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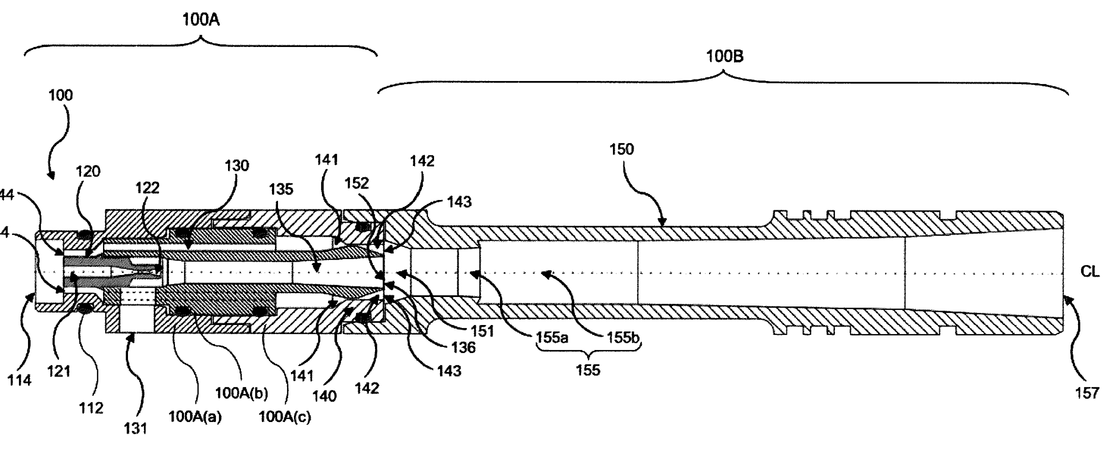
(54) **HIGH VACUUM EJECTOR**

(57) An ejector for generating a vacuum comprises a drive nozzle (120) and a ring drive nozzle (140). The drive nozzle (120) is for generating a drive jet of air from a flow of compressed air and directing the drive jet of air into a first section expansion nozzle (130) in order to entrain air in a volume surrounding the drive jet of air into the jet flow to generate a vacuum across the first section. The ring drive nozzle (140) is for generating a drive ring of air from the flow of compressed air and directing the drive ring of air onto the jet flow and the entrained air, and into an inlet of a second section expansion nozzle (150).

FIGURE 1A

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## Description

## Technical Field

**[0001]** The present invention relates to an ejector for generating a vacuum from a flow of compressed air. The present invention also relates to a method of generating a vacuum from a flow of compressed air.

## Background

**[0002]** Vacuum pumps are known which use a source of compressed air (or other high-pressure fluid) in order to generate a negative pressure or vacuum in a surrounding space. Compressed-air driven ejectors operate by accelerating the high pressure air through a drive nozzle and ejecting it as an air jet at high-speed across a gap between the drive nozzle and an outlet flow passage or nozzle. Fluid medium in the surrounding space between the drive nozzle and outlet nozzle is entrained into the high-speed flow of compressed air, and the jet flow of entrained medium and air originating from the compressed-air source is ejected through the outlet nozzle. As the fluid in the space between the drive and outlet nozzles is ejected in this way, a negative pressure or vacuum is created in the volume surrounding the air jet which this fluid or medium previously occupied.

**[0003]** For any given compressed-air source (which may also be called the drive fluid), the nozzles in the vacuum ejector may be tailored either to produce a high-volume flow, but not to obtain as high a negative pressure (i.e., the absolute pressure will not fall as low), or to obtain a higher negative pressure (i.e., the absolute pressure will be lower), but without achieving as high a volume flow rate. As such, any individual pair of a drive nozzle and outlet nozzle will be tailored either towards producing a high-volume flow rate or cut achieving a high negative pressure.

**[0004]** A high negative pressure is desirable in order to generate the maximum pressure differential with ambient pressure, and so generate the maximum suction forces which can be applied by the negative pressure, for example lifting applications. At the same time, a high-volume flow rate is necessary in order to ensure that a volume to be evacuated can be emptied sufficiently quickly to allow for repetitive actuation of the associated vacuum device, or equally in order to convey a sufficient volume of material, in vacuum conveyor applications.

**[0005]** In order to achieve both a high ultimate vacuum level and a high overall volume flow rate, so-called multi-stage ejectors have been devised, which comprise three or more nozzles arranged in series within a housing, each adjacent pair of nozzles in the series defining a respective stage across which a negative pressure is generated in the gap between the adjacent two nozzles. Again, in general, any individual pair of nozzles in the series may be tailored either towards producing a high-volume flow rate or achieving a high negative pressure, for a given source of compressed air.

**[0006]** In such multi-stage ejectors, the earliest stages produce the highest levels of negative pressure, i.e., the lowest absolute pressures, whilst the subsequent stages provide successively lower negative pressure levels, i.e., higher absolute pressures, but increase the overall volume throughput of the ejector device. In order to apply the generated vacuum across the multiple stages to a desired vacuum device or volume to be evacuated, the successive stages are typically connected to a common collection chamber, whilst valves are provided to each successive stage, at least after the first, drive stage, so that the subsequent stages can be closed off from the collection chamber once the negative pressure in that chamber has been reduced below the negative pressure which the second and subsequent stages are able to generate.

**[0007]** The drive stage is so-called because it is the only stage connected to the source of pressurised fluid (compressed air), and so drives the flow of pressurised fluid through all of the subsequent stages and nozzles in the series, before the drive fluid and entrained fluid is ejected from the vacuum ejector.

**[0008]** In order to provide for the entrainment of fluid across each successive stage, the series of nozzles present a through-channel with gradually increasing sectional opening area, through which the stream of high-speed fluid is fed in order to entrain air or other medium in the surrounding volume into the high-speed jet flow. The nozzles between each stage form the outlet nozzle of one stage and the inlet nozzle of the next stage, and are configured to successively accelerate the flow of air and other medium in order to direct a high-speed jet of the fluid across each successive stage.

**[0009]** Although different pressurised fluids may be utilised as the drive fluid, multi-stage ejectors of the present type are typically driven by compressed air, and most usually are used to entrain air as the medium to be evacuated from the volume surrounding the jet flow through each gap in the series of nozzles, across the respective stages.

**[0010]** One design of multi-stage ejector which has found commercial success is to present the series of nozzles in a coaxial arrangement within a substantially cylindrical housing which incorporates a series of suction ports therein in communication with each stage of the ejector, the suction ports being provided with suitable valve members for selectively communicating each stage with a surrounding volume of air. So presented, the cylindrical body is formed as a so-called ejector cartridge, which, when installed inside a housing module, or within a suitably dimensioned bore hole, can be used to evacuate the surrounding chamber, which is in turn fluidly coupled to the vacuum device to which the negative pressure is to be applied.

**[0011]** Such a device is disclosed in PCT International application WO 99/49216 A1, in the name of PIAB AB, and is shown in Figures 4 and 5 of the present application.

**[0012]** As shown in Figure 4, the ejector cartridge 1 comprises four jet-shaped nozzles 2, 3, 4 and 5 which define a through-channel 6 with gradually increasing cross-sectional opening area. The nozzles are arranged end-to-end in series with respective slots 7, 8 and 9 between them.

**[0013]** The nozzles 2, 3, 4 and 5 are formed in respective nozzle bodies, which are designed to be assembled together to form an integrated nozzle body 1. Through openings 10 are arranged in the wall of the nozzle body, to provide flow communication with an outer surrounding space.

**[0014]** Turning to Figure 5, it can be seen how the ejector cartridge 1 may be mounted within a bore hole or housing, in which the outer surrounding space corresponds to a chamber V to be evacuated. Each of the through openings 10 is provided with a valve member 11 in order to selectively permit the flow of air or other fluid from the surrounding space V into the space or chamber between each adjacent pair of nozzles. As shown in Figure 5, the ejector cartridge 1 has been mounted in a machine component 20, in which the bore hole has been drilled or otherwise formed. The ejector cartridge 1 extends from an inlet chamber i to an outlet chamber u, and is arranged to evacuate the three separate chambers constituting the outer surrounding space V, each of which is separated from the adjacent chamber by an O-ring 22. Although not shown, each of the chambers constituting the outer surrounding space V is connected to a common collection chamber or suction port, in order to apply the generated negative pressure to an associated vacuum-operated device, such as a suction cup.

**[0015]** Although such multi-stage ejector arrangements are beneficial in providing both a high-volume flow rate and a high level of negative pressure, there is necessarily still some degree of compromise in the design of each successive stage in the ejector, in order to obtain an overall desired performance characteristic for the multi-stage ejector as a whole. Accordingly, it has also been proposed to provide a further so-called booster nozzle, provided in parallel with the drive nozzle of the multi-stage ejector, where the booster nozzle is specifically designed to obtain the highest possible level of vacuum, but does not form part of the series of coaxially arranged nozzles which make up the multi-stage ejector. In this way, the booster nozzle can be configured to obtain the highest possible level of vacuum, whilst the parallel multi-stage ejector nozzle series can be arranged to obtain a high-volume throughput, which enables a high negative pressure (low absolute pressure) to be obtained within the volume to be evacuated within an acceptably short period of time.

**[0016]** Such an arrangement is disclosed in US 4,395,202, as shown in Figure 6 of the present application. In this arrangement, there is provided a set of ejector nozzles 12, 13, 14, 15 arranged successively for evacuation of associated chambers 5, 6, 7, which are in mutual communication with a vacuum collecting compartment 16 through respective ports 18, 19 and 20. Valves, 21, 22 and 23 are respectively provided to the ports 18, 19 and 20.

**[0017]** An additional pair of nozzles 24 and 25 is provided in parallel to the drive nozzle 12 of the multi-stage ejector, and is arranged in a separate booster chamber 4, connected to the collecting chamber 16 via a port 17. The booster stage is comprised of a pair of nozzles 24 and 25, with the inlet nozzle 24 being connected, together with the drive nozzle 12 of the multi-stage ejector, to the inlet chamber 3, which is supplied with compressed air. The pair of nozzles 24 and 25 across the booster stage serves to generate the highest possible vacuum (lowest negative pressure) in the booster chamber 4. The jet of compressed air which is generated by the nozzle 24 is ejected out of the booster stage through nozzle 25, into the same chamber 5 across which the drive nozzle 12 propels the drive jet of compressed air. In this way, the air expelled out of the booster stage is entrained into the drive jet flow to be expelled from the multi-stage ejector. Furthermore, the vacuum generated by the drive stage of the multi-stage ejector is applied to the exit of nozzle 25, so that the pressure differential across the booster stage is increased whereby the vacuum level which can be generated by the booster stage can be increased, i.e., the absolute pressure which can be obtained is reduced.

**[0018]** In operation of the vacuum ejector, the series of nozzles 12, 13, 14 and 15 of the multi-stage ejector is able to produce a high volume flow rate so as quickly to generate a vacuum to a low absolute pressure in the collecting chamber 16 within a short period of time by entraining fluid from each of the chambers 5, 6 and 7 and the collecting chamber 16 into the jet streams formed by each successive stage of the ejector. The booster stage functions in parallel to the multi-stage ejector, but typically produces a low volume flow rate, and so does not contribute significantly to the initial vacuum formation process. As the vacuum level in the collecting chamber 16 increases (i.e., as the absolute pressure falls), the associated valve members 23, 22 and 21 will close in turn, as the pressure in the vacuum collecting chamber 16 drops below the pressure in the associated chamber 7, 6 or 5, respectively. Eventually, the pressure in the collection chamber 16 will fall below the lowest pressure that any of the stages of the multi-stage ejector is able to generate, so that all of the valves are closed, and all further evacuation will then be done by the booster stage, which provides suction to the collection chamber 16 via suction port 17.

**[0019]** Such multi-stage ejectors and ejector cartridges as described above have found commercial success in a number of different industries, and in particular in the manufacturing industry, where such vacuum ejectors may be connected to suction cups and used for picking and placing components during an assembly process.

**[0020]** As the demands for high vacuum levels (i.e. low absolute pressures) in processes such as de-gassing, de-humidifying, filling of hydraulic systems, forced filtration, etc., continue to increase, there is increasing demand for vacuum ejectors which are able to repeatedly provide a high level of negative pressure (i.e., a low absolute pressure) in order to carry out the above and other processes.

**[0021]** Coupled with this, there is an increasing drive towards smaller-sized ejectors, which are able to provide the desired evacuation capability at remote locations on the machinery (i.e., at the ends of mechanical arms, and significant distances from the ultimate source of compressed air) without negatively impacting on the overall dimensions of the machine. In particular, there is a desire for ejector devices having a small footprint, and so able to apply a vacuum to increasingly compact working areas.

**[0022]** In view of the above, there is a need for an improved ejector capable of providing high vacuum levels whilst having a small footprint. There is also need for an improved method for generating a vacuum from a flow of compressed air.

**Summary of the Invention**

**[0023]** Accordingly, it is an object of the present invention to provide an improved ejector capable of providing high vacuum levels whilst having a small footprint. It is also an object of the present invention to provide an improved method for generating a vacuum from a flow of compressed air.

**[0024]** These objectives are achieved with the ejector with the technical features of claim 1 and with the method of claim 15.

**[0025]** Preferred embodiments are recited in the dependent claims.

**[0026]** In a first aspect, there is provided an ejector for generating a vacuum comprising a first stage. The first stage comprises a drive nozzle and a ring drive nozzle. The drive nozzle is for generating a drive jet of air from a flow of compressed air and directing the drive jet of air into a first stage expansion nozzle in order to entrain air in a volume surrounding the drive jet of air into the jet flow to generate a vacuum across the first stage. The ring drive nozzle is for generating a drive ring of air from the flow of compressed air and directing the drive ring of air onto the jet flow and the entrained air, and into an inlet of an exit expansion nozzle.

**[0027]** In one embodiment, the drive ring of air is directed onto the jet flow and the entrained air, and into the inlet of the exit expansion nozzle in order to accelerate the flow of air through the first stage expansion nozzle.

**[0028]** In such configurations, the jet flow and the entrained air are evacuated from the first stage expansion nozzle at a higher rate.

**[0029]** Accordingly, with such configurations, it is possible to provide an improved ejector capable of providing high vacuum levels whilst having a small footprint.

**[0030]** In one embodiment, the ejector comprises the exit expansion nozzle.

**[0031]** In one embodiment, the jet flow and the entrained air are directed into the inlet of the exit expansion nozzle.

**[0032]** In one embodiment, the first stage expansion nozzle comprises a diverging section. The diverging section of the first stage expansion nozzle diverges in a direction of airflow through the first stage expansion nozzle.

**[0033]** In one embodiment, the first stage expansion nozzle comprises a suction port across which the vacuum is generated.

**[0034]** In one embodiment, the suction port is upstream, in the direction of the airflow through the first stage expansion nozzle, of where the drive jet of air enters into the first stage expansion nozzle.

**[0035]** In one embodiment, the first stage expansion nozzle comprises a converging section, the converging section of the first stage expansion nozzle converges in a direction of airflow through the first stage expansion nozzle.

**[0036]** In one embodiment, the first stage expansion nozzle comprises a straight section, the straight section of the first stage expansion nozzle is straight in a direction of airflow through the first stage expansion nozzle.

**[0037]** In one embodiment, the converging section, the straight section and the diverging section of the first stage expansion nozzle are arranged in this order along the direction of airflow through the first stage expansion nozzle.

**[0038]** In one embodiment, the drive ring of air is directed over an outlet of the first stage expansion nozzle.

**[0039]** In one embodiment, the drive ring of air is directed over and around an outlet of the first stage expansion nozzle.

**[0040]** In one embodiment, an outlet section of the first stage expansion nozzle defines an outlet of the first stage expansion nozzle.

**[0041]** In these configurations, the jet flow and the entrained air may be accelerated by the drive ring of air as soon as they exit the first stage expansion nozzle. Moreover, in these configurations, the drive ring nozzle may be provided around the first stage expansion nozzle.

**[0042]** Hence, with such configurations, it is possible to provide a further improved ejector capable of providing high vacuum levels whilst having a small footprint.

**[0043]** In one embodiment, the outlet of the first stage comprises an outlet of the first stage expansion nozzle and an outlet of the ring drive nozzle.

**[0044]** In one embodiment, the inlet of the exit expansion nozzle defines a stepwise expansion in the diameters between an outlet of the first stage and the inlet of the exit expansion nozzle.

**[0045]** The stepwise expansion in the diameters between an outlet of the first stage and the inlet of the exit expansion nozzle aids in the expansion of the flow of air through the exit expansion nozzle.

**[0046]** Hence, with such a configuration, it is possible to provide a further improved ejector capable of providing yet higher vacuum levels.

**[0047]** In one embodiment, an inlet section of the exit expansion nozzle defines the inlet of the exit expansion nozzle. The inlet section of the exit expansion nozzle defines a stepwise expansion in the diameter of the inlet section.

**[0048]** The stepwise expansion in the diameter of the inlet section aids in the expansion of the flow of air through the exit expansion nozzle.

**[0049]** Hence, with such a configuration, it is possible to provide a further improved ejector capable of providing yet higher vacuum levels.

**[0050]** In one embodiment, the jet flow and the entrained air, and the drive ring of air exit the first stage at an outlet of the first stage.

**[0051]** In one embodiment, an outlet of the first stage expansion nozzle, an outlet of the ring drive nozzle and the stepwise expansion in the diameters between the outlet of the first stage and the inlet of the exit expansion nozzle, are aligned along a direction of airflow through the ejector.

**[0052]** In one embodiment, the drive ring of air is directed onto the jet flow and the entrained air at the inlet of the exit expansion nozzle and in the exit expansion nozzle.

**[0053]** Accordingly, the jet flow and the entrained air, and the drive ring of air immediately enter the exit expansion nozzle after exiting the first stage.

**[0054]** Hence, with such a configuration, it is possible to provide a further improved ejector capable of providing yet higher vacuum levels.

**[0055]** In one embodiment, the exit expansion nozzle comprises a diverging section. The diverging section of the exit expansion nozzle diverges in a direction of airflow through the exit expansion nozzle.

**[0056]** In one embodiment, the drive ring of air is directed onto the jet flow and the entrained air at least in the diverging section of the of the exit expansion nozzle.

**[0057]** In one embodiment, the diverging section of the exit expansion nozzle defines a stepwise expansion in the diameter of the diverging section.

**[0058]** In one embodiment, the exit expansion nozzle defines a stepwise expansion in the diameter of the exit expansion nozzle.

**[0059]** In these cases, the stepwise expansion in diameter serves to trip the fluid flow in the exit expansion nozzle, so as to generate a turbulent outlet flow along the nozzle wall, thereby reducing the friction at the exit expansion nozzle and correspondingly improving the efficiency with which the ejector can generate a vacuum from a given flow of compressed air.

**[0060]** Hence, with such configurations, it is possible to provide a further improved ejector capable of providing yet higher vacuum levels.

**[0061]** In one embodiment, the exit expansion nozzle comprises a converging section. The converging section of the exit expansion nozzle converges in a direction of airflow through the exit expansion nozzle.

**[0062]** In one embodiment, the converging section is an inlet section of the exit expansion nozzle.

**[0063]** In one embodiment, the drive ring of air is directed onto the jet flow and the entrained air at least in the converging section of the of the exit expansion nozzle.

**[0064]** In one embodiment, the exit expansion nozzle comprises a straight section. The straight section of the exit expansion nozzle is straight in a direction of airflow through the exit expansion nozzle.

**[0065]** In one embodiment, the drive ring of air is directed onto the jet flow and the entrained air at least in the straight section of the of the exit expansion nozzle.

**[0066]** In one embodiment, the drive ring of air is directed onto the jet flow and the entrained air in the converging section and the straight section of the exit expansion nozzle.

**[0067]** In one embodiment, the drive ring of air is directed onto the jet flow and the entrained air in the converging section, the straight section and the diverging section of the exit expansion nozzle.

**[0068]** In one embodiment, the converging section, the straight section and the diverging section of the exit expansion nozzle are arranged in this order along the direction of airflow through the exit expansion nozzle.

**[0069]** In a second aspect, there is provided a method of generating a vacuum from a flow of compressed air. The method comprises supplying the flow of compressed air to a drive nozzle to generate a drive jet of air. The method comprises directing the drive jet of air into a first stage expansion nozzle. The method comprises generating a vacuum by entraining air in a volume surrounding the drive jet of air into the jet flow. The method comprises supplying the flow of compressed air to a ring drive nozzle to generate a drive ring of air. The method comprises directing the drive ring of air onto the jet flow and the entrained air, and into an inlet of an exit expansion nozzle.

**[0070]** With such a method, it is possible to generate high vacuum levels whilst using a small footprint ejector.

**[0071]** In one implementation, the drive ring of air is directed onto the jet flow and the entrained air, and into the inlet of the exit expansion nozzle in order to accelerate the flow of air through the first stage expansion nozzle.

**[0072]** Further features and effects of the ejector and the method of generating a vacuum from a flow of compressed air according to the present invention will be evident from the following description of certain embodiments. In the description of these embodiments, reference is made to the accompanying drawings.

## Brief Description of the Drawings

**[0073]** For a better understanding of the present invention and to show how the same may be carried into effect, reference will now be made, by way of example only, to the accompanying drawings, in which:

Figure 1A shows a longitudinal, axial sectional view through an embodiment of an ejector cartridge according to the present invention, as seen in a direction perpendicular to the direction of airflow through the ejector cartridge;

Figure 1B shows a perspective side view of the ejector cartridge of Figure 1A from the same direction as Figure 1A;

Figure 2 shows a longitudinal, axial sectional view of the drive nozzle, the first section expansion nozzle and the second housing 100A(b) of the embodiment shown in Figures 1A and 1B;

Figure 3 shows a longitudinal, axial sectional view of parts of the first section expansion nozzle, ring drive nozzle and exit expansion nozzle of the embodiment shown in Figures 1A and 1B;

Figures 4 and 5 show sectional views of a prior art ejector cartridge, with Figure 5 illustrating a cartridge being mounted into a housing unit of an ejector; and

Figure 6 shows a prior art ejector unit including a booster stage incorporated into a common housing in parallel with the in-line series of multi-stage ejector nozzles.

**Detailed Description**

**[0074]** Embodiments of the present invention will now be described with reference to the accompanying figures. Like reference numerals have been used to refer to like features throughout the description of the various embodiments.

**[0075]** Figures 1A and 1B show an embodiment of an ejector according to the present invention. The embodiment of Figures 1A and 1B is configured as an ejector cartridge 100. Such a cartridge is intended to be installed within an ejector housing module, or within a bore or chamber formed in an associated piece of equipment, which defines the volume to be evacuated by the ejector cartridge.

**[0076]** Although the most preferred embodiment of the ejector, as shown in the drawings, is designed to work with air as the drive fluid, and as the fluid to be evacuated, the ejector will be applicable to any gas as the drive fluid, and any gas as the fluid to be evacuated. The drive fluid will have a primary direction of movement, or flow, through the ejector. This direction is parallel to the longitudinal axis of the ejector, shown horizontally in the drawings, and starting from the inlet 114. In the following, this direction will be referred as the direction of airflow.

**[0077]** Ejector cartridge 100 is a multi-section ejector having a first section 100A and a second section 100B. A vacuum may be generated across the first section 100A.

**[0078]** The first section 100A comprises a drive nozzle 120. The drive nozzle 120 has an inlet flow section 121 and an outlet flow section 122. The inlet flow section 121 is in fluid communication with an inlet 114 of the ejector cartridge 100 such that at least a portion of the compressed air supplied to the inlet 114 of the ejector cartridge 100 will be supplied to the inlet flow section 121 of the drive nozzle 120. The drive nozzle 120 is arranged to accelerate compressed air supplied to the inlet flow section 121 of the drive nozzle 120, so as to direct a jet flow of high-speed air (referred to as a drive jet of air) out of the outlet flow section 122 of the drive nozzle 120. The outlet flow section 122 of the drive nozzle 120 lies on the center axis CL of the ejector cartridge 100.

**[0079]** The flow of high-speed air is directed into a first section expansion nozzle 130 of the first section 100A. The outlet flow section 122 of the drive nozzle 120 is disposed within the first section expansion nozzle 130. Accordingly, the jet of high-speed air exiting the outlet flow section 122 of the drive nozzle 120 is immediately within the first section expansion nozzle 130.

**[0080]** The first section expansion nozzle 130 has at least one suction port 131 and a diverging section 135. The diverging section 135 of the first section expansion nozzle 130 defines an outlet 136 of the first section expansion nozzle 130. In this embodiment, the diverging section 135 of the first section expansion nozzle 130 is an outlet section of the first section expansion nozzle 130. The at least one suction port 131, an outlet of the outlet flow section 122 and the outlet 136 are arranged in this order along the airflow direction. In other words, the outlet 136 is downstream of the outlet of the outlet flow section 122, which is in turn downstream of the at least one suction port 131. Referring to Figure 1B, in this embodiment, the first section expansion nozzle 130 has four suction ports 131, three of which can be taken from the figure, the fourth of which lying diametrically opposite the one facing the viewer.

**[0081]** When compressed air is supplied to the inlet flow section 121 of the drive nozzle 120 via the inlet 114 of the ejector cartridge 100, a high-speed air jet will be generated by the drive nozzle 120, so as to form a jet flow in which the drive air jet is directed into the first section expansion nozzle 130. In this way, air or other fluid medium in a volume surrounding the drive jet of air will be entrained into the jet flow and driven through the first section expansion nozzle 130 and out of the outlet 136 of the first section expansion nozzle 130. The jet flow and the entrained air will be driven into the second section 100B of the ejector cartridge 100.

**[0082]** The consumption and the feed pressure of the supplied compressed air can vary in accordance with ejector size and desired evacuation characteristics. For smaller ejectors, a consumption range from about 0.1 to about 0.2 Nl/s (normalized litres per second) at feed pressures of from about 0.4 to about 0.5 MPa will usually be sufficient, and large ejectors typically consume from about 2 to about 2.4 Nl/s at about 0.4 to about 0.5 MPa. Ranges in between for sizes in between are possible and common. Without wishing to be bound to these particular ranges, compressed air as used herein is to be understood to have such properties.

**[0083]** The first section 100A of the ejector cartridge 100 has a first housing 100A(a), a second housing 100A(b) and a third housing 100A(c), which together form a housing of the first section 100A. The suction port 131 of the first section expansion nozzle 130 extends through the first housing 100A(a) and provides fluid communication between the inside of the first section expansion nozzle 130 and the outside of the ejector cartridge 100.

**[0084]** The first section 100A of the ejector cartridge 100 has a ring drive nozzle 140. The ring drive nozzle 140 is formed from an outer surface of the first section expansion nozzle 130 and an inner surface of the housing of the first section 100A. The ring drive nozzle 140 defines a substantially rotationally symmetric body, forming a body of revolution about the center axis CL.

**[0085]** The ring drive nozzle 140 has an inlet flow section 141 and an outlet flow section 142. The inlet 114 of the ejector cartridge 100 is in fluid communication with both the inlet flow section 121 of the drive nozzle 120 and the inlet flow section 141 of the ring drive nozzle 140. Accordingly, a source of compressed air may supply compressed air into the inlet 114 of the ejector cartridge 100 so as to supply compressed air to both the inlet flow section 121 of drive nozzle 120 and the inlet flow section 141 of ring drive nozzle 140. The ring drive nozzle 140 is arranged to accelerate compressed air supplied to the inlet flow section 141 of the ring drive nozzle 140, so as to direct a drive ring of air out of the outlet flow section 142 of the drive ring nozzle 140. The drive ring of air is a ring of high-speed air. The drive ring of air is driven into the second section 100B of the ejector cartridge 100. The compressed air is supplied to the inlet flow section 141 of the ring drive nozzle 140 via the inlet 144 defined by a surface formed from the outer surface of the drive nozzle 120 together with an outer surface of the first section expansion nozzle 130, and an inner surface of the first housing 100A(a).

**[0086]** The drive ring of air is directed onto the jet flow and the entrained air after the jet flow and the entrained air is driven out of the outlet 136 of the first section expansion nozzle 130. The drive ring of air is directed onto the jet flow and the entrained air in the second section 100B of the ejector cartridge 100. As the drive ring of air is directed onto the jet flow and the entrained air, it may be possible to accelerate the flow of air through the first section expansion nozzle 130.

**[0087]** An outlet of the outlet flow section 142 of the ring drive nozzle 140 defines an outlet 143 of the ring drive nozzle 140. An outlet of the first section 100A comprises the outlet 136 of the first section expansion nozzle 130 and the outlet 143 of the ring drive nozzle 140. The air driven out of the outlet of the first section 100A is driven into the second section 100B.

**[0088]** The first section 100A is a drive section as it is the only section connected to the source of compressed air, and so drives the flow of compressed air through the subsequent section (second section 100B), before the fluid is ejected from the ejector cartridge 100. Moreover, as the at least one suction port 131 is provided in the first section 100A, a vacuum may be generated across the first section 100A. The second section 100B of the ejector cartridge 100 has an exit expansion nozzle 150. The exit expansion nozzle 150 has an inlet section 151 which defines an inlet 152 of the exit expansion nozzle 150. The exit expansion nozzle 150 has a first diverging section 155a and a second diverging section 155b which define a diverging section 155 of the exit expansion nozzle 150. In this embodiment, both the first diverging section 155a and the second diverging section 155b have the same rate of divergence. The diverging section 155 defines an outlet 157 of the exit expansion nozzle 150. The outlet 157 is the outlet of the ejector cartridge 100.

**[0089]** The inlet 152 of the exit expansion nozzle 150 is an inlet of the second section 100B. The air exiting the outlet of the first section 100A is directly introduced into the inlet 152 of the exit expansion nozzle 150 (i.e. the inlet of the second section 100A). The air then passes through the exit expansion nozzle 150 and exits the ejector cartridge 100 via the outlet 157.

**[0090]** The second section 100B facilitates the mixing of the jet flow and the entrained air, and the drive ring of air. Furthermore, the second section 100B and may be configured such that the change from the flow and pressure conditions immediately after the first section 100A, to the expansion of the flow into ambient pressure, is less abrupt. This may improve the efficiency of the ejector cartridge 100.

**[0091]** Referring to Figure 1B, the ejector cartridge 100 is formed as a substantially rotationally symmetric body, forming a body of revolution about the center axis CL, with the exception of the suction ports 131. Although the suction ports 131 do not, strictly speaking, form bodies of revolution, they may be disposed with rotational symmetry about said axis of rotation CL, thus representing only minor discontinuities in what is otherwise a body of revolution about the center axis CL.

**[0092]** As shown in Figures 1A and 1B, the ejector cartridge 100 is a substantially cylindrical ejector cartridge having a substantially circular cross-sectional shape along its length in the plane perpendicular to the center axis CL, i.e., perpendicular to the direction of airflow through the ejector cartridge 100. However, it will be appreciated that it is not essential for the ejector cartridge 100 or the components thereof, to be formed with a circular cross-sectional shape. Nevertheless, a substantially cylindrical or tubular form is preferred for the ejector cartridge 100, since this permits the ejector cartridge 100 to be installed most easily within a bore hole or other ejector housing module, utilising appropriate seals such as the O-ring 112, shown in Figures 1A and 1B.

**[0093]** With reference also to Figures 2 and 3, the components of the ejector cartridge 100 will be described in more detail below.

**[0094]** Figure 2 shows the drive nozzle 120 and the first section expansion nozzle 130 of the ejector cartridge

100, and the second housing 100A(b) of the first section 100A.

**[0095]** As explained above, the drive nozzle 120 is arranged to accelerate compressed air supplied to the inlet flow section 121 so as to direct a jet flow of high-speed air out of the outlet flow section 122. In this embodiment, the drive nozzle 120 is a converging-diverging nozzle. Accordingly, the inlet flow section 121 of the drive nozzle 120 has a converging section and the outlet flow section 122 of the drive nozzle 120 has a diverging section.

**[0096]** The first section expansion nozzle 130 has a first straight section 132, a first converging section 133a, a second converging section 133b, a second straight section 134 and a diverging section 135 arranged in this order with respect to the direction of airflow. The first converging section 133a and the second converging section 133b together form a converging section 133 of the first section expansion nozzle 130. In this embodiment, the first converging section 133a is more converging than the second converging section 133b. The diverging section 135 defines an outlet 136 of the first section expansion nozzle 130.

**[0097]** The suction port 131 of the first section expansion nozzle 130 is formed in the first straight section 132 of the first section expansion nozzle 130. An outlet of the outlet flow section 122 of the drive nozzle 120 is disposed within the first section expansion nozzle 130. The outlet of the outlet flow section 122 is disposed downstream of the suction port 131 of the first section expansion nozzle 130. The outlet of the outlet flow section 122 is disposed such that the jet flow of high-speed air exiting the outlet flow section 122 is directed into the converging section 133 of the first section expansion nozzle 130. Accordingly, the outlet of the outlet flow section 122 is disposed upstream of the first converging section 133a.

**[0098]** The second straight section 134 is disposed between the converging section 133 and the diverging section 135.

**[0099]** As can be seen from Figure 2, the first section expansion nozzle 130 has at least one fixing element 137 which fixes the first section expansion nozzle 130 to the second housing 100A(b) and, in turn, to the first housing 100A(a) and the third housing 100A(c). The at least one fixing element 137 extends through the channel formed from the outer surface of the first section expansion nozzle 130 and the inner surface of the second housing 100A(b). The at least one fixing element 137 is configured such that the impedance to the flow in the channel is minimised. In one embodiment, the at least one fixing element 137 comprises a web of material. The web of material may form a plane which has an axis parallel to the direction of airflow and a perpendicular axis perpendicular to the direction of airflow. In one embodiment, the at least one fixing element 137 comprises a sheet of material. The sheet of material may form a plane which has an axis parallel to the direction of airflow and a perpendicular axis perpendicular to the direction of airflow. In one embodiment, there are four fixing elements 137. In one embodiment, the fixing elements 137 are disposed with rotational symmetry about the axis of rotation CL. In one embodiment, the first section expansion nozzle 130, the at least one fixing element 137 and the second housing 100A(b) are formed as a single entity.

**[0100]** Figure 3 shows parts of the first section expansion nozzle 130, ring drive nozzle 140 and exit expansion nozzle 150.

**[0101]** As can be seen from Figure 3, the ring drive nozzle 140 is a converging-diverging nozzle. Accordingly, the inlet flow section 141 of the ring drive nozzle 140 has a converging section and the outlet flow section 142 of the ring drive nozzle 140 has a diverging section. The outlet flow section 142 of the ring drive nozzle 140 directs air over the diverging section 135 of the first section expansion nozzle 130. The drive ring of air exiting the outlet flow section 142 passes over the outlet 136 of the first section expansion nozzle 130. The drive ring of air immediately enters the inlet section 151 of the exit expansion nozzle 150.

**[0102]** In this embodiment, the inlet section 151 is a converging section.

**[0103]** The outlet of the first section 100A comprises the outlet 136 of the first section expansion nozzle 130 and the outlet of the outlet flow section 142 of the ring drive nozzle 140. The outlet of the first section 100A defines an outer outlet diameter. In this embodiment, the inlet 152 of the exit expansion nozzle 150 defines a stepwise expansion 160 between the outer outlet diameter of the first section 100A and the diameter of the inlet 152 of the exit expansion nozzle 150. Specifically, outer outlet diameter of the first section 100A is smaller than the diameter of the inlet 152. In other words, an outer diameter of the outlet of the outlet flow section 142 is smaller than the diameter of the inlet 152. In this embodiment, the outlet of the first section expansion nozzle 130, the outlet of the ring drive nozzle 140 and the stepwise expansion 160 are aligned along the direction of airflow through the ejector cartridge 100.

**[0104]** The inlet section 151, straight section 153, and diverging section 155 of the exit expansion nozzle 150 are arranged in this order with respect to the direction of airflow.

**[0105]** The diverging section 155 defines a stepwise expansion 156 in the diameter of the diverging section 155. The stepwise expansion 156 in the diameter is formed part-way along the diverging section 155, in this example, nearer to the inlet section 151 of the exit expansion nozzle 150, rather than the outlet 157. The first diverging section 155a of the exit expansion nozzle 150 extends from the straight section 153 with a divergence angle which may be substantially constant, up to the point where the stepwise expansion in diameter is provided at a sharp corner 156a. Preferably, the sharp corner 156a is defined by an undercut in the diverging section 155 of the exit expansion nozzle 150. At the stepwise expansion 156 in diameter, the wall of the diverging section 155 reverses direction to form the sharp corner 156a, where the wall changes from diverging whilst extending in an axial direction towards the outlet 157 of the exit expansion nozzle 150, to being diverging whilst extending in an axial direction towards the inlet section 151 of the exit expansion nozzle 150, for a short distance, before reversing back to again diverge whilst extending in the axial direction towards the outlet 157 of the exit expansion nozzle 150. The last reversal back into a diverging shape is optional in that the second diverging section 155b as shown in the figures may initially, i.e. immediately downstream of the sharp corner 156a, may reverse back to continue in a cylindrical, straight-walled shape, before it continues in a diverging shape shortly before the outlet 157 of the exit expansion nozzle 150. A shape of the exit expansion nozzle 150 will be selected in accordance with the desired characteristics of the ejector, keeping in mind that the shape serves to render the change from the flow and pressure conditions in the exit expansion nozzle 150 to the expansion of the flow into ambient pressure less abrupt. In this manner, the design of the exit expansion nozzle can advantageously be used to influence pressure and flow rate conditions in the first section 100A. As a result, the skilled person will have greater freedom in designing the first section 100A of the ejector cartridge 100.

**[0106]** As shown in Figure 3, the stepwise expansion in diameter 156 can be measured by comparing the diameter Di immediately before the stepwise expansion 156, at the sharp corner 156a, with the diameter Do immediately after the stepwise expansion 156, which is radially in line with sharp corner 155a, but on the second diverging section 155b of the diverging section 155. A stepwise change in diameter serves to trip the fluid flow in the diverging section 155 of the exit expansion nozzle 150, so as to generate a turbulent outlet flow along the nozzle wall, thereby reducing the friction at the outlet 156 of the exit expansion nozzle 150 and correspondingly improving the efficiency with which the ejector cartridge 100 can generate a vacuum from a given source of compressed air.

**[0107]** The ratio Di:Do is preferably between 5:6 and 5:8.

**[0108]** Although the above explanation is considered to fully clarify how the present invention may straightforwardly be put into effect by those skilled in the art, it is to be regarded as purely exemplary.

**[0109]** In particular, there are a number of variations which are possible, as may be appreciated by those skilled in the art.

**[0110]** For example, the ring drive nozzle 140 may be arranged in any manner as long as the drive ring of air is directed onto the jet flow and the entrained air, and into an inlet 152 of the exit expansion nozzle 150.

**[0111]** Moreover, the ring drive nozzle 140 may not be formed from an outer surface of the first section expansion nozzle 130 and an inner surface of the housing of the first section 100A. Rather, the ring drive nozzle 140 may be formed from further elements.

**[0112]** In the embodiment shown in Figures 1 to 3, the inlet 114 is in fluid communication with both the inlet flow section 121 of the drive nozzle 120 and the inlet flow section 141 of the ring drive nozzle 140. Accordingly, in this embodiment, a source of compressed air may supply compressed air into the inlet 114 of the ejector cartridge 100 so as to drive both the drive nozzle 120 and the ring drive nozzle 140. However, in another embodiment, a first source of compressed air is configured to supply a first compressed air to the inlet flow section 121 of the drive nozzle 120 and a second source of compressed air is configured to supply a second compressed air to the inlet flow section 141 of the ring drive nozzle 140.

**[0113]** Furthermore, either of the stepwise expansions 156, 160 may be omitted in other embodiments. Also, the stepwise expansion 156 may be formed nearer the outlet 156 of the exit expansion nozzle 150, rather than the inlet section 152.

**[0114]** Also, the exit expansion nozzle 150 may have any combination of: a converging section; a straight section 153; and a diverging section 155, arranged in any order. The drive ring of air may be directed onto the jet flow and the entrained air in any of these sections or any combination of these sections.

**[0115]** Also, the first section expansion nozzle 130 may have any combination of: a first straight section 132; a converging section 133; a second straight section 134; and a diverging section 135, arranged in any order. The outlet of the outlet flow section 122 may be disposed such that the jet flow of high-speed air exiting the outlet flow section 122 is directed into any of these sections.

**[0116]** Throughout this disclosure, any reference to a converging section or a diverging section refers to a section which converges or diverges with respect to the direction of airflow, respectively. In other words, to a section in which the diameter decreases or increases with respect to the direction of airflow.

**[0117]** All of the above are fully within the scope of the present invention, and are considered to form the basis for alternative embodiments in which one or more combinations of the above-described features are applied, without limitation to the specific combinations disclosed above.

**[0118]** In light of this, there will be many alternatives which implement the teaching of the present invention. It is expected that one skilled in the art will be able to modify and adapt the above disclosure to suite its own circumstances and requirements within the scope of the present invention, while retaining some or all technical effects of the same, either disclosed or derivable from the above, in light of his comment general knowledge in this art. All such equivalents, modifications or adaptations fall within the scope of the invention hereby defined and claimed.

## Claims

1. An ejector for generating a vacuum comprising:

   a first section comprising:

   a drive nozzle for generating a drive jet of air from a flow of compressed air and directing the drive jet of air into a first section expansion nozzle in order to entrain air in a volume surrounding the drive jet of air into the jet flow to generate a vacuum across the first section; and
   a ring drive nozzle for generating a drive ring of air from the flow of compressed air and directing the drive ring of air onto the jet flow and the entrained air, and into an inlet of an exit expansion nozzle.

2. The ejector of claim 1, wherein the first section expansion nozzle comprises a diverging section, the diverging section of the first section expansion nozzle diverges in a direction of airflow through the first section expansion nozzle.

3. The ejector of any preceding claim, wherein the drive ring of air is directed over an outlet of the first section expansion nozzle.

4. The ejector of any preceding claim, wherein the outlet of the first section comprises an outlet of the first section expansion nozzle and an outlet of the ring drive nozzle.

5. The ejector of any preceding claim, wherein the inlet of the exit expansion nozzle defines a stepwise expansion in the diameters between an outlet of the first section and the inlet of the exit expansion nozzle.

6. The ejector of claim 5, wherein an outlet of the first section expansion nozzle, an outlet of the ring drive nozzle and the stepwise expansion in the diameters between the outlet of the first section and the inlet of the exit expansion nozzle, are aligned along a direction of airflow through the ejector.

7. The ejector of any preceding claim, wherein the drive ring of air is directed onto the jet flow and the entrained air at the inlet of the exit expansion nozzle.

8. The ejector of any preceding claim, wherein the exit expansion nozzle comprises a diverging section, the diverging section of the exit expansion nozzle diverges in a direction of airflow through the exit expansion nozzle.

9. The ejector of claim 8, wherein the drive ring of air is directed onto the jet flow and the entrained air at least in the diverging section of the of the exit expansion nozzle

10. The ejector of claim 8 or 9, wherein the diverging section of the exit expansion nozzle defines a stepwise expansion in the diameter of the diverging section.

11. The ejector of any preceding claim, wherein the exit expansion nozzle comprises a converging section, the converging section of the exit expansion nozzle converges in a direction of airflow through the exit expansion nozzle.

12. The ejector of claim 11, wherein the drive ring of air is directed onto the jet flow and the entrained air at least in the converging section of the of the exit expansion nozzle.

13. The ejector of any preceding claim, wherein the exit expansion nozzle comprises a straight section, the straight section of the exit expansion nozzle is straight in a direction of airflow through the exit expansion nozzle.

14. The ejector of claim 13, wherein the drive ring of air is directed onto the jet flow and the entrained air at least in the straight section of the of the exit expansion nozzle.

15. A method of generating a vacuum from a flow of compressed air, comprising:

   supplying the flow of compressed air to a drive nozzle to generate a drive jet of air;
   directing the drive jet of air into a first section expansion nozzle; generating a vacuum by entraining air in a volume surrounding the drive jet of air into the jet flow;
   supplying the flow of compressed air to a ring drive nozzle to generate a drive ring of air; and directing the drive ring of air onto the jet flow and the entrained air, and into an inlet of an exit expansion nozzle.

16. The method of claim 15, wherein the drive ring of air is directed onto the jet flow and the entrained air, and into the inlet of the exit expansion nozzle in order to accelerate the flow of air through the first section expansion nozzle.

**Amended claims in accordance with Rule 137(2) EPC.**

1. An ejector for generating a vacuum comprising:

   a first section (100A) comprising:

a drive nozzle (120) for generating a drive jet of air from a flow of compressed air and directing the drive jet of air into a first section expansion nozzle (130) in order to entrain air in a volume surrounding the drive jet of air into the jet flow to generate a vacuum across the first section (100A); and
a ring drive nozzle (140) for generating a drive ring of air from the flow of compressed air and directing the drive ring of air onto the jet flow and the entrained air, and into an inlet (152) of an exit expansion nozzle (150).

**2.** The ejector of claim 1, wherein the first section expansion nozzle (130) comprises a diverging section (135), the diverging section (135) of the first section expansion nozzle (130) diverges in a direction of airflow through the first section expansion nozzle (130).

**3.** The ejector of any preceding claim, wherein the drive ring of air is directed over an outlet (136) of the first section expansion nozzle (130).

**4.** The ejector of any preceding claim, wherein the outlet of the first section (100A) comprises an outlet (136) of the first section expansion nozzle (130) and an outlet (143) of the ring drive nozzle (140).

**5.** The ejector of any preceding claim, wherein the inlet (152) of the exit expansion nozzle (150) defines a stepwise expansion (160) in the diameters between an outlet of the first section (100A) and the inlet (152) of the exit expansion nozzle (150).

**6.** The ejector of claim 5, wherein an outlet (136) of the first section expansion nozzle (130), an outlet (143) of the ring drive nozzle (140) and the stepwise expansion (160) in the diameters between the outlet of the first section (100A) and the inlet (152) of the exit expansion nozzle (150), are aligned along a direction of airflow through the ejector (100).

**7.** The ejector of any preceding claim, wherein the drive ring of air is directed onto the jet flow and the entrained air at the inlet (152) of the exit expansion nozzle (150).

**8.** The ejector of any preceding claim, wherein the exit expansion nozzle (150) comprises a diverging section (155), the diverging section (155) of the exit expansion nozzle (150) diverges in a direction of airflow through the exit expansion nozzle (150).

**9.** The ejector of claim 8, wherein the drive ring of air is directed onto the jet flow and the entrained air at least in the diverging section (155) of the of the exit expansion nozzle (150).

**10.** The ejector of claim 8 or 9, wherein the diverging section (155) of the exit expansion nozzle defines a stepwise expansion in the diameter of the diverging section (155).

**11.** The ejector of any preceding claim, wherein the exit expansion nozzle (150) comprises a converging section, the converging section of the exit expansion nozzle (150) converges in a direction of airflow through the exit expansion nozzle (150).

**12.** The ejector of claim 11, wherein the drive ring of air is directed onto the jet flow and the entrained air at least in the converging section of the of the exit expansion nozzle (150).

**13.** The ejector of any preceding claim, wherein the exit expansion nozzle (150) comprises a straight section (153), the straight section (153) of the exit expansion nozzle (150) is straight in a direction of airflow through the exit expansion nozzle (150).

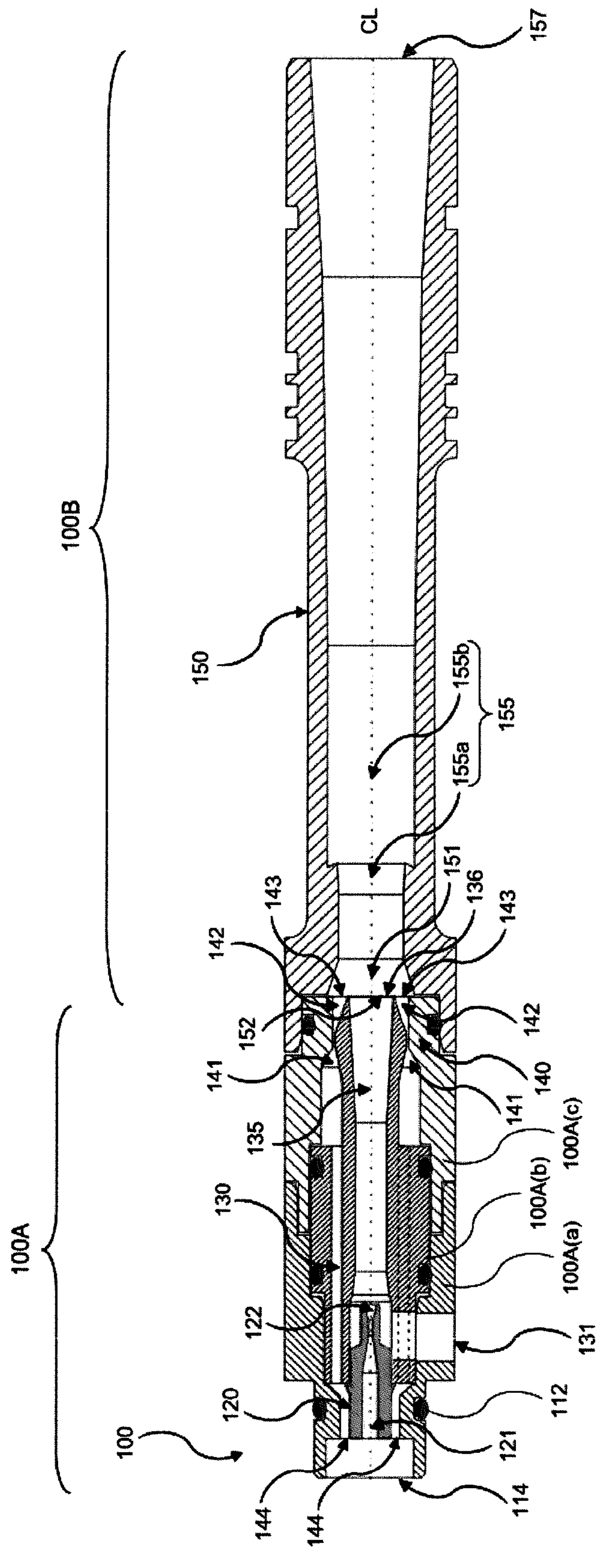
**14.** The ejector of claim 13, wherein the drive ring of air is directed onto the jet flow and the entrained air at least in the straight section (153) of the of the exit expansion nozzle (150).

**15.** A method of generating a vacuum from a flow of compressed air, comprising:

supplying the flow of compressed air to a drive nozzle (120) to generate a drive jet of air;
directing the drive jet of air into a first section expansion nozzle (130); generating a vacuum by entraining air in a volume surrounding the drive jet of air into the jet flow;
supplying the flow of compressed air to a ring drive nozzle (140) to generate a drive ring of air; and
directing the drive ring of air onto the jet flow and the entrained air, and into an inlet (152) of an exit expansion nozzle (150).

**16.** The method of claim 15, wherein the drive ring of air is directed onto the jet flow and the entrained air, and into the inlet (152) of the exit expansion nozzle (150) in order to accelerate the flow of air through the first section expansion nozzle (150).

FIGURE 1A


CL
157
100B
150
155b
155
155a
151
136
143
143
142
142
152
141
140
141
135
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100A(b)
130
100A(a)
100A
122
131
120
112
100
121
144
144
114

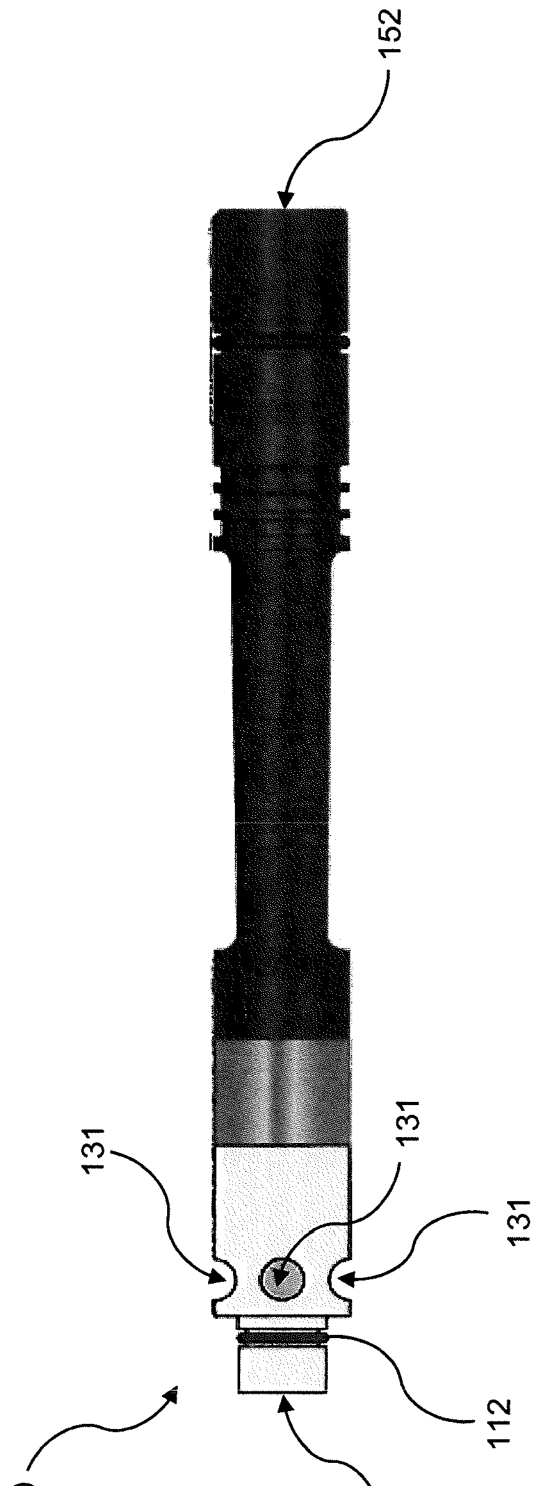



FIGURE 1B

FIGURE 2

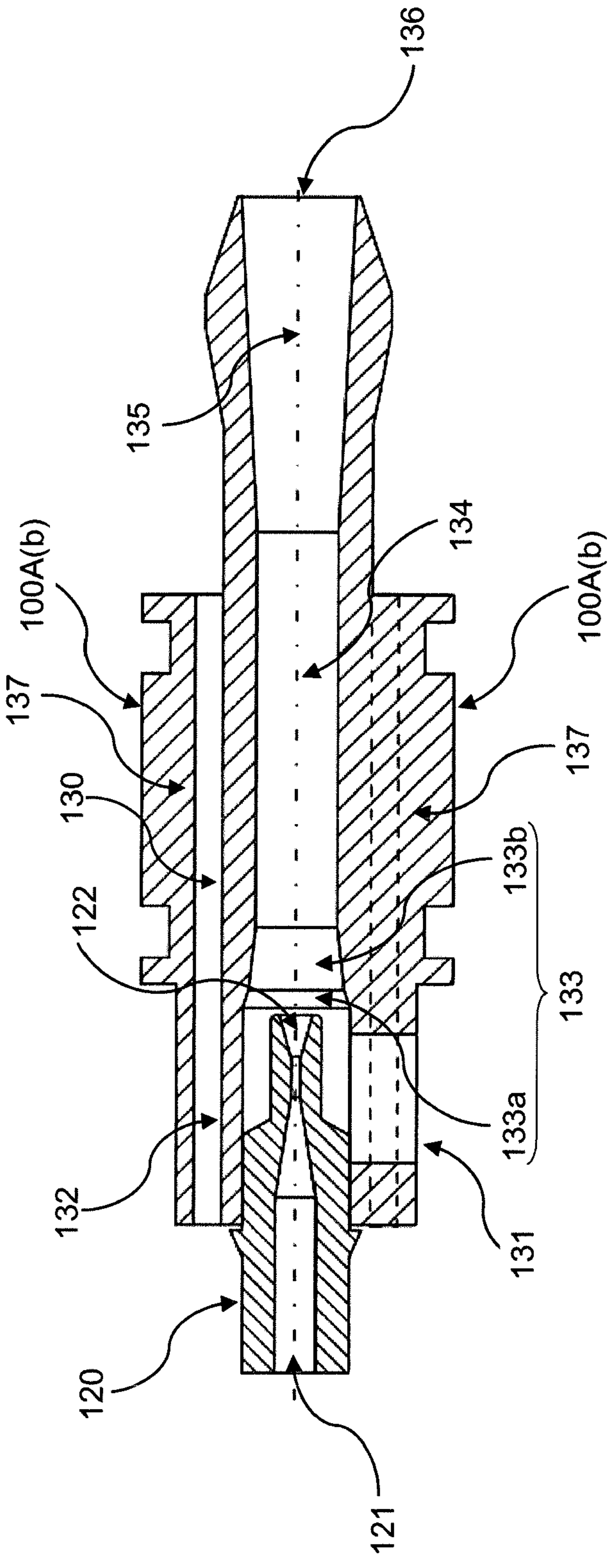

136
135
134
100A(b)
100A(b)
137
137
130
133b
133
122
133a
132
131
120
121

FIGURE 3

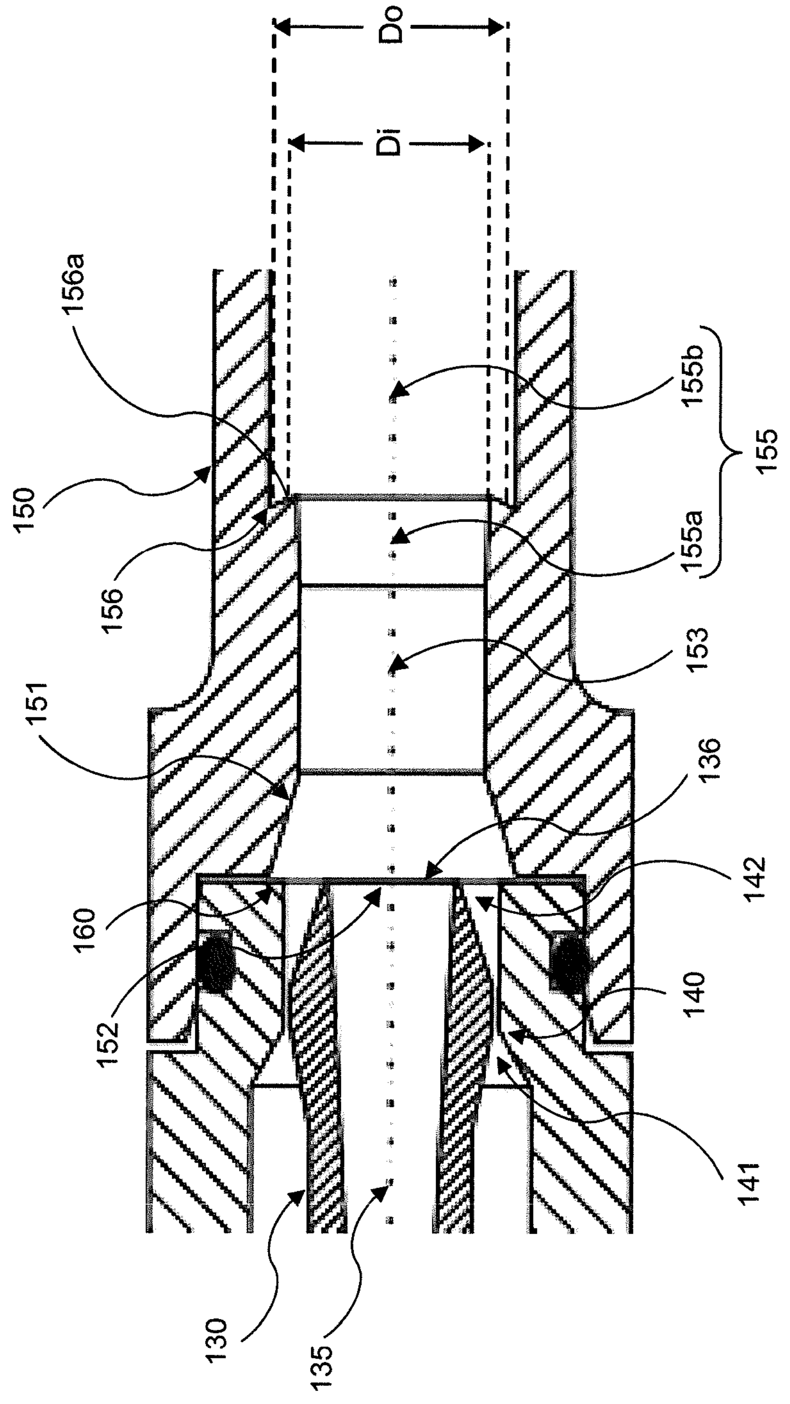

Do
Di
156a
155b
155
150
156
155a
151
153
136
142
160
152
140
141
130
135

FIGURE 4

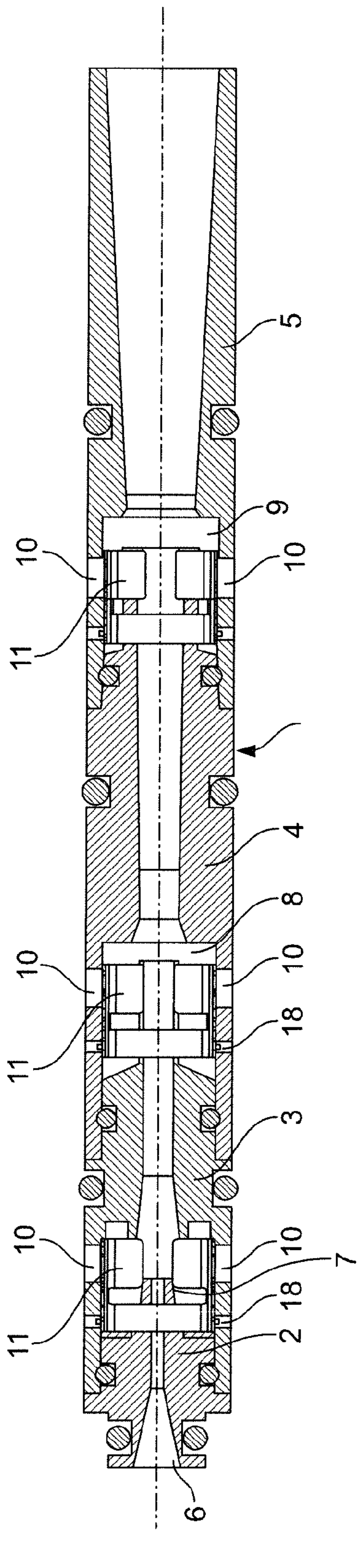


FIGURE 5

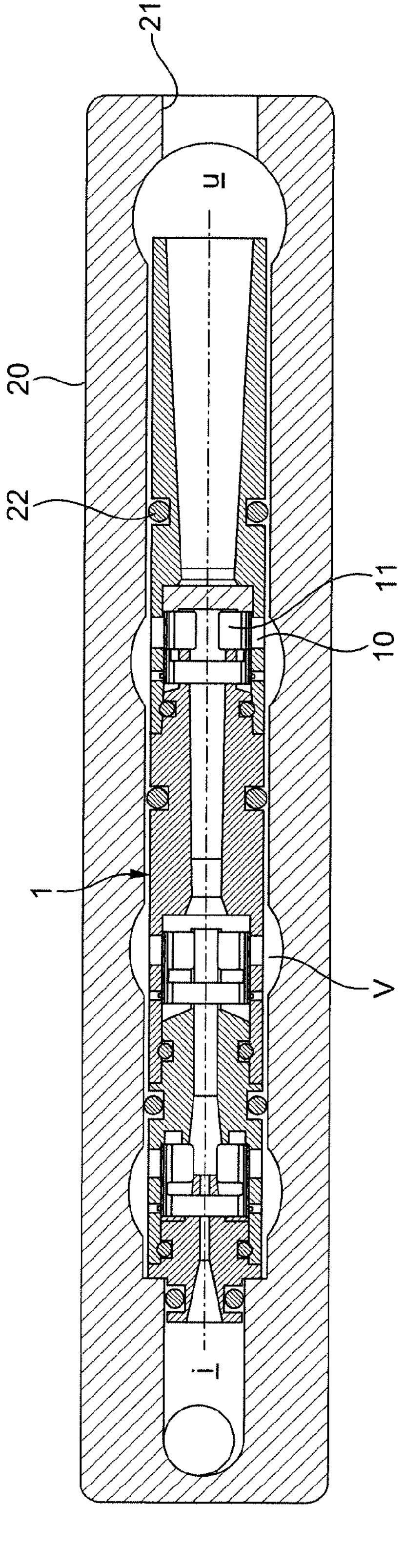
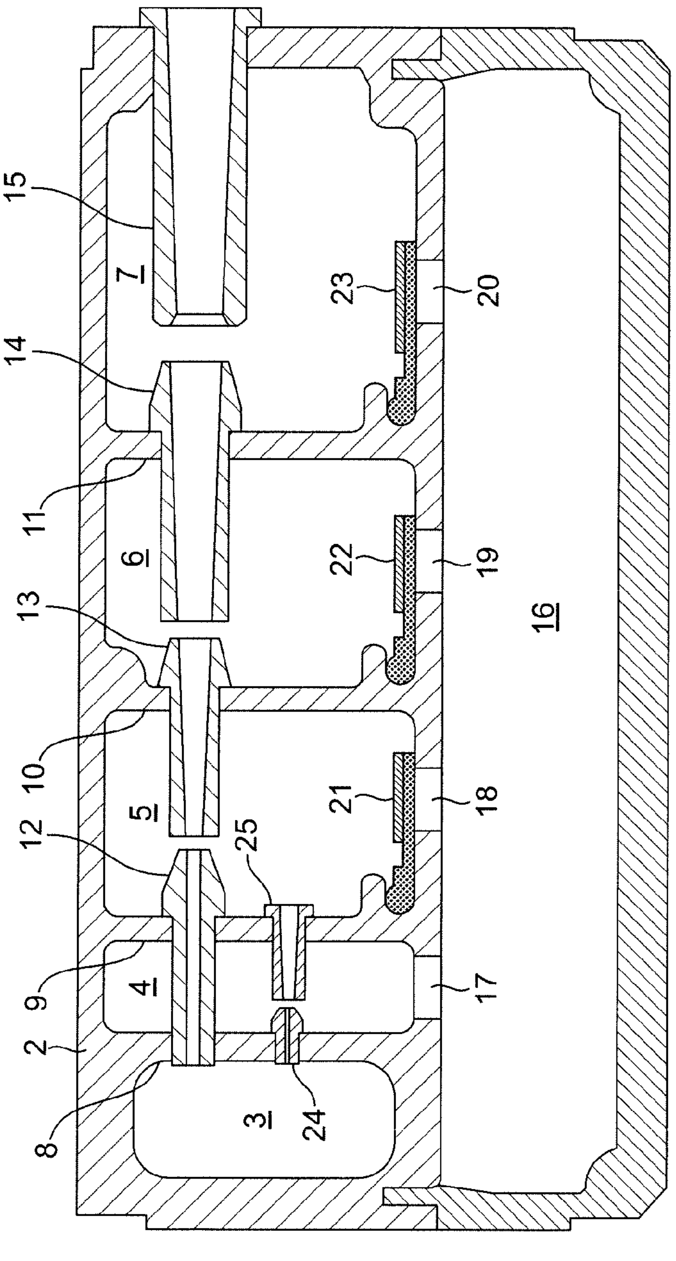


FIGURE 6



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Application Number
EP 15 19 2314

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| Munich | 22 April 2016 | Olona Laglera, C |

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