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(54) **DEVICE FOR GENERATING HIGHLY COMPRESSED GAS**

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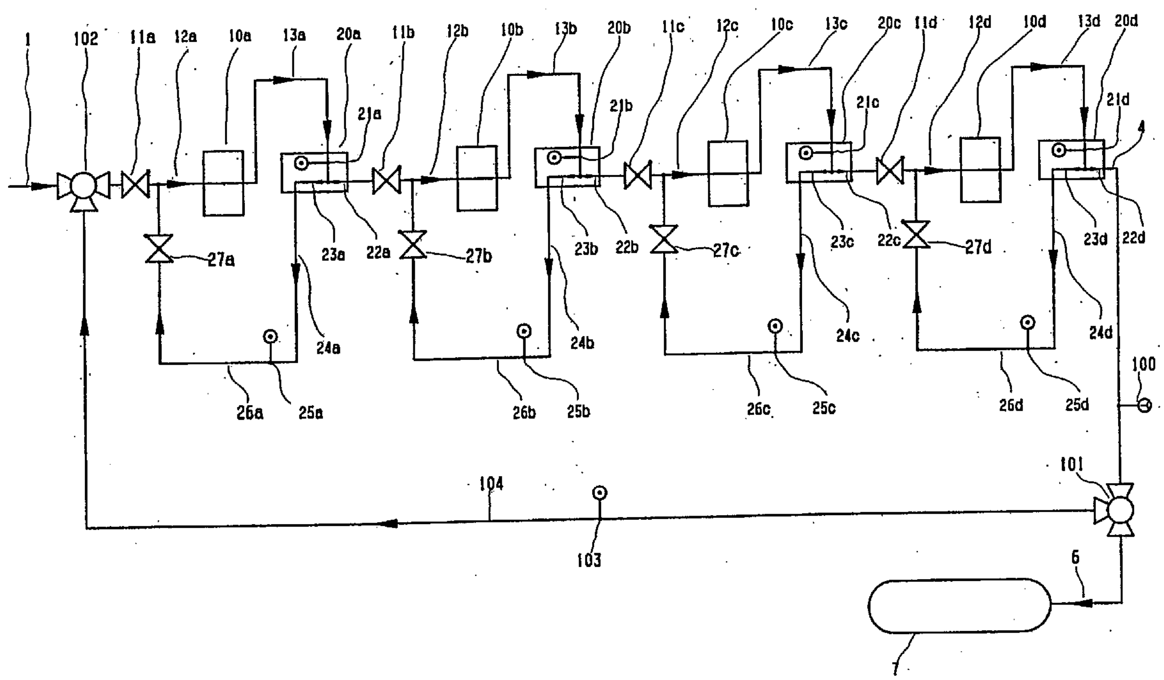
(57) **ABSTRACT**

In order to generate a highly compressed gas, a multistage high-pressure compressor is used, which has a number of 3 compressor stages (**10***a*, **10***b*, **10***c*, **10***d*). A vortex tube (**20***a*, **20***b*, **20***c*, **20***d*) is connected downstream from these compressor stages (**10***a*, **10***b*, **10***c*, **10***d*). The pressure difference between the pressure line (**4**) of the high-pressure compressor and the compressed gas reservoir (**7**) to be filled is used for driving, together with an expansion turbine (**5**), a pre-compressor (**2**) for pre-compressing the gas before entering the first compressor stage (**10***a*). Alternatively, a vortex tube for cooling gas can be mounted between the last compressor stage (**10***d*) and the compressed gas reservoir (**7**). The inventive device permits a direct filling of a compressed gas reservoir in order to reach a limit value of the pressure in the compressed gas reservoir at a predetermined limit temperature, said limit value being stipulated according to the technical rules.



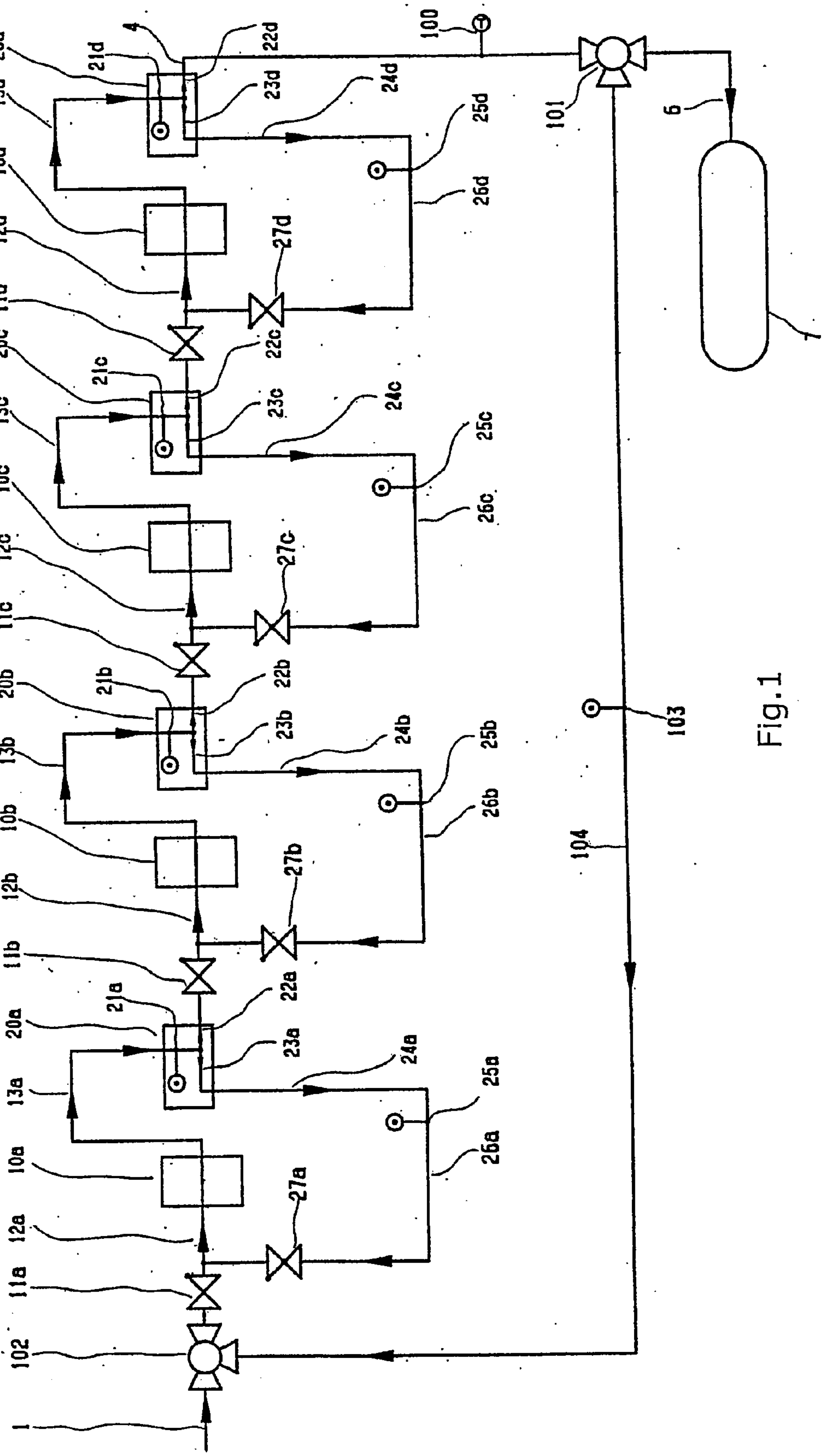

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Fig.1

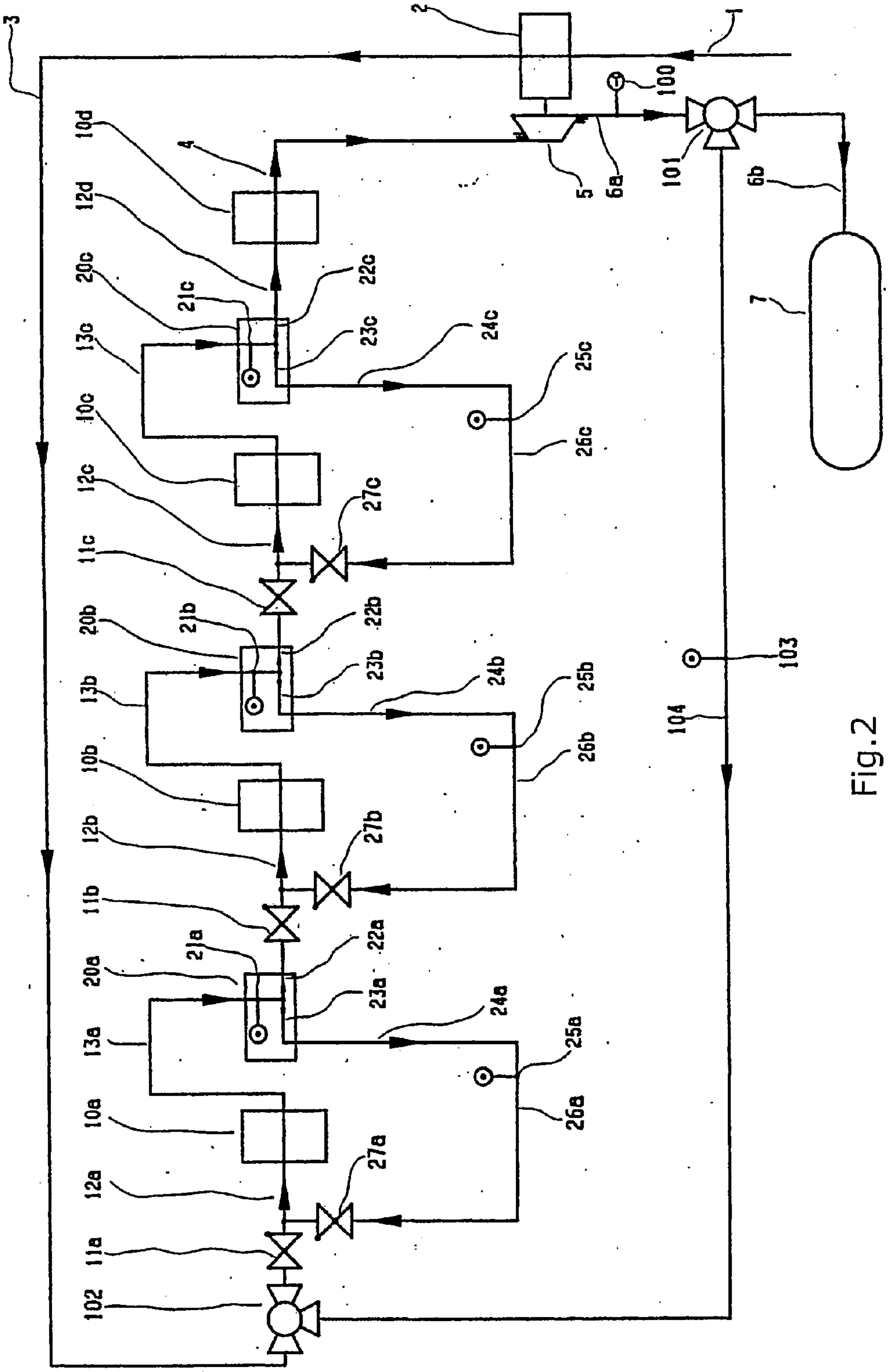
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Fig.2

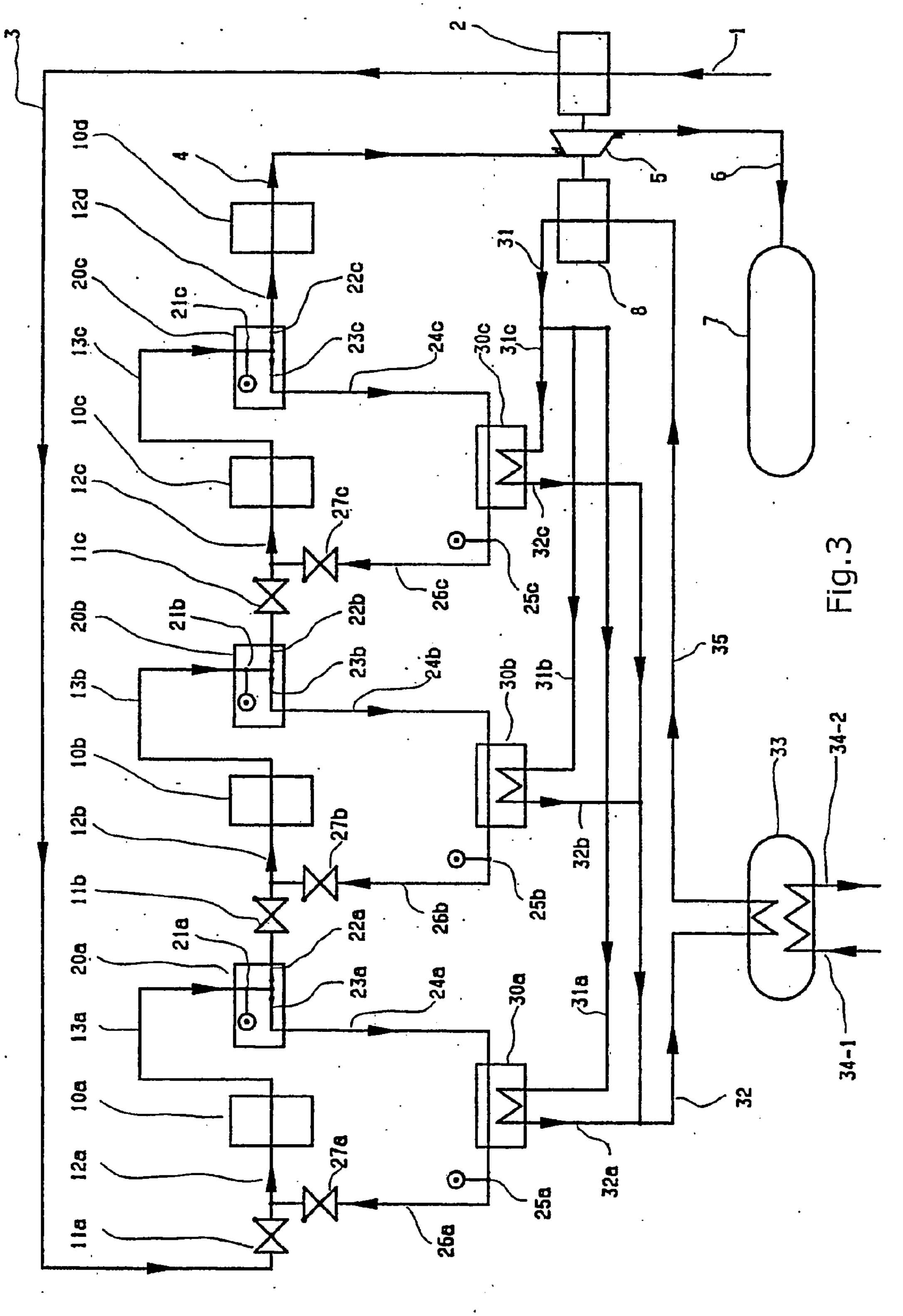
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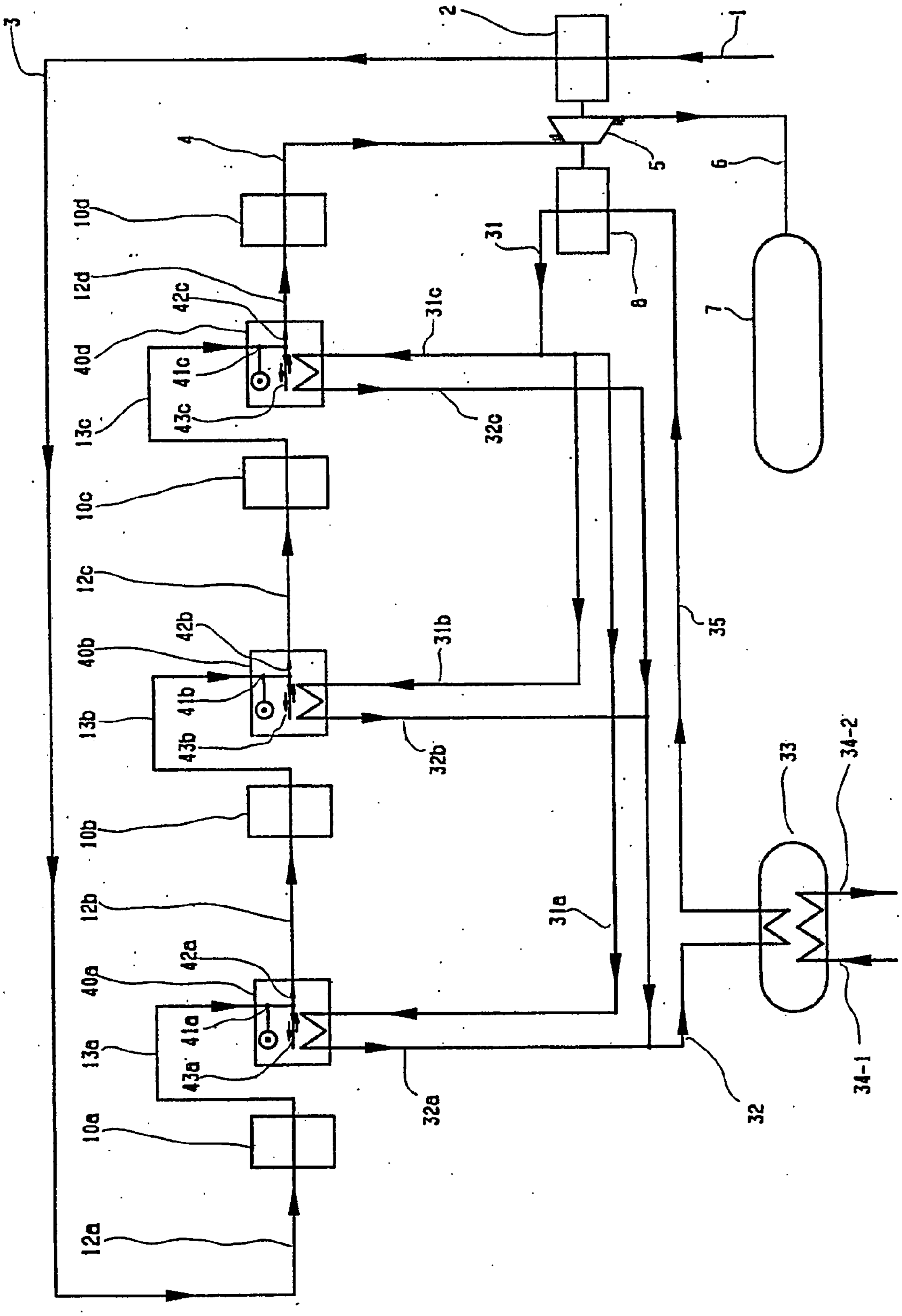
Fig.3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34-1
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Fig.4

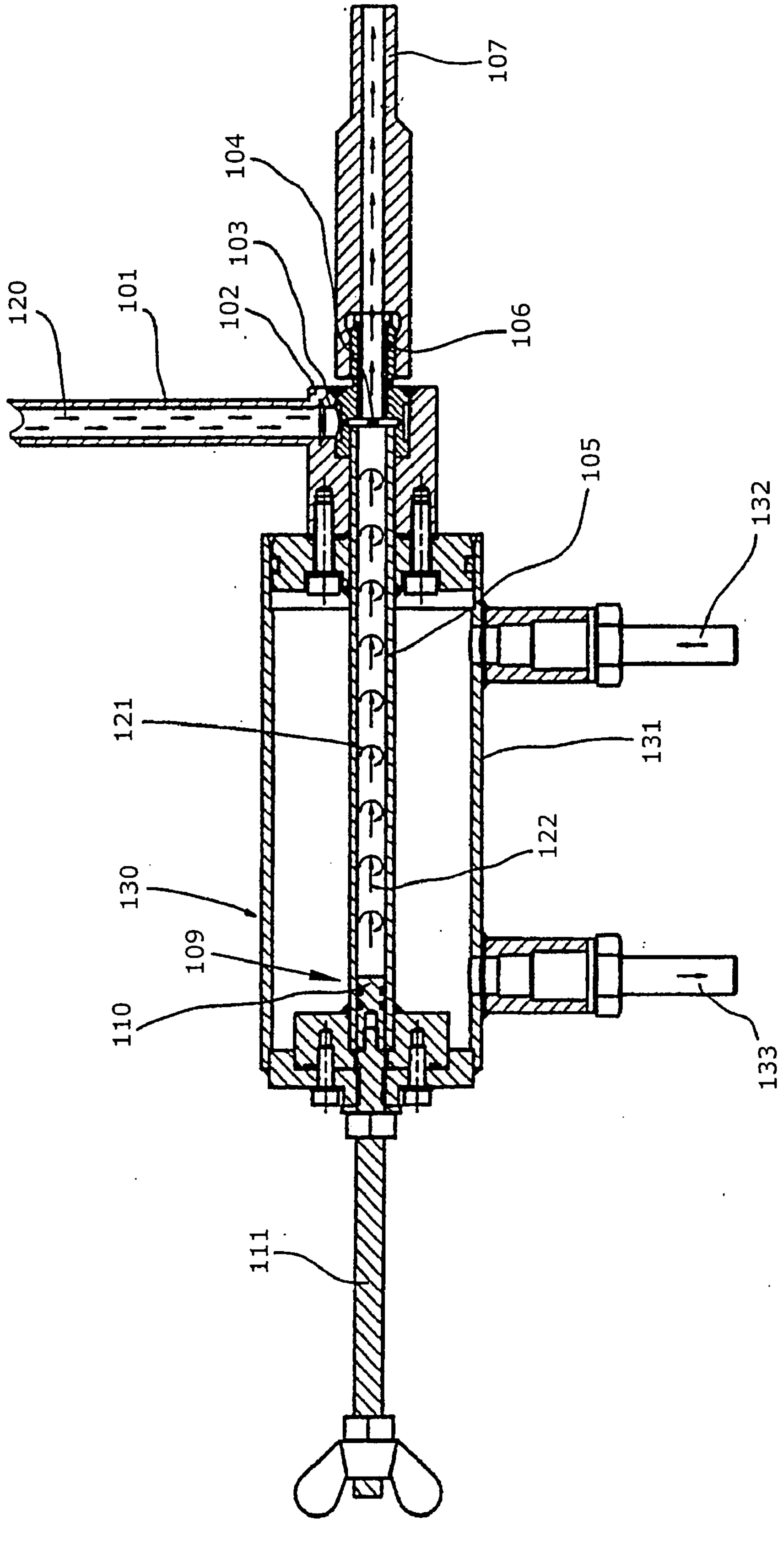
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Fig.5

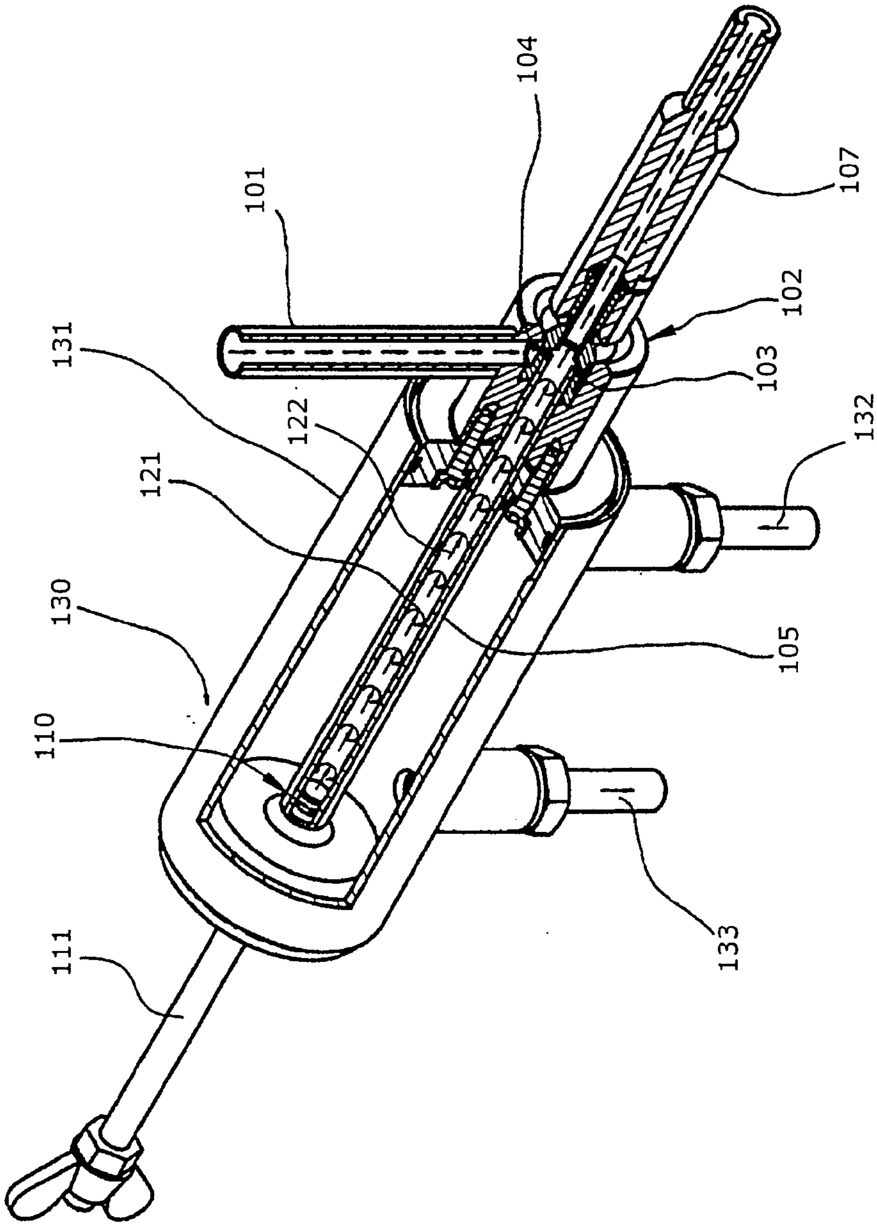

Fig.6

DEVICE FOR GENERATING HIGHLY COMPRESSED GAS

[0001] The invention refers to a device for generating highly compressed gas with a single-stage or a multistage compressor. Besides various other applications, the present device is useful in a gas fueling system for fueling vehicles running on natural gas, methane or similar gases or on hydrogen.

[0002] A problem with gases as an energy storage in vehicles is the greater storage volume required as compared to liquid energy sources, which, for natural gas, is greater by three orders of magnitude under ambient conditions. For this reason, it has been regulated that natural gas is available at gas stations at a pressure of 250 bar so that, as defined by technical rules, a pressure of 200 bar is reached and not exceeded in the pressure gas container of a vehicle at a reference temperature of 15° C. Thus, compared to a fuel-operated vehicle, at least only three times the storage volume has to be made available in a car.

[0003] In gas fueling installations, the pressurizing work to be performed causes a heating of the gas in the pressure gas container. The Joule-Thomson effect (a change in the gas temperature by throttling) of the real gas generally counteracts this heating. However, it is only under very favorable conditions, i.e. at sufficiently low temperatures, that the Joule-Thomson effect and the heat dissipation to the environment suffice to compensate for the heating caused by the pressurizing work of the gas. In gas fueling installations without a cooling device, if these favorable conditions do not exist, the pressure gas container will be filled short upon decanting. This is due to the fact that the pressurizing work creates a high temperature and thus a corresponding high pressure in the pressure gas container, whereby the available pressure difference for filling is reduced to such an extent that the fueling operation takes a long time and is therefore terminated before the pressure gas container holds the volume of gas possible according to technical specifications.

[0004] DE 197 05 601 A1 describes a natural gas fueling method without cooling of the gas, wherein the fueling of the pressure gas container is continued until the pressure in the conduit to the pressure gas container exceeds a maximum pressure. Another possibility provides that the fueling operation is terminated as soon as the mass flow falls below a limit value.

[0005] WO 97/06385 A1 describes a gas charging system for high-pressure gas bottles. Here, the gas is cooled by flushing the high-pressure gas bottle to be filled, whereby two connections for the feed and the return flow are needed. In the flushing circuit, the gas is cooled via a heat exchanger or by mixing it with gas in a reservoir.

[0006] EP 0 653 585 A1 describes a system for fueling a pressure gas container. Here, a test pulse is performed, which is evaluated with reference to the thermal equation of state for the real gas. Further, a switching to reservoirs at higher pressures (multiple unit method) during the fueling is described. The fueling operation is performed intermittently. No cooling device is provided for the gas.

[0007] DE 102 18 678 A1 describes a method and a device, wherein the gas for filling the pressure gas container is fed from a high-pressure reservoir through a vortex tube acting as a cooling device. The vortex tube takes advantage of the differential pressure prevailing in the fueling system to separate the gas flow into a hot gas flow and a cold gas flow. The latter is then supplied to the pressure gas container. The functionality of this method is based on the fact that the gas is fed to a swirl generator at a supercritical pressure ratio, the generator being arranged axially between two pipes having different inlet diameters. A decrease in temperature through the use of a vortex tube can be achieved if, and only if, supercritical pressure ratios exist. At a critical pressure ratio for natural gas of $\pi^*=0.5427$ and a pressure in the reservoir of $p_v=250$ bar, which is generally not reached, when a plurality of vehicles are refueled in shirt succession, a subcritical condition is obtained when the pressure in the pressure gas container has risen to $p_o=135$ bar. This means that, when filling a pressure gas container with natural gas in a pressure range from $p_o=135$ bar to $p_o=200$ bar, the use of a vortex tube will result in no further decrease in the gas temperature under the preconditions defined by the technical specifications.

[0008] A direct fueling is feasible where setting up publicly accessible natural gas fueling stations is not economic. Vehicles—and not only those of individual transport—could be refueled where they are during their standstill times. This may be in industrial parks, garages or car boards. Many households or buildings have natural gas available for heating. A compressor (natural gas compressor) could compress this natural gas at night from the regular natural gas network level of 50 mbar to 200 bar at a reference temperature of 15° C. A vehicle could be fueled therewith.

[0009] Another possible field of application for such a fueling system is seen in agriculture, where large volumes of biological gas are produced. Instead of feeding this biological gas into a public gas network, it could be compressed in situ and be used to operate agricultural vehicles and machines. In the future, this would allow to replace biodiesel in agriculture.

[0010] One requirement to be fulfilled by this compressor is that the compressor has to be configured such that a complete filling with fuel has to be possible within one night (about 8 hours) at 200 bar and a reference temperature of 15° C. The major problems of a multistage high-pressure compressor are the intermediate cooling and the cooling of the gas at the compressor outlet, which, when entering the pressure gas container, must not exceed 60° C. at any time during fueling.

[0011] It is an object of the invention to provide a device for generating highly compressed gas, wherein the compressed gas, which heats up during compression, is cooled in a cooling device which is of simple structure, provides a high cooling performance and is adapted to be realized with small dimensions.

[0012] The device of the present invention is defined in claim **1**. According to the invention, the cooling device arranged downstream of the compressor stage is designed as a vortex tube.

[0013] Vortex tubes are particularly well suited for ultra-short time decreases in temperature. In contrast to conventional gas coolers, these decreases in temperature can be achieved over very short path lengths. Moreover, the invention is based on the insight that the pressure ratio in the compressor stages of the high-pressure compressor is larger than 3. Thereby, it is guaranteed that the vortex tubes in all compressor stages will be in the supercritical range, which is essential for a trouble-free operation of the vortex tubes.

[0014] A particular embodiment of the invention provides to maintain, in direct fueling, the reference temperature of 15° C. at a pressure of 200 bar in the pressure gas container to be filled even if the decrease of the gas temperature in the vortex tubes is longer sufficient for this purpose under unfavorable peripheral and environmental conditions. Suitably, after the last compressor stage with an adjoining throttle point, the gas is not introduced into the pressure gas container to be filled, but is returned to the compressor inlet after an adiabatic throttling (Joule-Thomson effect). In the closed gas circuit, the gas temperature decreases continuously under isotropic compression and adiabatic throttling (production of cold by adiabatic throttling, caused by the Joule-Thomson effect in real gases). According to the invention, the gas circuit will remain closed until the decrease in temperature required by the technical specifications for the filling of the pressure gas container is reached.

[0015] A particularly suitable embodiment of the invention provides for using the heat produced in the vortex tubes to heat water for domestic use or to use it for heating a building.

[0016] Suitably, the output pressure of a multistage compressor is set so high that this pressure is above the critical pressure of the pressure gas container to be filled. In contrast to the filling of a pressure gas container by an overflow from a reservoir in which the gas pressure is limited to 250 bar according to the technical specifications for natural gas, these regulations do not apply to direct fueling using a high-pressure compressor, provided that the legal provisions for the pressure gas container are observed.

[0017] In a preferred embodiment of the invention, throttling via an expansion unit takes the gas flow leaving the final stage of the high-pressure compressor to the pressure allowed in the pressure container. The mechanical work arising at the expansion unit is used to drive a compressor for pre-compressing the gas taken from the gas network.

[0018] Using the pre-compression, the output pressure at the compressor can be varied via the input pressure at the high-pressure compressor. By throttling a defined output pressure, the ambient conditions during the fueling can be taken into account and the gas temperature in the pressure gas container can be influenced indirectly.

[0019] The invention further refers to a device for decreasing the temperature of a gas from a reservoir containing pressurized gas, comprising a feed pipe leading to a swirl generator, a filling pipe leading to the pressure gas container, and a vortex tube branching from the swirl generator for conducting a rotating vortex flow.

[0020] At higher temperatures, the volume of a gas is larger. Thus, for reasons of space, it is often necessary to cool the gas since then a larger gas mass can be stored in a determined volume. A typical application for gas cooling are gas fueling operations.

[0021] For a fast fueling of a gas-fueled vehicle, a fueling installation is required that is adapted to perform a fast decantation of high-pressure gas from a reservoir to a pressure gas container. Such gases to be decanted may comprise natural gas or methane or similar gases, as well as gases such as nitrogen, oxygen, argon, air or hydrogen.

[0022] In gas fueling operations it is intended to fill such a mass of gas into the pressure gas container, independent of the ambient temperature, that a limit value of pressure defined by the technical specifications is possibly reached in the pressure gas container at a predetermined reference temperature. For example, technical specifications provide that a pressure of 200 bar at a reference temperature of 15° C. must not be exceeded in a pressure gas container. For a fast fueling operation by overflow, the reservoir must be under high pressure for the required mass of gas to be transferred into the pressure gas container.

[0023] In gas fueling installations, the pressurizing work to be performed causes a heating o the gas in the pressure gas container. The Joule-Thomson effect (change in temperature of the gas by throttling) of the real gas generally counteracts this heating. However, it is only under very favorable conditions, i.e. at sufficiently low temperatures, that the Joule-Thomson effect and the heat dissipation to the environment will suffice to compensate the heat caused by the pressurizing work of the gas. If these favorable conditions do not exist, a fast decanting in gas fueling installations without cooling device will result in a short-filling of the pressure gas container. This is due to the fact that a high temperature and a corresponding high pressure are caused in the pressure gas container by the pressurizing work, whereby the pressure difference available for fueling is lowered to such a degree that the fueling operation takes a long time and is therefore terminated before the pressure gas container holds the mass of gas possible according to the technical specifications.

[0024] It is another object of the invention to provide a device for lowering the temperature of a gas, which can be manufactured with small dimensions, is of a simple structure and has a short response time with a great cooling effect.

[0025] The present device for lowering temperature has the features of claim **17**. The device is characterized in that the outside of the vortex tube is exposed to a cooling device, that a swirl brake for slowing the vortex flow is arranged in the vortex tube, and that a flow path leads from the swirl brake to the discharge pipe.

[0026] In the present device for lowering temperature, the entire gas flow is made substantially free of swirls after the temperature of the vortex flow has been lowered, and the gas flow is fed to the pressure gas container. No throttling means for controlling a hot gas flow is required. Compared to the known methods for filling pressure gas containers by overflow, it is an essential advantage that the pressure of the gas flow is lowered only to the instantaneous pressure in the pressure gas container, which is energetically advantageous.

[0027] In the present device, the gas is supplied tangentially to a swirl generator at a supercritical pressure ratio, i.e. at a speed just below the speed of sound. The swirl generator introduces a rotating vortex flow into the vortex tube. The vortex flow expands in the vortex tube at a high axial speed, whereby the tube wall is heated up strongly. The heavily turbulent mixing causes an adiabatic layering, and, due to the high centrifugal pressure, the outer portion of the vortex flow has a higher static temperature than the inner portion. The vortex flow is cooled by the cooling device acting on the vortex tube from outside, and is then slowed down by a swirl brake. The flow is then fed over a flow path to the filling tube leading to the pressure gas container. In this manner, the entire gas taken from the reservoir reaches the pressure gas container.

[0028] According to a preferred embodiment of the invention, it is provided that the flow path extends centrally through the vortex within the vortex flow. While the vortex flow rotates, a centric return flow forms along its axis. While the outer vortex flow continues to heat up, the linear inner return flow is much colder.

[0029] In an advantageous embodiment of the invention provides that the filling pipe also branches from the swirl generator and that the diameter of the filling pipe is smaller than the diameter of the vortex tube. In the process, the swirl-free linear return flow again reaches the swirl generator from where it gets into the filling pipe.

[0030] Preferably, the swirl brake is a closure arranged in the vortex tube. The same slows down the vortex flow near the wall because of the absence of centrifugal forces so that a radial inward flow is obtained. For reasons of continuity, a centric return flow in the form of a core flow is thus produced in the axial direction, flowing in a direction opposite to the rotating vortex flow. The lower speed of the return flow, as compared to the vortex flow, has effect in a further reduction of the static temperature of the inner flow with respect to the surrounding vortex flow, whereby the temperature difference between these two flows is still increased.

[0031] The invention starts from the insight that it is advantageous to dissipate the heat transferred from the rotating flow to the tube wall, which, as experience has shown, is at a high temperature level there.

[0032] According to a preferred embodiment of the invention, a water cooler designed as a coaxial pipe is used to cool the tube wall of the vortex tube in a counter current process. Thus, it is achieved, overall, that by cooling the tube wall, which is the more effective, the greater the temperature difference between the object to be cooled and the cooling medium is, an additional reduction in temperature of the inner flow in the tube is effected through a reduction in temperature of the outer flow of the tube.

[0033] A particularly advantageous embodiment of the invention provides that the closure forming the swirl brake is a piston adapted to adjusted axially in the vortex tube. Thereby, the effective length of the vortex flow is variable so as to optimize the filling operation in dependence on the pressure and the temperature of the gas in the reservoir. The effective length of the vortex tube, i.e. the length of the effective vortex tube section, can be changed by adjusting the piston, e.g. by means of a threaded bar.

[0034] The following is a detailed exemplary description of the invention with reference to a four-stage high-pressure compressor and to the accompanying drawings.

[0035] In the figures:

[0036] FIG. **1** is a schematic general view of the gas fueling system comprising a high-pressure compressor using a vortex tube according to Ranque-Hilsch for lowering the temperature of the gas after compression, wherein a separation into cold gas and hot gas is effected in the vortex tube,

[0037] FIG. **2** shows the same gas fueling system as FIG. **1**, however, using the pressure energy with its work capacity in an adiabatic throttling process after the last compressor stage in an expansion unit,

[0038] FIG. **3** illustrates the same gas fueling systems as FIG. **2**, however, using the heat in the hot gas for heating domestic and/or heating water via a heat exchanger,

[0039] FIG. **4** shows the same gas fueling system as FIG. **3**, however, using a vortex tube without gas separation, wherein the vortex tube is cooled from outside and the heat in the cooling water is available for heating domestic and/or heating water,

[0040] FIG. **5** is a longitudinal section through a device for lowering the temperature of gases, and

[0041] FIG. **6** is a perspective view of the device of FIG. **5** to illustrate the feeding and the distribution of the gas flow and the water cooling.

[0042] The gas fueling system illustrated in FIG. **1** has a take-off pipe **1** leading to the series-connected compressor stages **10***a*, **10***b*, **10***c* and **10***d*. A check valve **11***a*, **11***b*, **11***c*, **11***d* is arranged in the pipeline **1** upstream of each compressor stage. An inlet pipe **12***a*, **12***b*, **12***c*, **12***d* leads from the check valve to the following compressor stage. The outlet of the compressor stage is connected to the inlet of a vortex tube **20***a*, **20***b*, **20***c*, **20***d* via a take-off pipe **13***a*, **13***b*, **13***c*, **13***d*. The vortex tubes are generally structured as described in DE 102 18 678 A1 so that a detailed explanation of the structure of the vortex tubes can be omitted. The vortex tubes **20***a*, **20***b*, **20***c*, **20***d* serve to decrease the gas temperature after a previous compression.

[0043] The vortex tubes **20***a*, **20***b*, **20***c*, **20***d* operating according to the counter-current method are connected to the compressor stages **10***a*, **10***b*. **10***c*, **10***d* via the take-off pipes **13***a*, **13***b*, **13***c*, **13***d*. Through the take-off pipes **13***a*, **13***b*, **13***c*, **13***d*, the gas flow reaches the inflow nozzles forming the narrowest flown-through cross section **21***a*, **21***b*, **21***c*, **21***d* between two compressor stages. As a vortex flow at the speed of sound, the gas flows from the inflow nozzles into the central tube of the vortex tube where a separation into a cold gas flow and a hot gas flow is effected. At one end of the central tube, the cold core of the forming swirl is collected and fed to the subsequent compressor stage via the inlet pipes **12***b*, **12***c*, **12***d*. At the opposite end of the central tube, the hot gas flow **23***a*, **23***b*, **23***c*, **23***d* is collected and discharged via the pipelines **24***a*, **24***b*, **24***c*, **24***d*. The throttle points **25***a*, **25***b*, **25***c*, **25***d* provided in the pipelines **24***a*, **24***b*, **24***c*, **24***d* serve to preset the mass ratio between the cold gas and the hot gas portions. Downstream of the throttle points **25***a*, **25***b*, **25***c*, **25***d*, the hot gas flow flows through the return flow pipes **26***a*, **26***b*, **26***c*, **26***d* into the same compressor stage from which the gas was taken. The check valves **27***a*, **27***b*, **27***c*, **27***d* in the return flow pipes **26***a*, **26***b*, **26***c*, **26***d* and the check valves **11***a*, **11***b*, **11***c*, **11***d* in the inlet pipes **12***a*, **12***b*, **12***c*, **12***d* allow the gas to flow from the return flow pipes **26***a*, **26***b*, **26***c*, **26***d* into the inlet pipes **12***a*, **12***b*, **12***c*, **12***d*.

[0044] From the gas supplied, each vortex tube produces a hot gas flow **23***a*, **23***b*, **23***c*, **23***d* and a cold gas flow **22***a*, **22***b*, **22***c*, **22***d*. The hot gas flow **23***a*, **23***b*, **23***c*, **23***d* is returned to the respective compressor stage **10***a*, **10***b*, **10***c*, **10***d*.

[0045] On the other hand, the cold gas flow **22***a*, **22***b*, **22***c*, **22***d* is fed to the subsequent compressor stage. The check valves **11***a*, **11***b*, **11***c*, **11***d* prevent returned gas from entering the cold gas outlet of the previous vortex tube. The check valves **27***a*, **27***b*, **27***c*, **27***d* help to avoid that the cold gas of the previous vortex tube gets into the return pipe of the hot gas of the subsequent vortex tube.

[0046] From the vortex tube **20***d* of the last compressor stage **10***d*, the cold gas flow **22***d* reaches the pressure pipe **4**. If the gas temperature there, measured by a temperature measuring means **100**, is above a predetermined reference value, the three-way stopcocks **101**, **102** are operated as triggered by a measurement signal. Normally, these are set such that the gas flow leads from the take-off pipe **1** to the series-connected compressor stages **10***a*, **10***b*, **10***c*, **10***d* and the cold gas flow **22***d* is fed into the pressure gas container **7** through the pressure line **6**. If the cold gas temperature exceeds a predefined limit value at the measuring point **100**, the cold gas flow **22***d* is redirected via the return manifold **104** using the three-way stopcock **101**. Before the cold gas flow is again fed to the first compressor stage **10***a* through the return manifold **104** via the three-way stopcock **102** and the inlet pipe **12***a*, the cold gas flow is subjected to a further reduction in temperature at the throttle point **103**. The three-way valve **102** is operated simultaneously with the three-way valve **101** so that no gas is supplied through the take-off line **1** and a closed circuit is established after the three-way stopcocks **101**, **102** have been operated. In this closed system, an adiabatic throttling (Joule-Thomson effect) reduces the temperature in the hot gas flow **23***a*, **23***b*, **23***c*, **23***d* at the throttle points **25***a*, **25***b*, **25***c*, **25***d* and in the cold gas flow **22***d* at the throttle point **103**. Due to the Joule-Thomson effect, the decrease in temperature obtained by throttling is larger with a real gas like natural gas than the increase in temperature in the gas caused by the compression in the previous compressor stages **10***a*, **10***b*, **10***c*, **10***d*. Thus, in a closed gas circuit, the gas temperature can be lowered by compression and adiabatic throttling. As soon as the temperature measuring means detects that the temperature in the cold gas flow **22***d* corresponds to a predefined reference temperature, a measurement signal is triggered operating the three-way stopcocks **101**, **102** so that the take-off pipe **1** is again in communication with the compressor stages **10***a*, **10***b*, **10***c*, **10***d* and the cold gas flow **22***d* is introduced into the pressure gas container **7** via the pressure pipe **6**.

[0047] Other than the system in FIG. **1**, the gas fueling system illustrated in FIG. **2** has a pre-compressor **2** connected to the take-off pipe **1**. A pipeline **3** leads from the pre-compressor **2** to the series-connected compressor stages **10***a*, **10***b*, **10***c*, **10***d*. A check valve **11***a*, **11***b*, **11***c* is provided in the pipeline **3**, upstream of each compressor stage. The last compressor stage **10***d* is not provided with a check valve. An inlet pipe **12***a*, **12***b*, **12***c* leads from the check valve to the subsequent compressor stage. The outlet of the compressor stage is connected to the inlet of a vortex tube **20***a*, **20***b*, **20***c* via a take-off pipe **13***a*, **13***b*, **13***c*.

[0048] From the last compressor stage **10***d*, a pressure pipe **4** leads to an expansion unit **5**. In the expansion unit, the gas flow is subjected to a reduction in temperature after the last compressor stage **10***d*, before the gas is introduced into the pressure gas container **7**. Normally, the three-way stopcock **101** is set such that the pressure pipe **6***a*, **6***b* is connected through. At the same time, mechanical work is taken from the gas flow in the expansion unit **5** that is used to drive the pre-compressor **2**. The expansion unit **5** drives the pre-compressor **2**.

[0049] The gas compressed in the pre-compressor **2** is fed to the first compressor stage **10***a* through the pipeline **3** via the inlet pipe **12***a* provided with the check valve **11***a*. The vortex tubes **20***a*, **20***b*, **20***c* operating according to the counter-current process are connected to the compressor stages **10***a*, **10***b*, **10***c* via the take-off pipes **13***a*, **13***b*, **13***c*. Through the take-off pipes **13***a*, **13***b*, **13***c*, the gas flow reaches the inflow nozzles that form the narrowest cross section **21***a*, **21***b*, **21***c* between the compressor stages **20**, **20***b*, **20***c*. The cold gas flow **22***a*, **22***b*, **22***c* of the vortex tubes **20***a*, **20***b*, **20***c* is fed to the following compressor stage via the inlet pipes **12***b*, **12***c*, **12***d*, and the hot gas flow **23***a*, **23***b*, **23***c* is discharged via the pipelines **24***a*, **24***b*, **24***c*. The throttle points **25***a*, **25***b*, **25***c* provided in the pipelines **24***a*, **24***b*, **24***c* serve to preset the mass ratio between the cold gas and the hot gas portions. Downstream of the throttle points **25***a*, **25***b*, **25***c*, the hot gas flow **23***a*, **23***b*, **23***c* returns, via the return pipes **26***a*, **26***b*, **26***c*, into the same compressor stage from which the gas was taken. The check valves **27***a*, **27***b*, **27***c* in the return pipes **26***a*, **26***b*, **26***c* and the return valves **11***a*, **11***b*, **11***c* in the inlet pipes **12***a*, **12***b*, **12***c* allow the gas to flow from the return pipes **26***a*, **26***b*, **26***c* to the inlet pipes **12***a*, **12***b*, **12***c*.

[0050] From the gas supplied, each vortex tube produces a hot gas flow **23***a*, **23***b*, **23***c* and a cold gas flow **22***a*, **22***b*, **22***c*. The hot gas flow **23***a*, **23***b*, **23***c* is returned to the respective compressor stage **10***a*, **10***b*, **10***c*. On the other hand, the cold gas flow **22***a*, **22***b*, **22***c* is fed to the subsequent compressor stage. The check valves **11***a*, 1*b*, 1l*c* prevent returned gas from entering the cold gas outlet of the previous vortex tube. The check valves **27***a*, **27***b*, **27***c* help to avoid that the cold gas of the previous vortex tube gets into the return pipe of the hot gas of the subsequent vortex tube.

[0051] As is further obvious from FIG. **2**, the closed gas circuit can be designed as described with respect to FIG. **1**, so as to start a decrease in the gas temperature when the gas temperature exceeds a predetermined reference temperature at the temperature measurement point 100.

[0052] The embodiment of FIG. **3** differs from that of FIG. **2** in that the hot gas flow **23***a*, **23***b*, **23***c* of the vortex tubes is fed via a respective return pipe **26***b*, **26***c*, **26***d* that leads back to the inlet pipe **12***a*, **12***b*, **12***c* of the compressor stage **10***a*, **10***b*, **10***c*. The return pipes **26***a*, **26***b*, **26***c* each include a gas cooler **30***a*, **30***b*, **30***c* to draw heat from the gas. Downstream of each gas cooler, a throttle point **25***a*, **25***b*, **25***c* is mounted in the return pipe.

[0053] The gas coolers **30***a*, **30***b*, **30***c* are water-cooled heat exchangers. By forced circulation, a circulation pump **8** driven by the expansion unit **5** feeds the water through a pipe **31** to the gas coolers **30***a*, **30***b*, **30***c* that are connected in parallel to corresponding feed pipes **31***a*, **31***b*, **31***c*. From the gas coolers, the cooling medium flows in return pipes **32***a*, **32***b*, **32***c* that combine to a return manifold **32**. The return manifold **32** leads to a heat exchanger **33**. Here, the cooling medium that acts as a heat carrier transfers the heat received in the gas coolers to a second heat transfer medium that is supplied from a feed **34-1** of the secondary circuit and exits from the heat exchanger through a drain **34-2**. The heat transfer medium conveyed in the secondary circuit may be domestic water and/or heating water for a building heating. Having left the heat exchanger **33**, the heat transfer medium conveyed in the primary circuit returns to the intake side of the circulation pump **8** via a pipe **35**.

[0054] In the gas fueling system of FIG. **4**, a vortex tube is employed that operates without gas separation. The gas taken from the take-off pipe **1** is brought to a higher pressure level in a pre-compressor **2** driven by the expansion unit **5**. Via the pipe **3**, the pre-compressed gas is fed to the inlet pipe **12***a* of the first compressor stage **10***a* of the high-pressure compressor. After compression in the first compressor stage **10***a*, the gas reaches the vortex tube **40***a* via the take-off line **13***a* for a reduction in the temperature of the gas. The same is valid for the following compressor stages **10***b*, **10***c* with the take-off pipes **13***b*, **13***c* and the vortex tubes **40***b*, **40***c*.

[0055] The vortex tubes **40***a*, **40***b*, **40***c* are connected to the compressor stages **10***a*, **10***b*, **10***c* through the take-off pipes **13***a*, **13***b*, **13***c*. Through the take-off pipes **13***a*, **13***b*, **13***c*, the gas flow reaches the inflow nozzles that form the narrowest flown-through cross section **41***a*, **41***b*, **41***c* between two compressor stages. As a vortex flow at the speed of sound, the gas flows from the inflow nozzles into the central tube of the vortex tubes **40***a*, **40***b*, **40***c* which are closed at one end **43***a*, **43***b*, **43***c*. At the solid bottom of the closed-end tube, the flow is slowed down near the wall because of the absence of centrifugal forces so that at the end, near the bottom, a radial inward flow is obtained. For reasons of continuity, a rising flow is produced in the axial direction, which flows as a core flow in the direction opposite to the rotating flow and flows out at the opposite ends **42***a*, **42***b*, **42***c* of the closed tubes into the inlet pipes **12***a*, **12***b*, **12***c*.

[0056] The increase in static temperature on the outside and its decrease on the inside necessarily cause different temperatures between the inner flow in the tube and the outer flow in the tube. All in all, a decrease in temperature of the outer flow in the tube by cooling the tube wall allows for an additional decrease in the temperature of the inner flow in the tube. Thus, the vortex tubes **40***a*, **40***b*, **40***c* are equipped with water coolers **44***a*, **44***b*, **44***c* that surround the central tube of the vortex tubes **40***a*, **40***b*, **40***c* and are used for cooling the outer wall of the tube according to the counter-current technique. As is further obvious from FIG. **4**, the primary and the secondary circuit can be designed according to the cooling circuit described in connection with FIG. **3**.

[0057] The gas is supplied to the last compressor stage **10***d* via the inlet pipe **12***d*. In the expansion unit **5**, the gas flow is subjected to further temperature reduction downstream of the compressor stage **10***d*, before the gas is introduced into the pressure gas container **7**. At the same time, mechanical work is taken from the gas flow in the expansion unit **5**, which is used to drive the pre-compressor **2** and the circulation pump **8**.

[0058] The device for reducing the temperature illustrated in FIGS. **5** and **6** comprises a feed pipe **101** coming from a reservoir and leading to a swirl generator **102**. The functionally essential parts thereof are an annular plenum chamber **103**, from which tangential inflow nozzles **104** are directed inward and lead into the end of a vortex tube **105**. Adjoining the end of the vortex tube **105** is an oppositely directed pipe section **106** that is connected with a filling pipe **107** leading to the pressure gas container (not illustrated). The inner diameter of the pipe section **106** is clearly smaller than that of the vortex tube **105**. As a consequence, the rotating vortex flow **121** produced in the swirl generator **102** flows into the vortex tube where it moves away from the swirl generator **102** (to the left in FIG. **1**). The throttle point with the narrowest flown-through cross section between the reservoir and the pressure gas container to be filled is formed by the inflow nozzles **104** of the swirl generator **102**. From the inflow nozzles **104**, the gas flows into the vortex tube **105** as a rotating vortex flow **121** at almost the speed of sound. For dissipating the heat caused by the vortex flow **121** from the tube wall of the vortex tube **105**, a cooling device **130** is provided around the vortex tube **105**. The same comprises a cooling jacket **131** coaxially surrounding the vortex tube, which is provided with a feed pipe **132** and a drain pipe **133** and forms a water cooler according to the counter-current technique.

[0059] At the end averted from the swirl generator **102**, the vortex tube **105** is provided with a swirl brake **109**. The same comprises an axially adjustable piston **110** that is arranged in the vortex tube, closing it off sealingly. To adjust the piston **110**, a spindle **111** is used that can be turned manually. The vortex flow **121** is slowed down at the closure **110** so that, for reasons of continuity, an axially directed return core flow flowing back along a flow path **122** is formed, flowing in a direction opposite to the vortex flow **121**. The flow path **122** extends coaxially within the vortex flow **121**. The pressure difference between the inner and the outer flow in the vortex tube **105** has the effect that the core flow flowing along the inner flow path **122** flows through the pipe section **106** into the filling pipe **107** that is connected with the pressure gas container to be filled.

[0060] The perspective view in FIG. **6** represents the flow course of a gas in the device, the gas supply being effected through the feed pipe **101** in the direction of the arrows **120**. From here, the gas, e.g. natural gas, reaches the vortex tube **105** at a supercritical pressure ratio and at the speed of sound via the plenum chamber **103** and the inflow nozzles **104** of the swirl generator **102**. Caused by the swirl generated in the swirl generator **102**, the rotating flow **121** is formed in the vortex tube. Near the wall, due to the absence of centrifugal forces, this rotating flow is slowed down so far at the solid bottom of the vortex tube closed by the closure **110** that an oppositely directed core flow **122** is formed. The latter is then fed to the pressure gas container via the pipe section **106**.

1. A device for generating highly compressed gas comprising a single-stage or a multistage compressor (**10***a*, **10***b*, **10***c*, **10***d*) and a cooling device downstream of at least one compressor stage, the cooling device being configured as a vortex tube (**20***a*, **20***b*, **20***c*, **20***d*; **40***a*, **40***b*, **40***c*, **40***d*).

2. The device of claim 1, characterized by a multistage high-pressure compressor (**10***a*-**10***d*), wherein downstream of at least one compressor stage a vortex tube (**20***a*, **20***b*, **20***c*, **20***d*; **40***a*, **40***b*, **40***c*, **40***d*) is arranged, and an expansion unit (**5**) is arranged between the high-pressure compressor and a pressure gas container (**7**), the expansion unit driving a pre-compressor (**2**) for compressing the gas before it enters into the first compressor stage (**10***a*).

3. The device of claim 1, wherein, in a multistage high-pressure compressor, the vortex tube is arranged between the last compressor stage (**10***d*) and a pressure gas container (**7**).

4. The device of claim 1, wherein the vortex tubes (**20***a*, **20***b*, **20***c*, **20***d*) have a cold gas outlet (**22***a*, **22***b*, **22***c*, **22***d*) and a hot gas outlet (**24**a, **24**b, **24**c, **24**d), the gas being supplied from the cold gas outlet to the subsequent compressor stage and the temperature of the gas from the hot gas outlet is reduced by throttling the hot gas flow and is returned into the respective compressor stage.

5. The device of claim 1, wherein, between the individual compressor stages (**10**a, **10**b, **10**c, **10**d), the vortex tubes are supercritical and are operated at the same pressure ratio.

6. The device of claim 4, wherein the throttling is effected through throttle points (**25**a, **25**b, **25**c, **25**d) dimensioned such that a predetermined mass ratio between the cold gas and the hot gas is observed.

7. The device of claim 4, wherein the cold gas (**22**d) is redirected into the first compressor stage (**10**a) by means of a switching device (**101**), whereby the cold gas flow is subjected to further throttling and thus to an additional reduction in temperature, if the temperature of the cold gas exceeds a predefined temperature for filling the pressure gas container (**7**).

8. The device of claim 1, wherein the outlet of the last compressor stage (**10**d) of the multistage compressor is connected to a vortex tube (**20**d) whose cold gas outlet is adapted to be connected to the inlet of the first compressor stage (**10**a) via a return pipe (**104**).

9. The device of claim 8, wherein the return pipe (**104**) includes a throttle (**103**).

10. The device of claim 8, wherein the connection of the outlet of the last compressor stage (**10**d) with the inlet of the first compressor stage (**10**a) is established in dependence on the measured gas temperature in the cold gas flow (**22**d) of the vortex tube (**20**d) of the last compressor stage (**10**d).

11. The device of claim 1, wherein a pre-compression to between 0.5 bar and 2.0 bar is effected in a pre-compressor (**2**), the output pressure of the high-pressure compressor being freely selectable within a wide range.

12. The device of claim 11, wherein, by predefining the output pressure of the multistage high-pressure compressor, the temperature decrease is adjusted to the ambient temperature through the throttling effect an the Joule-Thomson effect during the filling of the pressure gas container (**7**), so that a pressure of 200 bar is reached in the pressure gas container (**7**) at a reference temperature of 15° C., independent of the ambient temperature.

13. The device of claim 1, wherein, for cooling, the com-pressed gas is passed over a cooler (**33**) using water as the cooling medium.

14. The device of claim 1, wherein at least some of the vortex tubes (**40**a, **40**b, **40**c, **40**d) are cooled from outside by a cooling device (**44**a, **44**b, **44**c, **44**d).

15. The device of claim 13, wherein the heated water dissipates its heat through a heat exchanger (**33**) for use in heating domestic water and/or heating water for room heating.

16. The device of claim 15, wherein the expansion unit (**5**) drives a pump (**8**) for an additional circulation of the water in the primary circuit of the heat exchanger (**33**).

17. A device for decreasing the temperature of a pressurized gas comprising a feed pipe (**101**) leading to a swirl generator (**102**) and a vortex tube (**105**) branching from the swirl generator (**102**) for conveying a rotating vortex flow (**121**), wherein the outside of the vortex tube (**105**) is exposed to a cooling device (**130**), that a swirl brake (**109**) for slowing the vortex flow (**121**) down is arranged in the vortex tube (**105**), and that a flow path (**122**) leads from the swirl brake (**109**) into a filling pipe (**107**).

18. The device of claim 17, wherein the flow path (**122**) extends centrically through the vortex tube (**105**) within the vortex flow (**121**).

19. The device of claim 17 or 18, wherein the filling pipe (**107**) also branches from the swirl generator (**102**) and wherein the diameter of the filling pipe (**107**) is smaller than the diameter of the vortex tube (**105**).

20. The device of claim 17, wherein the swirl brake (**109**) is a closure (**110**) arranged in the vortex tube (**105**).

21. The device of claim 20, wherein the closure (**110**) is a piston adapted to be adjusted axially in the vortex tube.

22. The device of claim 17, wherein the cooling device (**130**) comprises a cooling jacket (**131**) surrounding the vortex tube (**105**), a cooling medium flowing through the jacket.

23. The device of claim 17, characterized by its use for filling a pressure gas container.

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