



(51) International Patent Classification:

B01D 45/14 (2006.01) *A47L 9/12* (2006.01)
A47L 9/10 (2006.01) *A47L 9/14* (2006.01)
A47L 9/16 (2006.01)

(21) International Application Number:

PCT/GB2018/052143

(22) International Filing Date:

27 July 2018 (27.07.2018)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

1712933.9 11 August 2017 (11.08.2017) GB

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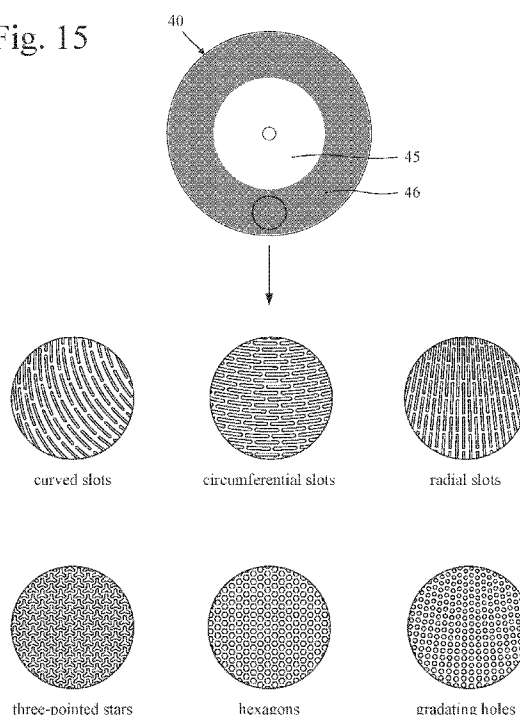
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(81) Designated States (*unless otherwise indicated, for every kind of national protection available*): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (*unless otherwise indicated, for every kind of regional protection available*): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ,

(54) Title: DIRT SEPARATOR FOR A VACUUM CLEANER

Fig. 15



(57) Abstract: A dirt separator for a vacuum cleaner comprising a chamber having an inlet through which dirt-laden fluid enters and an outlet through which cleansed fluid exits the chamber. A disc located at the outlet rotates about a rotational axis and comprises holes through which the cleansed fluid passes. The holes have a minimum dimension of between 0.1 mm and 1.0 mm.

TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*

Dirt Separator for a Vacuum Cleaner

The present invention relates to a dirt separator for a vacuum cleaner.

- 5 The dirt separator of a vacuum cleaner may comprise a porous bag or a cyclonic separator. However, both types of separator have their disadvantages. For example, the pores of a bag quickly clog with dirt during use, whilst the pressure consumed by a cyclonic separator can be high.
- 10 The present invention provides a dirt separator for a vacuum cleaner, the dirt separator comprising: a chamber having an inlet through which dirt-laden fluid enters the chamber and an outlet through which cleansed fluid exits the chamber; and a disc located at the outlet, the disc being arranged to rotate about a rotational axis and comprising holes through which the cleansed fluid passes, wherein the holes have a
- 15 minimum dimension of between 0.1 mm and 1.0 mm.

The dirt-laden fluid entering the chamber contacts the rotating disc, which imparts tangential forces to the fluid. As the dirt-laden fluid moves radially outward, the tangential forces imparted by the disc increase. The fluid is then drawn through the

20 holes in the disc whilst the dirt, owing to its greater inertia, continues to move outwards and collects at the bottom of the chamber.

The dirt separator of the present invention has advantages over conventional separators such as a porous bag or cyclonic separator. For example, the pores of a bag quickly

25 clog with dirt during use. This then reduces the suction that is achieved at the cleaner head. With the dirt separator of the present invention, rotation of the disc helps ensure that the holes in the disc are generally kept clear of dirt. As a result, no significant reduction in suction may be observed during use. The cyclonic separator of a vacuum cleaner typically comprises two or more stages of separation. The first stage often

30 comprises a single larger cyclone chamber for removing coarse dirt, and the second stage comprises a number of smaller cyclone chambers for removing fine dirt. As a

result, the overall size of the cyclonic separator can be large. A further difficulty with the cyclonic separator is that it typically requires high fluid speeds in order to achieve high separation efficiencies. Additionally, the fluid moving through the cyclonic separator often follows a relatively long path as it travels from the inlet to the outlet. As a result, the pressure drop associated with the cyclonic separator can be high. With the dirt separator of the present invention, relatively high separation efficiencies can be achieved in a more compact manner. In particular, the dirt separator may comprise a single stage having a single chamber. Furthermore, separation occurs primarily as a result of the angular momentum imparted to the dirt by the rotating disc. As a result, relatively high separation efficiencies may be achieved at relatively low fluid speeds. Additionally, the path taken by the fluid in moving from the inlet to the outlet of the chamber is relatively short. As a result, the pressure drop across the dirt separator may be smaller than that across a cyclonic separator having the same separation efficiency.

The separation efficiency of the dirt separator and the pressure drop across the dirt separator are sensitive to the size of the holes in the disc. For a given total open area, the separation efficiency of the dirt separator increases as the hole size decreases. Conversely, the pressure drop across the dirt separator increases as the hole size decreases. By employing holes having a minimum dimension (i.e. shortest distance across the hole) that is no less than 0.1, a significant increase in the pressure drop across the dirt separator may be avoided. Additionally, by employing holes having a minimum dimension that is no greater than 1.0 mm, a significant decrease in the separation efficiency of the dirt separator may be avoided.

When operated under conditions typically found in a domestic vacuum cleaner, a good balance between separation efficiency and pressure drop may be achieved with holes having a minimum dimension of between 0.2 mm and 0.5 mm.

As the disc rotates, the disc imparts swirl to the cleansed fluid moving through the holes. As the thickness of the disc increases, the swirl imparted to the cleansed fluid increases. This then has two adverse consequences. First, the pressure drop associated

with the dirt separator increases. Second, the power required to drive the disc at a particular speed increases. If the disc is driven by a turbine, a vacuum cleaner having a more powerful vacuum motor will be required to generate the higher flow rate necessary to drive the turbine and disc. If, on the other hand, the disc is driven by an electric motor, a more powerful electric motor will be required to drive the disc. Accordingly, the disc may have a thickness no greater than 0.5 mm.

The holes may be formed in a perforated region of the disc having an open area of at least 25%. As a result, a relatively large total open area may be achieved for the disc. By increasing the total open area of the disc, the axial speed of the fluid moving through the holes is likely to decrease. As a result, less dirt is likely to be carried by the fluid through the holes and thus an increase in separation efficiency may be observed. Additionally, by increasing the total open area of the disc, a smaller pressure drop across the dirt separator may be observed.

The diameter of the disc may be greater than the diameter of the inlet. This then has at least two benefits. First, a relatively large total open area may be achieved for the disc. Indeed, the disc may have a total open area greater than that of the inlet. As already noted, by increasing the total open area of the disc, the axial speed of the fluid moving through the holes is likely to decrease, as is the pressure drop associated with the dirt separator. Second, relatively high tangential speeds may be achieved by this disc. As the tangential speeds of the disc increase, the tangential forces imparted to the dirt-laden fluid by the disc increase. As a result, more dirt is likely to be separated from the fluid by the disc and thus an increase in separation efficiency may be observed.

The disc may comprise an inner region surrounded by an outer region, and the inner region may have an open area less than that of the outer region. In particular, the inner region may have an open area less than 10% and the outer region may have an open area greater than 20%. Since the tangential speed of the disc decreases from the perimeter to the centre of the disc, the tangential forces imparted to the dirt-laden fluid by the disc are smaller at the inner region. By ensuring that the open area of the inner

region is smaller than that of the outer region, an increase in separation efficiency may be observed.

The diameter of the inner region may be no less than a third of the diameter of the disc.

5 As a result, the majority of the holes are provided at a region of the disc where the tangential speeds and thus the tangential forces imparted to the dirt are relatively high. As a result, an increase in separation efficiency may be observed. Additionally, having a sizeable inner region with a smaller open area may increase the stiffness of the disc.

10 Additionally or alternatively, the diameter of the inner region may be no less than the diameter of the inlet. The dirt-laden fluid entering the chamber is then better encouraged to turn from an axial direction to a radial direction. This then has the benefit that the radial speed of the fluid moving over the holes is higher and thus less of the dirt carried by the fluid is able to match the turn and pass axially through the holes.

15 Relatively hard objects carried by the fluid may impact the disc and puncture or otherwise damage the land between holes. By having an inner region of the disc that is at least the same size as the inlet and has a smaller open area, the risk of the damaging the disc is reduced. In particular, by having a smaller open area, the land between holes is greater and thus the risk of dirt puncturing the land is reduced.

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The holes may be formed in the outer region and the inner region may be non-perforated. By ensuring that the inner region is non-perforated, the holes are provided at a region of the disc where the tangential speeds and thus the tangential forces imparted to the dirt are relatively high. As a result, an increase in separation efficiency

25 may be observed. Additionally, damage arising from hard objects impacting the disc may be reduced.

The dirt-laden fluid entering the chamber may be directed at the disc. That is to say that the dirt-laden fluid may enter the chamber via the inlet along a flow axis that intersects

30 the disc. The provision of a rotating disc within a dirt separator of a vacuum cleaner is known. However, there is an existing prejudice that the dirt separator must include a

cyclone chamber to separate the dirt from the fluid. The disc is then used merely as an auxiliary filter to remove residual dirt from the fluid as it exits the cyclone chamber. There is a further prejudice that the rotating disc must be protected from the bulk of the dirt that enters the cyclone chamber. As a result, the dirt-laden fluid is introduced into the cyclone chamber in a manner that avoids direct collision with the disc. However, by directing the dirt-laden fluid at the disc, the dirt is subjected to relatively high tangential forces upon contact with the rotating disc. Dirt within the fluid is then thrown radially outward whilst the fluid passes axially through the holes in the disc. As a result, effective dirt separation may be achieved without the need for cyclonic flow.

The dirt-laden fluid entering the chamber may be directed at the centre of the disc. That is to say that the flow axis may intersect the centre of the disc. This then has the advantage that the flow of the dirt-laden fluid over the surface of the disc may be more evenly distributed. By contrast, if the dirt-laden fluid were directed off-centre at the disc, the fluid would most likely be unevenly distributed. The axial speed of the fluid moving through the holes may then increase at those regions of the disc that are most heavily loaded, resulting in a decrease in separation efficiency. Additionally, dirt separated from the fluid may collect unevenly within the chamber, thereby compromising the capacity of the dirt separator. Re-entrainment of dirt may also increase, leading to a further decrease in the separation efficiency. A further disadvantage of directing the dirt-laden fluid off-centre is that the disc may be subjected to uneven structural load. The resulting imbalance may lead to increased vibration and noise, and/or may reduce the lifespan of any bearings used to support the rotating disc.

The holes may be formed by chemical etching or laser machining. As a result, a large number of holes at the specified dimensions may be accurately formed in a timely and cost-effective manner.

The dirt separator may comprise an electric motor for driving the disc. As a result, the speed of the disc and thus the tangential forces imparted to the dirt are relatively

insensitive to flow rates and fluid speeds. Consequently, in contrast to a turbine, relatively high separation efficiencies may be achieved at relatively low flow rates.

The present invention also provides a handheld vacuum cleaner comprising a dirt separator as described in any one of the preceding paragraphs.

Although the provision of a rotating disc within a dirt separator of a vacuum cleaner is known, there is an existing prejudice that the dirt separator must include a cyclone chamber to separate the dirt from the fluid. As a result, the overall size of the dirt separator is relatively large and is unsuited for use in a handheld unit. With the dirt separator of the present invention, effective separation may be achieved in a relatively compact manner. As a result, the dirt separator is particularly well suited for use in a handheld unit.

The present invention further provides a stick vacuum cleaner comprising a handheld unit attached to a cleaner head by an elongate tube, wherein the handheld unit comprises a dirt separator as described in any one of the preceding paragraphs, and the elongate tube extends along an axis parallel to the rotational axis.

By having an elongate tube that extends parallel to the rotational axis, dirt-laden fluid may be carried from the cleaner head to the dirt separator and the rotating disc along a relatively straight path. As a result, pressure losses may be reduced.

In order that the present invention may be more readily understood, embodiments of the invention will now be described, by way of example, with reference to the accompanying drawings in which:

Figure 1 is a perspective view of a vacuum cleaner;

Figure 2 is a section through a part of the vacuum cleaner;

Figure 3 is a section through a dirt separator of the vacuum cleaner;

Figure 4 is a plan view of a disc of the dirt separator;

5 Figure 5 illustrates the flow of dirt-laden fluid through the dirt separator;

Figure 6 illustrates emptying of the dirt separator;

10 Figure 7 is a section through a part of the vacuum cleaner when used for above-floor cleaning;

Figure 8 illustrates the tangential forces imparted by the disc to the dirt-laden fluid at the circumference of an inlet duct that is (a) directed at the centre of the disc and (b) is directed off-centre;

15 Figure 9 is a section through a first alternative dirt separator;

Figure 10 is a section through a part of a vacuum cleaner having a second alternative dirt separator;

20 Figure 11 is a section through a third alternative dirt separator;

Figure 12 is a section through a part of a vacuum cleaner having the third alternative dirt separator;

25 Figure 13 illustrates emptying of the third alternative dirt separator;

Figure 14 is a section through a fourth alternative dirt separator;

30 Figure 15 illustrates alternative hole shapes and sizes for the disc forming part of any one of the dirt separators; and

Figure 16 illustrates an alternative disc assembly that may form part of any one of the dirt separators.

- 5 The vacuum cleaner 1 of Figure 1 comprises a handheld unit 2 attached to a cleaner head 4 by means of an elongate tube 3. The elongate tube 3 is detachable from the handheld unit 2 such that the handheld unit 2 may be used as a standalone vacuum cleaner.
- 10 Referring now to Figures 2 to 7, the handheld unit 2 comprises a dirt separator 10, a pre-motor filter 11, a vacuum motor 12 and a post-motor filter 13. The pre-motor filter 11 is located downstream of the dirt separator 10 but upstream of the vacuum motor 12, and the post-motor filter 13 is located downstream of the vacuum motor 12. During use, the vacuum motor 12 causes dirt-laden fluid to be drawn in through a suction
- 15 opening in the underside of the cleaner head 4. From the cleaner head 4, the dirt-laden fluid is drawn along the elongate tube 3 and into the dirt separator 10. Dirt is then separated from the fluid and retained within the dirt separator 10. The cleansed fluid exits the dirt separator 10 and is drawn through the pre-motor filter 11, which removes residual dirt from the fluid before passing through the vacuum motor 12. Finally, the
- 20 fluid expelled by the vacuum motor 12 passes through the post-motor filter 13 and is exhausted from the vacuum cleaner 1 via vents 14 in the handheld unit 2.

The dirt separator comprises a container 20, an inlet duct 21, and a disc assembly 22.

- 25 The container 20 comprises a top wall 30, a side wall 31, and a bottom wall 32 that collectively define a chamber 36. An opening in the centre of the top wall defines an outlet 38 of the chamber 36. The bottom wall 32 is attached to the side wall 31 by means of a hinge 33. A catch 34 attached to the bottom wall 32 engages with a recess in the side wall 31 to hold the bottom wall 32 in a closed position. Releasing the
- 30 catch 34 then causes the bottom wall 32 to swing to an open position, as illustrated in Figure 6.

The inlet duct 21 extends upwardly through the bottom wall 32 of the container 20. The inlet duct 21 extends centrally within the chamber 36 and terminates a short distance from the disc assembly 22. One end of the inlet duct 21 defines an inlet 37 of the chamber 36. The opposite end of the inlet duct 21 is attachable to the elongate tube 3 or an accessory tool when the handheld unit 2 is used as a standalone cleaner.

The disc assembly 22 comprises a disc 40 coupled to an electric motor 41. The electric motor 41 is located outside of the chamber 36, and the disc 40 is located at and covers the outlet 38 of the chamber 36. When powered on, the electric motor 41 causes the disc 40 to rotate about a rotational axis 48. The disc 40 is formed of a metal and comprises a central non-perforated region 45 surrounded by a perforated region 46. The periphery of the disc 40 overlies the top wall 30 of the container 20. As the disc 40 rotates, the periphery of the disc 40 contacts and forms a seal with the top wall 30. In order to reduce friction between the disc 40 and the top wall 30, a ring of low-friction material (e.g. PTFE) may be provided around the top wall 30.

During use, the vacuum motor 12 causes dirt-laden fluid to be drawn into the chamber 36 via the inlet 37. The inlet duct 21 extends centrally within the chamber 36 along an axis that is coincident with the rotational axis 48 of the disc 40. As a result, the dirt-laden fluid enters the chamber 36 in an axial direction (i.e. in a direction parallel to the rotational axis 48). Moreover, the dirt-laden fluid is directed at the centre of the disc 40. The central non-perforated region of the disc 40 causes the dirt-laden fluid to turn and move radially outward (i.e. in a direction normal to the rotational axis). The rotating disc 40 imparts tangential forces to the dirt-laden fluid, causing the fluid to swirl. As the dirt-laden fluid moves radially outward, the tangential forces imparted by the disc 40 increase. Upon reaching the perforated region 46 of the disc 40, the fluid is drawn axially through the holes 47 in the disc 40. This requires a further turn in the direction of the fluid. The inertia of the larger and heavier dirt is too great to allow the dirt to follow the fluid. As a result, rather than being drawn through the holes 47, the dirt continues to move radially outwards and eventually collects at the bottom of the

chamber 36. Smaller and lighter dirt may follow the fluid through the disc 40. The bulk of this dirt is then subsequently removed by the pre-motor and post-motor filters 11,13. In order to empty the dirt separator 10, the catch 34 is released and the bottom wall 32 of the container 20 swings open. As illustrated in Figure 6, the container 20 and the inlet duct 21 are configured such that the inlet duct 21 does not prevent or otherwise hinder the movement of the bottom wall 32.

In addition to cleaning floor surfaces, the vacuum cleaner 1 may be used to clean above-floor surfaces such as shelves, curtains or ceilings. When cleaning these surfaces, the handheld unit 2 may be inverted as shown in Figure 7. Dirt 50 collected in the chamber 36 may then fall down towards the disc 40. Any dirt falling onto the disc 40 is likely to be drawn through or block some of the holes 47 in the perforated region 46. As a result, the available open area of the disc 40 will decrease and the speed of the fluid moving axially through the disc 40 will increase. More dirt is then likely to be carried by the fluid through the disc 40 and thus the separation efficiency of the dirt separator 10 is likely to decrease. The top wall 30 of the container 20 is not flat but is instead stepped. As a result, the chamber 36 comprises a gulley located between the side wall 31 and the step in the top wall 30. This gulley surrounds the disc 40 and acts to collect dirt 50 that falls down the chamber 36. As a result, less dirt is likely to fall onto the disc 40 when the handheld unit 2 is inverted.

The dirt separator 10 has several advantages over a conventional separator that employs a porous bag. The pores of a bag quickly clog with dirt during use. This then reduces the suction that is achieved at the cleaner head. Additionally, the bag must normally be replaced when full, and it is not always easy to determine when the bag is full. With the dirt separator described herein, rotation of the disc 40 ensures that the holes 47 in the perforated region 46 are generally kept clear of dirt. As a result, no significant reduction in suction is observed during use. Additionally, the dirt separator 10 may be emptied by opening the bottom wall 32 of the container 20, thus avoiding the need for replacement bags. Furthermore, by employing a transparent material for the side wall 31 of the container 20, a user is able to determine with relative ease when the dirt

separator 10 is full and requires emptying. The aforementioned disadvantages of a porous bag are well known and are solved equally well by a separator that employs cyclonic separation. However, the dirt separator 10 described herein also has advantages over a cyclonic separator.

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In order to achieve a relatively high separation efficiency, the cyclonic separator of a vacuum cleaner typically comprises two or more stages of separation. The first stage often comprises a single, relatively large cyclone chamber for removing coarse dirt, and the second stage comprises a number of relatively small cyclone chambers for removing
10 fine dirt. As a result, the overall size of the cyclonic separator can be relatively large. A further difficulty with the cyclonic separator is that it requires high fluid speeds in order to achieve high separation efficiencies. Furthermore, the fluid moving through the cyclonic separator often follows a relatively long path as it travels from the inlet to the outlet. The long path and high speeds result in high aerodynamic losses. As a result,
15 the pressure drop associated with the cyclonic separator can be high. With the dirt separator described herein, relatively high separation efficiencies can be achieved in a more compact manner. In particular, the dirt separator comprises a single stage having a single chamber. Furthermore, separation occurs primarily as a result of the angular momentum imparted to the dirt-laden fluid by the rotating disc 40. As a result,
20 relatively high separation efficiencies can be achieved at relatively low fluid speeds. Additionally, the path taken by the fluid in moving from the inlet 37 to the outlet 38 of the dirt separator 10 is comparatively short. As a consequence of the lower fluid speeds and shorter path, aerodynamic losses are smaller. As a result, the pressure drop across the dirt separator 10 is smaller than that across the cyclonic separator, for the same
25 separation efficiency. The vacuum cleaner 1 is therefore able to achieve the same cleaning performance as that of a cyclonic vacuum cleaner using a less powerful vacuum motor. This is particularly important should the vacuum cleaner 1 be powered by a battery, since any reduction in the power consumption of the vacuum motor 11 may be used to increase the runtime of the vacuum cleaner 1.

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The provision of a rotating disc within a dirt separator of a vacuum cleaner is known. For example, DE19637431 and US4382804 each describe a dirt separator having a rotating disc. However, there is an existing prejudice that the dirt separator must include a cyclone chamber to separate the dirt from the fluid. The disc is then used
5 merely as an auxiliary filter to remove residual dirt from the fluid as it exits the cyclone chamber. There is a further prejudice that the rotating disc must be protected from the bulk of the dirt that enters the cyclone chamber. The dirt-laden fluid is therefore introduced into the cyclone chamber in a manner that avoids direct collision with the disc.

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The dirt separator described herein exploits the finding that dirt separation may be achieved with a rotating disc without the need for a cyclone chamber. The dirt separator further exploits the finding that effective dirt separation may be achieved by introducing the dirt-laden fluid into a chamber in a direction directly towards the disc. By directing
15 the dirt-laden fluid at the disc, the dirt is subjected to relatively high forces upon contact with the rotating disc. Dirt within the fluid is then thrown radially outward whilst the fluid passes axially through the holes in the disc. As a result, effective dirt separation is achieved without the need for cyclonic flow.

20 The separation efficiency of the dirt separator 10 and the pressure drop across the dirt separator 10 are sensitive to the size of the holes 47 in the disc 40. For a given total open area, the separation efficiency of the dirt separator 10 increases as the hole size decreases. However, the pressure drop across the dirt separator 10 also increases as the hole size decreases. The separation efficiency and the pressure drop are also sensitive
25 to the total open area of the disc 40. In particular, as the total open area increases, the axial speed of the fluid moving through the disc 40 decreases. As a result, the separation efficiency increases and the pressure drop decreases. It is therefore advantageous to have a large total open area. However, increasing the total open area of the disc 40 is not without its difficulties. For example, as already noted, increasing the
30 size of the holes in order to increase the total open area may actually decrease the separation efficiency. As an alternative, the total open area may be increased by

increasing the size of the perforated region 46. This may be achieved by increasing the size of the disc 40 or by decreasing the size of the non-perforated region 45. However, each of these options has its disadvantages. For example, since a contact seal is formed between the periphery of the disc 40 and the top wall 30, more power will be required to drive a disc 40 having a larger diameter. Additionally, a rotating disc 40 of larger diameter may generate more stirring within the chamber 36. As a result, re-entrainment of dirt already collected in the chamber 36 may increase and thus there may actually be a net decrease in the separation efficiency. On the other hand, if the diameter of the non-perforated region 45 were decreased then, for reasons detailed below, the axial speed of the fluid moving through the disc 40 may actually increase. Another way of increasing the total open area of the disc 40 is to decrease the land between the holes 47. However, decreasing the land has its own difficulties. For example, the stiffness of the disc 40 is likely to decrease and the perforated region 46 is likely to become more fragile and thus more susceptible to damage. Additionally, decreasing the land between holes may introduce manufacturing difficulties. There are therefore many factors to consider in the design of the disc 40.

The disc 40 comprises a central non-perforated region 45 surrounded by a perforated region 46. The provision of a central non-perforated region 45 has several advantages, which will now be described.

The stiffness of the disc 40 may be important in achieving an effective contact seal between the disc 40 and the top wall 30 of the container 20. Having a central region 45 that is non-perforated increases the stiffness of the disc 40. As a result, a thinner disc may be employed. This then has the benefit that the disc 40 may be manufactured in a more timely and cost-effective manner. Moreover, for certain methods of manufacture (e.g. chemical etching), the thickness of the disc 40 may define the minimum possible dimensions for the holes 47 and land. A thinner disc therefore has the benefit that such methods may be used to manufacture a disc having relatively small hole and/or land dimensions. Furthermore, the cost and/or weight of the disc 40, along with the mechanical power required to drive the disc 40, may be reduced. Consequently, a less

powerful, and potentially smaller and cheaper motor 41 may be used to drive the disc 40.

5 By having a central non-perforated region 45, the dirt-laden fluid entering the chamber 36 is forced to turn from an axial direction to a radial direction. The dirt-laden fluid then moves outward over the surface of the disc 40. This then has at least two benefits. First, as the dirt-laden fluid moves over the perforated region 46, the fluid is required to turn through a relatively large angle (around 90 degrees) in order to pass through the holes 47 in the disc 40. As a result, less of the dirt carried by the fluid is
10 able to match the turn and pass through the holes 47. Second, as the dirt-laden fluid moves outward over the surface of the disc 40, the dirt-laden fluid helps to scrub the perforated region 46. Consequently, any dirt that may have become trapped at a hole 47 is swept clear by the fluid.

15 The tangential speed of the disc 40 decreases from the perimeter to the centre of the disc 40. As a result, the tangential forces imparted to the dirt-laden fluid by the disc 40 decrease from the perimeter to the centre. If the central region 45 of the disc 40 were perforated, more dirt is likely to pass through the disc 40. By having a central non-perforated region 45, the holes 47 are provided at regions of the disc 40 where the
20 tangential speeds and thus the tangential forces imparted to the dirt are relatively high.

As the dirt-laden fluid introduced into the chamber 36 turns from axial to radial, relatively heavy dirt may continue to travel in an axial direction and impact the disc 40. If the central region 45 of the disc 40 were perforated, relatively hard objects impacting
25 the disc 40 may puncture or otherwise damage the land between the holes 47. By having a central region 45 that is non-perforated, the risk of damaging the disc 40 is reduced.

The diameter of the non-perforated region 45 is greater than the diameter of the inlet 37.
30 As a result, hard objects carried by the fluid are less likely to impact the perforated region 46 and damage the disc 40. Additionally, the dirt-laden fluid is better

encouraged to turn from an axial direction to a radial direction on entering the chamber 36. The separation distance between the inlet 37 and the disc 40 plays an important part in achieving both these benefits. As the separation distance between the inlet 37 and the disc 40 increases, the radial component of the velocity of the dirt-laden fluid at the perforated region 46 of the disc 40 is likely to decrease. As a result, more dirt is likely to be carried through the holes 47 in the disc 40. Additionally, as the separation distance increases, hard objects carried by the fluid are more likely to impact the perforated region 46 and damage the disc 40. A relatively small separation distance is therefore desirable. However, if the separation distance is too small, dirt larger than the separation distance will be unable to pass between the inlet duct 21 and the disc 40 and will therefore become trapped. The size of the dirt carried by the fluid will be limited by, among other things, the diameter of the inlet duct 21. In particular, the size of the dirt is unlikely to be greater than the diameter of the inlet duct 21. Accordingly, by employing a separation distance that is no greater than the diameter of the inlet 37, the aforementioned benefits may be achieved whilst providing sufficient space for dirt to pass between the inlet duct 21 and the disc 40.

Irrespective of the separation distance that is chosen, the non-perforated region 45 of the disc 40 continues to provide advantages. In particular, the non-perforated region 45 ensures that the holes 47 in the disc 40 are provided at regions where tangential forces imparted to the dirt by the disc 40 are relatively high. Additionally, although the dirt-laden fluid follows a more divergent path as the separation distance increases, relatively heavy objects are still likely to continue along a relatively straight path upon entering the chamber 36. A central non-perforated region 45 therefore continues to protect the disc 40 from potential damage.

In spite of the advantages, the diameter of the non-perforated region 45 need not be greater than the diameter of the inlet 37. By decreasing the size of the non-perforated region 45, the size of the perforated region 46 and thus the total open area of the disc 46 may be increased. As a result, the pressure drop across the dirt separator 10 is likely to decrease. Additionally, a decrease in the axial speed of the dirt-laden fluid moving

through the perforated region 46 may be observed. However, as the size of the non-perforated region 45 decreases, there will come a point at which the fluid entering the chamber 36 is no longer forced to turn from axial to radial before encountering the perforated region 46. There will therefore come a point at which the decrease in axial speed due to the larger open area is offset by the increase in axial speed due to the smaller turn angle.

Conceivably, the central region 45 of the disc 40 may be perforated. Although many of the advantages described above would then be forfeited, there may nevertheless be advantages in having a disc 40 that is fully perforated. For example, it may be simpler and/or cheaper to manufacture the disc 40. In particular, the disc 40 may be cut from a continuously perforated sheet. Even if the central region 45 were perforated, the disc 40 would continue to impart tangential forces to the dirt-laden fluid entering the chamber 36, albeit smaller forces at the centre of the disc 40. The disc 40 would therefore continue to separate dirt from the fluid, albeit at a reduced separation efficiency. Additionally, if the central region 45 of the disc 40 were perforated, dirt may block the holes at the very centre of the disc 40 owing to the relatively low tangential forces imparted by the disc 40. With the holes at the very centre blocked, the disc 40 would then behave as if the centre of the disc 40 were non-perforated. Alternatively, the central region 45 may be perforated but have an open area that is less than that of the surrounding perforated region 46. Moreover, the open area of the central region 45 may increase as one moves radially outward from the centre of the disc 40. This then has the benefit that the open area of the central region 45 increases as the tangential speed of the disc 40 increases.

The inlet duct 21 extends along an axis that is coincident with the rotational axis 48 of the disc 40. As a result, the dirt-laden fluid entering the chamber 36 is directed at the centre of the disc 40. This then has the advantage that the dirt-laden fluid is distributed evenly over the surface of the disc 40. By contrast, if the inlet duct 21 were directed off-centre at the disc 40, the fluid would be unevenly distributed. In order to illustrate this point, Figure 8 shows the tangential forces imparted to the dirt-laden fluid by the

disc at the circumference of an inlet duct 21 that is (a) directed at the centre of the disc 40 and (b) is directed off-centre. It can be seen that, when the inlet duct 21 is directed off-centre, the dirt-laden fluid does not flow evenly over the surface of the disc 40. In the example shown in Figure 8(b), the lower half of the disc 40 sees very little of the dirt-laden fluid. This uneven distribution of fluid over the disc 40 is likely to have one or more adverse effects. For example, the axial speed of the fluid through the disc 40 is likely to increase at those regions that are most heavily exposed to the dirt-laden fluid. As a result, the separation efficiency of the dirt separator 10 is likely to decrease. Additionally, dirt separated by the disc 40 may collect unevenly within the container 20. As a result, the capacity of the dirt separator 10 may be compromised. Re-entrainment of dirt 50 already collected within the container 20 may also increase, leading to a further decrease in the separation efficiency. A further disadvantage of directing the dirt-laden fluid off-centre is that the disc 40 is subjected to uneven structural load. The resulting imbalance may lead to a poor seal with the top wall 30 of the container 20, and may reduce the lifespan of any bearings used to support the disc assembly 22 within the vacuum cleaner 1.

The inlet duct 21 is attached to and may be formed integrally with the bottom wall 32. The inlet duct 21 is therefore supported within the chamber by the bottom wall 32. The inlet duct 21 may alternatively be supported by the side wall 31 of the container 20, e.g. using one or more braces that extend radially between the inlet duct 21 and the side wall 31. This arrangement has the advantage that the bottom wall 32 is free to open and close without movement of the inlet duct 21. As a result, a taller container 20 having a larger dirt capacity may be employed. However, a disadvantage with this arrangement is that the braces used to support the inlet duct 21 are likely to inhibit dirt falling from the chamber 36 when the bottom wall 32 is opened, thus making emptying of the container 20 more difficult.

The inlet duct 21 extends linearly within the chamber 36. This then has the advantage that the dirt-laden fluid moves through the inlet duct 21 along a straight path. However, this arrangement is not without its difficulties. The bottom wall 32 is arranged to open

and close and is attached to the side wall 31 by means of a hinge 33 and catch 34. Accordingly, when a user applies a force to the handheld unit 2 in order to manoeuvre the cleaner head 4 (e.g. a push or pull force in order to manoeuvre the cleaner head 4 forwards and backwards, a twisting force in order to steer the cleaner head 4 left or right, or a lifting force in order to lift the cleaner head 4 off the floor), the force is transferred to the cleaner head 4 via the hinge 33 and catch 34. The hinge 33 and catch 34 must therefore be designed in order to withstand the required forces. As an alternative arrangement, the bottom wall 32 may be fixed to the side wall 31, and the side wall 31 may be removably attached to the top wall 30. The container 20 is then emptied by removing the side and bottom walls 31,32 from the top wall 30 and inverting. Although this arrangement has the advantage that it is not necessary to design a hinge and catch capable of withstanding the required forces, the dirt separator 10 is less convenient to empty.

An alternative dirt separator 101 is illustrated in Figure 9. Part of the inlet duct 21 extends along and is attached to or is formed integrally with the side wall 31 of the container 20. The bottom wall 32 is again attached to the side wall 31 by a hinge 33 and catch (not shown). However, the inlet duct 21 no longer extends through the bottom wall 32. Accordingly, when the bottom wall 32 moves between the closed and opened positions, the position of the inlet duct 21 is unchanged. This then has the advantage that the container 20 is convenient to empty without the need to design a hinge and catch capable of withstanding the required forces. However, as is evident from Figure 9, the inlet duct 21 is no longer straight. As a result, there will be increased losses due to the bends in the inlet duct 21 and thus the pressure drop associated with the dirt separator 10 is likely to increase. Although the inlet duct 21 of the arrangement shown in Figure 9 is no longer straight, the end portion of the inlet duct 21 continues to extend along an axis that is coincident with the rotational axis 48 of the disc 40. As a result, the dirt-laden fluid continues to enter the chamber 36 in an axial direction that is directed at the centre of the disc 40.

Figure 10 illustrates a further dirt separator 102 in which the inlet duct 21 extends linearly through the side wall 31 of the container 20. The bottom wall 32 is then attached to the side wall 31 by means of a hinge 33 and is held closed by a catch 34. In the arrangements illustrated in Figures 3 and 9, the chamber 36 of the dirt separator 10,101 is essentially cylindrical in shape, with the longitudinal axis of the chamber 36 coincident with the rotational axis 48 of the disc. The disc 40 is then located towards the top of the chamber 36, and the inlet duct 21 extends upwardly from the bottom of the chamber 36. Reference to top and bottom should be understood to mean that dirt separated from the fluid collects preferentially at the bottom of the chamber 36, and fills progressively in a direction towards the top of the chamber 36. With the arrangement shown in Figure 10, the shape of the chamber 36 may be thought of as the union of a cylindrical top portion and a cubical bottom portion. Both the disc 40 and the inlet duct 21 are then located towards the top of the chamber 36. Since the inlet duct 21 extends through the side wall 31 of the container 20, this arrangement has the advantage that the container 20 may be conveniently emptied via the bottom wall 32 without the need for a hinge and catch capable of withstanding the forces required to manoeuvre the cleaner head 4. Additionally, since the inlet duct 21 is linear, pressure losses associated with the inlet duct 21 are reduced. The arrangement has at least three further advantages. First, the dirt capacity of the dirt separator 102 is significantly increased. Second, when the handheld unit 2 is inverted for above-floor cleaning, dirt within the container 20 is less likely to fall onto the disc 40. There is therefore no need for the chamber 36 to include a protective gulley around the disc 40, and thus a larger disc 40 having a larger total open area may be used. Third, the bottom wall 32 of the container 20 may be used to support the handheld unit 2 when resting on a level surface. This arrangement is not, however, without its disadvantages. For example, the larger container 20 may obstruct access to narrow spaces, such as between items of furniture or appliances. Additionally, the bottom of the chamber 36 is spaced radially from the top of the chamber 36. That is to say that the bottom of the chamber 36 is spaced from the top of the chamber 36 in a direction normal to the rotational axis 48 of the disc 40. As a result, dirt and fluid thrown radially outward by the disc 40 may disturb the dirt collected in the bottom of the chamber 36.

Additionally, any swirl within the chamber 36 will tend to move up and down the chamber 36. Consequently, re-entrainment of dirt may increase, resulting in a decrease in separation efficiency. By contrast, in the arrangements illustrated in Figures 3 and 9, the bottom of the chamber 36 is spaced axially from the top of the chamber 36. Dirt and fluid thrown radially outward by the disc 40 is therefore less likely to disturb the dirt collected in the bottom of the chamber 36. Additionally, any swirl within the chamber 36 moves around the chamber 36 rather than up and down the chamber 36.

In each of the dirt separators 10, 101, 102 described above, at least the end portion of the inlet duct 21 (i.e. that portion having the inlet 37) extends along an axis that is coincident with the rotational axis 48 of the disc 40. As a result, the dirt-laden fluid enters the chamber 36 in an axial direction that is directed at the centre of the disc 40. The advantages of this have been described above. However, there may instances for which it is desirable to have an alternative arrangement. For example, Figures 11-13 illustrate a dirt separator 103 in which the inlet duct 21 extends along an axis that is angled relative to the rotational axis 48 of the disc 40. That is to say that the inlet duct 21 extends along an axis that is non-parallel to the rotational axis 48. As a consequence of this arrangement, the dirt-laden fluid enters the chamber in a direction that is non-parallel to the rotational axis 48. Nevertheless, the dirt-laden fluid entering the chamber 36 continues to be directed at the disc 40. Indeed, with the dirt separator 103 shown in Figures 11-13, the dirt-laden fluid continues to be directed at the centre of the disc 40. This particular arrangement may be advantageous for a couple of reasons. First, when the vacuum cleaner 1 is used for floor cleaning, as shown in Figure 1, the handheld unit 2 is generally directed downwards at an angle of about 45 degrees. As a result, dirt may collect unevenly within the dirt separator. In particular, dirt may collect preferentially along one side of the chamber 36. With the dirt separator 10 shown in Figure 3, this uneven collection of dirt may mean that dirt fills to the top of the chamber 36 along one side, thus triggering a chamber-full condition, even though the opposite side of the chamber 36 may be relatively free of dirt. As illustrated in Figure 12, the dirt separator 103 of Figures 11-13 may make better use of the available space. As a result, the capacity of the dirt separator 10 may be improved. The

dirt separator 101 of Figure 9 may also be said to have this advantage. However, the inlet duct 21 of the dirt separator 101 includes two bends. By contrast, the inlet duct 21 of the dirt separator 103 of Figures 11-13 is generally linear, and thus pressure losses are smaller. A further advantage of the arrangement shown in Figures 11-13 relates to emptying. As with the arrangement shown in Figure 3, the inlet duct 21 is attached to and is moveable with the bottom wall 32. As shown in Figure 6, when the dirt separator 10 of Figure 3 is held vertically and the bottom wall 32 is in the open position, the inlet duct 21 extends horizontally. By contrast, as shown in Figure 13, when the dirt separator 103 of Figures 11-13 is held vertically and the bottom wall 32 is opened, the inlet duct 21 is inclined downward. As a result, dirt is better encouraged to slide off the inlet duct 21.

In the arrangement shown in Figures 11-13, the dirt-laden fluid entering the chamber 36 continues to be directed at the centre of the disc 40. Although there are advantages in this arrangement, effective separation of dirt may nevertheless be achieved by directing the dirt-laden fluid off-centre. Moreover, there may be instances for which it is desirable to direct the dirt-laden fluid off-centre. For example, if the central region of the disc 40 were perforated, the dirt-laden fluid may be directed off-centre so as to avoid the region of the disc 40 where tangential speeds are slowest. As a result, a net gain in separation efficiency may be observed. By way of example, Figure 14 illustrates an arrangement in which the dirt-laden fluid entering the chamber 36 is directed off-centre at the disc 40. Similar to the arrangement shown in Figure 9, the inlet duct 21 is formed integrally with the side wall 31 of the container 20, and the bottom wall 32 is attached to the side wall 31 by a hinge 33 and catch (not shown). When the bottom wall 32 moves between the closed and opened positions, the position of the inlet duct 21 remains fixed. This then has the advantage that the container 20 is convenient to empty without the need to design a hinge and catch capable of withstanding the forces required to manoeuvre the cleaner head 4. Moreover, in contrast to the dirt separator 101 of Figure 9, the inlet duct 21 is straight and thus pressure losses arising from the movement of the dirt-laden fluid through the inlet duct 21 are reduced.

In a more general sense, the dirt-laden fluid may be said to enter the chamber 36 along a flow axis 49. The flow axis 49 then intersects the disc 40 such that the dirt-laden fluid is directed at the disc 40. This then has the benefit that the dirt-laden fluid impacts the disc 40 shortly after entering the chamber 36. The disc 40 then imparts tangential forces to the dirt-laden fluid. The fluid is drawn through the holes 47 in the disc 40 whilst the dirt, owing to its greater inertia, moves radially outward and collects in the chamber 36. In the arrangements shown in Figures 3, 9, 10 and 11, the flow axis 49 intersects the centre of the disc 40, whilst in the arrangement shown in Figure 14, the flow axis 49 intersects the disc 40 off-centre. Although there are advantages in having a flow axis 49 that intersects the centre of the disc 40, effective separation of dirt may nevertheless be achieved by having a flow axis 49 that intersects the disc 40 off-centre.

In each of the arrangements described above, the inlet duct 21 has a circular cross-section and thus the inlet 37 has a circular shape. Conceivably, the inlet duct 21 and the inlet 37 may have alternative shapes. Likewise, the shape of the disc 40 need not be circular. However, since the disc 40 rotates, it is not clear what advantages would be gained from having a non-circular disc. The perforated and non-perforated regions 45,46 of the disc 40 may also have different shapes. In particular, the non-perforated region 45 need not be circular or located at the centre of the disc 40. For example, where the inlet duct 21 is directed off-centre at the disc 40, the non-perforated region 45 may take the form of an annulus. In the above discussions, reference is sometimes made to the diameter of a particular element. Where that element has a non-circular shape, the diameter corresponds to the maximal width of the element. For example, if the inlet 37 were rectangular or square in shape, the diameter of the inlet 37 would correspond to the diagonal of the inlet 37. Alternatively, if the inlet were elliptical in shape, the diameter of the inlet 37 would correspond to the width of the inlet 37 along the major axis.

The disc 40 is formed of a metal, such as stainless steel, which has at least two advantages over, say, a plastic. First, a relatively thin disc 40 having a relatively high stiffness may be achieved. Second, a relatively hard disc 40 may be achieved that is

less susceptible to damage from hard or sharp objects that are carried by the fluid or fall onto the disc 40 when the handheld unit 2 is inverted, as shown in Figure 7. Nevertheless, in spite of these advantages, the disc 40 could conceivably be formed of alternative materials, such as plastic. Indeed, the use of a plastic may have advantages over a metal. For example, by forming the disc 40 of a low-friction plastic, such as polyoxymethylene, the ring of low-friction material (e.g. PTFE) provided around the top wall 30 of the container 20 may be omitted.

As noted above, the separation efficiency of the dirt separator 10 and the pressure drop across the dirt separator 10 are sensitive to the size of the holes 47 in the disc 40. Under conditions typically found in a domestic vacuum cleaner (e.g. flow rates, type of dirt), the separation efficiency of the dirt separator 10 was observed to decrease significantly when the size of the holes was greater than 1.0 mm. The pressure drop, on the other hand, was observed to increase significantly when the size of the holes was less than 0.1 mm. Accordingly, benefits in terms of separation efficiency and pressure drop may be achieved by ensuring that the holes are between 0.1 mm and 1.0 mm. A hole size of between 0.2 mm and 0.5 mm was found to provide a good balance between separation efficiency and pressure drop over a range of flow rates typically found in a domestic vacuum cleaner.

The thickness of the disc 40 is also an important factor. A thicker disc 40 is naturally stiffer and less susceptible to damage. However, a thicker disc 40 is not without its disadvantages. As the disc 40 rotates, the wall of each hole 47 pushes the fluid moving through it. As a result, the disc 40 imparts swirl to the cleansed fluid moving through the disc 40. As the thickness of the disc 40 increases, the swirl imparted to the cleansed fluid increases. This then has two adverse consequences. First, the pressure drop associated with the dirt separator 10 increases. Second, the power required to drive the disc 40 at a particular speed increases. A further difficulty in having a thicker disc 40 is that the manufacturing time and cost are likely to increase. Accordingly, the disc is ideally no greater than 0.5 mm thick. This then provides a reasonable balance of the various factors.

The separation efficiency and the pressure drop are also sensitive to the total open area of the disc 40. In particular, as the total open area increases, the separation efficiency increases and the pressure drop decreases. It is therefore advantageous to have a large total open area. The total open area of the disc may be increased by decreasing the land between holes 47. However, decreasing the land has its difficulties, particularly in terms of manufacture. Nevertheless, as will now be described, methods have been identified for manufacturing a disc 40 having a relatively high open area.

Of the many methods that may be used to manufacture the disc 40 (e.g. stamping, laser beam machining, micro electro-discharge machining, water jet machining, electrochemical machining), chemical etching has been found to be particularly beneficial. Chemical etching is capable of producing relatively small holes with a relatively good degree of accuracy. Additionally, chemical etching is relatively quick and can be used to etch relatively hard metals, such as stainless steel. Moreover, the holes are free of burrs and the metal is not stressed, which might otherwise deform the shape of the disc 40. A difficulty with chemical etching, however, is that the thickness of the disc 40 directly affects the minimum dimensions of the holes and land. In particular, at the hole dimensions described above (i.e. between 0.1 and 1.0 mm), the minimum possible hole diameter is typically about 120% of the disc thickness, whilst the minimum possible land dimension is typically no less than the disc thickness.

Chemical etching was used to create a perforated region with a 60 degree triangular pitch, a hole diameter of 0.25 mm, and a land dimension of 0.125 mm. The relatively small hole diameter enables relatively high separation efficiencies to be achieved. In spite of the relatively small hole diameter, the open area of the perforated region was an impressive 40%. This was achieved by having a land dimension of just 0.125 mm. However, since the land dimension was 0.125 mm, the thickness of the disc was likewise 0.125 mm. A thicker disc may be desirable for reasons already discussed above, e.g. stiffness and/or hardness.

A stiffer and/or harder disc may be achieved by increasing the size of the land. However, the stiffness and hardness of the disc 40 are more sensitive to the thickness of the disc 40. That is to say that a stiffer and harder disc would be achieved by increasing the thickness by 0.1 mm than by increasing the land by 0.1 mm. Increasing the thickness rather than the land also allows for a relatively large open area to be maintained. However, as noted above, increasing the thickness of the disc 40 is not without its disadvantages or difficulties. If the thickness of the disc 40 were increased to say 0.3 mm, the smallest hole diameter and land dimension that could be achieved with chemical etching would be around 0.4 mm and 0.3 mm respectively. With a 60 degree triangular pitch, this would result in an open area of around 30%, which is still relatively high. However, if one wanted to achieve a higher open area at this thickness then an alternative manufacturing method must be used. Of the methods listed above, laser beam machining (LBM) has particular benefits. With LBM, the hole and land dimensions are not defined or otherwise limited by the thickness of the disc 40. Consequently, it is quite possible to use LBM to create a perforated region with a 60 degree triangular pitch, a hole diameter of 0.25 mm, and a land dimension of 0.125 mm to achieve an open area of 40% in a disc that is 0.5 mm thick. Additionally LBM can be used to create holes through non-metallic materials. In comparison to chemical etching, LBM has two distinct disadvantages. First, LBM has a relatively low material-removal rate. As a result, manufacturing times are slower. Second, LBM uses thermal energy to remove material and the thermal stresses may distort the disc. Nevertheless, when manufacturing a disc having geometries that preclude the use of chemical etching, LBM has distinct advantages over other methods. For example, micro stamping creates burrs and generates significant stress at the impact sites. Moreover, stamping a hard metal such as stainless steel with the hole and land geometries described above in a disc that is 0.5 mm thick is likely to prove challenging.

With chemical etching or laser beam machining, it is possible to create a perforated region having relatively small holes (diameter no greater than 1.0 mm) with a relatively high open area (at least 25%) in a timely and cost-effective manner.

As can be seen in Figure 4, the holes 47 in the disc 40 are circular in shape and have a constant size. However, as illustrated in Figure 15, alternative shapes and varying sizes are possible. In contrast to circular holes, the alternative shapes illustrated in Figure 15 are capable of providing a greater open area for the same land dimension. Figure 15 also includes an example of circular holes that increase gradually in size as one moves radially outward. The holes are therefore smallest where the tangential speeds of the disc 40 are slower. This may then lead to improvements in separation efficiency without necessarily increasing the pressure drop across the dirt separator.

When circular holes were employed, the separation efficiency was observed to decrease significantly when the diameter of the holes was greater than 1.0 mm, and the pressure drop was observed to increase significantly when the diameter of the holes was less than 0.1 mm. Where holes of a different shape are used, benefits in terms of separation efficiency and pressure drop may be observed by ensuring that the minimum dimension of each hole (i.e. the shortest distance across each hole) is no less than 0.1 mm and no greater than 1.0 mm. The critical dimension is thought to be in a direction parallel to the direction of flow of the fluid over the hole, which will depend on several factors, such as the location of the hole 47 on the disc 40, the speed of the disc 40, the speed of the fluid moving through the dirt separator 10, and the total open area of the disc 40.

In the arrangements described above, the disc assembly 22 comprises a disc 40 directly attached to a shaft of an electric motor 41. Conceivably, the disc 40 may be attached indirectly to the electric motor, e.g. by means of a gearbox or drive dog. Furthermore, the disc assembly 22 may comprise a carrier to which the disc 40 is attached. By way of example, Figure 16 illustrates a disc assembly 23 having a carrier 70. The carrier 70 may be used to increase the stiffness of the disc 40. As a result, a thinner disc 40 or a disc 40 having a larger diameter and/or a larger total open area may be used. The carrier 70 may also be used to form the seal between the disc assembly 23 and the container 20. In this regard, whilst a contact seal between the disc 40 and the top wall 30 has thus far been described, alternative types of seal may equally be employed, e.g. labyrinth seal or fluid seal. The carrier 70 may also be used to obstruct the central

region of a wholly perforated disc. In the example shown in Figure 16, the carrier 70 comprises a central hub 71, connected to a rim 72 by radial spokes 73. Fluid then moves through the carrier 70 via the apertures 74 between adjacent spokes 73.

- 5 Each of the disc assemblies 22,23 described above comprises an electric motor 41 for driving the disc 40. Conceivably, the disc assembly 22,23 may comprise alternative means for driving the disc 40. For example, the disc 40 may be driven by the vacuum motor 12. This arrangement is particularly viable with the layout shown in Figure 1, in which the vacuum motor 12 rotates about an axis that is coincident with the rotational
- 10 axis 48 of the disc 40. Alternatively, the disc assembly 22,23 may comprise a turbine powered by the flow of fluid moving through the disc assembly 22,23. A turbine is generally cheaper than an electric motor, but the speed of the turbine, and thus the speed of the disc 40, depends on the flow rate of fluid moving through the turbine. As a result, high separation efficiencies can be difficult to achieve at low flow rates.
- 15 Additionally, if dirt were to clog any of the holes 47 in the disc 40, the open area of the disc 40 would decrease, thereby restricting the flow of fluid to the turbine. As a result, the speed of the disc 40 would decrease and thus the likelihood of clogging would increase. A runaway effect then arises in which the disc 40 becomes increasingly slower as it clogs, and the disc 40 becomes increasingly clogged as it slows. Furthermore, if
- 20 the suction opening in the cleaner head 4 were to become momentarily obstructed, the speed of the disc 40 would decrease significantly. Dirt may then build up significantly on the disc 40. When the obstruction is subsequently removed, the dirt may restrict the open area of the disc 40 to such an extent that the turbine is unable to drive the disc 40 at sufficient speed to throw off the dirt. An electric motor, whilst generally more
- 25 expensive, has the advantage that the speed of the disc 40 is relatively insensitive to flow rates or fluid speeds. As a result, high separation efficiencies may be achieved at low flow rates and low fluid speeds. Additionally, the disc 40 is less likely to clog with dirt. A further advantage of using an electric motor is that it requires less electrical power. That is to say that, for a given flow rate and disc speed, the electrical power
- 30 drawn by the electric motor 41 is less than the additional electrical power drawn by the vacuum motor 12 in order to drive the turbine.

The dirt separator 10 has thus far been described as forming part of a handheld unit 2 that may be used as a standalone cleaner or may be attached to a cleaner head 4 via an elongate tube 3 for use as a stick cleaner 1. The provision of a disc assembly in a handheld unit is by no means intuitive. Although the provision of a rotating disc within a dirt separator of a vacuum cleaner is known, there is an existing prejudice that the dirt separator must include a cyclone chamber to separate the dirt from the fluid. As a result, the overall size of the dirt separator is relatively large and is unsuitable for use in a handheld unit. With the dirt separator described herein, effective separation may be achieved in a relatively compact manner. As a result, the dirt separator is particularly well suited for use in a handheld unit.

The weight of a handheld unit is clearly an important consideration in its design. The inclusion of an electric motor in addition to the vacuum motor is not therefore an obvious design choice. Additionally, where the handheld unit is battery powered, one might reasonably assume that the power consumed by the electric motor would shorten the runtime of the vacuum cleaner. However, by using an electric motor to drive the disc, relatively high separation efficiencies may be achieved for a relatively modest drop in pressure. Consequently, in comparison to a conventional handheld cleaner, the same cleaning performance may be achieved using a less powerful vacuum motor. A smaller vacuum motor may therefore be used that consumes less electrical power. As a result, a net reduction in weight and/or power consumption may be possible.

Although the dirt separator described herein is particularly well suited for use in a handheld vacuum cleaner, it will be appreciated that the dirt separator may equally be used in alternative types of vacuum cleaner, such as an upright, canister or robotic vacuum cleaner.

CLAIMS

1. A dirt separator for a vacuum cleaner, the dirt separator comprising:
a chamber having an inlet through which dirt-laden fluid enters the chamber and
5 an outlet through which cleansed fluid exits the chamber; and
a disc located at the outlet, the disc being arranged to rotate about a rotational
axis and comprising holes through which the cleansed fluid passes,
wherein the holes have a minimum dimension of between 0.1 mm and 1.0 mm.
- 10 2. A dirt separator as claimed in claim 1, wherein the holes have a minimum
dimension of between 0.2 mm and 0.5 mm.
3. A dirt separator as claimed in claim 1 or 2, wherein the disc has a thickness no
greater than 0.5 mm.
- 15 4. A dirt separator as claimed in any one of the preceding claims, wherein the holes
are formed in a perforated region of the disc, and the perforated region has an open area
of at least 25%.
- 20 5. A dirt separator as claimed in any one of the preceding claims, wherein the
diameter of the disc is greater than the diameter of the inlet.
6. A dirt separator as claimed in any one of the preceding claims, wherein the holes
have a total open area greater than that of the inlet.
- 25 7. A dirt separator as claimed in any one of the preceding claims, wherein the disc
comprises an inner region surrounded by an outer region, the diameter of the inner
region is no less than a third of the diameter of the disc, and the inner region has an
open area less than that of the outer region.

8. A dirt separator as claimed in any one of the preceding claims, wherein the disc comprises an inner region surrounded by an outer region, the diameter of the inner region is no less than the diameter of the inlet, and the inner region has an open area less than that of the outer region.

5

9. A dirt separator as claimed in claim 7 or 8, wherein the inner region has an open area less than 10% and the outer region has an open area greater than 20%.

10. A dirt separator as claimed in any one of claims 7 to 9, wherein the holes are formed in the outer region and the inner region is non-perforated.

11. A dirt separator as claimed in any one of the preceding claims, wherein the dirt-laden fluid entering the chamber is directed at the disc.

12. A dirt separator as claimed in any one of the preceding claims, wherein the holes are formed by chemical etching or laser beam machining.

13. A dirt separator as claimed in any one of the preceding claims, wherein the dirt separator comprises an electric motor for driving the disc about the rotational axis.

20

14. A handheld vacuum cleaner comprising a dirt separator as claimed in any one of the preceding claims.

15. A stick vacuum cleaner comprising a handheld unit attached to a cleaner head by an elongate tube, wherein the handheld unit comprises a dirt separator as claimed in any one of claims 1 to 13, and the elongate tube extends along an axis parallel to the rotational axis.

25

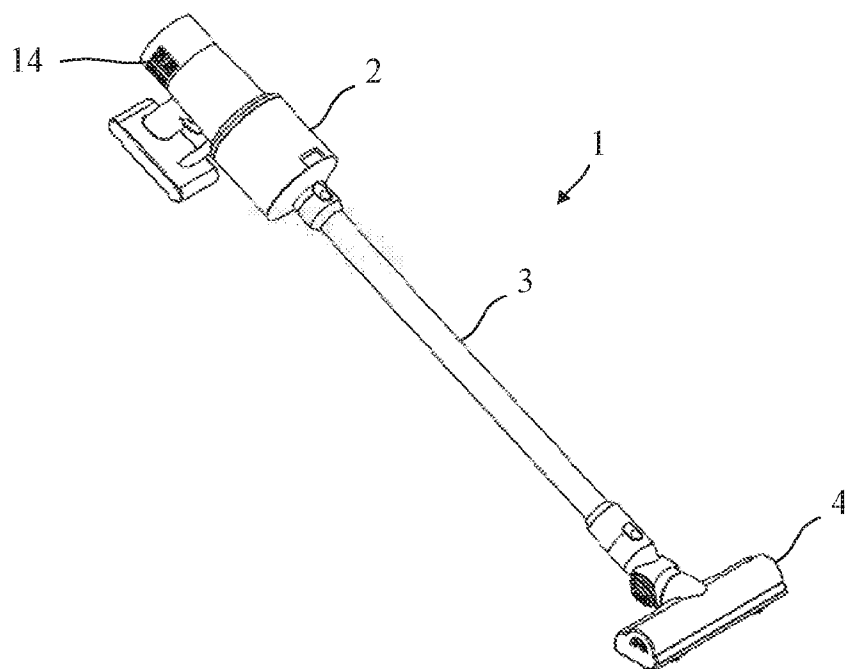


Fig. 1

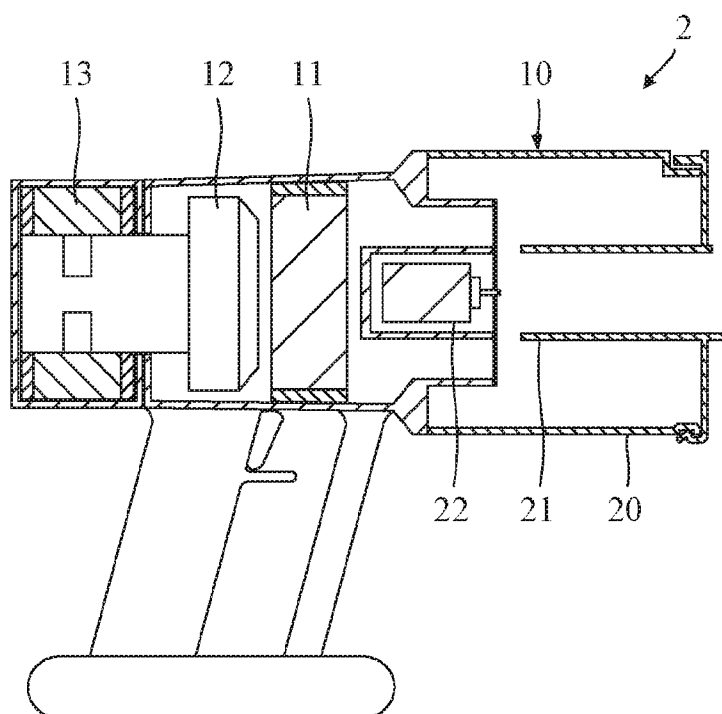


Fig. 2

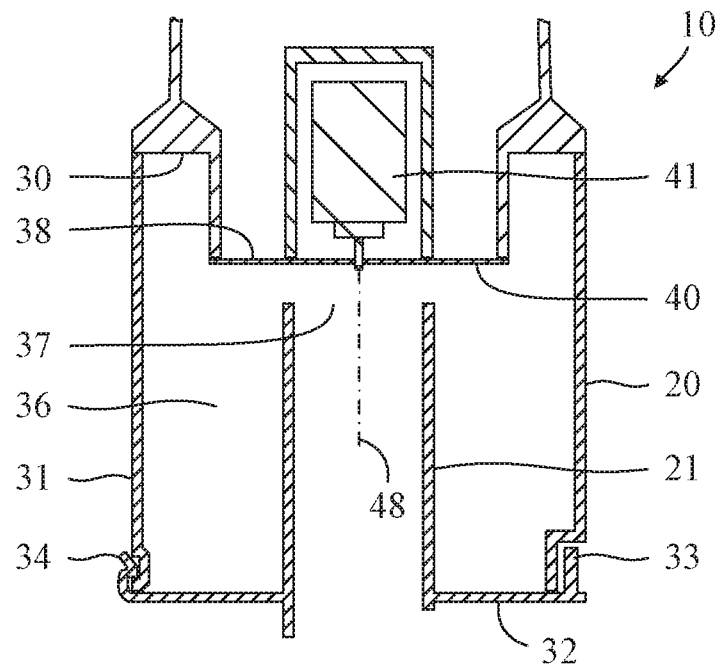


Fig. 3

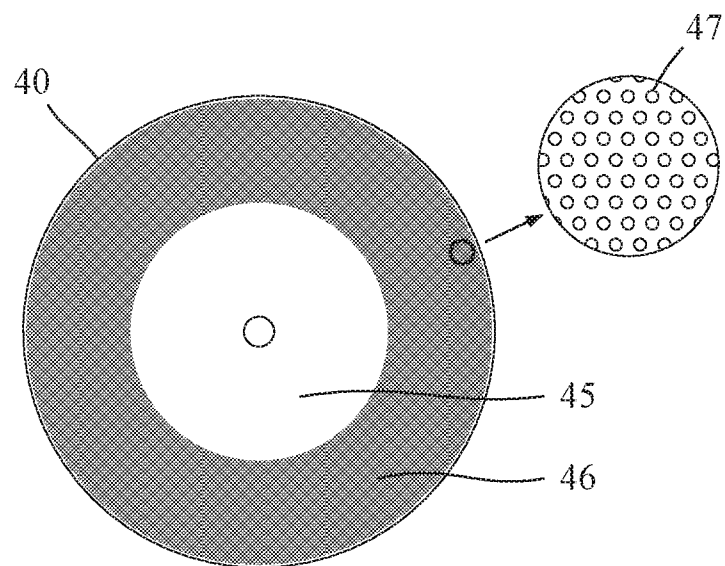


Fig. 4

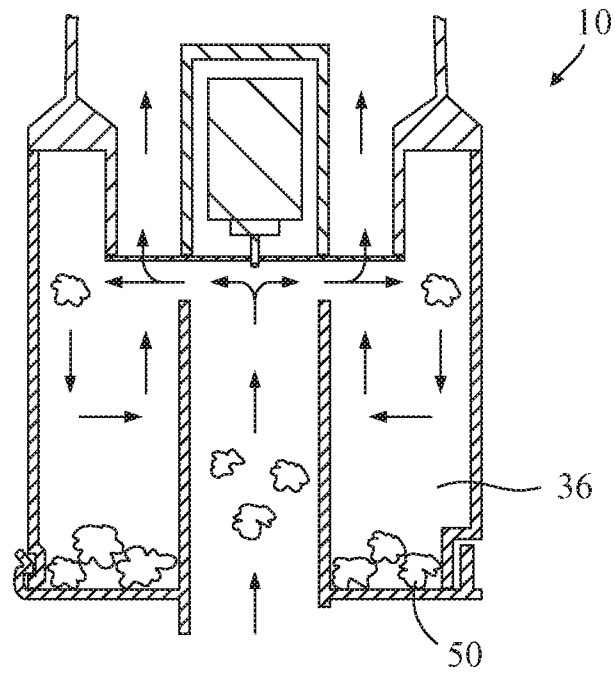


Fig. 5

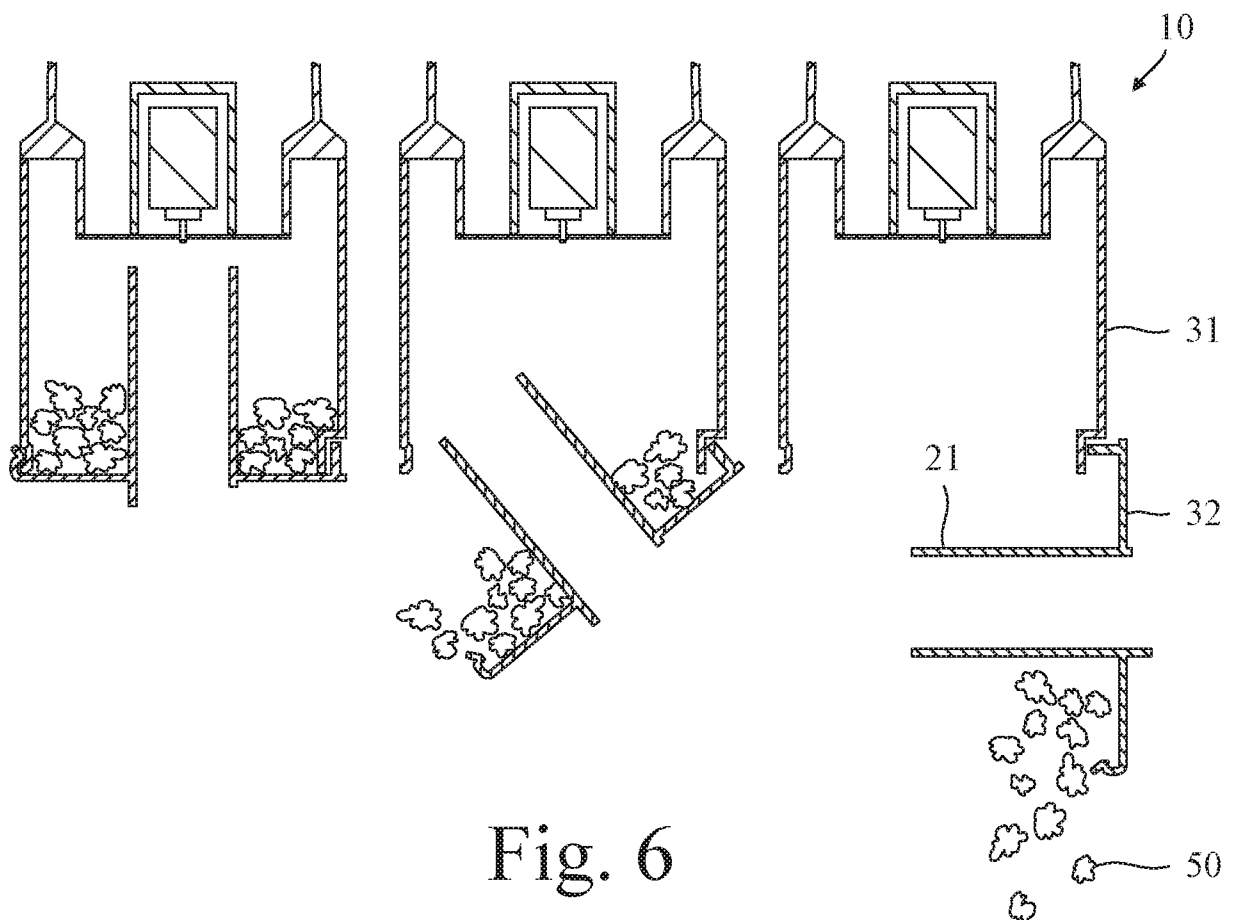


Fig. 6

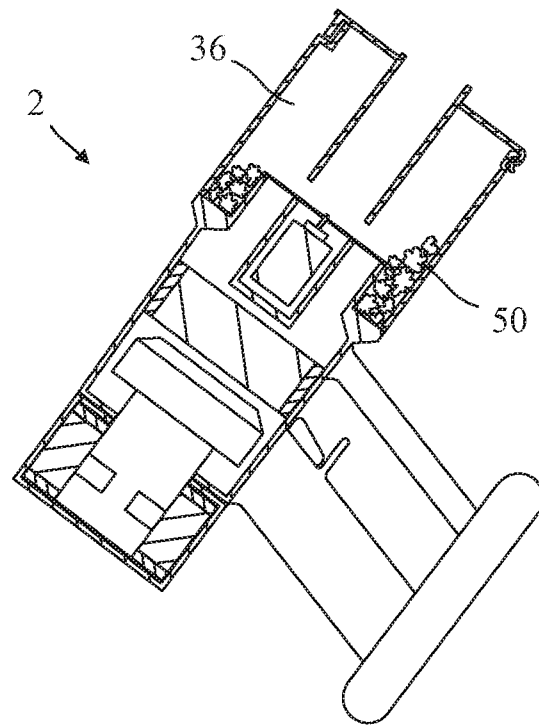


Fig. 7

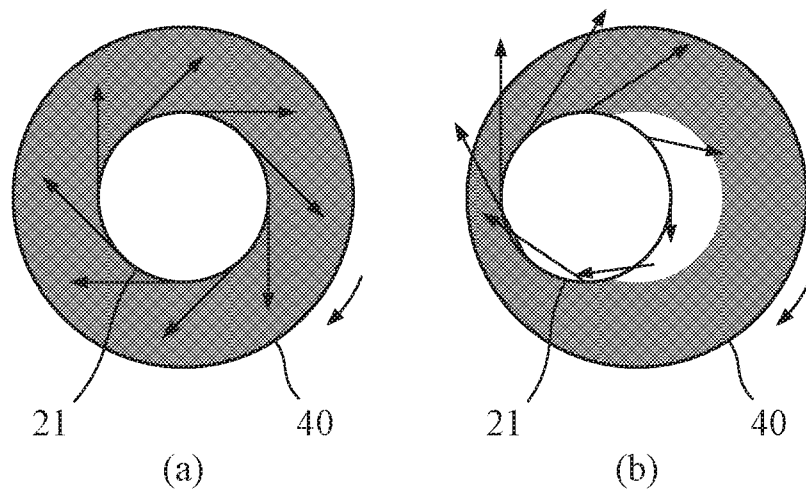


Fig. 8

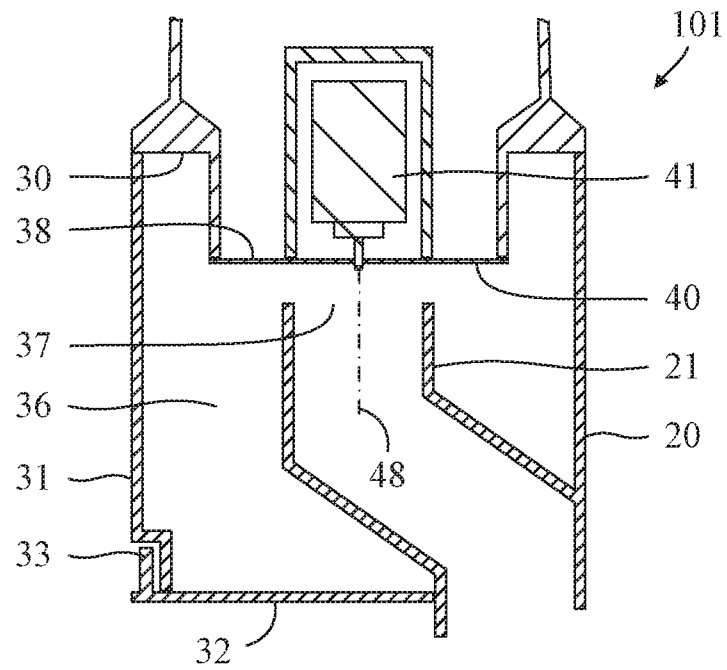


Fig. 9

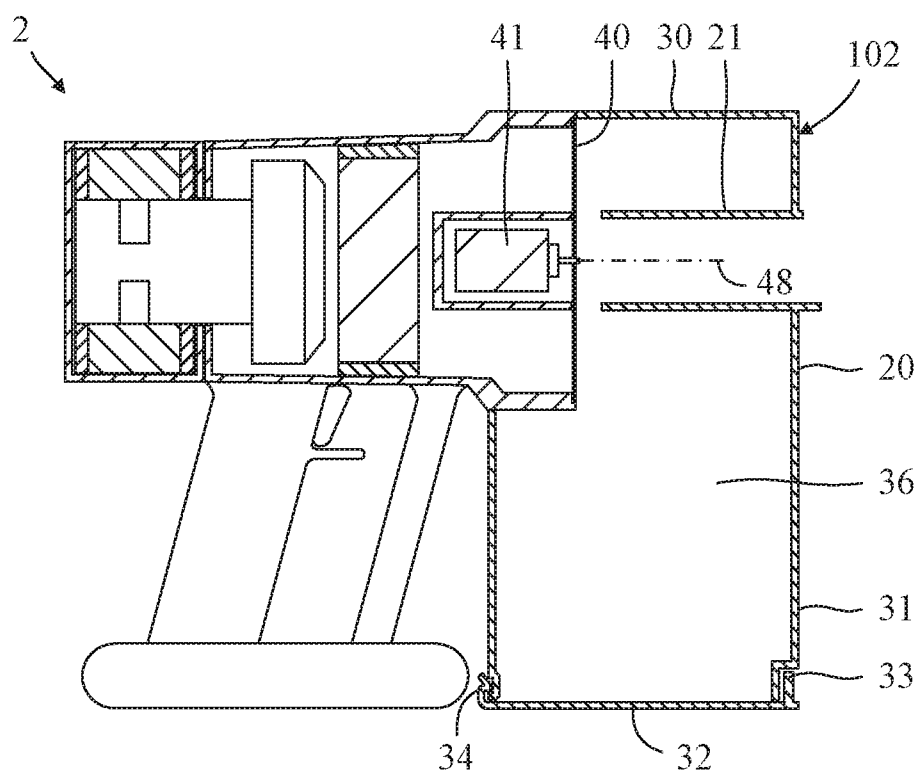


Fig. 10

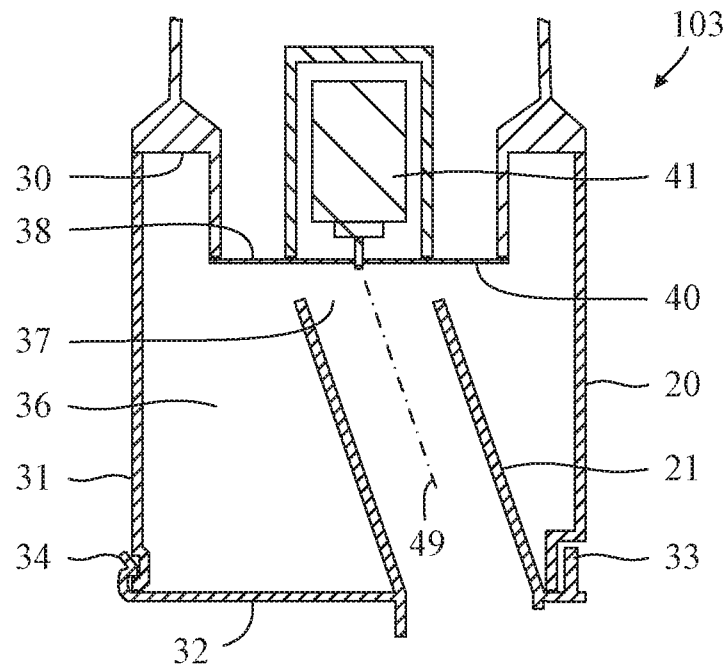


Fig. 11

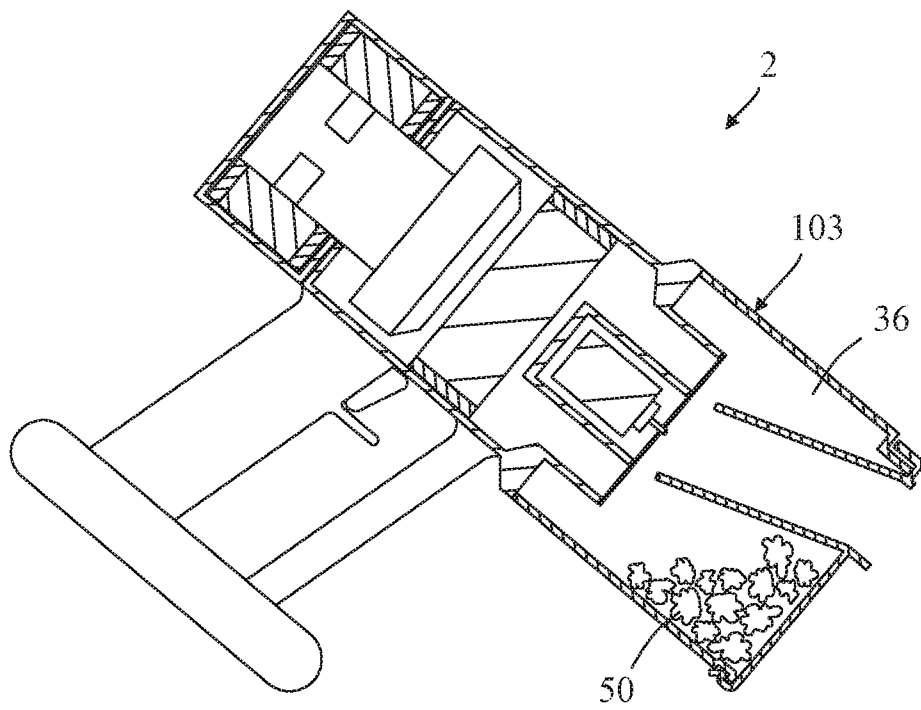


Fig. 12

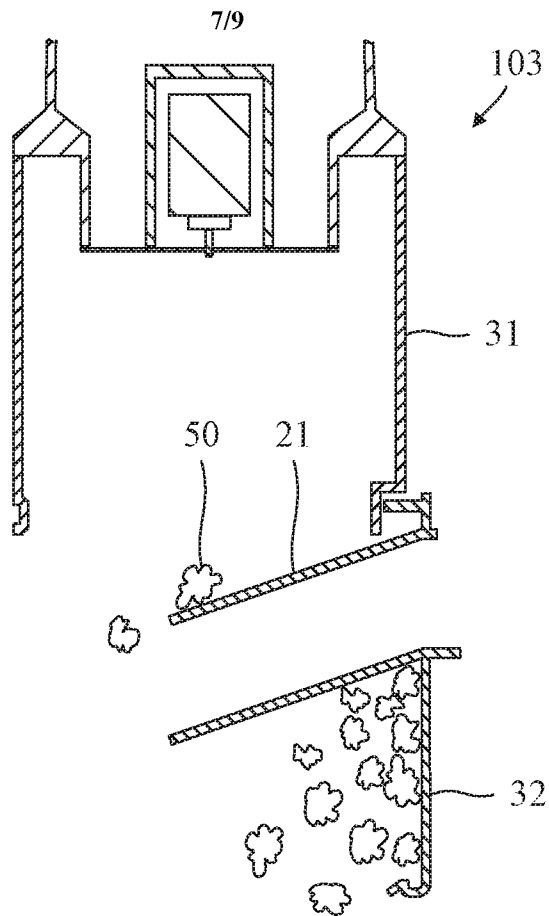


Fig. 13

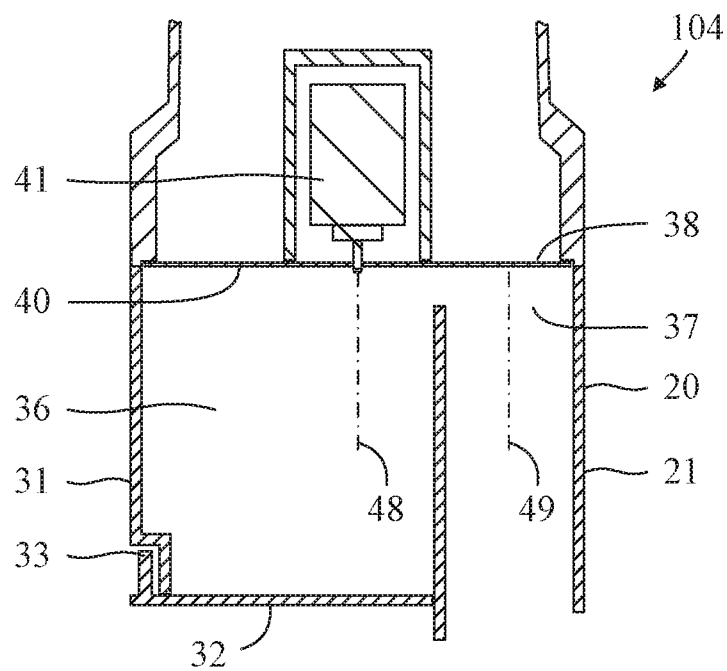


Fig. 14

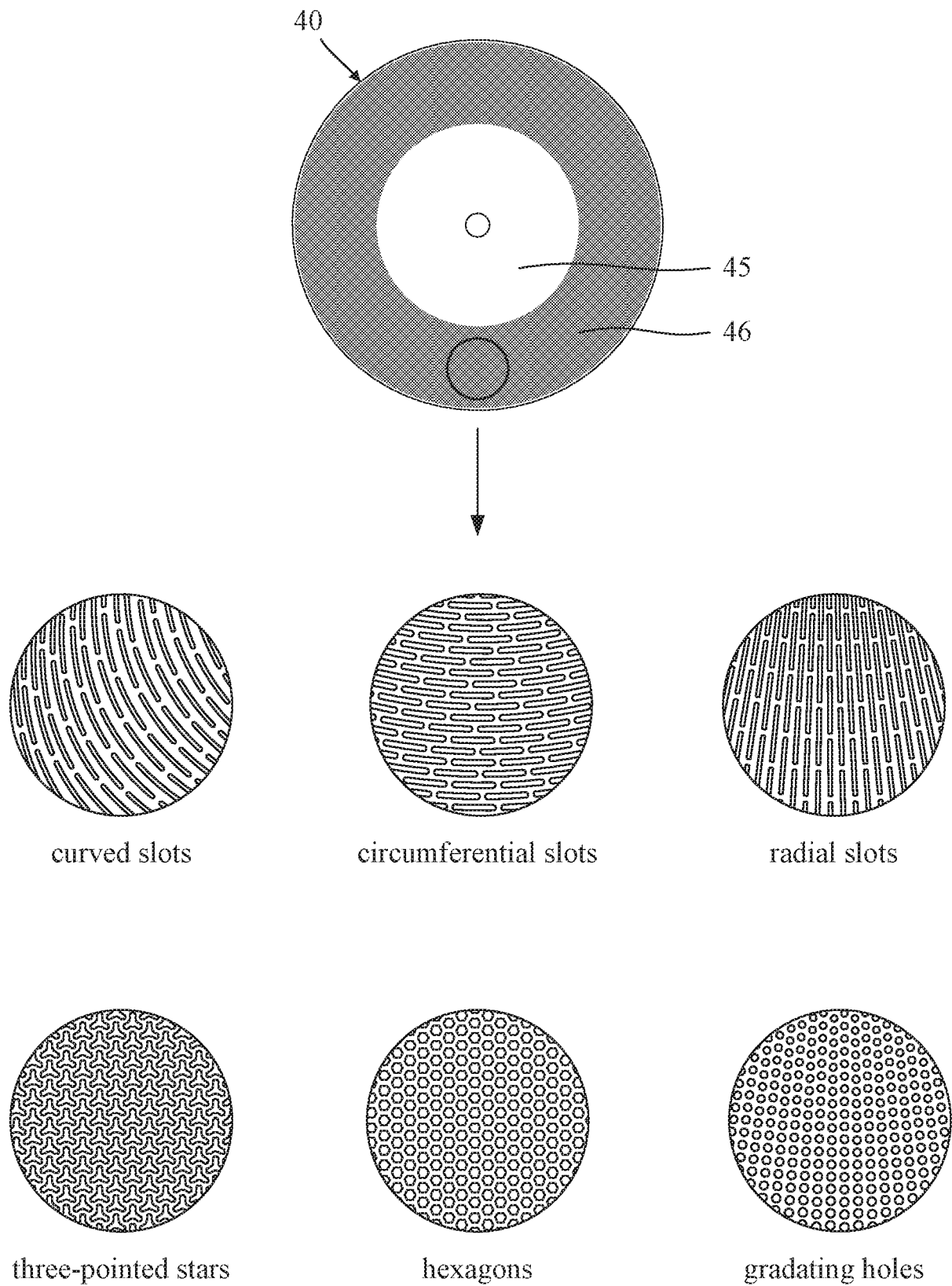


Fig. 15

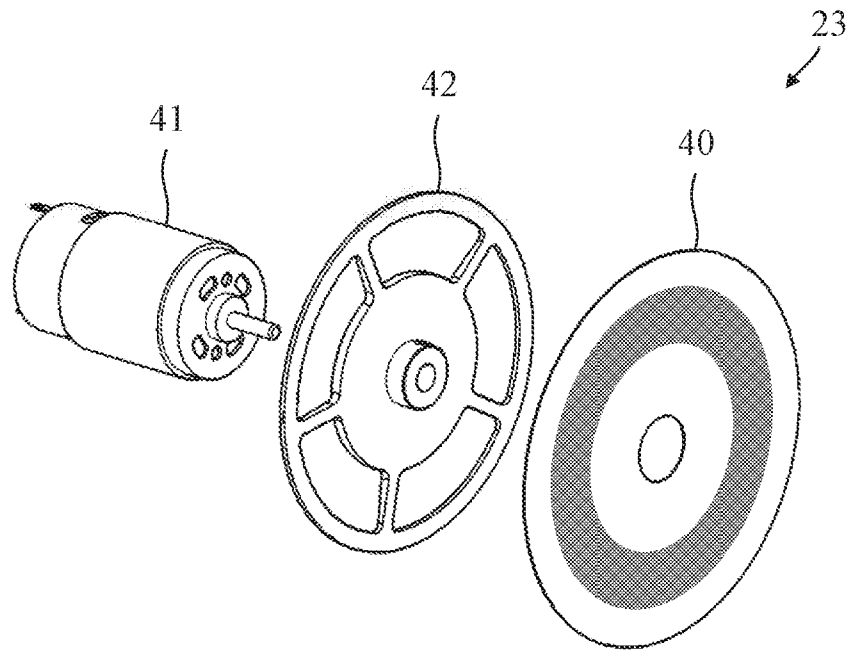


Fig. 16

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2018/052143

A. CLASSIFICATION OF SUBJECT MATTER

INV. B01D45/14 A47L9/10 A47L9/16 A47L9/12 A47L9/14
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

B01D A47L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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Y	figures 1,2	3,9,14, 15
Y	----- DE 196 37 431 A1 (KIEFER GMBH [DE]) 19 March 1998 (1998-03-19)	14,15
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Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search

9 October 2018

Date of mailing of the international search report

18/10/2018

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Trimarchi, Roberto

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2018/052143

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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A	paragraph [0032] - paragraph [0034]; figure 6	1,2,4-15
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