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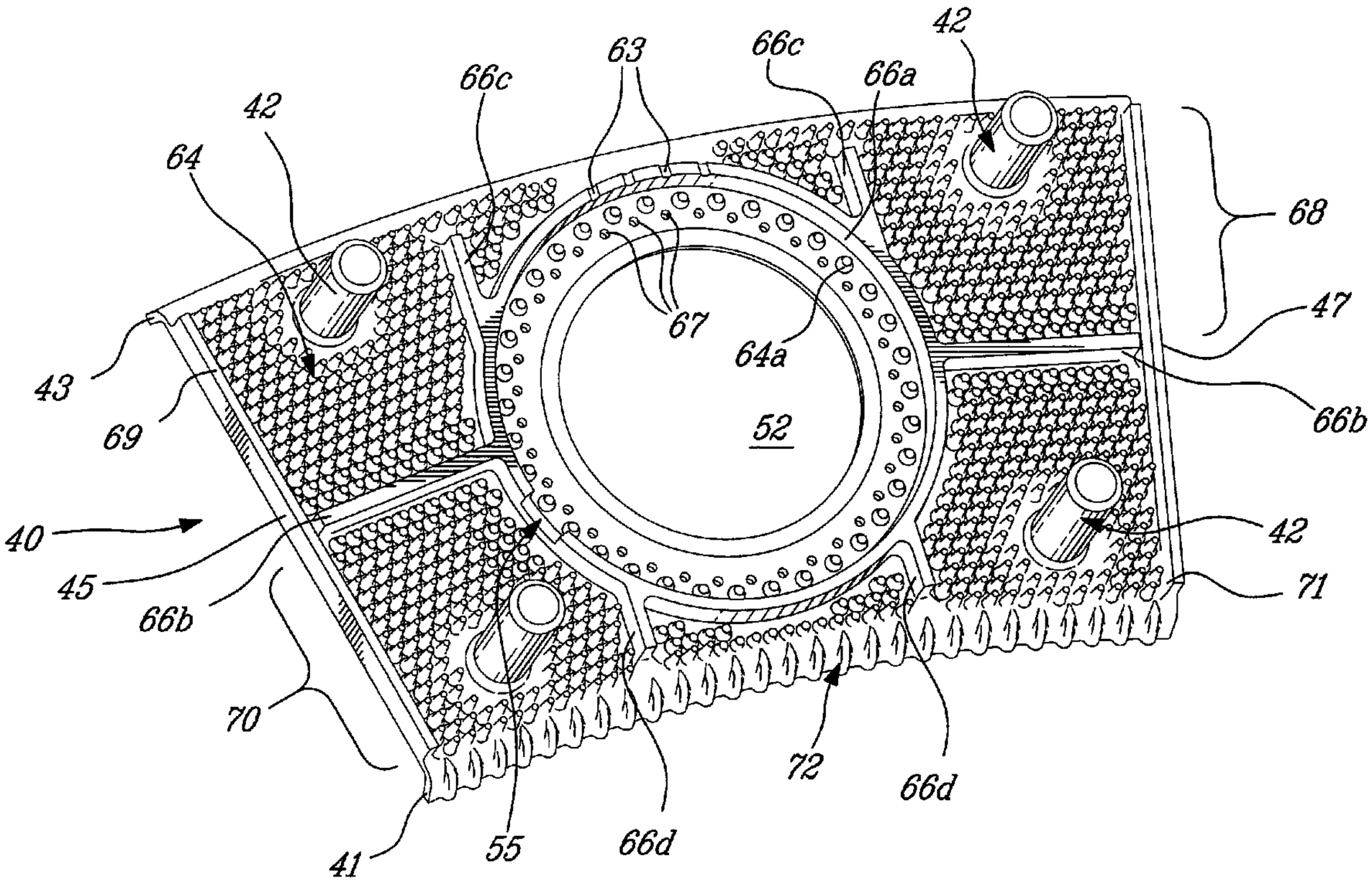
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(54) **Titre : ENSEMBLE CHEMISE DE CHAMBRE DE COMBUSTION ET BOUCLIER THERMIQUE**
(54) **Title: COMBUSTOR LINER AND HEAT SHIELD ASSEMBLY**



(57) **Abrégé/Abstract:**
A combustor heat shield has a body defining a fuel nozzle hole. The back face of the body is mounted adjacent and spaced-apart from a combustor dome. A ridge extends around the nozzle opening to a height adapted to substantially contact the combustor dome. The ridge thereby defines a cooling compartment between the body and the combustor dome. A plurality of slots is provided through the ridge. The slots are closed by the combustor dome to provide cooling holes when the heat shield is mounted on the combustor. The cooling holes direct pressurized cooling air from the compartment to adjacent regions of the back face of the heat shield body.

ABSTRACT

A combustor heat shield has a body defining a fuel nozzle hole. The back face of the body is mounted adjacent and spaced-apart from a combustor dome. A ridge extends around the nozzle opening to a height adapted to substantially contact the combustor dome. The ridge thereby defines a cooling compartment between the body and the combustor dome. A plurality of slots is provided through the ridge. The slots are closed by the combustor dome to provide cooling holes when the heat shield is mounted on the combustor. The cooling holes direct pressurized cooling air from the compartment to adjacent regions of the back face of the heat shield body.

COMBUSTOR LINER AND HEAT SHIELD ASSEMBLY

TECHNICAL FIELD

The invention relates generally to gas turbine engine combustors and, more particularly, to combustor heat shield cooling.

BACKGROUND OF THE ART

Heat shields, which protect the dome panel of combustor shells, are exposed to hot gases in the primary combustion zone. The amount of coolant available for cooling the heat shields must be minimized to improve the combustion efficiency and to reduce the smoke, unburned hydrocarbon and CO/NOx emission. Example heat shields are shown in US Patent Nos. 4,934,145 and 5,419,115.

There is a continuing need for improved heat shields and cooling schemes.

SUMMARY

In one aspect, there is provided a heat shield for a combustor dome, the heat shield comprising a body defining a fuel nozzle hole, a back face adapted to be mounted adjacent and spaced-apart from a combustor dome, a ridge extending around the nozzle opening and extending from the back face substantially to a height adapted to substantially contact the combustor dome, the ridge thereby define a cooling compartment interior of the ridge between the body and the combustor dome, a plurality of slots provided through the ridge, the slots adapted to be closed by the combustor dome to provide cooling holes when heat shield is mounted on the combustor, the slots adapted to direct pressurized cooling air within the compartment therethrough to cool an adjacent region of the body exterior of the compartment.

In a second aspect, there is provided a combustor dome comprising at least one heat shield mounted to an annular dome panel, the at least one heat shield having a heat shield body extending between opposed lateral edges and radially inner and outer edges, at least one fuel nozzle opening defined in the heat shield body, the heat shield body having a back face facing the combustor dome, the back face and the dome panel defining an air space therebetween, a ridge extending from the back face of the heat shield body around the fuel nozzle opening and generally circumscribing

a central annular area, a plurality of impingement holes defined in the dome panel and disposed to direct impingement jets in the central annular area upon the back face of the heat shield body, and at least one fluid passage extending through the ridge for discharging coolant from said central annular area to an adjacent region of the back face of the heat shield body.

Further details of these and other aspects will be apparent from the detailed description and figures included below.

DESCRIPTION OF THE DRAWINGS

Reference is now made to the accompanying figures, in which:

Figure 1 is a schematic cross-sectional view of a turbofan engine having a reverse flow annular combustor and dome panel heat shields;

Figure 2 is an enlarged view of a combustor shell of the engine combustor shown in Fig. 1;

Figure 2b is an enlarged view of Figure 2;

Figure 3 is an outside end view of the dome panel of the combustor shell, illustrating an impingement hole pattern;

Figure 4 is a perspective view of a back face of a dome heat shield of the combustor;

Figure 5 is a plan view of a back face of the heat shield shown in Fig. 4;

Figure 5b is a view similar to Fig. 5a, showing impingement areas and pin fin density regions;

Figure 6 is a sectional view of the portion of Fig. 5 indicated 6-6; and

Figure 7 is a sectional view of the indicated portion of Fig. 5 indicated 7-7.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Fig.1 illustrates a gas turbine engine 10 of a type preferably provided for use in subsonic flight, generally comprising in serial flow communication a fan 12 through which ambient air is propelled, a multistage compressor 14 for pressurizing the air, a combustor 16 in which the compressed air is mixed with fuel and ignited for generating an annular stream of hot combustion gases, and a turbine section 18 for extracting energy from the combustion gases.

The combustor 16 is housed in a plenum 17 supplied with compressed air from compressor 14. As shown in Fig. 2, the combustor 16 comprises a reverse flow annular combustor shell 20 composed of a radially inner liner 20a and a radially outer liner 20b, defining a combustion chamber 22. The combustor 16 has a bulkhead or inlet dome portion or panel 24 and an exit potion 26 for communicating combustion

gases with the turbine section 18. As shown in Fig. 1, a plurality of fuel nozzles 28 are mounted to extend through the inlet dome end portion 24 of the combustor 20 to deliver a fuel-air mixture to the chamber 22.

A plurality of effusion holes (not shown) are preferably defined in the inner and outer liners 20a and 20b for cooling purposes, and dilution holes (not shown) are also preferably provided for combustion purposes. Inner and outer liners 20a and 20b may have any suitable configuration, and thus are shown in dotted line only in Fig. 2. The inner and outer liners 20a and 20b are preferably made out of sheet metal, though any suitable material(s) and manufacturing method(s) may be used. A thermal barrier coating (not shown) is preferably applied to the inner or combustion facing surfaces 32, 34 of the liners 20a and 20b to protect them against the high temperatures prevailing in the combustion chamber 22.

As shown in Fig. 2, the inner and outer liners 20a and 20b respectively include flanges 38 and 36 which overlap each other so as to form the dome panel 24 of the combustor shell 20 (Alternatively, any other suitable dome panel could be employed). The flanges 36 and 38 are directly fixedly secured together by a plurality of circumferentially distributed dome heat shields 40 mounted inside the combustion chamber 22 to protect the end wall of the dome 24 from the high temperatures in the combustion chamber 22. The dome heat shields 40 are typically castings made out of high temperature materials. Each dome heat shield 40 has a plurality of threaded studs 42 (four according to the example shown in Fig. 4) extending from a back face of the heat shield and through holes 44 (Fig. 3) defined in flanges 36 and 38. Self-locking nuts 46 are threadably engaged on the studs 42 from outside of the combustion chamber 22 for holding flanges 36 and 38 (and thus inner and outer liners 20a and 20b), and the dome heat shields 40 tightly together.

As shown in Figs. 2 and 3, fuel nozzles openings 48 are defined through the dome panel 24 for allowing mounting of the fuel nozzles 28 to the combustor 16. A central hole 52 is defined in each of the heat shields 40 and is aligned with a corresponding fuel nozzle opening 48 for accommodating an associated fuel nozzle therein. As illustrated in Fig. 2, a floating collar 54 is mounted in the nozzle opening 48 to provide sealing between the combustor shell 20 and the fuel nozzles 28 while

allowing relative movement therebetween. The floating collar 54 has an anti-rotation tab (not shown) which fits within an anti-rotation slot 55 on heat shield 40 (see Fig. 4.) The fuel nozzles 28 are slidably received in the floating collars 54. The floating collars 54 are axially trapped between the heat shields 40 and the end wall (i.e. flange 36) of the combustor dome 24. The fuel nozzle openings 48 are slightly oversized relative to the floating collars 54, thereby allowing limited radial movement of the collars 54 with the fuel nozzles 28 relative to the combustor shell 20.

As shown in Fig. 2b, the heat shields 40 are spaced from the dome panel 24 by a distance of about .1 inch so as to define a heat shield back face cooling air space 60. Relatively cool air from plenum 17 is admitted in the back cooling air space 60 via impingement holes 62 defined in the dome panel of the combustor shell 20 (see Figure 3). The impingement hole patterns are arranged in the dome panel of the combustor shell 20 to optimize the heat shield cooling, in co-operation with pin fins located on the heat shield, as will be described further below. As shown in Fig. 3, the impingement holes include a first set of holes 62a arranged on two circular paths concentrically arranged with fuel nozzle opening 48. Preferably the inner circle of set 62a comprises holes equally spaced on a first pitch about the nozzle opening 48, while the outer circle of set 62a comprises only 10 holes (6 outer and 4 inner) but on a pitch similar to the first pitch. Placement of the outer circle of set 62a will be discussed further below. Holes 62b are also provided in two rows extending laterally from each side of nozzle hole 48, both rows concentric with the central axis of the annular combustor 20. Preferably the holes 62 of inner row have an angular position which is staggered relative to the holes of the outer row of the set of 62b. Preferably 8 holes are provided in the outer row, and 7 holes 62 on the inner row, in each set 62b on either side of nozzle hole 48. Though this is the preferred embodiment, other hole placements and numbers maybe used. Placement of the holes 62 of set 62b will also be discussed further below. Holes 62 are preferably straight-through holes generally perpendicular to the dome panel face, thus having an axis generally parallel to the combustor (or engine) axis. By placing holes sets 62a and 62b in circular arrays allows the holes to be laser drilled using drilling-on-the-fly (DOF) techniques, which speeds manufacturing time. As will be discussed further below, impingement holes 62 are positioned and arranged directly (i.e. generally

perpendicularly) above reduced-height pin fins 64a on the back face of the heat shield to improve cooling by minimising the resistance to the air flow, which facilitates combustor cooling where a low pressure drop or gradient is available to energize combustor cooling. This allows for an optimized cooling to be achieved on the heat shield while still providing enough momentum to the air exiting from behind the heat shield to form a uniform film around the circumference of the surfaces 32 and 34 of the inner and outer liners.

Figs. 4 and 5 show an individual dome heat shield 40. Each heat shield 40 is provided in the form of a circular sector having a radially inner lip 41, having a plurality of ribs 72 discussed further below, a radially outer lip 43 and lateral edges 45, 47 extending between the inner and outer lips 41 and 43. Heat exchange promoting protuberances, such as pin fins 64, pedestals or other raised cooling structures, are provided preferably in rows, and preferably in staggered position from row to row, on the back face of the heat shields 40 for augmenting the heat transfer between the back face and the cooling air. The pin fin density and location are defined based on the heat shield hot spots and to minimize the pressure drop, as will be discussed further below. As will be discussed further below, the pin fins 64 have different heights, depending on their location on the back face of the heat shield 40. The pin fin 64 height is preferably substantially the same as the distance between the heat shield back face and the inner surface of the dome panel (e.g. in this example, about 0.095" to 0.1" from the back face). The pin fin-to-pin fin spacing is based on required cooling, and in the present embodiment ranges from 0.05 inch to 0.1 inch. Each pin fin 64 preferably has a frustoconical shape.

As shown in Figs. 4 and 5, ribs or ridges 66 are provided extending from the back face of the heat shields 40 to strengthen the heat shield and direct the flow of cooling air as desired, as will be discussed further below. The ridges 66 preferably extend from the heat shield back face all the way into substantially sealing contact with the inner surface of the dome panel (e.g. in this example, about 0.095" to 0.1" from the back face), and thus more or less sealing engage the dome panel and thereby direct the cooling air from impingement hole sets 62a and 62b to the various regions of the heat shield, as will be described further below. The ridges 66 include a central circular ridge 66a concentrically disposed with the fuel nozzle opening 52, a pair of

generally diametrically opposed primary ridges 66b extending laterally from the central circular ridge 66a, a pair of generally radially disposed ridges 66c extending radially outwardly from the central circular ridge 66a, and a pair of generally radially disposed ridges 66d extending radially inwardly from the central circular ridge 66a.

As shown in Fig. 2, the central circular ridge 66a preferably extends around fuel nozzle opening 52 in the heat shield in sealing contact with the inner surface of the dome panel. Referring to Fig. 5b, the areas of impingement by air passing through holes 62 of sets 62a and 62b are indicated by corresponding ellipses overlaid on the heat shield 40. As can be seen from Fig. 5b, the rows of impingement holes 62a align with one on either side of the central circular ridge 66a. Outer circle of holes 62 of set 62a generally align with the short pin fins 64a adjacent the central circular ridge 66a. Referring again to Figs. 4 and 5, the cooling air from holes 62 of the inner circle of the set 62a impinges upon the portion of the back surface of the heat shield 40 bounded by circular ridge 66a and is then mostly directed into cooling holes 67 extending through the heat shield 40 for exhausting through the face of the heat shield. A portion of the cooling air, however, is directed through (preferably) four grooves 63 defined at the radially outer side of the heat shield through the circular ridge 66a. When mated against the combustor dome panel, the grooves 63 provide cooling holes or slots for allowing a portion of the cooling air to be discharged through the grooves 63 towards the radially outer lip 43 of the heat shield 40, as shown in Fig. 5, and thereby cool an adjacent area 81 where no pin fins 64 are provided, due to space limitations on the heat shield back face for a given dome panel and fuel nozzle geometry. Grooves 63 also permit a proper radial airflow to exit the back of the heat shield and into the combustion chamber 22 (e.g. see upper arrows a1 in Figs. 2, 2a). The cooling air from holes 62 of the outer circle of the set 62a impinges upon the portion 80a (Fig. 5) of the back surface of the heat shield 40, and thus tends to be directed generally radially outwardly or radially inwardly, as the case may be, by the ridge 66a in co-operation with ridges 66c or 66d, as the case may be, due to the substantially sealing contact provided by the ridges 66 with the combustor dome panel. Also as shown in Figure 4 (only), a circular array of short pin fins 64a may optionally be provided within circular ridge 66a.

Referring back to Fig. 4, ridges 66b extend laterally from the central circular ridge 66a such as to divide the back surface area of the heat shield 40 into a radially outer half 68 and a radially inner half 70 (the term "half" is used approximately). Ridges 66b preferably extend parallely to impingement holes 62 of set 62b, and disposed to be intermediate the inner and outer circle of holes 62 of set 62b, as can be seen with reference to Fig. 5b. Inner and outer circle of holes 62 of set 62b generally align with a first row of the short pin fins 64a immediately adjacent ridges 66b. Thus, the two rows (i.e. inner and outer circles) of impingement holes 62 of the set 62b in the dome panels are located one on either side of the ridges 66b. The air from impingement holes 62b impinges upon the portions 80b of the back face of the shield adjacent the ridges 66b, and thus tends to be directed generally radially outwardly or radially inwardly of the ridges 66b, as the case may be, due to the substantially sealing contact provided by the ridges 66 with the combustor dome panel.

As mentioned, the ridges 66c extend generally radially outwardly from opposed sides of the central circular ridge 66a towards, but stopping preferably short of, the radially outer lip 43. Likewise, the ridges 66d extend generally radially inwardly from opposed sides of the central circular ridge 66a towards, but stopping preferably short of, the radially inner lip 41. The ridges 66c are thus preferably generally aligned with the ridges 66d, and bound regions 80a, for radially directing cooling air in that region.

As mentioned, and shown in Figs. 4 and 5, the heat shield 40 provided with arrays of "full height" pin fins 64 (i.e. extending substantially, but preferably not quite, the entire distance between the heat shield back face and the combustor dome panel, or about 0.090" to 0.1" in this example, and more preferably to 0.090" to 0.095"), however, in regions 80a and 80b (see Fig. 5), adjacent to ridges 66, partial height pin fins 64a are provided. Preferably, partial height pin fins 64a are about one half of the height of full-height pin fins 64, but otherwise have the same shape and configuration (i.e. preferably partial height pin fins 64a appear as a "sawed off" version of pin fins 64). The pin fin height is reduced to improve the impingement cooling effectiveness while maximizing surface area for heat transfer. The ratio (R_{dh}) of the diameter of cooling hole to the height from the impingement surface should preferably greater than one and less than five (i.e. $1 < R_{dh} < 5$) for maximum

impingement cooling effectiveness. Depending on pin fin density in the impingement zone, the height from the impingement surface may be considered to be the distance from the impingement holes to either the tops of the pin fins, the heat shield back face surface, or a suitable averaging of the two. Typically, the first (pin fin tops) will be used. Thus, this desired requirement would not be met with a full-height pin fin 64, but in the current embodiment, the pin fins 64a and holes 62 can be respectively sized such that an optimum impingement height is achieved and an increased cooling surface area can still be provided in the impingement regions 80a, 80b of impingement holes 62. In the present example, the tops of reduced-height pin fins 64a are in the range of 0.045-0.055 below the impingement holes, and the impingement holes have a diameter in the range of 0.025-0.035, thus providing an R_{dh} in the range of about 1.3 to 2.2 or, generally speaking, $1 < R_{dh} < 3$.

An area (unindicated) of pin fins 64 adjacent anti-rotation slot 55 may require height reduction to some extent, to avoid interference with the anti-rotation tab of floating collar 54.

The skilled reader will appreciate that, in general, a higher pin fin density will increase surface area, and thus generally increase heat transfer. However, in situations were insufficient flow is available to overcome the additional flow resistance provided by increased pin fin density, improvements are needed to augment heat transfer. Referring to Fig. 5b, at hot spots regions of the heat shield, such as the peripheral regions 68a and 70a, the pin fin 64 density is preferably reduced, relative to central regions 68b and 70b, to increase the heat transfer coefficients by increasing the coolant flow in these peripheral areas, by reducing flow resistance by reducing pin fin density to increase the flow. Preferably, pin fin densities in regions 68a and 70a are between 0.4 and 0.7 of the densities in regions 68b and 70b, respectively, however the exact densities will be determined based on cooling air flow and heat transfer requirements. For example, pin fin densities for regions 68a, 68b, 70a, and 70b may be 144, 250, 170, 289 respectively. Due to lower overall pressure drop experienced in the hot spot regions 68a and 70a due to lower pin fin densities, the heat transfer is optimised by directing more coolant flow through these regions than would be possible if higher densities were used. It is

noted that in this example, studs 42 correspond to regions 68a and 70a, although this is not necessary.

Lateral ridges or ribs 69 and 71 are provided at lateral edges 45, 47 of each heat shield 40 provide a means for redirecting the flow of cooling air behind the heat shield away from the interface of mating sides of adjacent heat shields 40, and thus impede leakage between adjacent heat shields. The cooling air directed through impingement holes 62 or set 62b is, thus, preferably eventually fully exhausted at the inner and outer lips 41 and 43 of each heat shield 40. As shown in Fig. 4, straightener ribs 72 can be provided along the inner and outer lips 41 and 43 to straighten the cooling air flow before being discharged in the combustion chamber 22.

In use, impingement holes 62a and 62b in the combustor dome allows air to pass into the cooling air space 60 between heat shield 40 back face and the combustor dome panel. The air from combustor impingement holes 62 of sets 62a impinges upon the partial height pin fins 64a in regions 80a on the back face area of the heat shield 40 adjacent circular ridge 66a, and air from combustor impingement holes 62 of set 62b impinges upon the partial height pin fins 64a in regions 80b on the back face area of the heat shield 40 adjacent ridges 66b. The partial height pins 64a provide sufficient clearance with the dome panel such that an optimal impingement height of 2-5 times the diameter of holes 62 is provided. After impinging the partial height pins 64a, impingement air moves generally radially relative the heat shield, to move past full height pin fins 64, in the case of air provided by holes 62 of set 62b. The splashed air from impingement holes 62b is caused to flow over the pin fins towards the inner and the outer lips 41 and 43 by the ridges 66, 69 and 71. This provides effective convection cooling. The air cools the back face of the heat shields by impingement and convection heat transfer. The cooling air is eventually discharged from the space 60 behind the heat shield at the inner and outer lips 41 and 43, where the flow may be straightened by the straightener ribs 72 before being expelled into the combustion chamber 22 to travel downstream along the inner and outer liners of the combustor. Once travelling along the combustor liners, dilution holes, etc. (not shown) redirect the flow into a double torroidal flow, as indicated by arrows **a1** and **a2** in Fig. 2. Meanwhile, the majority of the air received within circular ridge 66a impingement cools the back face of the

heat shield 40 before flowing through the holes 67, preferably to provide cooling to the upstream face of the heat shield. The remaining portion of the air received within circular ridge 66a flows through grooves 63 to cool the back face of the heat shield radially outwardly therefrom, before being discharged radially at the outer lip 43.

The above description is meant to be exemplary only, and one skilled in the art will recognize that changes may be made to the embodiments described without department from the scope of the invention disclosed. For example, the invention can be provided in any suitable heat shield configuration and in any suitable combustor configuration, and is not limited to application in turbofan engines. Still other modifications which fall within the scope of the present invention will be apparent to those skilled in the art, in light of a review of this disclosure, and such modifications are intended to fall within the appended claims.

CLAIMS:

1. A heat shield for a combustor dome, the heat shield comprising a body defining a fuel nozzle hole, a back face adapted to be mounted adjacent and spaced-apart from a combustor dome, a first ridge extending around the nozzle opening and extending from the back face to a height adapted to substantially contact the combustor dome, the first ridge thereby defining a cooling compartment interior of the first ridge between the body and the combustor dome, a plurality of slots provided through the first ridge, the slots adapted to be closed by the combustor dome to provide cooling holes when heat shield is mounted on the combustor, the cooling holes adapted to direct pressurized cooling air within the compartment therethrough to cool an adjacent region of the body exterior of the compartment, wherein first and second arrays of pin fins are provided on the back face outwardly of the compartment on opposed sides of said plurality of slots, the plurality of slots being aligned with a pin fin free region

2. The heat shield defined in claim 1, wherein the body extends between opposed lateral edges and radially inner and outer edges, and wherein said slots are radially oriented to direct the cooling air from the compartment towards one of said radially inner and outer edges.

3. The heat shield defined in claim 1, wherein said plurality of slots is provided on a radially outer side of the heat shield.

4. The heat shield defined in claim 2, wherein the plurality of slots are substantially parallel to one another and symmetrically disposed relative to a central radial axis of the body.

5. The heat shield defined in claim 1, wherein at least two additional ridges extend outwardly from the first ridge along said back face, and wherein said plurality of slots are provided in said first ridge between said at least two additional ridges.

6. A combustor dome comprising at least one heat shield mounted to an annular dome panel, the at least one heat shield having a heat shield body extending between opposed lateral edges and radially inner and outer edges, at least one fuel nozzle opening defined in the heat shield body, the heat shield body having a back face facing the combustor dome, the back face and the dome panel defining an air space therebetween, a ridge extending from the back face of the heat shield body around the fuel nozzle opening and generally circumscribing a central annular area, a plurality of impingement holes defined in the dome panel and disposed to direct impingement jets in the central annular area upon the back face of the heat shield body, and at least one fluid passage extending through the ridge for discharging coolant from said central annular area to an adjacent region of the back face of the heat shield body.

7. The combustor dome defined in claim 6, wherein the ridge extends from the back face to a height adapted to substantially contact the dome panel, the at least one fluid passage being formed by the dome panel and at least one slot defined in the ridge.

8. The combustor dome defined in claim 6, wherein heat exchange promoting protuberances project from the back face of the heat shield body, and wherein the at least one passage is aligned with a protuberance-free region.

9. The combustor dome defined in claim 6, wherein the at least one passage is radially oriented to direct the coolant towards one of the radially inner and outer edge of the heat shield body.

10. The combustor dome defined in claim 8, wherein said protuberance-free region is provided between a pair of secondary ridges extending outwardly from the ridge circumscribing the central annular area.

11. The combustor dome defined in claim 10, wherein first and second groups of heat exchange promoting protuberances are provided on both sides of the protuberance free-region and inwardly of said secondary ridges.

12. The combustor dome defined in claim 7, wherein a plurality of parallel slots is defined in a radially outer portion of the ridge.

13. The combustor dome defined in claim 6, wherein said plurality of impingement holes comprises a first set of holes arranged in at least one circular array around the fuel nozzle opening within the central annular area, and a second set of holes circumferentially distributed about a central axis of the annular dome panel, said second set of holes being disposed outside of said at least one circular array for directing the cooling fluid upon the regions of the back face of the heat shield located outside of the central annular area.

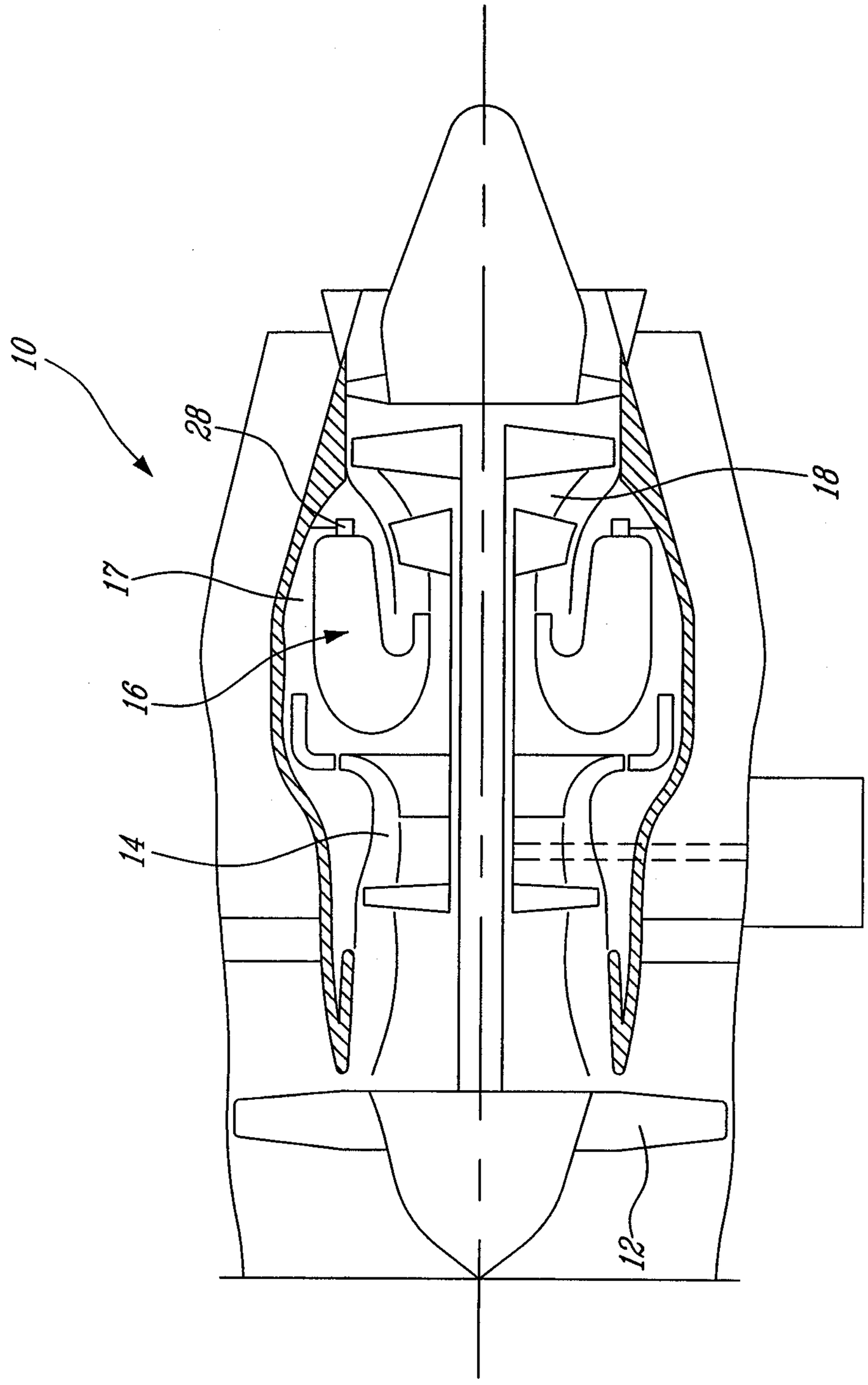


Fig-1

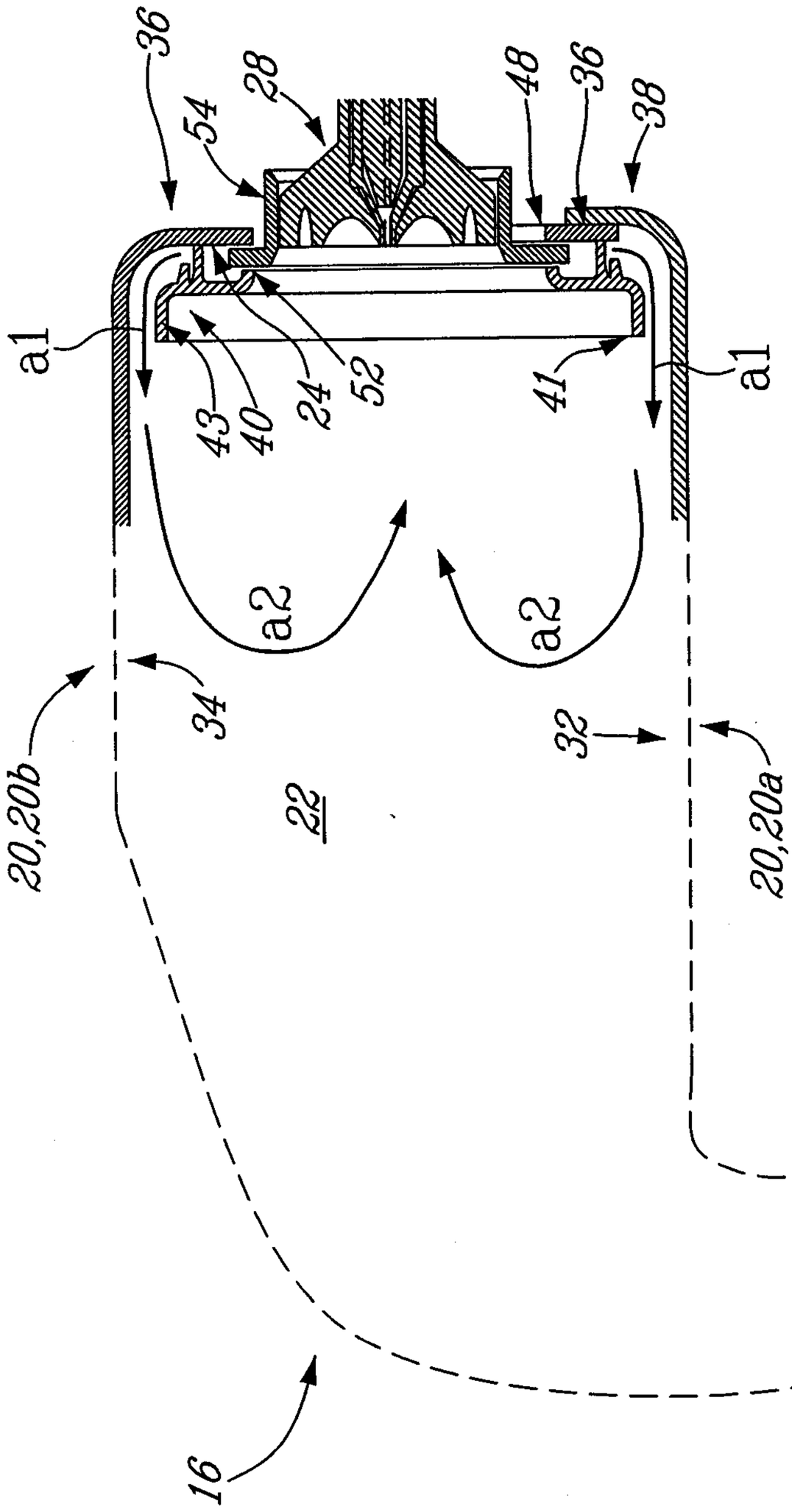

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16

Fig-2

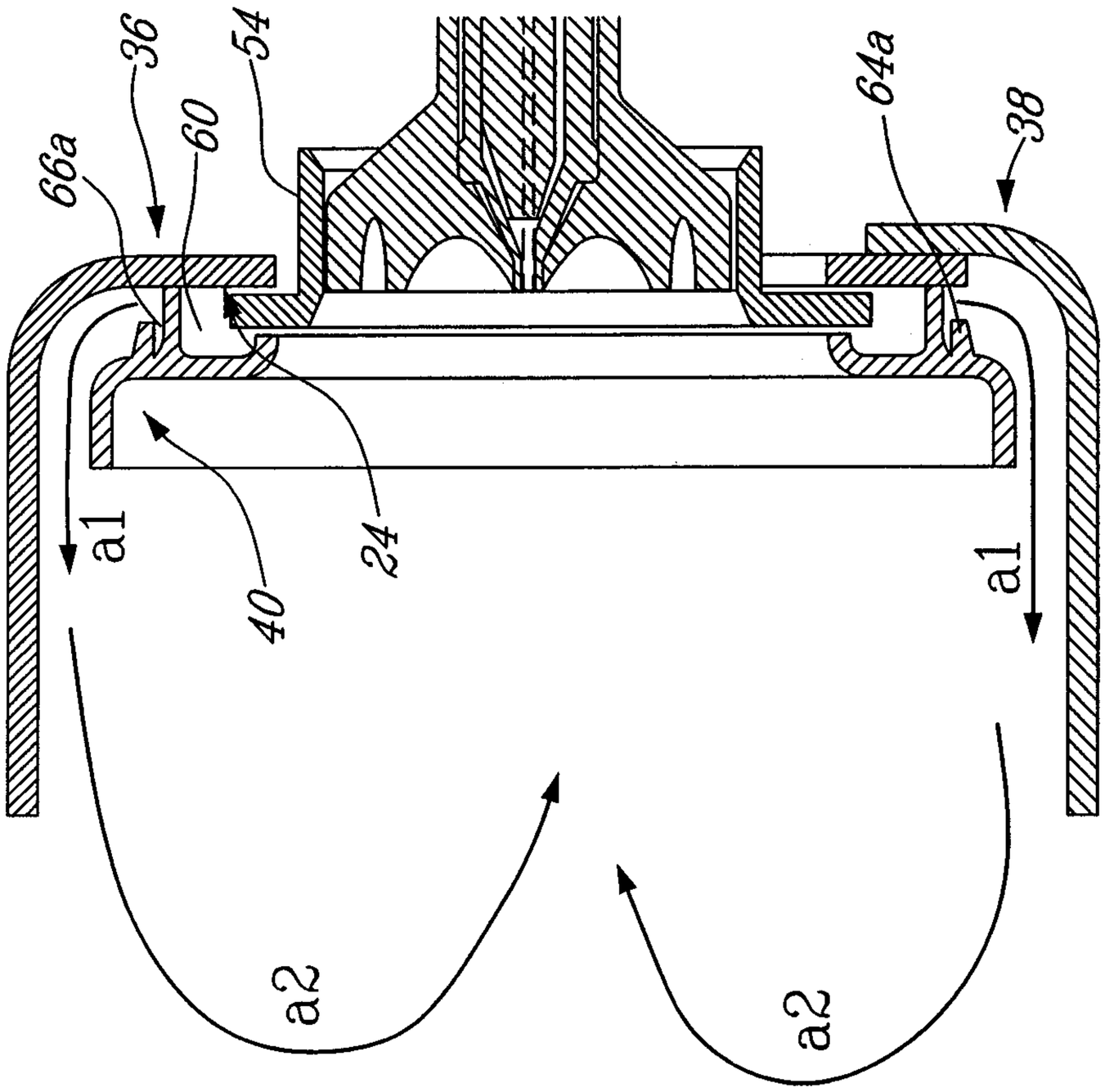


Fig-2b

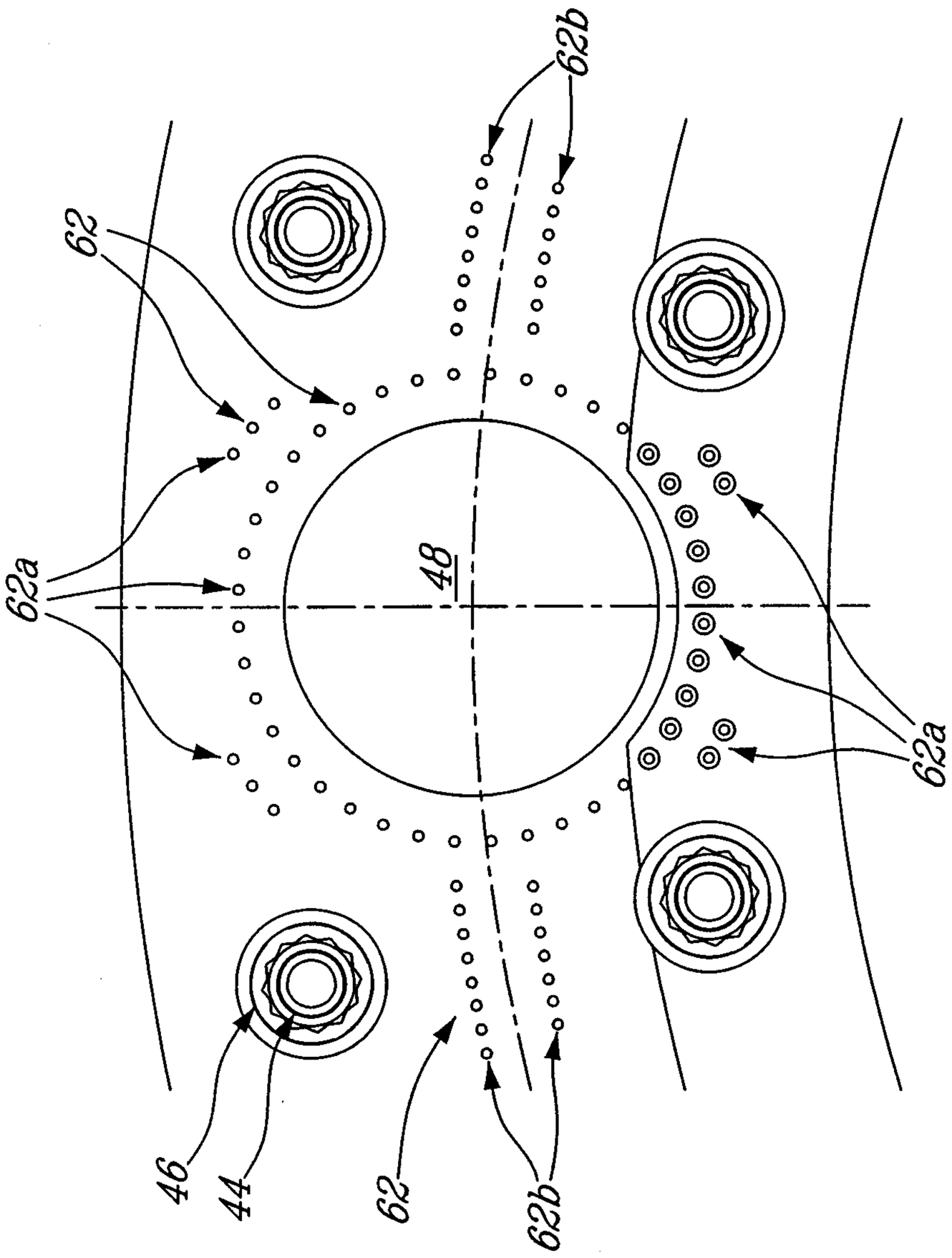


Fig-3

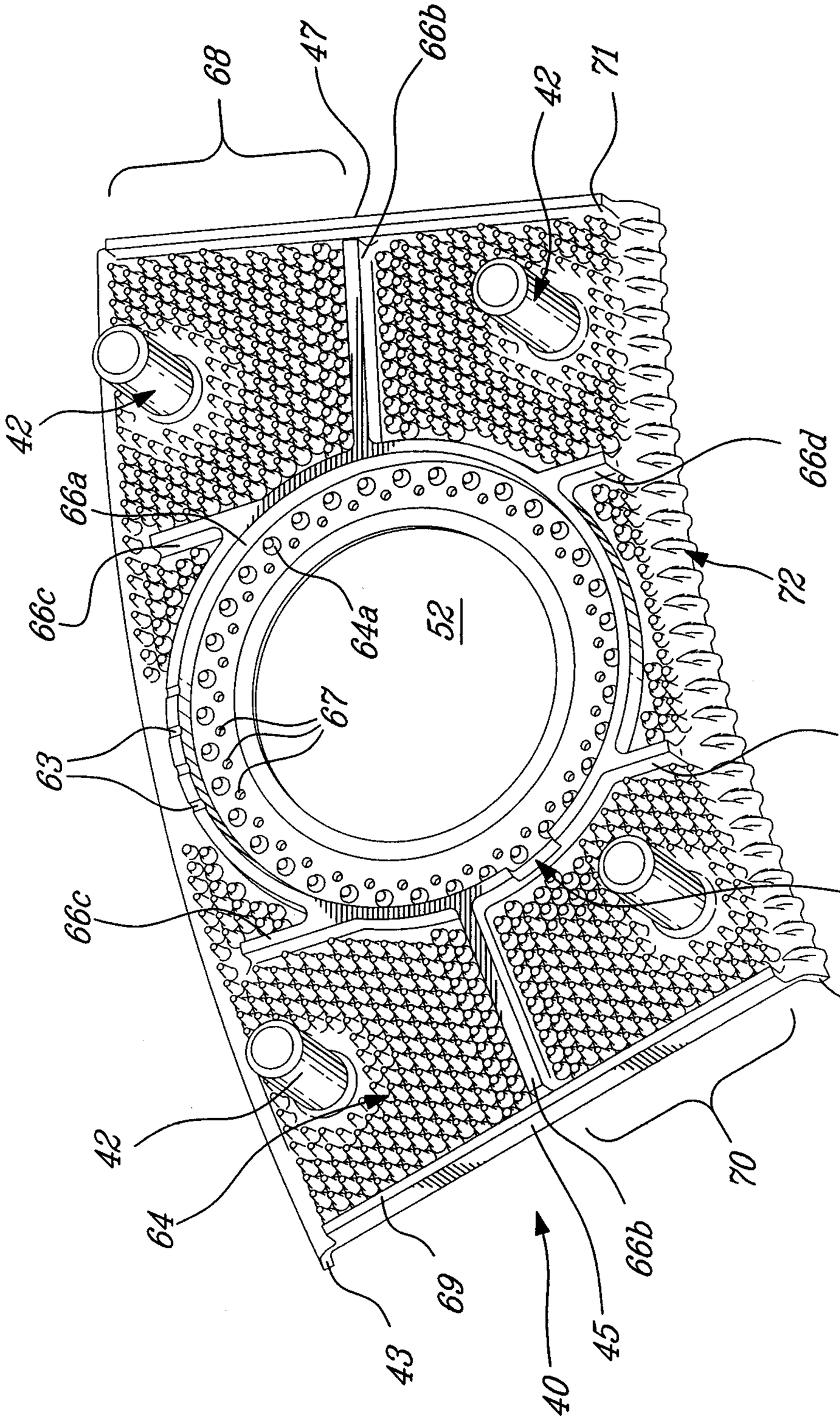

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Fig-4

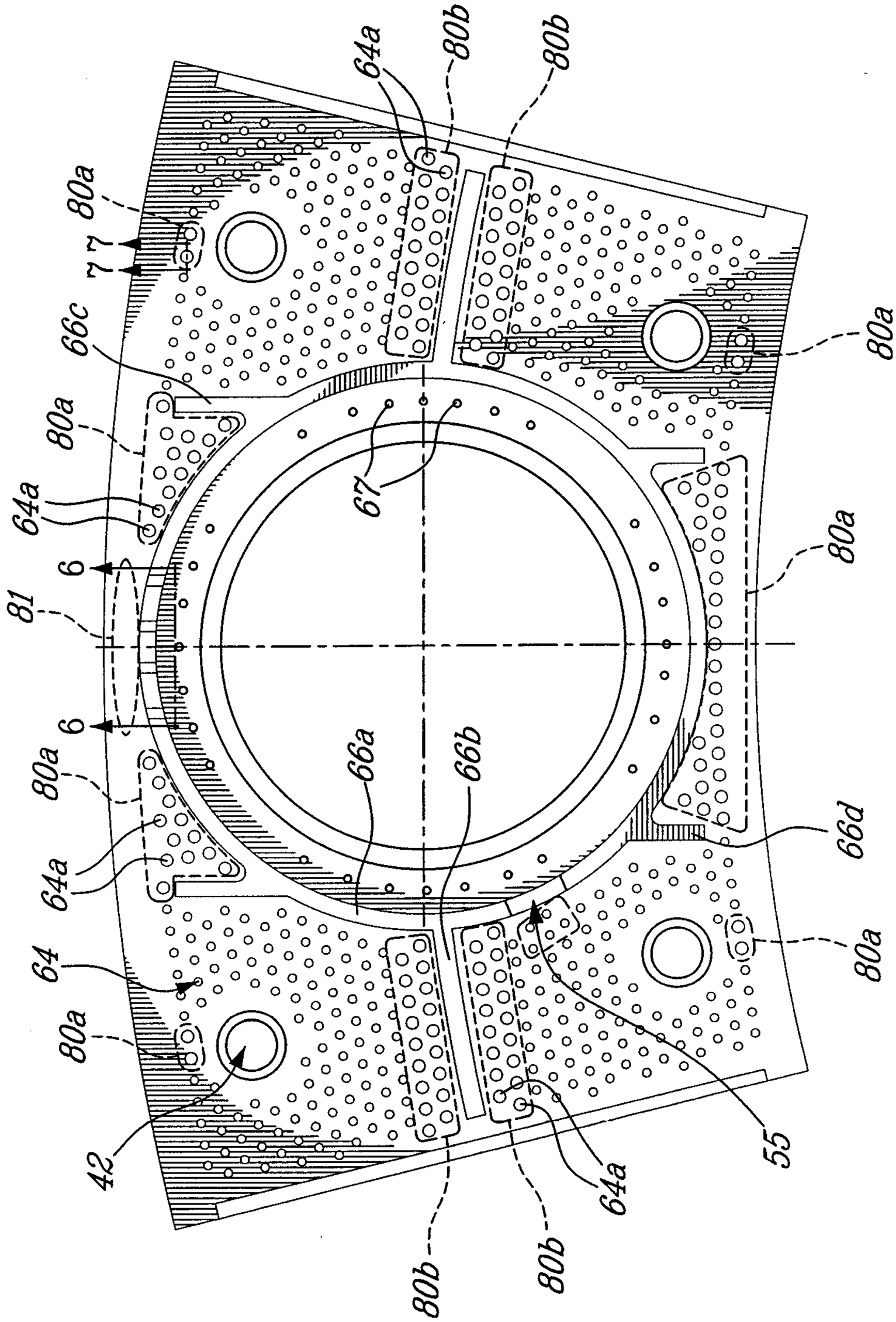

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81
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80b

Fig-5

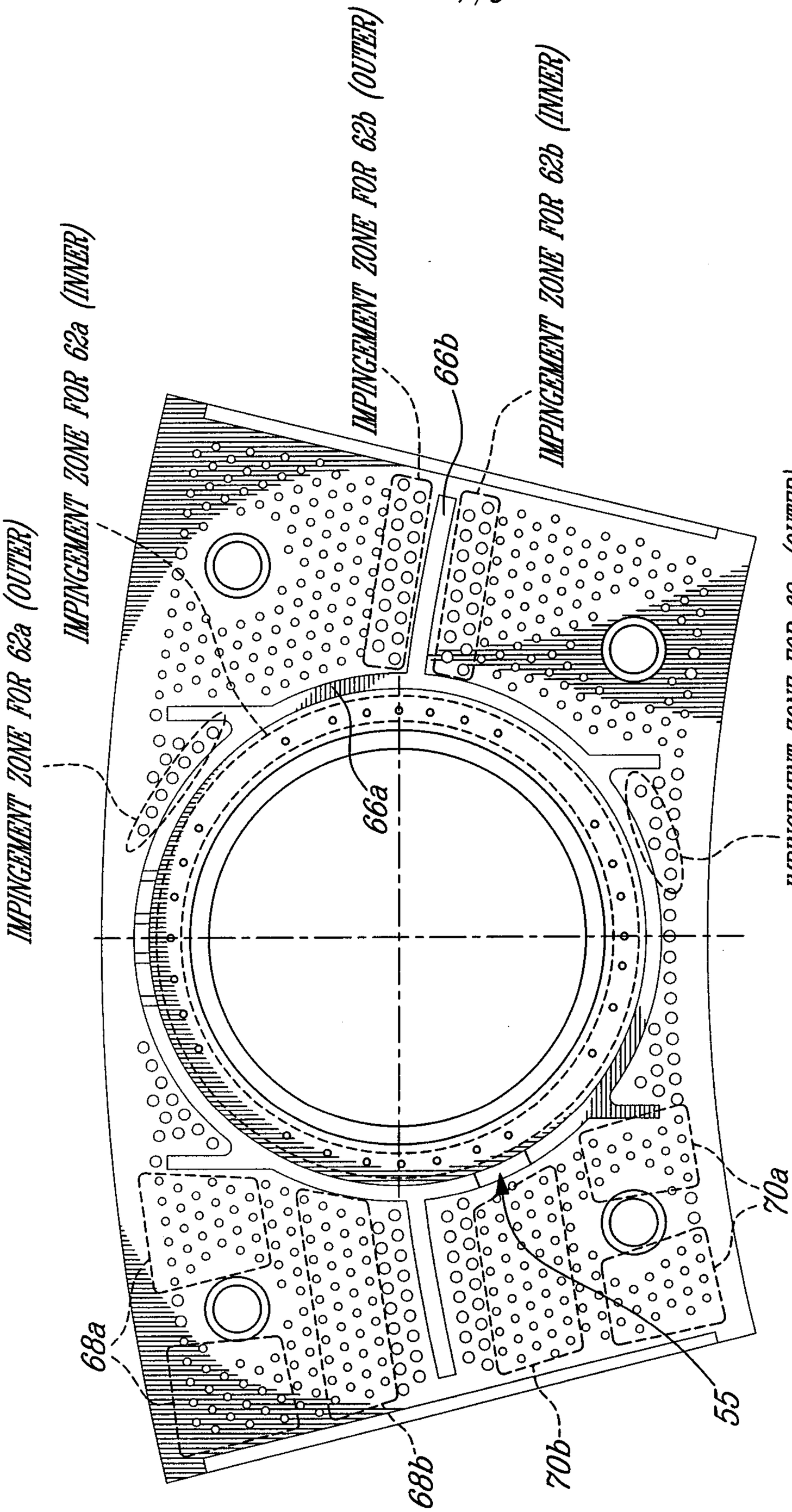

IMPINGEMENT ZONE FOR 62a (OUTER)
IMPINGEMENT ZONE FOR 62a (INNER)
IMPINGEMENT ZONE FOR 62b (OUTER)
IMPINGEMENT ZONE FOR 62b (INNER)
66b
66a
68a
68b
70b
70a
55

Fig. 5b

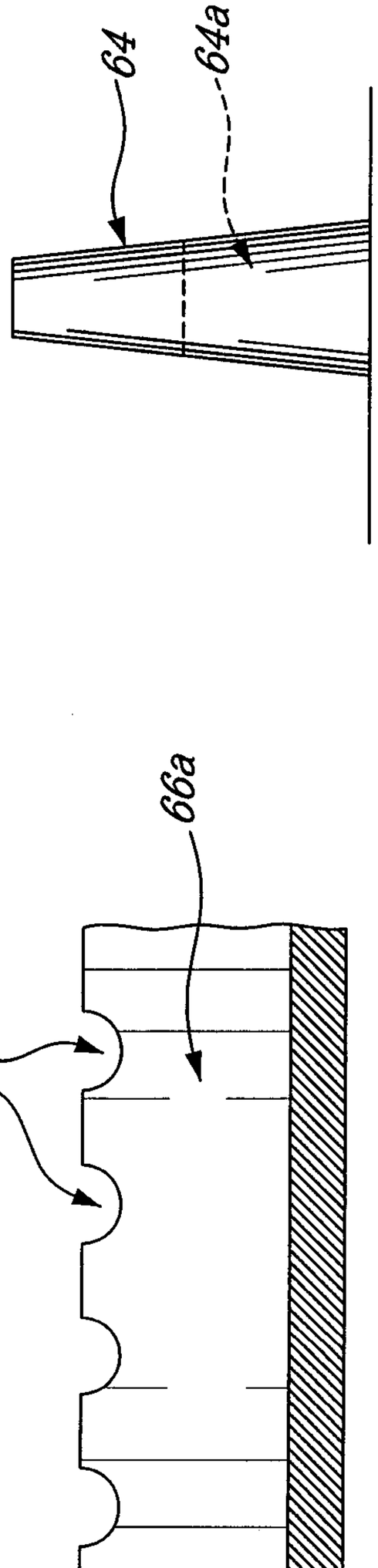
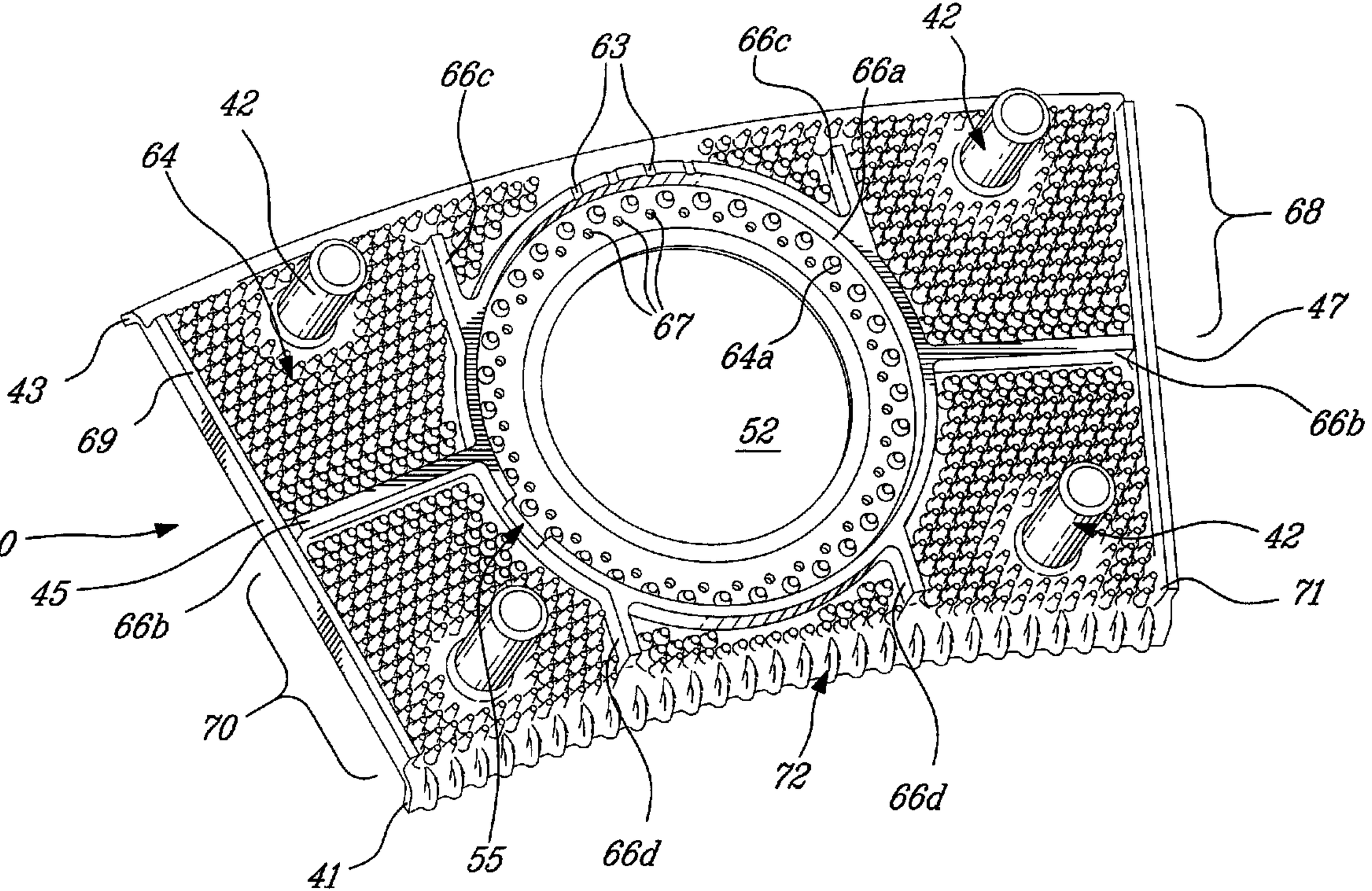


Fig. 7

Fig. 6


42
63
66c
66c
66a
42
64
68
67
64a
47
43
52
66b
69
40
42
45
71
66b
70
72
66d
41
55
66d