Description

Title: ASSEMBLY FOR A VEHICLE AND CORRESPONDING METHODS

Technical field

[1] This disclosure relates to the field of braking devices for vehicles (automotive or rail). The context focuses in particular on aspects of protecting the environment by suctioning the brake particles emitted by friction brakes, particularly disc brakes.

Prior art

[2] Document FR 3 057 040 A1 describes a disc brake pad lining equipped with a collection groove and a through-hole fluidically connected to suction means. This lining allows efficiently suctioning brake dust over the entire radial height of the lining. The suction means comprise a fan generating negative pressure that suctions in the dust to direct it toward a collection filter.

[3] Documents DE 198 46 887 A1 and DE 196 43 869 A1 illustrate two examples of suction means control in which the maximum suction is activated during braking.

[4] Document FR 3 088 395 A1 introduces the concept of suction compensation based on the fill level of the collection filter: to ensure satisfactory suction throughout the service life of the filter, the suction power can be increased if necessary.

[5] The existing systems therefore consistently advocate suction activation during braking phases and suction deactivation after braking phases. Furthermore, the existing systems utilize a separate negative pressure source for each brake, rendering these designs complex, costly, and heavy.

Summary

[6] The present disclosure improves this situation by proposing a braking system that is simpler and equally effective in suctioning particles.

[7] An assembly for a vehicle is therefore proposed, comprising: N disc brakes, where N is an integer greater than or equal to two, each of the N disc brakes being equipped with a particle collection element; and a brake particle capture system comprising: a single negative pressure source; a pneumatic circuit extending from the negative pressure source to the collection elements of each of the N brakes; and a control unit configured to fluidically connect the negative pressure source to each of the N brakes sequentially according to a predefined cycle, such that at any given time t, only n(t) brakes are fluidically connected to the negative pressure source, where n(t) is an integer between 0 and N-1 for any value of t.

[8] The inventors have surprisingly demonstrated that suctioning particles from a brake in a cyclical manner (rather than continuously or at brake activation) allows capturing a significant and sufficient amount of particles. Without wishing to be bound by any theory, these positive results appear to stem from two factors. The first factor appears to be the fact that the collection element (for example, a groove at the trailing edge of the brake pad, a peripheral groove, a central suction port, a caliper housing, a suction nozzle, a network of grooves within the pad, etc.) can serve as a particle reservoir during braking phases, even in the absence of active suction. The second factor is the fact that during suction, particles trapped within the surface irregularities of the disc are suctioned in, whether this suctioning occurs during active braking or when not braking. By activating suction cyclically on a brake, meaning independently of the brake’s activation, it becomes possible

to utilize a single suction source to extract particles from multiple brakes without requiring that source to be more powerful. Indeed, without this cyclic suction, using a single source for multiple brakes would require a source with a power output proportional to the number of brakes. An excessively powerful negative pressure source entails disadvantages in terms of weight, cost, noise, and dimensions.

[9] Each of the brakes is fluidically connected in succession to the negative pressure source in a specific sequence (fixed or variable). The cycle may be designed to allow for more than one brake to be fluidically connected to the source at any given time (for example, $n > 1$ at all times). For example, the two front brakes of a vehicle may have suction simultaneously, followed by the two rear brakes. In a variant where $N=4$ and n alternates between 1 and 2, one front brake has suction, followed by the two rear brakes, and then the other front brake.

[10] The phrase "the negative pressure source" is fluidically connected "to a brake" is to be understood as a figure of speech, meaning that a negative pressure flow can be established between the particle collection elements of that brake (groove in a brake lining, suction nozzles, etc.) and the negative pressure source.

[11] Although this document focuses on the sequential suctioning of multiple brakes, the same approach may also be applied at the brake level, i.e. by alternating the applied suction between one brake lining and another (or between one nozzle and another), or at the lining level, i.e. by successively applying suction to one suction element (groove) and then to another suction element of the same lining. These various levels may be superimposed: for example, within a given cycle, the suctioning may be directed toward a specific brake for a specific duration, which may be subdivided into sub-stages wherein the suction alternates between different linings—each sub-stage itself further divided into sub-stages for suctioning in each of the grooves of a lining.

[12] "Control unit" is to be understood as a hardware and/or software component dedicated to controlling the particle capture system, or integrated into one of the main controllers of the vehicle (CAN, ECU, EMS, etc.) or of the industrial machine.

[13] In this document, the term "connection" or the fact that two elements are "connected" are used to describe a physical link between two elements (usually via a pneumatic line). A "fluidic connection" or two elements being "fluidically connected" signifies that the flow of suction air is enabled between said elements (typically by opening a valve on the physical connection between the two elements).

[14] According to another aspect, the pneumatic circuit comprises N branches respectively connected to each of the N brakes, each branch housing a filter. The small-capacity filters typically installed in such systems may be utilized. This design therefore makes use of components already present on a given brake, enabling the new solution to be retrofitted onto existing systems.

[15] In one variant, the pneumatic circuit comprises N branches respectively connected to each of the N brakes, and one branch connected to the negative pressure source and housing a single filter. This arrangement requires a higher-capacity filter but simplifies maintenance operations, since only one filter requires replacement when this becomes necessary. Furthermore, the airflow velocity through the filter medium may be reduced, thereby commensurately lowering the pressure drop across the filter. Compared to the use of N individual filters, the use of a single, larger filter also allows accumulating a greater volume of dust before clogging occurs, using a filter medium with higher filtration efficiency, and using (in total) a smaller surface area of filter medium.

[16] Compared to a situation where each brake has a fan and a filter, an arrangement with a single fan and a single filter allows reducing the aerodynamic power required for the fan. Indeed, if the pressure drop is 50 mbar at the brake linings, 10 mbar in the lines connecting the linings to the filter, and 30 mbar across the filter, the total pressure drop amounts to 90 mbar per brake. If the airflow is reduced by a factor of N, the pressure drop across the filter is reduced by a factor of N^2. Thus, when N=4, the pressure drop across the filter (one filter replacing four) is reduced from 30 mbar to $30/4^2 = 1.9$ mbar. The pressure drop for a single brake falls to less than 62 mbar, which is 1.45 times lower than the initial 90 mbar. For all four brakes combined, this translates to an aerodynamic power requirement that is 5.8 times lower (1.45 × 4).

[17] According to another aspect, the N branches respectively connect each of the N brakes to a single valve, which itself is connected to the negative pressure source. Under the action of the control unit, this valve is capable of fluidically connecting the negative pressure source to each of the N brakes in accordance with the predefined cycle. This valve may comprise a single inlet connected to the negative pressure source and at least N outlets, of which at least one may be connected to the inlet. The term "valve" is to be interpreted broadly here, as the valve may be formed of several simple valves that collectively perform the function described above. The valve may be a solenoid spool valve. It is thus possible to control the suction in the collection elements of each of the brakes, by means of a single physical component.

[18] According to another aspect, each of the N branches houses a valve which is switchable, under the action of the control unit, between an open position in which the respective brake is fluidically connected to the negative pressure source, and a closed position in which the respective brake is not fluidically connected to the negative pressure source. In this arrangement, the N valves are of simpler design.

[19] It is understood that hybrid designs are conceivable, i.e. falling between the single-valve solution and the N-valve solution. Thus, a series of pneumatic branching points may convey negative pressure to each of the brakes through an arrangement of appropriately controlled valves. For example, two or more brakes may be connected to a common valve (for example a solenoid spool valve), which serves to reduce the number of actuators and pneumatic lines.

[20] According to another aspect, N is between 4 and 10. Indeed, based on the assumption that each of the brakes is fluidically connected to the negative pressure source for a duration of 1/Nth of the cycle duration, the suction efficiency decreases (as demonstrated below) when the suction time is less than 1/10th of the cycle time. It is therefore advantageous to use a single negative pressure source for at most 10 brakes.

[21] According to another aspect, the control unit is configured to fluidically connect the negative pressure source to each of the N brakes in alternation, with n(t) being equal to 1 at any given time.

[22] According to another aspect, n is equal to 1 or 2 at any given time, and the value of n(t) alternates between 1 or 2 during the cycle, the control unit being configured such that, at a given time, the negative pressure source is fluidically connected to a pair of brakes on the same axle or to a single brake.

[23] According to another aspect, each brake comprises a pair of linings, and the particle collection element comprises a groove arranged in each of the linings. The groove may be positioned at or near the trailing edge of the lining. Alternatively, the groove may be a peripheral groove around the entire lining. The groove may be oblique and/or provided with a suction port, such that the suction airflow is at least partially directed counter to the direction of movement of the disc.

[24] According to another aspect, each brake comprises a pair of linings, and the particle collection element comprises a groove arranged in a nozzle positioned at a distance from the linings.

[25] According to another aspect, each brake comprises a disc having two annular friction surfaces which are the respective locations of friction between the linings and the disc, each annular friction surface being delimited by an inner circle and an outer circle; the collection element comprises two suction grooves fluidically connected to the negative pressure source and arranged at a distance from the friction linings, each groove being arranged facing a respective annular friction surface, and each groove extending from the inner circle to the outer circle.

[26] "Each groove extending from the inner circle to the outer circle," is understood to mean that the groove overlies the entirety of one of the friction surfaces as the disc rotates. The groove may be slightly larger or slightly smaller (for example, +/- 10%) than the distance between the inner circle and the outer circle.

[27] According to another aspect, each groove is substantially rectilinear and has a width, measured in a circumferential direction, that is between 1 and 6 mm and is preferably 2 or 4 mm.

[28] Each groove may be configured to create a suction flow that is perpendicular to the annular friction surfaces. In one variant, the flow is parallel to the radial direction.

[29] According to another aspect, each groove is arranged within a respective nozzle. There are thus two nozzles facing one another, on opposite sides of the disc.

[30] According to another aspect, each nozzle has at least one bleed port in fluidic communication with the groove. Such a port serves to initiate an airflow that is counter to the direction of movement of the disc. In one variant, the nozzle comprises two ports located on two opposite faces (upstream and downstream) of the nozzle. In another variant, two bleed ports may be provided on a rear face of the nozzle, and suction may then be performed via a suction port that is centered relative to the two bleed ports, to minimize the path traveled by the air within the grooves and to enhance suction efficiency.

[31] According to another aspect, each nozzle is arranged at an axial distance of less than three millimeters, preferably less than 0.1 mm, from its respective annular friction surface.

[32] According to another aspect, each nozzle comprises a downstream edge fitted with a seal or a brush in contact with its respective annular friction surface. Thus, an upstream edge of the nozzle, i.e. the first edge "seen" by a point on the disc as it rotates, can be at a distance from the disc, while the downstream edge, fitted with the seal, is in contact with the disc. This seal serves to scrape away any particles present, further improving their removal.

[33] According to another aspect, each nozzle comprises an upstream edge and a downstream edge, the downstream edge being further from its respective annular friction surface than the upstream edge. This arrangement makes it possible to suction in air downstream of the nozzle and to initiate an airflow that is counter to the movement of the disc.

[34] According to another aspect, the groove of each nozzle has a longitudinal direction that is in alignment with a radius of the disc, the radius preferably being angularly offset from a median radius of the linings by an angle that is between 20° and 60°. This angle defines the clearance between the brake pads and the nozzles. An angle that is too small imposes design constraints on the nozzles due to their proximity to the caliper. An angle that is too large complicates the mounting of the nozzles, as they can no longer be attached to the caliper.

[35] According to another aspect, each brake comprises a fixed caliper or a floating caliper that slides relative to a yoke, the nozzles being attached to the fixed caliper or to the yoke. This serves, in particular, to eliminate a complex system for attaching the nozzles to the vehicle.

[36] According to another aspect, the particle capture system comprises two pipes, each connected to a respective nozzle and by means of which the nozzles are held in position facing the disc.

[37] According to another aspect, a mounting bracket connects the pipes to the caliper or to the yoke, the mounting bracket comprising two holes traversed by the pipes.

[38] According to another aspect, the two grooves are arranged within a single nozzle. This single nozzle may incorporate the same characteristics set forth above for the pair of nozzles, particularly with regard to the bleed port(s), the upstream edge and/or downstream edge, the seal, the distance to the disc, the clearance angle relative to the linings, or the attachment to the caliper by means of a bracket.

[39] According to another aspect, an auxiliary groove that straddles the side of the disc interconnects the two suction grooves. This auxiliary groove may be narrower than the two suction grooves.

[40] According to another aspect, each brake comprises a disc covered with a ceramic coating. The coating may be tungsten carbide or chromium carbide. Since these types of discs undergo less wear (approximately 0.2 to 0.3 mm of thickness lost between the new state and the worn state, compared to 1 mm for a cast iron disc), the positioning of the nozzles is easier, and suction efficiency is maintained throughout the service life of the disc.

[41] It is understood that, in the above examples, the properties discussed in relation to "each brake" may apply to only one or to some of the brakes.

[42] The invention also relates to a method for operating the assembly as described above, the method comprising a sequence of cycles, each cycle comprising a sequence of suction stages during each of which exactly a number n(t) of N brakes are fluidically connected to the negative pressure source, where n(t) is an integer between 0 and N-1 for any value of t.

[43] According to another aspect, within a given cycle, each of the N brakes is connected exactly once to the negative pressure source. In a variant, some of the N brakes (for example, the most powerful ones often located at the front of the vehicles) may undergo suction multiple times per cycle.

[44] According to another aspect, each of the suction stages extends for the same duration. In a variant, some of the N brakes (for example, the most powerful ones often located at the front of the vehicles) may undergo suction for a longer duration than the less powerful brakes which generate fewer particles.

[45] According to another aspect, over the course of a cycle, the duration T(t) of each suction stage is proportional to the number n(t) of brakes connected to the negative pressure source during said stage.

[46] According to another aspect, the cycles of fluidic connection of the N brakes to the negative pressure source take place independently of the activation of the brake.

[47] According to another aspect, each cycle comprises a waiting stage during which none of the N brakes is fluidically connected to the negative pressure source, and/or during which the negative pressure source is inactive. At any given time t during this stage, n(t) is therefore zero. This control strategy allows optimizing

power consumption so that an unnecessary generation of suction is avoided. In a variant, multiple waiting stages may be provided, for example distributed evenly throughout each cycle.

[48] The invention also relates to a method for operating the assembly as described above, the method comprising the switching of the negative pressure source from an inactive state to an active state while it is not fluidically connected to any of the N brakes, followed by fluidically connecting the negative pressure source to one of the N brakes. It is thus possible to clear the lines of any particles that may have accumulated therein by generating a pressure fluctuation or wave of negative pressure that propagates through the system when applying negative pressure to the brake(s). Before fluidically connecting the brake(s) to the negative pressure source, it may be advantageous to allow a few seconds to elapse to allow the negative pressure source to reach its nominal negative pressure (for example maximum negative pressure).

[49] Beyond the benefits of easy assembly, maintenance, and control, the use of a single negative pressure source alternately connected to each of the brakes opens up new possibilities: indeed, in contrast to a system where one fan suctions particles from two brakes (simultaneously), and where each brake receives only half of the fan's nominal suction power, the solution presented here allows each individual brake to access the full power of the fan. It is therefore possible to install brake pads with larger collection elements (e.g., wider grooves or larger perforations). It also becomes possible to utilize smaller-diameter hoses, which are therefore easier to integrate into a vehicle (as they are both more flexible and less bulky).

Brief description of drawings

[50] Other features, details, and advantages will become apparent upon reading the detailed description below and analyzing the accompanying drawings, in which:

[51] FIG. 1 shows a vehicle, a disc brake, and an assembly with a particle capture system.

[52] FIG. 2 shows an assembly with a particle capture system.

[53] FIG. 3 illustrates three examples of a brake pad.

[54] FIG. 4A shows a timing diagram of a first method.

[55] FIG. 4B represents a flowchart of the method of FIG. 4A.

[56] FIG. 5A illustrates a timing diagram of a second method.

[57] FIG. 5B shows a flowchart of the method of FIG. 4A.

[58] FIG. 6 represents a flowchart of a third method.

[59] FIG. 7 illustrates an isometric view of a disc brake.

[60] FIG. 8 represents an isometric view of a suction nozzle.

[61] FIG. 9 shows a cross-section view of suction nozzles mounted around the disc.

[62] FIG. 10 schematically illustrates a front view of the positioning of the nozzles.

[63] FIG. 11 represents a design variant for a nozzle.

[64] FIG. 12 shows a design variant for a nozzle.

[65] FIG. 13 illustrates an example of a single nozzle that accommodates two grooves.

Description of embodiments

[66] The figures schematically represent various aspects of the invention. Unless explicitly stated otherwise, each aspect presented in a figure may be combined with other aspects presented in other figures, in any technically feasible combination.

[67] The figures and their accompanying descriptions focus on a scenario in which suction alternates between one brake and another (n=1, or potentially n=0 during waiting phases). The reader will be able to extrapolate this to scenarios in which n assumes other values during a cycle.

[68] FIG. 1 illustrates a vehicle 1, which may be a road vehicle (car, van, truck, etc.) or a rail vehicle (train, tram, subway, etc.), comprising at least two braking devices 2 of the disc brake type. The vehicle 1 comprises at least one braking assembly 100. The first brake 2 is labeled (1), and the second is labeled (2). FIG. 1 schematically illustrates the fact that there may be a number N of brakes, the Nth brake being labeled (N) in FIG. 1. N may be between 2 to 40, preferably between 2 and 10, and more preferably N is 4, 6, 8, or 10.

[69] Each brake 2 is essentially composed of a disc 4, integrally secured to a wheel of the vehicle 1 and rotating about an axis 6 at a rotational speed denoted W. The rotational speed W is proportional to the forward linear speed V of the vehicle 1. A caliper 8, which straddles part of the periphery of the disc 4, houses two brake pads, each consisting of a backing plate and a friction lining 10, 12. For example, the brake pads may be those depicted in FIG. 3, inspired by FIG. 1 of document FR 3 087 238 A1, FIG. 3A of document GB 2 533 476 A, or FIGS. 3 or 4 of document KR 2020 0016 690 A. The application of a force parallel to the axis 6, by means of one or more pistons, generates a braking torque via the friction of the linings 10, 12 against the respective faces of the disc 4.

[70] During a braking operation, the friction of the linings 10, 12 against the disc 4 generates particles (dust, PM10, PM2.5, etc.). These particles are harmful to the environment: their composition may include elements that are difficult for the environment to assimilate and are detrimental to the respiratory functions of individuals regularly exposed to them.

[71] A particle capture system 20 is thus provided to recover particles produced by the brakes 2.

[72] The capture system 20 comprises a single negative pressure source 22, represented here as a fan.

[73] The negative pressure source 22 is connected to each brake via a pneumatic circuit. The pneumatic circuit comprises N branches 24, with a filter 26 arranged on each branch.

[74] The operation of the fan 22 may be controlled by a control unit 30, via a connection 28. The control unit 30 is represented schematically here. It may comprise a memory, a processor, and communication buses. It may take the form of hardware and/or software elements dedicated to controlling the capture system, or it may be integrated into one of the vehicle's main controllers (CAN, ECU, EMS, etc.).

[75] In addition to the branches 24 and filters 26, the pneumatic circuit may comprise branches 32, 34 that connect branches 24 to the negative pressure source 22. Valves 36 may be provided on branches 24, and their state (open or closed) may be controlled by the control unit 30 via a connection 38. The valves 36 are controlled according to one of the methods described below, in order to execute suction cycles in which a certain number n(t) of branches 24 (where n is between 0 and N-1) is fluidically connected to the negative pressure source 22 at any given time. While FIG. 1 depicts several nodes between branches 24 and branch 34, in one variant all branches 24 converge at a single node that connects to the sole branch 34 leading to the

negative pressure source 22. A hybrid variant in which groups of branches 24 converge to a valve 36 is also conceivable.

[76] The branches 24 are connected to collection elements (44, 54, 64 in FIG. 3), i.e. elements of linings 10, 12 in the vicinity of the interface between the linings 10, 12 and the disc 4.

[77] The valves 36 are represented schematically. They may be solenoid valves, for example solenoid spool valves. In this example, they may be 2/2 valves (two-way, two-position).

[78] The control unit 30 regulates the amount of current supplied to the motor of the fan 22, thereby controlling its speed. When no electric current is supplied to the motor driving the fan 22, the fan 22 does not move and no negative pressure is created within the line 34. No particle suction is possible. In such a scenario, the negative pressure source is said to be in an inactive state. When electric current is supplied to the motor driving the fan 22, the fan begins to move and suction becomes possible. In such a scenario, the negative pressure source is said to be in an active state, regardless of its speed (non-zero) and/or the magnitude of the electric current (non-zero) supplied to the motor.

[79] The pneumatic circuit structure illustrated in FIG. 1 is adaptable to existing systems in which each brake is already equipped with a filter.

[80] FIG. 2 shows a variant of the pneumatic circuit. In this example, a single filter 26 is provided on line 34, and a single valve 36 selects the brake or brakes 2 that are fluidically connected to the fan 22. Each of the N lines 24 is directly connected to the valve 36, which itself is controlled by the control unit 30 via the connection 38. This design offers advantages in terms of the number of components and control simplification.

[81] FIGS. 1 and 2 show two examples of pneumatic circuit structures. Other variants requiring no specific explanation are also conceivable; for example, one with a single filter 26 on branch 34 (as in FIG. 2) and N valves on branches 24 (as in FIG. 1), or, conversely, with N filters (as in FIG. 1) and a single valve 36 (as in FIG. 2). Finally, a person skilled in the art will understand that other configurations are possible, involving any combination of filters and valves, with the number of each being between 1 and N.

[82] FIG. 3 shows three examples of brake pads 40, 50, 60 that can be used with the particle capture system. Other variants are also conceivable.

[83] Brake pad 40 comprises a backing plate 42, to which the friction lining 10 is attached. A particle collection groove 44 is formed within the lining 10. This groove is connected to suction means.

[84] Brake pad 50 comprises a peripheral groove 54 that follows the contours of the friction lining 10. An air inlet is provided at the center of the friction lining 10, and an air outlet is positioned within the groove 54.

[85] Brake pad 60 is composed of a lining 10 and a skirt 62 which is intended to be positioned around the lining 10 to form a suction zone 64 between the lining 10 and the skirt 62.

[86] Thus, various collection elements 44, 54, 64 may be provided on a brake pad for the suctioning of particles.

[87] FIG. 4A shows a timing diagram illustrating suction which alternates between each of the brakes ($n(t)=1$ for all t). In this figure, four timelines are depicted, one for each of the four brakes, i.e. for the case where N equals 4. The reader will easily be able to extrapolate the operation to other values of N.

[88] The horizontal axis represents time. Each axis corresponds to one of the brakes. The pulses represent a fluidic connection between the specific brake and the negative pressure source.

[89] At time t0, the first brake (1) is connected to the negative pressure source, until time t1. At time t1, the fluidic connection of the first brake (1) with the negative pressure source is cut off and simultaneously the second brake (2) is connected to the negative pressure source. At time t2, the fluidic connection of the second brake (2) with the negative pressure source is cut off and simultaneously the third brake (3) is connected to the negative pressure source. At time t3, the fluidic connection of the third brake (3) with the negative pressure source is cut off and simultaneously the fourth brake (4) is connected to the negative pressure source. At time t4, the fluidic connection of the fourth brake (4) with the negative pressure source is cut off and simultaneously the first brake (1) is connected to the negative pressure source. All these steps together describe a cycle C which is repeated continuously.

[90] The durations between t0 and t1, between t1 and t2, between t2 and t3, and between t3 and t4 may all be equal to a duration denoted T. Thus, in this example, all of the fluidic connection phases for each of the brakes have the same duration T.

[91] The suction duration T for each brake may be between 5 seconds and 2 minutes, preferably between 10 seconds and 1 minute.

[92] Other configurations are of course possible. For example, the suction duration for two of the four brakes (the largest ones) may be longer, for example 20% or 30% longer, than the suction duration for the other two brakes.

[93] The most powerful brakes may, for example, be two consecutive brakes in the cycle (for example (1) and (2)). The cycle thus comprises two long phases followed by two short phases. Alternatively, the most powerful brakes may be spaced apart within the cycle (for example as brakes (1) and (3)). The cycle then comprises an alternation between long phases and short phases. In a variant, several suction phases may be repeated for the same brake during a single cycle.

[94] Furthermore, in a variant where n(t) varies, the steps during which suction is applied to a larger number of brakes may last longer than the steps during which a smaller number of brakes are connected to the negative pressure source. The duration of a step thus becomes a variable T(t) that may be proportional to n(t).

[95] FIG. 4B shows a flowchart illustrating a method 1000 related to FIG. 4A, generalized to N brakes. The method 1000 comprises a step 1100.1 of fluidically connecting the first brake to the negative pressure source, followed by a step 1100.2 of fluidically connecting the second brake to the negative pressure source, followed by an equal number of similar steps for the other brakes, up to step 1100.N. At any given time, only one brake is fluidically connected to the negative pressure source. After step 1100.N, the cycle restarts at step 1100.1.

[96] FIG. 5A illustrates a method in which suction for a given brake does not always start simultaneously with the cutoff of suction for another brake. In the illustrated example, a waiting stage 2200 begins at time t4 (when suction is cut off for the fourth brake). Suction does not resume for the first brake until time t5. During this waiting stage, no brake is fluidically connected to the negative pressure source and/or the negative pressure source is inactive. It is understood that multiple waiting stages, distributed throughout the cycle, may be provided. For example, cutting off suction for any given brake may be followed by a waiting stage before beginning suction for another brake. The cycle therefore consists of suction stages where n(t)=1, and waiting stages where n(t)=0.

[97] If T denotes the duration of each fluidic connection phase, or the average duration of these phases in cases where they are not of identical duration, the waiting stage has a duration T' which may be greater than or less than T. For example, T' may be equal to twice or three times T. In one variant, T' = N*T.

[98] It is understood that, in the same manner as described in relation to FIG. 4A, certain brakes may undergo suction for a longer duration than others, or at multiple times during a cycle.

[99] FIG. 5B shows a flowchart illustrating a method 2000 related to FIG. 5A, generalized to N brakes. The method 2000 comprises a step 2100.1 of fluidically connecting the first brake to the negative pressure source, followed by a step 2100.2 of fluidically connecting the second brake to the negative pressure source, followed by a corresponding number of similar steps for the remaining brakes, up to step 2100.N. At any given time, only one brake is fluidically connected to the negative pressure source (since n(t)=1 during these steps). Following step 2100.N, the cycle continues with a waiting stage 2200 (n(t)=0 during this step). After the waiting stage 2200, the cycle restarts at step 2100.1. As mentioned above, a waiting stage may also be provided between a step 2100.x and a step 2100.x+1 (where x is an integer ranging from 1 to N).

[100] In both methods 1000 or 2000 (FIGS. 4 or 5), the length of time a given brake is not in the suction phase may range from 30 seconds to 30 minutes, preferably between 4 and 10 minutes. Advantageously, the ratio for each of the brakes between the suction duration and the no-suction duration may range from 1/3 to 1/10.

[101] FIG. 6 illustrates a method 3000 of using the assembly described in FIGS. 1 or 2. The method 3000 consists of: blocking all fluidic connections to the brakes; creating negative pressure; and then opening one or more connections to the brakes. Step 3100 thus consists of closing the valve or valves of the pneumatic circuit. Step 3200 consists of activating or maintaining the activation of the negative pressure source, for example until a desired pressure level is reached. Step 3300 consists of opening one or more of the valves in the pneumatic circuit, thereby creating a pressure fluctuation or wave of negative pressure that propagates through the pneumatic circuit to dislodge particles adhering to the inner walls of the pneumatic lines and of the collection groove. The method 3000 may be repeated for each of the brakes, either one after the other or for any combination of brakes, until all lines have been cleaned.

[102] In the examples presented in the preceding figures, it is implicit that the valves are controlled by the control unit to be open or closed, or to establish a specific fluidic connection between the negative pressure source and a specific brake.

[103] The reasons for an effective particle capture despite the use of intermittent suction are explained below.

[104] The following table shows the amounts of PM10 particles detected (produced by the brake but not captured) during a standardized WLTP cycle, in various suction configurations (expressed in mg per km per vehicle brake):

Standard pad without groove or suction port	Pad with collection groove		
No suction	Continuous suction	Suction during braking phases only	No suction
8.0	1.8	2.7	3.8

Table 1

[105] One will note that the mere presence of a collection groove on a brake pad halves the amount of particles escaping into the environment. This confirms that it is not strictly necessary to suction particles precisely during

braking to have an impact on the amount of captured particles. Of course, if no suction is ever applied, the groove will fill up and its ability to serve as a reservoir will disappear.

[106] The above tests were conducted with a groove positioned in the downstream portion of the lining, which is the portion of the lining that is last encountered by any given point on the disc as it travels its path. This generally represents the optimal arrangement for collecting particles that have been abraded from the lining.

[107] Other tests, conducted with a groove positioned in the upstream portion of the lining (or performed using the same system but with the disc rotating in the opposite direction), demonstrated that continuous suction, or suction performed solely during braking phases, allowed capturing approximately 40% of the particles produced. This indicates that it is possible to capture particles that were not freshly abraded from the lining. In all likelihood, these particles were therefore those that were deposited within the surface irregularities of the disc.

[108] The following table shows the amounts of detected PM10 particles (produced by the brake but not captured) during a standardized WLTP cycle, in various suction configurations (expressed in mg per km per vehicle brake):

No suction (standard pad)	Continuous suction	Suction only during braking phases	Cyclic suction (T1=1min; T2=6min)
8.0	1.8	2.7	2.6

Table 2

[109] It appears that cyclic suction is just as effective as suction limited to braking sequences. The capture rate is approximately 67% of the PM10 particles produced. Cyclic suction allows a single fan to be used for multiple brakes.

[110] The following table shows the amounts of detected PM10 particles (produced by the brake and not captured) during a standardized WLTP cycle, for various suction configurations (in mg per km per vehicle brake):

Continuous suction	Cyclic suction (T1=1min; T2=3min)	Cyclic suction (T1=1min; T2=6min)	Cyclic suction (T1=1min; T2=13min)	Cyclic suction (T1=1min; T2=27min)
1.8	2.2	2.6	3.6	3.7

Table 3

[111] Tests conducted with different values for T1 and T2 show that when the ratio of T1/T2 is less than 10%, the amount of detected particles (produced but not captured) is close to 3.7 mg/km/brake, which is the amount detected in the absence of suction. Thus, depending on the chosen efficiency threshold (for example, a threshold of 67%), using a single suction fan for more than 10 brakes is not desirable, as the suction time per brake becomes insufficient relative to the no-suction time. For lower efficiency thresholds (whether chosen or mandated by regulations), it is possible to provide only one fan for more than 10 brakes.

[112] The invention has been illustrated with a disc brake, but it is also applicable to other types of friction brakes comprising a rotor and (at least) one friction lining. The invention may thus also relate to an assembly for a vehicle comprising: N rotor brakes (disc, drum, or other types), where N is an integer greater than or equal to two, each of the N brakes being equipped with at least one friction lining intended to rub against the rotor during a braking phase, and each lining featuring a particle collection element; and a brake particle capture system comprising: a single negative pressure source, a pneumatic circuit extending from the negative

pressure source to the collection elements of the linings of each of the N brakes; and a control unit configured to fluidically connect the negative pressure source to each of the N brakes in an alternating manner.

[113] FIGS. 7 to 13 illustrate particle collection means that may serve as an alternative to or be complementary to the grooves 44, 54, and 64.

[114] FIG. 7 shows an isometric view of suction means arranged adjacent to the disc 4. The disc 4 comprises, on each side, an annular friction surface 5 delimited by an inner circle C1 of radius R1 and an outer circle C2 of radius R2. The annular friction surface 5 is the set of points encountered by the linings 10, 12 during the rotation of the disc 4.

[115] In this example, the caliper 8 is a floating caliper, meaning it is slidably movable relative to a yoke 9 fixed to the wheel hub. The invention is, of course, adaptable to a fixed-caliper brake.

[116] In order to extract particles lodged within the surface irregularities or on the surface of the disc 4, two nozzles 140 are positioned in close proximity to the disc 4, each nozzle facing one of the two annular friction surfaces 5. Pipes 148, 149 are provided to fluidically connect the nozzles 140 to the negative pressure source 22 and to hold the nozzles 140 in their position facing the disc 4.

[117] A mounting bracket 150 serves to attach the pipes 148, 149 to the yoke 9. The pipes 148, 149 fit tightly through two holes 152 in the bracket 150. A third hole allows the attachment of the bracket 150 to the yoke 9. The bracket 150 may be V-shaped. In a variant, the bracket is formed in the yoke 9. The pipes 148, 149 protrude from the bracket 150. They may be connected to the negative pressure source 22 by means of hoses (not shown).

[118] Pipe 148 may be U-shaped, and pipe 149 may be straight.

[119] FIG. 8 shows an isometric view of a nozzle 140. The nozzle comprises an upstream edge 141 (the edge first encountered by a point on the disk) and a downstream edge 142 (encountered last). The downstream edge 142 may be fitted with a seal (for example, a brush seal or elastomer seal) that scrapes against the disk 4. Additionally or alternatively, the downstream edge 142 may be further away from the disk than the upstream edge, for example at a distance that is at least 50% greater.

[120] A groove 146 serves to create a suction airflow directed primarily perpendicularly to the surface 5 of the disk 4. The groove may run parallel to the longitudinal direction A of the nozzle 140. In the circumferential direction, the groove 146 may have a substantially constant width along its entire radial length. The width of the groove 146 may be between 1 and 6 mm, and is preferably 4 mm. The groove may have a depth of a few millimeters, preferably approximately 0.5 mm. Too great of a depth (for example, 15 mm) is not conducive to effective suction.

[121] At least one bleed port 143 may be provided on a rear face of the nozzle. This port 143 is in fluidic communication with the groove and induces the creation of a flow having a component directed counter to the direction of movement of the disk; this may offer advantages in preventing particles from remaining trapped within the groove. The position and number of bleed ports 143 may vary: two ports 143 may be provided, not only on the downstream face (as depicted in FIG. 8) but also on the upstream face of the nozzle 140. A bleed port 143 may be provided at the rear of the nozzle (the face of the nozzle opposite to the face that faces the disk). In such a configuration, the suction port 147 may be situated at one end (along axis A) of the groove 146, and the bleed port 143 may be situated at the other end of the groove 146.

[122] The nozzle 140 may have a substantially longitudinal, elliptical, or oval shape, with a longitudinal axis A. In a variant not shown, the nozzle 140 has a different shape, for example a crescent shape.

[123] The pipe 148, 149 creates suction within the groove 146. A suction port 147 is provided in the nozzle 140 for this purpose.

[124] FIG. 9 shows a cross-section view of the installation of the nozzles 140. In this example, the suction port 147 is centered relative to the groove 146 in the longitudinal direction A. The groove 146 of the nozzles 140 faces the friction surfaces 5 of the disc 4. The nozzles 140 are at a distance B from the friction surfaces 5. The distance B may be less than 3 millimeters, or even less than 0.1 millimeters.

[125] Pipe 148 is U-shaped, while pipe 149 is straight. In this example, pipes 148 and 149 are coplanar; however, other designs are conceivable.

[126] In the examples shown in FIGS. 7 through 9, the nozzles 140 are arranged symmetrically; however, other arrangements are possible. They may be angularly offset relative to one another, or they may be of different designs.

[127] FIG. 10 schematically illustrates the positioning of the nozzles 140. The linings 10 and 12 can define a median radius R0, and the longitudinal axis A of the nozzles 140 may be aligned with a radius R that is angularly offset from radius R0 by an angle α. This angle is preferably between 20° and 160°. The caliper design does not always allow for a smaller angle. An angle that is too large may not be compatible with attaching the nozzles via a mounting bracket, and could therefore complicate the nozzle attachment.

[128] FIGS. 11 and 12 illustrate two design variants of the nozzle 140.

[129] In FIG. 11, the suction pipe 148, 149 is parallel to the groove 146. The suction flow is in a direction substantially perpendicular to the surface of the disc.

[130] FIG. 12 shows a pair of nozzles 140 with two bleed ports 143 at the two radial ends of the groove 146. Air is drawn in both from the disc side and at the ports 143, which forces air to flow within the groove in a direction parallel to the friction surfaces of the disc.

[131] FIG. 13 shows an example in which a single nozzle 140 receives both grooves 146. This nozzle may have a general U-shape. Suction may be effected via a single line 48, positioned within the plane of the disc. A narrower auxiliary groove 160 may serve to connect the two grooves 146. For example, the circumferential width of the auxiliary groove is half the circumferential width of the grooves 146. The auxiliary groove 160 straddles the side of the disc.

Claims

[**Claim 1]** An assembly (100) for a vehicle (1), comprising:

- N disc brakes (2), where N is an integer greater than or equal to two, each of the N disc brakes (2) being equipped with a particle collection element (44, 54, 64, 146); and
- a brake particle capture system (20) comprising:
    - a single negative pressure source (22);
    - a pneumatic circuit (24, 26, 32, 34, 36, 38, 148, 149) extending from the negative pressure source (22) to the collection elements (44, 54, 64, 146) of each of the N brakes (2); and
    - a control unit (30) configured to fluidically connect the negative pressure source (22) to each of the N brakes (2) sequentially according to a predefined cycle (C), such that at any given time t, only n(t) brakes are fluidically connected to the negative pressure source (22), where n(t) is an integer between 0 and N-1 for any value of t.

[Claim 2] Assembly (100) according to Claim 1, wherein the pneumatic circuit (24, 26, 32, 34, 36, 38) comprises N branches (24) respectively connected to each of the N brakes (2), each branch (24) housing a filter (26).

[Claim 3] Assembly (100) according to Claim 1, wherein the pneumatic circuit comprises N branches (24) respectively connected to each of the N brakes (2), and one branch (34) connected to the negative pressure source (22) and housing a single filter (26).

[Claim 4] Assembly (100) according to one of Claims 2 or 3, wherein the N branches (24) respectively connect each of the N brakes (2) to a single valve (36), which itself is connected to the negative pressure source (22), the valve (36) being capable, under the action of the control unit (30), of fluidically connecting the negative pressure source (22) to each of the N brakes (2) in accordance with the predefined cycle (C).

[Claim 5] Assembly (100) according to one of Claims 2 or 3, wherein each of the N branches (24) houses a valve (36) which is switchable, under the action of the control unit (30), between an open position in which the respective brake (2) is fluidically connected to the negative pressure source (22), and a closed position in which the respective brake (2) is not fluidically connected to the negative pressure source (22).

[Claim 6] Assembly (100) according to one of claims 1 to 5, wherein N is between 4 and 10.

[Claim 7] Assembly (100) according to one of claims 1 to 6, wherein the control unit (30) is configured to fluidically connect the negative pressure source (22) to each of the N brakes (2) in alternation, with n(t) being equal to 1 at any given time.

[Claim 8] Assembly according to one of claims 1 to 6, wherein the value of n(t) alternates between 1 or 2 during the cycle (C), the control unit (30) being configured such that, at any given time, the

negative pressure source (22) is fluidically connected to a pair of brakes on the same axle or to a single brake.

[Claim 9] Assembly (100) according to one of claims 1 to 8, wherein each brake (2) comprises a pair of linings (10, 12) and the particle collection element comprises a groove (44, 54, 64) arranged in each of the linings (10, 12).

[Claim 10] Assembly (100) according to one of claims 1 to 9, wherein each brake (2) comprises a pair of linings (10, 12) and the particle collection element comprises a groove (146) arranged in a nozzle (140) positioned at a distance from the linings (10, 12).

[Claim 11] Assembly (100) according to Claim 10, wherein each brake (2) comprises a disc (4) having two annular friction surfaces (5) which are the respective locations of friction between the linings (10, 12) and the disc (4), each annular friction surface (5) being delimited by an inner circle (C1) and an outer circle (C2), the collection element comprising two suction grooves (146) fluidically connected to the negative pressure source (22) and arranged at a distance from the friction linings (10, 12), each groove (146) being arranged facing a respective annular friction surface (5), and each groove (146) extending from the inner circle (C1) to the outer circle (C2).

[Claim 12] Assembly (100) according to Claim 11, wherein each groove (146) is substantially rectilinear and has a width, measured in a circumferential direction, that is between 1 and 6 mm, and is preferably 2 or 4 mm.

[Claim 13] Assembly (100) according to one of Claims 11 or 12, wherein each groove (146) is arranged within a respective nozzle (140).

[Claim 14] Assembly (100) according to Claim 13, wherein each nozzle (140) has at least one bleed port (143) in fluidic communication with the groove (146).

[Claim 15] Assembly (100) according to one of Claims 13 or 14, wherein each nozzle (140) is arranged at an axial distance (B) of less than three millimeters, preferably less than 0.1 mm, from its respective annular friction surface (5).

[Claim 16] Assembly (100) according to one of Claims 13 to 15, wherein each nozzle (140) comprises a downstream edge (42) fitted with a seal (44) or a brush in contact with its respective annular friction surface.

[Claim 17] Assembly (100) according to one of Claims 13 to 16, wherein each nozzle (140) comprises an upstream edge (141) and a downstream edge (142), the downstream edge (142) being further from its respective annular friction surface (5) than the upstream edge (141).

[Claim 18] Assembly (100) according to one of claims 13 to 17, wherein the groove (146) of each nozzle (140) has a longitudinal direction (A) that is in alignment with a radius (R) of the disc (4), said radius (R) preferably being angularly offset from a median radius (R0) of the linings (10, 12) by an angle (α) that is between 20° and 60°.

[Claim 19] Assembly (100) according to one of claims 13 to 18, wherein each brake (2) comprises a fixed caliper or a floating caliper (8) that slides relative to a yoke (9), the nozzles (140) being attached to the fixed caliper or to the yoke (9).

[Claim 20] Assembly (100) according to one of claims 13 to 19, wherein the particle capture system (20) comprises two pipes (148, 149), each connected to a respective nozzle (140) and by means of which the nozzles (140) are held in position facing the disc (4).

[Claim 21] Assembly (100) according to claims 19 and 20, wherein a mounting bracket (150) connects the pipes (148, 149) to the caliper or to the yoke (9), the mounting bracket (150) comprising two holes (152) traversed by the pipes (148, 149).

[Claim 22] Assembly (100) according to one of claims 11 or 12, wherein the two grooves (146) are arranged within a single nozzle (140).

[Claim 23] Assembly (100) according to Claim 22, wherein an auxiliary groove (160) that straddles the side of the disc interconnects the two suction grooves (146).

[Claim 24] Assembly (100) according to one of Claims 1 to 23, wherein each brake comprises a disc (4) covered with a ceramic coating.

[Claim 25] A method (1000, 2000) for operating the assembly according to one of Claims 1 to 24, the method comprising a sequence of cycles (C), each comprising a sequence of suction stages (1100.1, 1100.2, … 1100.N, 2100.1, 2100.2, … 2100.N), during each of which exactly a number n(t) of N brakes (2) are fluidically connected to the negative pressure source (22), where n(t) is an integer between 0 and N-1 for any value of t.

[Claim 26] Method according to Claim 25, wherein, within a given cycle (C), each of the N brakes (2) is connected exactly once to the negative pressure source (22).

[Claim 27] Method according to one of Claims 25 or 26, wherein each of the suction stages (1100.1, 1100.2, … 1100.N, 2100.1, 2100.2, … 2100.N) extends for the same duration (T).

[Claim 28] Method according to one of claims 25 to 27, wherein, within a cycle, the duration (T(t)) of each suction stage (1100.1, 1100.2, … 1100.N, 2100.1, 2100.2, … 2100.N) is proportional to the number n(t) of brakes connected to the negative pressure source during said stage.

[Claim 29] Method according to one of claims 25 to 28, wherein the cycles (C) of fluidic connection of the N brakes (2) to the negative pressure source (22) take place independently of the activation of the brake (2).

[Claim 30] Method according to one of claims 25 to 29, wherein each cycle (C) comprises a waiting stage (2200) during which none of the N brakes (2) is fluidically connected to the negative pressure source (22), and/or during which the negative pressure source (22) is inactive.

[Claim 31] A method (3000) for operating the assembly according to one of claims 1 to 24, comprising the switching of the negative pressure source from an inactive state to an active state

while it is not fluidically connected to any of the N brakes, followed by fluidically connecting (3300) the negative pressure source (22) to one of the N brakes (2).