasma column at the acceleration region. The particle accelerator described above may include one or more of the following features, either alone or in combination.

The first tube portion and the second tube portion may be completely separated from each other. Alternatively, only one or more portions of the first tube portion may be separated from corresponding portions of the second tube portion. In this latter configuration, the PIG source may comprise a physical connection between a part of the first tube portion and the second tube portion. The physical connection may enable particles accelerating out of the plasma column to complete a first turn upon escaping from the plasma column without running into the physical connection.

The PIG source may pass through a first dee that is electrically connected to ground. A second dee that is electrically connected to an alternating voltage source may provide the voltage at the acceleration region.

The particle accelerator may comprise a structure that substantially encloses the PIG source. The particle accelerator may comprise magnetic yokes that define a cavity containing the acceleration region. The magnetic yokes may be for generating a magnetic field across the acceleration region. The magnetic field may be at least 2 Tesla (T). For example, the magnetic field may be at least 10.5 T. The voltage may comprise a radio frequency (RF) voltage that is less than 15 kV.

The particle accelerator may comprise one or more electrodes for use in accelerating the particles out of the particle accelerator. At least one cathode may be used in generating the plasma column. The at least one cathode used in generating the plasma column may comprise a cold cathode (e.g., one that is not heated by an external source). A capacitive circuit may couple at least some of the voltage to the cold cathode. The cold cathode may be configured to pulse voltage to generate the plasma column from gas in the first tube portion and the second tube portion.

Any of the foregoing features may be combined to form implementations not specifically described herein.

The details of one or more examples are set forth in the accompanying drawings and the description below. Further features, aspects, and advantages will become apparent from the description, the drawings, and the claims.

DESCRIPTION OF THE DRAWINGS

FIG. 1A is a cross-sectional view of a synchrocyclotron. FIG. 1B is a side cross-sectional view of the synchrocyclotron shown in FIG. 1A.

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FIG. 2 is an illustration of an idealized waveform that can be used for accelerating charged particles in the synchrocyclotron of FIGS. 1A and 1B.

FIG. 3A is a side view of a particle source, such as a Penning ion gauge source.

FIG. 3B is a close-up side view of a portion of the particle source of FIG. 3A passing through a dummy dee and adjacent to an RF dee.

FIG. 4 is a side view of the particle source of FIG. 3 showing spiral acceleration of a particle from a plasma column generated by the particle source.

FIG. 5 is a perspective view of the particle source of FIG. 4

FIG. 6 is a perspective view of the particle source of FIG. 4 containing a stop for blocking one or more phases of particles.

FIG. 7 is a perspective view of an alternative embodiment, in which a substantial portion of the ion source is removed.

DETAILED DESCRIPTION

A synchrocyclotron-based system is described herein. However, the circuits and methods described herein may be used with any type of cyclotron or particle accelerator.

Referring to FIGS. 1A and 1B, a synchrocyclotron 1 includes electrical coils 2a and 2b around two spaced apart ferro-magnetic poles 4a and 4b, which are configured to generate a magnetic field. Magnetic poles 4a and 4b are defined by two opposing portions of yokes 6a and 6b (shown in cross-section). The space between poles 4a and 4b defines vacuum chamber 8 or a separate vacuum chamber can be installed between poles 4a and 4b. The magnetic field strength is generally a function of distance from the center of vacuum chamber 8 and is determined largely by the choice of geometry of coils 2a and 2b and the shape and material of magnetic poles 4a and 4b.

The accelerating electrodes are defined as dee 10 and dee 12, having gap 13 between them. Dee 10 is connected to an alternating voltage potential whose frequency is changed from high to low during an accelerating cycle in order to account for the increasing relativistic mass of a charged particle and radially decreasing magnetic field (measured from the center of vacuum chamber 8) produced by coils 2a and 2b and pole portions 4a and 4b. Accordingly, dee 10 is referred to as the radio frequency (RF) dee. The idealized profile of the alternating voltage in dees 10 and 12 is shown in FIG. 2 and will be discussed in detail below. In this example, RF dee 10 is a half-cylinder structure, which is hollow inside. Dee 12, also referred to as the "dummy dee", does not need to be a hollow cylindrical structure, since it is grounded at the vacuum chamber walls 14. Dee 12, as shown in FIGS. 1A and 1B, includes a strip of metal, e.g., copper, having a slot shaped to match a substantially similar slot in RF dee 10. Dee 12 can be shaped to form a mirror image of surface 16 of RF dee 10.

Ion source 18 is located at about the center of vacuum chamber 8, and is configured to provide particles (e.g., protons) at a center of the synchrocyclotron for acceleration, as described below. Extraction electrodes 22 direct the charged particles from an acceleration region into extraction channel 24, thereby forming beam 26 of the charged particles. Here, ion source 18 is inserted axially into the acceleration region.

Dees 10 and 12 and other pieces of hardware included in a synchrocyclotron define a tunable resonant circuit under an oscillating voltage input that creates an oscillating electric

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field across gap **13**. The result is a resonant cavity in vacuum chamber **8**. This resonant frequency of the resonant cavity can be tuned to keep its Q-factor high by synchronizing the frequency being swept. In one example, the resonant frequency of the resonant cavity moves, or “sweeps”, within a range of about 30 Megahertz (MHz) and about 135 MHz (VHF range) over time, e.g., over about 1 millisecond (ms). In another example, the resonant frequency of the resonant cavity moves, or sweeps, between about 95 MHz and about 135 MHz in about 1 ms. Resonance of the cavity may be controlled in the manner described in U.S. patent application Ser. No. 11/948,359, entitled “Matching A Resonant Frequency Of A Resonant Cavity To A Frequency Of An Input Voltage”, the contents of which are incorporated herein by reference as if set forth in full.

The Q-factor is a measure of the “quality” of a resonant system in its response to frequencies close to the resonant frequency. In this example, the Q-factor is defined as

$$Q=1/R \times v/(L/C),$$

where R is the active resistance of the resonant circuit, L is the inductance, and C is the capacitance of the resonant circuit.

The tuning mechanism can be, e.g., a variable inductance coil or a variable capacitance. A variable capacitance device can be a vibrating reed or a rotating capacitor. In the example shown in FIGS. **1A** and **1B**, the tuning mechanism includes rotating capacitor **28**. Rotating capacitor **28** includes rotating blades **30** that are driven by a motor **31**. During each cycle of motor **31**, as blades **30** mesh with blades **32**, the capacitance of the resonant circuit that includes dees **10** and **12** and rotating capacitor **28** increases and the resonant frequency decreases. The process reverses as the blades unmesh. Thus, the resonant frequency is changed by changing the capacitance of the resonant circuit. This serves the purpose of reducing, by a large factor, the power required to generate the high voltage applied at the dee/dummy dee gap at the frequency necessary to accelerate the particle beam. The shape of blades **30** and **32** can be machined so as to create the required dependence of resonant frequency on time.

The blade rotation can be synchronized with RF frequency generation so the frequency of the resonant circuit defined by the synchrocyclotron is kept close to the frequency of the alternating voltage potential applied to the resonant cavity. This promotes efficient transformation of applied RF power to RF voltage on the RF dee.

A vacuum pumping system **40** maintains vacuum chamber **8** at a very low pressure so as not to scatter the accelerating beam (or to provide relatively little scattering) and to substantially prevent electrical discharges from the RF dee.

To achieve substantially uniform acceleration in the synchrocyclotron, the frequency and the amplitude of the electric field across the dee gap is varied to account for the relativistic mass increase and radial variation of magnetic field as well as to maintain focus of the beam of particles. The radial variation of the magnetic field is measured as a distance from the center of an outwardly spiraling trajectory of a charged particle.

FIG. **2** is an illustration of an idealized waveform that may be required for accelerating charged particles in a synchrocyclotron. It shows only a few cycles of the waveform and does not necessarily represent the ideal frequency and amplitude modulation profiles. FIG. **2** illustrates the time varying amplitude and frequency properties of the waveform used in the synchrocyclotron. The frequency changes from

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high to low as the relativistic mass of the particle increases while the particle speed approaches a significant fraction of the speed of light.

Ion source **18** is deployed near to the magnetic center of synchrocyclotron **1** so that particles are present at the synchrocyclotron mid-plane, where they can be acted upon by the RF field (voltage). The ion source may have a Penning ion gauge (PIG) geometry. In the PIG geometry, two high voltage cathodes are placed about opposite each other. For example, one cathode may be on one side of the acceleration region and one cathode may be on the other side of the acceleration region and in line with the magnetic field lines. The dummy dee housings **12** of the source assembly may be at ground potential. The anode includes a tube extending toward the acceleration region. When a relatively small amount of a gas (e.g., hydrogen/H₂) occupies a region in the tube between the cathodes, a plasma column may be formed from the gas by applying a voltage to the cathodes. The applied voltage causes electrons to stream along the magnetic field lines, essentially parallel to the tube walls, and to ionize gas molecules that are concentrated inside the tube, thereby creating the plasma column.

A PIG geometry ion source **18**, for use in synchrocyclotron **1**, is shown in FIGS. **3A** and **3B**. Referring to FIG. **3A**, ion source **18** includes an emitter side **38a** containing a gas feed **39** for receiving gas, and a reflector side **38b**. A housing, or tube, **44** holds the gas, as described below. FIG. **3B** shows ion source **18** passing through dummy dee **12** and adjacent to RF dee **10**. In operation, the magnetic field between RF dee **10** and dummy dee **12** causes particles (e.g., protons) to accelerate outwardly. The acceleration is spiral about the plasma column, with the particle-to-plasma-column radius progressively increasing. The spiral acceleration, labeled **43**, is depicted in FIGS. **5** and **6**. The radii of curvature of the spirals depend on a particle’s mass, energy imparted to the particle by the RF field, and a strength of the magnetic field.

When the magnetic field is high, it can become difficult to impart enough energy to a particle so that it has a large enough radius of curvature to clear the physical housing of the ion source on its initial turn(s) during acceleration. The magnetic field is relatively high in the region of the ion source, e.g., on the order of 2 Tesla (T) or more (e.g., 8 T, 8.8 T, 8.9 T, 9 T, 10.5 T, or more). As a result of this relatively high magnetic field, the initial particle-to-ion-source radius is relatively small for low energy particles, where low energy particles include particles that are first drawn from the plasma column. For example, such a radius may be on the order of 1 mm. Because the radii are so small, at least initially, some particles may come into contact with the ion source’s housing area, thereby preventing further outward acceleration of such particles. Accordingly, the housing of ion source **18** is interrupted, or separated to form two parts, as shown in FIG. **3B**. That is, a portion of the ion source’s housing is removed at the acceleration region **41**, e.g., at about the point where the particles are to be drawn from the ion source. This interruption is labeled **45** in FIG. **3B**. The housing may also be removed for distances above, and below, the acceleration region. All or part of dummy dee **12** at the acceleration region may, or may not, also be removed.

In the example of FIGS. **3A** and **3B**, the housing **44** includes a tube, which holds a plasma column containing particles to be accelerated. The tube may have different diameters at different points, as shown. The tube may reside within dummy dee **12**, although this is not necessary. A portion of the tube in about a median plane of the synchrocyclotron is completely removed, resulting in a housing

comprised of two separate portions with an interruption **45** between the portions. In this example, the interruption is about 1 millimeter (mm) to 3 mm (i.e., about 1 mm to 3 mm of the tube is removed). The amount of the tube that is removed may be significant enough to permit particle acceleration from the plasma column, but small enough to hinder significant dissipation of the plasma column in the interrupted portion.

By removing the physical structure, here the tube, at the particle acceleration region, particles can make initial turn(s) at relatively small radii—e.g., in the presence of relatively high magnetic fields—without coming in to contact with physical structures that impede further acceleration. The initial turn(s) may even cross back through the plasma column, depending upon the strength of the magnetic and RF fields.

The tube may have a relatively small interior diameter, e.g., about 2 mm. This leads to a plasma column that is also relatively narrow and, therefore, provides a relatively small set of original radial positions at which the particles can start accelerating. The tube is also sufficiently far from cathodes **46** used to produce the plasma column—in this example, about 10 mm from each cathode. These two features, combined, reduce the amount of hydrogen (H₂) gas flow into the synchrocyclotron to less than 1 standard cubic centimeter per minute (SCCM), thereby enabling the synchrocyclotron to operate with relatively small vacuum conductance apertures into the synchrocyclotron RF/beam cavity and relatively small capacity vacuum pump systems, e.g., about 500 liters-per-second.

Interruption of the tube also supports enhanced penetration of the RF field into the plasma column. That is, since there is no physical structure present at the interruption, the RF field can easily reach the plasma column. Furthermore, the interruption in the tube allows particles to be accelerated from the plasma column using different RF fields. For example, lower RF fields may be used to accelerate the particles. This can reduce the power requirements of systems used to generate the RF field. In one example, a 20 kilowatt (kW) RF system generates an RF field of 15 kilovolts (kV) to accelerate particles from the plasma column. The use of lower RF fields reduces RF system cooling requirements and RF voltage standoff requirements.

In the synchrocyclotron described herein, a particle beam is extracted using a resonant extraction system. That is, the amplitude of radial oscillations of the beam are increased by a magnetic perturbation inside the accelerator, which is in resonance with these oscillations. When a resonant extraction system is used, extraction efficiency is improved by limiting the phase space extent of the internal beam. With attention to the design of the magnetic and RF field generating structures, the phase space extent of the beam at extraction is determined by the phase space extent at the beginning of acceleration (e.g., at emergence from the ion source). As a result, relatively little beam may be lost at the entrance to the extraction channel and background radiation from the accelerator can be reduced.

A physical structure, or stop, may be provided to control the phase of the particles that are allowed to escape from the central region of the synchrocyclotron. An example of such a stop **51** is shown in FIG. 6. Stop **51** acts as an obstacle that blocks particles having certain phases. That is, particles that hit the stop are prevented from accelerating further, whereas particles that pass the stop continue their acceleration out of the synchrocyclotron. A stop may be near the plasma column, as shown in FIG. 6, in order to select phases during the initial turn(s) of particles where the particle energy is low,

e.g., less than 50 kV. Alternatively, a stop may be located at any other point relative to the plasma column. In the example shown in FIG. 6, a single stop is located on the dummy dee **12**. There, however, may be more than one stop (not shown) per dee.

Cathodes **46** may be “cold” cathodes. A cold cathode may be a cathode that is not heated by an external heat source. Also, the cathodes may be pulsed, meaning that they output signal burst(s) periodically rather than continuously. When the cathodes are cold, and are pulsed, the cathodes are less subject to wear and can therefore last relatively long. Furthermore, pulsing the cathodes can eliminate the need to watercool the cathodes. In one implementation, cathodes **46** pulse at a relatively high voltage, e.g., about 1 kV to about 4 kV, and moderate peak cathode discharge currents of about 50 mA to about 200 mA at a duty cycle between about 0.1% and about 1% or 2% at repetition rates between about 200 Hz to about 1 KHz.

Cold cathodes can sometimes cause timing jitter and ignition delay. That is, lack of sufficient heat in the cathodes can affect the time at which electrons are discharged in response to an applied voltage. For example, when the cathodes are not sufficiently heated, the discharge may occur several microseconds later, or longer, than expected. This can affect formation of the plasma column and, thus, operation of the particle accelerator. To counteract these effects, voltage from the RF field in cavity **8** may be coupled to the cathodes. Cathodes **46** are otherwise encased in a metal, which forms a Faraday shield to substantially shield the cathodes from the RF field. In one implementation, a portion of the RF energy may be coupled to the cathodes from the RF field, e.g., about 100V may be coupled to the cathodes from the RF field. FIG. 3B shows an implementation, in which a capacitive circuit **54**, here a capacitor, is charged by the RF field and provides voltage to a cathode **46**. An RF choke and DC feed may be used to charge the capacitor. A corresponding arrangement (not shown) may be implemented for the other cathode **46**. The coupled RF voltage can reduce the timing jitter and reduce the discharge delay to about 100 nanoseconds (ns) or less in some implementations.

An alternative embodiment is shown in FIG. 7. In this embodiment, a substantial portion, but not all, of the PIG source housing is removed, leaving the plasma beam partly exposed. Thus, portions of the PIG housing are separated from their counterpart portions, but there is not complete separation as was the case above. The portion **61** that remains physically connects the first tube portion **62** and the second tube portion **63** of the PIG source. In this embodiment, enough of the housing is removed to enable particles to perform at least one turn (orbit) without impinging on the portion **61** of the housing that remains. In one example, the first turn radius may be 1 mm, although other turn radii may be implemented. The embodiment shown in FIG. 7 may be combined with any of the other features described herein.

The particle source and accompanying features described herein are not limited to use with a synchrocyclotron, but rather may be used with any type of particle accelerator or cyclotron. Furthermore ion sources other than those having a PIG geometry may be used with any type of particle accelerator, and may have interrupted portions, cold cathodes, stops, and/or any of the other features described herein.

Components of different implementations described herein may be combined to form other embodiments not

specifically set forth above. Other implementations not specifically described herein are also within the scope of the following claims.

What is claimed is:

1. A synchrocyclotron comprising: magnetic structures to provide a magnetic field to a cavity; a particle source [to provide] *comprising cathodes for generating* a plasma column [to] *in* the cavity, the particle source having a housing to hold the plasma column, the housing being interrupted at an acceleration region to expose the plasma column, wherein the housing is interrupted such that the housing is completely separated at the acceleration region [or such that a part of the housing is physically connected at the acceleration region]; and a voltage source to provide a radio frequency (RF) voltage to the cavity to accelerate particles from the plasma column at the acceleration region[; wherein, in a case that part of the housing is physically connected, the part of the housing has structure that allows particles accelerated from the plasma column to perform at least one turn without impinging on the part of the housing].
2. The synchrocyclotron of claim 1, wherein the magnetic field is above 2 Tesla (T)[, and the particles move from the plasma column outwardly in spirals with radii that progressively increase].
3. The synchrocyclotron of claim 1, wherein the housing comprises two portions that are completely separated at the acceleration region to expose the plasma column.
4. The synchrocyclotron of claim 1, wherein the voltage source comprises a first dee that is electrically connected to an alternating voltage and a second dee that is electrically connected to ground; and wherein at least part of the particle source passes through the second dee.
5. The synchrocyclotron of claim 1, further comprising a stop in the acceleration region, the stop for blocking acceleration of at least some of the particles from the plasma column.
6. The synchrocyclotron of claim 5, wherein the stop is substantially orthogonal to the acceleration region and is configured to block certain phases of particles from the plasma column.
7. The synchrocyclotron of claim 1,[further comprising: cathodes for use in generating the plasma column,] *wherein* the cathodes [being] *are* operable to pulse a voltage to ionize gas to generate the plasma column; and wherein the cathodes are not heated by an external heat source.
8. The synchrocyclotron of claim 7, wherein the cathodes are configured to pulse at voltages between about 1 kV to about 4 kV.
9. The synchrocyclotron of claim 7, further comprising: a circuit to couple voltage from the RF voltage to the at least one of the cathodes.
10. The synchrocyclotron of claim 9, wherein the circuit comprises a capacitive circuit.
11. The synchrocyclotron of claim 1, wherein the magnetic structures comprise magnetic yokes, wherein the voltage source comprises a first dee that is electrically connected to an alternating voltage and a second dee that is electrically connected to ground, wherein the first dee and the second

dee form a tunable resonant circuit, and wherein the cavity comprises a resonant cavity containing the tunable resonant circuit.

12. A synchrocyclotron comprising:

- a tube containing a gas;
- a first cathode adjacent to a first end of the tube; and
- a second cathode adjacent to a second end of the tube, the first and second cathodes applying voltage to the tube to form a plasma column from the gas;
- wherein particles are available to be drawn from the plasma column for acceleration; and
- a circuit to couple energy from [an external] a radio frequency (RF) field to at least one of the cathodes;
- wherein the tube is interrupted at an acceleration region where the particles are accelerated to expose the plasma column, wherein the tube is interrupted such that the tube is completely separated into two parts at the acceleration region [or such that a part of the tube is physically connected at the acceleration region where the particles are accelerated;
- wherein, in a case that part of the tube is physically connected, the part of the tube has structure that allows particles accelerated from the plasma column to perform at least one turn without impinging on the part of the tube].

13. The synchrocyclotron of claim 12, wherein the first cathode and the second cathode are not heated by an external source.

14. The synchrocyclotron of claim 13, further comprising: a voltage source to provide the RF field, the RF field for accelerating the particles from the plasma column at the acceleration region where the particles are accelerated.

15. The synchrocyclotron of claim 14, wherein the energy comprises a portion of the RF field provided by the voltage source.

16. The synchrocyclotron of claim 13, wherein the circuit comprises a capacitor to couple energy from the [external] RF field to at least one of the first cathode and the second cathode.

17. The synchrocyclotron of claim [13] 12, wherein the tube comprises a first [portion] *part* and a second [portion] that are completely separated at the acceleration region where the particles are accelerated] *part that are separated by a space that is between 1 mm and 3 mm.*

18. The synchrocyclotron of claim 13, further comprising: a stop at the acceleration region, the stop to block at least one phase of the particles from further acceleration.

19. The synchrocyclotron of claim [13] 12, further comprising:

- a voltage source to provide the RF field to the plasma column, the RF field for accelerating the particles from the plasma column at the acceleration region where the particles are accelerated, wherein the RF field comprises voltage that is less than 15 kV; and
- magnetic [yokes] *structures* to provide a magnetic field that crosses the acceleration region where the particles are accelerated, the magnetic field being greater than about 2 Tesla (T).

20. The synchrocyclotron of claim 12, wherein the first cathode is on a different side of the acceleration region than the second cathode.

21. A synchrocyclotron comprising:

- a Penning ion gauge (PIG) source comprising a first tube portion and a second tube portion, the first tube portion *having a first cathode* and the second tube portion *having a second cathode, the first cathode and the second cathode* for [holding] *generating* a plasma

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column that extends across an acceleration region from which particles are accelerated from the plasma column; and

a voltage source to provide a voltage at the acceleration region, the voltage for accelerating particles out of the plasma column at the acceleration region;

wherein the first tube portion is completely separated from the second tube portion at the acceleration region [or a connection exists between the first tube portion and the second tube portion at the acceleration region; wherein, in a case that the connection exists, the connection has structure that allows particles accelerated from the plasma column to perform at least one turn without impinging on the connection].

22. The synchrocyclotron of claim **21**, wherein the PIG source comprises a physical connection between a part of the first tube portion and the second tube portion, the physical connection enabling particles accelerating out of the plasma column to complete a first turn upon escaping from the plasma column without running into the physical connection.]

23. The synchrocyclotron of claim **21**, wherein the PIG source passes through a first dee that is electrically connected to ground, and wherein a second dee that is electrically connected to an alternating voltage source provides the voltage at the acceleration region.

24. The synchrocyclotron of claim **21**, further comprising: magnetic [yokes] structures that [define] border a cavity containing the acceleration region, the magnetic [yokes] structures for generating a magnetic field across the acceleration region.

25. The synchrocyclotron of claim **24**, wherein the magnetic field is at least 2 Tesla (T).

26. The synchrocyclotron of claim **25**, wherein the magnetic field is at least 10.5 T.

27. The synchrocyclotron of claim **[26]** **21**, wherein the voltage comprises a radio frequency (RF) voltage that is less than 15 kV.

28. The synchrocyclotron of claim **21**, further comprising one or more [electrodes for use in accelerating] structures to direct the particles out of the particle accelerator.

29. The synchrocyclotron of claim **21**, [further comprising:

at least one cathode for use in generating the plasma column, the at least one cathode comprising] wherein the first cathode comprises a cold cathode and the second cathode comprises a cold cathode; and

a capacitive circuit to couple at least some of the voltage to [the] at least one cathode.

30. The synchrocyclotron of claim **21**, wherein the [at least one cathode is] first cathode and the second cathode are configured to pulse voltage to generate the plasma column from gas in the first tube portion and the second tube portion.

31. A particle accelerator comprising:

a tube containing a gas;

a first cathode adjacent to a first end of the tube;

a second cathode adjacent to a second end of the tube, the first and second cathodes applying voltage to the tube to form a plasma column from the gas;

wherein particles are available to be drawn from the plasma column for acceleration;

a circuit to couple energy from [an external] a radio frequency (RF) field to at least one of the cathodes; and

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magnetic structures to provide a magnetic field that crosses an acceleration region where the particles are accelerated, the magnetic field being greater than about 2 Tesla (T);

wherein the tube is interrupted at the acceleration region where the particles are accelerated to expose the plasma column, and wherein the tube is interrupted such that the tube is completely separated into two parts at the acceleration region [or such that a part of the tube is physically connected at the acceleration region where the particles are accelerated;

wherein, in a case that part of the tube is physically connected, the part of the tube has structure that allows particles accelerated from the plasma column to perform at least one turn without impinging on the part of the tube].

32. The particle accelerator of claim **31**, wherein the first cathode and the second cathode are not heated by an external source.

33. The particle accelerator of claim **32**, wherein the circuit comprises a capacitor to couple energy from the [external] RF field to at least one of the first cathode and the second cathode.

34. The particle accelerator of claim **32**, wherein the tube comprises a first portion and a second portion that are completely separated at the acceleration region where the particles are accelerated.]

35. The particle accelerator of claim **[32]** **31**, further comprising:

a stop at the acceleration region where the particles are accelerated, the stop to block at least one phase of the particles from further acceleration.

36. The particle accelerator of claim **[32]** **31**, further comprising:

a voltage source to provide the RF field to the plasma column, the RF field for accelerating the particles from the plasma column at the acceleration region where the particles are accelerated, wherein the RF field comprises voltage that is less than 15 kV; and

[where] wherein the magnetic structures comprise magnetic yokes.

37. The particle accelerator of claim **31**, wherein the first cathode is on a different side of the acceleration region where the particles are accelerated than the second cathode.

38. The particle accelerator of claim **37**, further comprising:

a voltage source to provide the RF field, the RF field for accelerating the particles from the plasma column at the acceleration region where the particles are accelerated.

39. The particle accelerator of claim **33**, wherein the energy comprises a portion of the RF field [provided by the voltage source].

40. The particle accelerator of claim **31**, wherein the magnetic field is greater than 8 T.

41. The particle accelerator of claim **31**, wherein the magnetic field is greater than 10.5 T.

42. A synchrocyclotron comprising:

ferromagnetic pole pieces that border a cavity containing an acceleration region;

electrical coils adjacent to the ferromagnetic pole pieces to produce a magnetic field of at least 2 Tesla (T) within the cavity; and

a Penning ion gauge (PIG) source comprised of a first part and a second part that are completely separated at the acceleration region to allow extraction of charged particles from a plasma column for acceleration, the first part having a first cathode and the second part

- having a second cathode, the first cathode and the second cathode for generating the plasma column.
43. The synchrocyclotron of claim 42, wherein the magnetic field is at least 8 T.
44. The synchrocyclotron of claim 42, further comprising:
 a voltage system to provide radio frequency (RF) voltage to the cavity, the voltage system comprising a first dee that is electrically connected to an alternating voltage and a second dee that is electrically connected to ground;
 wherein at least part of the PIG source passes through the second dee.
45. A synchrocyclotron comprising:
 ferromagnetic pole pieces that border a cavity containing an acceleration region;
 electrical coils adjacent to the ferromagnetic pole pieces to produce a magnetic field of at least 2 Tesla (T) within the cavity;
 a Penning ion gauge (PIG) source comprised of a first part and a second part that are completely separated at the acceleration region to allow extraction of charged particles from a plasma column for acceleration; and
 a stop in the acceleration region, the stop for blocking at least some of the charged particles.
46. The synchrocyclotron of claim 45, wherein the stop is substantially orthogonal to the acceleration region and is configured to block certain phases of the charged particles.
47. The synchrocyclotron of claim 42, wherein the first cathode and the second cathode are operable to pulse a voltage to ionize gas to generate the plasma column; and
 wherein the first and second cathodes are not heated by an external heat source.
48. The synchrocyclotron of claim 47, wherein the first and second cathodes are controllable to pulse at voltages between about 1 kV to about 4 kV.
49. The synchrocyclotron of claim 48, further comprising:
 a circuit to couple voltage to at least one of the first and second cathodes.
50. The synchrocyclotron of claim 49, wherein the circuit comprises a capacitive circuit.
51. A synchrocyclotron comprising:
 ferromagnetic pole pieces that border a cavity containing an acceleration region in which charged particles are accelerated, the cavity containing a magnetic field of at least 2 Tesla (T);
 a particle source comprising a first part and a second part, the first part having a first cathode and the second part having a second cathode, the first part and the second part being completely separated at the acceleration region;
 accelerating electrodes to provide a radio frequency (RF) voltage to the acceleration region to extract the charged particles, the RF voltage sweeping over a frequency range; and
 circuitry to couple energy from the RF voltage to at least one of the first cathode or the second cathode.
52. The synchrocyclotron of claim 51, wherein the cavity contains a magnetic field that is at least 8 T.
53. The synchrocyclotron of claim 51, wherein the cavity contains a magnetic field that is at least 10.5 T.
54. The synchrocyclotron of claim 51, further comprising:
 a voltage system to provide radio frequency (RF) voltage to the cavity, the voltage system comprising a first dee

- that is electrically connected to an alternating voltage and a second dee that is electrically connected to ground;
 wherein at least part of the particle source passes through the second dee.
55. The synchrocyclotron of claim 51, further comprising a stop in the acceleration region, the stop for blocking at least some of the charged particles.
56. The synchrocyclotron of claim 55, wherein the stop is substantially orthogonal to the acceleration region and is configured to block certain phases of the charged particles.
57. The synchrocyclotron of claim 51, wherein the first and second cathodes are controllable to pulse at voltages between about 1 kV to about 4 kV.
58. The synchrocyclotron of claim 51, wherein the circuitry comprises a capacitive circuit.
59. A synchrocyclotron comprising:
 ferromagnetic pole pieces that border a cavity containing an acceleration region;
 a voltage system to provide radio frequency (RF) voltage to the cavity,
 electrical coils around part of the ferromagnetic pole pieces to produce a magnetic field having a magnitude of at least 2 Tesla (T) within the cavity; and
 a particle source that is completely separated at least at the acceleration region to allow extraction of charged particles from a plasma column for acceleration in response to the RF voltage, the particle source comprising a first part and a second part, the first part having a first cathode and the second part having a second cathode, the first and second cathodes for generating the plasma column.
60. The synchrocyclotron of claim 59, wherein the magnetic field is at least 8 T within the cavity.
61. The synchrocyclotron of claim 59, wherein the voltage system comprises a first dee that is electrically connected to an alternating voltage and a second dee that is electrically connected to ground; and
 wherein the RF voltage provided to the cavity is less than 15 kV.
62. The synchrocyclotron of claim 59, wherein the first part and the second part are separated for distances above and below the acceleration region.
63. The synchrocyclotron of claim 59, wherein the plasma column is produced from a gas, and wherein flow of the gas into the synchrocyclotron is less than one standard cubic centimeter per minute (SCCM).
64. A synchrocyclotron comprising:
 ferromagnetic pole pieces that border a cavity containing an acceleration region;
 a voltage system to provide radio frequency (RF) voltage to the cavity,
 electrical coils around part of the ferromagnetic pole pieces to produce a magnetic field having a magnitude of at least 2 Tesla (T) within the cavity;
 a particle source that is interrupted at least at the acceleration region to allow extraction of charged particles from a plasma column for acceleration in response to the RF voltage; and
 one or more stops at the acceleration region, the one or more stops to block at least one phase of the charged particles extracted from the particle source from further acceleration.