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Systems and Methods for Timing of Valve Lift Events

Abstract

A rocker arm assembly is configured to selectively actuate one or more exhaust valves. A method for timing valve lift events comprises actuating an exhaust rocker arm based on an exhaust lift profile and actuating an engine brake rocker arm based on an engine brake profile. The exhaust lift profile and the engine brake lift profile can have cross points. A method disclosed comprises minimizing an angle defined between the exhaust lift profile and the engine brake lift profile at a cross point.

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Background/Summary

CROSS REFERENCE TO RELATED APPLICATIONS [0001] This application is a continuation under 35 U.S.C. § 365(c) of International Patent Application No. PCT/EP2023/025484, filed on 15 Nov. 2023, which claims the benefit under 35 U.S.C. § 119(e) of U.S. Provisional Application No. 63/383,892, filed on 15 Nov. 2022, all of which are incorporated by reference herein in their entirety.

TECHNICAL FIELD

[0002] This disclosure relates generally to valve train systems, and more particularly to systems and methods for timing of valve lift events.

BACKGROUND

[0003] Internal combustion engines typically use valve train systems to actuate engine valves. For example, these systems may include a combination of cams, shafts, rocker arms, and various motion-conveying mechanisms that may be driven by the engine's crankshaft rotation, selectively conveying actuation motion to the downstream valves.

SUMMARY OF PARTICULAR EMBODIMENTS

[0004] To deliver different valve lift events such as for main exhaust or engine brake modes, the timing of valve actuation needs to be strategically controlled to achieve the desired functions of the valve train system and ensure proper engine operation. Embodiments disclosed herein may provide a solution to the above problem by timing and aligning individual valve lift events to the beginning and ending moments of the exhaust valve action. Such timing and alignment design may reduce the impact force between different movable parts in the valve train system, prevent overloading of the intake side components by cylinder pressure, and allow for both 1.5-stroke and 1-stroke engine braking modes.

[0005] In one embodiment, a method for timing valve lift events by a rocker arm assembly of an internal combustion engine is provided. The rocker arm assembly comprises an exhaust rocker arm and an engine brake rocker arm, and is configured to selectively actuate a first exhaust valve or a second exhaust valve. The method comprises: enabling actuation of the first exhaust valve and the second exhaust valve by the exhaust rocker arm; actuating the exhaust rocker arm based on an exhaust lift profile; enabling actuation of the second exhaust valve by the engine brake rocker arm independent from actuation of the first exhaust valve; and actuating the engine brake rocker arm based on an engine brake lift profile. In particular, the exhaust lift profile and the engine brake lift profile have a first cross point and a second cross point. Moreover, the exhaust lift profile is tangent with the engine brake lift profile at the first cross point and the second cross point.

[0006] In particular embodiments, the engine brake lift profile comprises a first engine brake lift sub-profile, a second engine brake lift sub-profile, a third engine brake lift sub-profile, and a fourth engine brake lift sub-profile. In particular embodiments, the exhaust lift profile is subsequent to the second engine brake lift sub-profile and overlaps with the third engine brake lift sub-profile at the first cross point and with the fourth engine brake lift sub-profile at the second cross point. In particular embodiments, the exhaust lift profile is tangent with the third engine brake lift sub-profile at the first cross point and is tangent with the fourth engine brake lift sub-profile at the second cross point. In particular embodiments, when the actuation of the first exhaust valve and the second exhaust valve by the exhaust rocker arm is enabled and the actuation of the second exhaust valve by the engine brake rocker arm is enabled, the actuation of the first exhaust valve is based on the exhaust lift profile, and the actuation of the second exhaust valve is based on the first engine brake lift sub-profile, the second engine brake lift sub-profile, and the exhaust lift profile. In particular embodiments, when the actuation of the first exhaust valve and the second exhaust valve by the exhaust rocker arm is enabled and the actuation of the second exhaust valve by the engine brake rocker arm is enabled, one cylinder pressure peak is generated in a four-stroke cycle of the internal combustion engine. In particular embodiments, the second engine brake lift sub-profile is configured to release cylinder pressure such that the cylinder pressure peak is generated in a compression stroke of the four-stroke cycle of the internal combustion engine.

[0007] In particular embodiments, at the first cross point or the second cross point, the engine brake lift profile is configured to deliver valve lift in a same direction as the exhaust lift profile. In particular embodiments, at the first cross point or the second cross point, the engine brake lift profile is configured to deliver valve lift at a similar velocity as the exhaust lift profile.

[0008] In particular embodiments, the method further comprises disabling actuation of the first exhaust valve and the second exhaust valve by the exhaust rocker arm. In particular embodiments, when the actuation of the first exhaust valve and the second exhaust valve by the exhaust rocker arm is disabled and the actuation of the second exhaust valve by the engine brake rocker arm is enabled, the first exhaust valve is unactuated, and the actuation of the second exhaust valve is based on the engine brake lift profile. In particular embodiments, when the actuation of the first exhaust valve and the second exhaust valve by the exhaust rocker arm is disabled and the actuation of the second exhaust valve by the engine brake rocker arm is enabled, two cylinder pressure peaks are generated in a four-stroke cycle of the internal combustion engine. In particular embodiments, the second engine brake lift sub-profile is configured to release cylinder pressure such that a first cylinder pressure peak is generated in a compression stroke of the four-stroke cycle of the internal combustion engine, wherein the fourth engine brake lift sub-profile is configured to release cylinder pressure such that a second cylinder pressure peak is generated before an intake stroke of the four-stroke cycle of the internal combustion engine.

[0009] In particular embodiments, the rocker arm assembly further comprises an intake rocker arm configured to activate at least two intake valves. In particular embodiments, the method further comprises enabling actuation of the at least two intake valves by the intake rocker arm based on an intake lift profile.

[0010] In one embodiment, a method for timing valve lift events by a rocker arm assembly of an internal combustion engine is provided. The rocker arm assembly comprises an exhaust rocker arm and an engine brake rocker arm and configured to selectively actuate a first exhaust valve or a second exhaust valve. The method comprises enabling actuation of the first exhaust valve and the second exhaust valve by the exhaust rocker arm; actuating the exhaust rocker arm based on an exhaust lift profile; enabling actuation of the second exhaust valve by the engine brake rocker arm independent from actuation of the first exhaust valve; actuating the engine brake rocker arm based on an engine brake lift profile; maintaining the actuation of the exhaust rocker arm and the engine brake rocker arm for at least one engine cycle comprising an intake stroke, a compression stroke, an exhaust stroke, and an intake stroke; and disabling actuation of the first exhaust valve and the second exhaust valve by the exhaust rocker arm. In particular, the exhaust lift profile and the engine brake lift profile have a first cross point and a second cross point. Moreover, the exhaust lift profile is tangent with the engine brake lift profile at the first cross point and the second cross point.

[0011] In particular embodiment, the engine brake lift profile comprises a first engine brake lift sub-profile, a second engine brake lift sub-profile, a third engine brake lift sub-profile, and a fourth engine brake lift sub-profile. In particular embodiment, the exhaust lift profile is subsequent to the second engine brake lift sub-profile and overlaps with the third engine brake lift sub-profile at the first cross point and with the fourth engine brake lift sub-profile at the second cross point. In particular embodiment, the exhaust lift profile is tangent with the third engine brake lift sub-profile at the first cross point and is tangent with the fourth engine brake lift sub-profile at the second cross point. In particular embodiment, at the first cross point or the second cross point, the engine brake lift profile is configured to deliver valve lift in a same direction as the exhaust lift profile. In particular embodiment, at the first cross point or the second cross point, the engine brake lift profile is configured to deliver valve lift at a similar velocity as the exhaust lift profile. In particular embodiment, when the actuation of the first exhaust valve and the second exhaust valve by the exhaust rocker arm is disabled and the actuation of the second exhaust valve by the engine brake rocker arm is enabled, two cylinder pressure peaks are generated in a four-stroke cycle of the internal combustion engine. In particular embodiment, the second engine brake lift sub-profile is configured to release cylinder pressure such that a first cylinder pressure peak is generated in a compression stroke of the four-stroke cycle of the internal combustion engine, wherein the fourth engine brake lift sub-profile is configured to release cylinder pressure such that a second cylinder pressure peak is generated before an intake stroke of the four-stroke cycle of the internal combustion engine.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] Embodiments in accordance with this disclosure will now be described by reference to the accompanying drawings, in which:

[0013] FIG. **1** illustrates an example embodiment of a valve train assembly according to this disclosure;

[0014] FIG. **2** illustrates example valve operations in a drive mode of an engine brake system;

[0015] FIG. **3** illustrates example valve operations in a 1-stroke engine brake mode of the engine brake system;

[0016] FIG. **4** illustrates an example 1.5-stroke engine brake mode of the engine brake system according to an embodiment of this disclosure;

[0017] FIG. **5** illustrates example operations of the engine brake system as it transitions from the drive mode to the 1.5-stroke engine brake mode according to one embodiment of this disclosure;

[0018] FIG. **6** illustrates example operations of a general 1.5-stroke engine brake mode of the engine brake system;

[0019] FIG. **7** illustrates example operations of an improved 1.5-stroke engine brake mode of the engine brake system according to one embodiment of this disclosure;

[0020] FIG. **8** illustrates how the traditional engine brake system may fail due to overloading;

[0021] FIG. **9** illustrates example operations of the engine brake system as it runs from the drive mode to the safe transition mode and to the 1.5-stroke engine brake mode according to one embodiment of this disclosure;

[0022] FIG. **10** illustrates example brake levels of the engine brake system according to particular embodiments of this disclosure;

[0023] FIG. **11** illustrates example scaling of brake levels of the engine brake system according to particular embodiments of this disclosure; and

[0024] FIG. **12** illustrates a flow diagram of an example method for timing valve lift events according to particular embodiments of this disclosure.

DESCRIPTION OF EXAMPLE EMBODIMENTS

[0025] Reference will now be made in detail to the examples which are illustrated in the accompanying drawings. Wherever possible, the same reference numbers will be used throughout the drawings to refer to the same or like parts. Directional references such as “up”, “down”, “right”, and “left” are for ease of reference to the figures and not intended to limit the scope of this disclosure.

[0026] Various valve system designs have been produced in the past for use in connection with internal combustion engines for the purpose of controlling valve actuation such as for main exhaust event. Generally, in a typical valve train, a rocker arm system is coupled on one side to a camshaft and on the other side to a number of engine valves via a valve bridge in a way for delivering actuation motion from the camshaft to downstream valves in synchronization. In some scenarios, it may be desirable to provide auxiliary functionality, such as compression engine braking, in addition to the main lift event so that a selected valve may be separately controlled. To enable engine brake operation and assist in slowing down the vehicle, the valve train assembly may operate by releasing compression in the engine cylinders during its compression stroke, which may reduce the engine's power and create a braking effect. In other words, this may cause the engine to function as a power-consuming compressor, which slows the vehicle. To achieve such goal, the valve train assembly may need to control timing of valve lift events associated with the main exhaust event and the engine braking event such that they can take place at the desired sequence and timing to ensure proper engine operation.

[0027] In certain embodiments, a valve train system enabling engine brake mode may be equipped with a main exhaust rocker arm (which is capable of deactivation) and a dedicated engine brake rocker arm (which may be activated, e.g., by a capsule). When there is an overlap between the engine brake valve lift profile and standard exhaust valve lift profile, and both profiles cross each other at high relative lift velocities, the deactivation devices in the valve train system (e.g., hydraulic or mechanical capsule) may experience strong mechanical impact force during the drive mode (firing mode of the engine) and also during the transitions between the engine brake and driving mode. Further, the system may not be able to run both the standard rocker arm and engine brake rocker arm simultaneously to facilitate downscaling from a 1.5-stroke to 1-stroke engine brake mode. Overlap of the engine brake lift with the standard intake lift may also overload the intake valves due to high cylinder pressure during intake valve opening.

[0028] Embodiments disclosed herein present special alignment or timing of the engine brake valve lift events, which may ensure low overlap with the standard exhaust valve lift profile with smooth transition between the profiles (e.g., low relative crossing velocities between both profiles). Such valve (cam) lift profile may consequently reduce mechanical impact force between movable parts in the valve train system, allowing a smooth transition between the driving and engine braking modes and downscaling from the 1.5-stroke to 1-stroke engine brake mode, and avoiding overloading on the intake side.

[0029] FIG. **1** illustrates an example embodiment of a valve train assembly **100** according to this disclosure. With initial reference to FIG. **1**, a valve train assembly constructed in accordance with one example of this disclosure is partially shown and generally identified at **100**. In particular embodiments, the valve train assembly **100** may be configured with auxiliary functionality such as engine braking and may be employed in a three-cylinder bank portion of a six-cylinder engine. As an example and not by way of limitation, the valve train assembly **100** may be mechanically mounted to one cylinder head of the three-cylinder bank. Although described as such, it will be appreciated that the systems, methods, and processes described in this disclosure are not limited to such an application. In this regard, the systems, methods, and processes described in this disclosure may be used in any valve train assemblies associated with any suitable engine configurations equipped with any suitable number of cylinders.

[0030] In particular embodiments, the valve train assembly **100** may be supported by a valve train carrier and may include three rocker arm structures per cylinder. Specifically, in particular embodiments, each cylinder may include an intake rocker arm **102**, an exhaust rocker arm **104**, and an engine brake rocker arm **106**. As an example and not by way of limitation, as illustrated in FIG. **1**, the exhaust rocker arm **104** and the engine brake rocker arm **106** may be separate bodies and may act independently from each other and cooperate to control opening or closing of two exhaust valves, i.e., an exhaust standard valve **108** and an exhaust brake valve **110**. In this case, two switchable systems (e.g., an exhaust capsule **112** and an engine brake capsule **114**) may be employed to separately control exhaust and engine brake operations. For example, the switchable system may be selectively controlled by deactivated and activated configurations. The deactivated configuration may disable actuation of the associated valve(s) by the corresponding rocker arm and the activated configuration may enable actuation of the valve(s). As another example and not by way of limitation, although not illustrated, the exhaust rocker arm and the engine brake rocker arm may be combined into a single rocker arm body and controlled to enable or disable valve actuation motion specifically through their respective switchable systems. In particular embodiments, the intake rocker arm **102** may be configured to control motion of at least two intake valves **116**A, **116**B. The exhaust rocker arm **104** may be configured to control exhaust valve motion of the two exhaust valves **108**, **110**. The engine brake rocker arm **106** may be configured to act on one of the two exhaust valves, i.e., the exhaust brake valve **110**, in an engine brake mode such as 1.5-stroke engine braking, as will be described later. In particular embodiments, each of the intake rocker arm **102**, exhaust rocker arm **104**, and engine brake rocker arm **106** may be mechanical, electrical, hydro-mechanical, or other suitable valve actuation systems.

[0031] With continued reference to FIG. **1**, in particular embodiments, a rocker shaft **118** may be received by the valve train carrier and support rotation of the intake rocker arm **102**, the exhaust rocker arm **104**, and the engine brake rocker arm **106**. As an example and not by way of limitation, the rocker shaft **118** may communicate control fluid (e.g., oil) to the rocker arms **104**, **106** for controlling activation of the exhaust capsule **112** and the engine brake capsule **114**. In particular embodiments, a camshaft (not shown) may be provided, which may include multiple lift profiles or cam lobes configured to rotate the rocker arms **104** and **106** under a desired lift sequence according to this disclosure. As an example and not by way of limitation, a cam end of the exhaust rocker arm **104** may be configured to be engaged by an exhaust lift lobe of the camshaft, which may cause the exhaust rocker arm **104** to rotate according to the exhaust lift profile, thereby actuating both the exhaust standard valve **108** and the exhaust brake valve **110** as needed. Similarly, as another example and not by way of limitation, a cam end of the engine brake rocker arm **106** may be configured to be engaged by an engine brake lift lobe of the camshaft, which may cause the engine brake rocker arm **106** to rotate according to the engine brake lift profile, thereby actuating the exhaust brake valve **110** as needed. Alternatively, in other embodiments, the valve train assembly **100** may include other suitable motion-transmitting features such as a push rod that operatively couples between the rocker arm bodies and the camshaft for conveying valve actuation motion.

[0032] In particular embodiments, the exhaust rocker arm **104** and the engine brake rocker arm **106** may respectively accommodate the exhaust capsule **112** and the engine brake capsule **114**. For example, the exhaust and engine brake capsules **112**, **114** may be incorporated into or coupled to each of the exhaust rocker arm **104** and engine brake rocker arm **106** and may be configured to transfer force or motion to a valve bridge **120**. As an example and not by way of limitation, the exhaust and engine brake capsules **112**, **114** may be switchable between activation and deactivation. For example, when activated, the capsule may be rigid, allowing motion from the associated rocker arm to be transmitted down to the valve bridge **120**. Conversely, when deactivated, the capsule may be collapsible, e.g., by means of lost motion mechanisms inside the capsule, such that valve actuation motion is absorbed by the lost motion mechanism or by relative movement of the capsule and the rocker arm such that the downstream valve bridge **120** is not actuated.

[0033] In particular embodiments, the valve bridge **120** may be configured to span and sit atop the two exhaust valves **108**, **110** so as to transfer motion thereto. As illustrated, in particular embodiments, a top surface of the valve bridge **120** may engage with the exhaust rocker arm **104**. For example, a lower end of the exhaust capsule **112** of the exhaust rocker arm **104** may rest against the valve bridge **120**. When activated, the exhaust capsule **112** may push down the valve bridge **120** along its center so as to push down the two exhaust valves **108**, **110** to the same lift. As further illustrated, in particular embodiments, the valve bridge **120** may include a movable component **122** (such as a sliding pin) that may move relative to the valve bridge body and may operatively couple between a lower end of the engine brake capsule **114** and the exhaust brake valve **110**. When activated, the engine brake capsule **114** may press onto the movable component

122, thereby solely actuating the exhaust brake valve **110** without affecting the exhaust standard valve **108**.

[0034] It should be understood that the valve train system described herein is provided for the purposes of explanation only, and not intended to limit the scope of this disclosure. Although this disclosure describes a valve train system having a particular configuration in a particular manner, this disclosure contemplates any suitable valve train systems having any suitable configurations in any suitable manner. For example, in certain embodiments, the valve train systems may include none, some, or all of the components disclosed herein. For example, in certain embodiments, the valve train system may include additional components that are not described herein without departing from the scope of this disclosure.

[0035] FIG. **2** illustrates example operations in a drive mode of an engine brake system, which may utilize the valve train assembly **100** as described at length above or any other suitable valve train assemblies. In particular embodiments, the valve lift sequence of the engine brake system may be described in relation to the engine's four-stroke cycle, that is, intake stroke, compression (CMP) stroke, power stroke, and exhaust stroke. In particular embodiments, in drive mode where positive engine power is demanded to drive the vehicle, for example, the valve operation may begin first with the intake stroke (although not shown, a first intake stroke may occur prior to the compression stroke in the diagram, which is the same as the intake stroke after the exhaust stroke as illustrated). During the intake stroke, the intake valves may be lifted up by the intake rocker arm based on an intake lift profile **202**, opening a flow passage for example with an intake manifold to allow air and fuel to enter the associated cylinder. As an example and not by way of limitation, opening of the intake valves may be timed to coincide with the downward movement of a piston of the cylinder, creating a vacuum in the cylinder to draw in the air-fuel mixture. Once the intake stroke is complete, the intake valves may be closed. The cylinder is sealed off and ready for the compression stroke where the piston may move upward, compressing the air-fuel mixture inside the cylinder in preparation for ignition. As shown by the cylinder pressure curve, in particular embodiments, peak cylinder pressure may occur just after the compression stroke. With the intake valves and the exhaust valves closed, the compressed air-fuel mixture may be ignited, e.g., by a spark plug, in the power stroke. The resulting combustion may force the piston downward, creating mechanical energy to power the vehicle. Thereafter, the exhaust stroke may follow, in which both exhaust valves open—upon activation and actuation of the exhaust rocker arm based on an exhaust lift profile **204**—allowing the piston to move upward again for example under pressure differentiation between the engine's exhaust port pressure and in-cylinder pressure, pushing the burnt gases out of the cylinder and into the engine's exhaust system (for example, through an exhaust manifold) for gas evacuation and emission control. Following the exhaust stroke, in particular embodiments, the system may then have another intake stroke to implement multiple cycles of valve lift sequence as described, thereby continuously powering the vehicle as needed.

[0036] For compression engine brake, the timing of the valve lift may be configured and operated differently from the regular drive mode operation so that the system may function as a power-consuming compressor that produces negative engine power. To achieve this, in particular embodiments, the intake valves may operate substantially similarly as in the drive mode. The exhaust valves—or the exhaust brake valve of the two exhaust valves—on the other hand may participate in the engine braking process, whose opening and closing are precisely controlled to deliver the desired braking power. As an example and not by way of limitation, the exhaust brake valve may prematurely open during the compression and power strokes to release compressed air in the cylinder. By releasing the compressed air, the pressure in the cylinder may be released or reduced, preventing the air spring (compressed air) from returning back energy to the piston (by pushing back the piston). As such, the engine brake may convert some of the engine's power into braking force, assisting control the vehicle's speed and reducing wear on the conventional service brakes. This may be particularly useful for heavy-duty vehicles, such as trucks, buses, or the like, when descending steep grades or maintaining control in adverse driving conditions.

[0037] With reference to FIG. **3**, example operations in 1-stroke engine brake mode of the engine brake system are depicted. In particular embodiments, the intake valves may operate substantially similarly as in the drive mode of FIG. **2**, e.g., the intake valves may lift during the intake stroke based on the intake lift profile **302** and remain closed in the following compression, power, and exhaust strokes. In particular embodiments, the exhaust lift profile **304** acting upon the two exhaust valves by the exhaust rocker arm during the exhaust stroke may also be similar to the drive mode. In particular embodiments, two additional engine brake lifts may be applied, for example, in the compression stroke and the power stroke. As an example and not by way of limitation, the engine brake rocker arm may be activated to act upon one of the exhaust valves, i.e., the exhaust brake valve, based on an engine brake lift profile having a brake gas recirculation lift sub-profile **306** and a first compression release lift sub-profile **308**, which will be described in detail in the following.

[0038] In particular embodiments, the brake gas recirculation lift sub-profile **306** may be utilized, which may be timed to follow the first intake lift profile **302** with a slight overlap. As an example and not by way of limitation, the brake gas recirculation lift sub-profile **306** may recirculate a portion of the engine's exhaust gases back into the cylinder to supplement the cylinder air charge. Explaining further, for example, high pressure pulses originated from other cylinders of the six-cylinder engine and traveling in the exhaust system—e.g., air may be compressed to a peak pressure and released through the exhaust system at the speed of sound—may be advantageously redirected and introduced into the particular cylinder undergoing engine brake to supercharge the cylinder with additional air. In the diagram as illustrated, in particular embodiments, the exhaust brake valve may open in late intake stroke until the early part of the compression stroke to induct exhaust pressure pulse into the cylinder in addition to the main intake action. By loading the cylinder with recirculated exhaust pulse, the brake gas recirculation lift sub-profile **306** may help increase the amount of air in the cylinder and achieve high peak cylinder pressure, thereby providing higher retarding or braking power in the engine brake mode as more energy is consumed for compression.

[0039] In particular embodiments, following the brake gas recirculation in the compression stroke, the piston may move up, compressing the air in the cylinder. Before the piston reaches its uppermost position in the cylinder (e.g., at 0-degree crank angle), pressure may be released from the cylinder through the first compression release lift sub-profile **308** that opens the exhaust brake valve for compressed air to escape. This opening of the exhaust brake valve may permit the cylinder to release the compressed air, consequently reducing the cylinder pressure so that the energy is not returned to the piston. In other words, any air spring effect of the compressed air in the cylinder that would otherwise press down the piston later again may be effectively removed or at least reduced.

[0040] In particular embodiments, the engine brake system may then operate under the exhaust lift profile **304** where the exhaust rocker arm pushes open both the exhaust brake valve and the exhaust standard valve during the exhaust stroke and repeat the intake lift profile **302** again for another intake stroke if additional engine braking cycles are demanded.

[0041] FIG. **4** illustrates example operations in 1.5-stroke engine brake mode of the engine brake system in accordance with one embodiment of this disclosure, which may deliver higher retarding power and enhance engine brake performance. This may be achieved by having additional brake valve event(s) per engine cycle than the 1-stroke engine brake of FIG. **3**. In particular embodiments, the intake valves may operate substantially similarly as in the drive mode of FIG. **2**, e.g., the intake valves may lift during the intake stroke based on the intake lift profile **402** and remain close in the following compression, power, and exhaust strokes. On the other hand, in particular embodiments, the exhaust lift profile that would otherwise be activated during the exhaust stroke may be removed or deactivated. As an example and not by way of limitation, this may be done by deactivating the exhaust rocker arm, or the exhaust capsule of the exhaust rocker arm, in a way to disable actuation of both the exhaust standard valve and the exhaust brake valve by the exhaust rocker arm. That is, the exhaust standard valve may stay still, and the exhaust brake valve may receive zero lift from the exhaust rocker arm during the engine cycle. In particular embodiments, additional engine brake lifts may be applied, for example, in the compression stroke, the power stroke, and the exhaust stroke. As an example and not by way of limitation, the engine brake rocker arm may be controlled to act upon one of the exhaust valves, i.e., the exhaust brake valve, according to an engine brake lift profile that times multiple actuation events and includes a brake gas recirculation lift sub-profile **406**, a first compression release lift sub-profile **408**, a rebreather lift sub-profile **410**, and a second compression release lift sub-profile **412**, which will be described in detail in the following.

[0042] In particular embodiments, the brake gas recirculation lift sub-profile **406** may be utilized, which may be timed to follow the first intake lift profile **402** with no overlap. As an example and not by way of limitation, the brake gas recirculation lift sub-profile **406** may recirculate a portion of the engine's exhaust gases back into the cylinder to supplement the cylinder air charge. Explaining further, for example, high pressure pulses originated from other cylinders of the six-cylinder engine and traveling in the exhaust system—e.g., air may be compressed to a peak pressure and released through the exhaust system at the speed of sound—may be advantageously redirected and introduced into the particular cylinder undergoing engine brake to supercharge the particular cylinder with additional air. In the diagram as illustrated, in particular embodiments, the exhaust brake valve may open after the intake stroke until the mid or late part of the compression stroke to induct exhaust pressure pulse into the cylinder in addition to the main intake action. By loading the cylinder with recirculated exhaust pulse, the brake gas recirculation lift sub-profile **406** may help increase the amount of air in the cylinder and achieve high peak cylinder pressure, thereby providing higher retarding or braking power in the engine brake mode as more energy is consumed for compression.

[0043] In particular embodiments, following the brake gas recirculation in the compression stroke, the piston may move up, compressing the air in the cylinder. Before the piston reaches its uppermost position in the cylinder (e.g., at 0-degree crank angle), pressure may be released from the cylinder through the first compression release lift sub-profile **408** that opens the exhaust brake valve for compressed air to escape. As an example and not by way of limitation, the first compression release lift sub-profile **408** may open the exhaust brake valve by an amount greater than that of the 1-stroke engine brake mode (e.g., the first compression release lift sub-profile **308** of FIG. **3**), although other suitable values are also envisioned by this disclosure. This opening of the exhaust brake valve may permit the cylinder to release the compressed air, consequently reducing the cylinder pressure so that the energy is not returned to the piston. In other words, any air spring effect of the compressed air in the cylinder that would otherwise press down the piston later again may be effectively removed or at least reduced.

[0044] In particular embodiments, the exhaust brake valve may then be actuated to lift again after completion of the first compression release event. This is referred to as the rebreather lift sub-profile **410**, where the exhaust brake valve opens to draw the exhaust air from the exhaust system again, rebreathing the air that was already expelled into the exhaust system back to the cylinder once more. As an example and not by way of limitation, rebreathing may occur as a result of pressure difference between the high exhaust gas pressure and the low in-cylinder pressure. As illustrated in FIG. **4** by the cylinder pressure curve, for example, the pressure inside the cylinder during rebreathing may be decreased to minimal, although other suitable values are also envisioned by this disclosure. Charging the cylinder with exhaust air following the first compression release may allow the system to utilize the exhaust air again by compressing it in the exhaust stroke subsequent to the power stroke. As an example and not by way of limitation, since the amount of valve opening is not as high as compared to the main intake action by the intake valves based on the intake lift profile **402**, the volume of exhaust mass drawn into the cylinder is lower.

Consequently, the second peak pressure of the cylinder generated as the piston drives up in the exhaust stroke may be lower than the first peak pressure of the cylinder in the compression stroke. As an example and not by way of limitation, the second peak pressure may be approximately half of the first pressure peak, hence the name of the 1.5-stroke engine brake, although other suitable values are also envisioned by this disclosure.

[0045] In particular embodiments, following the rebreathing in the exhaust stroke, as the piston moves upward to compress the recovered air in the cylinder, a second compression release lift sub-profile **412** of the exhaust brake valve may be implemented, which serves a similar function as the first compression release lift sub-profile **408**, that is, to release the air out of the cylinder to eliminate or at least reduce the air spring effect due to compression so that the energy is not returned to the piston. Considering the relatively small amount of air rebreathed into the cylinder, the second compression release valve lift may be lower than the first compression release valve lift, yet sufficient to release the compressed air out of the cylinder, effectively reducing cylinder pressure.

[0046] In particular embodiments, the engine brake system may then repeat the intake lift profile **402** again for another intake stroke if additional engine braking cycles are demanded.

[0047] FIG. **5** illustrates how a valve train system may operate to transition between the standard drive mode and the engine brake mode. For the purpose of explanation only and not by way of limitation, the example operation is described with reference to the valve train assembly **100** depicted in FIG. **1**. It should be understood that the embodiments according to this disclosure may be implemented by other suitable valve train systems. In particular embodiments, the intake valves **116**A, **116**B may be activated, for example, by activating the intake rocker arm **102** such that valve actuation motion may be transmitted from an intake cam to the intake valves **116**A, **116**B following the intake lift profile **502**. Activation of the intake rocker arm **14** may be maintained throughout engine operation such that the intake valves **116**A, **116**B are periodically lifted in the intake stroke of each engine cycle. In particular embodiments, during the drive mode, the exhaust valves **108**, **110** may be activated, for example, by activating the exhaust rocker arm **104**. As an example and not by way of limitation, activation of the exhaust rocker arm **104** may be achieved by switching on the exhaust capsule **112** to enable transmission of valve actuation motion from an exhaust cam to the exhaust valves **108**, **110** through the valve bridge **120**. On the other hand, in particular embodiments, during the drive mode, the engine brake rocker arm **106** may be deactivated, for example, by switching off the engine brake capsule **114** such that any motion to independently act upon the exhaust brake valve **110** via the movable component **122** of the valve bridge **120** is lost—in this case, lift of the exhaust brake valve **110** does not follow rotation of the engine brake rocker arm **106** but only the exhaust rocker arm **104**. In other words, when in the drive mode, the exhaust standard valve **108** and the exhaust brake valve **110** are actuated in synchronization by the exhaust rocker arm **104** based on the exhaust lift profile **504**.

[0048] In particular embodiments, in the subsequent engine cycle after the drive mode, a transition mode may be introduced, during which the exhaust rocker arm **104** and the engine brake rocker arm **106** may both be activated. This way, in the exhaust stroke, the exhaust standard valve **108** and the exhaust brake valve **110** may open simultaneously to the same valve position under actuation by the exhaust rocker arm **104** based on the exhaust lift profile **504**. In addition to this main exhaust lift event, the exhaust brake valve **110** may perform additional brake lifts—namely, a brake gas recirculation lift sub-profile **506** and a first compression release lift sub-profile **508** similar to the ones discussed at length above—based on rotation of the engine brake rocker arm **106**. Specifically, as an example and not by way of limitation, the engine brake capsule **114** of the engine brake rocker arm **106** may be switched on and configured to press down on the movable component **122** of the valve bridge **120** responsive to the engine brake lift profile, thereby activating the exhaust brake valve **110** separately from the exhaust standard valve **108**. Note that in the embodiment as illustrated, while the engine brake rocker arm **106** may be actuated during the entire engine brake lift profile by the brake gas recirculation lift sub-profile **506**, the first compression release lift sub-profile **508**, a rebreather lift sub-profile **510**, and a second compression release lift sub-profile **512** similar to the ones discussed at length above, the exhaust brake valve **110** in the exhaust stroke only follows the exhaust lift profile **504** of the exhaust rocker arm **104**. In particular embodiments, by having both the exhaust rocker arm **104** and the engine brake rocker arm **106** activated, the engine brake system may experience a smooth transition especially as the exhaust brake valve **110** is handed over from the first compression release lift sub-profile **508** by the engine brake rocker arm **18** to the exhaust lift profile **504** by the exhaust rocker arm **104**. Moreover, in particular embodiments, the engine brake system in the transition mode may function basically similarly to the 1-stroke engine brake where the air in the cylinder is compressed once by the piston stroke to create a high braking force. In the embodiment as illustrated, the transition mode may be implemented for one cycle before the valve train assembly **100** enters the engine brake mode. Alternatively, in other embodiments, the transition mode may last for several cycles before switching to engine brake mode.

[0049] In particular embodiments, after the transition mode, the exhaust rocker arm **104** may be deactivated, allowing the system to operate under the full or 1.5-stroke engine brake mode. Specifically, in the 1.5-stroke engine brake mode, by switching off the exhaust rocker arm **104**—e.g., either directly or by deactivating the exhaust capsule **112**—the exhaust lift profile **504** is removed from the cycle such that the exhaust standard valve **108** receives zero lift during the entire process of 1.5-stroke engine braking. In particular embodiments, the exhaust brake valve **110** is active and responsive only to movement of the engine brake rocker arm **106**. As an example and not by way of limitation, the exhaust brake valve **110** may open based on the brake gas recirculation lift sub-profile **506**, the first compression release lift sub-profile **508**, the rebreather lift sub-profile **510**, and the second compression release lift sub-profile **512**, allowing the air in the cylinder to be compressed twice to resist against the piston's upward movement, thereby providing higher retarding power for slowing down the vehicle.

[0050] Referring now to FIG. **6**, in certain embodiments that employ a general 1.5-stroke engine brake with different timing of valve lift events than the embodiments of FIG. **5**, valve train components may experience severe mechanical impact due to the overlapping main exhaust and engine brake operations. For example, in the embodiment as illustrated, the exhaust rocker arm **104** may rotate based on a main exhaust lift curve, and the engine brake rocker arm **106** may rotate based on an engine brake lift curve. Consequently, two cross points **602**, **604** between the main exhaust lift curve and the engine brake lift curve may be created as the general 1.5-stroke engine brake event coincides with the main exhaust event, inducing significant differences in lift velocities, which are represented by the different slopes of the two lift curves. As an example and not by way of limitation, when the valve train assembly **100** operates with the exhaust rocker arm **104** activated and the engine brake rocker arm **106** deactivated (e.g., in the drive mode), the engine brake capsule **114** may be in the lost motion state where the engine brake capsule **114** (e.g., a bolt **124** shown as resting on a top surface of the engine brake rocker arm **106**), as well as its lost motion components, are movable relative to the engine brake rocker arm **106**. Free movement between the engine brake capsule **114** and the engine brake rocker arm **106** may be particularly sensitive to variations in lift velocities, which may result in undesirable dynamic behavior that may damage the system.

[0051] In particular embodiments, at the first cross point **602**, the engine brake rocker arm **106** may pivot down toward its lowest position of a rebreather lift following the engine brake lift curve, while the engine brake capsule **114** may move up relative to the engine brake rocker arm **106** due to the upward support by the movable component **122** of the valve bridge **120**. When this happens, a lost motion gap may be formed between the bolt **124** of the engine brake capsule **114** and the engine brake rocker arm **106** so as to absorb the valve actuation motion by the engine brake lift. On the other hand, due to the offset between the engine brake lift curve and the main exhaust lift curve, actuation of the exhaust rocker arm **104** may lag that of the engine brake rocker arm **106**. For example, when the engine brake rocker arm **106** is about to reach its lowest rebreather lift position, the exhaust rocker arm **104** may just begin to press down the valve bridge **120** based on the main exhaust lift curve, consequently separating the movable component **122** in a downward direction away from the engine brake capsule **114**. Absent the support by the movable component **122**, the engine brake capsule **114** may drop due to gravity, rapidly closing the lost motion gap until it hits against the engine brake rocker arm **106**, resulting in operation noise, severe mechanical impact, and possible system failure. Moreover, in the embodiments in which a lost motion spring is disposed in the engine brake capsule **114**, the spring force may further accelerate the downward movement of the engine brake capsule **114**, causing the engine brake capsule **114** to hit against the engine brake rocker arm **106** even harder.

[0052] In particular embodiments, at the second cross point **604**, the engine brake rocker arm **106** may rotate down, for example, approximately to its lowest position of the second compression release lift based on the engine brake lift curve. In contrast, the exhaust rocker arm **104** and consequently the valve bridge **120** may travel up to return to the zero-lift position on the main exhaust lift curve. When this happens, the movable component **122** may impinge onto the engine brake capsule **114** in an upward direction under great force. Moreover, significant momentum and kinetic energy of the movable component **122** generated by the velocity difference between the engine brake lift curve and the main exhaust lift curve may shoot up the engine brake capsule **114** away from the engine brake rocker arm **106** until the engine brake capsule **114** is suddenly stopped, for example, when the lost motion components hit a mechanical stopper inside the engine brake rocker arm **106**. This may introduce severe mechanical impact particularly to the lost motion components, shortening the service life of the system, and causing critical engine failure. Afterward, the engine brake capsule **114** may land back due to gravity and once again hit the engine brake rocker arm **106**.

[0053] To minimize the severity of mechanical impact, in particular embodiments according to this disclosure, timing of the valve lift sequence may be carefully designed to improve the tangency and ensure low overlap between the exhaust lift and the engine brake lift, thereby reducing possible mechanical impacts in the valve train system.

[0054] FIG. **7** illustrates improved engine brake operations according to one embodiment of this disclosure. For the purpose of explanation only and not by way of limitation, the example operation is described with reference to the valve train assembly **100** depicted in FIG. **1**. It should be understood that the embodiments according to this disclosure may be implemented by other suitable valve train systems. In the embodiment as illustrated, the exhaust rocker arm **104** may rotate based on a main exhaust lift curve, and the engine brake rocker arm **106** may rotate based on an engine brake lift curve. Consequently, two cross points **702**, **704** between the main exhaust lift curve and the engine brake lift curve may be created as the improved 1.5-stroke engine brake event coincides with the main exhaust event. The timing of the two cross points **702** and **704** between the main exhaust lift curve and the engine brake lift curve may be specifically designed. In particular embodiments, since the main exhaust lift curve and the engine brake lift curve are substantially tangent with each other at the two cross points **702** and **704**, the differences in lift velocities may be reduced, allowing a smoother transition of engine operation. The two cross points **702** and **704** may be positioned close to the beginning and end of the main exhaust lift curve. As such, the impact force between different moving parts that will contact each other may be reduced or eliminated. As an example and not by way of limitation, when the valve train assembly **100** operates with the exhaust rocker arm **104** activated and the engine brake rocker arm **106** deactivated (e.g., in the drive mode), the engine brake capsule **114** may be in the lost motion state where the engine brake capsule **114**, as well as its lost motion components, are movable relative to the engine brake rocker arm **106**. Since variations in lift velocities are kept low, its effect on the free movement between the engine brake capsule **114** and the engine brake rocker arm **106** may be minimized, ensuring the valve train assembly **100** to operate with optimal system kinematics.

[0055] In particular embodiments, at the first cross point **702**, the engine brake rocker arm **106** may pivot down according to the engine brake lift curve, while the exhaust rocker arm **104** may also move down based on the main exhaust lift curve substantially simultaneously and under similar velocities as the engine brake rocker arm **106**, which may be due to the tangency at the first cross point **702**. As such, the lost motion gap created by the relative movement between the engine brake capsule **114** and the engine brake rocker arm **106** may be much smaller. This way, as the engine brake capsule **114** translates down under gravity and closes the gap, it may land back onto the engine brake rocker arm **106** gently with small potential energy (e.g., a light impact force), thereby minimizing the mechanical impacts that would otherwise damage the system.

[0056] In particular embodiments, at the second cross point **704**, actuation of the engine brake rocker arm **106** and of the exhaust rocker arm **104** may also occur substantially in synchronization. As an example and not by way of limitation, the engine brake rocker arm **106** and the exhaust rocker arm **104** may both rotate in an upward direction toward their zero lift positions under similar velocities due to the tangency at the second cross point **704**. While the engine brake capsule **114** in this scenario may still be urged upward away from the engine brake rocker arm **106** as a result of valve lift difference, the travel velocity and impact force of the engine brake capsule **114** is significantly reduced, thus minimizing the mechanical impacts in the system and optimizing operational dynamics compared to the general 1.5-stroke engine brake described with reference to FIG. **6**.

[0057] Referring now to FIG. **8**, in certain embodiments in which the transition mode from the drive mode to the engine brake mode is absent, critical system failure may occur. For example, in the embodiment as illustrated, in the drive mode, which is shown at the top of FIG. **8**, the exhaust rocker arm **104** may be activated and the engine brake rocker arm **106** may be deactivated, i.e., both the exhaust standard valve **108** and the exhaust brake valve **110** are lifted open during the exhaust stroke according to the exhaust lift profile. As the valve train system is turned on in an attempt to switch the engine to the engine brake mode, which is shown at the bottom of FIG. **8**, the exhaust rocker arm **104** may be suddenly deactivated, removing the exhaust lift profile from the operation cycle. However, by this time, the engine brake rocker arm **106** may not be activated yet, for example, due to a delay in control signal transmission. That is, in this scenario, only the intake valves **116**A, **116**B may be opened, drawing in a large amount of air mass into the cylinder. The piston may then be driven up in the compression stroke, compressing the air into high pressure. Absent any compression release by the exhaust valves **108**, **110** following the power stroke, the air is trapped inside the cylinder, which is then compressed again as the piston moves up in the exhaust stroke, consequently generating significant pressure in the cylinder. Such a high cylinder pressure is detrimental to the intake valves **116**A, **116**B as they try to open later in the intake stroke, particularly when the intake side of the rocker arm assembly is not designed to withstand high pressure, thereby resulting in valve breakage and engine malfunction.

[0058] FIG. **9** illustrates improved engine brake operation according to this disclosure, in which the transition mode is introduced between the drive mode and the engine brake mode. In particular embodiments, the engine may first operate under the drive mode, which is indicated at **910**, with the exhaust rocker arm activated and the engine brake rocker arm deactivated. In the event that engine braking is desired, the engine brake lift may then be activated. That is, in the transition mode, which is indicated at **920**, both the 1.5-stroke engine brake lift profile and the exhaust lift profile may be performed. In this way, high compression pressure that would otherwise damage the system may be effectively avoided. Furthermore, since the engine brake lift profile is timed to be tangent to the rebreather lift sub-profile **922** and the second compression release lift sub-profile **924** of the 1.5-stroke engine brake lift profile, smooth handover between the engine brake lift and the exhaust lift acting on the exhaust brake valve may be ensured. Note that while the transition mode may produce some braking power, it is not rated for the full 1.5-stroke engine brake. As an example and not by way of limitation, the peak cylinder pressure in the embodiment as illustrated may only reach a relatively low level, limiting the amount of braking power generated. In particular embodiments, the transition mode may be implemented for one cycle before the valve train assembly enters the engine brake mode. Alternatively, in other embodiments, the transition mode may last for several cycles before switching to the engine brake mode. In particular embodiments, to perform the engine brake mode, the exhaust lift may then be deactivated such that only the exhaust brake valve may remain actuated based on the 1.5-stroke engine brake lift profile while the exhaust standard valve becomes inactive. At this time, the engine may run in full engine brake mode. By allowing the smooth transmission between the drive mode and the engine brake mode, the special timing of the valve lift sequence according to this disclosure may optimize engine brake performance and protect the intake valve system against overloading due to high cylinder pressure.

[0059] FIG. **10** illustrates scaling of engine brake power according to this disclosure. In particular embodiments, in the transition mode as already discussed at length above, both the exhaust lift profile and the engine brake lift profile may be active at the same time, allowing compressed air in the compression stroke to be rapidly released out of the cylinder. Explaining further, since the exhaust brake valve during the exhaust stroke is lifted open by the exhaust rocker arm responsive to the exhaust lift profile rather than the engine brake rocker arm that performs the rebreathing event based on the engine brake lift profile, no exhaust air is circulated back into the cylinder after the first compression release. Devoid of sufficient gases in the cylinder, the cylinder pressure remains low even though the piston compresses in the exhaust stroke. As an example and not by way of limitation, as illustrated in the cylinder pressure diagram at the bottom of the FIG. **10**, the pressure profile during the transition mode may include only one peak pressure, allowing the valve train system to function substantially similarly to the 1-stroke engine brake as described with reference to FIG. **3**. This transition mode may also be referred to as 1-stroke engine brake as it produces a lower braking force than the full 1.5-stroke engine brake. Moreover, in particular embodiments, during the engine brake mode with the exhaust lift off and the engine brake lift on, two peak cylinder pressure may be induced, i.e., one large peak due to the intake operation, the other small peak due to the rebreathing of the exhaust brake valve where the cylinder is re-charged with the exhaust air. As an example and not by way of limitation, the small peak pressure may be approximately half of the large pressure peak, hence the name of the 1.5-stroke engine brake. This engine brake mode may also be referred to as 1.5-stroke engine brake and produces a full amount of braking power available to the engine. By designing the sequence of valve lift events in this particular way according to this disclosure, a single system may be employed to deliver two levels of engine braking.

[0060] FIG. **11** illustrates two example power levels of the engine brake system according to this disclosure, that is, the 1-stroke engine brake and 1.5-stroke engine brake. In particular embodiments in which the engine brake system according to this disclosure is used in a six-cylinder engine, all of the six cylinders may remain active, and scaling of brake power may be regulated by switching the exhaust lift on or off. As an example and not by way of limitation, if a low brake force is desired, the engine brake system may be scaled down to the 1-stroke engine brake by activating both the exhaust lift and the engine brake lift. Alternatively, as another example and not by way of limitation, if a higher brake force is desired, for example, when the vehicle travels down a steep slope and needs to slow down fast, the engine brake system may be scaled up to the 1.5 stroke engine brake by switching off the exhaust lift while keeping the engine brake lift activated. In the embodiment as illustrated, the 1.5-stroke engine brake may provide 80% more brake power compared with the 1-stroke engine brake, although other suitable values are also envisioned. By contrast, in other embodiments that employ general braking strategy without the ability to deliver varying braking power by a single engine brake system, scaling of brake power may only be achieved by activating a selected number of engine cylinders, for example, by actuating three cylinders for low brake power or six cylinders for high brake power, which undesirably drives up operation cost and increases system complexity. The system and method for timing of valve lift events according to this disclosure advantageously allow running both the exhaust rocker arm and engine brake rocker arm simultaneously, which facilitates downscaling from the 1.5-stroke to 1-stroke engine brake mode.

[0061] FIG. **12** illustrates a flow diagram of an example method for timing valve lift events according to particular embodiments of this disclosure. In particular embodiments, the method may be implemented by a rocker arm assembly of an internal combustion engine. As an example and not by way of limitation, the rocker arm assembly may be similar to the one described with reference to FIG. **1** in that the rocker arm assembly may comprise an exhaust rocker arm (e.g., the exhaust rocker arm **104**) and an engine brake rocker arm (e.g., the engine brake rocker arm **106**) and may be configured to selectively actuate a first exhaust valve (e.g., the exhaust standard valve **108**) or a second exhaust valve (e.g., the exhaust brake valve **110**). Although this disclosure describes a method for timing valve lift events using a particular rocker arm assembly in a particular manner, this disclosure contemplates methods for timing valve lift events using any suitable rocker arm assemblies in any suitable manner. At step **1202**, the exhaust rocker arm may be activated to enable actuation of the first exhaust valve and the second exhaust valve by the exhaust rocker arm. As an example and not by way of limitation, this may be done by activating an exhaust capsule of the exhaust rocker arm such that the exhaust capsule is extended to contact a valve bridge coupled to the first and second exhaust valves as the exhaust rocker arm rotates. At step **1204**, the exhaust rocker arm may be actuated based on an exhaust lift profile. As an example and not by way of limitation, the exhaust lift profile may correlate the degree of rotation of the exhaust rocker arm or the valve lift movement to a crank angle of a crankshaft of the internal combustion engine. At step **1206**, an engine brake capsule of the engine brake rocker arm may be activated. As an example and not by way of limitation, the engine brake capsule may be extended to contact a movable component of the valve bridge, which is coupled to the second exhaust valve, as the engine brake rocker arm rotates. Specifically, the engine brake rocker arm may actuate the second exhaust valve independently from the first exhaust valve. At step **1208**, the engine brake rocker arm may be actuated based on an engine brake lift profile. As an example and not by way of limitation, the engine brake lift profile may correlate the degree of rotation of the engine brake rocker arm or the valve lift movement to the crank angle of the crankshaft of the internal combustion engine. In particular embodiments, the timing of the exhaust lift profile and the engine brake lift profile may be specifically designed such that the exhaust lift profile and the engine brake lift profile have a first cross point and a second cross point. Moreover, the exhaust lift profile may be tangent with the engine brake lift profile at the first cross point and the second cross point. This may reduce the differences in lift velocities of the rocker arm assembly and ensure low overlap between the exhaust lift and the engine brake lift, thereby reducing possible mechanical impacts in the rocker arm assembly. In particular embodiments, both the exhaust rocker arm and the engine brake rocker arm may remain actuated for one or more engine cycles. When this happens, the engine is in the transition mode as described at length above. For example, the transition mode may provide a 1-stroke engine brake where only one peak cylinder pressure is generated. At step **1210**, the exhaust rocker arm may be deactivated. This may be done by directly deactivating the exhaust rocker arm such that it stops rotating, or by deactivating the exhaust capsule to disable motion transmission from the exhaust rocker arm to the valve bridge. As a result, the engine may enter the 1.5-stroke brake mode, where only the engine brake rocker arm is in operation to actuate the engine brake valve based on the engine brake profile. By introducing the transition mode between the drive mode and the engine brake mode, smooth operation of the rocker arm assembly may be ensured, optimizing engine brake performance, facilitating upscaling or downscaling of brake power, and protecting the rocker arm assembly against overloading.

[0062] Herein, “or” is inclusive and not exclusive, unless expressly indicated otherwise or indicated otherwise by context. Therefore, herein, “A or B” means “A, B, or both,” unless expressly indicated otherwise or indicated otherwise by context. Moreover, “and” is both joint and several, unless expressly indicated otherwise or indicated otherwise by context. Therefore, herein, “A and B” means “A and B, jointly or severally,” unless expressly indicated otherwise or indicated otherwise by context.

[0063] The scope of this disclosure encompasses all changes, substitutions, variations, alterations, and modifications to the example embodiments described or illustrated herein that a person having ordinary skill in the art would comprehend. The scope of this disclosure is not limited to the example embodiments described or illustrated herein. Moreover, although this disclosure describes and illustrates respective embodiments herein as including particular components, elements, feature, functions, operations, or steps, any of these embodiments may include any combination or permutation of any of the components, elements, features, functions, operations, or steps described or illustrated anywhere herein that a person having ordinary skill in the art would comprehend. Furthermore, reference in the appended claims to an apparatus or system or a component of an apparatus or system being adapted to, arranged to, capable of, configured to, enabled to, operable to, or operative to perform a particular function encompasses that apparatus, system, component, whether or not it or that particular function is activated, turned on, or unlocked, as long as that apparatus, system, or component is so adapted, arranged, capable, configured, enabled, operable, or operative. Additionally, although this disclosure describes or illustrates particular embodiments as providing particular advantages, particular embodiments may provide none, some, or all of these advantages.

Claims

1. A method for timing valve lift events of a rocker arm assembly of an internal combustion engine, the rocker arm assembly comprising an exhaust rocker arm and an engine brake rocker arm and configured to selectively actuate one or more of a first exhaust valve or a second exhaust valve, the method comprising: enabling actuation of the first exhaust valve and the second exhaust valve by the exhaust rocker arm; actuating the exhaust rocker arm based on an exhaust lift profile; enabling actuation of the second exhaust valve by the engine brake rocker arm independent of actuation of the first exhaust valve; and actuating the engine brake rocker arm based on an engine brake lift profile, wherein the exhaust lift profile and the engine brake lift profile have a first cross point and a second cross point, and wherein an angle defined between a tangent to the exhaust lift profile and a tangent to the engine brake lift profile is minimized at the first cross point and the second cross point so as to respectively minimize a velocity difference between the first exhaust valve and the second exhaust valve at each of the first cross point and the second cross point.

2. The method of claim 1, wherein the engine brake lift profile comprises a first engine brake lift sub-profile, a second engine brake lift sub-profile, a third engine brake lift sub-profile, and a fourth engine brake lift sub-profile.

3. The method of claim 2, wherein the exhaust lift profile is subsequent to the second engine brake lift sub-profile and overlaps with the third engine brake lift sub-profile at the first cross point and with the fourth engine brake lift sub-profile at the second cross point, wherein the exhaust lift profile is tangent with the third engine brake lift sub-profile at the first cross point and is tangent with the fourth engine brake lift sub-profile at the second cross point.

4. The method of claim 2, wherein, when the actuation of the first exhaust valve and the second exhaust valve by the exhaust rocker arm is enabled and the actuation of the second exhaust valve by the engine brake rocker arm is enabled, the actuation of the first exhaust valve is based on the exhaust lift profile, and the actuation of the second exhaust valve is based on the first engine brake lift sub-profile, the second engine brake lift sub-profile, and the exhaust lift profile.

5. The method of claim 2, wherein, when the actuation of the first exhaust valve and the second exhaust valve by the exhaust rocker arm is enabled and the actuation of the second exhaust valve by the engine brake rocker arm is enabled, one cylinder pressure peak is generated in a four-stroke cycle of the internal combustion engine.

6. The method of claim 5, wherein the second engine brake lift sub-profile is configured to release cylinder pressure such that the one cylinder pressure peak is generated in a compression stroke of the four-stroke cycle of the internal combustion engine.

7. The method of claim 1, wherein, at the first cross point or the second cross point, the engine brake lift profile is configured to deliver valve lift in a same direction as the exhaust lift profile.

8. The method of claim 7, wherein, at the first cross point or the second cross point, the engine brake lift profile is configured to deliver valve lift at a similar velocity as the exhaust lift profile.

9. The method of claim 2, further comprising: disabling actuation of the first exhaust valve and the second exhaust valve by the exhaust rocker arm.

10. The method of claim 9, wherein, when the actuation of the first exhaust valve and the second exhaust valve by the exhaust rocker arm is disabled and the actuation of the second exhaust valve by the engine brake rocker arm is enabled, the first exhaust valve is unactuated, and the actuation of the second exhaust valve is based on the engine brake lift profile.

11. The method of claim 9, wherein, when the actuation of the first exhaust valve and the second exhaust valve by the exhaust rocker arm is disabled and the actuation of the second exhaust valve by the engine brake rocker arm is enabled, two cylinder pressure peaks are generated in a four-stroke cycle of the internal combustion engine.

12. The method of claim 11, wherein the second engine brake lift sub-profile is configured to release cylinder pressure such that a first cylinder pressure peak is generated in a compression stroke of the four-stroke cycle of the internal combustion engine, wherein the fourth engine brake lift sub-profile is configured to release cylinder pressure such that a second cylinder pressure peak is generated before an intake stroke of the four-stroke cycle of the internal combustion engine.

13. The method of claim 1, wherein the rocker arm assembly further comprises an intake rocker arm configured to activate at least two intake valves, the method further comprising: enabling actuation of the at least two intake valves by the intake rocker arm based on an intake lift profile.

14. A method for timing valve lift events of a rocker arm assembly of an internal combustion engine, the rocker arm assembly comprising an exhaust rocker arm and an engine brake rocker arm and configured to selectively actuate one or more of a first exhaust valve or a second exhaust valve, the method comprising: enabling actuation of the first exhaust valve and the second exhaust valve by the exhaust rocker arm; actuating the exhaust rocker arm based on an exhaust lift profile; enabling actuation of the second exhaust valve by the engine brake rocker arm independent of actuation of the first exhaust valve; actuating the engine brake rocker arm based on an engine brake lift profile; maintaining the actuation of the exhaust rocker arm and the engine brake rocker arm for at least one engine cycle following an initial actuation of the engine brake rocker arm; and disabling actuation of the first exhaust valve and the second exhaust valve by the exhaust rocker arm.

15. The method of claim 14, wherein the exhaust lift profile and the engine brake lift profile have a first cross point and a second cross point, and wherein an angle defined between a tangent to the exhaust lift profile and a tangent to the engine brake lift profile is minimized at the first cross point and the second cross point so as to respectively minimize a velocity difference between the first exhaust valve and the second exhaust valve at each of the first cross point and the second cross point.

16. The method of claim 15, wherein the engine brake lift profile comprises a first engine brake lift sub-profile, a second engine brake lift sub-profile, a third engine brake lift sub-profile, and a fourth engine brake lift sub-profile, and wherein the exhaust lift profile is subsequent to the second engine brake lift sub-profile and overlaps with the third engine brake lift sub-profile at the first cross point and with the fourth engine brake lift sub-profile at the second cross point, wherein the exhaust lift profile is tangent with the third engine brake lift sub-profile at the first cross point and is tangent with the fourth engine brake lift sub-profile at the second cross point.

17. The method of claim 15, wherein, at the first cross point or the second cross point, the engine brake lift profile is configured to deliver valve lift in a same direction as the exhaust lift profile.

18. The method of claim 17, wherein, at the first cross point or the second cross point, the engine brake lift profile is configured to deliver valve lift at a similar velocity as the exhaust lift profile.

19. The method of claim 16, wherein, when the actuation of the first exhaust valve and the second exhaust valve by the exhaust rocker arm is disabled and the actuation of the second exhaust valve by the engine brake rocker arm is enabled, two cylinder pressure peaks are generated in a four-stroke cycle of the internal combustion engine.

20. The method of claim 19, wherein the second engine brake lift sub-profile is configured to release cylinder pressure such that a first cylinder pressure peak of the two cylinder pressure peaks is generated in a compression stroke of the four-stroke cycle of the internal combustion engine, wherein the fourth engine brake lift sub-profile is configured to release cylinder pressure such that a second cylinder pressure peak of the two cylinder pressure peaks is generated before an intake stroke of the four-stroke cycle of the internal combustion engine.