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McCarthy

(54) **COMPRESSER FOR PUMPING FLUID HAVING CHECK VALVES ALIGNED WITH FLUID PORTS**

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(72) Inventor: **Dan McCarthy**, Moosomin (CA)

(21) Appl. No.: **18/087,763**

(22) Filed: **Dec. 22, 2022**

Related U.S. Application Data

(63) Continuation-in-part of application No. 17/982,291, filed on Nov. 7, 2022, which is a continuation of application No. 17/483,452, filed on Sep. 23, 2021, now Pat. No. 11,519,403.

Publication Classification

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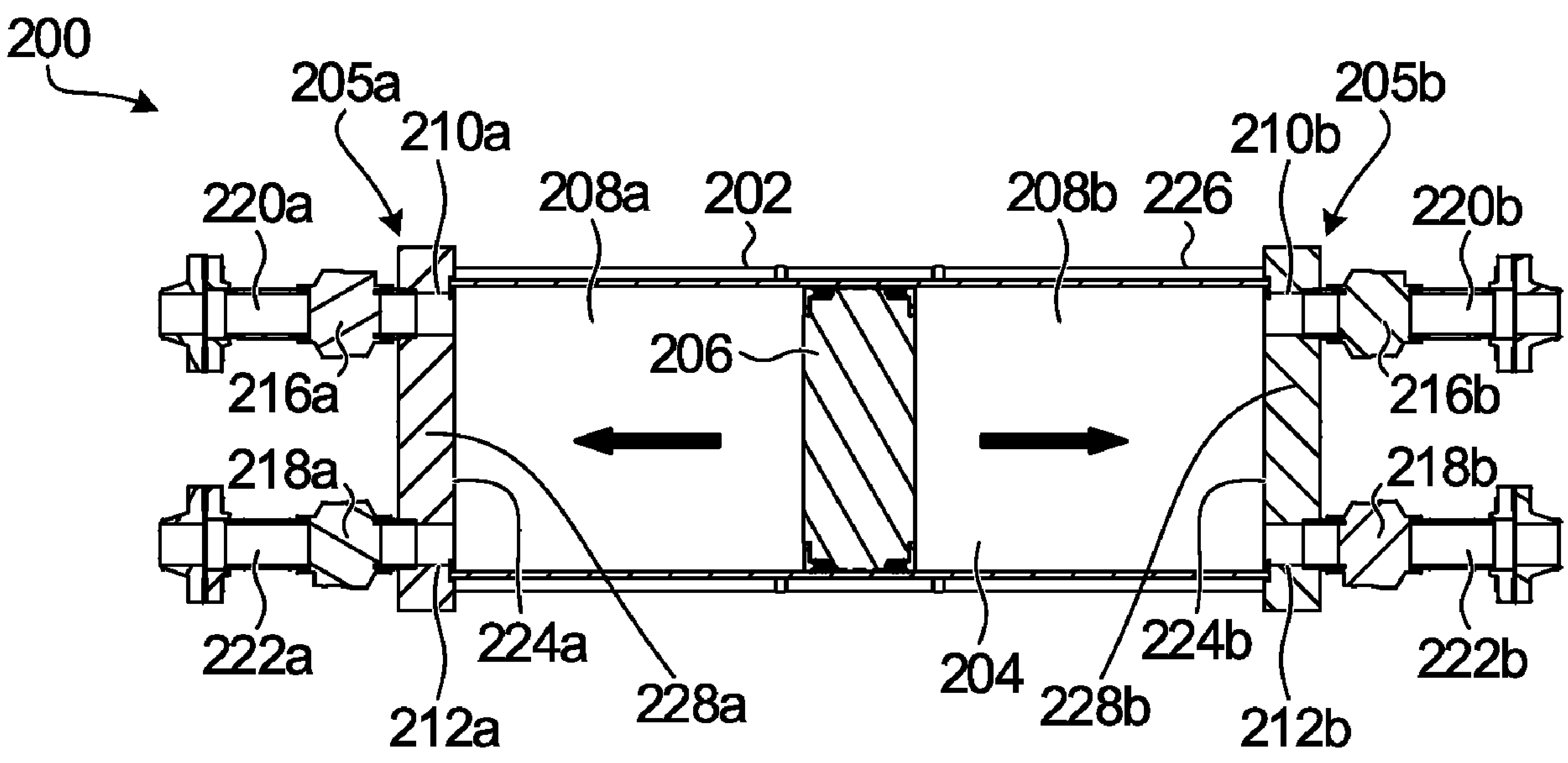
F04B 39/12 (2006.01)
F04B 5/02 (2006.01)
F04B 9/109 (2006.01)

(52) **U.S. Cl.**
CPC ***F04B 39/123*** (2013.01); ***F04B 5/02*** (2013.01); ***F04B 9/109*** (2013.01)

(57) **ABSTRACT**

A compressor comprises a first cylinder for compressing a fluid and a second cylinder for driving a piston in the first cylinder. The first cylinder comprises a chamber configured to receive the fluid. The piston is reciprocally movable in the chamber for compressing the fluid. The chamber comprises four ports at the first end including two inlet ports and two outlet ports with a check valve is connected to each port. Each of the four ports is slanted such that the plurality of check valves and inlet and outlet conduits are spaced apart from the second cylinder. The compressor further comprises an inlet conduit to supply the fluid from a fluid source to the chamber through the inlet ports and an outlet conduit for receiving fluid from the chamber through the outlet ports.



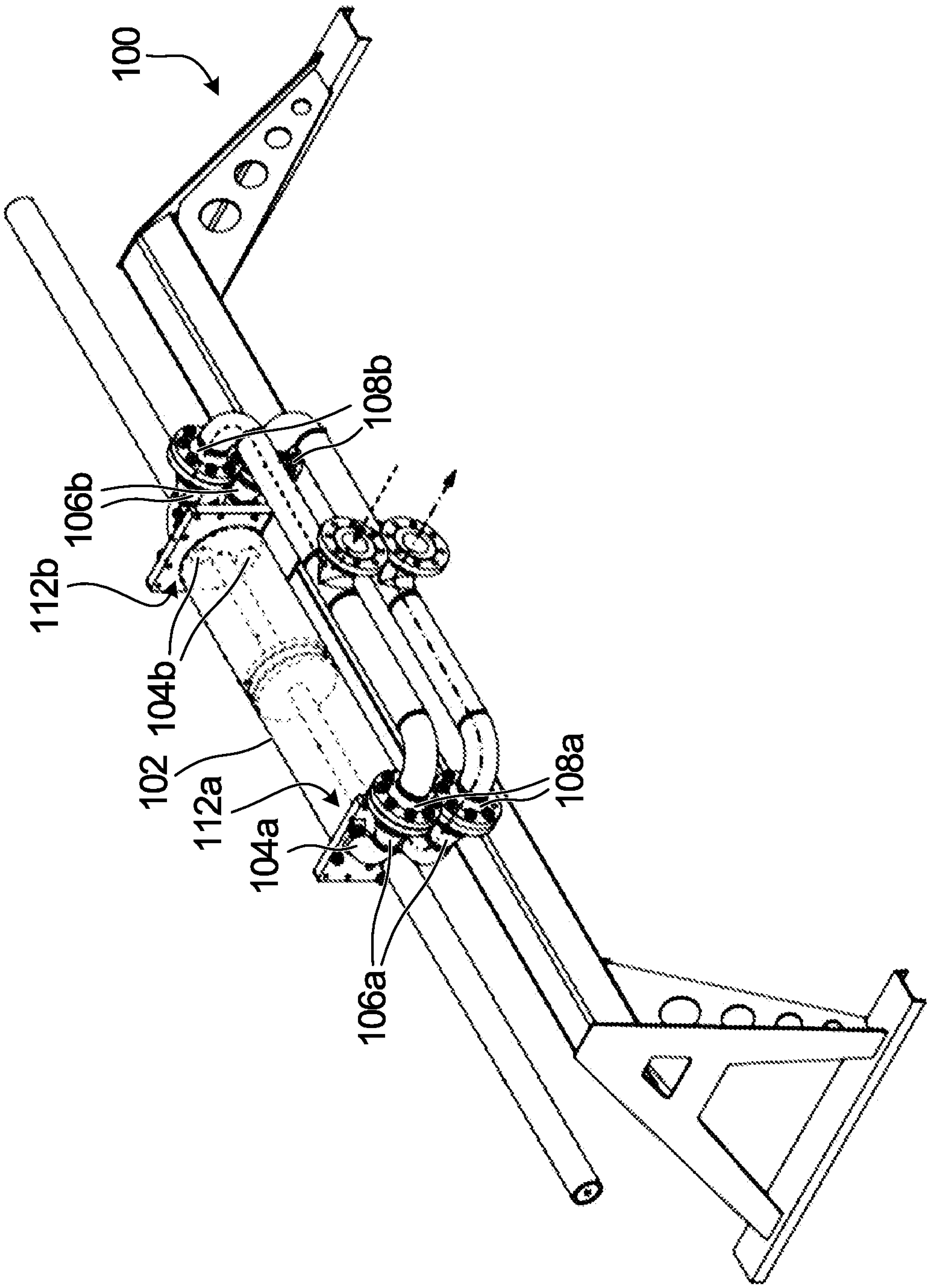


FIG. 1 PRIOR ART

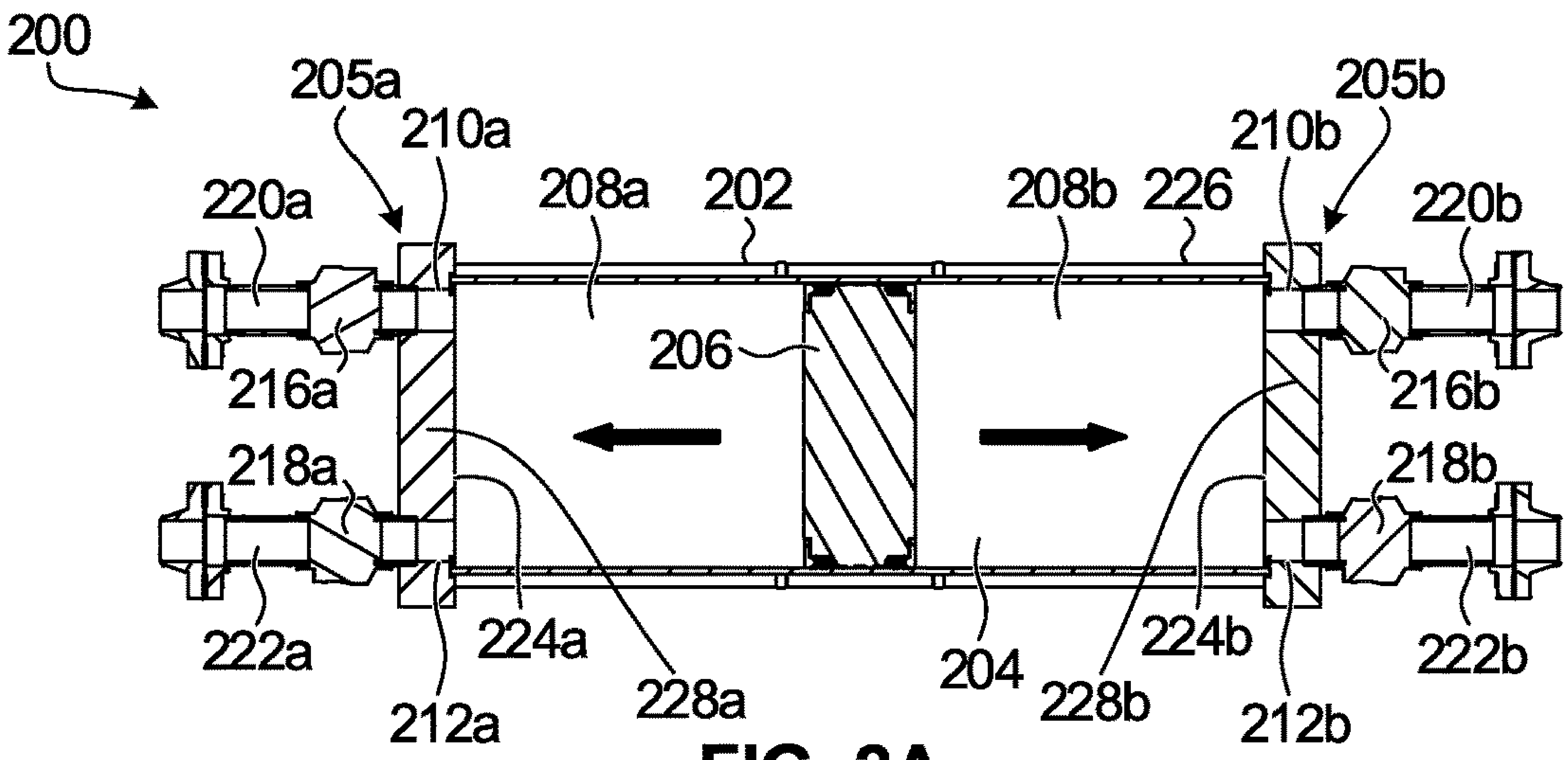


FIG. 2A

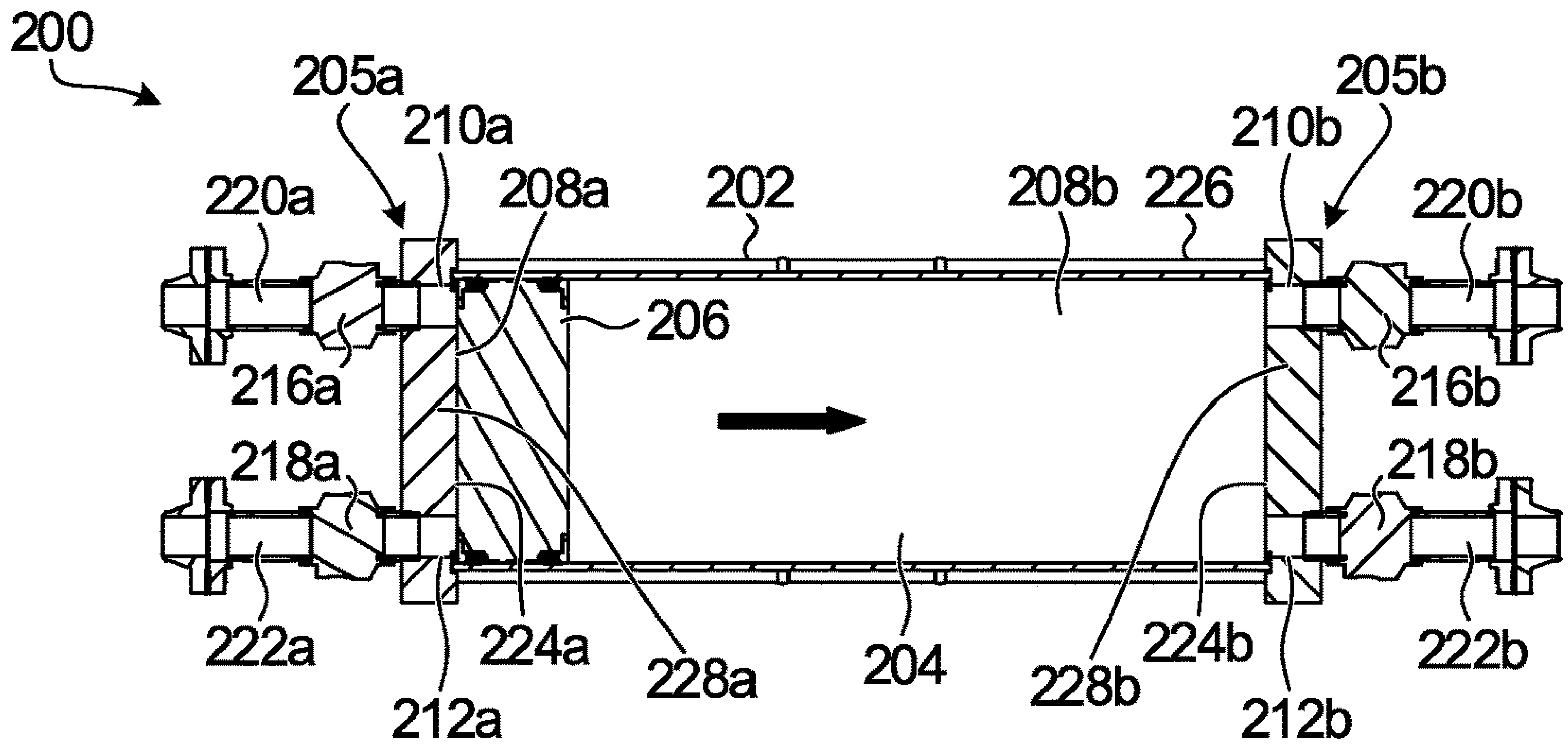


FIG. 2B

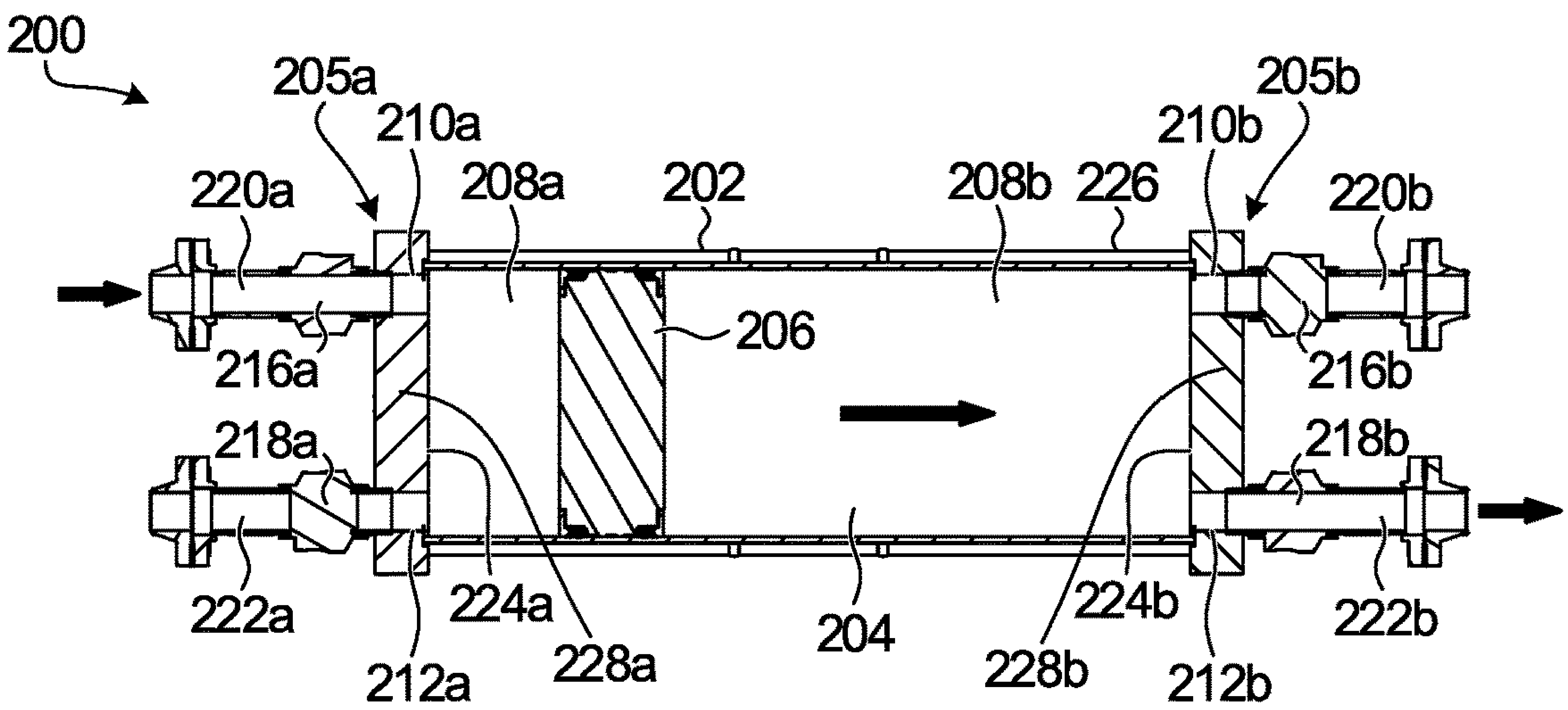
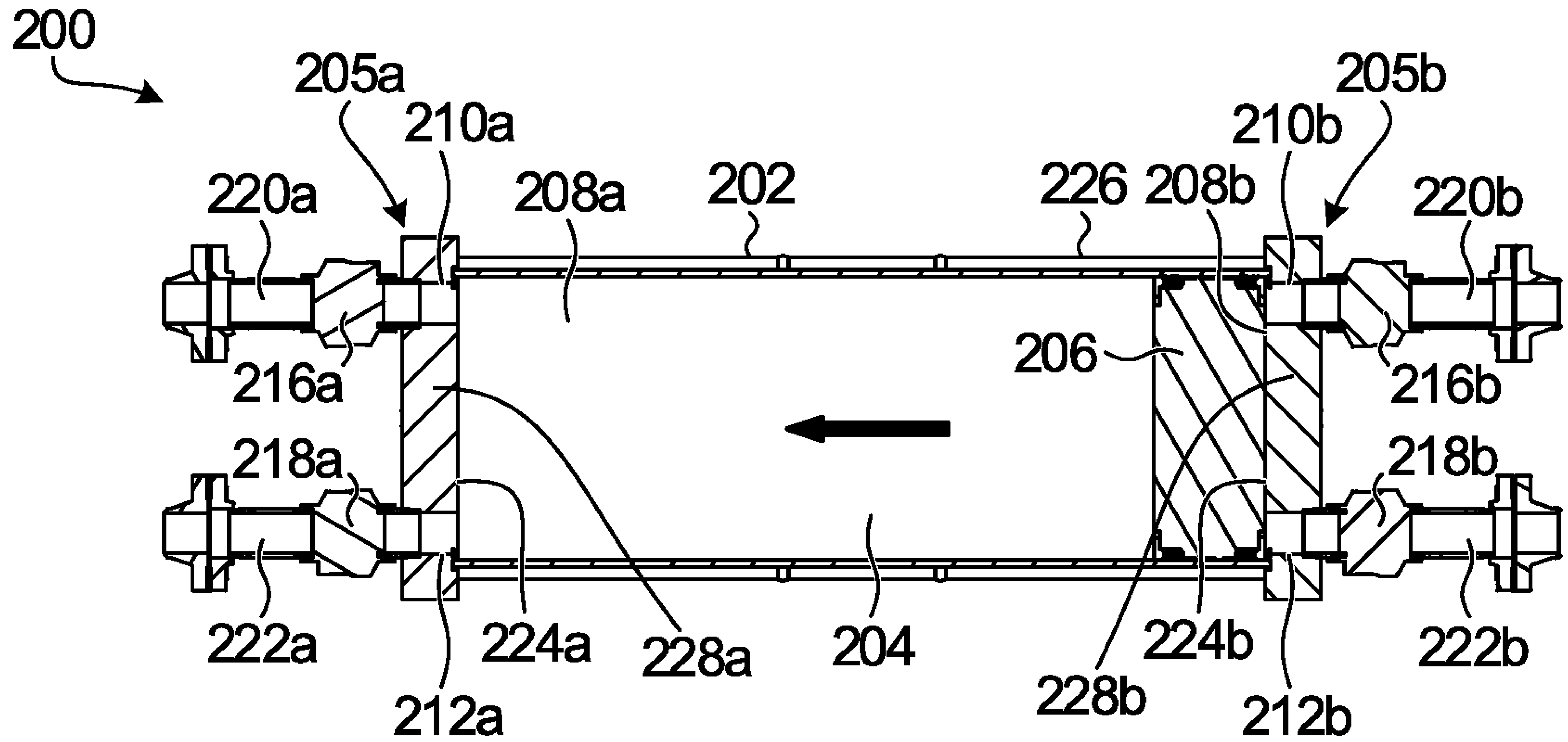


FIG. 2C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205a
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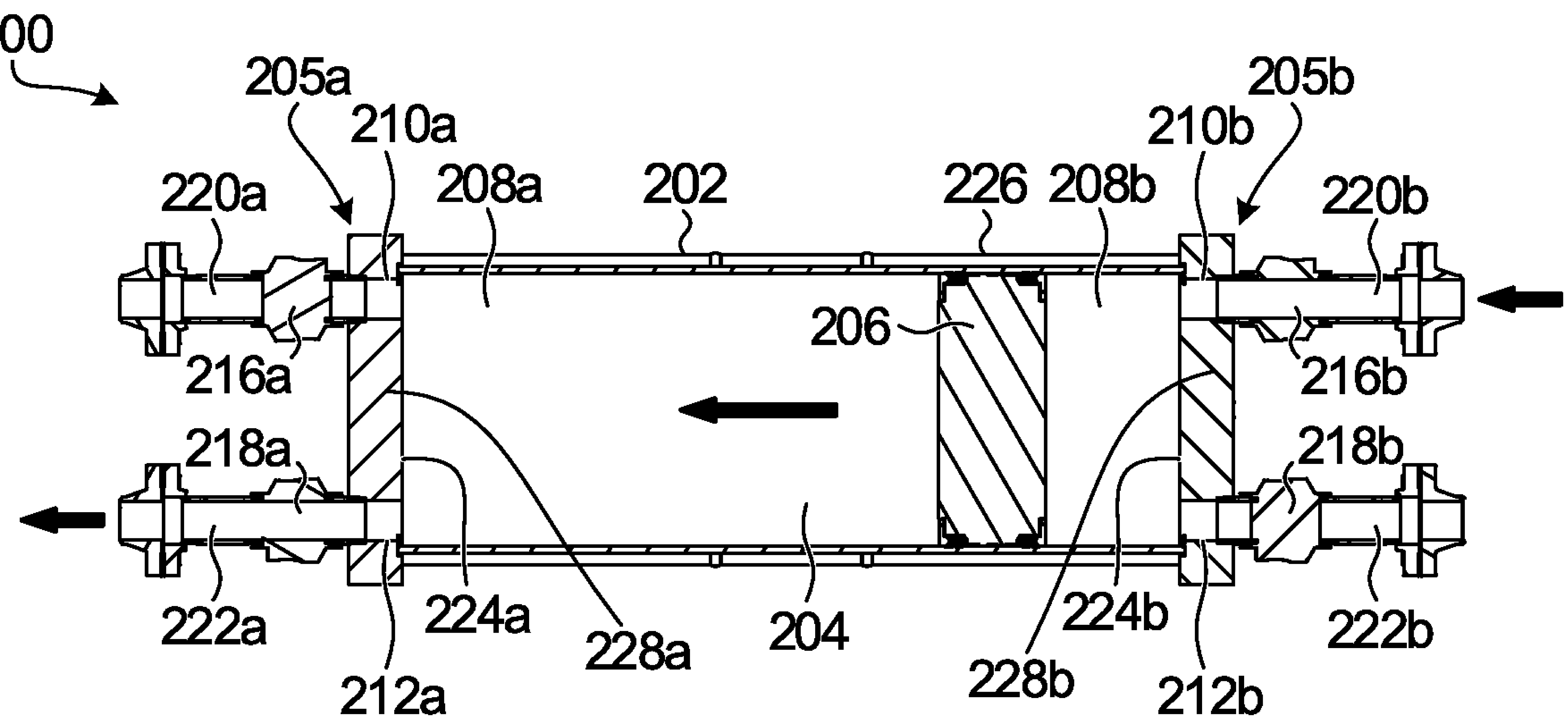
220a
208a
202
226
208b
210b
205b
220b
206
216a
216b
218a
218b
222a
224a
228a
204
228b
224b
222b
212a
212b

FIG. 2D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208a
202
226
208b
210b
205b
220b
206
216a
216b
218a
218b
222a
224a
228a
204
228b
224b
222b
212a
212b

FIG. 2E

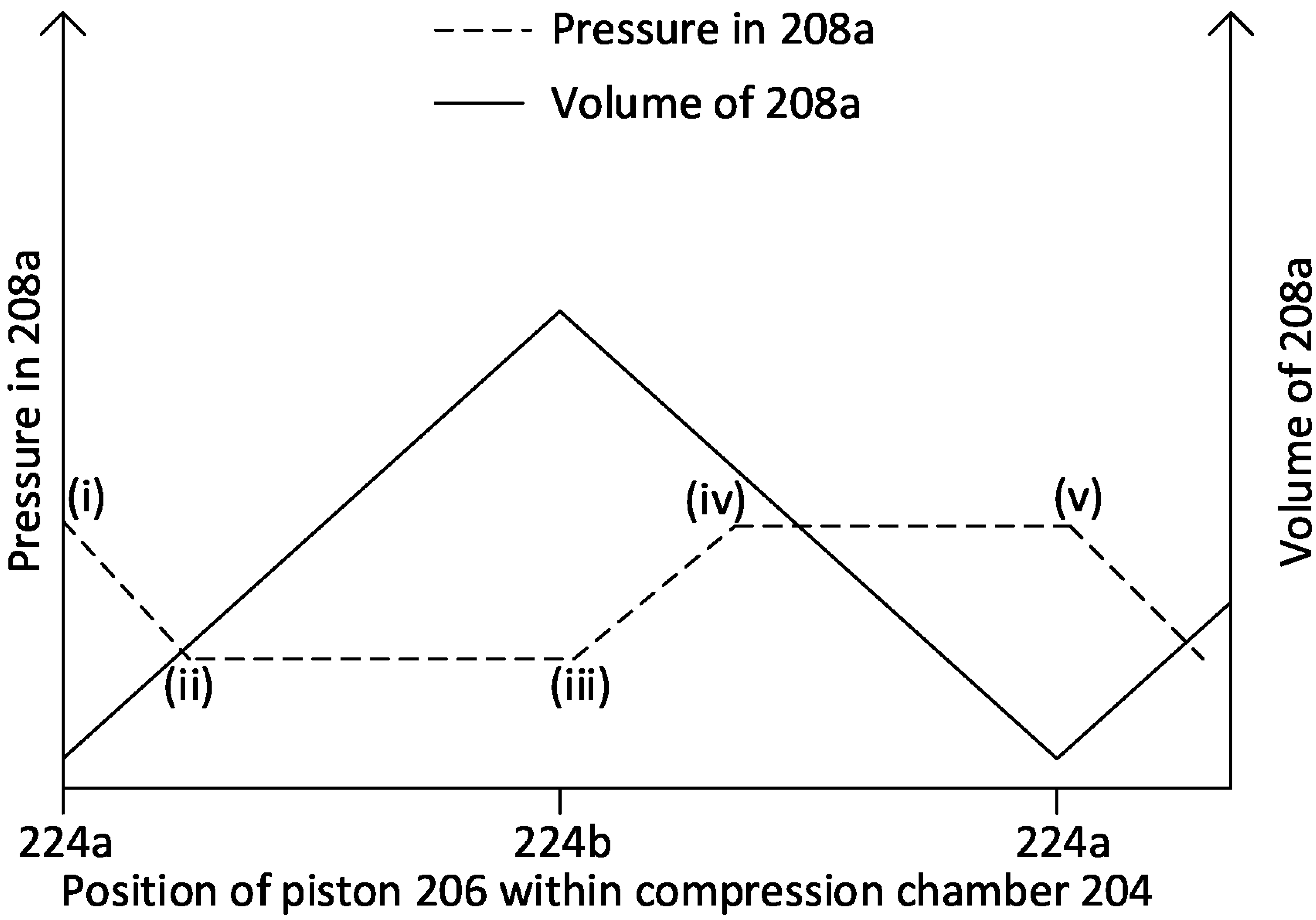

Pressure in 208a
Volume of 208a
Pressure in 208a
Volume of 208a
(i)
(ii)
(iii)
(iv)
(v)
224a
224b
224a
Position of piston 206 within compression chamber 204

FIG. 3A

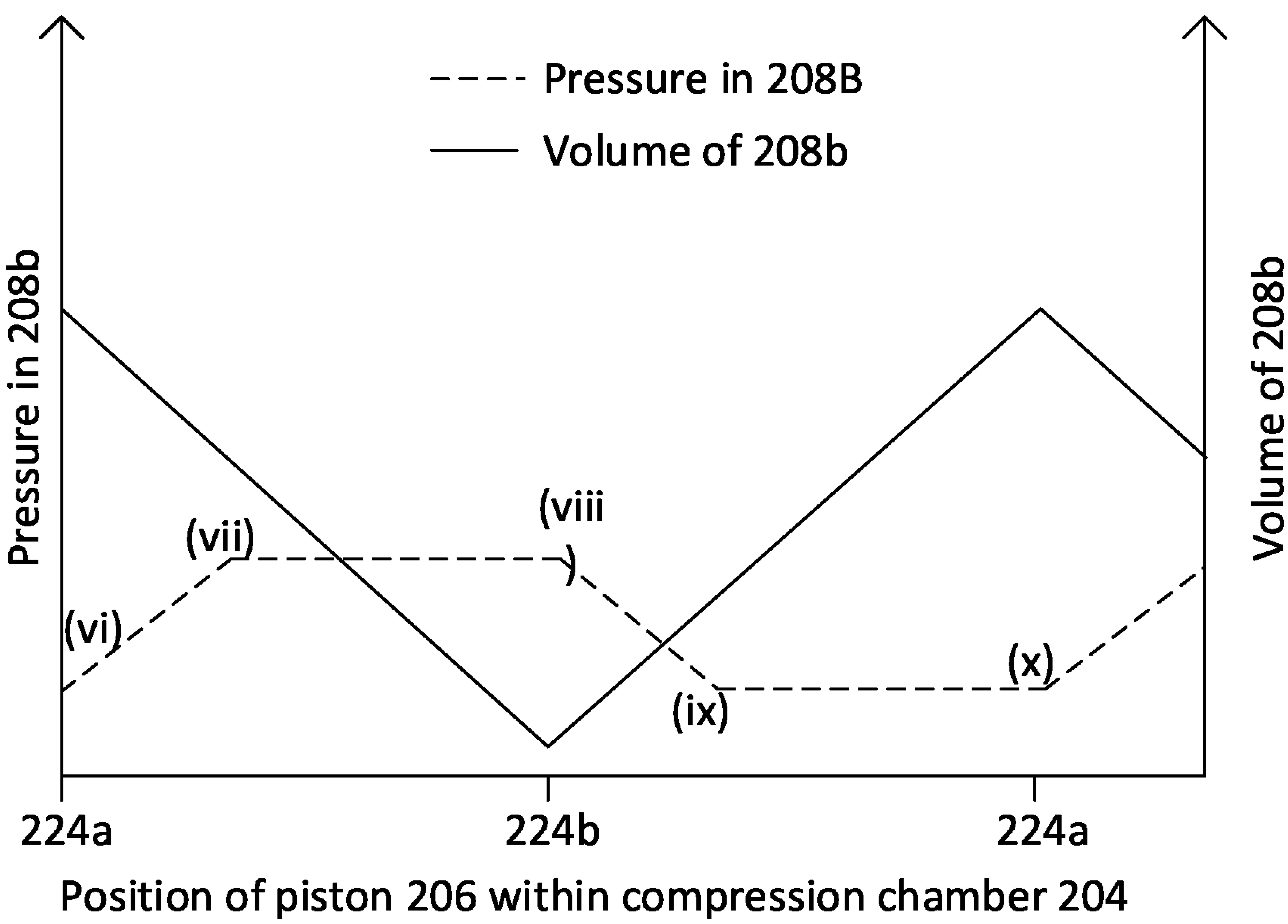

Pressure in 208B
Volume of 208b
Pressure in 208b
Volume of 208b
(vi)
(vii)
(viii
)
(ix)
(x)
224a
224b
224a
Position of piston 206 within compression chamber 204

FIG. 3B

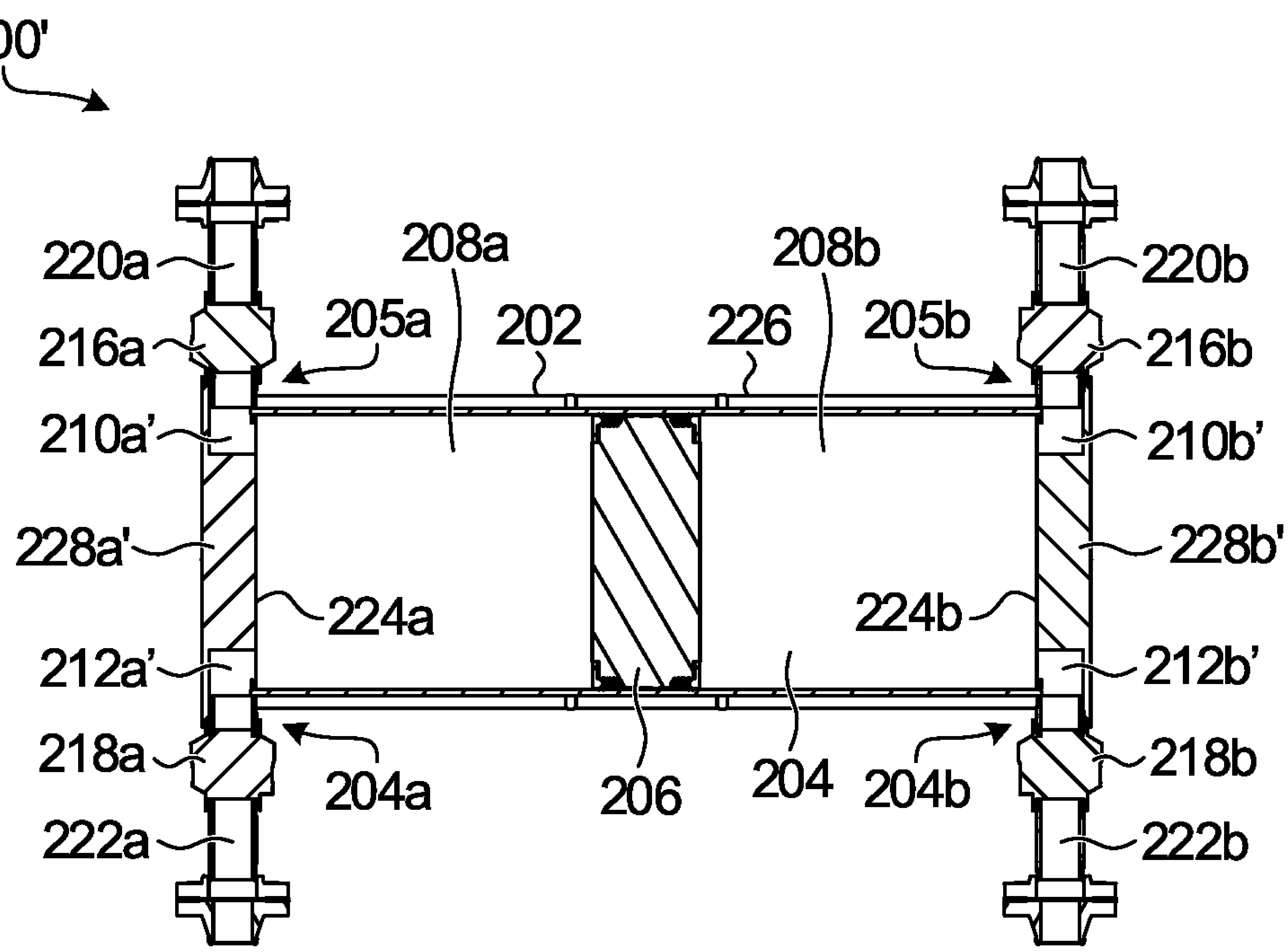
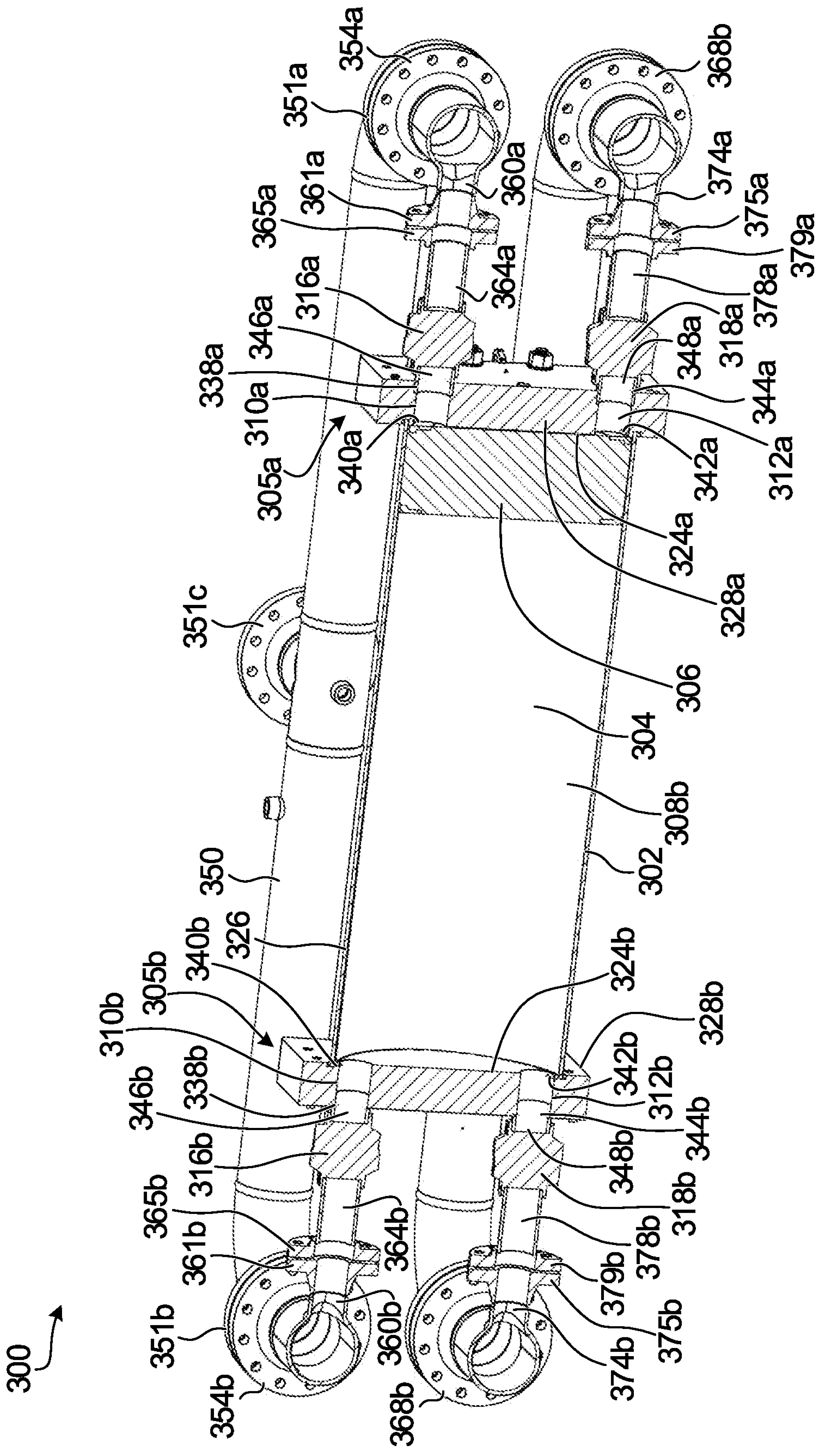

200'
208a
208b
220a
220b
205a
202
226
205b
216a
216b
210a'
210b'
228a'
228b'
224a
224b
212a'
212b'
218a
218b
204a
206
204
204b
222a
222b

FIG. 4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364a
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338a
310a
305a
340a
368b
374a
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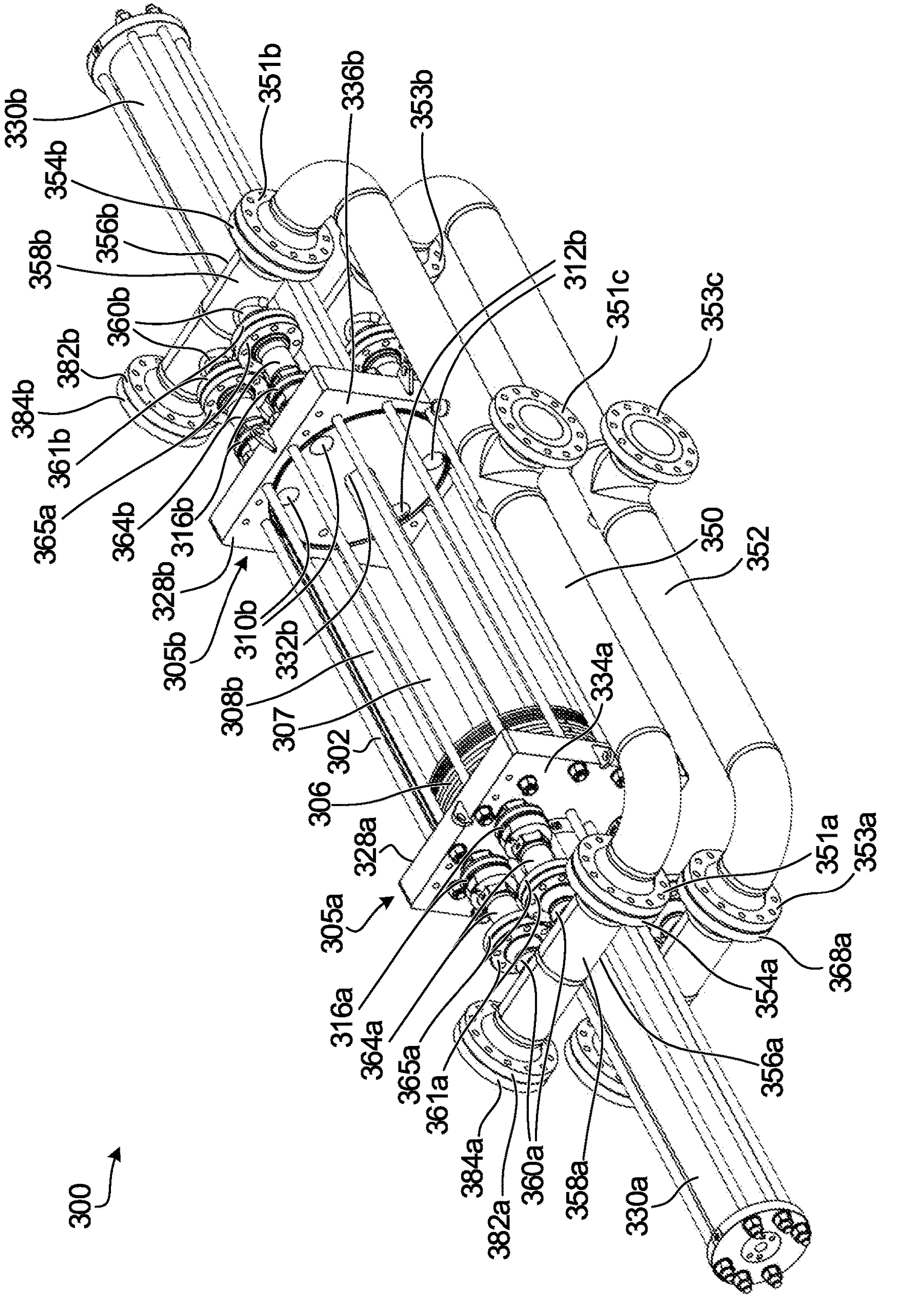
379a
378a
318a
348a
344a
342a
312a
324a
328a
351c
306
304
308b
302
350
326
340b
305b
310b
338b
346b
316b
365b
361b
351b
354b
360b
364b
368b
324b
328b
342b
312b
344b
348b
318b
378b
379b
375b
374b
300

FIG. 5A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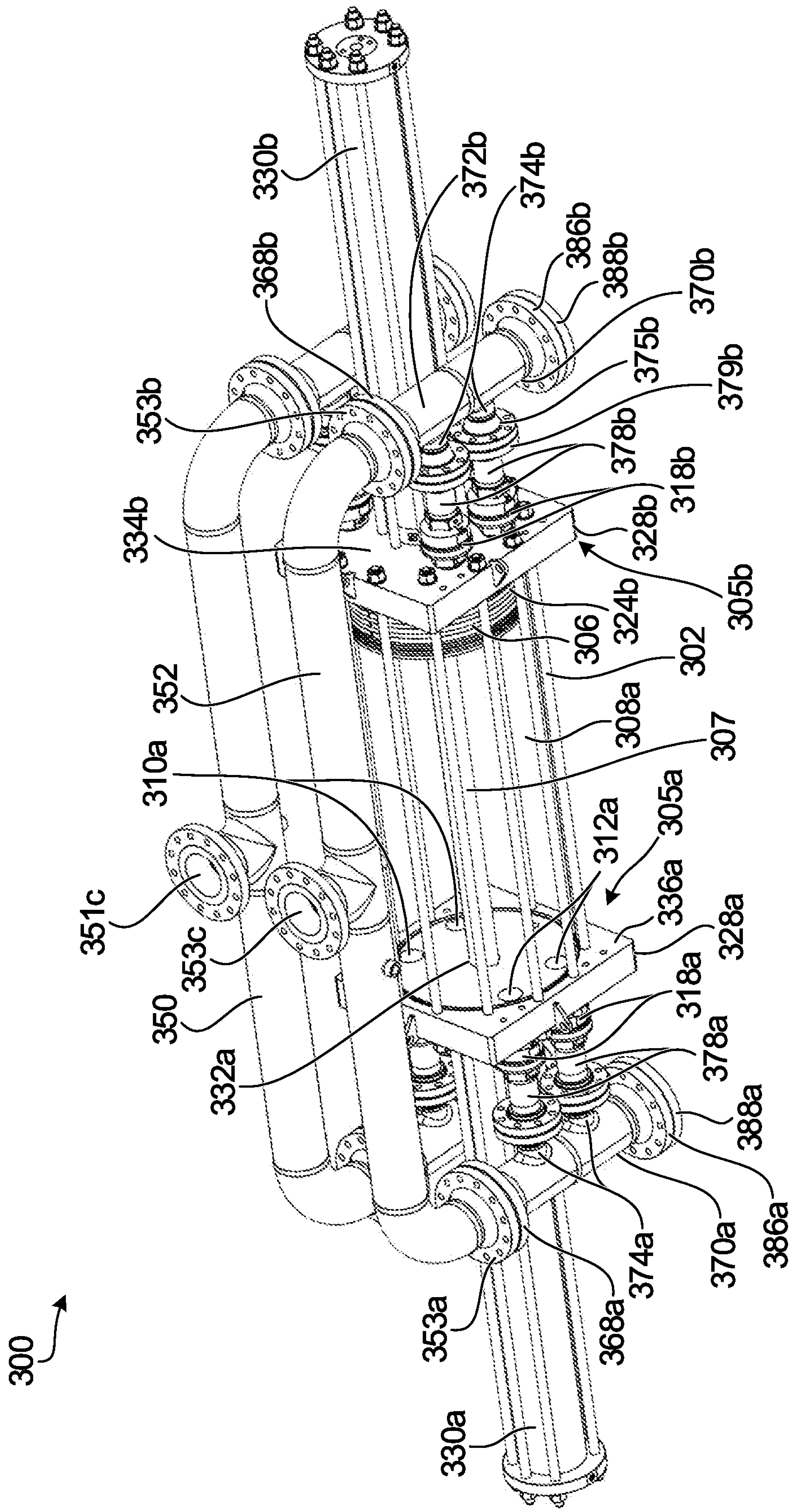
353b
354b
356b
358b
360b
382b
384b
361b
365a
364b
316b
328b
305b
310b
332b
312b
351c
353c
350
352
308b
307
302
306
334a
328a
305a
316a
364a
365a
361a
384a
382a
360a
358a
330a
356a
354a
368a
351a
353a

FIG. 5B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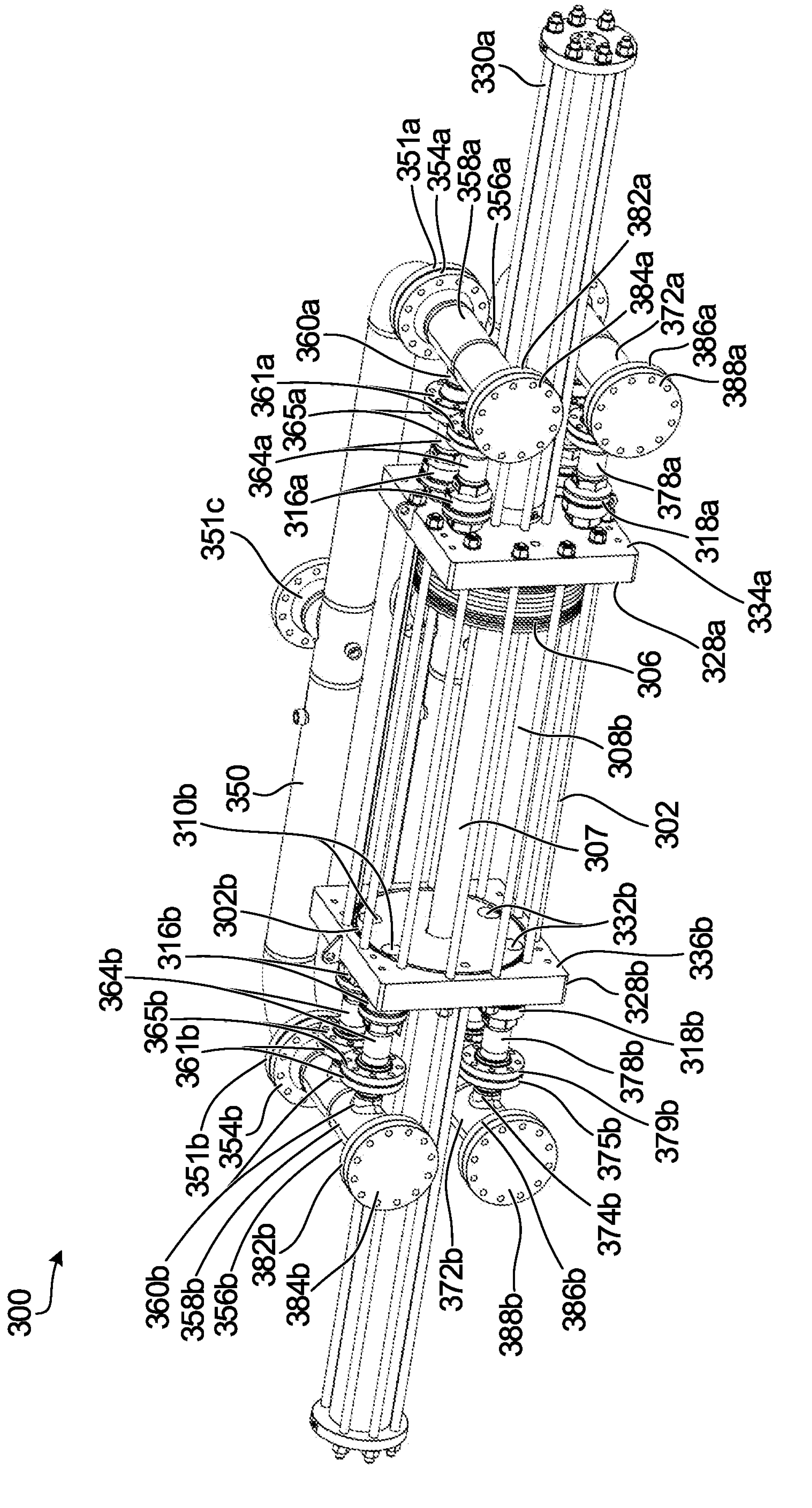
330a
330b
372b
374b
368b
386b
388b
370b
375b
379b
353b
378b
318b
328b
334b
305b
324b
306
302
352
308a
307
310a
305a
312a
336a
328a
351c
353c
350
332a
318a
378a
388a
386a
370a
374a
368a
353a

FIG. 5C


300
330a
351a
354a
358a
356a
382a
384a
372a
386a
388a
360a
361a
365a
364a
316a
378a
318a
334a
351c
328a
306
308b
350
302
307
310b
302b
332b
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336b
364b
328b
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361b
318b
378b
379b
375b
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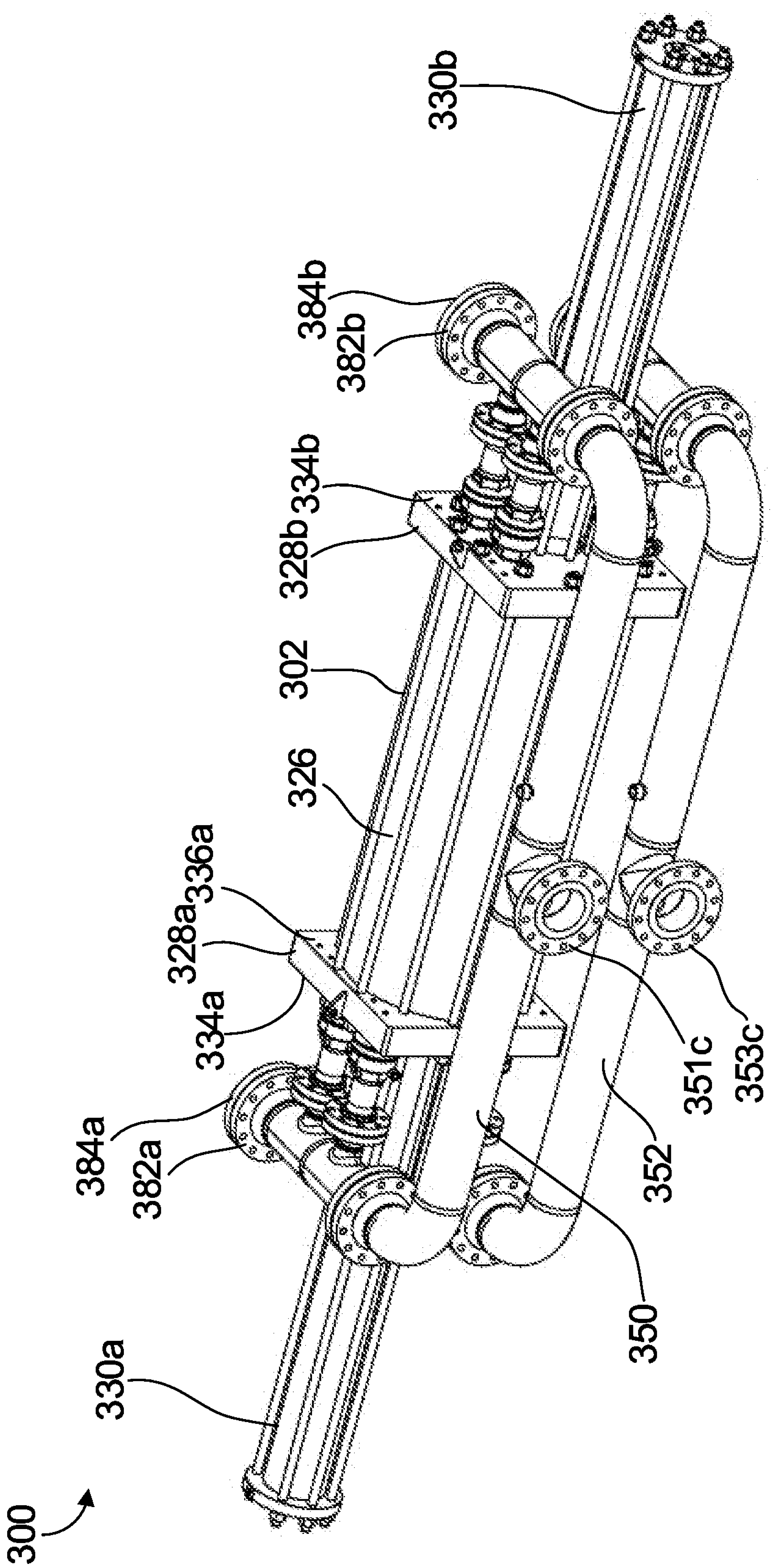
354b
374b
360b
358b
356b
382b
384b
372b
388b
386b

FIG. 5D


330b
384b
382b
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328b
302
326
336a
328a
334a
384a
382a
351c
353c
352
350
330a
300

FIG. 5E

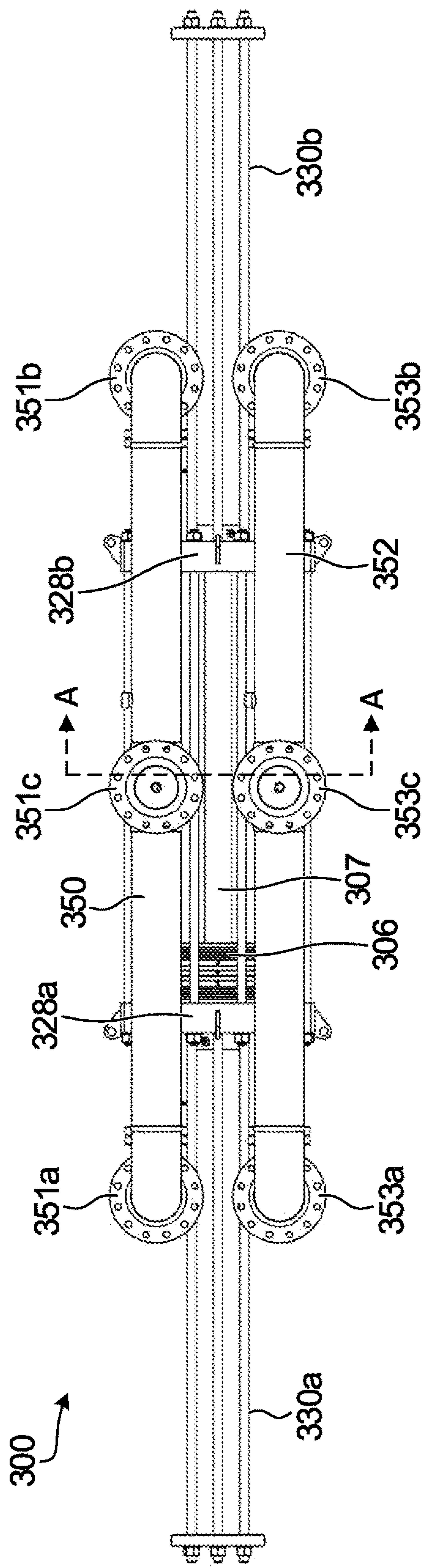
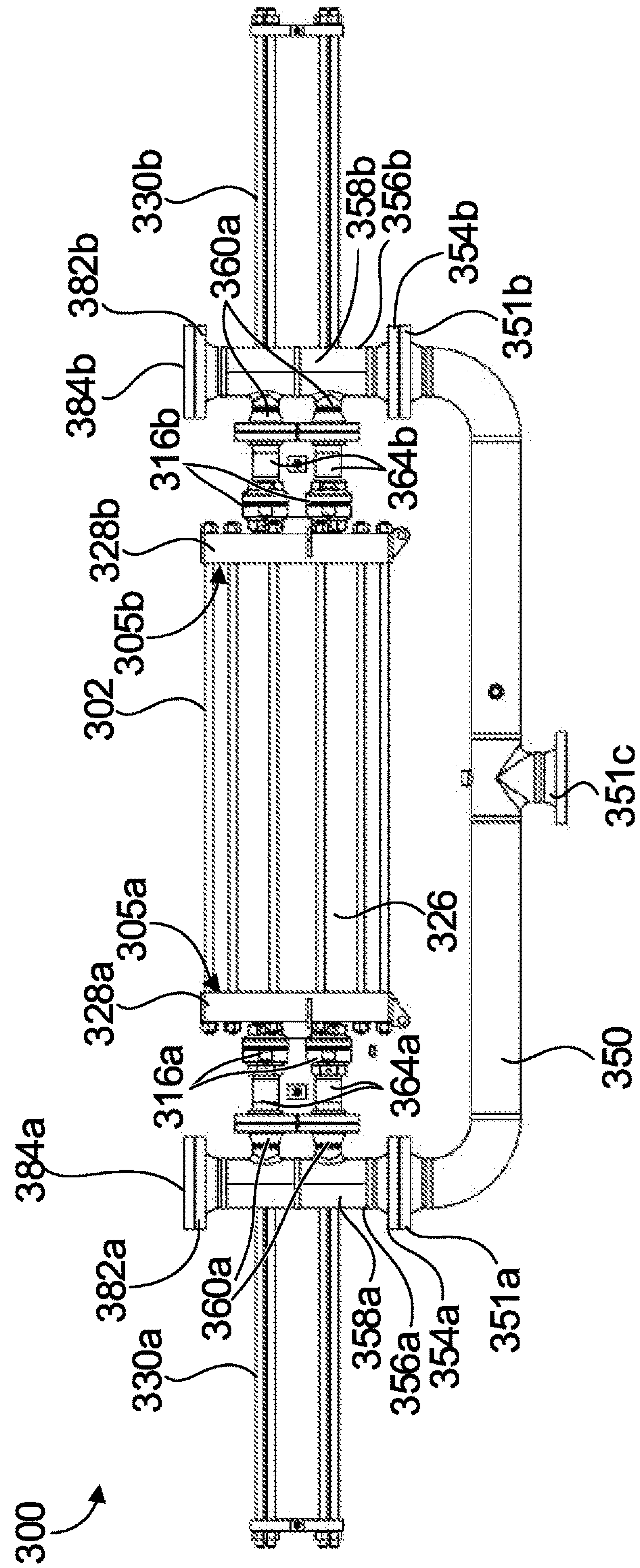

300
330a
330b
351a
353a
351b
353b
328a
328b
352
350
307
306
351c
353c
A
A

FIG. 5F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330b
382a
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384b
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356a
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351a
358b
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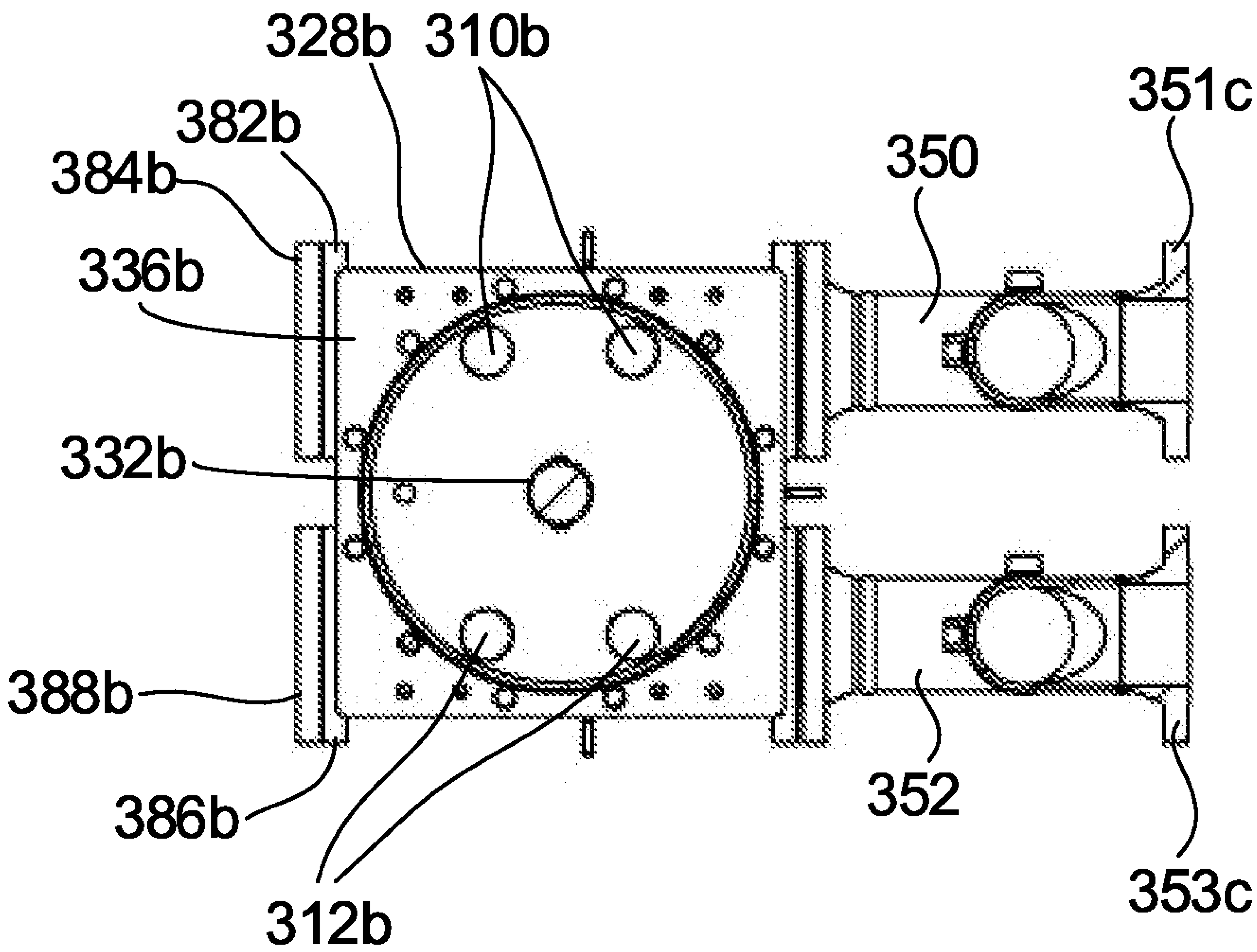
354b
351b
316a
316b
364a
364b
328a
328b
305a
305b
302
326
350
351c

FIG. 5G


328b
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384b
336b
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388b
386b
312b
350
351c
352
353c

FIG. 5H

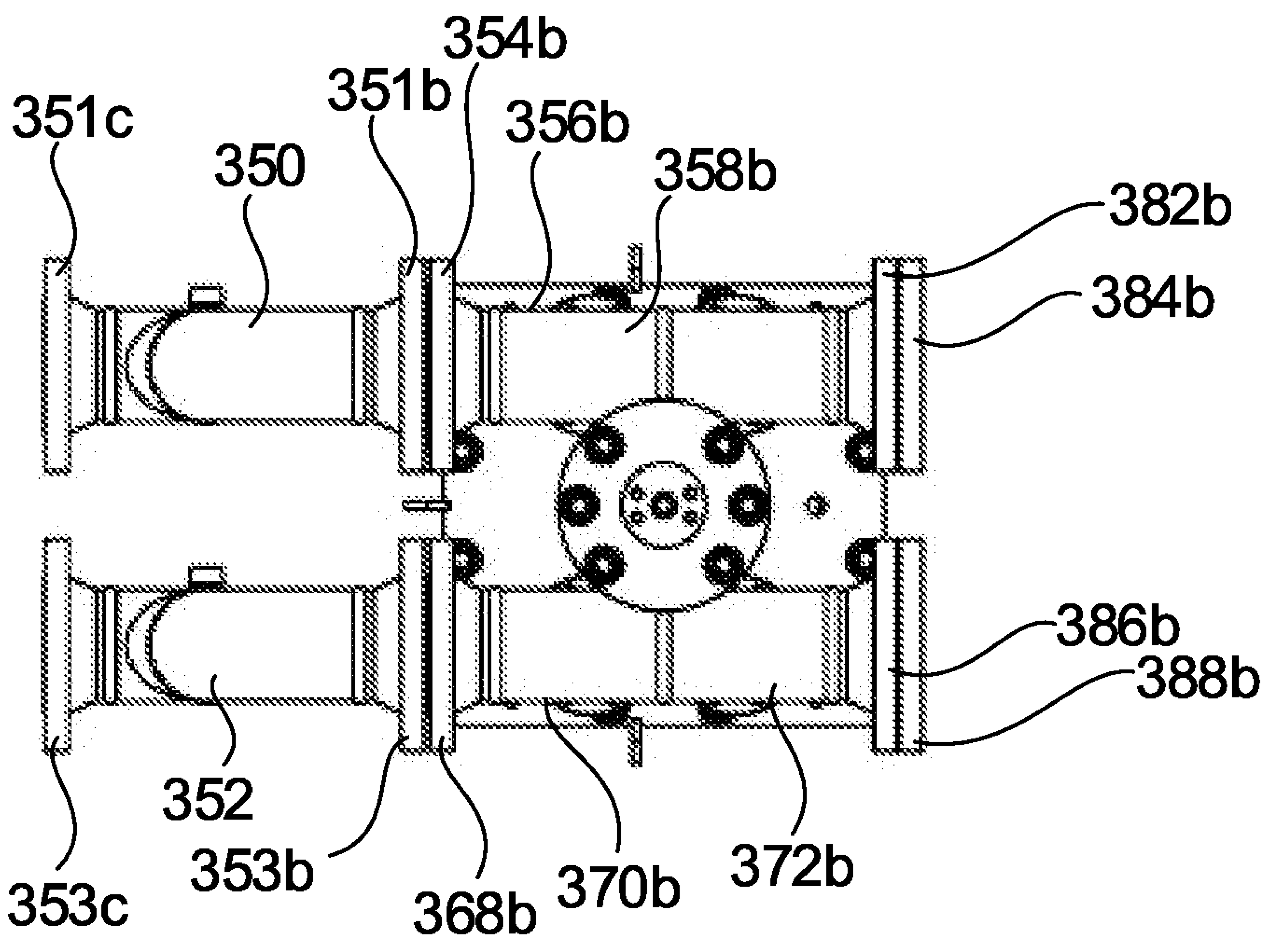
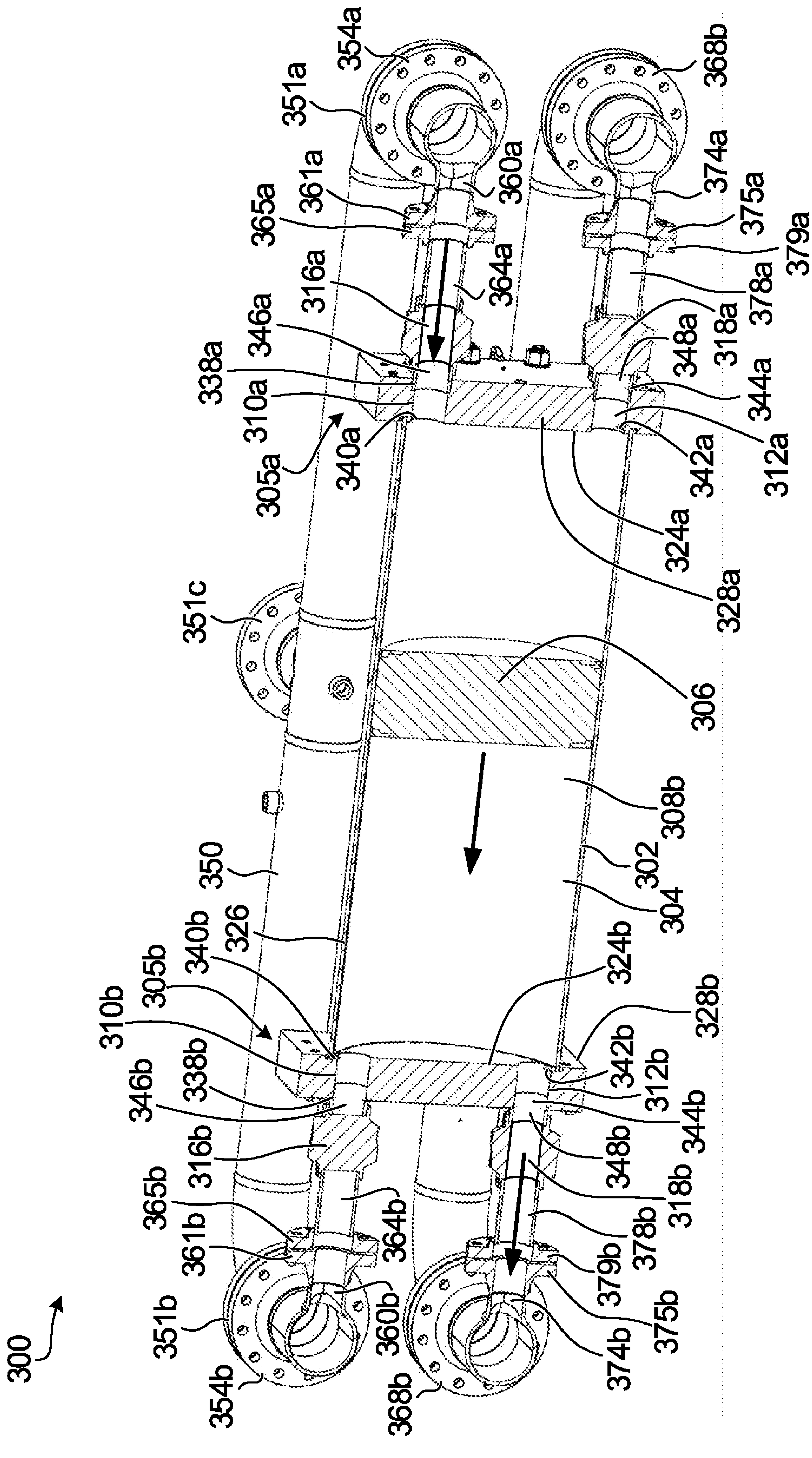

354b
351c
351b
356b
350
358b
382b
384b
386b
388b
352
353c
353b
368b
370b
372b

FIG. 5I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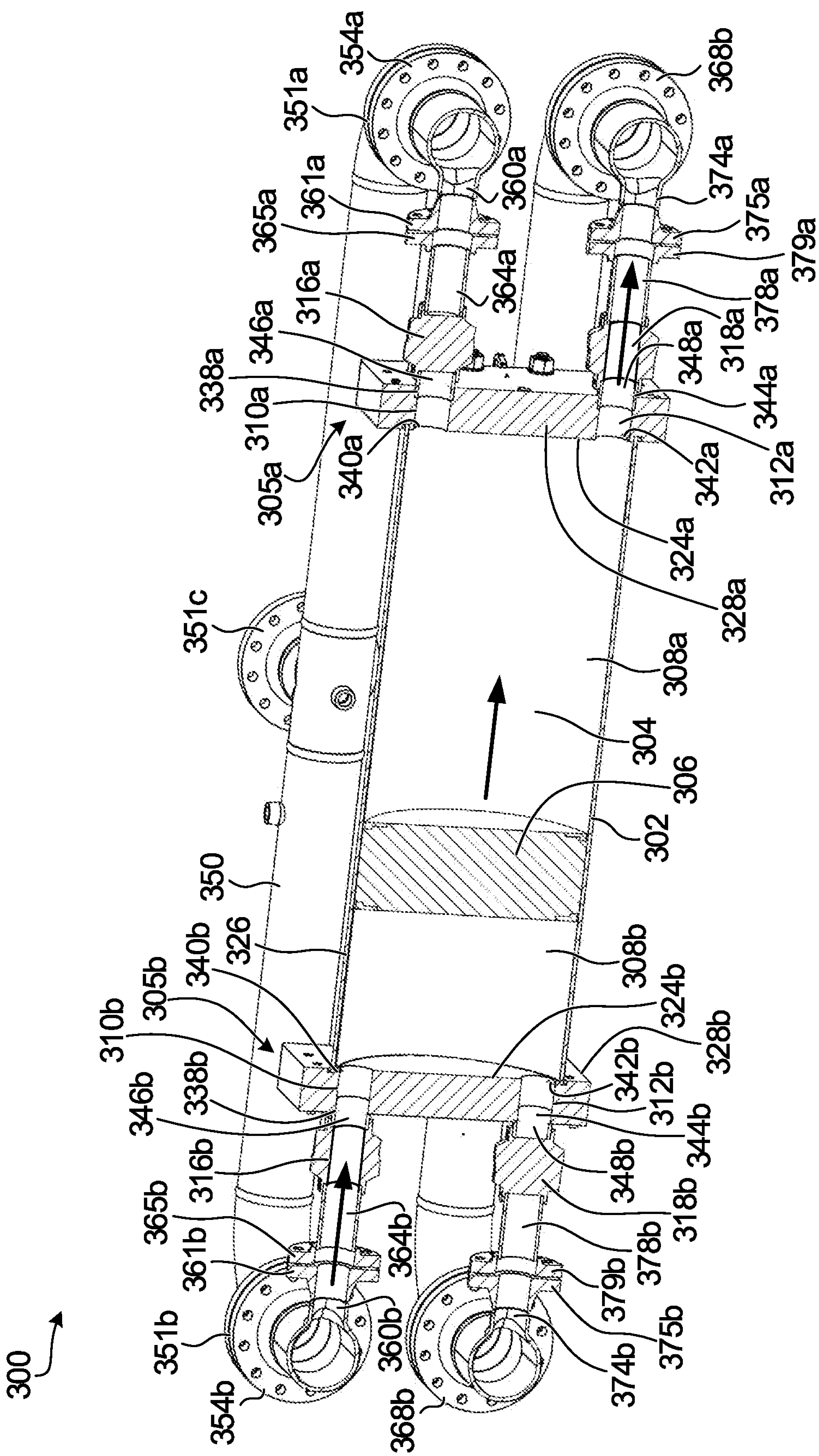
310a
305a
340a
342a
312a
324a
328a
351c
306
308b
350
302
304
326
340b
305b
324b
310b
328b
338b
342b
312b
346b
344b
316b
348b
365b
364b
318b
361b
378b
379b
351b
360b
375b
300
374b
354b
368b

FIG. 5J


354a
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360a
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316a
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340a
305a
378a
318a
348a
344a
342a
312a
324a
328a
351c
308a
304
306
302
350
326
340b
305b
310b
338b
346b
316b
365b
361b
351b
354b
360b
364b
368b
308b
324b
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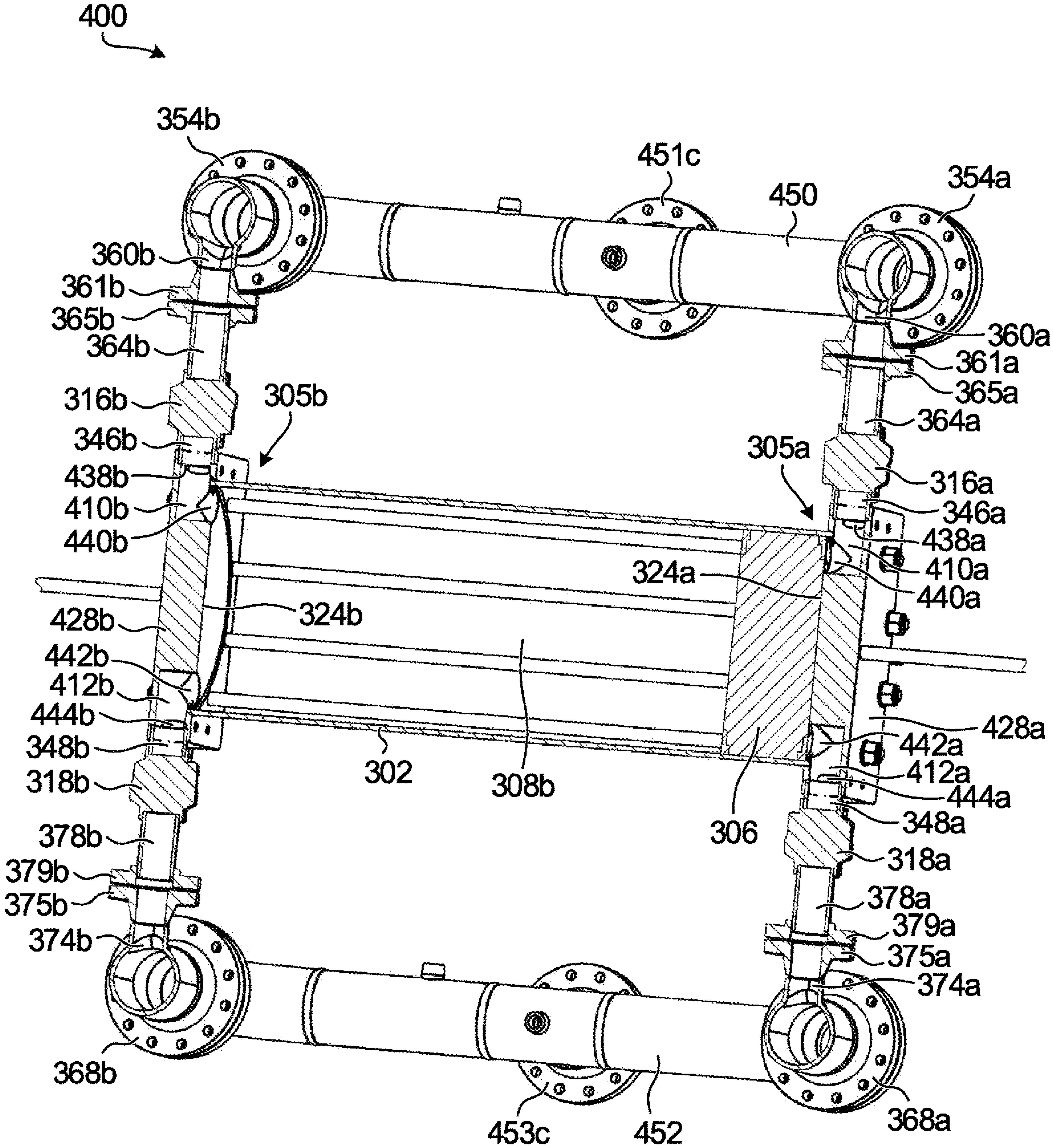
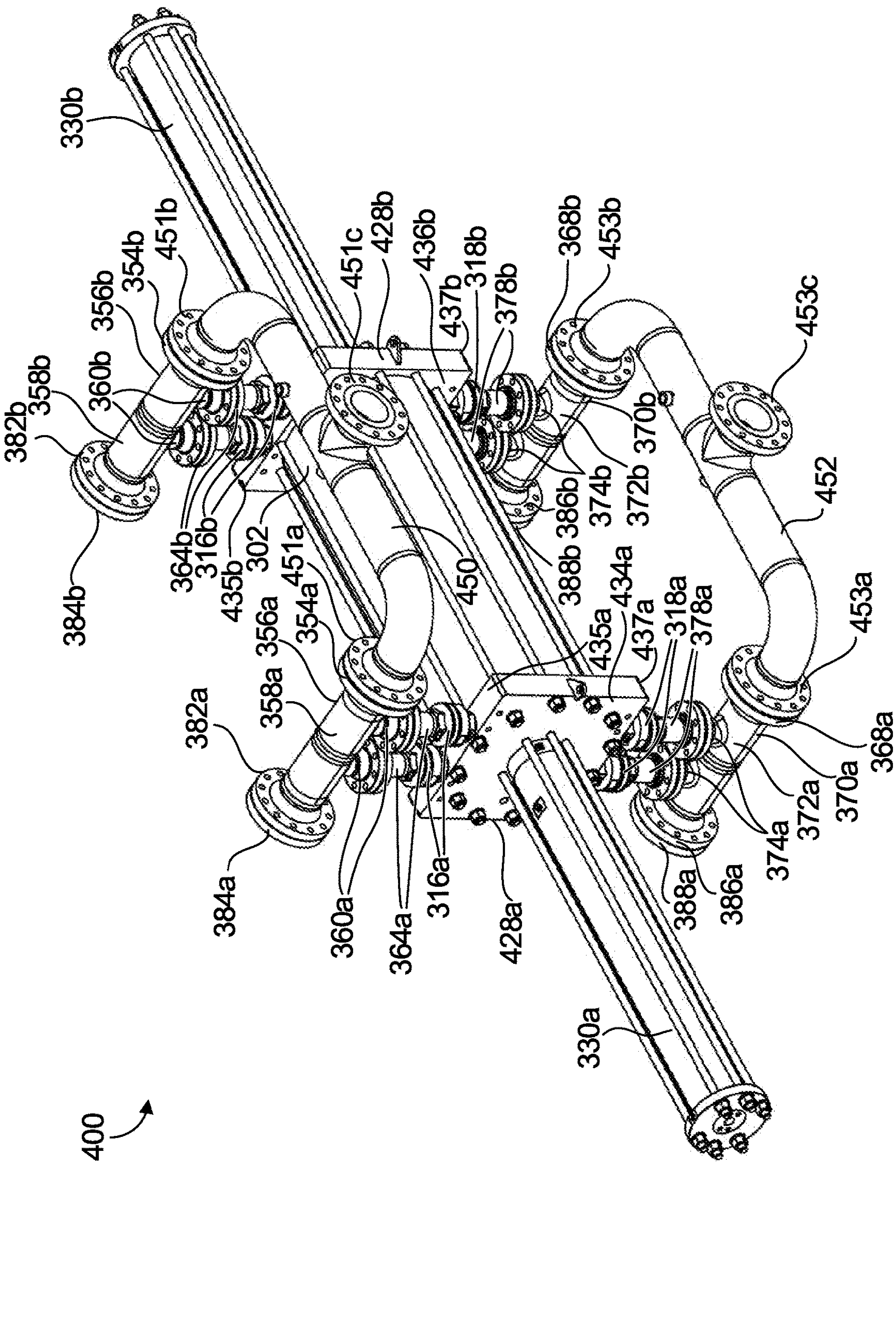
342b
312b
344b
348b
318b
378b
379b
375b
374b
300

FIG. 5K



400
354b
451c
450
354a
360b
361b
365b
364b
360a
361a
365a
364a
316b
305b
346b
438b
410b
440b
305a
316a
346a
438a
410a
440a
324a
324b
428b
442b
412b
444b
348b
318b
302
308b
306
428a
442a
412a
444a
348a
318a
378b
379b
375b
374b
378a
379a
375a
374a
368b
453c
452
368a

FIG. 6A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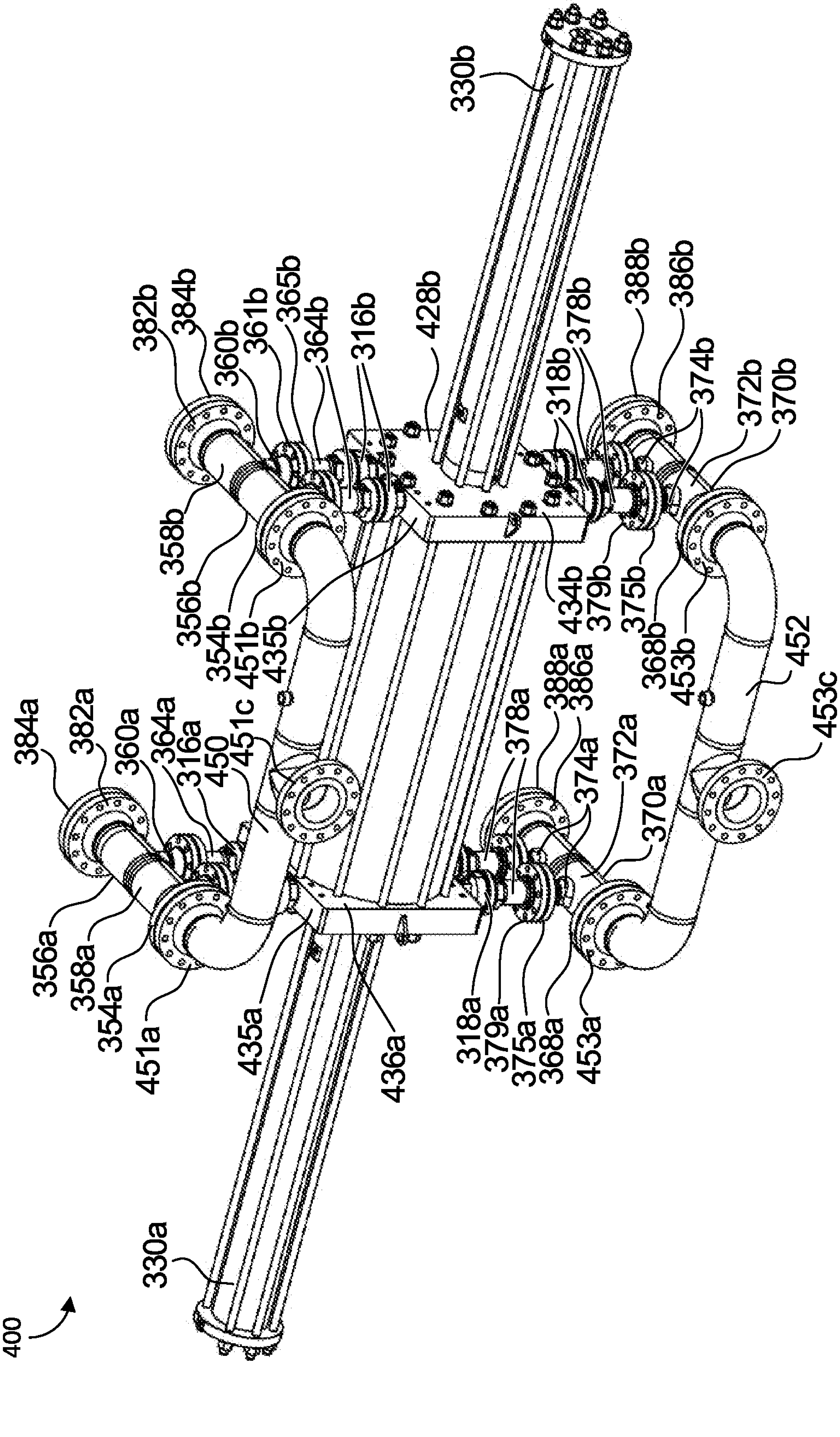
368b
370a
370b
372a
372b
374a
374b
378a
378b
382a
382b
384a
384b
386a
386b
388a
388b
428a
428b
434a
435a
435b
436b
437a
437b
450
451a
451b
451c
452
453a
453b
453c

FIG. 6B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378b
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386b
374b
372b
370b
358b
356b
354b
451b
435b
434b
379b
375b
368b
453b
452
453c
384a
382a
360a
364a
316a
450
451c
378a
388a
386a
374a
372a
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358a
354a
451a
435a
436a
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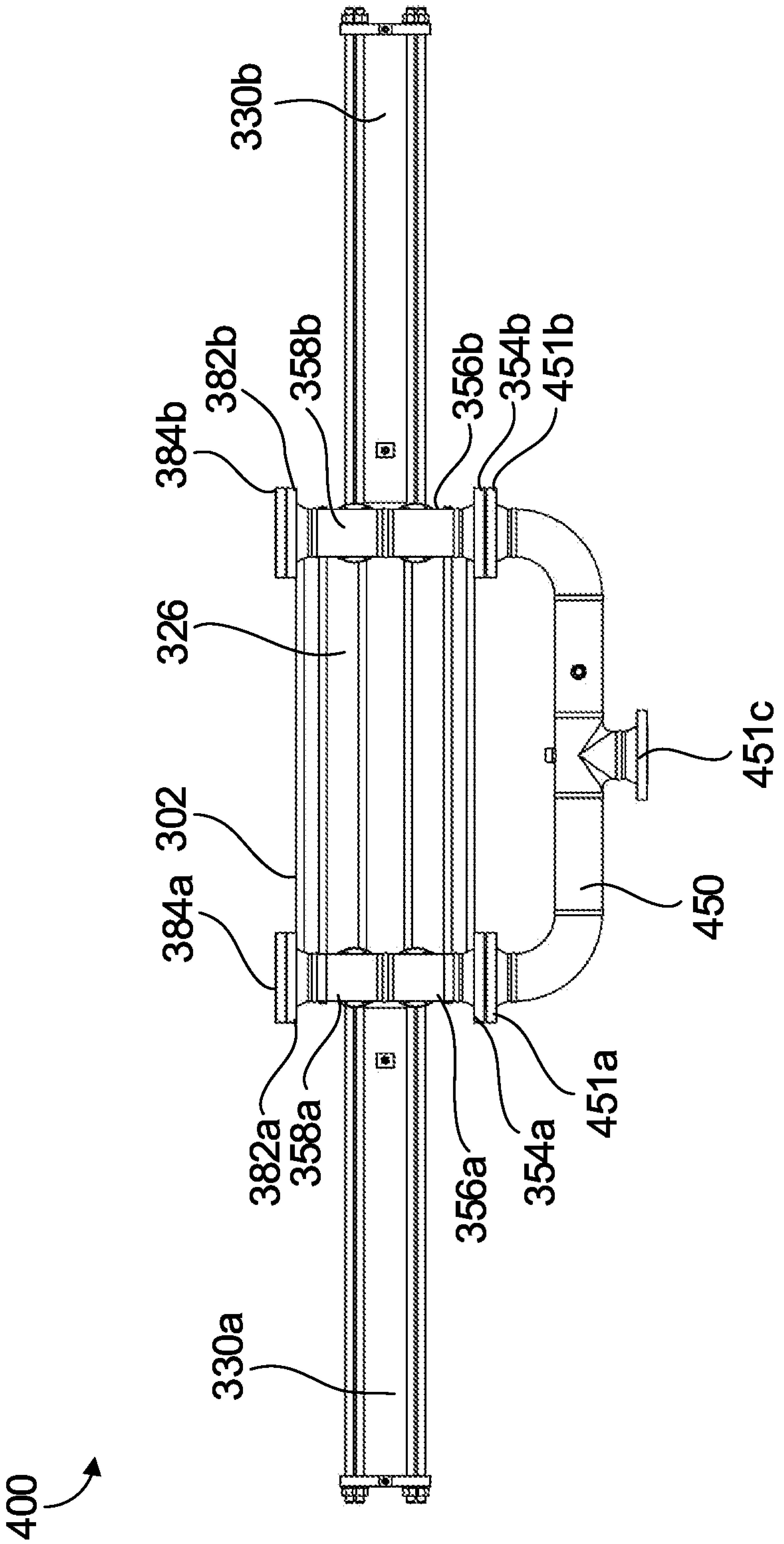
379a
375a
368a
453a

FIG. 6C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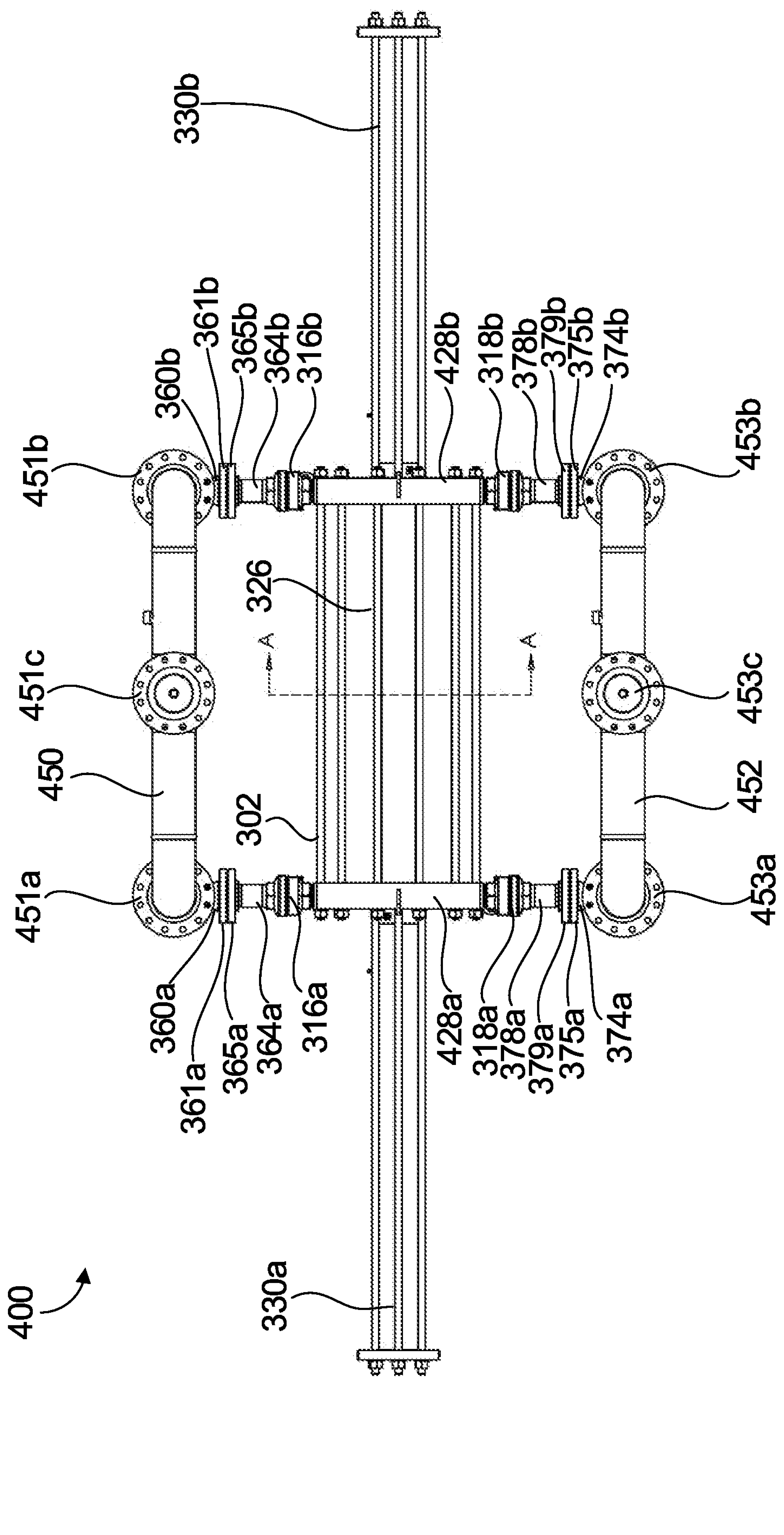
356a
354a
451a
330a
400

FIG. 6D


400
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451c
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450
360b
361b
365b
364b
316b
428b
318b
378b
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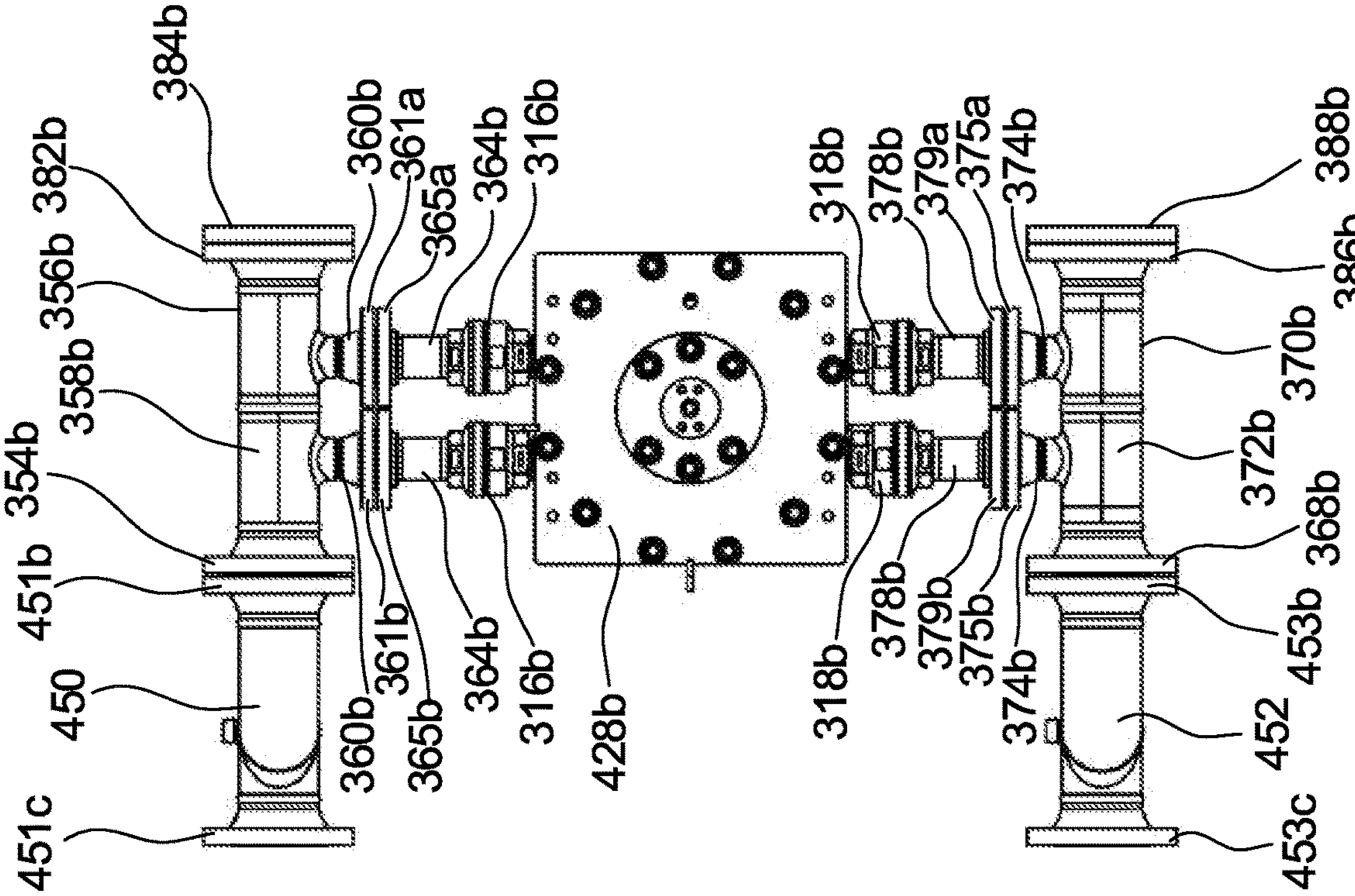
375b
374b
453b
453c
453a
452
326
302
A
A
360a
361a
365a
364a
316a
428a
318a
378a
379a
375a
374a

FIG. 6E


384b
382b
356b
358b
354b
451b
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360b
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365a
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428b
318b
378b
379a
375a
374b
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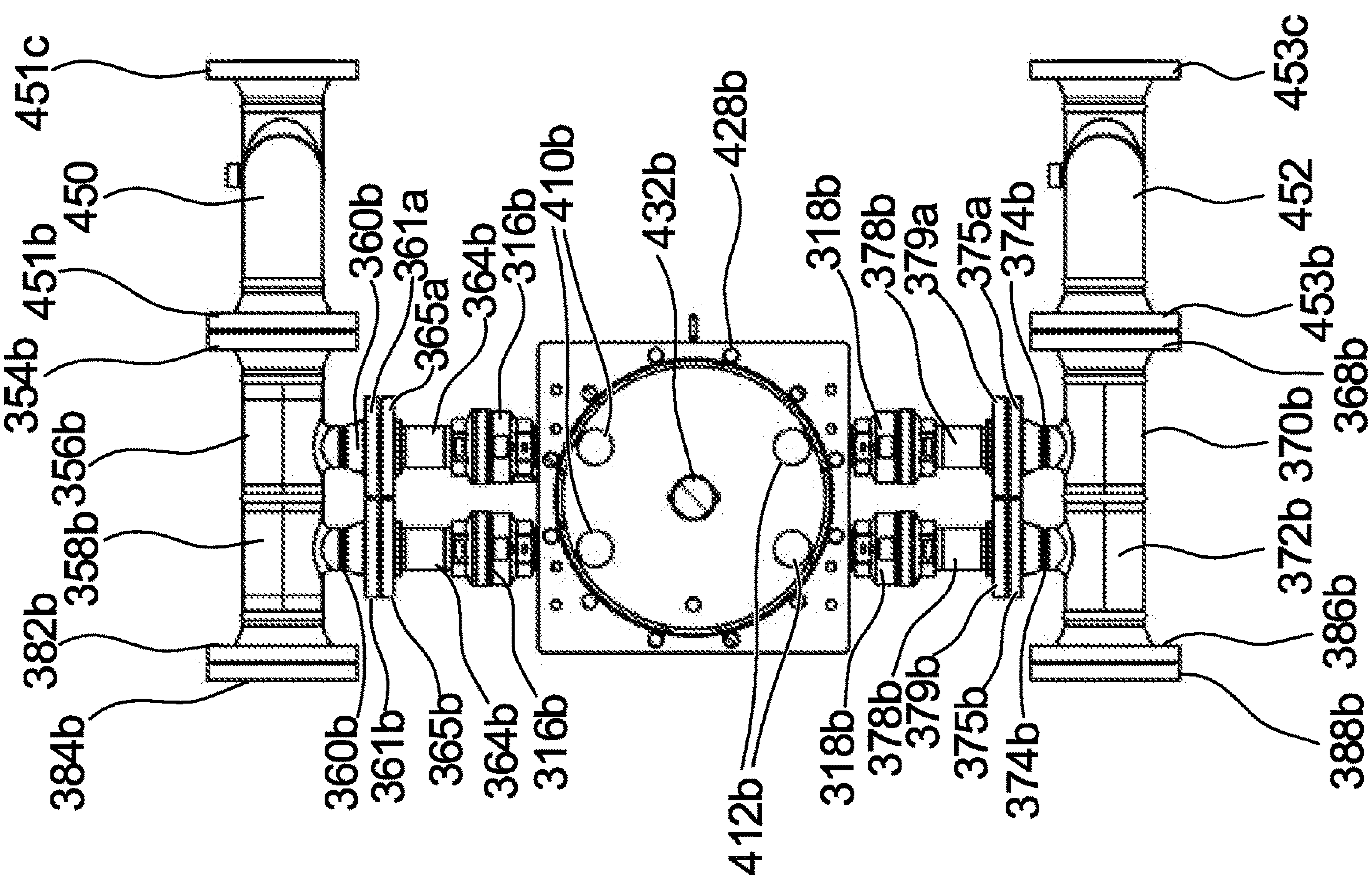
375b
388b
386b
370b
372b
368b
453b
452
453c

FIG. 6G


451c
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356b
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382b
384b
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365a
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432b
428b
361b
365b
412b
318b
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375b
453c
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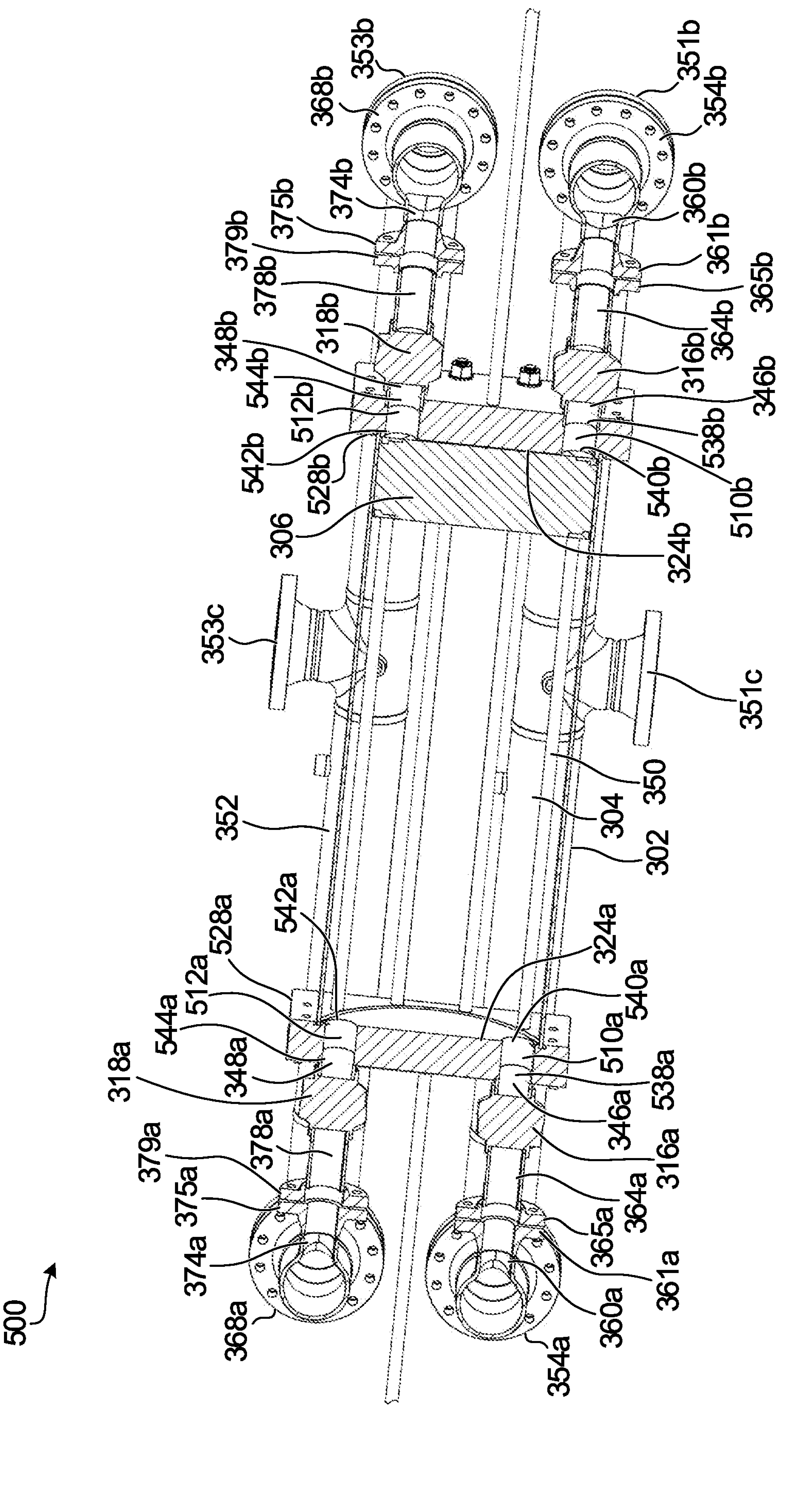
453b
368b
370b
372b
386b
388b

FIG. 6F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368b
351b
354b
374b
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379b
378b
318b
348b
544b
512b
542b
528b
306
360b
361b
365b
364b
316b
346b
538b
540b
510b
324b
353c
351c
352
350
304
302
542a
528a
512a
544a
348a
318a
378a
379a
375a
374a
368a
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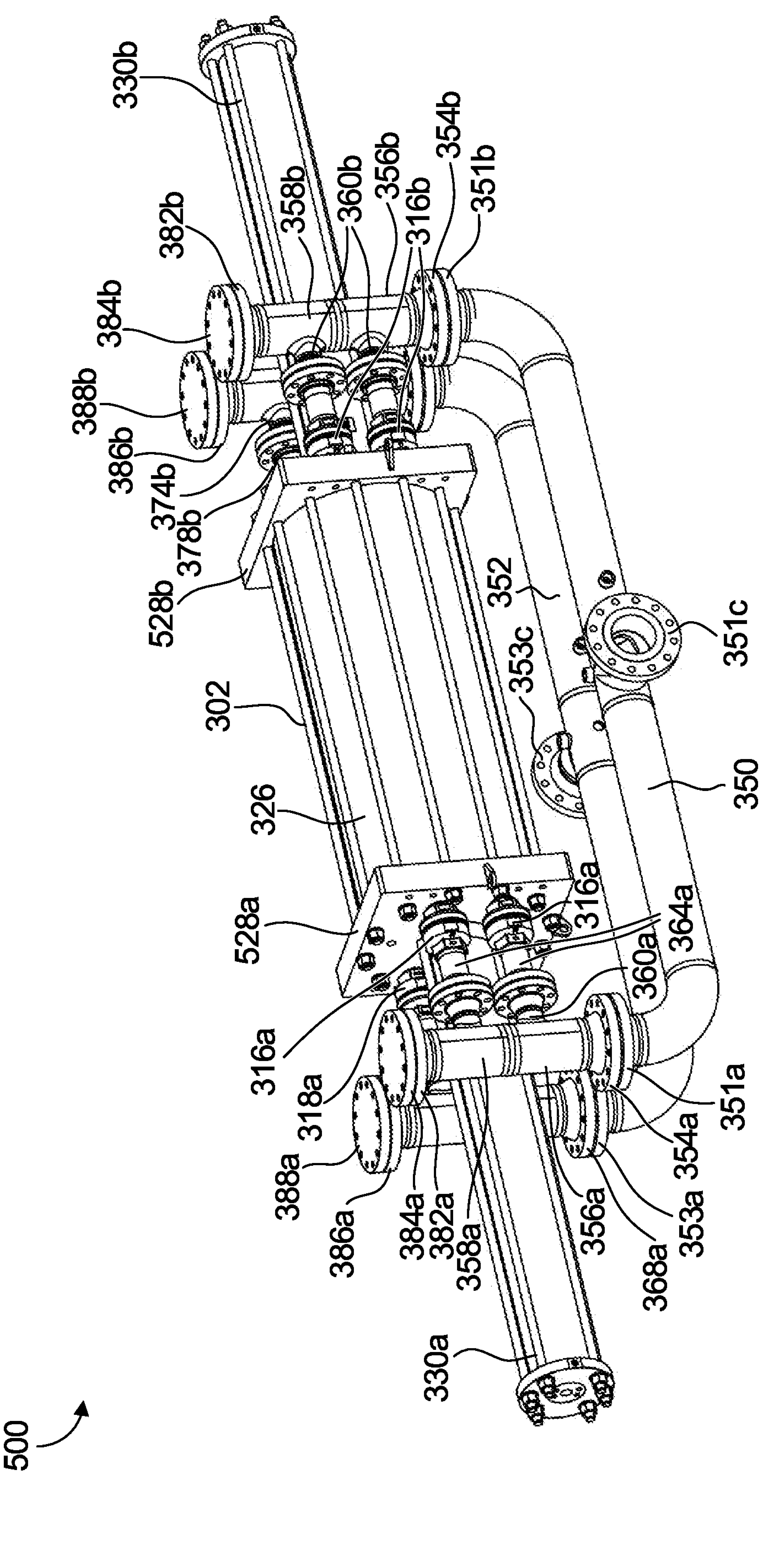
346a
316a
364a
365a
361a
360a
354a

FIG. 7A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330a
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353c
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354b
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356b
358a
358b
360a
360b
364a
368a
316a
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382b
384a
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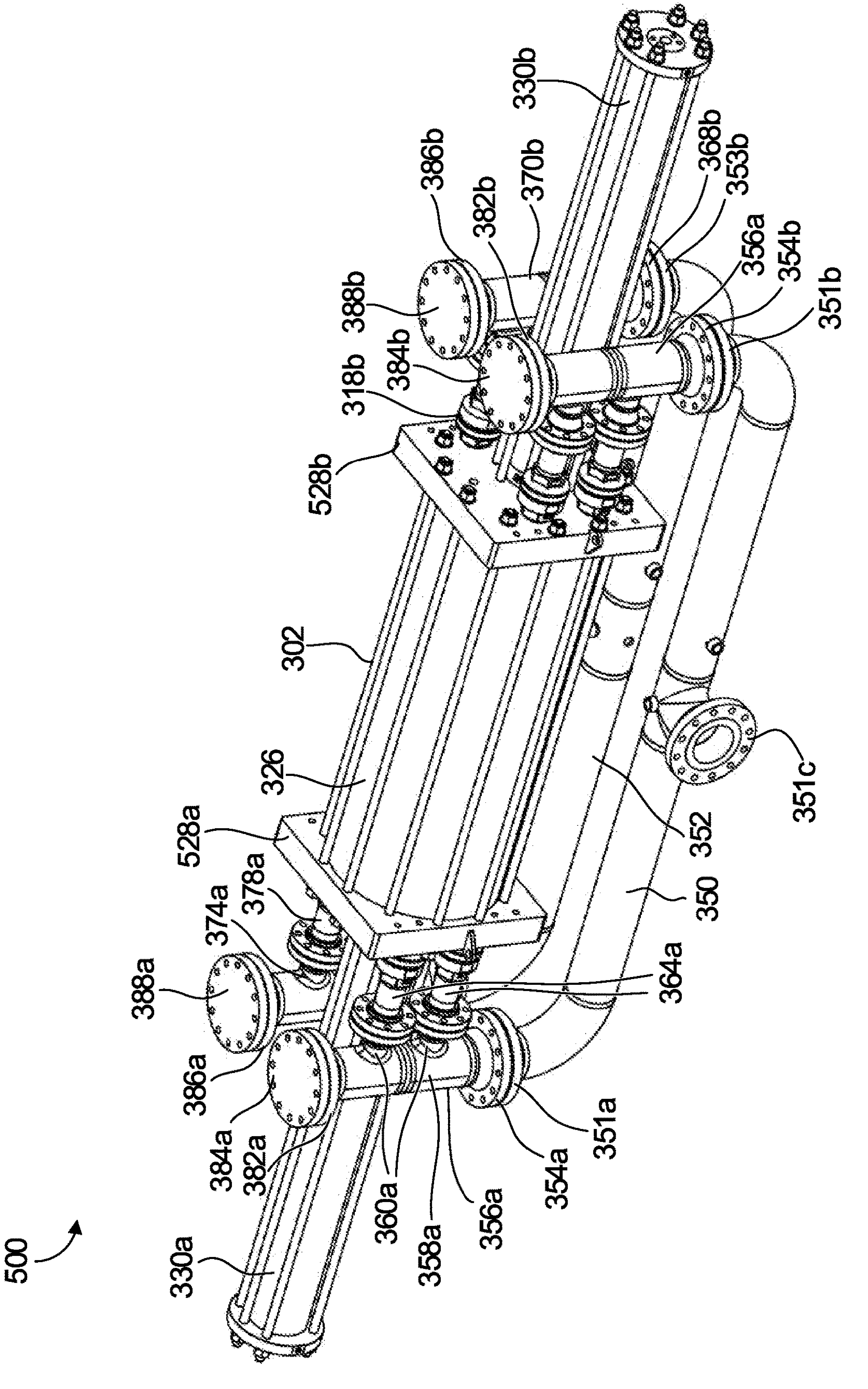
386a
386b
388a
388b

FIG. 7B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330a
330b
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528b
318b
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388b
386b
382b
370b
368b
353b
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354b
351b
351c
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364a
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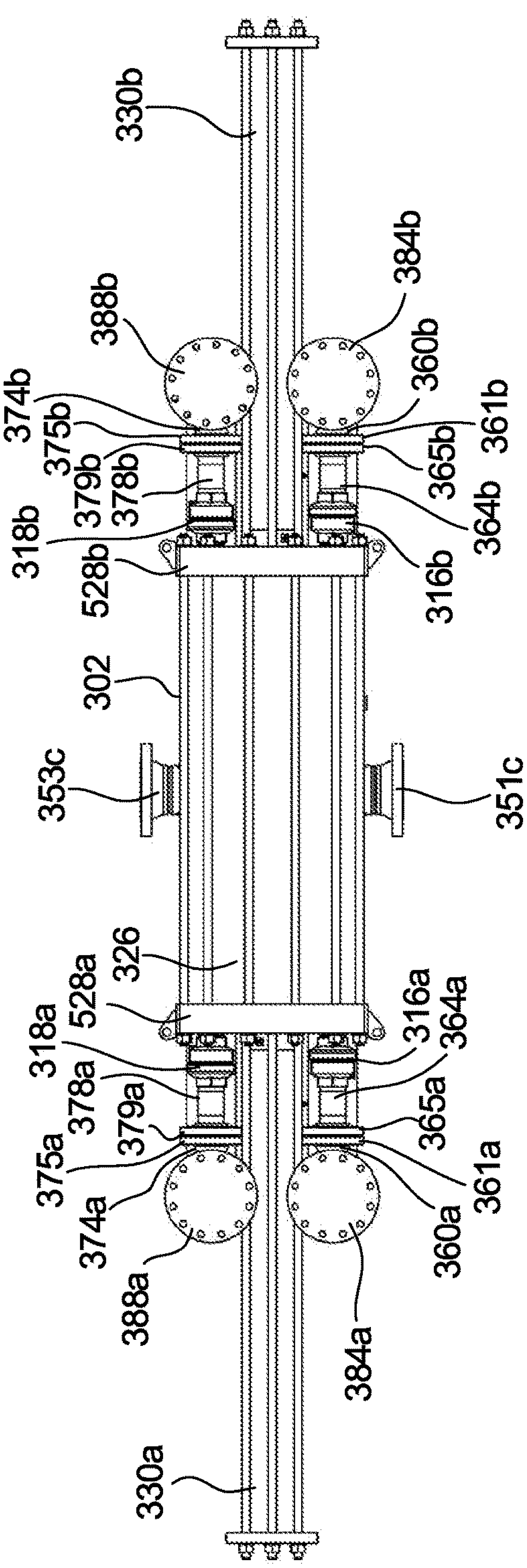
358a
356a
354a
351a

FIG. 7C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351c
326
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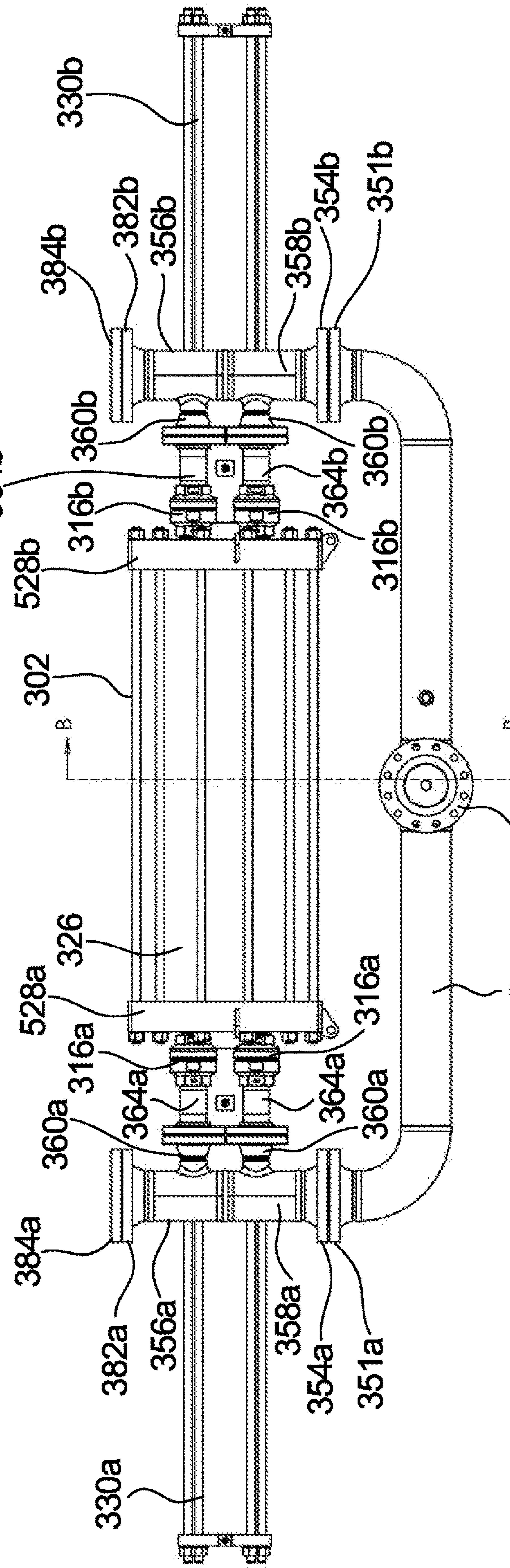
FIG. 7D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316b
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302
B
B
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358a
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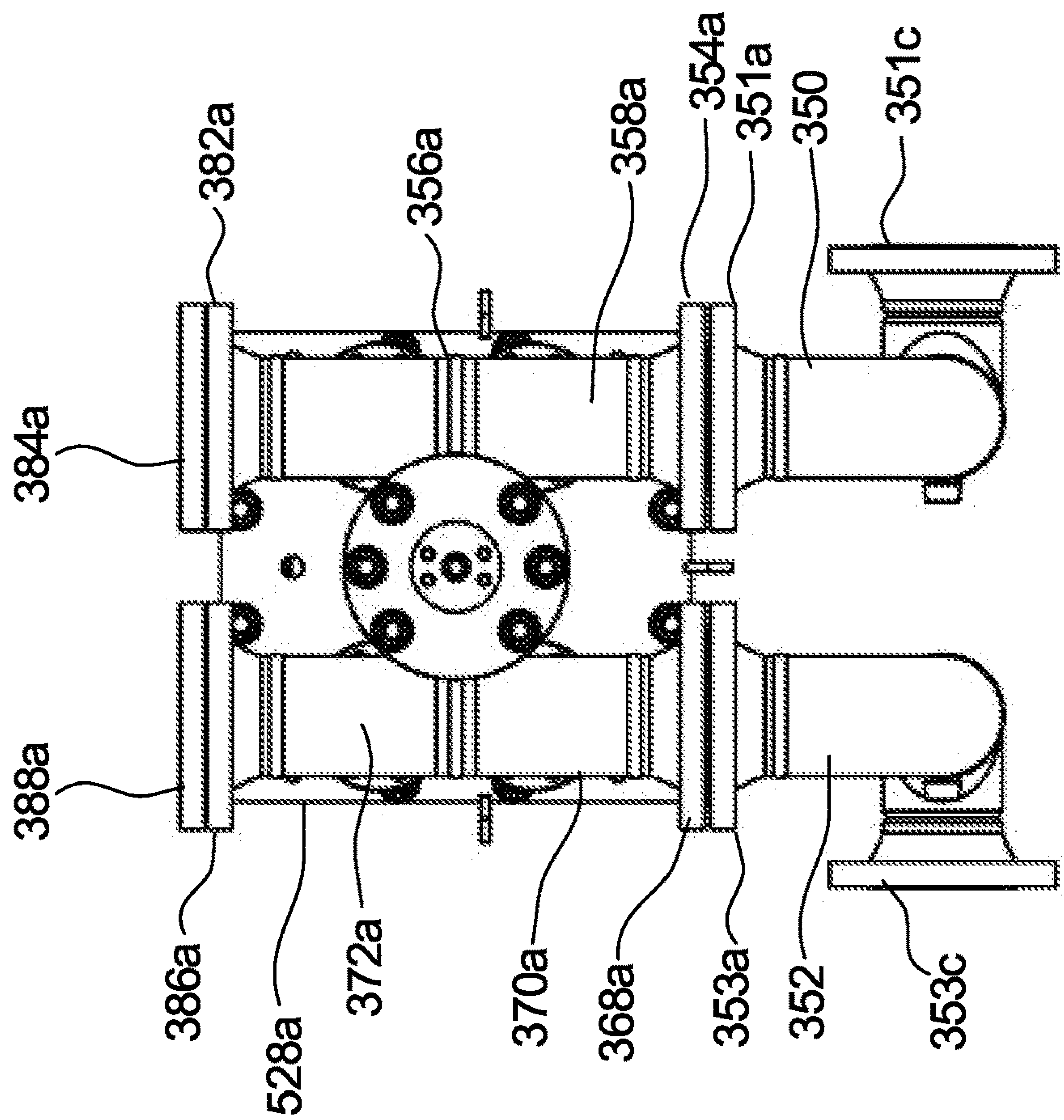
351a
330a

FIG. 7E


382a
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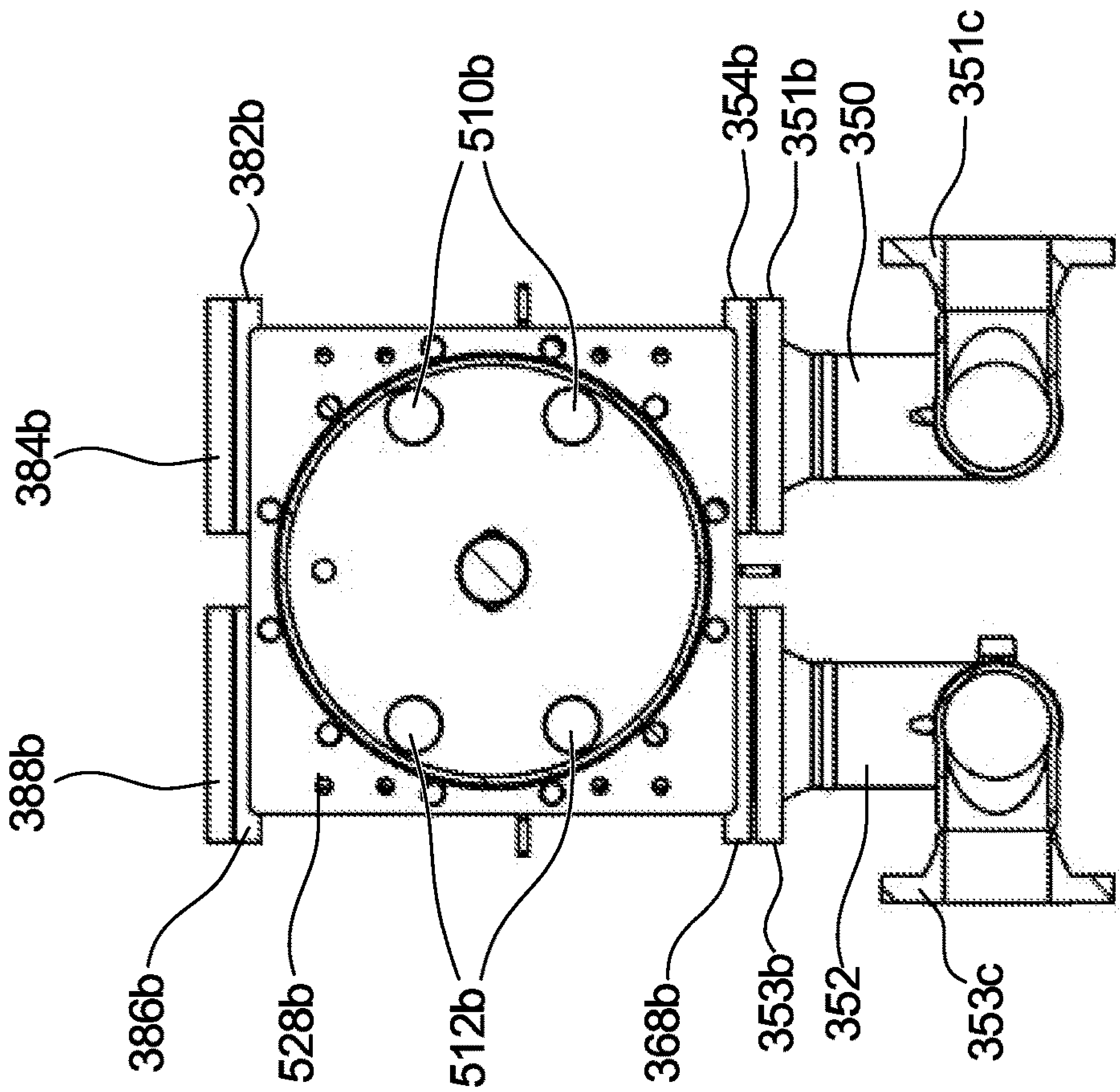
354a
351a
350
351c
384a
388a
386a
528a
372a
370a
368a
353a
352
353c

FIG. 7G


382b
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388b
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528b
512b
368b
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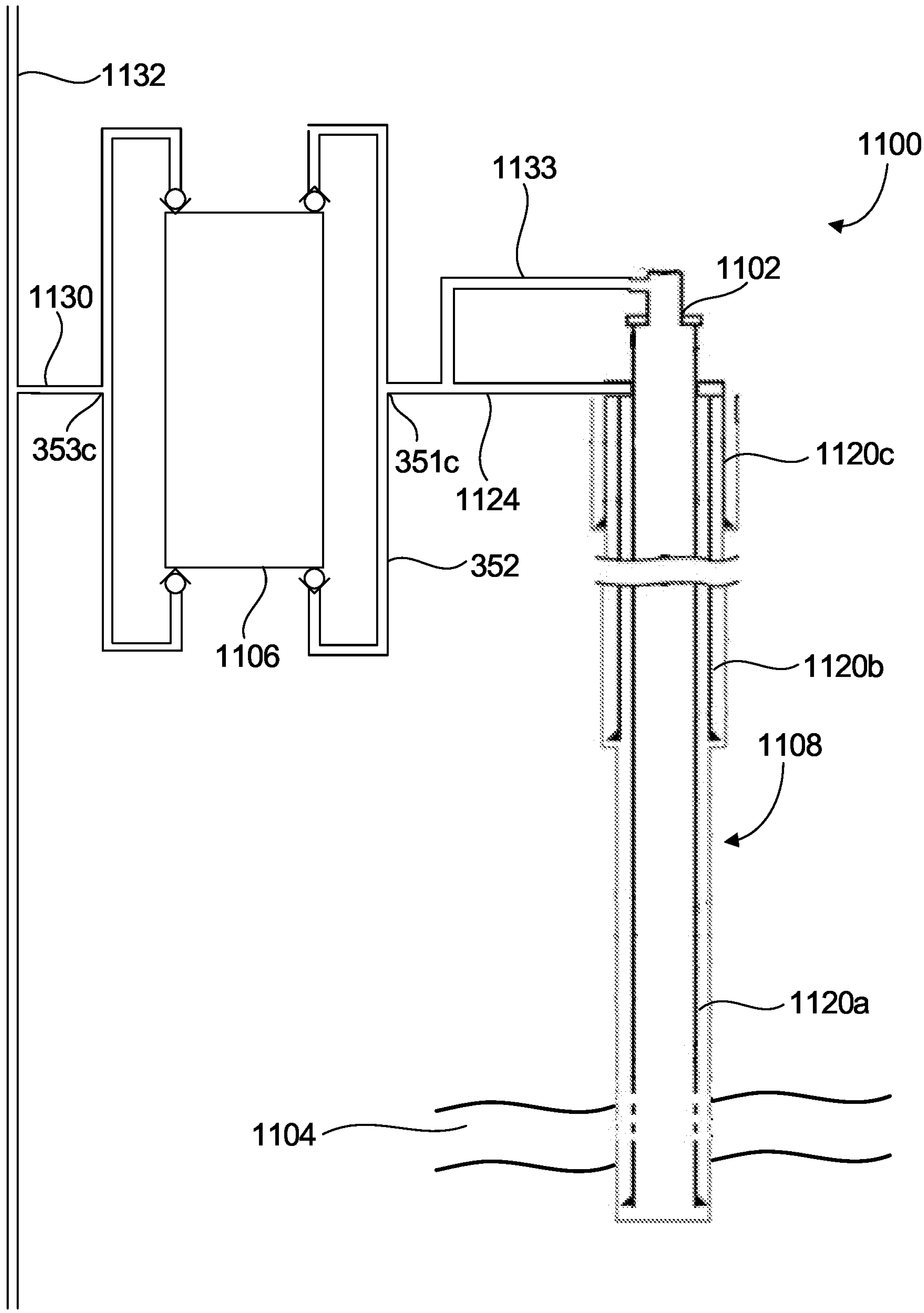
352
353c

FIG. 7F


1132
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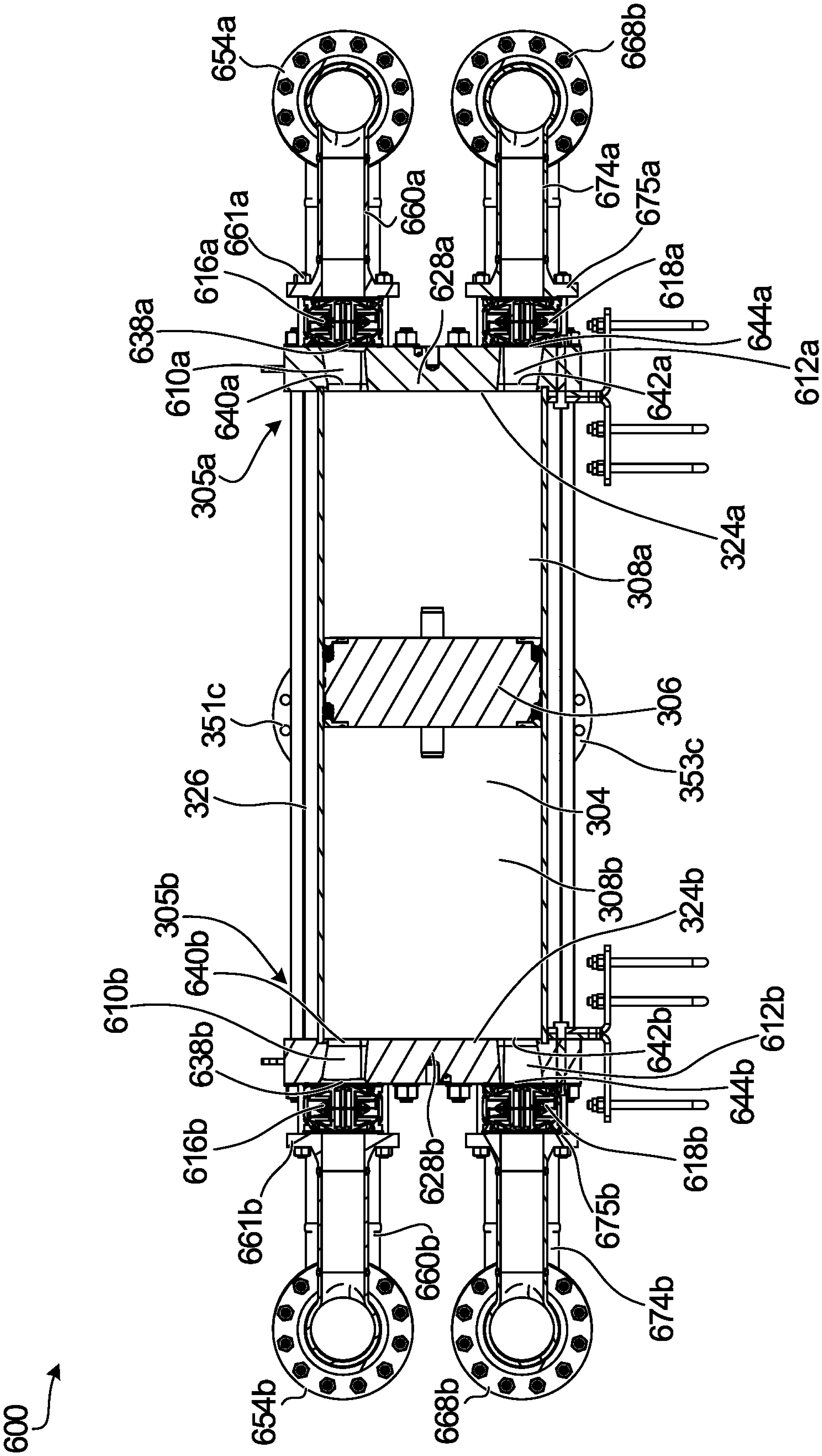
1120a
1104

FIG. 8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324a
308a
351c
306
326
353c
304
305b
308b
324b
640b
610b
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612b
638b
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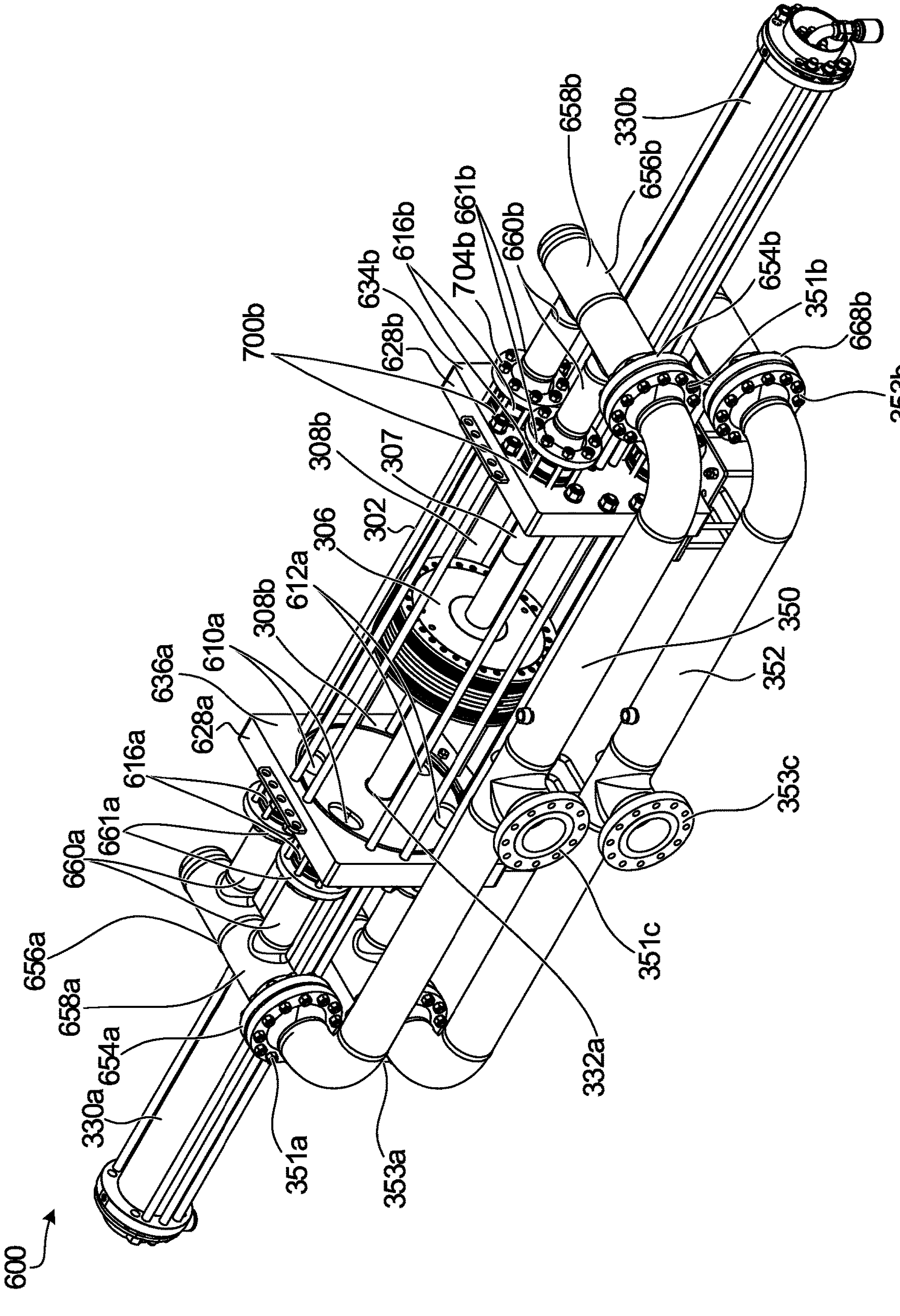
616b
628b
618b
661b
675b
660b
674b
654b
668b
600

FIG. 9A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658a
656a
660a
661a
616a
628a
636a
610a
308b
612a
306
302
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700b
628b
634b
616b
704b
661b
660b
658b
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330b
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351b
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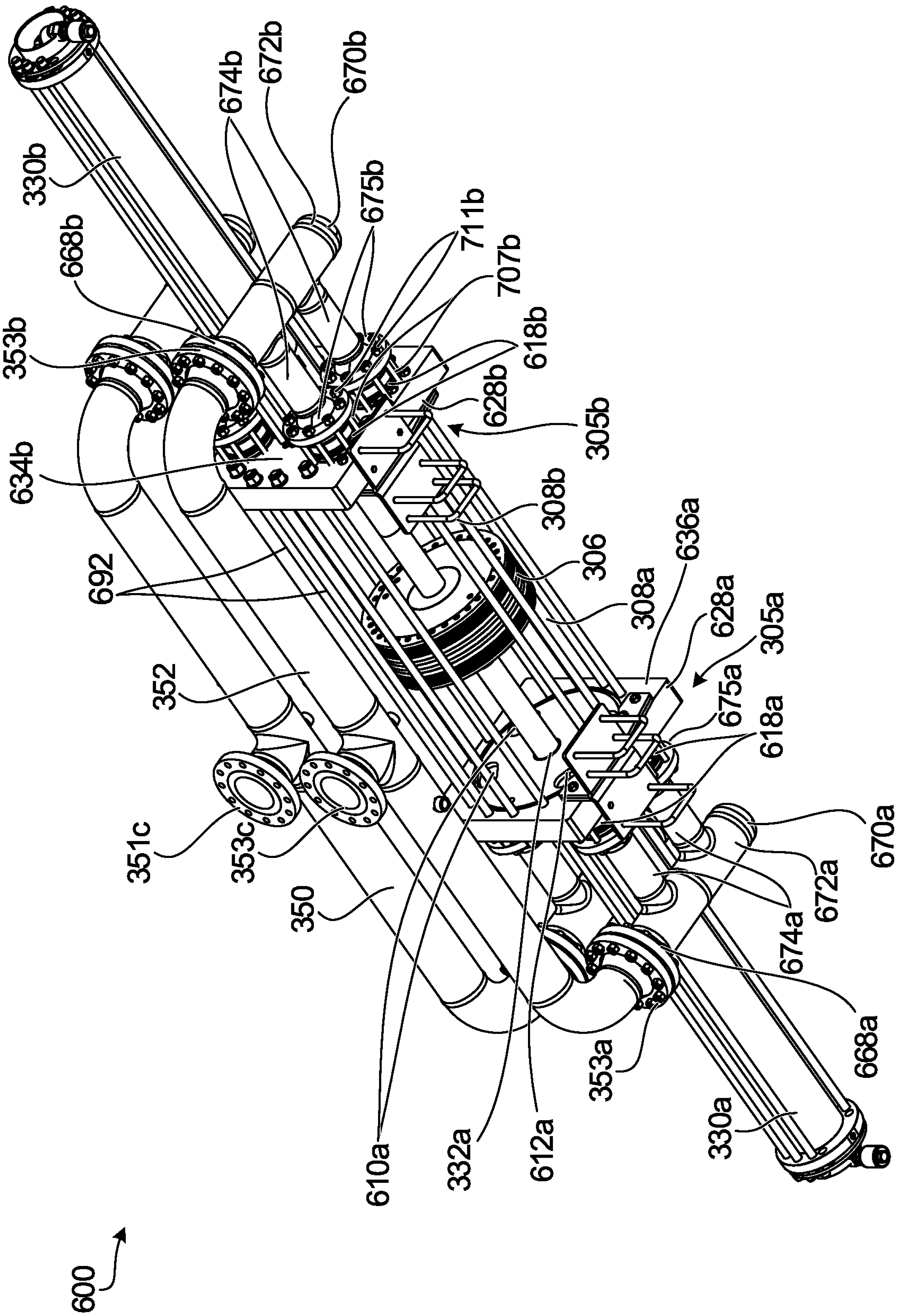
353b
350
352
353c
351c
332a
351a
353a

FIG. 9B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618b
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628a
305a
692
352
675a
618a
351c
353c
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674a
668a
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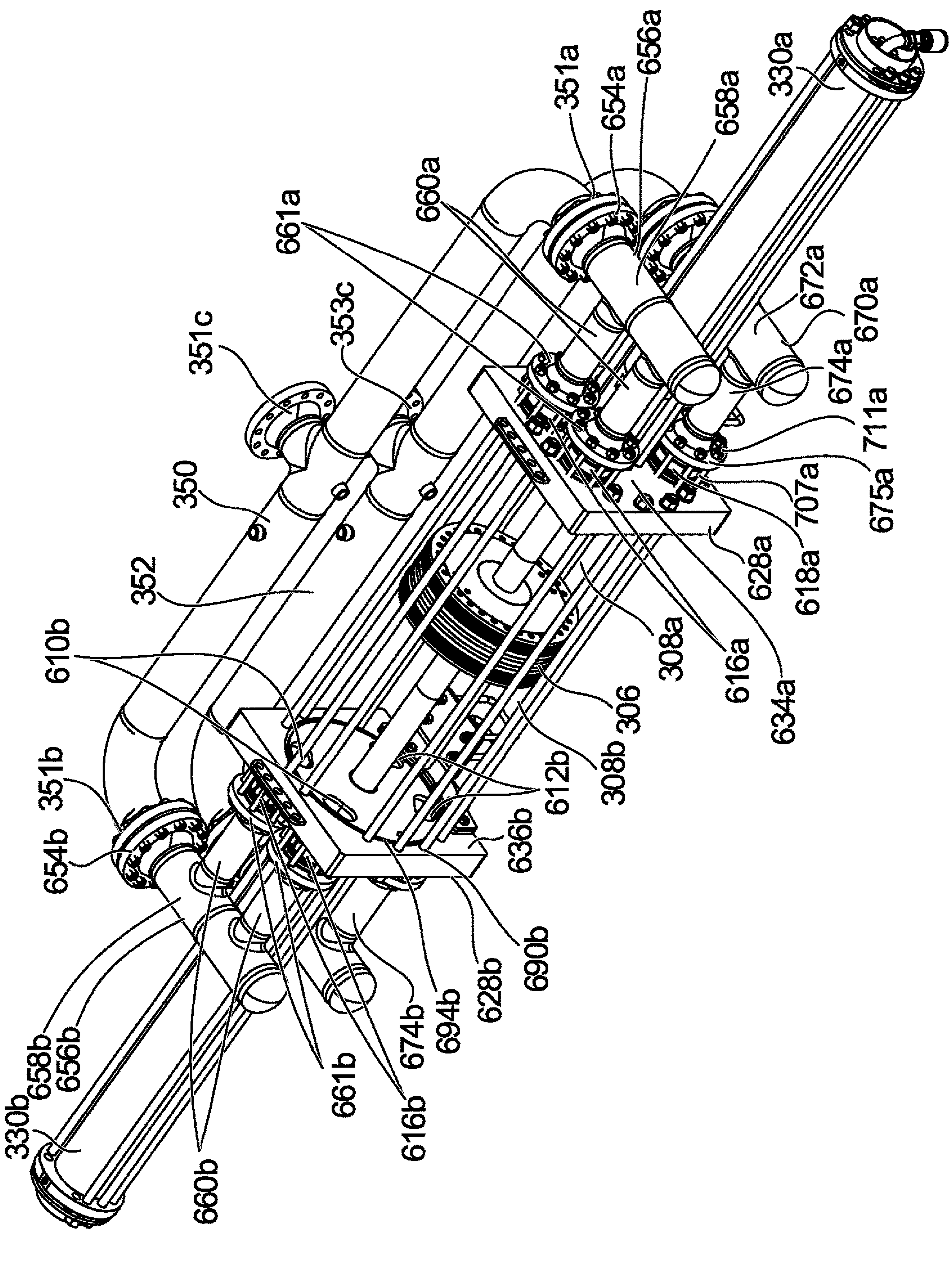
330a
612a
332a
610a
600

FIG. 9C



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308b
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628b
694b
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352
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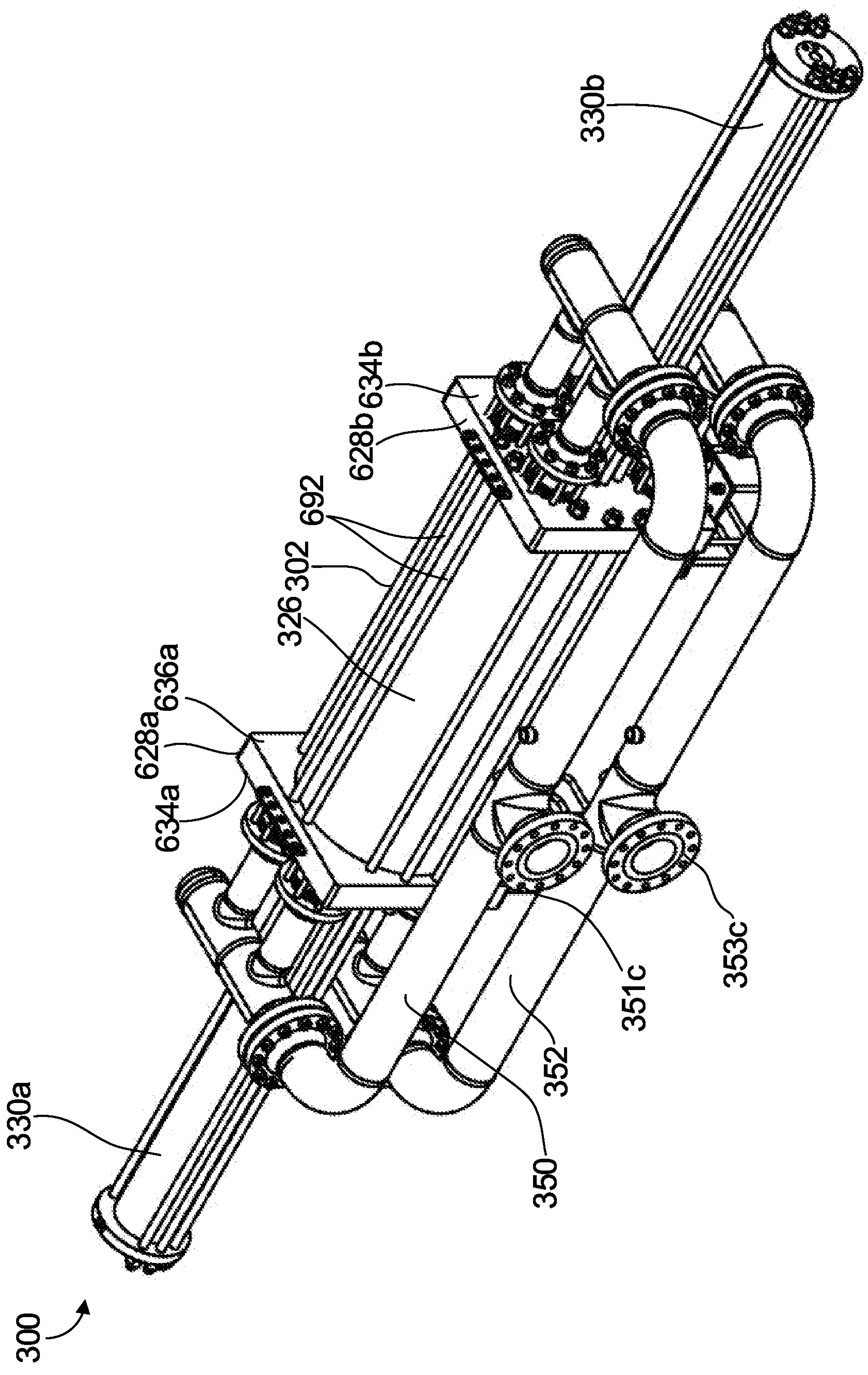
353c
351c

FIG. 9D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352
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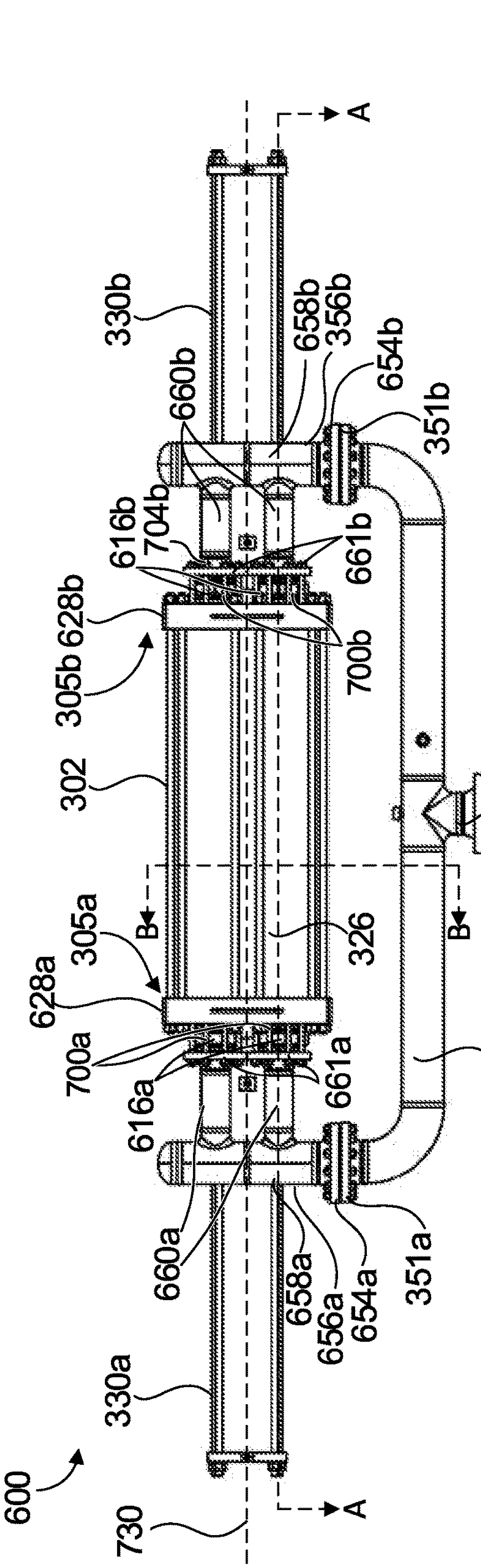
330a
300

FIG. 9E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B
326
350
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351c
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704b
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660b
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356b
654b
351b
330b

FIG. 9F

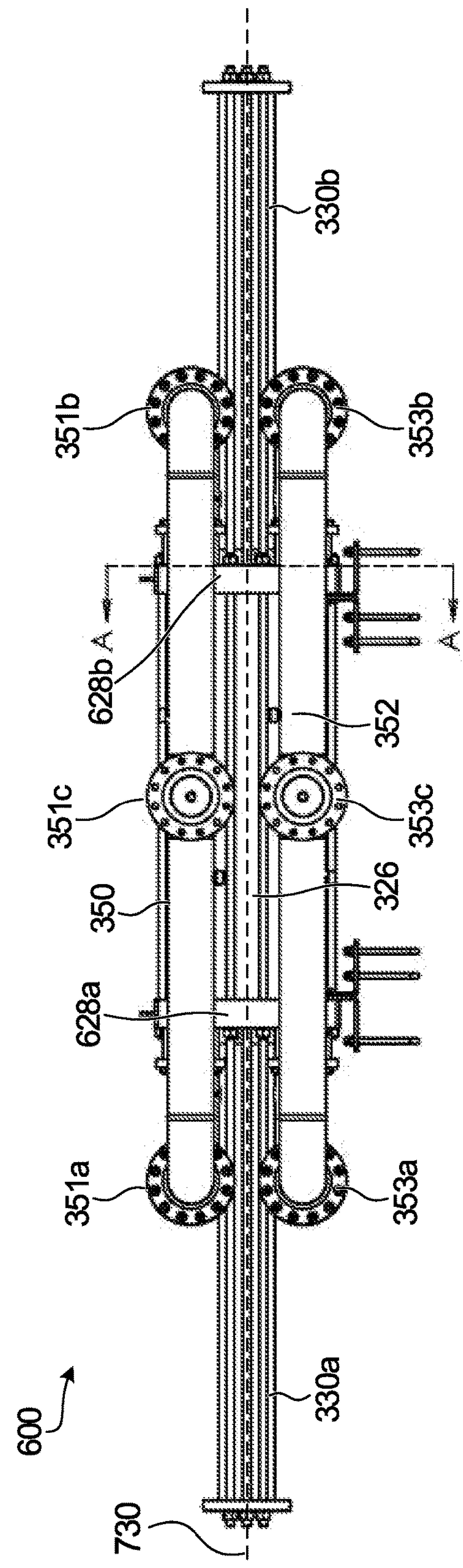
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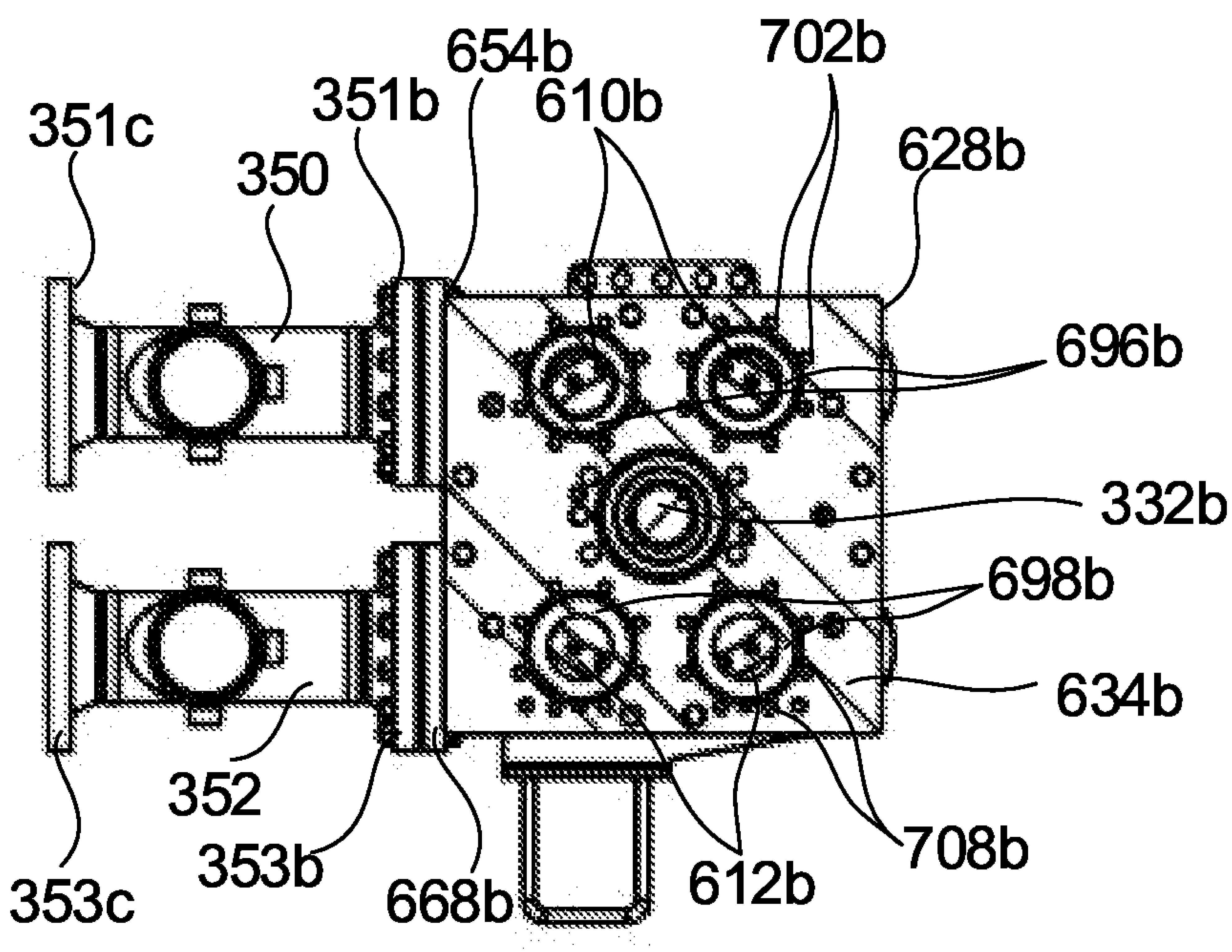
FIG. 9G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353c
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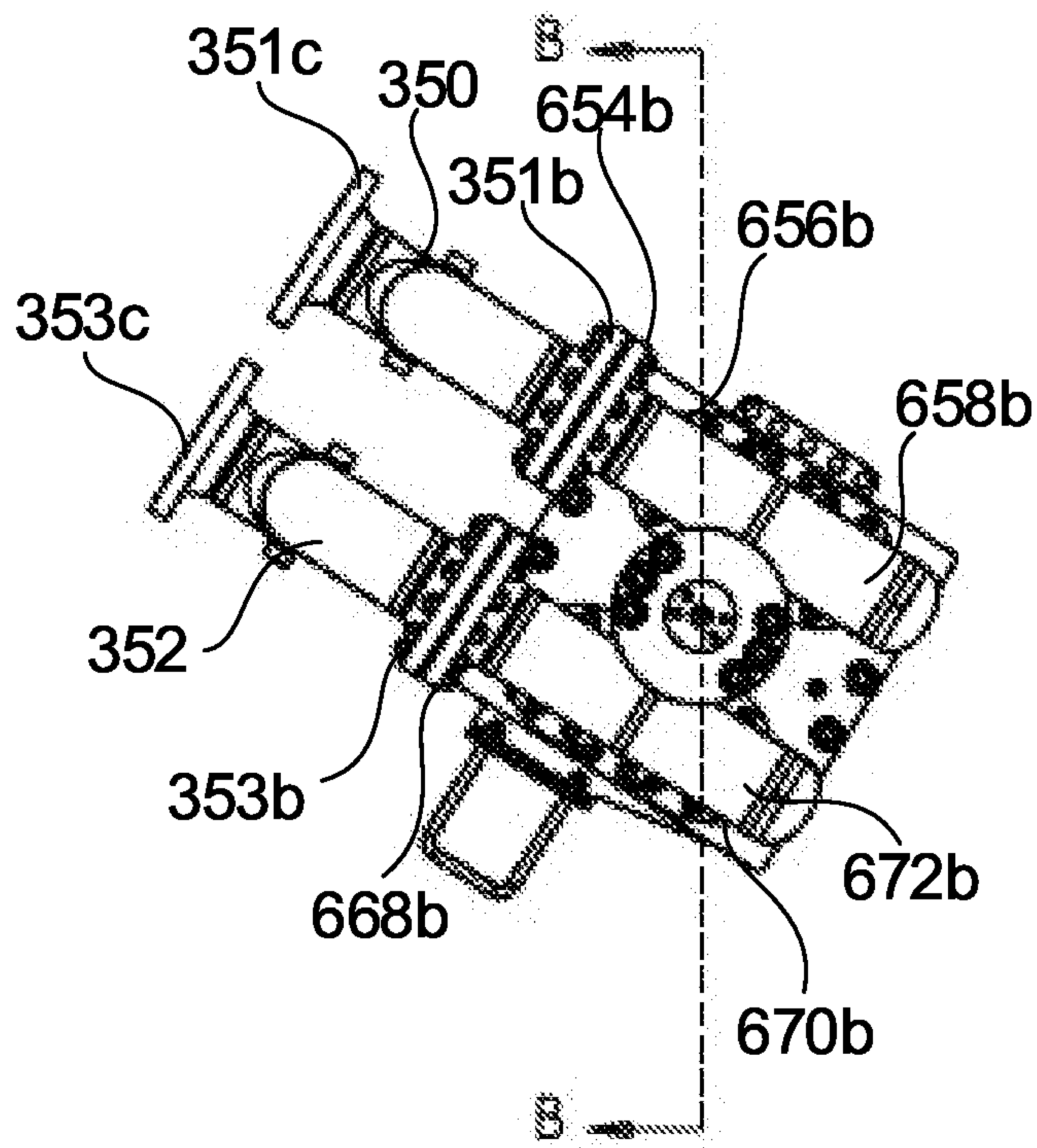
668b
612b
708b

FIG. 9H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352
353b
668b
672b
670b
B

FIG. 9I

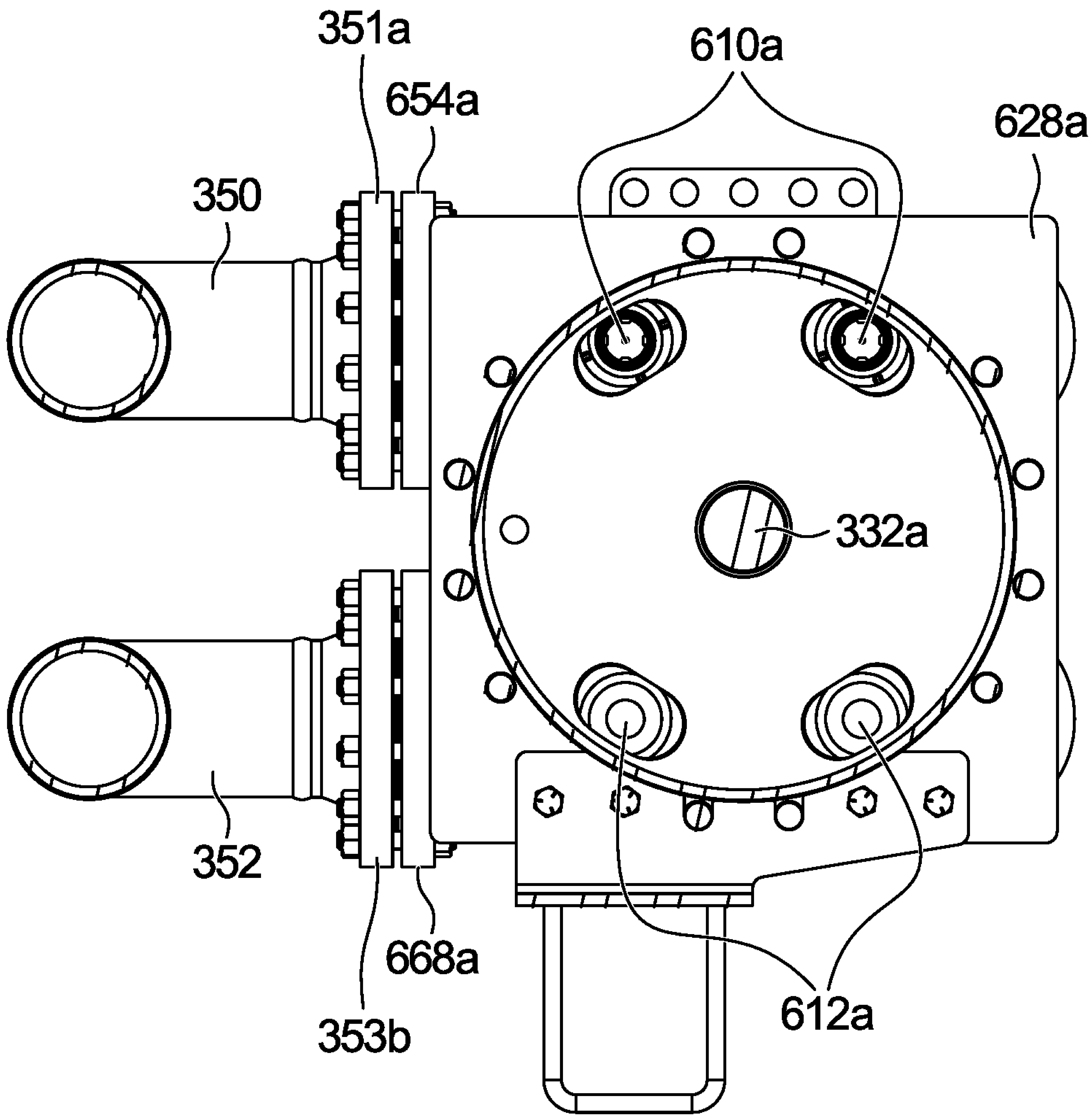
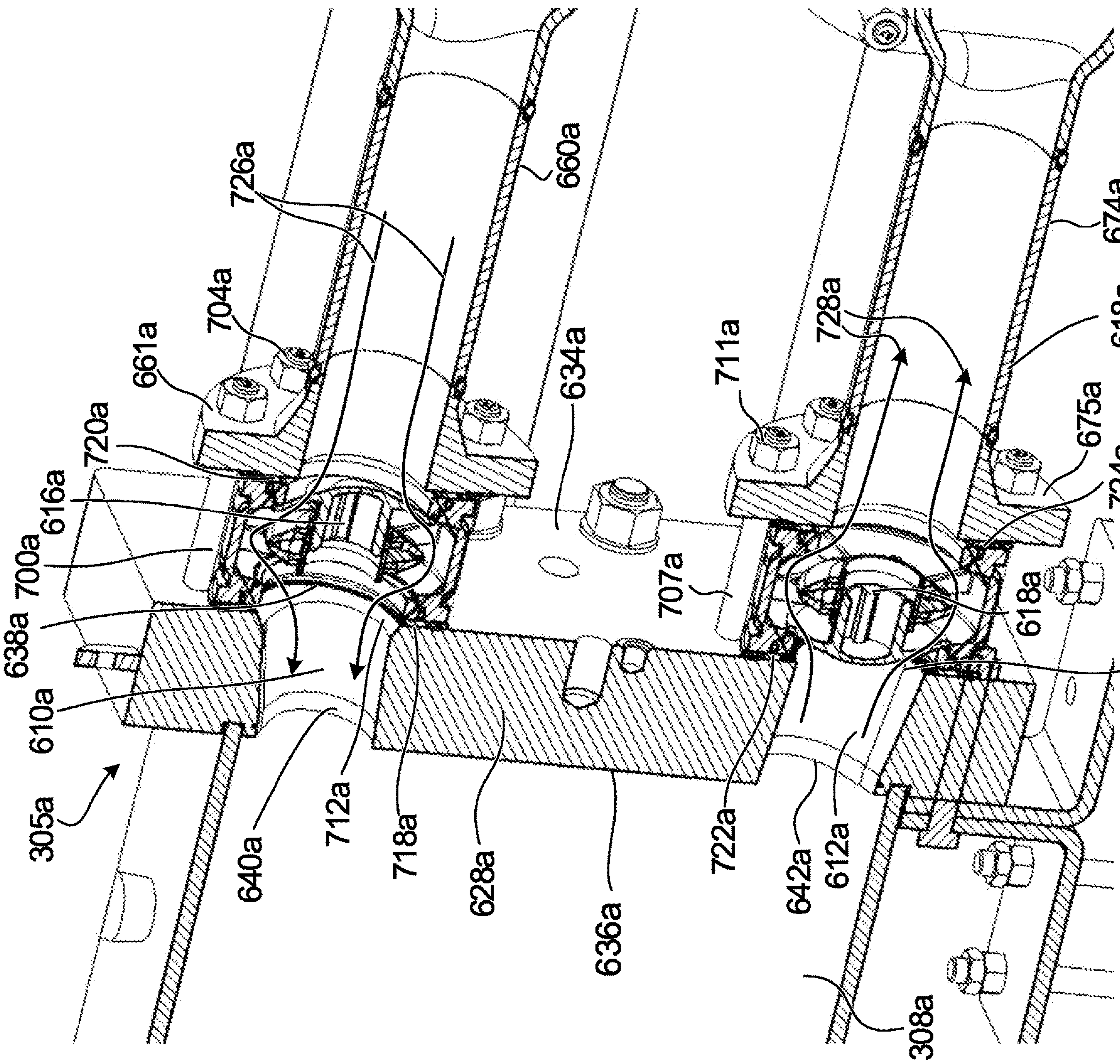


FIG. 9J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722a
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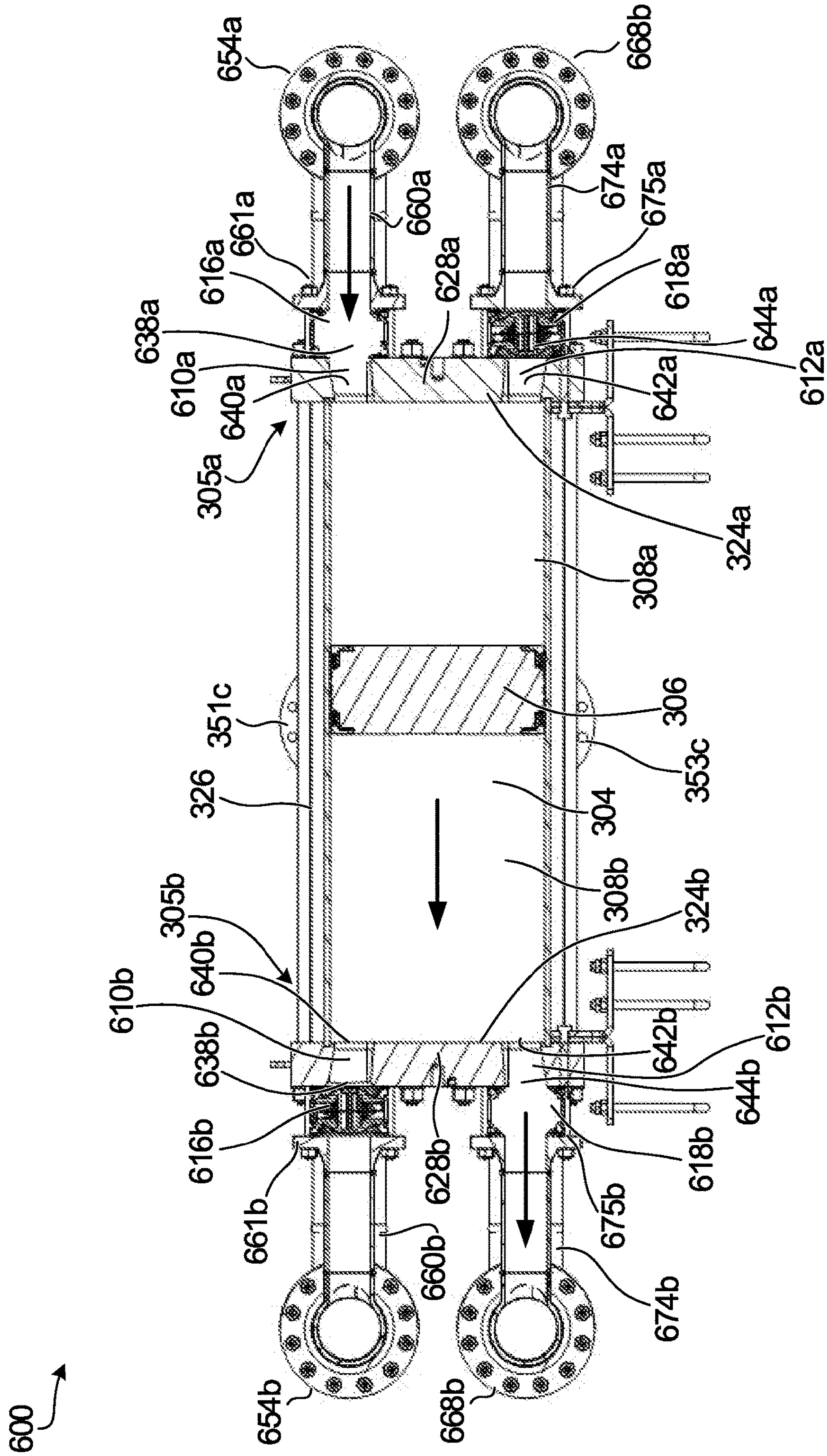
612a
308a

FIG. 9K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618b
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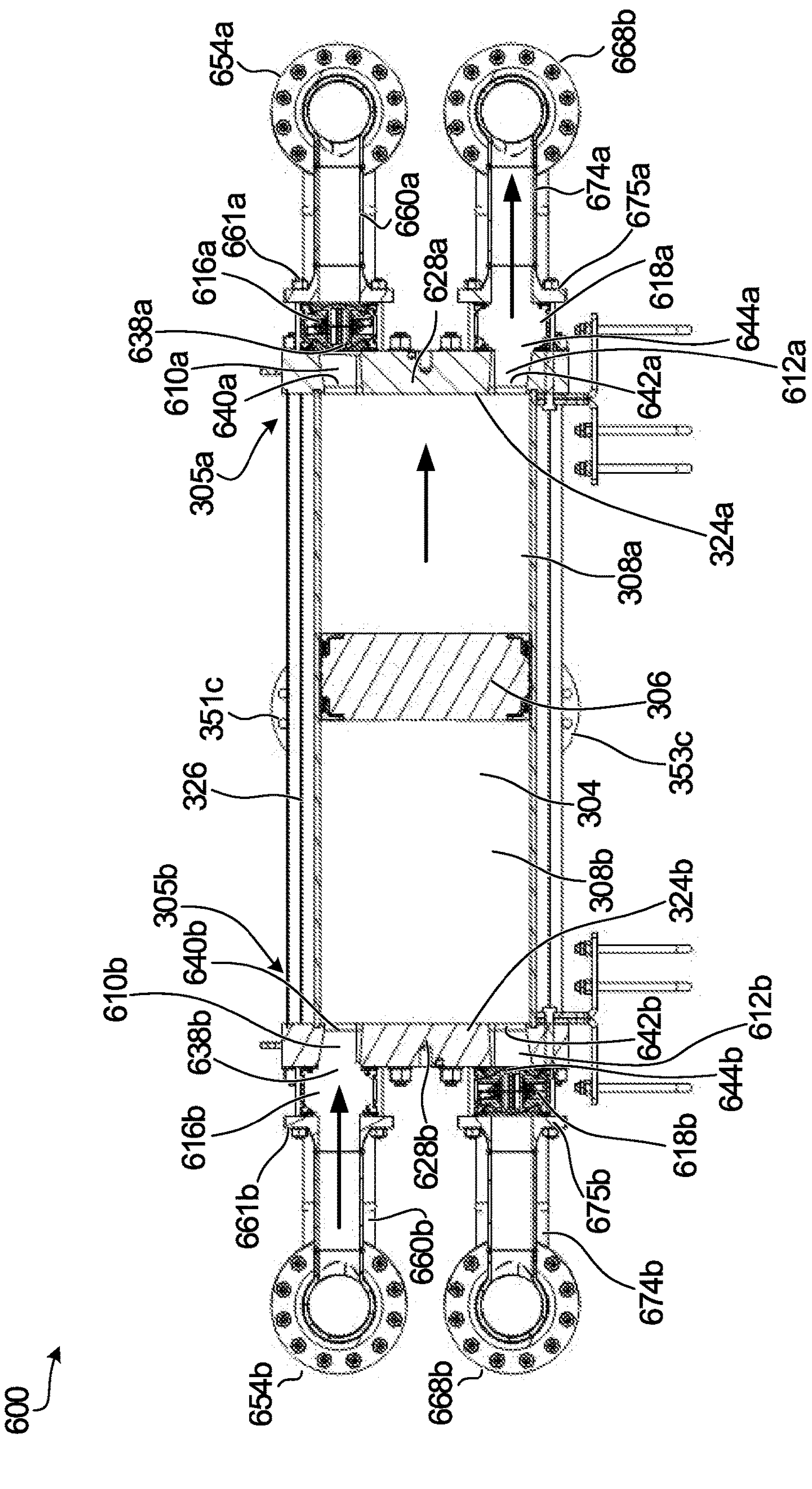
660b
674b
654b
668b
600

FIG. 9L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308a
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353c
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305b
308b
324b
640b
610b
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618b
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675b
660b
674b
654b
668b
600

FIG. 9M

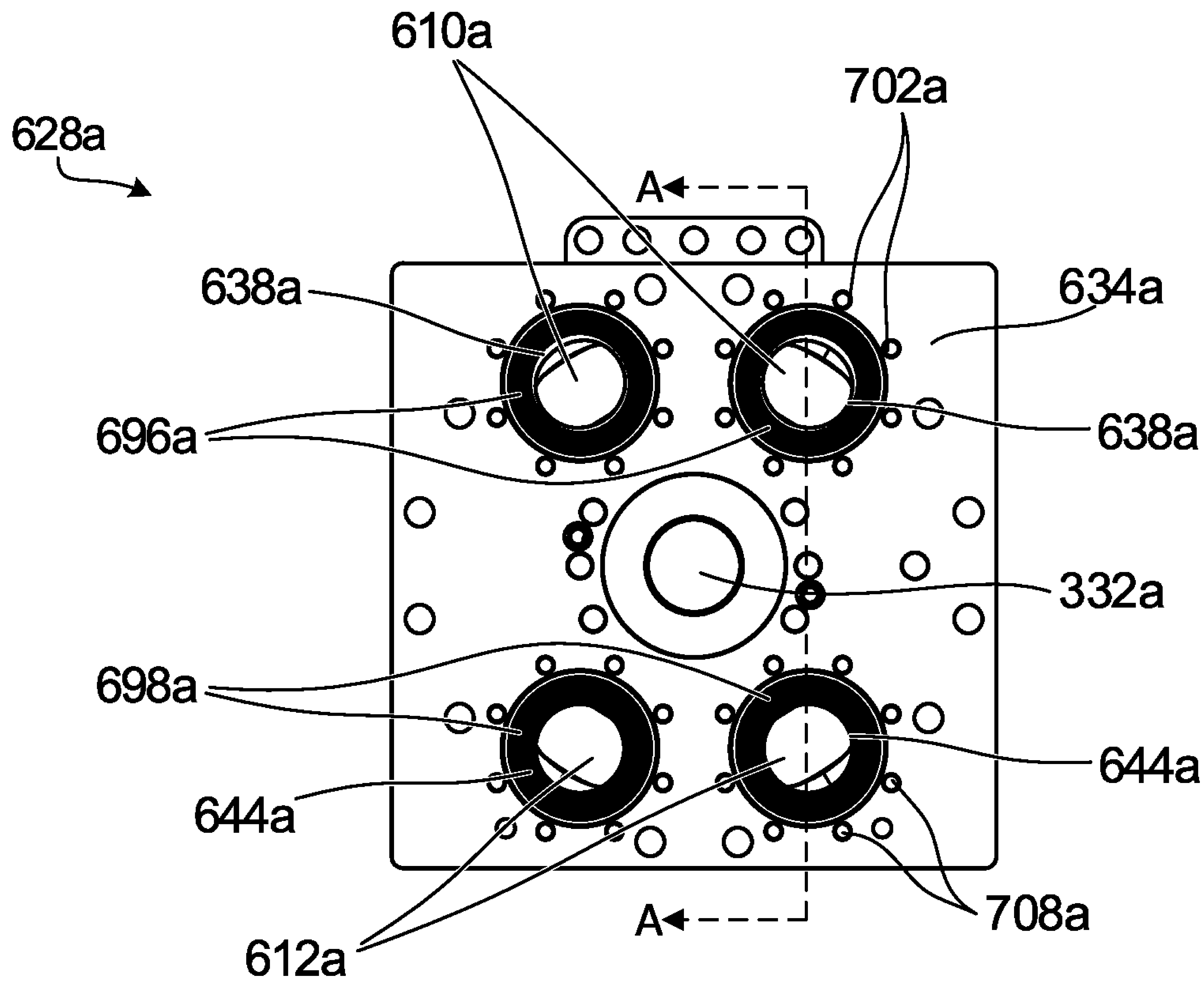


FIG. 10A

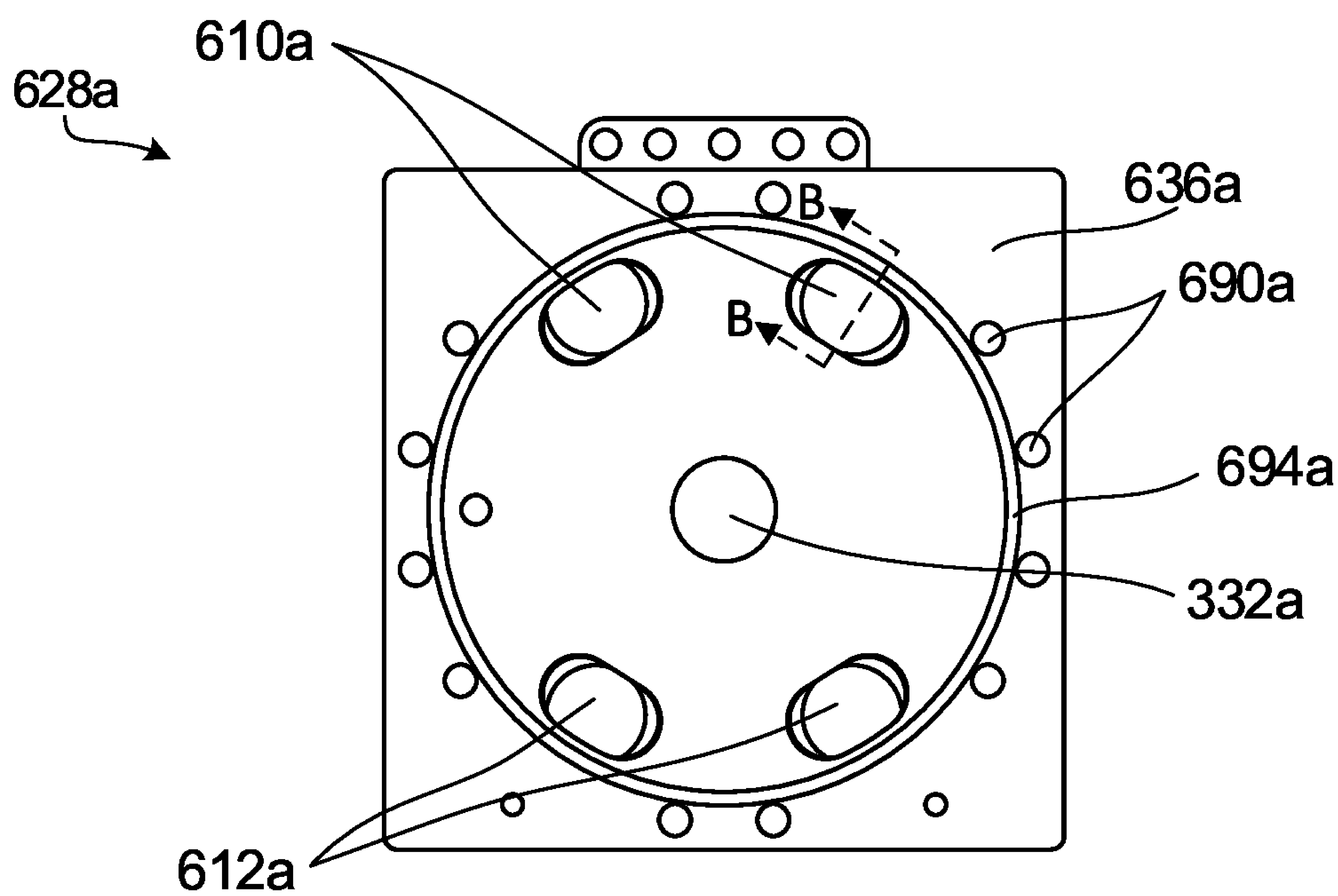


FIG. 10B

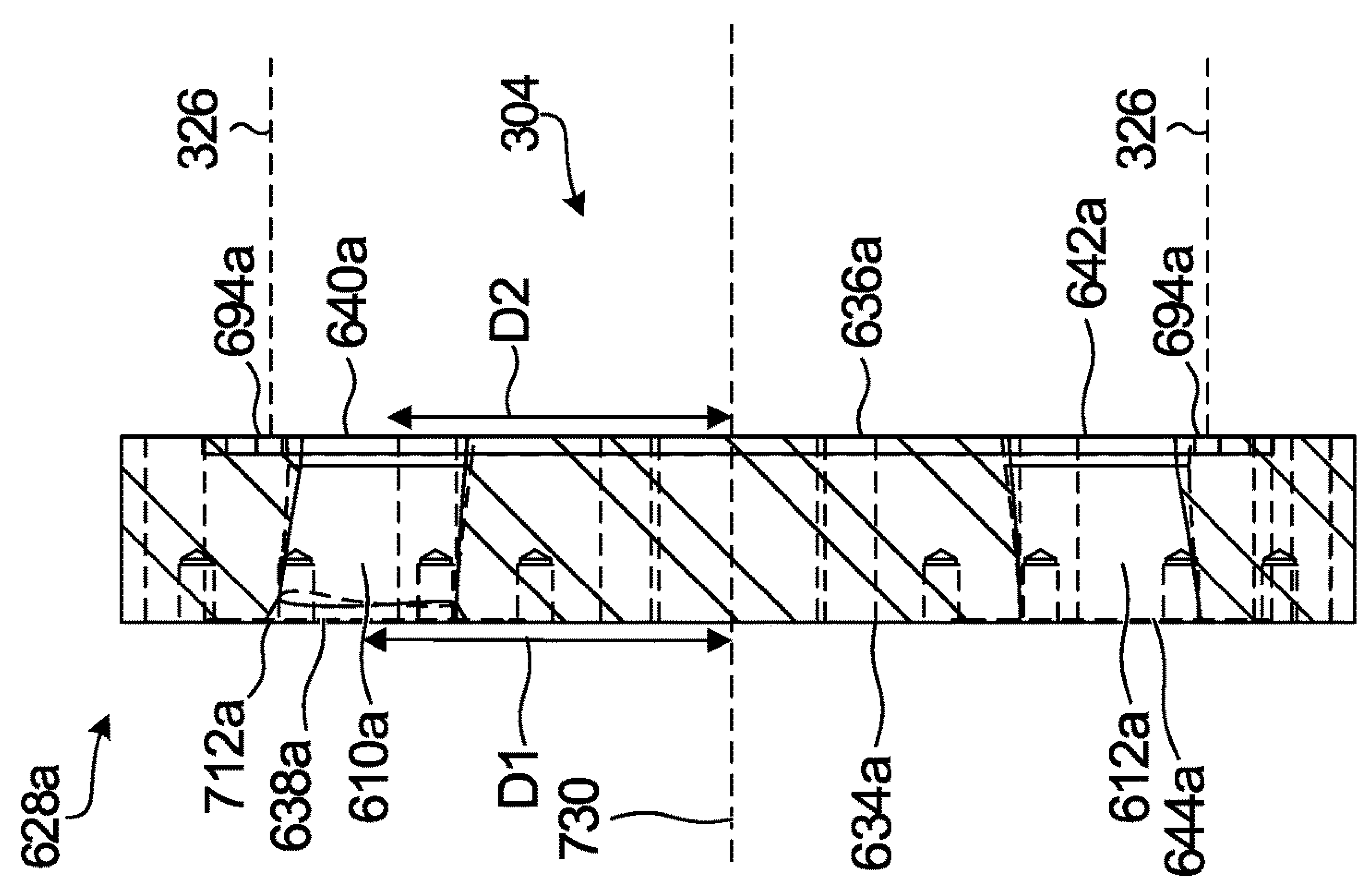


FIG. 10C

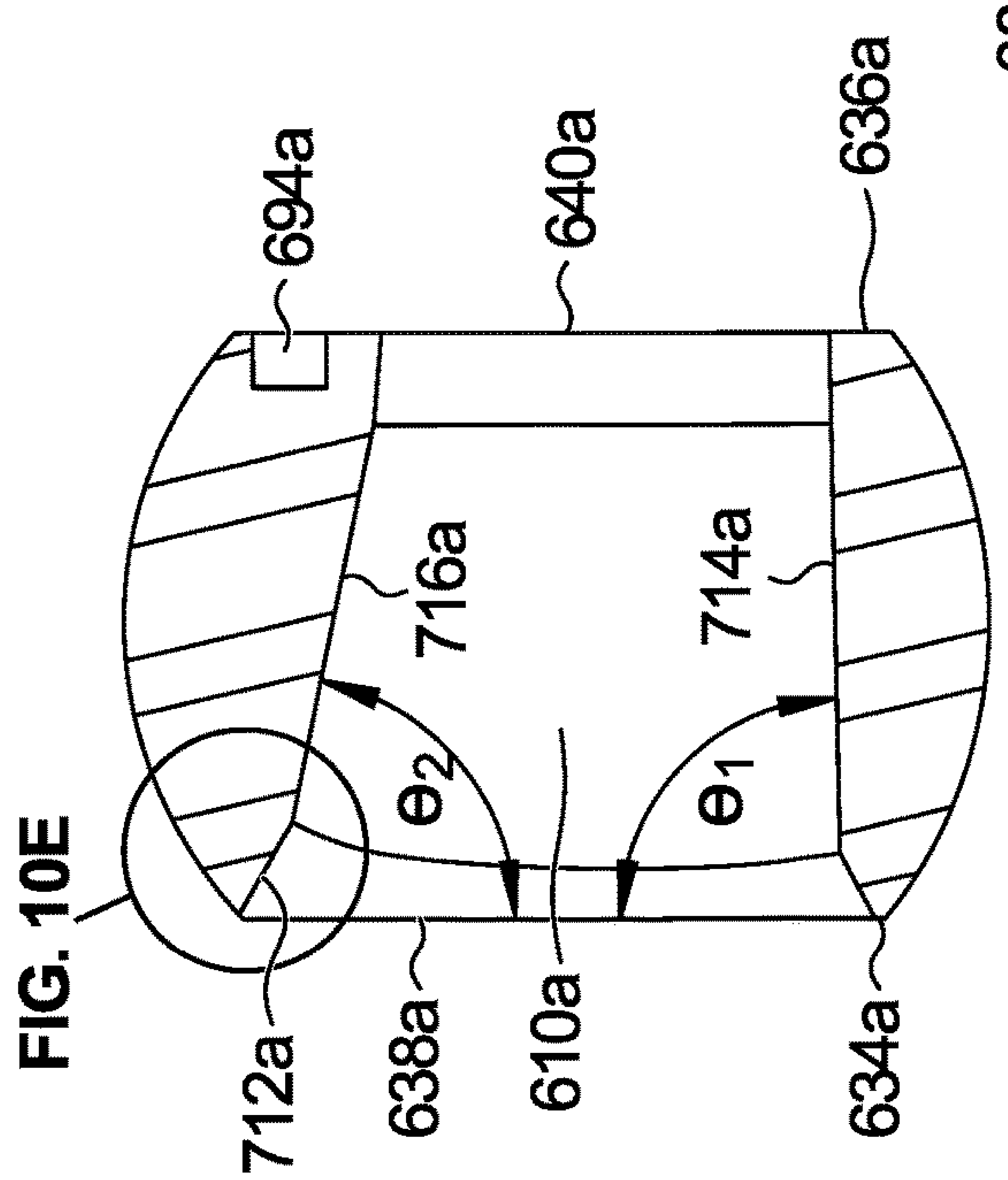


FIG. 10D

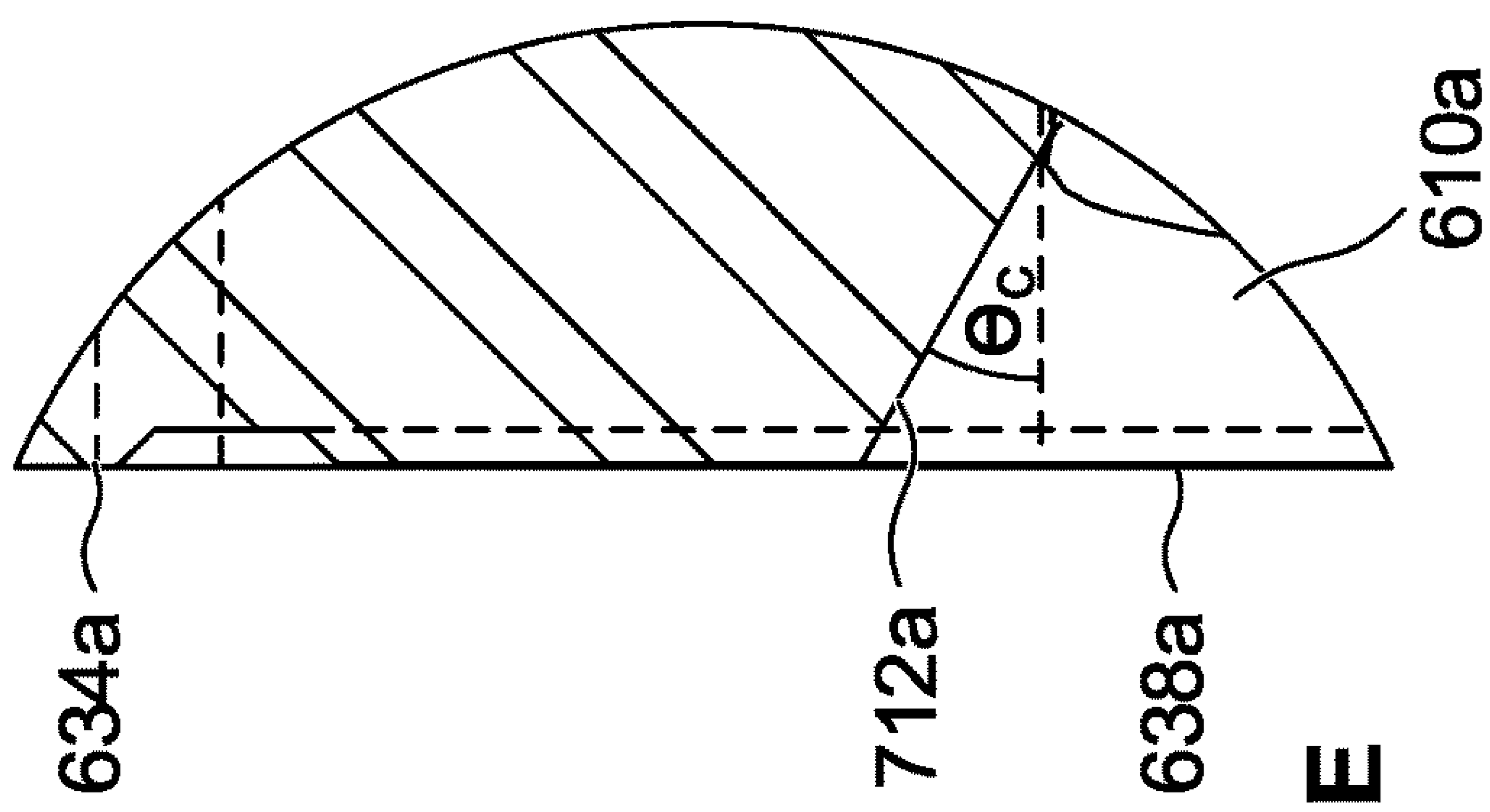


FIG. 10E

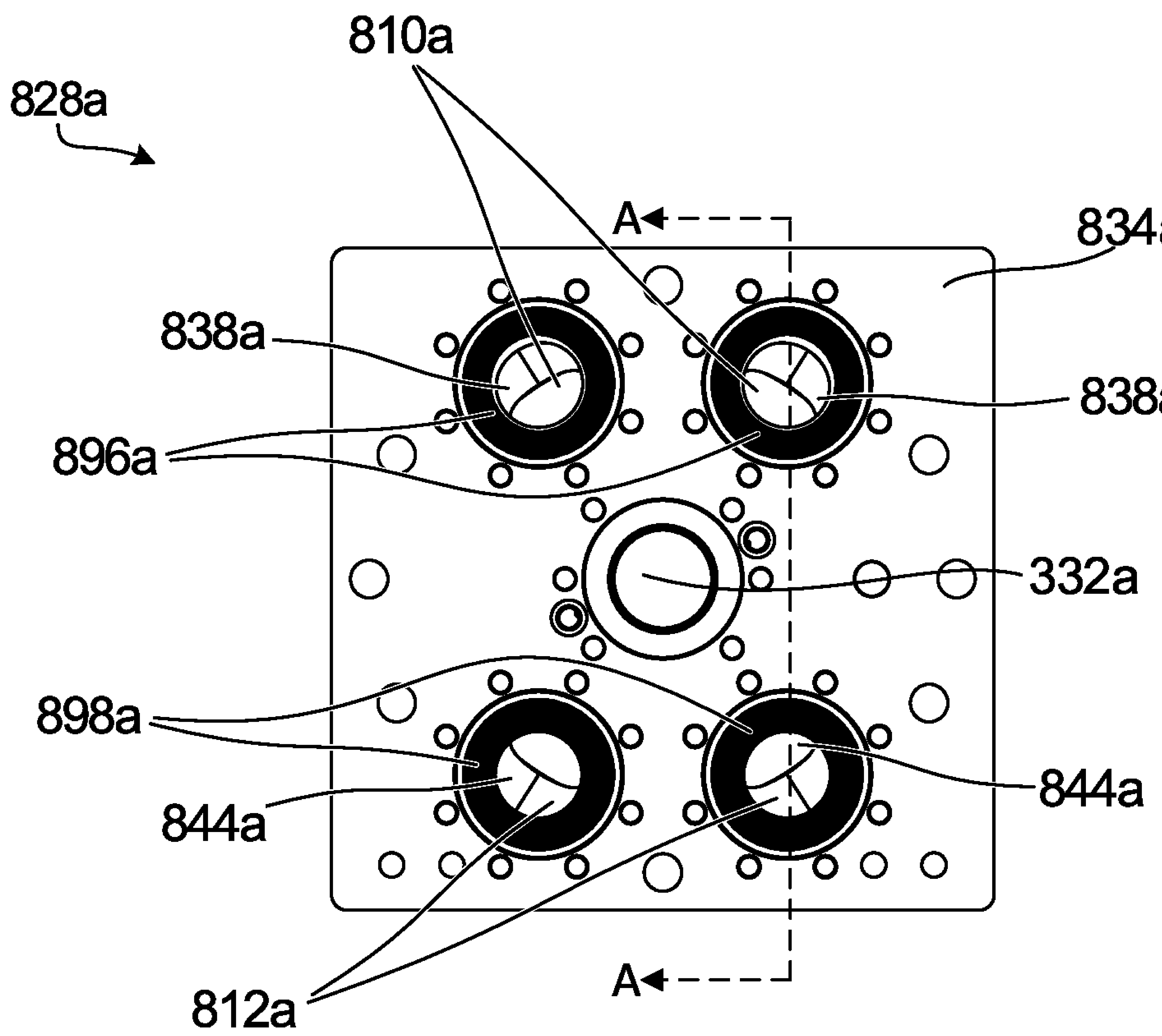


FIG. 11A

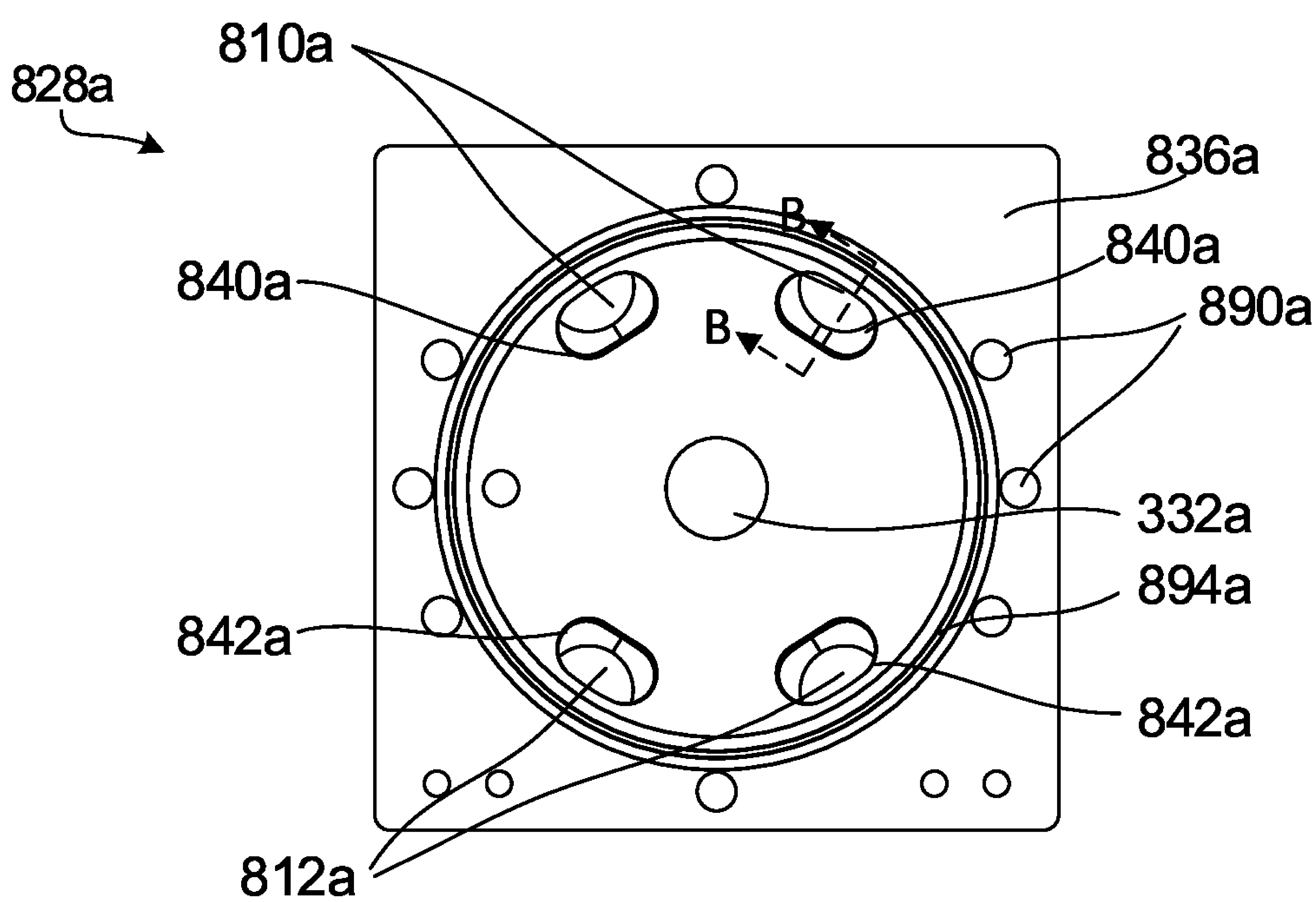


FIG. 11B

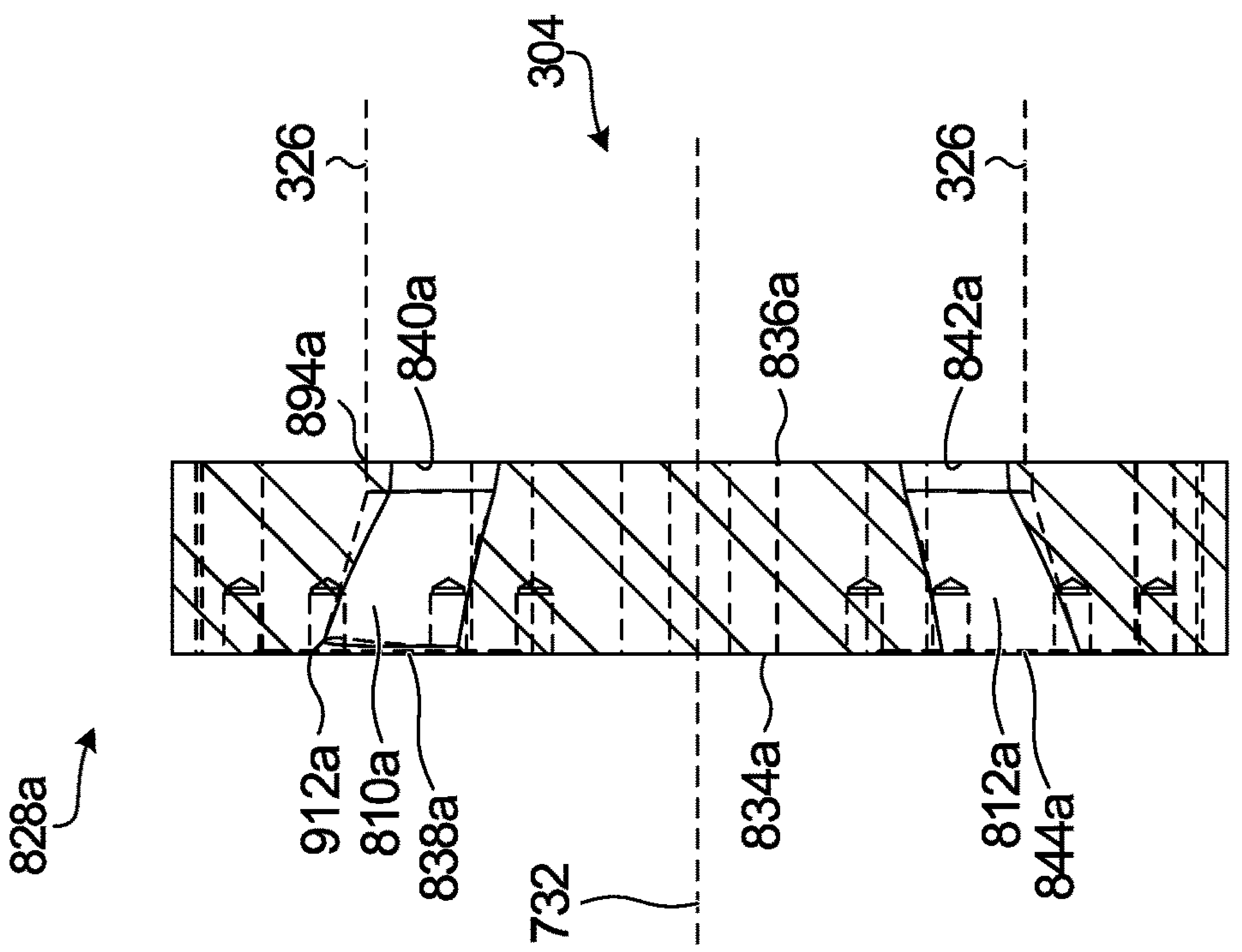


FIG. 11C

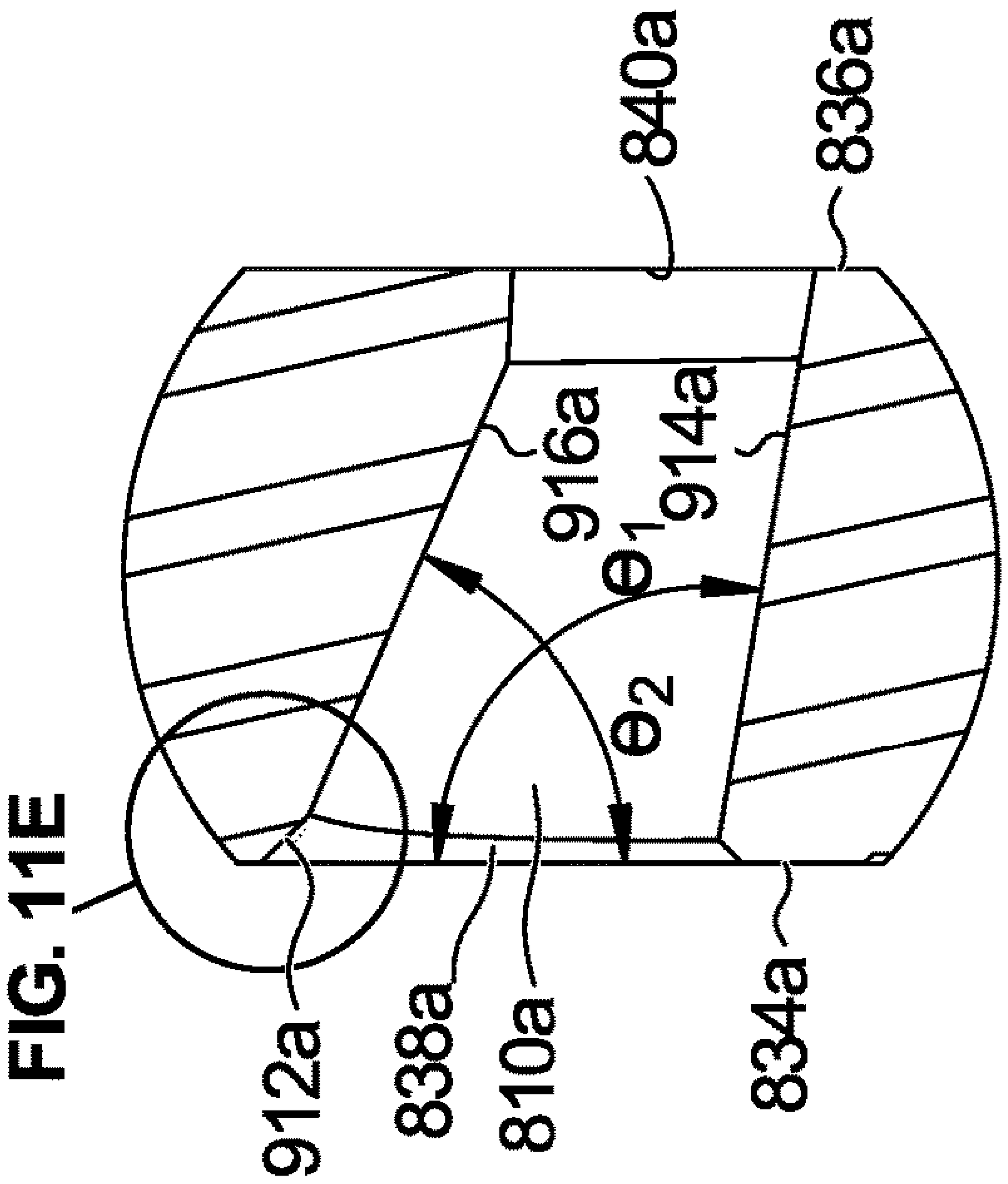


FIG. 11D

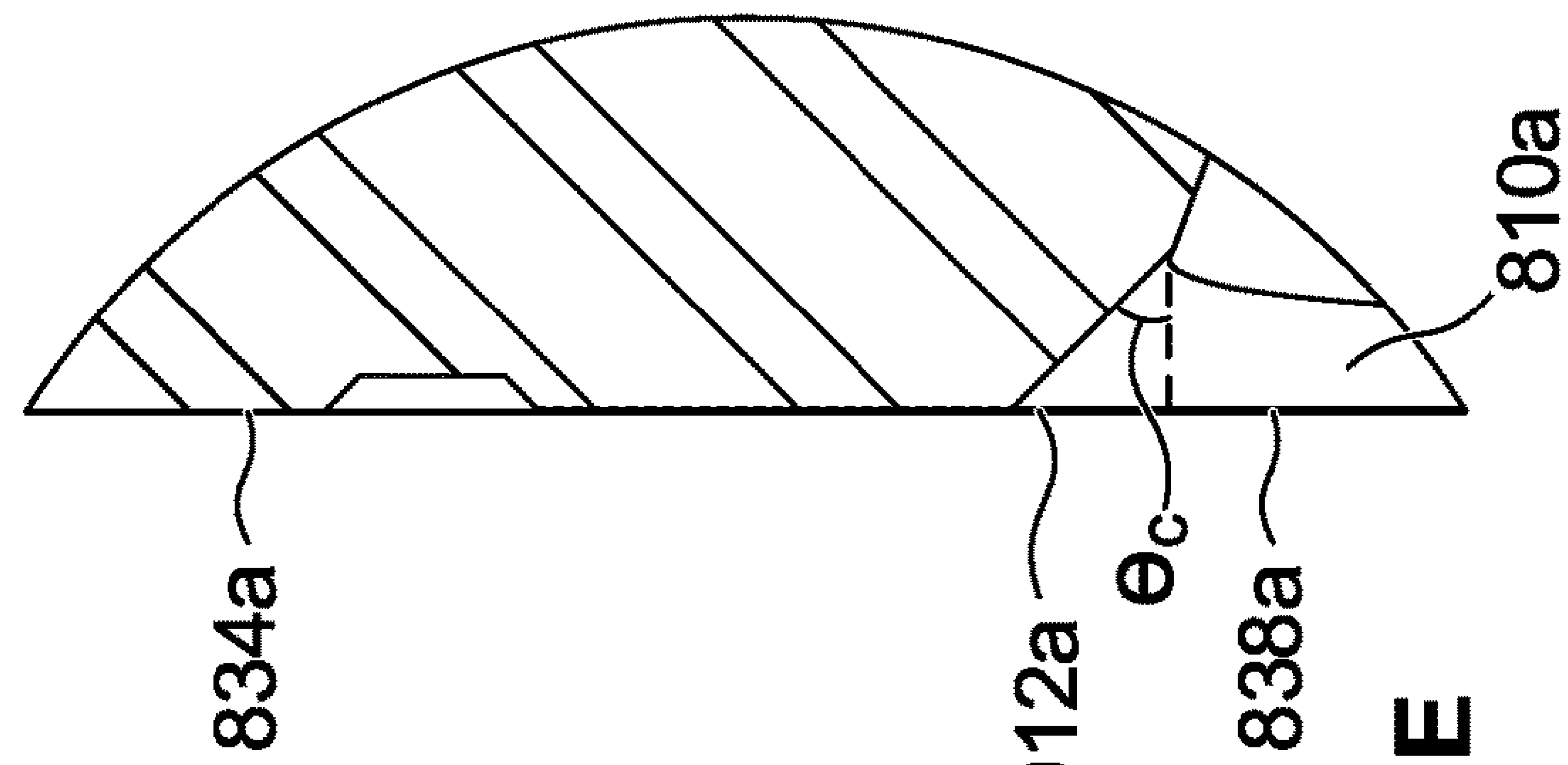


FIG. 11E

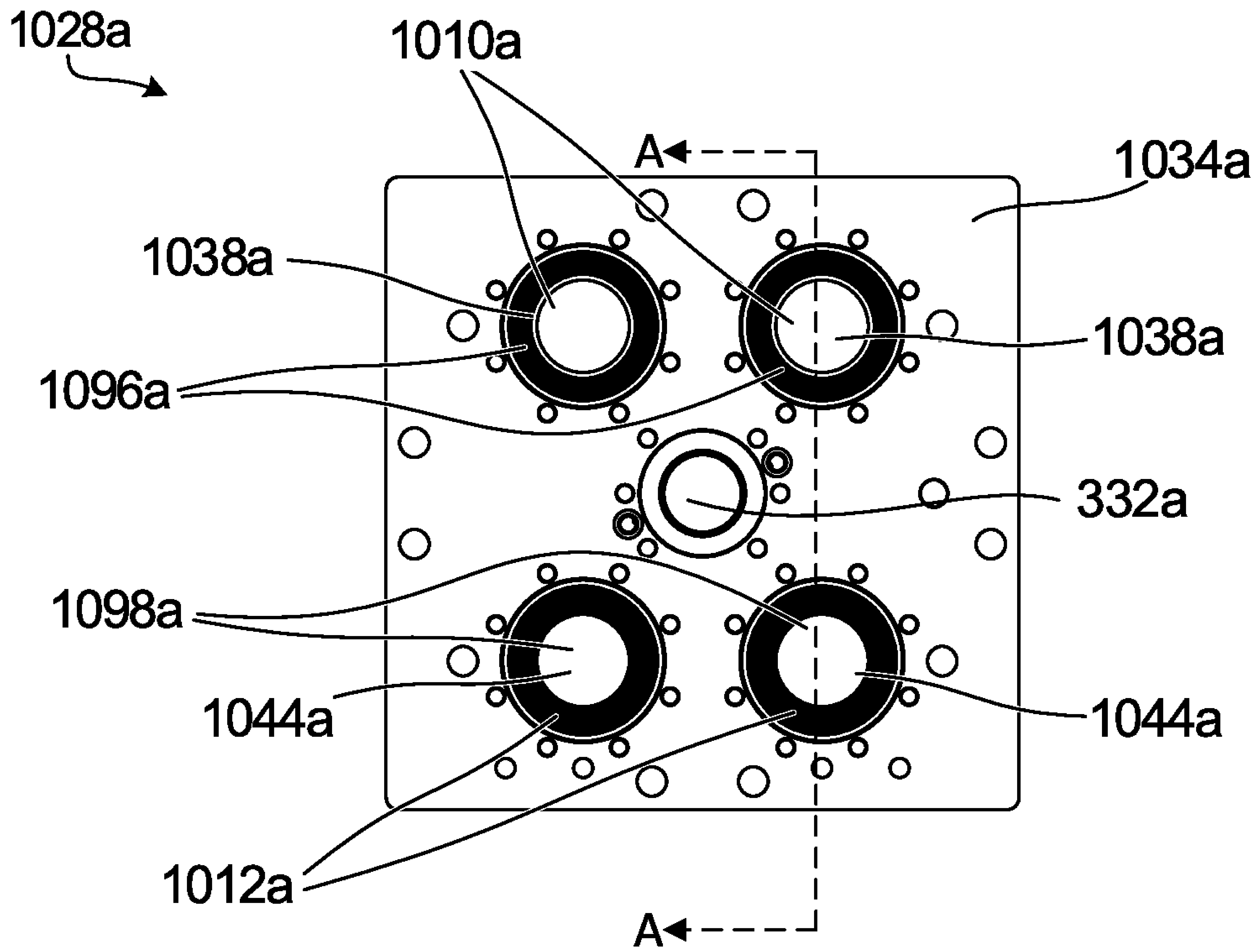


FIG. 12A

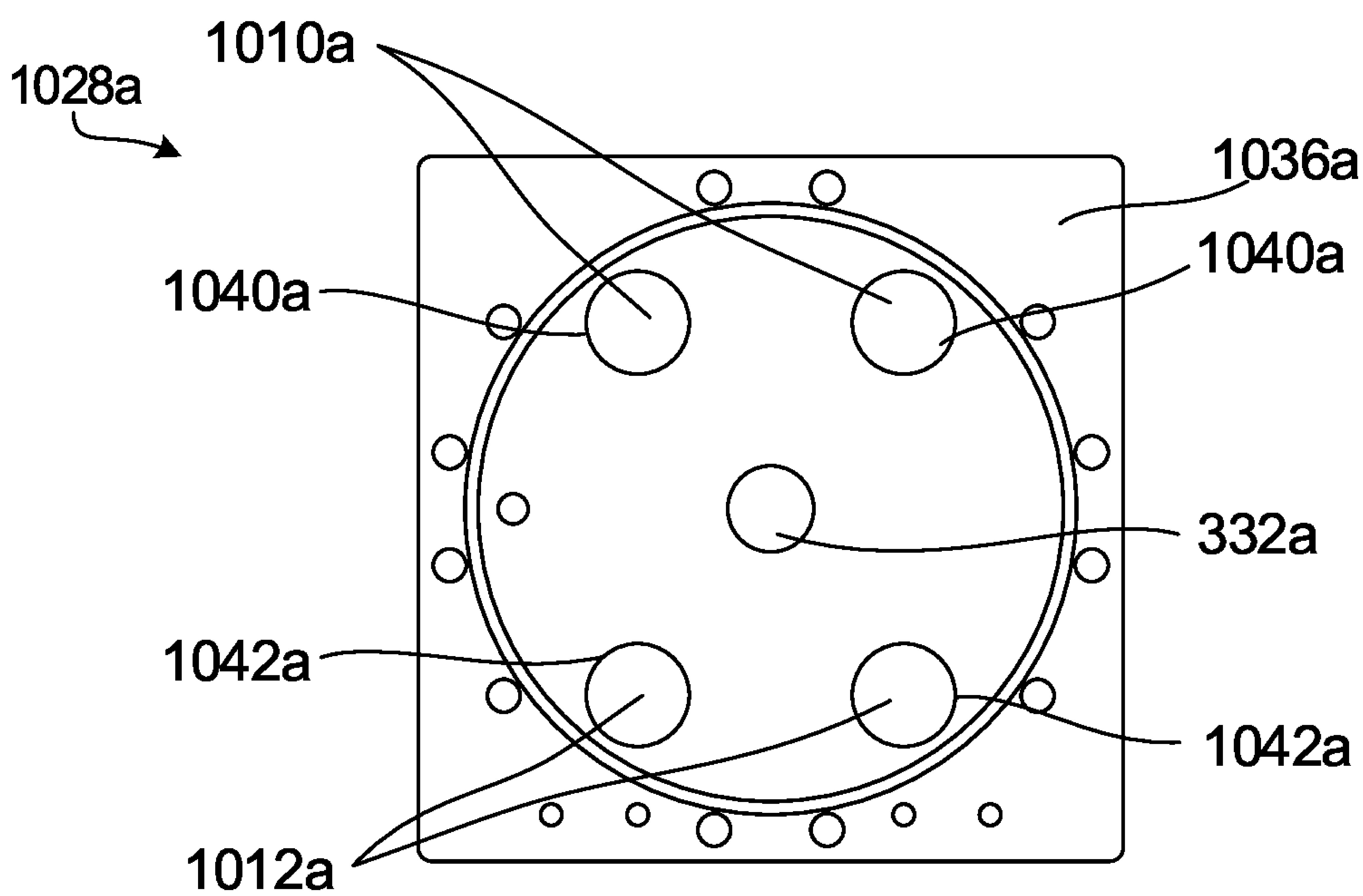
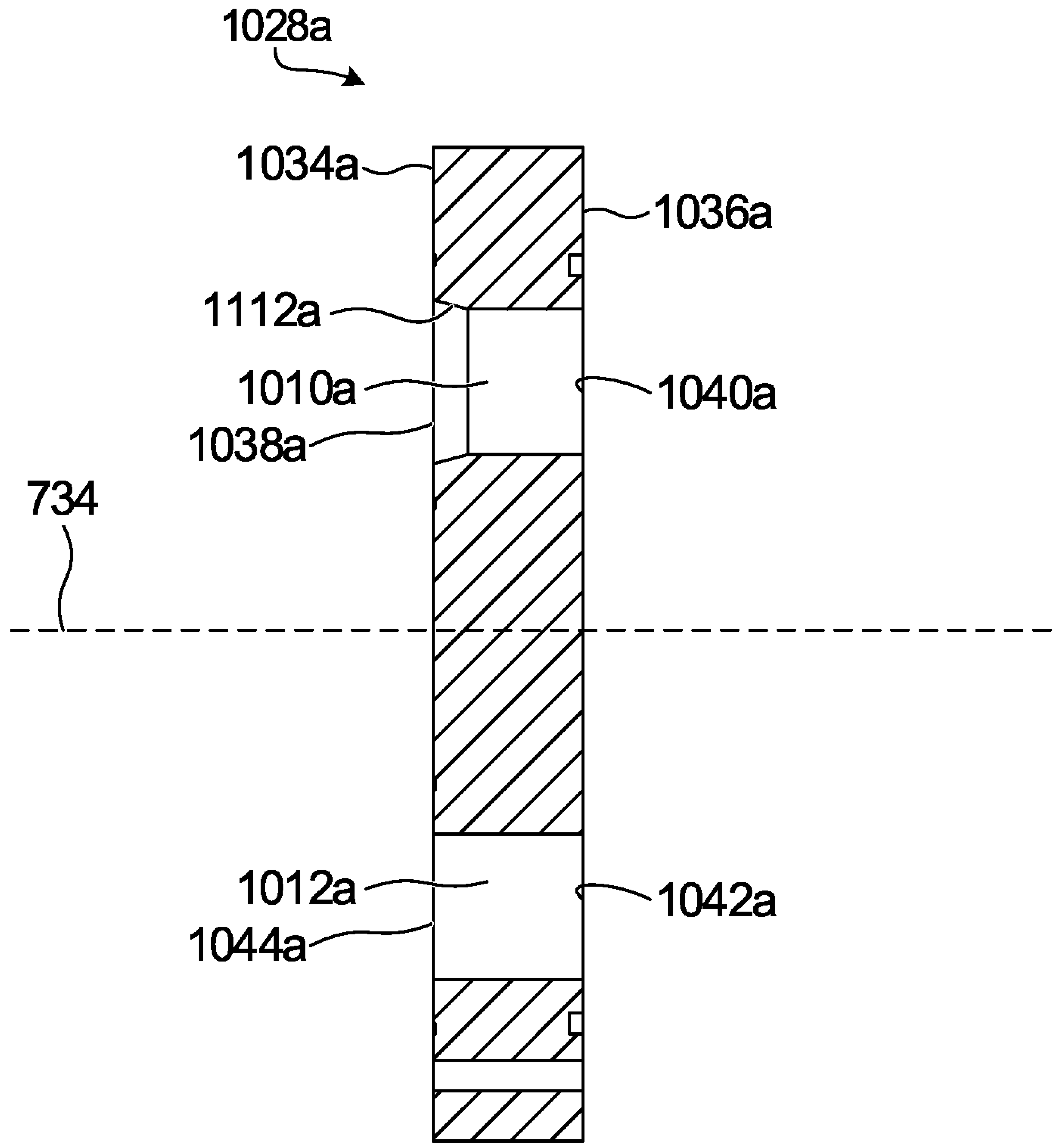


FIG. 12B


1028a
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1010a
1040a
1038a
734
1012a
1042a
1044a

FIG. 12C

COMPRESSER FOR PUMPING FLUID HAVING CHECK VALVES ALIGNED WITH FLUID PORTS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is a Continuation-in-part of U.S. patent application Ser. No. 17/982,291 filed on Nov. 7, 2022, which is a Continuation of U.S. patent application Ser. No. 17/483,452 filed on Sep. 23, 2021 (now U.S. Pat. No. 11,519,403 issued on Dec. 6, 2022), the entire contents of both applications being hereby incorporated by reference herein.

FIELD

[0002] The present disclosure relates generally to fluid compression or pumping devices and systems, and specifically to fluid compressors having fluid ports and check valves connected to the ports.

BACKGROUND

[0003] Fluid compressors are useful for pumping fluids. A fluid compressor typically has a fluid chamber and a pair of fluid ports serving as an inlet or outlet of the fluid chamber. Check valves may be connected to the fluid ports for controlling fluid flow through the inlet or outlet ports.

[0004] For example, United States patent publication no. US20210270257, published on Sep. 2, 2021, disclosed fluid compressors for pumping multiphase fluids. A representative view of a compressor **100** disclosed therein is shown in FIG. **1**. Compressor **100** includes a compression cylinder **102** having opposite ends **112***a*, **112***b*. The compression cylinder **100** has a double-acting compression piston for compressing a fluid towards one or the other of the two ends **112***a*, **112***b*. The compression piston is driven by two hydraulic cylinders each coupled to the compression cylinder at one of the ends **112***a*, **112***b* through a central port. Each end **112***a*, **112***b* also has two fluid ports **104***a*, **104***b* spaced from the central port, one of which is an inlet port and the other of which is an outlet port. The fluid to be pumped can flow in and out of compression cylinder **102** through ports **104***a* and ports **104***b*. Each port **104***a*, **104***b* is connected to a check valve **108***a*, **108***b* by an elbow connector **106***a*, **106***b*. The elbow connectors **106***a*, **106***b* are used and have sufficient size so that the check valves **108***a*, **108***b* are offset from the hydraulic cylinders at each end **112***a*, **112***b* of the compression cylinder **100**. The check valves **108***a*, **108***b* are connected by flanges and pipes to the fluid input source and the output destination. The check valves **108***a*, **108***b* are configured and oriented to control the fluid flow at the ports **104***a*, **104***b*.

[0005] It is desirable to improve the efficiency or performance of such fluid compressors.

SUMMARY

[0006] In an embodiment, the present disclosure relates to a compressor that comprises a first cylinder for compressing a fluid. The first cylinder comprises a chamber configured to receive the fluid, a piston reciprocally movable in the chamber for compressing the fluid towards a first end of the chamber, a centrally located opening at the first end of the chamber; and four ports at the first end of the chamber, comprising two inlet ports and two outlet ports. The compressor further comprises a plurality of check valves each associated with one of the four ports for controlling fluid flow through the ports, including two inlet check valves connected to the two inlet ports and two outlet check valves connected to the two outlet ports. The compressor further comprises a centrally located second cylinder at the first end of the chamber, the second cylinder connected and configured to drive movement of the piston in the first cylinder through the centrally located opening, an inlet conduit connected to each one of the inlet check valves to supply the fluid from a fluid source to the chamber through the inlet ports, an outlet conduit connected to each one of the outlet check valves for receiving fluid from the chamber through the outlet ports. Each of the four ports is slanted such that the plurality of check valves and inlet and outlet conduits are spaced apart from the second cylinder.

[0007] In some embodiments, each of the inlet and outlet conduits comprises a first end comprising a first flange and a plurality of second ends each comprising a second flange, each of the second flanges of the inlet conduit for connecting the respective second end to the inlet check valves and each of the second flanges of the outlet conduit for connecting the respective second end to the outlet check valves.

[0008] In some embodiments, each one of the four ports comprises a first end located proximal to the chamber and a second end located distal to the chamber. The first ends of each of the four ports are also located proximal to an edge of an internal side wall of the chamber. In some embodiments, the first ends of each of the four ports are oval. In some embodiments, the first ends of each of the four ports are circular. In some embodiments, the second ends of each one of the inlet ports comprise a chamfered edge.

[0009] In some embodiments, the first ends of the chamber comprises a head plate, and each one of the check valves is secured to the head plate.

[0010] In some embodiments, the fluid is a multiphase fluid comprising a solid material.

[0011] In another embodiment, the present disclosure relates to a compressor that comprises a compression chamber. The compression chamber comprises a tubular wall extending between first and second ends along a central axis and an end plate attached to each one of the first and second ends, the end plate comprising an inner surface, an external surface, and a central opening and a plurality of peripheral fluid ports extending from the inner surface to the external surface. Each one of the peripheral fluid ports comprises an inner opening at the inner surface and an outer opening at the external surface and is inclined with respect to the central axis such that the outer opening is farther away from the central axis than the inner opening. The compressor further comprises a piston movably housed in the compression chamber and a piston rod for driving the piston to move within the compression chamber, the piston rod connected to the piston through the central opening of the end plate and extending along the central axis.

[0012] In some embodiments, the end plate has a thickness of 4 inches, and the outer opening is farther away from the central axis than the inner opening by between about 0.5 and about 2 inches.

[0013] In some embodiments, the plurality of the peripheral fluid ports comprises four ports.

[0014] In some embodiments, the inner opening is located 0 to about ⅜ inch from the tubular wall.

[0015] In some embodiments, the inner opening is circumferentially elongated with respect to the central axis.

[0016] In some embodiments, the inner opening is smaller than the outer opening.

[0017] In some embodiments, the outer opening comprises a chamfered edge.

[0018] In some embodiments, the compressor comprises a plurality of valves each connected to one of the peripheral fluid ports. In some embodiments, the valves comprise check valves. In some embodiments, the compressor comprises a plurality of conduits connecting the valves to an input line and an output line respectively. In some embodiments, each one of the conduits comprises a flange connected to a corresponding one of the valves. The flange is spaced away from the piston rod due to inclination of the peripheral fluid port connected to the corresponding valve. The valves may comprise check valves each compressed between a corresponding one of the head plates and a corresponding one of the flanges.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019] In the figures, which illustrate example embodiments:

[0020] FIG. **1** is a front perspective view of a comparison compressor;

[0021] FIG. **2**A is a schematic cross-sectional view of a simplified compressor, according to an example embodiment;

[0022] FIG. **2**B is a schematic view of the compressor of FIG. **2**A in operation at a first state;

[0023] FIG. **2**C is a schematic view of the compressor of FIG. **2**A in operation at a second state;

[0024] FIG. **2**D is a schematic view of the compressor of FIG. **2**A in operation at a third state;

[0025] FIG. **2**E is a schematic view of the compressor of FIG. **2**A in operation at a fourth state;

[0026] FIG. **3**A is a line graph illustrating schematically the changes in the fluid volume and pressure between an end of the compression chamber and the piston during a piston stroke in the compressor of FIG. **2**A;

[0027] FIG. **3**B is a line graph illustrating schematically the changes in the fluid volume and pressure between another end of the compression chamber and the piston during a piston stroke in the compressor of FIG. **2**A;

[0028] FIG. **4** is a schematic cross-sectional view of a simplified compressor, according to another example embodiment;

[0029] FIG. **5**A is a cross-sectional rear perspective view of a compressor according to a further example embodiment;

[0030] FIGS. **5**B and **5**C are partially transparent, front perspective views of the compressor of FIG. **5**A;

[0031] FIG. **5**D is a partially transparent, rear perspective view of the compressor of FIG. **5**A;

[0032] FIGS. **5**E and **5**F are front perspective and top plan views of the compressor of FIG. **5**A;

[0033] FIG. **5**G is a partially transparent front view of the compressor of FIG. **5**A;

[0034] FIG. **5**H is a cross sectional end view of the compressor of FIG. **5**A, along the line A-A in FIG. **5**G;

[0035] FIG. **5**I is an end view of the compressor of FIG. **5**A;

[0036] FIG. **5**J is a cross-sectional rear perspective view of the compressor of FIG. **5**A, with some check valves in an open configuration;

[0037] FIG. **5**K is a cross-sectional rear perspective view of the compressor of FIG. **5**A, with some check valves in an open configuration;

[0038] FIG. **6**A is a partially transparent, cross-sectional rear perspective view of a compressor according to a further embodiment;

[0039] FIGS. **6**B and **6**C are front perspective views of the compressor of FIG. **6**A;

[0040] FIGS. **6**D and **6**E are top plan and front views of the compressor of FIG. **6**A;

[0041] FIG. **6**F is a cross sectional end view of the compressor of FIG. **6**A, along the line A-A in FIG. **6**E;

[0042] FIG. **6**G is an end view of the compressor of FIG. **6**A;

[0043] FIG. **7**A is a partially transparent, cross-sectional top perspective view of a compressor according to a further embodiment;

[0044] FIGS. **7**B and **7**C are front perspective views of the compressor of FIG. **7**A;

[0045] FIGS. **7**D and **7**E are top plan and front views of the compressor of FIG. **7**A;

[0046] FIG. **7**F is a cross sectional end view of the compressor of FIG. **7**A, along the line B-B in FIG. **7**E;

[0047] FIG. **7**G is an end view of the compressor of FIG. **7**A;

[0048] FIG. **8** is a schematic view of an oil and gas producing well system.

[0049] FIG. **9**A is a cross-sectional rear view of a compressor according to a further embodiment;

[0050] FIGS. **9**B and **9**C are partially transparent front perspective views of the compressor of FIG. **9**A;

[0051] FIG. **9**D is a partially transparent rear perspective view of the compressor of FIG. **9**A;

[0052] FIG. **9**E is front perspective view of the compressor of FIG. **9**A;

[0053] FIGS. **9**F and **9**G are top plan and front views of the compressor of FIG. **9**A;

[0054] FIG. **9**H is a cross sectional end view of the compressor of FIG. **9**A, along the line A-A in FIG. **9**G;

[0055] FIG. **9**I is an end view of the compressor of FIG. **9**A;

[0056] FIG. **9**J is a cross sectional end view of the compressor of FIG. **9**A, along the line B-B in FIG. **9**F;

[0057] FIG. **9**K is a partial cross-sectional front perspective view of the compressor of FIG. **9**A, along the line A-A in FIG. **9**F;

[0058] FIG. **9**L is a cross-sectional rear view of the compressor of FIG. **9**A along the line A-A in FIG. **9**F, with some check valves in an open configuration;

[0059] FIG. **9**M is a cross-sectional rear view of the compressor of FIG. **9**A along the line A-A in FIG. **9**F, with some check valves in an open configuration;

[0060] FIG. **10**A is a front view of the head plate of the compressor of FIG. **9**A;

[0061] FIG. **10**B is rear view of the head plate of FIG. **10**A;

[0062] FIG. **100** is a cross sectional end view of the head plate of FIG. **10**A, along the line A-A in FIG. **10**A;

[0063] FIG. **10**D is an enlarged view of a portion of FIG. **100**;

[0064] FIG. **10**E is an enlarged view of a portion of FIG. **10**D;

[0065] FIG. **11**A is a front view of a head plate according to a further embodiment;

[0066] FIG. **11**B is rear view of the head plate of FIG. **11**A;

[0067] FIG. **11**C is a cross sectional end view of the head plate of FIG. **11**A, along the line A-A in FIG. **11**A;

[0068] FIG. **11**D is an enlarged view of a portion of FIG. **11**C;

[0069] FIG. **11**E is an enlarged view of a portion of FIG. **11**D;

[0070] FIG. **12**A is a front view of a head plate according to a further embodiment;

[0071] FIG. **12**B is rear view of the head plate of FIG. **12**A; and

[0072] FIG. **12**C is a cross sectional end view of the head plate of FIG. **12**A, along the line A-A in FIG. **12**A.

DETAILED DESCRIPTION

[0073] It has been recognized that when the compression piston within the compression chamber of the compressor **100** as shown in FIG. **1** reaches an end of stroke position, a relatively large dead volume (or minimal chamber volume) still undesirably remains within the space between the piston face and the check valves **108***a* or **108***b*, particularly in the ports **104***a* or **104***b* and the elbow connectors **106***a* or **106***b*. This large dead volume leads to decreased pumping efficiency and performance. This problem would be exaggerated when the sizes of the elbow connectors **106***a*, **106***b* and the check valves **108***a*, **108***b* are increased to provide increased throughput or to pump certain liquids such as liquids produced from a well in oil and gas applications. It is thus desirable to provide a fluid compressor with reduced dead volume to increase the compression ratio of the compressor without reducing or limiting the pumping throughput.

[0074] The present inventor has discovered a number of solutions to address the above problem. First, connecting a check valve to an inlet/outlet port without an elbow connector therebetween can provide a straight, shortened fluid flow path between the port and the check valve, thus reducing the dead volume. The straight flow path will also improve the flow characteristics in the flow path, thereby increasing pumping efficiency.

[0075] As can be appreciated, when the elbow connector between the check valve and the port is eliminated or replaced with a straight connector, the check valve can be positioned closer to the port, reducing the path volume between the end of the piston and the check valve. This will beneficially reduce the dead volume (i.e., the volume of compressed fluid retained within the compressor at the end of each stroke) of the compressor. With a smaller dead volume, the compressor will be able to draw in, compress and expel a larger volume of liquid on each stroke, and provide a higher compression ratio on each stroke.

[0076] Due to the limited room at each end of the compression cylinder in the presence of the hydraulic cylinder coupled to the compression cylinder, the sizes of the inlet and outlet ports and the check valves are constrained, which in turn limits the fluid throughput. However, the present inventor realized that three or more fluid communication ports may be provided at each end of the compressor to increase the fluid throughput. For example, at least two of the end ports may be inlet ports, or at least two of the end ports may be outlet ports. In some embodiments, two inlet ports and two outlet ports may be provided at each end of the compressor. The multiple inlet or outlet ports can be sized and arranged so they are offset from the hydraulic cylinder at the same end.

[0077] Accordingly, an example embodiment herein relates to a compressor for receiving a fluid supply, compressing the fluid and then moving the fluid to another location. The fluid may be a gas, a liquid or a multiphase fluid that comprises 100% gas, 100% liquid, or any proportion of gas/liquid therebetween. The compressor may include a compression chamber configured to receive a fluid which is compressed towards a first end or a second end of the compression chamber by a piston that is reciprocally moveable along an axial direction. The first and second ends of the chamber may each include three or more ports for fluid communication. At least one first inlet port at the first end of the compression chamber and at least one second inlet port at the second end of the compression chamber are configured to allow fluid to enter the compression chamber. The compressor may also include at least one first outlet port at the first end of the compression chamber and at least one second outlet port at the second end of the compression chamber, both configured to allow fluid to exit the compression chamber. Movement of the piston may be driven by at least one second cylinder connected to the piston within the first cylinder. The compressor may also include a plurality of check valves, each connected to one of the inlet and outlet ports, inline with the respective port along the axial direction. The position and alignment of the check valves relative to their respective port reduces dead volume and provides a straight flow path for fluid in and out of the compression chamber.

[0078] In an embodiment the check valves are oriented to be aligned with the axial direction of movement of the piston within the compression chamber. In a further embodiment, the check valves are perpendicular to the axial direction of movement of the piston within the compression chamber.

[0079] In an embodiment, the compressor may have two first inlet ports at the first end of the compression chamber and two second inlet ports at the second end of the compression chamber. The compressor may also include two first outlet ports at the first end of the compression chamber and two second outlet ports at the second end of the compression chamber. These ports may advantageously increase space at each end of the compressor for additional components to be accommodated such as for example, different sizes of hydraulic cylinders to drive movement of the piston.

[0080] In an embodiment, a first compressor may be configured to be connected to a second compressor. The first compressor may compress a fluid to a first pressure P**1** and the second compressor may further compress the fluid to a second higher pressure P**2**.

[0081] The compressors may be configured to be operable to transfer multiphase mixtures of substances that comprise 100% gas, 100% liquid, or any proportion of gas/liquid therebetween, wherein during operation, the ratio of gas/liquid is changing, either intermittently, periodically, or substantially continuously. The compressors can also handle fluids that may also carry abrasive solid materials such as sand without damaging important components of the compressor system such as the surfaces of various cylinders and pistons.

[0082] An example compressor **200** is schematically illustrated in FIG. **2**A. As depicted, compressor **200** may include first cylinder **202** for compressing a fluid. First cylinder **202** may include tubular wall **226** with first and second end plates **228***a*, **228***b* at either end. The inner surface of tubular wall **226** and the inner surfaces of end plates **228***a*, **228***b* define compression chamber **204**, which has first end **205***a* and second end **205***b*. Piston **206** may be reciprocally moveable within compression chamber **204** in an axial direction towards first end **205***a* or second end **205***b* as indicated by the arrows in FIG. **2**A. Piston **206** divides compression chamber **204** into two adjacent first and second compression chamber sections **208***a*, **208***b*. At first end **205***a* of compression chamber **204** there may be two ports **210***a*, **212***a* configured to allow fluid to flow into and out of compression chamber section **208***a*. As shown in FIG. **2**A, ports **210***a*, **212***a* may be cylindrical linear channels extending from the outer vertical side to the inner vertical side of plate **228***a*. At second end **205***b* there may be two ports **210***b*, **212***b* configured to allow fluid to flow into and out of compression chamber section **208***b*. As shown in FIG. **2**A, ports **210***b*, **212***b* may be cylindrical linear channels extending from the outer vertical side to the inner vertical side of plate **228***b*. To each of ports **210***a*, **210***b*, **212***a*, **212***b*, respective check valves **216***a*, **216***b*, **218***a*, **218***b* may be connected. Check valves **216***a*, **216***b*, **218***a*, **218***b*, may be any suitable check valve, also known as a non-return valve, reflux valve, foot valve or one way valve, and are configured to move between an open configuration and a closed configuration. When in a closed configuration fluid flow is not permitted in either direction through the check valve. When in an open configuration, the check valves allow fluid to flow through in one direction only from an inlet side to an outlet side of the check valve. The check valve may switch from a closed configuration to an open configuration when the pressure is greater on the inlet side of the port than the outlet side, creating a pressure differential across the check valve. Once the pressure differential reaches a pre-determined value, known as the threshold pressure (also known as the cracking pressure), the check valves are configured to open, permitting fluid flow from the inlet side to the outlet side only. The check valves may be operable to be adjustable such that the threshold pressure that causes the check valve to open may be set at a desired value. The check valves are configured to switch from the open configuration back to the closed configuration, preventing fluid flow therethrough once the pressure differential drops to a lower pressure, known as the reseal pressure.

[0083] Check valves **216***a*, **216***b*, **218***a*, **218***b* may be any suitable type as is known in the art. For example, the check valves may be ball check valves, diaphragm check valves, swing check valves, lift check valves, in-line check valves or reed valves. In a specific embodiment, check valves **216***a*, **216***b*, **218***a*, **218***b* may be a threaded in-line check valve such as a 3" SCV Check Valve made by DFT Inc.

[0084] Check valves **216***a*, **216***b*, **218***a*, **218***b* may be connected to their respective ports **210***a*, **210***b*, **212***a*, **212***b* by any suitable method. For example, check valves **216***a*, **216***b*, **218***a*, **218***b* may have threaded fittings at either end configured to engage with corresponding threaded fittings at the outer end of ports **210***a*, **210***b*, **212***a*, **212***b*. In other embodiments, check valves **216***a*, **216***b*, **218***a*, **218***b* may be configured to be partially inserted into their respective ports **210***a*, **210***b*, **212***a*, **212***b* and secured by a suitable method such as welding.

[0085] The orientation of check valves **216***a*, **216***b*, **218***a*, **218***b* relative to ports **210***a*, **210***b*, **212***a*, **212***b* will determine if each port functions as an inlet port or an outlet port. As depicted in FIG. **2**A, check valves **216***a*, **216***b* may be oriented such that ports **210***a*, **210***b* operate as inlet ports to supply fluid to compression chamber **204**. This is achieved by connecting the outlet side of check valve **216***a* to the outer end of port **210***a* such that, when check valve **216***a* is in an open configuration, fluid is only permitted to flow into chamber section **208***a* through port **210***a*. Fluid is prevented from flowing out of chamber section **208***a* through check valve **216***a* at all times by the orientation of check valve **216***a*.

[0086] Similarly, the outlet side of check valve **216***b* may be connected to the outer end of port **210***b* such that, when check valve **216***b* is in an open configuration, fluid is only permitted to flow into chamber section **208***b* through port **210***b*. Fluid is prevented from flowing out of chamber section **208***b* through check valve **216***b* at all times by the orientation of check valve **216***b*.

[0087] Check valves **218***a*, **218***b* may be oriented such that ports **212***a*, **212***b* operate as outlet ports to remove fluid from compression chamber **204**. The inlet side of check valve **218***a* may be connected to the outer end of port **212***a* such that, when check valve **218***a* is in an open configuration, fluid is only permitted to flow from chamber section **208***a* through port **212***a*. Fluid is prevented from flowing into chamber section **208***a* through check valve **218***a* at all times by the orientation of check valve **218***a*.

[0088] Similarly, the inlet end of check valve **218***b* may be connected to the outer end of port **212***b* such that, when check valve **218***b* is in an open configuration, fluid is only permitted to flow from chamber section **208***b* through port **212***b*. Fluid is prevented from flowing into chamber section **208***b* through check valve **218***b* at all times.

[0089] A pair of inlet conduits **220***a*, **220***b* may be connected to respective check valves **216***a*, **216***b* to supply fluid from a fluid source and a pair of outlet conduits **222***a*, **222***b* may be connected to respective check valves **218***a*, **218***b*, to receive compressed fluid from check valves **218***a*, **218***b*. In the embodiment shown in FIG. **2**A, check valves **216***a*, **216***b*, **218***a*, **218***b* may be positioned inline with their respective ports **210***a*, **210***b*, **212***a*, **212***b* in the axial direction, which are in turn positioned inline with the axial direction of movement of piston **206**.

[0090] With reference to FIGS. **2**B to **2**E, piston **206** may reciprocally move between first end of stroke position **224***a* at first end **205***a* of compression chamber **204** (shown in FIG. **2**B) and second end of stroke position **224***b* at second end **205***b* of compression chamber **204** (shown in FIG. **2**D). FIGS. **3**A and **3**B depict the change in volume of compression chamber sections **208***a*, **208***b* with the position of piston **206**. With reference to FIG. **3**A, when piston **206** is at position **224***a*, the volume of first compression chamber **208***a* is at a minimum volume (also referred to as the dead volume) and increases to a maximum volume once piston **206** reaches second end of stroke position **224***b*. As piston **206** returns to first end of stroke position **224***a*, the volume of first compression chamber will decease back to the minimum volume.

[0091] Similarly, as shown in FIG. **3**B, the volume of second compression chamber **208***b* will increase from a minimum volume at the second end of stroke position **224***b* to a maximum volume at the first end of stroke position **224***a*.

[0092] As check valves **216***a*, **216***b*, **218***a*, **218***b* are positioned inline with their respective ports **210***a*, **210***b*, **212***a*, **212***b*, they may be positioned closer to their respective port. This will beneficially reduce the path volume between check valves **216***a*, **218***a* and piston **206** when piston **206** is first end of stroke position **224***a* and between check valves **216***b*, **218***b* and piston **206** when piston **206** is second end of stroke position **224***b*. As such, the dead volumes in the compressors shown in FIGS. **3**A and **3**B are less than that of the comparative compressor shown in FIG. **1**.

[0093] As will be explained below, as piston **206** reciprocates within compression chamber **204**, fluid may alternately enter, and exit each of the compression chamber sections **208***a*, **208***b*. Flow of fluid in and out of each compression chamber section **208***a*, **208***b* is controlled by the state of each of the check valves attached to the ports. One complete cycle of compressor **200** is illustrated in FIGS. **2**B to **2**D, with direction of fluid flow at each stage indicated. Piston **206** may start at first end of stroke position **224***a* shown in FIG. **2**B and move, via the intermediate position shown in FIG. **2**C to second stroke position **224***b* shown in FIG. **2**D. Piston **206** may then reverse direction from second end of stroke position **224***b* and return to first end of stroke position shown in FIG. **2**B, via the intermediate position shown in FIG. **2**E. The change in volume and representative examples for the variation in pressure of first and second compression chambers **208***a*, **208***b* are shown in FIGS. **3**A and **3**B respectively.

[0094] Turning first to FIG. **2**B, piston **206** is shown at first end of stroke position **224***a*. Check valves **216***a*, **216***b*, **218***a*, **218***b* are all closed such that fluid cannot flow into or out of first or second compression chamber sections **208***a*, **208***b*. Fluid will already be located in first and second compression chamber sections **208***a*, **208***b* having previously been drawn in during previous strokes.

[0095] As piston **206** moves in direction indicated by the arrow in FIG. **2**B, the pressure in first compression chamber section **208***a* will drop as the volume increases (as shown between (i) and (ii) of FIG. **3**A), causing a pressure differential to develop between the outer and inner sides of inlet check valve **216***a*. Once the differential pressure reaches the threshold pressure of valve **216***a*, valve **216***a* will open and fluid will flow from conduit **220***a* into first compression chamber section **208***a*, via inlet port **210***a* as shown in FIG. **2**C. Once valve **216***a* is open, the pressure within first compression chamber section **208***a* will remain generally constant until piston **206** reaches the second end of stroke position **224***b*, (as shown between (ii) and (iii) of FIG. **3**A). Once piston **206** reaches second end of stroke position **224***b* (FIG. **2**D), valve **216***a* will close when the pressure differential between the outer and inner sides of valve **216***a* drops and reaches the reseal pressure of valve **216***a*.

[0096] At the same time, movement of piston **206** decreases the volume of second compression chamber **208***b* and increases the pressure within chamber section **208***b* as the fluid within chamber section **208***b* is compressed (as shown between (vi) to (vii) of FIG. **3**B). This will cause a pressure differential to develop between the inner and outer side of outlet check valve **218***b*. Once the pressure differential reaches the threshold pressure of valve **218***b*, valve **218***b* will open and will flow out of second compression chamber section **208***b* and into conduit **222***b*, via outlet port **212***b*. Once valve **218***b* is open, the pressure within second compression chamber section **208***b* will remain generally constant (as shown between (vii) to (viii) of FIG. **3**B) until piston **206** reaches second end of stroke position **224***b*. Once piston **206** reaches second end of stroke position **224***b* (FIG. **2**D), valve **218***b* will close due to the pressure differential between the outer and inner sides of valve **218***b* dropping and reaching the reseal pressure of valve **218***b*.

[0097] Next, compressor **200** is configured for the return drive stroke. At second end of stroke position **224***b* shown in FIG. **2**D, all check valves will be closed and with reference to (iii) of FIG. **3**A, first compression chamber **208***a* will be at a maximum volume and contain fluid drawn in during the previous stroke. At the same time, with reference to (viii) of FIG. **3**B, second compression chamber **208***b* will have its minimum volume and contain a volume of pressurised fluid (i.e. fluid at a higher pressure than the fluid in first compression chamber **208***a*).

[0098] As piston **206** moves in the direction indicated by the arrow in FIG. **2**D, the pressure in second compression chamber section **208***b* will drop as the volume increases (as shown between (viii) and (ix) of FIG. **3**B), causing a pressure differential to develop between the outer and inner sides of inlet check valve **216***b*. Once the differential pressure reaches the threshold pressure of valve **216***b*, valve **216***b* will open and fluid will flow from conduit **220***b* into first compression chamber section **208***b*, via inlet port **210***b* (FIG. **2**E). Once valve **216***b* is open, the pressure within second compression chamber will remain generally constant until piston **206** reaches the first end of stroke position **224***a*, (as shown between (ix) and (x) of FIG. **3**B). Once piston **206** reaches first end of stroke position **224***a* (FIG. **2**B), valve **216***b* will close when the pressure differential between the outer and inner sides of valve **216***b* drops and reaches the reseal pressure of valve **216***b*.

[0099] At the same time, movement of piston **206** decreases the volume of first compression chamber **208***a* and increases the pressure in chamber section **208***a* as the fluid within is compressed (as shown between (iii) to (iv) of FIG. **3**A). This will cause a pressure differential to develop between the inner and outer side of outlet check valve **218***a*. Once the pressure differential reaches the threshold pressure of valve **218***a*, valve **218***a* will open and will flow out of first compression chamber section **208***a* and into conduit **222***a*, via outlet port **212***a*. Once valve **218***a* is open, the pressure within first compression chamber section **208***a* will remain generally constant (as shown between (iv) to (v) of FIG. **3**A) until piston **206** reaches first end of stroke position **224***a*. Once piston **206** reaches first end of stroke position **224***a* (FIG. **2**B), valve **218***a* will close due to the pressure differential between the outer and inner sides of valve **218***a* dropping, reaching the reseal pressure of valve **218***a*.

[0100] The foregoing movement and compression of fluid within compression chamber **204** will continue as piston **206** continues to move between the first and second end of stroke positions **224***a*, **224***b*.

[0101] Turning to FIG. **4**, an example compressor **200'** according to another embodiment is shown schematically. Compressor **200'** may be generally similar to compressor **200** as described above but in this embodiment, at either end of tubular wall **226** are first and second end plates **228***a*', **228***b*'. At first end **205***a* there may be two ports **210***a*', **212***a*' configured to allow fluid to flow into and out of first compression chamber section **208***a*. Ports **210***a*', **212***a*' may be cylindrical channels within plate **228***a*' extending from an outer side to an inner side of second end plate **228***a*'. Port **210***a*' may extend from the upper horizontal face to the inner vertical face of first end plate **228***a*'. Port **212***a*' may extend from the lower horizontal face to the inner vertical face of first end plate **228***a*'.

[0102] Similarly, at second end **205***b* there may be two ports **210***b*', **212***b*' configured to allow fluid to flow into and out of second compression chamber section **208***b*. Ports **210***b*', **212***b*' may be cylindrical channels within plate **228***b*' extending from an outer side to an inner side of second end plate **228***b*'. Port **210***b*' may extend from the upper horizontal face to the inner vertical face of first end plate **228***b*'. Port **212***b*' may extend from the lower vertical face to the inner vertical face of second end plate **228***b*'.

[0103] Similar to compressor **200**, to each of ports **210***a*', **210***b*', **212***a*', **212***b*' respective check valves **216***a*, **216***b*, **218***a*, **218***b* may be connected. As the outer ends of ports **210***a*', **212***a*' are on the respective upper and lower faces of first end plate **228***a*' and the outer ends of ports **210***b*', **212***b*' are on the respective upper and lower faces of second end plate **228***b*', check valves **216***a*, **216***b*, **218***a*, **218***b* are positioned perpendicular to the axial direction of movement of piston **206**.

[0104] As shown in FIG. **4**, ports **210***a*', **210***b*', **212***a*', **212***b*' extend vertically though the respective end plate, before turning at 90 degrees inwards. In other embodiments, ports **210***a*', **210***b*', **212***a*', **212***b*' may follow any other suitable path, such as a curved path.

[0105] FIGS. **5**A to **5**I illustrate a compressor **300**, which is an example embodiment of compressor **200**. Compressor **300** may include first cylinder **302** for compressing a fluid within compression chamber **304** having first end **305***a* and second end **305***b* (FIG. **5**A). First cylinder **302** may include cylinder barrel/tubular wall **326** positioned between first and second cylinder head plates **328***a*, **328***b* at respective first and second ends **305***a*, **305***b* of compression chamber **304**. First cylinder **302** may also include piston **306**, reciprocally moveable within compression chamber **304** in an axial direction towards first end **305***a* or second end **305***b*. Piston **306** may divide compression chamber **302** into two adjacent compression chamber sections **308***a* (FIG. **5**C), **308***b* (FIG. **5**B). First compression chamber section **308***a* may be defined by the interior surface of tubular wall **326**, a surface of piston **306** and the inner face **336***a* of first head plate **328***a* (FIG. **5**C). Second compression chamber section **308***b* may be formed on the opposite side of piston **306** to first compression chamber section **308***a* and may be defined by the interior surface of tubular wall **326**, a surface of piston **306** and the inner face **336***b* of second head plate **328***b* (FIG. **5**B).

[0106] Piston **306** may be reciprocally moveable within first cylinder **302** between a first end of stroke position **324***a* (FIGS. **5**A and **5**B) and second end of stroke position **324***b* (FIG. **5**C). The end of stroke positions may be a physical end of stroke positions whereby for a physical first end of stroke position, the surface of piston **306** will contact the inner face **336***a* of first head plate **328***a*. Likewise, for a physical second end of stroke position, the surface of piston **306** will contact the inner face **336***b* of second head plate **328***b*. More desirably, for example to reduce noise and wear on components of compressor **300** during operation, the end of stroke positions are pre-defined end of stroke positions selected such that when piston **306** is almost at the physical end of stroke position, but not yet in contact with first or second head plates **328***a*, **328***b*. For example, in an embodiment, a pre-defined end of stroke position may be 0.5" away from first or second head plates **328***a*, **328***b*.

[0107] Compressor **300** may also include first and second, one way acting, hydraulic cylinders **330***a*, **330***b* (FIG. **5**B) positioned at opposite ends of compressor **300**. Hydraulic cylinders **330***a*, **330***b* may each include a hydraulic piston therewithin, each connected to opposite ends of piston rod **307** and each configured to provide a driving force that acts in an opposite direction to each other, both acting inwardly towards each other and towards first cylinder **302**, thus driving reciprocal movement of piston **306**.

[0108] First cylinder **302** and hydraulic cylinders **330***a*, **330***b* may have generally circular cross-sections although alternately shaped cross sections are possible in some embodiments.

[0109] With reference to FIG. **5**C, first head plate **328***a* may have a generally square or rectangular shape with a pair of upper first inlet ports **310***a*, a pair of lower first outlet ports **312***a* and centrally located piston rod opening **332***a*. First inlet ports **310***a* and first outlet ports **312***a* may be circular openings that extend through first head plate **328***a* from outer face **334***a* to inner face **336***a* of first head plate **328***a*. Similarly, with reference to FIGS. **5**B and **5**H, second head plate **328***b* may have a generally square or rectangular shape with a pair of upper second inlet ports **310***b*, a pair of lower second outlet ports **312***b* and centrally located piston rod opening **332***b*. Second inlet ports **310***b* and second outlet ports **312***b* may be circular openings that extend through first head plate **328***b* from outer face **334***b* to inner face **336***b* of first head plate **328***b*.

[0110] First inlet ports **310***a* are configured to receive fluid at outer first end **338***a* and communicate fluid to inner second end **340***a* inside first chamber section **308***a* (FIG. **5**A). Similarly, second inlet ports **310***b* are configured to receive fluid at outer first end **338***b* and communicate fluid to an inner, second end **340***b* inside second chamber section **308***b* (FIG. **5**A).

[0111] First outlet ports **312***a* are configured to receive fluid from first chamber section **308***a* at inner first end **342***a* and communicate fluid to outer second end **344***a*. Similarly, second outlet ports **312***b* are configured to receive fluid from second chamber section **308***b* at inner first end **342***b* and communicate fluid to outer second end **344***b*.

[0112] Connected to each of first ends **338***a*, **338***b* of inlet ports **310***a*, **310***b* may be respective inlet check valves **316***a*, **316***b* configured to ensure that fluid may flow into compression chamber **304** from inlet ports **310***a*, **310***b* (i.e., fluid only travels from first ends **338***a*, **338***b* to second ends **340***a*, **340***b*). In some embodiments, inlet check valves **316***a*, **316***b* may be connected directly to first ends **338***a*, **338***b* of inlet ports **310***a*, **310***b*. In the embodiment shown in FIG. **5**A, short conduits **346***a*, sized to be partially received within first ends **338***a* of inlet ports **310***a*, may be disposed between inlet check valve **316***a* and first inlet ports **310***a* to facilitate connection of check valves **316***a*. Similarly, short conduits **346***b*, sized to be partially received within first ends **338***b* of inlet ports **310***b*, may be disposed between inlet check valve **316***b* and second inlet port **310***b* to facilitate connection of check valve **316***b*.

[0113] Similarly, connected to each of the second ends **344***a*, **344***b* of outlet ports **312***a*, **312***b* may be respective outlet check valves **318***a*, **318***b* configured to ensure that fluid may only flow from compression chamber **304** into outlet ports **312***a*, **312***b*, (i.e., fluid only travels in the direction from first ends **342***a*, **342***b* to second ends **344***a*, **344***b*). In some embodiments, outlet check valves **318***a*, **318***b* may be connected directly to second ends **344***a*, **344***b* of outlet ports **312***a*, **312***b*. In the embodiment shown in FIG. **5**A, short conduits **348***a*, sized to be partially received within second ends **344***a* of outlet ports **312***a*, may be disposed between outlet check valve **318***a* and first outlet port **312***a* to facilitate connection of check valve **318***a*. Similarly, short conduits **348***b*, sized to be partially received within second ends **344***b* of outlet ports **312***b*, may be disposed between outlet check valve **318***b* and second outlet port **312***b* to facilitate connection of check valve **318***b*.

[0114] Connections between ports **310***a*, **310***b*, **312***a*, **312***b*, conduits **346***a*, **346***b*, **348***a*, **348** and check valves **316***a*, **316***b*, **318***a*, **318***b* may be facilitated by any suitable method, such as welding or by providing complementary threaded ends between adjoining components.

[0115] In operation, compressor **300** may operate in a similar manner to as previously described for compressor **200**. Similar to as described above for compressor **200**, check valves **316***a*, **316***b*, **318***a*, **318***b* are operable to move between open and closed configurations depending on the pressure differential across each check valve. When in a closed configuration, fluid is not permitted to flow in either direction through the check valve. When in an open configuration, fluid is permitted to flow in one direction only through the check valve. As shown in FIG. **2**A, check valves **316***a*, **316***b*, **318***a*, **318***b* are all in a closed configuration and fluid may not enter or leave compression chamber **304**.

[0116] With reference to FIG. **5**J, inlet check valve **316***a* and outlet check valve **318***b* are shown in the open configuration. This configuration is similar to as shown in FIG. **2**C for compressor **200** and may occur when piston **306** is moving from first end of stroke position **324***a* to second end of stroke position **324***b* and the pressure differential across check valves **316***a*, **318***b* has reached the threshold pressure of the valves. With inlet check valves **316***a* in an open configuration, fluid can flow as indicated through secondary conduits **360***a*, inlet check valve connectors **364***a*, inlet check valves **316***a*, conduits **346***a* and into first compression chamber section **308***a* through first inlet ports **310***a*. With outlet check valves **318***b* in an open configuration, fluid can flow as indicated from second compression chamber section **308***b*, through second outlet ports **312***b*, conduits **348***b*, outlet check valves **318***b*, and into outlet check valve connectors **378***b*.

[0117] With reference to FIG. **5**K, inlet check valve **316***b* and outlet check valve **318***a* are shown in the open configuration. This configuration is similar to as shown in FIG. **2**E for compressor **200** and may occur when piston **306** is moving from second end of stroke position **324***b* to first end of stroke position **324***a* and the pressure differential across check valves **316***b*, **318***a* has reached the threshold pressure of the valves. With inlet check valves **316***b* in an open configuration, fluid can flow as indicated through secondary conduits **360***b*, inlet check valve connectors **364***b*, inlet check valves **316***b*, conduits **346***b* and into second compression chamber section **308***b* through first inlet ports **310***b*. With outlet check valves **318***a* in an open configuration, fluid can flow as indicated from first compression chamber section **308***a*, through first outlet ports **312***a*, conduits **348***a*, outlet check valves **318***a*, and into outlet check valve connectors **378***a*.

[0118] By providing multiple, smaller inlet and outlet ports on each of first and second head plates **328***a*, **328***b* (and corresponding smaller check valves and connectors) as opposed to single larger ports on each head plate, larger hydraulic cylinders may be used with compressor **300**, which may be desirable in some applications such as when compressing a fluid with a high proportion of liquid.

[0119] With reference to FIGS. **5**B-D in particular, the fluid communication system is shown, which provides fluid to compressor **300** to be compressed within compression chamber **304**, may include suction intake manifold **350** and pressure discharge manifold **352**.

[0120] On the fluid intake side of compressor **300**, suction intake manifold **350** may have two manifold outlets **351***a* and **351***b* and a single manifold inlet **351***c*. A flange associated with outlet **351***a* is connected to first flange **354***a* of inlet connector **356***a*. Inlet connector **356***a* may include primary conduit **358***a*, which may have the same interior channel diameter as manifold **350**, and a pair of smaller, spaced apart secondary conduits **360***a* extending orthogonally from primary conduit **358***a* (FIG. **5**B). Flanges **361***a* associated with secondary conduits **360***a* are each connected to flanges **365***a* associated with inlet check valve connectors **364***a* which are in turn configured to connect to input check valves **316***a*. As such, inlet connector **356***a* and inlet check valve connectors **364***a* may provide fluid communication from outlet **351***a* of suction intake manifold **350** to inlet check valves **316***a*.

[0121] Similarly, a flange associated with outlet **351***b* is connected to first flange **354***b* of inlet connector **356***b*. Inlet connector **356***b* may include a primary conduit **358***b*, which may have the same interior channel diameter as manifold **350**, and a pair of smaller, spaced apart secondary conduits **360***b* extending orthogonally from primary conduit **358***b* (FIGS. **5**B, **5**D). Flanges **361***b* associated with secondary conduits **360***b* are connected to flanges **365***b* associated with check valve connectors **364***b*, configured to connect to input check valves **316***b*. As such, inlet connector **356***b* and inlet check valve connectors **364***b* may provide fluid communication from outlet **351***b* of suction intake manifold **350** to inlet check valves **316***b*.

[0122] With reference to FIG. **5**C, on the fluid pressure discharge side of compressor **300**, pressure discharge manifold **352** may have two manifold inlets **353***a* and **353***b* and a single manifold outlet **353***c*. A flange associated with inlet **353***a* is connected to first flange **368***a* of outlet connector **370***a*. Outlet connector **370***a* may include primary conduit **372***a*, which may have the same interior channel diameter as manifold **352** and a pair of smaller, spaced apart secondary conduits **374***a* extending orthogonally from primary conduit **372***a*. Flanges **375***a* associated with secondary conduits **374***a* are connected to flanges **379***a* associated with outlet check valve connectors **378***a*, which are configured to connect to outlet check valves **318***a*. As such, outlet connector **370***a* and outlet check valve connectors **378***a* may provide fluid communication from outlet check valves **318***a* to manifold inlet **353***a* of pressure discharge manifold **352**.

[0123] Similarly, a flange associated with inlet **353***b* is connected to a first flange **368***b* of outlet connector **370***b*. Outlet connector **370***a* may include a primary conduit **372***b*, which may have the same interior channel diameter as manifold **352** and a pair of smaller, spaced apart secondary conduits **374***b* extending orthogonally from primary conduit **372***b*. Flanges **375***b* associated with secondary conduits **374***b* are connected to flanges **379***b* associated with outlet check valve connectors **378***b*, which are configured to connect to outlet check valves **318***b*. As such, outlet connector **370***b* and outlet check valve connectors **378***b* may provide fluid communication from outlet check valves **318***b* to manifold inlet **353***b* of pressure discharge manifold **352**.

[0124] Inlet connector **356***a* may also include second flange **382***a* at the opposite end of conduit **358***a* to first flange **354***a* and inlet connector **356***b* may also include second flange **382***b* at the opposite end of conduit **358***b* to first flange **354***b* (FIG. **5**B). Blanking plates **384***a*, **384***b* may be secured to second flanges **382***a*, **382***b* respectively.

[0125] Outlet connector **370***a* may also include second flange **386***a* at the opposite end of conduit **372***a* to first flange **368***a* and outlet connector **370***b* may also include a second flange **386***b* at the opposite end of conduit **372***b* to first flange **368***b* (FIG. **5**C). Blanking plates **388***a*, **388***b* may be secured to second flanges **386***a*, **388***b* respectively.

[0126] Second flanges **382***a*, **382***b*, **386***a*, **386***b*, may be operable to facilitate connections between multiple compressors, a representative example of which will be discussed later.

[0127] The manifolds, conduits and connectors described above may be sized dependent upon the required output/discharge pressures and output flow rates to be produced by compressor **300** and may be sized in order to achieve a desired maximum required flow velocity through compressor **300**. In an embodiment the maximum flow velocity is 23 feet per second. For example, in some embodiments, suction intake manifold **350**, pressure discharge manifold **352** and primary conduits **358***a*, **358***b*, **372***a*, **372***b* may all have approximately the same interior channel diameter, such as in the range of 4-6 inches or even greater. Secondary conduits **360***a*, **360***b*, **374***a*, **374***b*, check valve connectors **364***a*, **364***b*, **378***a*, **378***b* and conduits **346***a*, **346***b*, **348***a*, **346***b* may all have approximately the same interior channel diameter, such as in the range of 2-4 inches or even greater. Connections between the manifolds, check valves and conduits described above may be secured by any suitable method, such as by welding or by using threaded connections.

[0128] As shown in FIGS. **5**A to **5**I, compressor **300** is configured with inlet ports **310***a*, **310***b* at the top and outlet ports **312***a*, **312***b* at the bottom of cylinder heads **328***a*, **328***b*. This configuration may be beneficial, for example when compressor **300** is handling a fluid that contains a significant proportion of solids and/or debris which will migrate to the bottom of compression chamber **304** due to gravity and will be pumped out of chamber **304** during reciprocal movement of piston **306**. This may increase the reliability of compressor **300** as the accumulation of solids and/or debris within compression chamber **304** is reduced.

[0129] However, the configuration of inlet and outlet ports may be selected according to the particular application of compressor **300** and may depend on a number of factors such as the desired inlet (suction) pressure, outlet pressure, gas and liquid volume fraction of the fluid and the proportion of solids and other debris in the fluid.

[0130] In other embodiments, the upper two ports on each of cylinder heads **328***a*, **328***b* may be outlet ports whilst the lower two ports may be inlet ports. This configuration may be beneficial, for example, when handling a fluid with a higher gas volume fraction and when a lower inlet pressure is desired.

[0131] Compressor **300** may be in hydraulic fluid communication with a hydraulic fluid supply system which may provide an open loop or closed loop hydraulic fluid supply circuit. The hydraulic fluid supply system may be configured to supply a driving fluid to drive the hydraulic pistons in hydraulic cylinders **330***a*, **330***b*.

[0132] Compressor **300** may also include a controller to control the operation of compressor **300**, such as by changing the operational mode of the hydraulic fluid supply system. The control system may include a number of sensors such as proximity sensors in order to detect the position of components such as piston **306** within first cylinder **302** or pistons within hydraulic cylinders **330***a*, **330***b* in order to determine when piston **306** is approaching or has reached either of the end of stroke positions **324***a*, **324***b*. The controller may use information from the sensors to control the hydraulic fluid system in order to control and adjust the reversal of piston **306** in either direction. Examples of hydraulic cylinders, hydraulic fluid supply system and a control system suitable for use with compressor **300** are disclosed in U.S. Pat. No. 10,544,783, and US 20210270257, the entire contents of each of which are incorporated herein by reference.

[0133] Turning to FIGS. **6**A to **6**G, another embodiment of a compressor **400** is shown, which is an example embodiment of the compressor **200'** shown in FIG. **4**. First cylinder **302** of compressor **400** may include cylinder barrel/tubular wall **326** positioned between first and second cylinder head plates **428***a*, **428***b* at respective first and second ends **305***a*, **305***b* of compression chamber **304**. First head plate **428***a* may have a generally square or rectangular shape with a pair of upper first inlet ports **410***a*, a pair of lower first outlet ports **412***a* and a centrally located piston rod opening **432***a* (not shown). As shown in FIG. **6**A, first inlet ports **410***a* may extend within first head plate **428***a* in a downwards direction from first ends **438***a* in top face **435***a* before turning at 90 degrees inwards to second ends **440***a* in inner face **436***a* of first head plate **428***a*. First outlet ports **412***a* may extend in an outwards direction from first ends **442***a* in inner face **436***a* of first head plate **428***a* before turning at 90 degrees downwards to second ends **444***a* in bottom face **437***a* of first head plate **428***a*.

[0134] Similarly, second head plate **428***b* may have a generally square or rectangular shape with a pair of upper second inlet ports **410***b*, a pair of lower second outlet ports **412***b* and a centrally located piston rod opening **432***b* (FIG. **6**F). Second inlet ports **410***b* may extend within second head plate **428***b* in a downwards direction from first ends **438***b* in top face **435***b* before turning at 90 degrees inwards to second ends **440***b* in inner face **436***a* of second head plate **428***a*. Second outlet ports **412***a* may extend in an outwards direction from first ends **442***b* in inner face **436***a* of second head plate **428***b* before turning at 90 degrees downwards to second ends **444***b* in bottom face **437***b* of second head plate **428***b*.

[0135] Connected to each of the first ends **438***a*, **438***b* of inlet ports **410***a*, **410***b* may be respective inlet check valves **316***a*, **316***b* configured to ensure that fluid may flow into compression chamber **304** from inlet ports **410***a*, **410***b* (i.e., fluid only travels in the direction from first ends **438***a*, **438***b* to second ends **440***a*, **440***b* of inlet ports **410***a*, **410***b*). In some embodiments, inlet check valves **316**_a_, **316**_b_ may be connected directly to first ends **438**_a_, **438**_b_ of inlet ports **410**_a_, **410**_b_. In the embodiment shown in FIG. **6**A, short conduits **346**_a_, sized to be partially received within first ends **438**_a_ of inlet ports **410**_a_, may be disposed between inlet check valves **316**_a_ and first inlet ports **410**_a_. Similarly, short conduits **346**_b_, sized to be partially received within first ends **438**_b_ of inlet ports **410**_b_, may be disposed between inlet check valves **316**_b_ and second inlet ports **410**_b_.

[0136] Similarly, connected to each of the second ends **444**_a_, **444**_b_ of outlet ports **412**_a_, **412**_b_ may be respective outlet check valves **318**_a_, **318**_b_ configured to ensure that fluid may flow into outlet ports **412**_a_, **412**_b_, from compression chamber **304** (i.e., fluid only travels in the direction from first ends **442**_a_, **442**_b_ to second ends **444**_a_, **444**_b_ of outlet ports **412**_a_, **412**_b_). In some embodiments, outlet check valves **318**_a_, **318**_b_ may be connected directly to second ends **444**_a_, **444**_b_ of outlet ports **412**_a_, **412**_b_. In the embodiment shown in FIG. **6**A, short conduits **348**_a_, sized to be partially received within second ends **444**_a_ of outlet ports **412**_a_, may be disposed between outlet check valves **318**_a_ and first outlet ports **412**_a_. Similarly, short conduits **348**_b_, sized to be partially received within second ends **444**_b_ of outlet ports **412**_b_, may be disposed between outlet check valves **318**_b_ and second outlet ports **412**_b_.

[0137] Configuring compressor **400** such that the inlet and outlet ports are on the upper and lower faces of cylinder heads **428**_a_, **428**_b_ provides additional space on the outer faces **434**_a_, **434**_b_ of cylinder heads **428**_a_, **428**_b_. This may provide space for accommodating larger diameter hydraulic cylinders on compressor **400** as desired.

[0138] In other embodiments of compressor **400**, the upper ports on each of cylinder heads **428**_a_, **428**_b_ may be outlet ports whilst the lower ports may be inlet ports.

[0139] Referring to FIGS. **6**B to **6**E, the fluid communication system that provides fluid to compressor **400** may be generally similar to the fluid communication system of compressor **300**, but is sized to connect to the differently positioned check valves **316**_a_, **316**_b_, **318**_a_, **318**_b_ on compressor **400**. The fluid communication system may include suction intake manifold **450** and pressure discharge manifold **452**. Suction intake manifold **450** may have two manifold outlets **451**_a_ and **451**_b_ and a single manifold inlet **451**_c_. A flange associated with outlet **451**_a_ is connected to a first flange **354**_a_ of inlet connector **356**_a_, which is in turn connected to first inlet check valves **316**_a_ through inlet check valve connectors **364**_a_. A flange associated with outlet **451**_b_ is connected to a first flange of inlet connector **356**_b_ which is in turn connected to second inlet check valves **316**_b_ through check valve connectors **364**_b_.

[0140] On the fluid pressure discharge side of compressor **400**, pressure discharge manifold **452** may have two manifold inlets **453**_a_ and **453**_b_ and a single manifold outlet **453**_c_. A flange associated with inlet **453**_a_ is connected to first flange **368**_a_ of outlet connector **370**_a_ which is in turn connected to first outlet check valves **318**_a_ through outlet check valve connectors **378**_a_. A flange associated with inlet **453**_b_ is connected to a first flange **368**_b_ of outlet connector **370**_b_ which is in turn connected to second outlet check valves **318**_a_ through outlet check valve connectors **378**_b_.

[0141] Providing first and second inlet and first and second outlet ports through each of first and second head plates **428**_a_, **428**_b_ as opposed to a larger single inlet and single outlet port in each head plate may be desirable in order to reduce the thickness of head plates **428**_a_, **428**_b_. For example, the pair of first inlet ports **410**_a_ may each have a diameter of around 2 inches. In order to achieve a similar flow velocity of fluid, a single inlet port to replace ports **410**_a_ would be required to have a larger diameter, for example about 4 inches. This would undesirably significantly increase the thickness of head plate **428**_a_ in order to accommodate the larger port within, increasing the size, weight and cost (through the extra material required for the thicker cylinder head) of the compressor.

[0142] Turning to FIGS. **7**A to **7**G, another embodiment of a compressor **500** is shown, which is another example embodiment of compressor **200** shown in FIG. **2**A.

[0143] In comparison to compressor **300** described above, first head plate **528**_a_, whilst generally similar to first head plate **328**_a_, may be configured with a pair of first inlet ports **510**_a_ vertically spaced from each other on a first side of first head plate **528**_a_. Similar to first inlet ports **310**_a_, first inlet ports **510**_a_ may extend through first head plate **528**_a_ and are configured to receive fluid at an outer, first end **538**_a_ and communicate fluid to an inner, second end **540**_a_ inside first chamber section **308**_a_ (FIG. **7**A). First head plate **528**_a_ may also be configured with a pair of first outlet ports **512**_a_, vertically spaced from each other on the opposite side of first head plate **528**_a_ to first inlet ports **510**_a_. Similar to first outlet ports **312**_b_, first outlet ports **512**_b_ may extend through first head plate **528**_a_ and are configured to receive fluid at an inner, first end **542**_a_ inside first chamber section **308**_a_ and communicate fluid to an outer, second end **544**_a_.

[0144] Second head plate **528**_b_ may be generally similar to first head plate **328**_b_ and may be configured with a pair of second inlet ports **510**_b_ vertically spaced from each other on a first side of second head plate **528**_b_. Similar to second inlet ports **310**_b_, second inlet ports **510**_b_ may extend through second head plate **528**_b_ and are configured to receive fluid at an outer, first end **538**_b_ and communicate fluid to an inner, second end **540**_b_ inside second chamber section **308**_b_ (FIG. **7**A). Second head plate **528**_b_ may also be configured with a pair of first outlet ports **512**_b_, vertically spaced from each other on the opposite side of second head plate **528**_b_ to first inlet ports **510**_a_. Similar to second outlet ports **312**_b_, second outlet ports **512**_b_ may extend through second head plate **528**_b_ and are configured to receive fluid at an inner, first end **542**_b_ inside second chamber section **308**_b_ and communicate fluid to an outer, second end **544**_b_.

[0145] First and second inlet ports **510**_a_, **510**_b_ may be connected to suction intake manifold **350** in a similar manner to as described above for compressor **300** through inlet connectors **356**_a_, **356**_b_, inlet check valve connectors **364**_a_, **364**_b_ and inlet check valves **316**_a_, **316**_b_ for supplying fluid to compression chamber **304**, with inlet connectors **356**_a_, **356**_b_ and intake manifold **350** oriented to accommodate the different inlet port configuration of compressor **500**.

[0146] First and second outlet ports **512**_a_, **512**_b_ may be connected to pressure discharge manifold **352** in a similar manner to as described above for compressor **300** through outlet check valves **318**_a_, **318**_b_, outlet check valve connectors **378**_a_, **378**_b_ and outlet connectors **370**_a_, **370**_b_ for receiving fluid from compression chamber **304**, with outlet connectors **370**_a_, **370**_b_ and pressure discharge manifold **352** oriented to accommodate the different outlet port configuration of compressor **500**.

[0147] With reference to FIG. **8** an example oil and gas producing well system **1100** is illustrated, which utilises a compressor **1106**, which may be any compressors described above. Oil and gas producing well system **1100** is illustrated schematically and may be installed at, and in, a well shaft (also referred to as a well bore) **1108** and may be used for extracting liquid and/or gases (e.g., oil and/or natural gas) from an oil and gas bearing reservoir **1104**.

[0148] Extraction of liquids including oil as well as other liquids such as water from reservoir **1104** may be achieved by methods such as the use of a down-well pump, which operates to bring a volume of oil toward the surface to a well head **1102**. An example of a suitable down-well pump is disclosed in U.S. patent application Ser. No. 16/147,188, filed Sep. 28, 2018 (now U.S. Pat. No. 10,544,783, issued Jan. 28, 2020), the entire contents of which is hereby incorporated herein by reference.

[0149] Well shaft **1108** may have along its length, one or more generally hollow cylindrical tubular, concentrically positioned, well casings **1120***a*, **1120***b*, **1120***c*, including an inner-most production casing **1120***a* that may extend for substantially the entire length of the well shaft **1108**. Intermediate casing **1120***b* may extend concentrically outside of production casing **1120***a* for a substantial length of the well shaft **1108**, but not to the same depth as production casing **1120***a*. Surface casing **1120***c* may extend concentrically around both production casing **1120***a* and intermediate casing **1120***b*, but may only extend from proximate the surface of the ground level, down a relatively short distance of the well shaft **1108**.

[0150] Natural gas may exit well shaft **1108** into piping **1124** whilst liquid may exit well shaft **1108** through a well head **1102** to an oil flow line **1133**. Oil flow line **1133** may carry the liquid to piping **1124**, which in turn carries the combined gas and oil to inlet manifold **351***c* of compressor **1106**. Compressor **1106** may operate substantially as described above to compress gas and liquid supplied by piping **1124**. Compressed fluid that has been compressed by compressor **1106** may exit though outlet manifold **353***c* and flow via piping **1130** to interconnect to pipeline **1132**.

[0151] In another embodiment, a plurality of compressors may be connected in series in order to provide a pressure boost to a fluid. An advantage to this approach is that less energy is required to compress fluid, such as gas, in multiple stages.

[0152] In an example embodiment, a first compressor may be connected to a second compressor such that fluid flows through the first compressor to the second compressor. Fluid at a first pressure P**1** may have its pressure boosted to a second pressure P**2** (that is greater than P**1**) by the first compressor. Fluid may then flow to the second compressor, where the pressure of the fluid will be boosted to a third pressure P**3** (that is greater than P**2**).

[0153] The first and second compressors may be interconnected in a number of suitable configurations in order for fluid that has been compressed in compression chamber sections **308***a*, **308***b* of the first compressor to flow to the second compressor. For example, when the first and second compressors are both similar to compressor **300**, second flanges **386***a*, **386***b* (with blanking plates **388***a*, **388***b* removed) on the first compressor may be interconnected to manifold inlet **351***c* or second flanges **382***a*, **382***b* of the second compressor.

[0154] In one embodiment, the first and second compressors may have different specifications. For example, the second compressor may be configured to handle fluid at a higher pressure and have hydraulic cylinders and a piston with a larger diameter than the first compressor.

[0155] For example, in an embodiment, the first compressor may have an inlet pressure of 50 psi and an outlet pressure of 250 psi and the second compressor may have an inlet pressure of 250 psi and an outlet pressure of 500 psi.

[0156] The compressors may also be employed in other oilfield and other non-oilfield environments to transfer gas and multi-phase fluids efficiently and quietly.

[0157] Whilst the illustrated embodiments depict compressors with two inlet ports and two outlet ports on each cylinder head, other variations are contemplated with different numbers of inlet and/or outlet ports on each cylinder head.

[0158] Turning to FIGS. **9**A to **9**J, another embodiment of a compressor **600** is shown, which is another example embodiment of compressor **200** shown in FIG. **2**A.

[0159] Compressor **600** may include a first head plate (also known as an end plate) **628***a*, which may be generally similar to first head plate **328***a* and may have a generally square or rectangular shape and may be configured with a pair of first inlet ports **610***a* horizontally spaced from each other at an upper end of first head plate **628***a*. Similar to first inlet ports **310***a*, first inlet ports **610***a* may extend through first head plate **628***a* and are configured to receive fluid at an outer, first end **638***a* and communicate fluid to an inner, second end **640***a* inside first chamber section **308***a* (FIG. **9**A). First head plate **628***a* may also be configured with a pair of first outlet ports **612***a*, horizontally spaced from each other at the opposite end of first head plate **628***a* to first inlet ports **610***a*. Similar to first outlet ports **312***a*, first outlet ports **612***a* may extend through first head plate **628***a* and are configured to receive fluid at an inner, first end **642***a* inside first chamber section **308***a* and communicate fluid to an outer, second end **644***a*.

[0160] Second head plate (also known as an end plate) **628***b* may be generally similar to first head plate **328***b* and may be configured with a pair of second inlet ports **610***b* horizontally spaced from each other at an upper end of second head plate **628***b*. Similar to second inlet ports **310***b*, second inlet ports **610***b* may extend through second head plate **628***b* and are configured to receive fluid at an outer, first end **638***b* and communicate fluid to an inner, second end **640***b* inside second chamber section **308***b* (FIG. **9**A). Second head plate **628***b* may also be configured with a pair of first outlet ports **612***b*, horizontally spaced from each other at the opposite end of second head plate **628***b* to first inlet ports **610***b*. Similar to second outlet ports **312***b*, second outlet ports **612***b* may extend through second head plate **628***b* and are configured to receive fluid at an inner, first end **642***b* inside second chamber section **308***b* and communicate fluid to an outer, second end **644***b*.

[0161] Connected to each of first ends **638***a*, **638***b* of inlet ports **610***a*, **610***b* may be respective inlet check valves **616***a*, **616***b* configured to ensure that fluid may flow into compression chamber **304** from inlet ports **610***a*, **610***b* (i.e., fluid only travels from first ends **638***a*, **638***b* to second ends **640***a*, **640***b*). Inlet check valves **616***a*, **616***b* may be generally similar to inlet check valves **316***a*, **316***b* described above.

[0162] Similarly, connected to each of the second ends **644***a*, **644***b* of outlet ports **612***a*, **612***b* may be respective outlet check valves **618***a*, **618***b* configured to ensure that fluid may only flow from compression chamber **304** into outlet ports **612***a*, **612***b*, (i.e., fluid only travels in the direction from first ends **642***a*, **642***b* to second ends **644***a*, **644***b*). Outlet check valves **618***a*, **618***b* may be generally similar to outlet check valves **318***a*, **318***b* described above.

[0163] In a specific embodiment, check valves **616***a*, **616***b*, **618***a*, **618***b* may be 888VFD flange valves made by Flomatic Valves.

[0164] First and second inlet ports **610***a*, **610***b* may be connected to suction intake manifold **350** through inlet connectors **656***a*, **656***b* and inlet check valves **616***a*, **616***b* for supplying fluid to compression chamber **304**.

[0165] Check valves **616***a*, **616***b*, **618***a*, **618***b* may be directly connected to their respective port by any suitable method. As can be appreciated, by directly connecting each check valve to its respective port, the check valve is positioned closer to the port, reducing the path volume between the end of the piston and the check valve. This will beneficially reduce the dead volume (i.e., the volume of compressed fluid retained within the compressor at the end of each stroke) of the compressor. With a smaller dead volume, the compressor will be able to draw in, compress and expel a larger volume of liquid on each stroke, and provide a higher compression ratio on each stroke.

[0166] As can be appreciated, when the elbow connector between the check valve and the port is eliminated or replaced with a straight connector, the check valve can be positioned closer to the port, reducing the path volume between the end of the piston and the check valve. This will beneficially reduce the dead volume (i.e., the volume of compressed fluid retained within the compressor at the end of each stroke) of the compressor. With a smaller dead volume, the compressor will be able to draw in, compress and expel a larger volume of liquid on each stroke, and provide a higher compression ratio on each stroke.

[0167] With reference to FIG. **9**B, inlet connectors **656***a*, **656***b* may be generally similar to inlet connectors **356***a*, **356***b* described above. A flange associated with outlet **351***a* of suction intake manifold **350** is connected to first flange **654***a* of inlet connector **656***a*. Inlet connector **656***a* may include primary conduit **658***a*, which may have the same interior channel diameter as manifold **350**, and a pair of smaller, spaced apart secondary conduits **660***a* extending orthogonally from primary conduit **658***a* (FIG. **9**B). The opposite end of primary conduit **658***a* to first flange **654***a* may be sealed and/or welded closed. With reference to FIG. **9**K, flanges **661***a* associated with secondary conduits **660***a* are each attached and affixed to first head plate **628***a* with bolts **700***a* and nuts **704***a*. The bolts **700***a* are received and mounted in bolt openings **702***a* (see FIG. **10**A) in first head plate **628***a*. Each inlet check valve **616***a* is sandwiched and compressed between the head plate **628***a* and the corresponding flange **661***a*. In this manner, inlet check valves **616***a*, the gasket between first head plate **628***a* and each of the inlet check valves **616***a*, the gasket between each of the inlet check valves **616***a* and each of the flanges **661***a* are securely held together to provide a fluid tight seal. As such, inlet connector **656***a* may provide fluid communication from outlet **351***a* of suction intake manifold **350** to inlet check valves **616***a*.

[0168] Similarly, a flange associated with outlet **351***b* of suction intake manifold **350** is connected to first flange **654***b* of inlet connector **656***b*. Inlet connector **656***b* may include primary conduit **658***b*, which may have the same interior channel diameter as manifold **350**, and a pair of smaller, spaced apart secondary conduits **660***b* extending orthogonally from primary conduit **658***b* (FIG. **9**B). The opposite end of primary conduit **658***b* to first flange **654***b* may be sealed and/or welded closed. Flanges **661***b* associated with secondary conduits **660***b* are each attached and affixed to second head plate **628***b* with bolts **700***b* and nuts **704***b* (FIG. **9**F). The bolts **700***b* are received and mounted in bolt openings **702***b* (see FIG. **9**H) in second head plate **628***b*. Each inlet check valve **616***b* is sandwiched and compressed between the head plate **628***b* and the corresponding flange **661***b*. In this manner, inlet check valves **616***b*, the gasket between second head plate **628***b* and each of the inlet check valves **616***b*, the gasket between each of the inlet check valves **616***b* and each of the flanges **661***b* are securely held together to provide a fluid tight seal. As such, inlet connector **656***b* may provide fluid communication from outlet **351***b* of suction intake manifold **350** to inlet check valves **616***b*.

[0169] With reference to FIG. **9**C, on the fluid pressure discharge side of compressor **600**, first and second outlet ports **612***a*, **612***b* may be connected to pressure discharge manifold **352** through outlet connectors **670***a*, **670***b* and outlet check valves **618***a*, **618***b* for receiving fluid from compression chamber **304**.

[0170] Outlet connectors **670***a*, **670***b* may be generally similar to outlet connectors **370***a*, **370***b* described above. A flange associated with inlet **353***a* of pressure discharge manifold **352** is connected to first flange **668***a* of inlet connector **670***a*. Inlet connector **670***a* may include primary conduit **672***a*, which may have the same interior channel diameter as manifold **352**, and a pair of smaller, spaced apart secondary conduits **674***a* extending orthogonally from primary conduit **670***a* (FIG. **9**C). The opposite end of primary conduit **670***a* to first flange **668***a* may be sealed and/or welded closed. Flanges **675***a* associated with secondary conduits **674***a* are each attached and affixed to first head plate **628***a* with bolts **707***a* and nuts **711***a* (FIG. **9**K). The bolts **707***a* are received and mounted in bolt openings **708***a* (see FIG. **10**A) in first head plate **628***a*. Each outlet check valve **618***a* is sandwiched and compressed between the head plate **628***a* and the corresponding flange **675***a*. In this manner, outlet check valves **618***a*, the gasket between first head plate **628***a* and each of the outlet check valves **618***a*, the gasket between each of the outlet check valves **618***a* and each of the flanges **675***a* are securely held together to provide a fluid tight seal. As such, inlet connector **670***a* may provide fluid communication from outlet check valves **618***a* to inlet **353***a* of pressure discharge manifold **352**.

[0171] Similarly, a flange associated with outlet **353***b* of pressure discharge manifold **352** is connected to first flange **668***b* of inlet connector **670***b*. Inlet connector **670***b* may include primary conduit **672***b*, which may have the same interior channel diameter as manifold **352**, and a pair of smaller, spaced apart secondary conduits **674***b* extending orthogonally from primary conduit **670***b* (FIG. **9**C). The opposite end of primary conduit **670***b* to first flange **668***b* may be sealed and/or welded closed. Flanges **675***b* associated with secondary conduits **674***b* are each attached and affixed to second head plate **628***b* with bolts **707***b* and nuts **711***b* (FIG. **9**C). The bolts **707***b* are received and mounted in bolt openings **708***b* (see FIG. **9**H) in second head plate **628***b*. Each outlet check valve **618***b* is sandwiched and compressed between the head plate **628***b* and the corresponding flange **675***b*. In this manner, outlet check valves **618***b*, the gasket between second head plate **628***b* and each of the outlet check valves **618***b*, the gasket between each of the outlet check valves **618***b* and each of the flanges **675***b* are securely held together to provide a fluid tight seal. As such, outlet connector **670***b* may provide fluid communication from outlet check valves **618***b* to inlet **353***b* of pressure discharge manifold **352**.

[0172] In other embodiments, connections between ports **610***a*, **610***b*, **612***a*, **612***b*, check valves **616***a*, **616***b*, **618***a*, **618***b* and flanges **661***a*, **661***b*, **675***a*, **675***b* may be facilitated by any suitable method, such as welding.

[0173] First head plate **628***a* is shown in isolation in FIGS. **10**A-E. As shown in FIG. **10**A, at the outer face **634***a* of first head plate **628***a*, first inlet ports **610***a* may be generally circular (i.e., at their first ends **638***a*). Similarly, at outer face **634***a*, first outlet ports **612***a* may be generally circular (i.e., at their second ends **644***a*).

[0174] In order to provide a seal between each inlet or outlet port and first head plate **628***a*, gaskets may be positioned between first head plate **628***a*, each check valve **616***a*, **618***a* and each respective flange **661***a*, **675***a* to provide a seal between the respective ports, check valves and flanges. With reference to FIG. **9**K, gaskets **718***a* may be positioned between first inlet ports **610***a* and each of the inlet check valves **616***a* and gaskets **720***a* may be positioned between inlet check valves **616***a* and each of the flanges **661***a*. Similarly, gaskets **722***a* may be positioned between first outlet ports **612***a* and each of the outlet check valves **618***a* and gaskets **724***a* may be positioned between each of the outlet check valves **618***a* and each of the flanges **675***a*.

[0175] Similarly, gaskets **718***b* (not shown in FIGS.) may be positioned between second inlet ports **610***b* and each of the inlet check valves **616***b* and gaskets **720***b* (not shown in FIGS.) may be positioned between inlet check valves **616***b* and each of the flanges **661***b*. Similarly, gaskets **722***b* (not shown in FIGS.) may be positioned between second outlet ports **612***b* and each of the outlet check valves **618***b* and gaskets **724***b* (not shown in FIGS.) may be positioned between each of the outlet check valves **618***b* and each of the flanges **675***b*.

[0176] The peripheral area around first inlet ports **610***a* and first outlet ports **612***a* provides gasket contact surfaces **696***a*, **698***a* respectively (FIG. **10**A). Gasket contact surfaces **696***a*, **698***a* may generally have a complimentary size and shape to the respective gasket and may have a roughened surface such that an improved seal is formed between gasket contact surfaces **696***a*, **698***a* and gaskets **718***a*, **722***a*. In some embodiments, the gasket contact surfaces **696***a*, **698***a* comprise a continuous spiral groove (which is sometimes referred to as a phonographic groove). In some embodiments, the gasket contact surfaces **696***a*, **698***a* may have an arithmetic average roughness (Ra) between about 3.2 and about 12.5.

[0177] Similarly, as shown in FIG. **9**H, at the outer face **634***b* of second head plate **628***b*, second inlet ports **610***b* may be generally circular (i.e., at their first ends **638***b*). Similarly, at outer face **634***b*, second outlet ports **612***b* may be generally circular (i.e., at their second ends **644***b*). The peripheral area around second inlet ports **610***b* and second outlet ports **612***b* provides gasket contact surfaces **696***b*, **698***b* respectively, which may be similar to gasket contact surfaces **696***a*, **698***a* described above.

[0178] Each of check valves **616***a*, **616***b*, **618***a*, **618***b* may include an area of roughened surface (similar to gasket contact surfaces **696***a*, **698***a* described above) at a region of each end of the respective check valve where an end of the check valve contacts the respective gasket. The roughened surfaces may comprise a continuous spiral groove as described above.

[0179] Flanges **661***a*, **661***b* associated with secondary conduits **660***a*, **660***b* respectively may also include an area of roughened surface (similar to gasket contact surfaces **696***a*, **698***a* described above) such that an improved seal is formed with the gasket that is positioned between flanges **661***a*, **661***b* and their respective check valve. The roughened surfaces may comprise a continuous spiral groove as described above.

[0180] Similarly, flanges **675***a*, **675***b* associated with secondary conduits **674***a*, **674***b* respectively may also include an area of roughened surface (similar to gasket contact surfaces **696***a*, **698***a* described above) such that an improved seal is formed with the gasket that is positioned between flanges **675***a*, **675***b* and their respective check valve. The roughened surfaces may comprise a continuous spiral groove as described above.

[0181] In an embodiment, the gaskets **718***a*, **718***b*, **720***a*, **720***b*, **722***a*, **722***b*, **724***a*, **724***b* be ANSI (American National Standards Institute) 300 # stainless steel spiral wound gaskets

[0182] With reference to FIG. **10**B, inner face **636***a* of first head plate **628***a* is depicted. First head plate **628***a* may include a plurality of openings **690***a* (FIG. **10**B) therethrough in a generally circular arrangement for receiving a plurality of tie rods **692** (FIG. **9**C) therethrough. Similarly, second head plate **628***b* includes a plurality of openings **690***b* (FIG. **9**D) for receiving the opposite end of tie rods **692**. Tie rods **692** are secured by nuts and function to tie together the head plates **628***a* and **628***b* with gas cylinder barrel **326** (FIG. **9**E).

[0183] The inner face **636***a* of first head plate **628***a* may include a circular groove **694***a* for receiving and retaining an O-ring (not shown in FIGS.) to provide a seal between head plate **628***a* and gas cylinder barrel **326** at first end **305***a* of compression chamber **304**. Similarly, the inner face **636***b* of second head plate **628***b* may include a circular groove **694***b* (FIG. **9**D) for receiving and retaining an O-ring (not shown in FIGS.) to provide a seal between second head plate **628***b* and gas cylinder barrel **326** at second end **305***b* of compression chamber **304**.

[0184] As shown in FIG. **10**B, at the inner face **636***a* of first head plate **628***a*, first inlet ports **610***a* may be generally oval in shape (i.e., at their second ends **640***a*) with the long axis of the oval perpendicular to the radius of the compression chamber such that the second ends **640***a* of ports **610***a* are circumferentially elongated with respect to a central axis **730** of compressor **600** (FIG. **9**F). The second ends **640***a* may be positioned proximal to the internal side walls of compression chamber **304**, i.e., proximal to the inner surface of cylinder barrel/tubular wall **326**. Further, the outer edge of the port at the second ends **640***a*, i.e., edge **695***a* as shown in FIG. **10**A may be curved to generally follow the internal side walls of compression chamber **304**. This ensures that a larger portion of the ports may be placed as close as possible to the internal side walls of compression chamber **304**. The generally oval shape of first inlet ports **610***a* enables a constant cross sectional area of the port to be maintained across throughout the flow path of the port whilst allowing the port to define a flow path that is slanted (as will be explained in greater detail below).

[0185] In some embodiments the second ends may be between 0 and about ⅜ inch from the inner surface of cylinder barrel/tubular wall **326**.

[0186] In comparison, at the outer face **634***a* of first head plate **628***a*, first outlet ports **610***a* may be generally circular. As will be described below, the inner profile of first inlet ports **610***a* may be profiled to transition in shape whilst still maintaining optimal fluid flow through first inlet ports **610***a*. Similarly, at the inner face **636***a* of first head plate **628***a*, first outlet ports **612***a* may be generally oval in shape (i.e., at their first ends **642***a*) and the outer face **634***a* of first head plate **628***a*, first outlet ports **612***a* may be generally circular. First outlet ports **612***a* may be profiled in a similar manner to first inlet ports **610***a*.

[0187] With reference to FIGS. **9**H and **9**J, the second inlet and outlet ports **610***b*, **612***b* of second head plate **628***b* may be configured similarly to first inlet and outlet ports **610***a*, **612***a* of first head plate **628***a*.

[0188] The ends of the inlet ports and outlet ports on first and second head plates **628***a*, **628***b* may be offset such that each port defines a flow path that is slanted (or inclined) with respect to central axis **730** of compressor **600** (FIG. **100**). This means the first ends **638***a* of first inlet ports **610***a* will be positioned further from central axis **730** than the second ends **640***a*. Similarly, the second ends **644***a* of the first outlet ports **612***a* will be positioned radially further from central axis **730** than the first ends **642***a*.

[0189] Similarly, the first ends **638***b* of second inlet ports **610***b* may also be positioned further from central axis **730** than the second ends **640***b* and second ends **644***b* of the second outlet ports **612***b* may also be positioned further from central axis **730** than the first ends **642***b*.

[0190] For example, with reference to FIG. **100**, the midpoint of the first end **638***a* of first inlet port **610***a* may be spaced a distance D1 from central axis **730** and the midpoint of the second end **640***a* of first inlet port **610***a* may be spaced a distance D2 from central axis **730**, where the distance D**1** is greater than the distance D**2**. The same may be applicable for the other inlet and outlet ports of first and second head plates **628***a* and **628***b*.

[0191] In some embodiments, the openings of ports **610***a*, **610***b*, **612***a*, **612***b* at the outer faces **634***a*, **634***b* of head plates **628***a*, **628***b* are further away from central axis **730** than the openings of ports **610***a*, **610***b*, **612***a*, **612***b* at the inner faces **636***a*, **636***b* of head plates **628***a*, **628***b* by a distance of between about 0.5 and 2 inches.

[0192] As a result, the ends of the inlet ports and outlet ports on the outer faces **634***a*, **634***b* of first and second head plates **628***a*, **628***b* (and therefore the connected check valves) will be located a greater distance from the centre of each head plate (i.e. further from piston rod openings **332***a*, **332***b*). As such, the ports and each attached check valve are further offset from the hydraulic cylinder at each end of each head plate. This configuration may advantageously increases space at each end of the compressor for additional components to be accommodated. For example, compressor **600** may be able to accommodate a larger hydraulic cylinders without reducing or limiting the size of the inlet and outlet ports, which would limit the pumping throughput of compressor **600**.

[0193] In some embodiments, the compressor may be able to accommodate larger check valves, larger inlet/outlet conduits (and their associated flanges) and/or inlet or outlet ports having a larger internal diameter.

[0194] With reference to FIG. **100**, the extent to which the ends of inlet and outlet ports **610***a*, **612***a* are slanted/inclined may be sufficient such that first end **638***a* of first inlet port **610***a* and a portion of second end **644***a* of first outlet port **612***a* may extend beyond the circumference of compression chamber **304** (as defined by inner surface cylinder barrel/tubular wall **326** in FIG. **100**).

[0195] With reference to FIGS. **100** and **10**D, the internal profiles of first inlet and outlet ports **610***a*, **612***a* of first head plate **628***a* are depicted. Second inlet and outlet ports **610***b*, **612***b* of second head plate **628***b* may be configured with a similar profile as will be described below for first inlet and outlet ports **610***a*, **612***a*.

[0196] In order to achieve the desired slanted flowpath of first inlet and outlet ports **610***a*, **612***a*, the inner walls of the ports are angled, rather than perpendicular to outer face **634***a*/inner face **636***a* of first head plate **628***a*. An example of the angle of the inner walls of a first inlet port **610***a* is shown in FIG. **10**D, which may be similar to the profile of first outlet ports **612***a*.

[0197] The inner wall of first inlet port **610***a* may include a first portion **714***a* and a second, opposed portion **716***a*. As depicted in FIG. **10**D, the angles described below for first and second portions **714***a*, **714***b* represent the angle relative to the outer face **634***a* of first head plate (which is in turn perpendicular to central axis **730**). First portion **714***a*, located at a lower end of the inner wall of first inlet port **610***a*, may be angled relative to outer face **634***a* at an angle θ_1. In some embodiments the angle θ_1 as indicated in FIG. **10**D may be between about 80 degrees and about 100 degrees. In an embodiment the angle θ_1 is about 89 degrees. Second portion **716***a*, located at an upper end of the inner wall of first inlet port **610***a*, may be angled relative to outer face **634***a* at an angle θ_2. In some embodiments the angle θ_2 as indicated in FIG. **10**D may be between about 70 degrees and about 90 degrees. In an embodiment the angle θ_2 is about 78 degrees. First outlet ports **612***a* may be profiled in a similar manner to as described above for first inlet ports **610***a*.

[0198] The angle of the inner wall of first inlet port **610***a* between first portion **714***a* and second portion **716***a* may be varied to smoothly transition between the differing angles of first and second portions **714***a*, **716***a*.

[0199] The angles θ_1 and θ_2 may be selected from any angle to achieve the desired flowpath of first inlet ports **610***a* and to maximise fluid throughput through the ports.

[0200] First inlet ports **610***a* may have a generally constant cross sectional area from second end **640***a* to the first end **642***a*. For example, the cross sectional area of first inlet ports **610***a* may be between 11 and 13 in^2. In an embodiment the cross sectional area is 12.56 in^2. As shown in FIG. **10**D, due to the oval shape of ports **610***a* at second end **640***a* and the round shape at first end **638**, the diameter of first inlet ports **610***a* may gradually increase from second end **640***a* to the first end **642***a* in order to maintain the cross sectional area of the port. For example, the second end **640***a* of first ports **610***a* may have a diameter of between about 3 inches and about 7 inches whilst the first end **638***a* may have a diameter of between about 3 inches and about 5 inches. In an embodiment, the second end **640***a* of first ports **610***a* may have a diameter of about 5 inches. In an embodiment the first end **638***a* may have a diameter of about 4 inches.

[0201] Similarly, the diameter of first outlet ports **612***a* may gradually increase from the first end **642***a* to the second end **644***a*.

[0202] The first ends **638***a* of first inlet ports **610***a* may each include chamfered portions **712***a*, shown in greater detail in FIG. **10**E. In some embodiments the chamfer angle (θ_c), (which is the angle of the chamfered portions **912***a* of the inner wall relative to an axis perpendicular to outer face **634***a*, as indicated in FIG. **10**E) may be between about 20 degrees and about 40 degrees. In an embodiment the chamfer angle is about 30 degrees.

[0203] With reference to FIG. **9**K, the fluid flowpath through inlet check valve **616***a* and first inlet port **610***a* is indicated by arrows **726***a*. As depicted, fluid may flow through conduit **660***a* and, when the pressure differential across check valve **616***a* has reached the threshold pressure such that check valve **616***a* is an open configuration, fluid may flow through check valve **616***a* as indicated and into first inlet port **610***a* at first end **638***a*. Fluid may then flow through port **610***a* to second end **640***a* and into first compression chamber section **308***a*. As shown in FIG. **9**K, the internal diameter of check valve **616***a* at the inner end of check valve **616***a* (i.e., the end adjacent to first end **638***a* of first inlet port **610***a*) is larger than the diameter of first inlet port **610***a*. The larger internal diameter of check valve **616***a* combined with the chamfered portions **712***a* of first inlet ports **610***a* may improve the fluid flow (and therefore allow a higher flow rate) into inlet ports **610***a*, such as by providing a wider entry into inlet ports **610***a* and/or by reducing turbulent fluid flow around the second ends **640***a* of inlet ports **610***a*.

[0204] The fluid flowpath through outlet check valve **618***a* and first outlet port **612***a* is indicated by arrows **728***a*. As depicted, fluid may flow through from first compression chamber section **308***a* and through first outlet port **618***a* from first end **642***a* to second end **644***a*. When the pressure differential across check valve **618***a* has reached the threshold pressure such that check valve **618***a* is an open configuration, fluid may flow through check valve **618***a* as indicated and into conduit **674***a*. In comparison to first inlet ports **610***a*, outlet ports **612***a* may not include a chamfered portion at second end **644***a* and end **644***a* may thus have a relatively narrow internal diameter (when comparing first end **638***a* of port **610***a* with second end **644***a* of port **612***a*). However, a high flow rate may still be achieved through first outlet ports **612***a* and outlet check valves **616***a* due to the higher pressure of the fluid as a result of the compression of fluid within compression chamber **304** by piston **306**.

[0205] The placement and profile of first inlet and outlet ports **610***a*, **612***a* on first head plate **628***a* may be influenced by factors such as the internal diameter of compression chamber **304**, the size (diameter) of hydraulic barrel **330***a*, the size (diameters) of check valves **616***a*, **618***a* and the sizes of flanges **661***a*, **675***a*.

[0206] In operation, compressor **600** may operate in a similar manner to as previously described for compressor **200**. Similar to as described above for compressor **200**, check valves **616***a*, **616***b*, **618***a*, **618***b* are operable to move between open and closed configurations depending on the pressure differential across each check valve. When in a closed configuration, fluid is not permitted to flow in either direction through the check valve. When in an open configuration, fluid is permitted to flow in one direction only through the check valve. As shown in FIG. **9**A, check valves **616***a*, **616***b*, **618***a*, **618***b* are all in a closed configuration and fluid may not enter or leave compression chamber **304**.

[0207] With reference to FIG. **9**L, inlet check valve **616***a* and outlet check valve **618***b* are shown in the open configuration. This configuration is similar to as shown in FIG. **2**C for compressor **200** and may occur when piston **306** (note piston rod **307** is not shown in FIG. **9**L) is moving from first end of stroke position **324***a* to second end of stroke position **324***b* and the pressure differential across check valves **616***a*, **618***b* has reached the threshold pressure of the valves. With inlet check valves **616***a* in an open configuration, fluid can flow as indicated through secondary conduits **660***a*, inlet check valves **516***a*, and into first compression chamber section **308***a* through first inlet ports **610***a*. With outlet check valves **618***b* in an open configuration, fluid can flow as indicated from second compression chamber section **308***b*, through second outlet ports **612***b*, outlet check valves **518***b*, and into conduits **674***b*.

[0208] With reference to FIG. **9**M, inlet check valve **616***b* and outlet check valve **618***a* are shown in the open configuration. This configuration is similar to as shown in FIG. **2**E for compressor **200** and may occur when piston **306** (note piston rod **307** is not shown in FIG. **9**L) is moving from second end of stroke position **324***b* to first end of stroke position **324***a* and the pressure differential across check valves **616***b*, **618***a* has reached the threshold pressure of the valves. With inlet check valves **616***b* in an open configuration, fluid can flow as indicated through secondary conduits **660***b*, inlet check valves **616***b*, and into second compression chamber section **308***b* through first inlet ports **610***b*. With outlet check valves **618***a* in an open configuration, fluid can flow as indicated from first compression chamber section **308***a*, through first outlet ports **612***a*, outlet check valves **618***a*, and into conduits **674***a*.

[0209] Turning to FIGS. **11**A to **11**E, another embodiment of a first head plate **828***a* is shown, which is another example embodiment of head plate that may be used with a compressor, such as compressor **600**. When used with a compressor a second head plate **828***b* may also be used which may similarly configured to first head plate **828***a*.

[0210] First head plate **828***a* may be similar to first head plate **628***a* described above and may have a generally square or rectangular shape with a pair of first inlet ports **810***a* horizontally spaced from each other at an upper end of first head plate **828***a* and a pair of first outlet ports **812***a*, horizontally spaced from each other at the opposite end of first head plate **828***a* to first inlet ports **810***a*.

[0211] Similar to first inlet and outlet ports **610***a*, **612***a*, first inlet and outlet ports **810***a*, **812***b* are each configured to be connected to a check valve, such as inlet check valves **616***a* and outlet check valves **618***a* respectively.

[0212] With reference to FIG. **11**A, at the outer face **834***a* of first head plate **828***a*, first inlet ports **810***a* may be generally circular (i.e., at their first ends **838***a*). Similarly, at outer face **834***a*, first outlet ports **612***a* may be generally circular (i.e., at their second ends **844***a*).

[0213] Similar to first head plate **628***a*, the peripheral area around first inlet ports **610***a* and first outlet ports **612***a* provide gasket contact surfaces **896***a*, **898***a* respectively (FIG. **10**A) which may be similar to gasket contact surfaces **696***a*, **698***a* described above.

[0214] With reference to FIG. **11**B, inner face **836***a* of first head plate **828***a* is depicted. Similar to first head plate **628***a*, first head plate **828***a* may include a plurality of openings

890*a* therethrough in a generally circular arrangement for receiving a plurality of tie rods which perform a similar function to tie rods **692** described above for compressor **600**. First head plate **828***a* also includes a circular groove **894***a* for receiving and retaining an O-ring (not shown in FIGS.) to provide a seal between head plate **828***a* and a gas cylinder barrel.

[0215] As shown in FIG. **11**B, at the inner face **836***a* of first head plate **828***a*, first inlet ports **810***a* may be generally oval in shape (i.e., at their second ends **840***a*). At the outer face **834***a* of first head plate **628***a*, first outlet ports **812***a* may be generally oval in shape (i.e., at their first ends **842***a*).

[0216] With reference to FIGS. **11**C and **11**D, the internal profiles of first inlet and outlet ports **810***a*, **812***a* of first head plate **828***a* are depicted. Similar to first and second head plates **628***a*, **628***b*, the ends of the inlet ports and outlet ports on first head plate **628***a* may be offset such that each port defines a flow path that is slanted (or inclined) with respect to central axis **732** (FIG. **11**C) from the inner face **836***a* to the outer face **834***a* of first head plate **628***a*. This means the first ends **838***a* of first inlet ports **810***a* will be positioned further from central axis **732** than the second ends **840***a*. Similarly, the second ends **844***a* of the first outlet ports **812***a* will be positioned radially further from central axis **732** than the first ends **842***a*.

[0217] Similar to first inlet and outlet ports **610***a*, **612***a*, in order to achieve the inclined/slanted flow path of first inlet and outlet ports **810***a*, **812***a*, the inner walls of the ports are angled, rather than perpendicular to outer face **834***a*/inner face **836***a* of first head plate **828***a*. An example of the angle of the inner walls of a first inlet port **810***a* is shown in FIG. **11**D, which may also be similar to the profile to the first outlet ports **812***a*.

[0218] The inner wall of first inlet port **810***a* may include a first portion **914***a* and a second opposed portion **916***a*. First portion **914***a*, located at a lower end of the inner wall of first inlet port **810***a*, may be angled relative to outer face **834***a* at an angle θ_1. In some embodiments the angle θ_1, as indicated in FIG. **11**D may be between about 90 degrees and about 110 degrees. In an embodiment θ_1 is about 100 degrees.

[0219] Second portion **916***a*, located at an upper end of the inner wall of first inlet port **810***a*, may be angled relative to outer face **834***a* at an angle θ_2. In some embodiments the angle θ_2 as indicated in FIG. **11**D may be between about 55 degrees and about 75 degrees. In an embodiment θ_2 is about 66 degrees.

[0220] The angle of the inner wall of first inlet port **810***a* between first portion **914***a* and second portion **916***a* may be varied to smoothly transition between the differing angles of first and second portions **914***a*, **916***a*. The angles θ_1 and θ_2 may be selected from any angle to achieve the desired flowpath of first inlet ports **810***a* and to maximise fluid throughput through the ports.

[0221] With reference to FIG. **11**E, similar to first inlet ports **610***a* of first head plate **628***a*, the first ends **838***a* of first inlet ports **810***a* may each include chamfered portions **912***a*. In some embodiments the chamfer angle (θ_c), (which is the angle of the chamfered portions **912***a* of the inner wall relative to an axis perpendicular to outer face **834***a*, as indicated in FIG. **11**E) may be between about 35 degrees and about 55 degrees. In an embodiment the chamfer angle is about 45 degrees. The chamfer angle may be selected, for example, based on the specific type/configuration of check valve that is attached to the port.

[0222] In some embodiments, outlet ports **812***a* may also have a chamfered portion similar to chamfered portion **912***a* at first end **842***a*.

[0223] When first head plate **828***a* is incorporated into a compressor, in comparison to first inlet and outlet ports **610***a* **612***a* of first head plate **628***a*, due to the greater value for angle θ_1 and smaller value for angle θ_2, the first end **838***a* of inlet port **810***a* and second end **844***a* of first outlet port **812** may extend a greater distance beyond the circumference of compression chamber **304** (as defined by inner surface cylinder barrel/tubular wall **326** indicated FIG. **11**C). This arrangement may provide additional space in the vicinity around piston rod opening **332***a* for accommodation of hydraulic cylinders, check valves and/or larger ports.

[0224] Turning to FIGS. **12**A to **12**C, another embodiment of a first head plate **1028***a* is shown, which is another example embodiment of head plate that may be used with a compressor, such as compressor **600**. When used with a compressor a second head plate **1028***b* may also be used which may similarly configured to first head plate **1028***a*.

[0225] First head plate **1028***a* may be similar to first head plate **628***a* described above and may have a generally square or rectangular shape with a pair of first inlet ports **1010***a* horizontally spaced from each other at an upper end of first head plate **1028***a* and a pair of first outlet ports **1012***a*, horizontally spaced from each other at the opposite end of first head plate **1028***a* to first inlet ports **1010***a*.

[0226] First inlet and outlet ports **1010***a*, **1012***b* are each configured to be connected to a check valve, similar to as described above for first inlet and outlet ports **610***a*, **612***a*.

[0227] First inlet ports **1010***a* may be generally circular in cross section and define a straight fluid flowpath (i.e., generally perpendicular to central axis **734** shown in FIG. **12**C) through first head plate **1028***a* from first end **1038***a* (at outer face **1034***a*) to second end **1040***a* (at inner face **1036***a*). First outlet ports **1012***a* may be generally circular in cross section and define a straight fluid flowpath (i.e., generally perpendicular to central axis **734** shown in FIG. **12**C) through first head plate **1028***a* from first end **1042***a* (at inner face **1036***a*) to second end **1044***a* (at outer face **1034***a*).

[0228] Similar to first head plate **628***a*, the peripheral area around first inlet ports **1010***a* and first outlet ports **1012***a* provide gasket contact surfaces **1096***a*, **1098***a* respectively (FIG. **10**A) which may be similar to gasket contact surfaces **696***a*, **698***a* described above.

[0229] With reference to FIG. **12**C, similar to first inlet ports **610***a* of first head plate **628***a*, the first ends **1038***a* of first inlet ports **1010***a* may each include chamfered portions **1112***a*. In some embodiments, outlet ports **1012***a* may also have a chamfered portion similar to chamfered portion **1012***a* at first end **1042***a*.

[0230] According to another embodiment, the present disclosure relates to a compressor comprising a compression chamber. The compression chamber comprises a tubular wall extending between first and second ends along a central axis and an end plate attached to each one of the first and second ends. The end plate comprises an inner surface, an external surface, and a central opening and a plurality of peripheral fluid ports extending from the inner surface to the external surface. Each one of the peripheral fluid ports comprises an inner opening at the inner surface and an outer opening at the external surface and is inclined with respect to the central axis such that the outer opening is farther away from the central axis than the inner opening. The compressor further comprises a piston movably housed in the compression chamber and a piston rod for driving the piston to move within the compression chamber, the piston rod connected to the piston through the central opening of the end plate and extending along the central axis.

[0231] In some embodiments, the end plate has a thickness of about 4 inches, and the outer opening is farther away from the central axis than the inner opening by between about 0.5 and 2 inches.

[0232] In some embodiments, the plurality of the peripheral fluid ports comprises four ports.

[0233] In some embodiments, the inner opening is located 0 to about ⅜ inches from the tubular wall.

[0234] In some embodiments, the inner opening is circumferentially elongated with respect to the central axis.

[0235] In some embodiments, the inner opening is smaller than the outer opening.

[0236] In some embodiments, the outer opening comprises a chamfered edge.

[0237] In some embodiments, the compressor further comprises a plurality of valves, each connected to one of the peripheral fluid ports. In some embodiments, the valves comprise check valves. In some embodiments, the compressor further comprises a plurality of conduits connecting the valves to an input line and an output line respectively. In some embodiments, each one of the conduits comprises a flange connected to a corresponding one of the valves, wherein the flange is spaced away from the piston rod due to inclination of the peripheral fluid port connected to the corresponding valve.

[0238] When introducing elements of the present invention or the embodiments thereof, the articles "a," "an," "the," and "said" are intended to mean that there are one or more of the elements. The terms "comprising," "including," and "having" are intended to be inclusive and mean that there may be additional elements other than the listed elements.

[0239] Of course, the above described embodiments are intended to be illustrative only and in no way limiting. The described embodiments of carrying out the invention are susceptible to many modifications of form, arrangement of parts, details, and order of operation. The invention, therefore, is intended to encompass all such modifications within its scope.

What is claimed is:

1. A compressor comprising:

a first cylinder for compressing a fluid, comprising:

a chamber configured to receive the fluid;

a piston reciprocally movable in the chamber for compressing the fluid towards a first end of the chamber;

a centrally located opening at the first end of the chamber;

four ports at the first end of the chamber, comprising two inlet ports and two outlet ports;

a plurality of check valves each associated with one of the four ports for controlling fluid flow through the ports, including two inlet check valves connected to the two inlet ports and two outlet check valves connected to the two outlet ports;

a centrally located second cylinder at the first end of the chamber, the second cylinder connected and configured to drive movement of the piston in the first cylinder through the centrally located opening;

an inlet conduit connected to each one of the inlet check valves to supply the fluid from a fluid source to the chamber through the inlet ports;

an outlet conduit connected to each one of the outlet check valves for receiving fluid from the chamber through the outlet ports;

wherein each of the four ports is slanted such that the plurality of check valves and inlet and outlet conduits are spaced apart from the second cylinder.

2. The compressor of claim **1**, wherein each of the inlet and outlet conduits comprises a first end comprising a first flange; and a plurality of second ends each comprising a second flange, each of the second flanges of the inlet conduit for connecting the respective second end to the inlet check valves and each of the second flanges of the outlet conduit for connecting the respective second end to the outlet check valves.

3. The compressor of claim **1**, wherein each one of the four ports comprises a first end located proximal to the chamber and a second end located distal to the chamber wherein the first ends of each of the four ports are also located proximal to an edge of an internal side wall of the chamber.

4. The compressor of claim **3**, wherein the first ends of each of the four ports are oval.

5. The compressor of claim **3**, wherein the second ends of each of the four ports are circular.

6. The compressor of claim **3**, wherein the second ends of each one of the inlet ports comprises a chamfered edge.

7. The compressor of claim **1**, wherein the first ends of the chamber comprises a head plate, and each one of the check valves is secured to the head plate.

8. The compressor of claim **1**, wherein the fluid is a multiphase fluid comprising a solid material.

9. A compressor comprising:

a compression chamber comprising:

a tubular wall extending between first and second ends along a central axis, and

an end plate attached to each one of the first and second ends, the end plate comprising an inner surface, an external surface, and a central opening and a plurality of peripheral fluid ports extending from the inner surface to the external surface, wherein each one of the peripheral fluid ports comprises an inner opening at the inner surface and an outer opening at the external surface and is inclined with respect to the central axis such that the outer opening is farther away from the central axis than the inner opening;

a piston movably housed in the compression chamber;

a piston rod for driving the piston to move within the compression chamber, the piston rod connected to the piston through the central opening of the end plate and extending along the central axis.

10. The compressor of claim **9**, wherein the end plate has a thickness of about 4 inches, and the outer opening is farther away from the central axis than the inner opening by between about 0.5 and about 2 inches.

11. The compressor of claim **9**, wherein the plurality of the peripheral fluid ports comprises four ports.

12. The compressor of claim **9**, wherein the inner opening is located 0 to about ⅜ inches from the tubular wall.

13. The compressor of claim **9**, wherein the inner opening is circumferentially elongated with respect to the central axis.

14. The compressor of claim **9**, wherein the inner opening is smaller than the outer opening.

15. The compressor of claim **9**, wherein the outer opening comprises a chamfered edge.

16. The compressor of claim **9**, comprising a plurality of valves each connected to one of the peripheral fluid ports.

17. The compressor of claim **16**, wherein the valves comprise check valves.

18. The compressor of claim **16**, comprising a plurality of conduits connecting the valves to an input line and an output line respectively.

19. The compressor of claim **18**, wherein each one of the conduits comprises a flange connected to a corresponding one of the valves, wherein the flange is spaced away from the piston rod due to inclination of the peripheral fluid port connected to the corresponding valve.

20. The compressor of claim **19**, wherein the valves comprise check valves each compressed between a corresponding one of the head plates and a corresponding one of the flanges.

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