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(54) **DIRECT-ACTING SOLENOID HAVING VARIABLE TRIGGERING TIMING FOR ELECTRO-MECHANICAL VALVETRAIN AND ACTUATION LEVERS FOR SWITCHING ROCKER ARMS**

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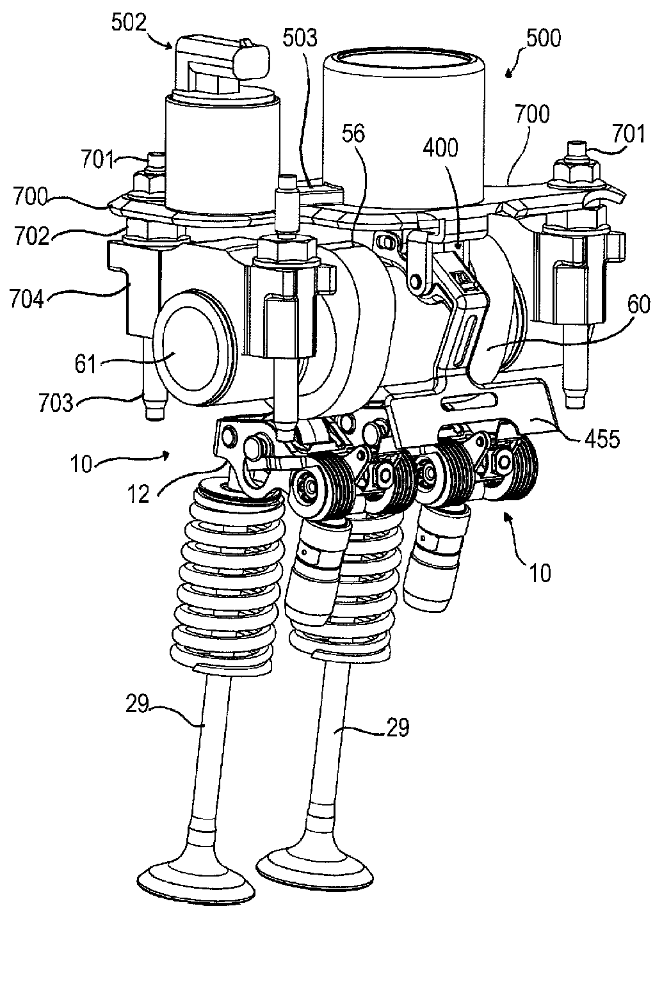
(57) **ABSTRACT**

Systems, methods, and control systems for a switching rocker arm assembly are disclosed. A switching rocker arm (**10**) engages a valve (**29**), the switching rocker arm (**10**) is movable by contact with a cam (**60**) having a lift portion (**59**) and a base circle (**58**). The switching rocker arm (**10**) comprises an inner arm (**20**), an outer arm (**12**) pivotably secured to the inner arm (**20**) and having a latch bore, and a latch pin (**28**) selectively movable between a first position where the latch pin (**28**) does not contact the inner arm (**20**), and a second position wherein the latch pin (**28**) contacts the inner arm (**20**). A solenoid assembly (**500**) is energized while the rocker arm is in contact with the lift portion (**59**) of the cam. The solenoid assembly is direct-acting and overhead and is calibratable with respect to the rocker arm.



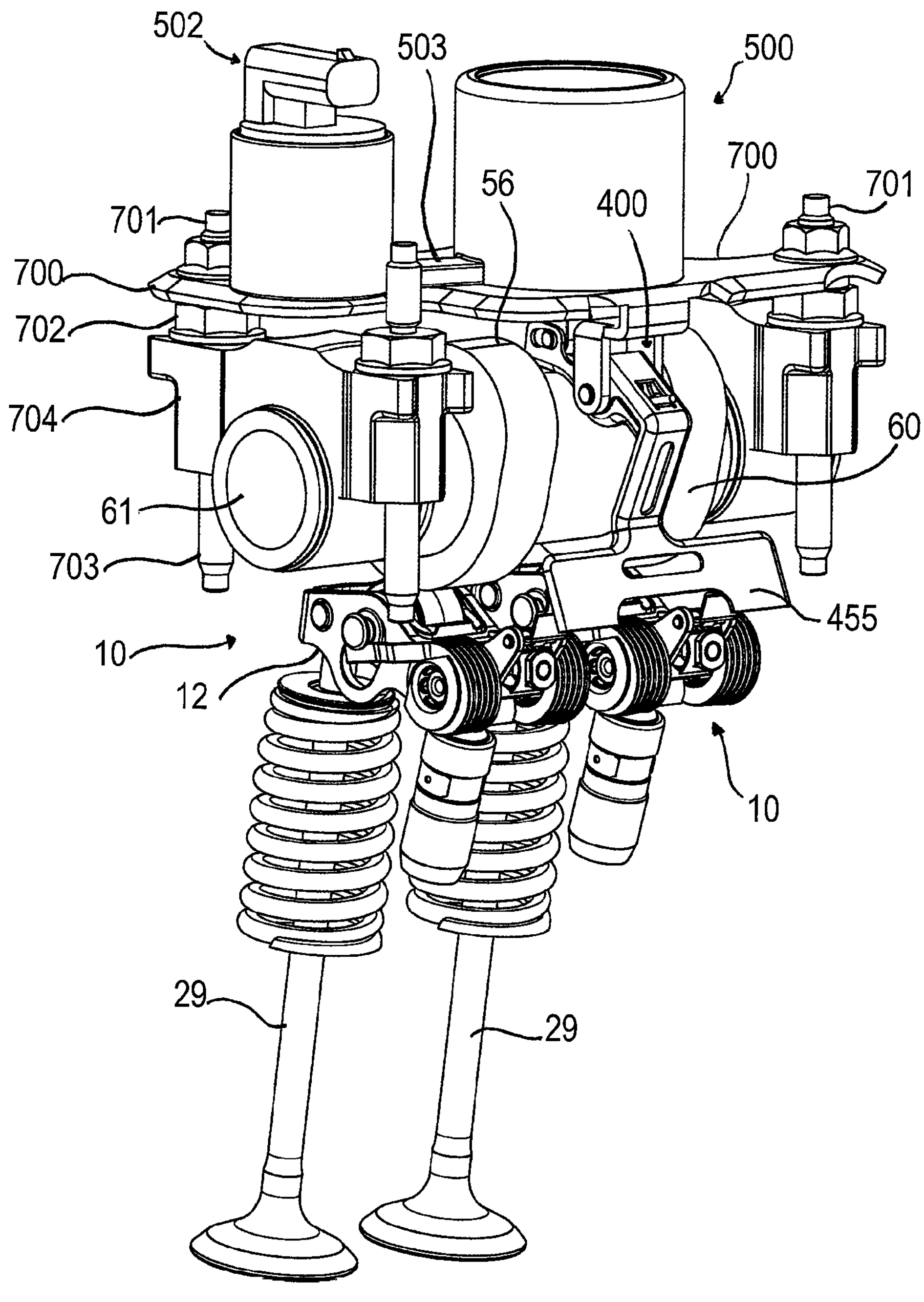

502
503
500
700
701
56
400
701
700
702
704
60
61
703
455
10
12
10
29
29

FIG. 1

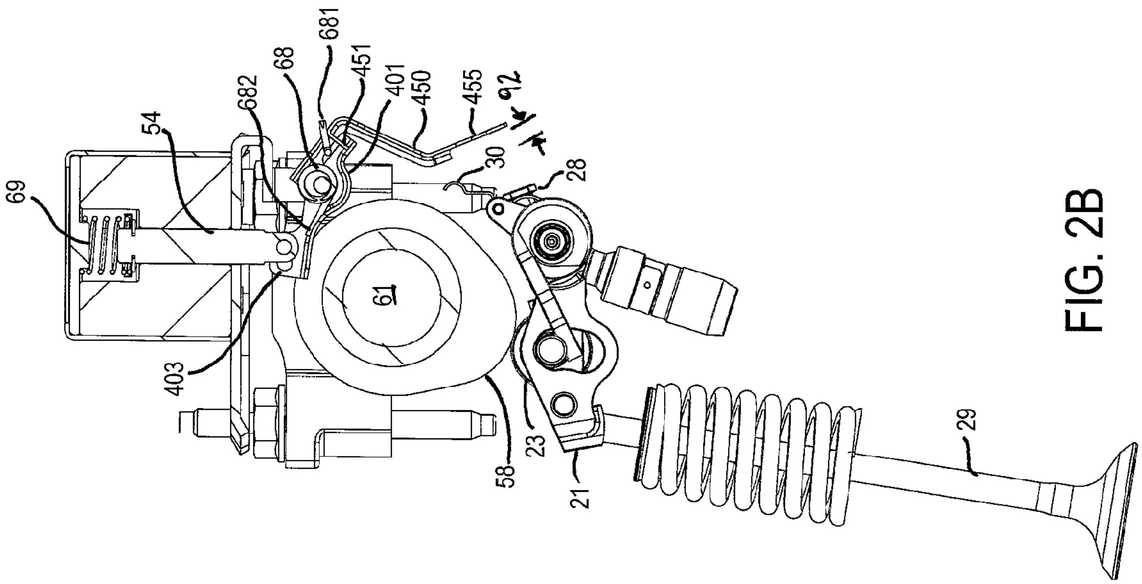

69
54
682
68
681
451
401
450
455
92
30
28
61
403
58
23
21
29

FIG. 2B

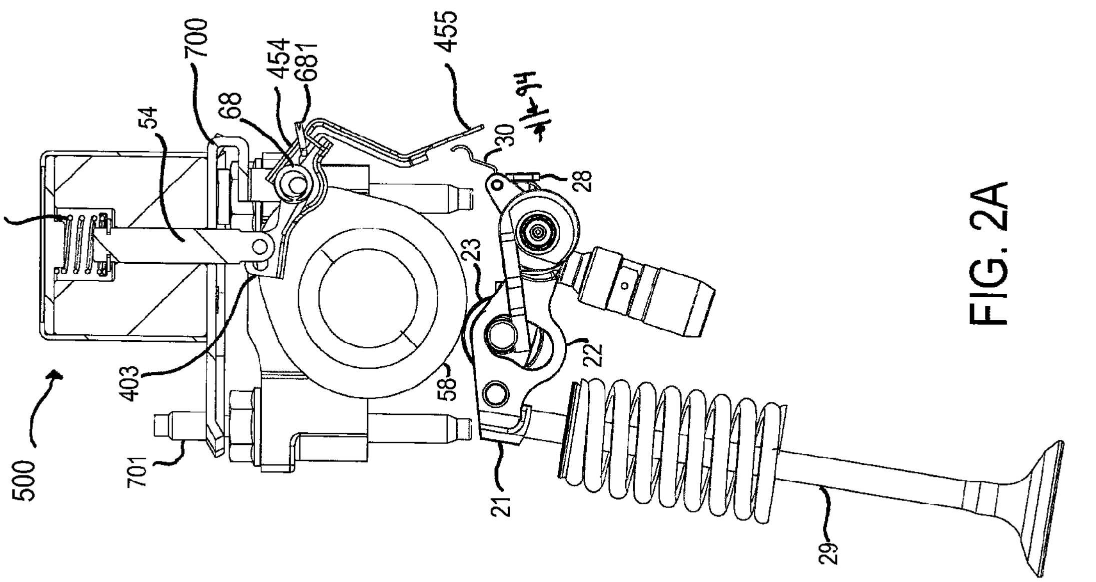

500
69
54
700
68
454
681
455
94
30
28
23
22
58
403
701
21
29

FIG. 2A

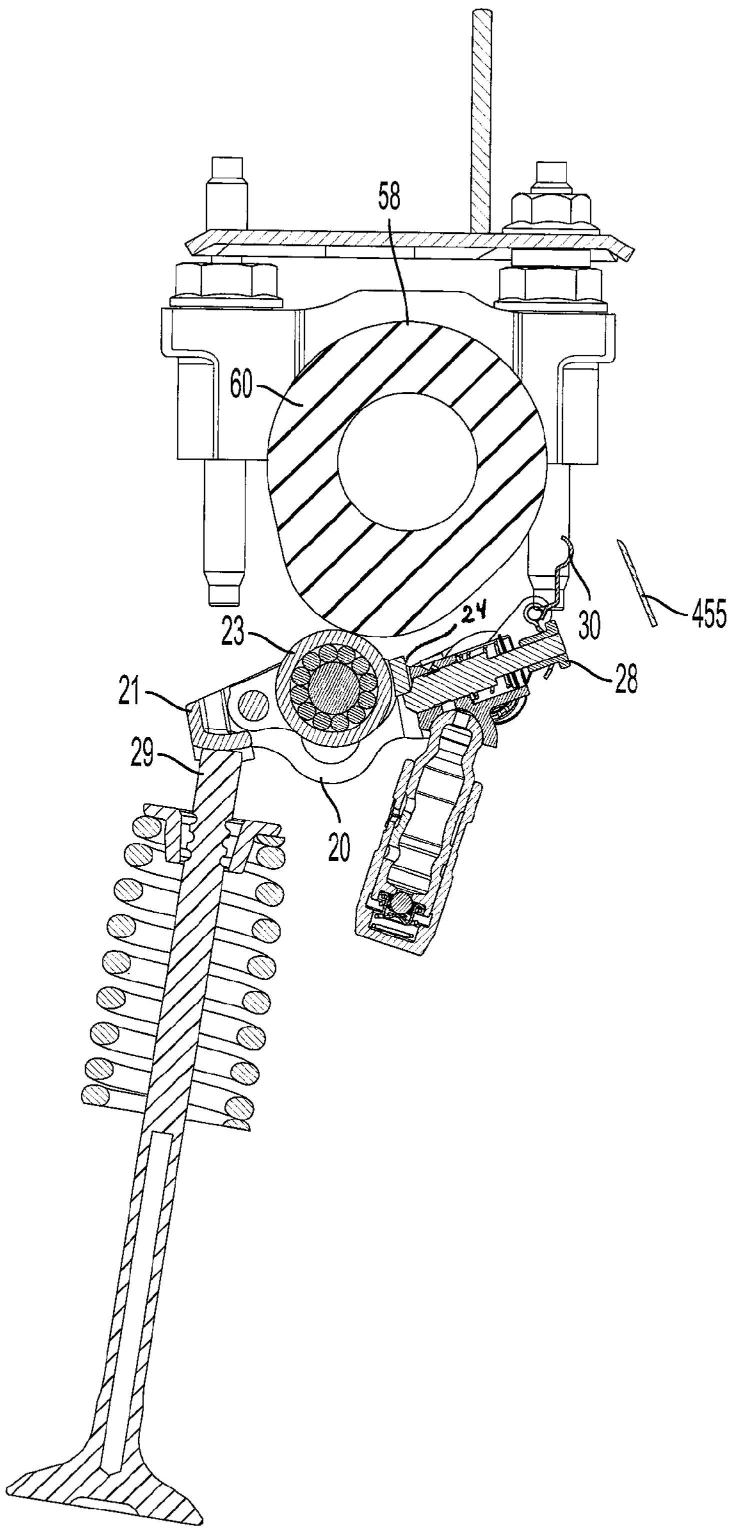


FIG. 2C

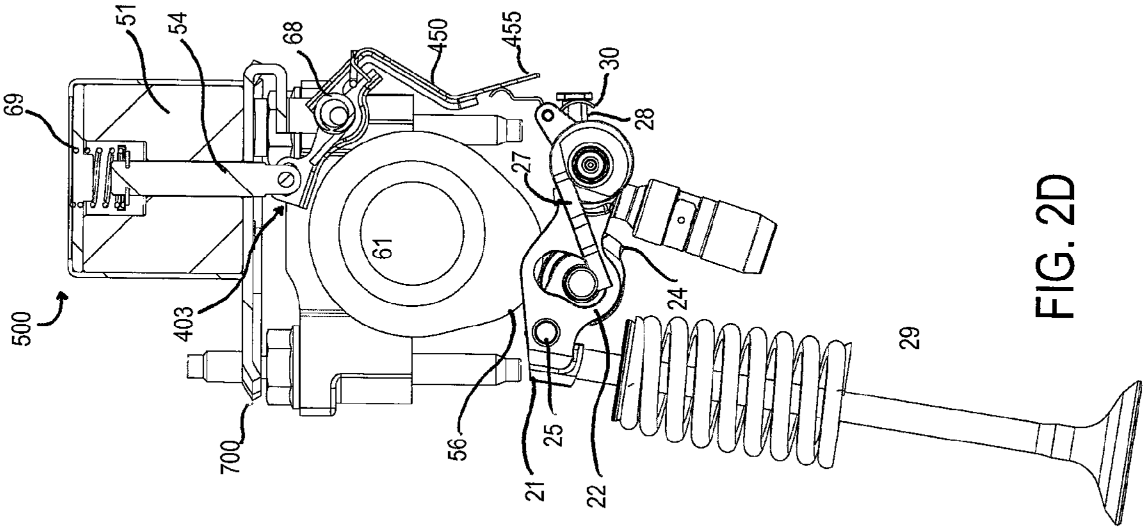

500
69
51
54
68
450
455
30
28
27
403
61
24
29
700
56
25
21
22

FIG. 2D

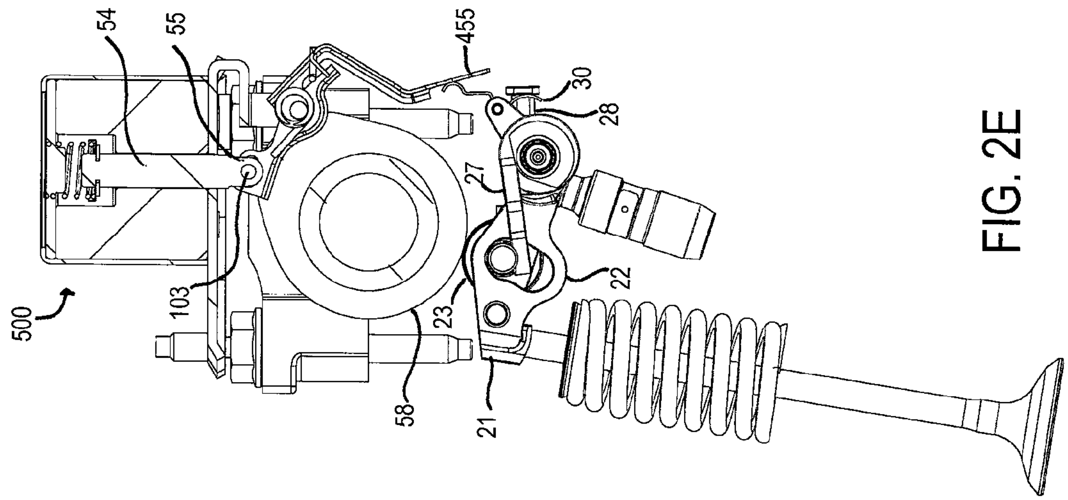

54
55
455
30
28
27
500
103
23
22
58
21

FIG. 2E

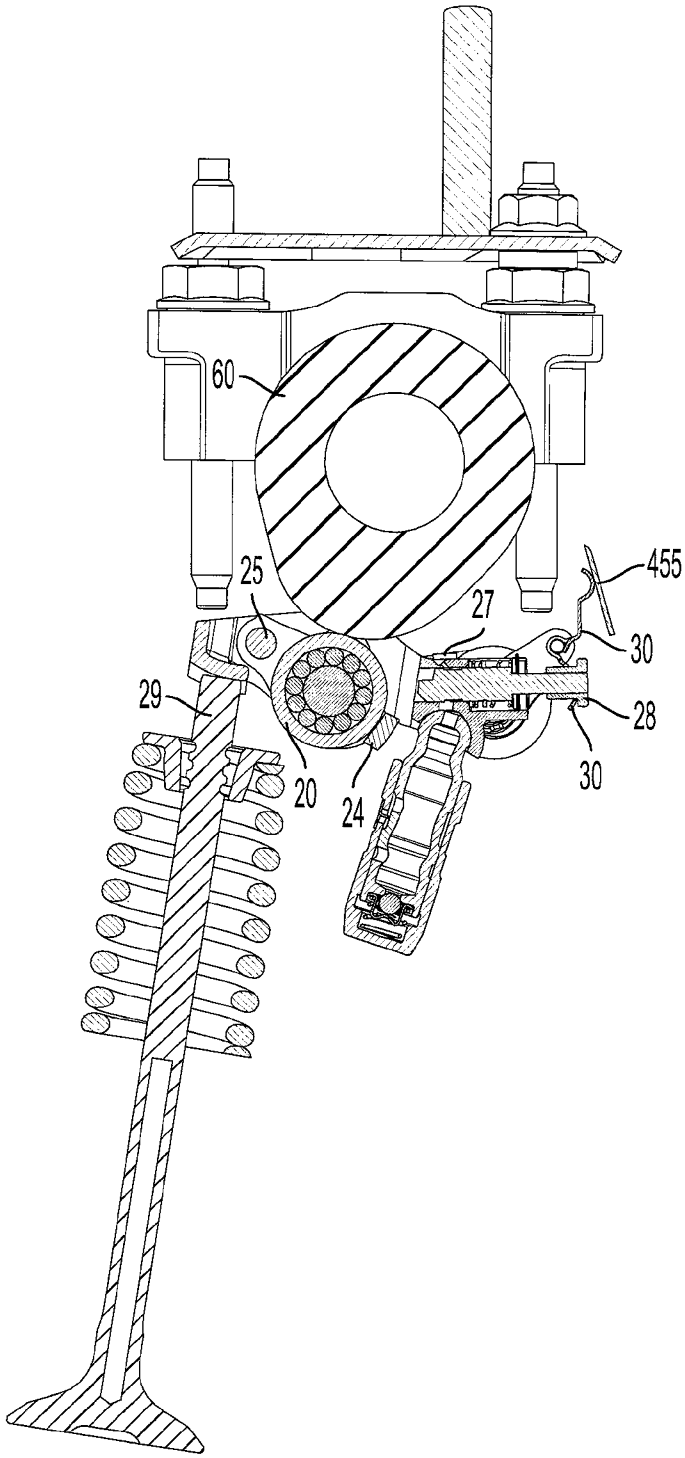


FIG. 2F

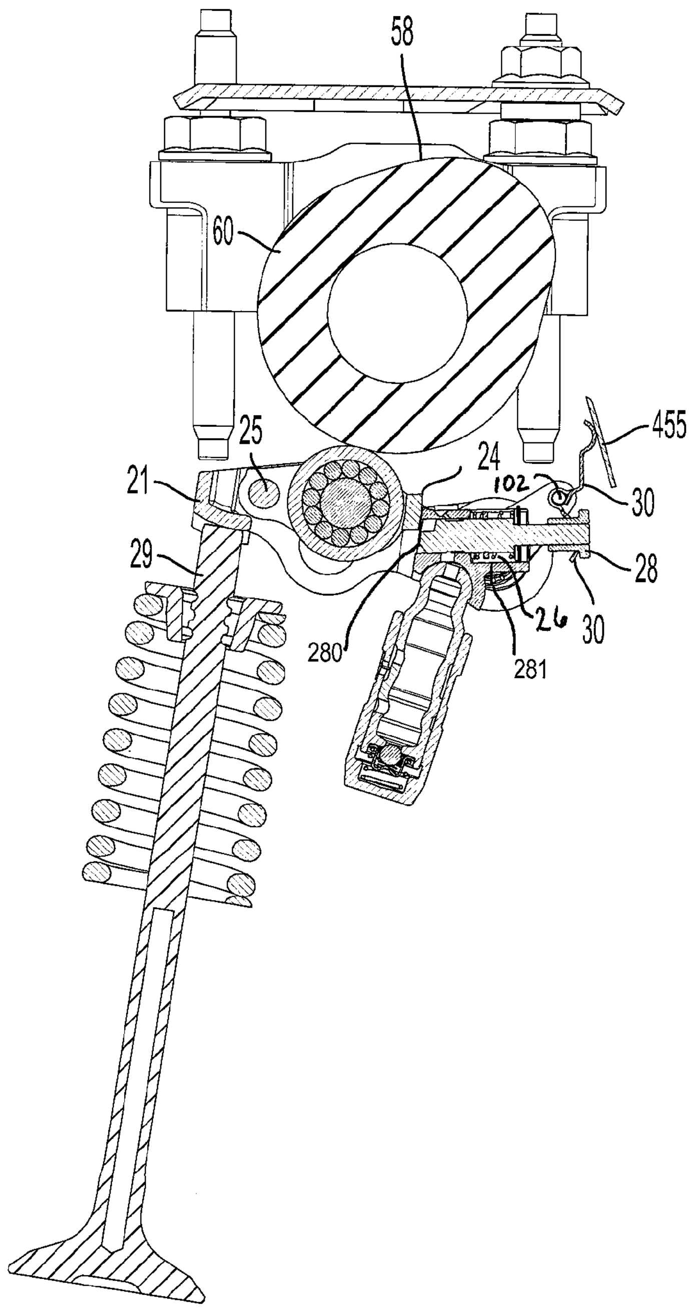


FIG. 2G

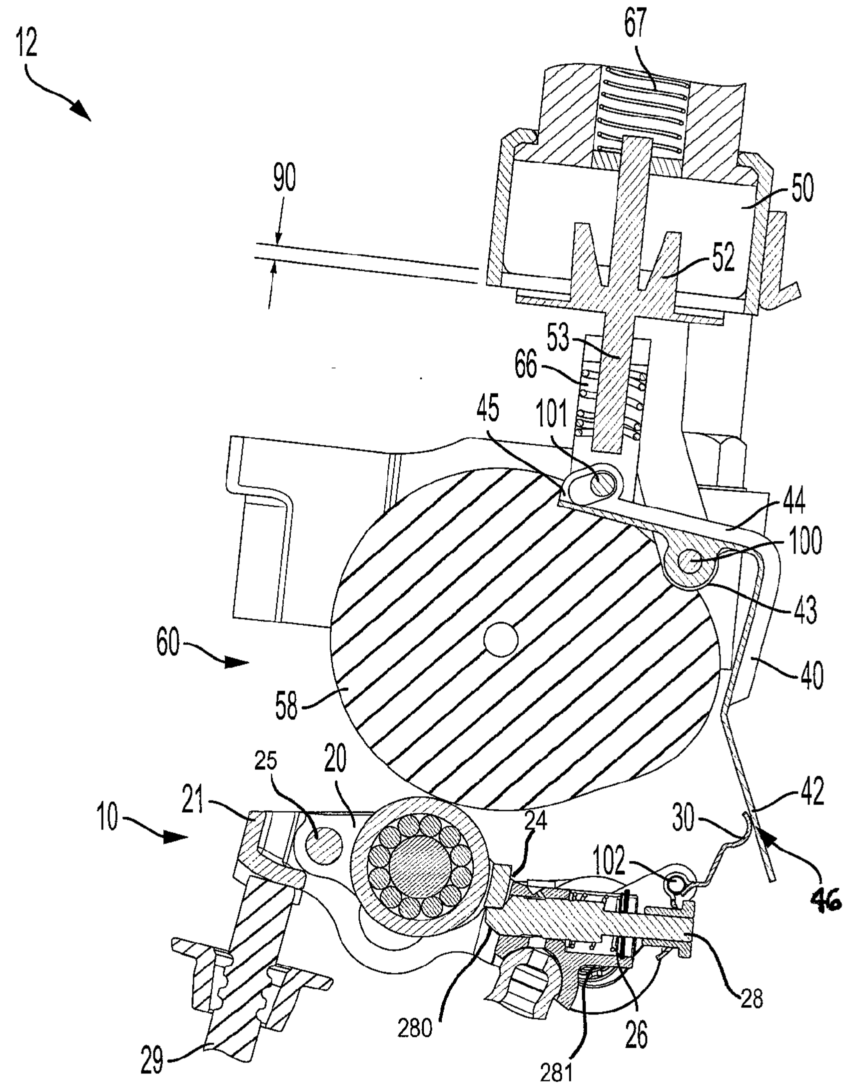


FIG. 3

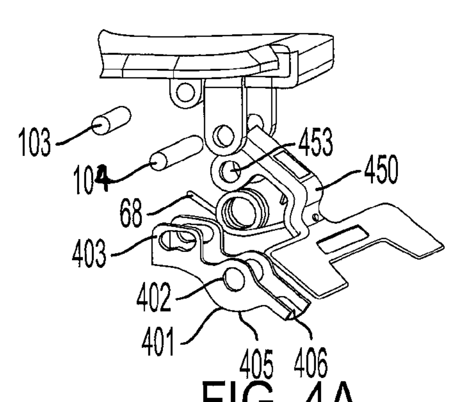


FIG. 4A

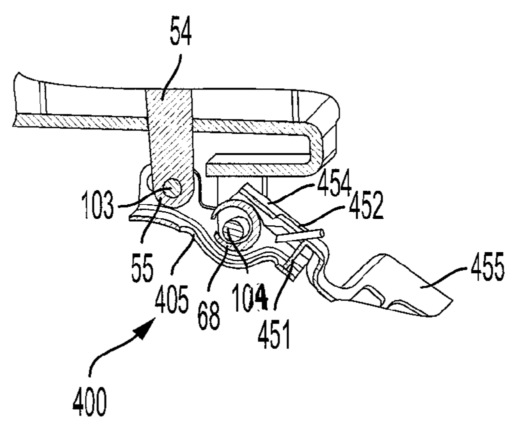


FIG. 4B

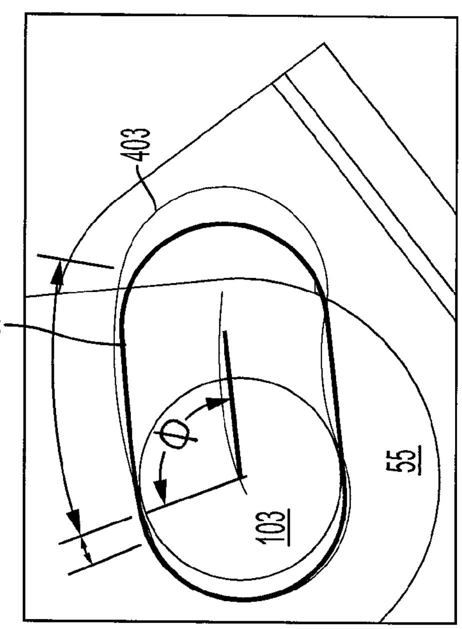

87
403
Φ
103
55

FIG. 5A

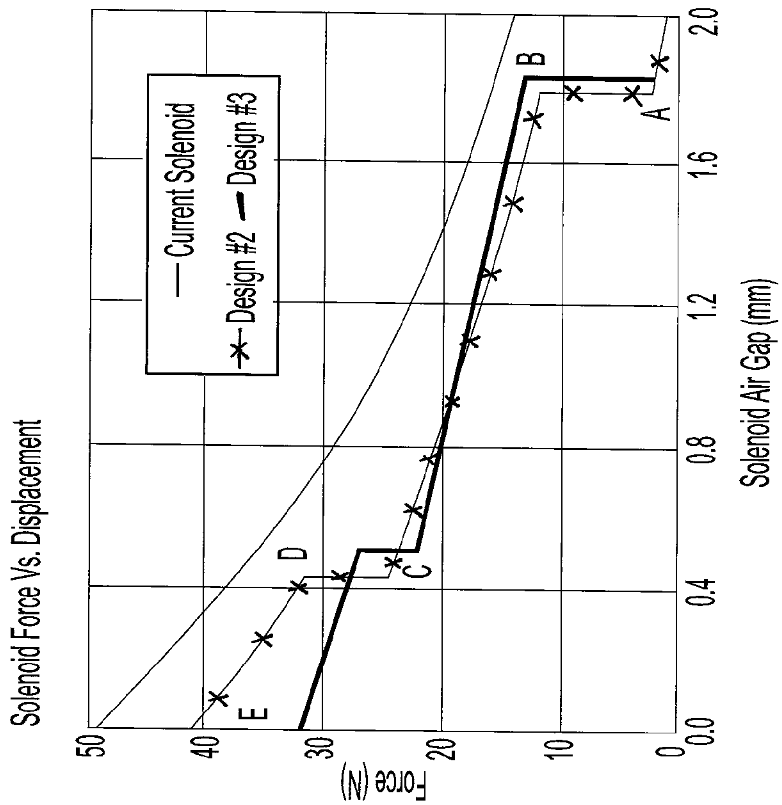

Solenoid Force Vs. Displacement
Current Solenoid
Design #2
Design #3
A
B
C
D
E
Force (N)
Solenoid Air Gap (mm)
0
10
20
30
40
50
0.0
0.4
0.8
1.2
1.6
2.0

FIG. 5B

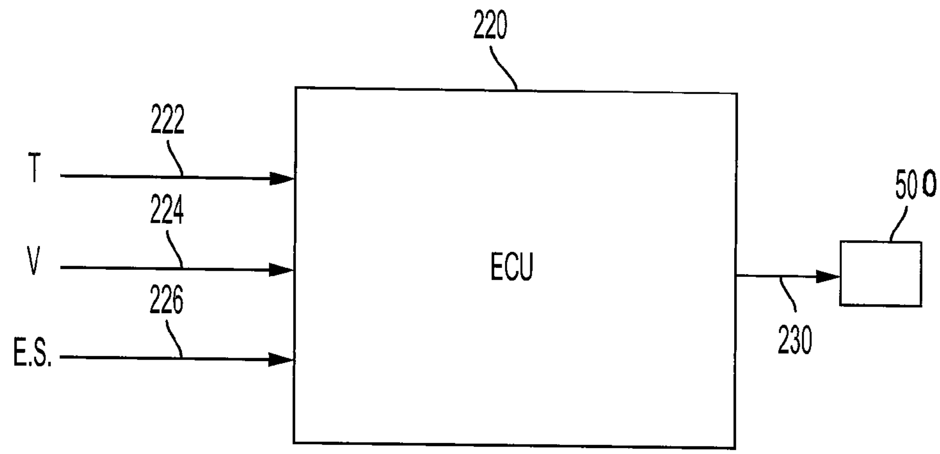

220
222
T
224
V
226
E.S.
ECU
500
230

FIG. 6

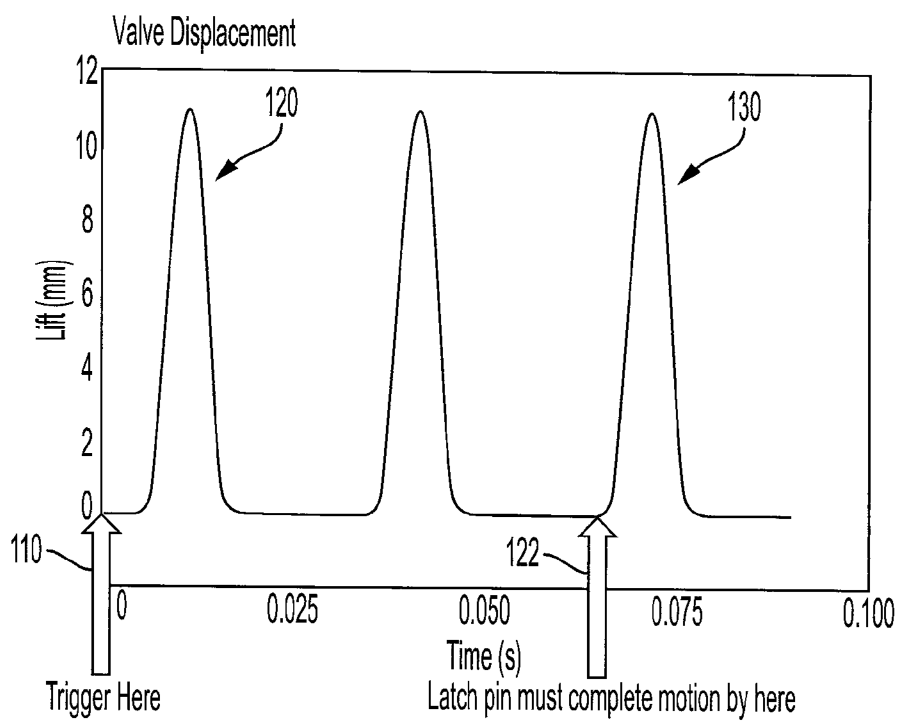

Valve Displacement
12
10
8
6
4
2
0
Lift (mm)
120
130
110
122
0
0.025
0.050
0.075
0.100
Time (s)
Trigger Here
Latch pin must complete motion by here

FIG. 7

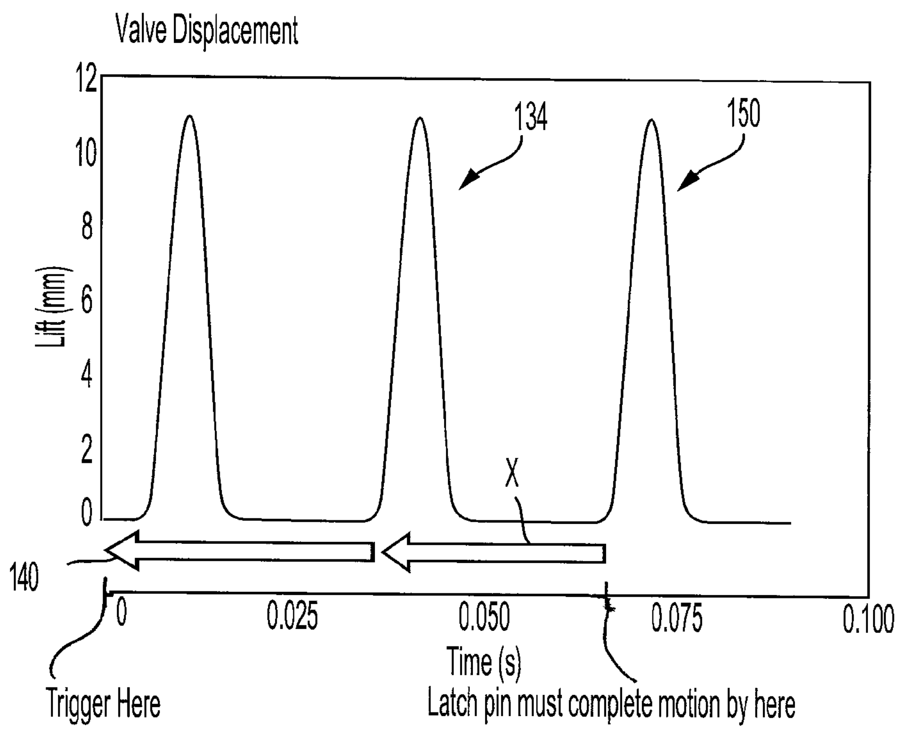

Valve Displacement
12
10
8
6
4
2
0
Lift (mm)
134
150
X
140
0
0.025
0.050
0.075
0.100
Time (s)
Trigger Here
Latch pin must complete motion by here

FIG. 8

DIRECT-ACTING SOLENOID HAVING VARIABLE TRIGGERING TIMING FOR ELECTRO-MECHANICAL VALVETRAIN AND ACTUATION LEVERS FOR SWITCHING ROCKER ARMS

FIELD

[0001] This application provides an overhead solenoid arrangement, an actuation lever arrangement, a switching rocker arm arrangement, and methods for their use including methods for minimizing the mechanical resistance at the solenoid, methods for commanding switching of the solenoid while the rocker arm is on lift, and methods for varying the triggering timing for the valvetrain.

BACKGROUND

[0002] A switching roller finger follower or rocker arm allows for control of valve actuation by alternating between two or more states. In some examples, the rocker arm can include multiple arms, such as an inner arm and an outer arm. In some circumstances, these arms can engage different cam lobes, such as low-lift lobes, high-lift lobes, and no-lift lobes. Mechanisms are required for switching rocker arm modes in a manner suited for operation of internal combustion engines.

[0003] The switching mechanisms must fit into a tight compartment and it is challenging to arrange the switching mechanisms according to all customer constraints. Particularly, it has been difficult to fit electrification equipment into the engine compartment.

[0004] The background description provided herein is for the purpose of generally presenting the context of the disclosure. Work of the presently named inventors, to the extent it is described in this background section, as well as aspects of the description that may not otherwise qualify as prior art at the time of filing, are neither expressly nor impliedly admitted as prior art against the present disclosure.

SUMMARY

[0005] In the context of cylinder deactivation actuation, the time "window" allowed for switching between activated and deactivate modes is dependent on engine speed. However, solenoid response time is independent of engine speed. If the solenoid were to be triggered at a constant point in the engine cycle, it would complete its motion at a different point in the engine cycle depending on speed. So, it is desired to vary the timing for the solenoid triggering so that the actual motion of the solenoid comports with the desired valve actuation.

[0006] The inventors have also discovered a timing for triggering the solenoid that ultimately permits reduction in the mass of the solenoid. Alternative compliance spring arrangements, alternative actuator assemblies, and various latches and rocker arms are compatible with the timing technique. The smaller solenoid is better suited to install directly over the rocker arm or arms on which it is acting. This fits the engine compartment footprint efficiently. And, the solenoid is direct-acting. Additional benefits can accumulate because the relationship among the solenoid, actuator assembly and rocker arm is calibratable. Gap settings and variances are tighter through alignment techniques.

[0007] Systems, methods, and control systems for a switching rocker arm assembly are disclosed. A switching rocker arm engages a valve, the switching rocker arm is movable by contact with a cam having a lift portion and a base circle. The switching rocker arm comprises an inner arm, an outer arm pivotably secured to the inner arm and having a latch bore, and a latch pin selectively movable between a first position where the latch pin does not contact the inner arm, and a second position wherein the latch pin contacts the inner arm. A solenoid assembly is energized while the rocker arm is in contact with the lift portion of the cam. The solenoid assembly is direct-acting and overhead and is calibratable with respect to the rocker arm. Actuating the solenoid as disclosed leads to the switching of the switchable rocker arm occurring on base circle such that the latch pin moves to the first position where the latch pin does not contact the inner arm

[0008] The switching rocker arm can comprise a latch pin and a latch lever extending from the latch pin. With the solenoid assembly overhead, new actuation levers have been developed. So, a switching rocker arm assembly can comprise an actuation lever that is selectively movable into contact with the latch lever, the latch lever configured to urge the latch pin into the second position when the actuation lever contacts the latch lever. The actuation lever can comprise a spring-loaded hinge, and energizing the solenoid while the rocker arm is in contact with the lift portion of the cam can result in the spring-loaded hinge being pre-loaded so that the actuation lever acts on the latch lever to urge the latch pin into the second position as the cam rotates from the lift portion to base circle.

[0009] The solenoid assembly can be an electromechanical solenoid and can comprise an armature biased by at least one compliance spring out of the solenoid assembly. The actuation lever extending between the solenoid assembly and the switching rocker arm can alternatively or additionally comprise a linkage between the armature and the actuation lever comprising a pin in a slot. The slot can be tailored to control actuation forces for moving the actuation lever and the latch pin. The slot can vary between an oblong "pill" shape and a curved shape such as a crescent.

[0010] When applying methods for switching the switchable rocker arm assembly, several alternatives are available. The methods can comprise processing engine speed data to select a timing of triggering for the solenoid assembly to energize, and adjusting the timing of triggering of the solenoid assembly as the engine speed data indicates a change in engine speed. The methods can comprise determining an operating temperature of the system; determining a voltage available to the solenoid in the system; determining a timing of triggering of the solenoid based on the determined temperature and voltage; and commanding the solenoid to trigger based on the determined timing. Control hardware and stored programming can enable the methods, and a storage device of the control hardware can further comprise a look-up table ("LUT") that corresponds to a given engine speed. Additional data such as temperature data can be collected and correlated to the LUT. The methods can vary the valve actuation timing for variable valve actuation techniques such as cylinder deactivation (CDA), internal exhaust gas recirculation (iEGR, reverse breathing, rebreathing), Negative Valve Overlap (NVO), early or late valve opening or closing techniques (EEVO, EIVO, EIVC, EEVC, LIVO, LEVO, LIVC, LEVC), engine braking (EB, CRB), among the many alternative variable lift events. So, the timing of triggering determined relative to a sequence of a first, a second and a third lift event, and wherein determining the timing comprises determining a preferred timing such that switching of a rocker arm associated with the solenoid concludes subsequent to the second lift event.

[0011] The rocker arm can include design features for variable lift as can the cam lobe associated with rocker arm. While a type II end pivot rocker arm is shown in the drawings, the assembly is not limited thereto. Other latched rocker arms can benefit from the overhead solenoid and actuation levers disclosed herein.

[0012] A control system can be implemented for operating an electro-mechanical valvetrain cylinder deactivation system. The control system can comprise a switching rocker arm having an inner arm, an outer arm and a latch pin selectively movable between a first position where the latch pin does not contact the inner arm, and a second position wherein the latch pin contacts the inner arm. A solenoid assembly connected to the control system can be triggered by the control system, resulting in selective actuation of the latch pin. A controller determines a timing of the triggering of the solenoid assembly based on a temperature and a voltage of the electro-mechanical valvetrain cylinder deactivation system.

[0013] Additional objects and advantages will be set forth in part in the description which follows, and in part will be obvious from the description, or may be learned by practice of the disclosure. The objects and advantages will also be realized and attained by means of the elements and combinations particularly pointed out in the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] FIG. **1** is a view of a rocker arm assembly comprising two switching rocker arms and one solenoid assembly; the actuation lever is adapted to actuate both switching rocker arms.

[0015] FIGS. **2**A-**2**G are section views of the rocker arm assembly showing the cam position relative to the rocker arm and actuation lever.

[0016] FIG. **3** is a cross-section view of an alternative rocker arm assembly comprising one switching rocker arm and one solenoid assembly; an alternative actuation lever is also shown.

[0017] FIGS. **4**A & **4**B show an exploded and assembled view of a spring-loaded hinge actuation lever and a linkage between the armature of the solenoid assembly and the actuation lever.

[0018] FIG. **5**A illustrates alternative slots in the linkage.

[0019] FIG. **5**B illustrates alternative actuation forces.

[0020] FIG. **6** is a schematic of a control system.

[0021] FIGS. **7** & **8** illustrate aspects of triggering versus valve lift.

DETAILED DESCRIPTION

[0022] Reference will now be made in detail to the examples which are illustrated in the accompanying drawings. Directional references such as "left" and "right" are for ease of reference to the figures and are not limiting of the invention in its practical installation. Overhead, however, can be construed as being atop the rocker arm assembly and as pertains the solenoid assembly, overhead can be construed as the armature arranged to actuate substantially transverse to the latch pin.

[0023] FIG. **1** shows an example of a switching rocker arm system comprising a solenoid assembly **500** connected to a mounting plate **700** (sometimes called a tower). A plug assembly **502** and line **503** can transfer electrical power and control system signals to the solenoid assembly **500**. In this example, two switching rocker arms **10** are actuated by one solenoid assembly **500**. Cam lobes **60** on a camshaft **61** can comprise one or more lift profiles and a base circle to impart any one of normal valve lift, no lift, or variable valve lift profiles. The tower can be mounted relative to the camshaft **61** or can comprise mountings for the camshaft **61**. The paddle **455** of swinging second actuation arm **450** is adapted to actuate latch pins in both switching rocker arms **10**.

[0024] The plate **700** can be aligned relative to the rocker arms **10** as by a calibratable alignment of mounting pins **701**, which improves the accuracy of the actuation of the valves **29**. For example, the mounting pins **701** can be aligned with the engine block or a carrier **704** comprising cam rail mount or both. A first alignment nut or bushing **702** can be welded or tightened to secure the tower with respect to the engine block and cam rail mount **704**. But, the mounting plate **700** can comprise holes surrounding top ends of mounting pins **701**. The holes can comprise an amount of "play" or variance such that the solenoid assembly **500** can be moved relative to the cam shaft **61** and switching rocker arms **10**. A gage or other calibration device can be used to set the location of the solenoid assembly **500** relative to the rocker arms **10**. Or, the actuation lever **400** can be the aligned relative to the rocker arms **10**, particularly relative to the latch pin **28** and latch lever **30**. Mounting pins **701** can be locked in place once the alignment technique is completed.

[0025] In an alternative, bushing **702** can be aligned via a gage or other alignment tool in an alignment slot of plate **700**. The bushing can be secured as by welding, tightening or the like to the carrier **704**, which carrier also serves as a base for the solenoid assembly when the carrier **704** is aligned with the cylinder head, which has the rocker arms **10** aligned thereto, the solenoid assembly **500** is aligned, the actuation arm is aligned, and the contact gap **92**, **94** is constrained. An alignment pin of the cylinder head can protrude through the bushing **702**. The carrier can comprise one or more alignment slots with corresponding aligned bushing **702**.

[0026] FIGS. **2**A-**2**G show section views of the rocker arm assembly showing the cam **60** position relative to the switching rocker arms **10** and actuation lever **400**. A nominal operation is shown in FIGS. **2**A-**2**C. The solenoid assembly **500** is not powered, so a spring **69** pushes the armature **54** out of the solenoid assembly **500**. The latch pin **28** has its latch end **280** engaged with the inner arm ledge **24**. The valves **29** can operate in the nominal mode as a default.

[0027] In FIG. **2**A, base circle **58** of the cam lobe **60** is acting on the roller **23** of the switching rocker arm **10**. Switching rocker arm **10** is movable by contact with cam **60** having a lift portion **59** and a base circle **58**. Switching rocker arm **10** engages a valve **29**. Valve **29** on valve end **21** is closed with respect to a corresponding engine cylinder. The switching rocker arm **10** comprises an inner arm **20** and an outer arm **12** pivotably secured to the inner arm **20** at pivot **25**. Inner arm can swing as shown in FIGS. **2**D & **2**F and a travel limit **22** in outer arm **12** can be reached by a pin extending from inner arm **20**. A lost motion spring **27** can bias the inner arm **20** towards the cam **60**. On latch end of switching rocker arm, a latch pin **28** can be biased in a latch bore. Latch pin **28** is selectively movable between a first position where the latch pin does not contact the inner arm ledge **24** of inner arm, and a second position wherein the latch pin **28** contacts the inner arm ledge **24**. A latch spring **26** can bias the latch pin **28** in the bore **281** towards the second position. FIGS. **2**A-**2**C comprise the latch pin **28** in the second position. FIGS. **2**D-**2**G comprise the latch pin **28** in the first position. The switching rocker arm **10** can comprise latch lever **30** extending from the latch pin **28**. Latch lever **30** can couple to an end of the latch pin **28** as by legs, a cleat, or other catch surrounding the end of the latch pin **28**, and the latch pin **28** can further comprise a divot, cap or other anchor for the legs, catch, or cleat.

[0028] The solenoid assembly **500** is direct-acting and overhead and is calibratable and alignable with respect to the switching rocker arm **10**. In FIGS. **2**A-**2**C, the coil **51** is not powered. With the solenoid assembly **500** overhead, new actuation levers have been developed. In a first alternative, actuation lever **400** is selectively movable into contact with the latch lever **30**. In FIGS. **2**A & **2**B, the nominal lift modes, the actuation lever **400** does not act on the latch lever **30**. So, a gap is present between the actuation lever **400** and the latch lever **30**.

[0029] In FIGS. **2**D-**2**G, the latch lever **30** is configured to urge the latch pin **28** into the first position when the actuation lever **400** contacts the latch lever **30**. The actuation lever **400** can comprise a spring-loaded hinge, and energizing the solenoid assembly coil **51** while the rocker arm **10** is in contact with the lift portion **56** of the cam **60** can result in the spring-loaded hinge being pre-loaded so that the actuation lever **400** acts on the latch lever **30** to urge the latch pin **28** into the first position as the cam **60** rotates from the lift portion **56** to base circle **58**.

[0030] The solenoid assembly **500** can be energized while the rocker arm **10** is in contact with the lift portion **56** of the cam **60**. Actuating the solenoid as disclosed leads to the switching of the switchable rocker arm **10** occurring on base circle **58** such that the latch pin **28** moves to the first position where the latch pin does not contact the inner arm **20**. Preloading the actuation lever **400** while the valve **29** is on lift and the lift portion **56** is in contact with the roller **23** yields benefits in downsizing the solenoid. The spring **68** in the spring-hinge provides actuation force to move the latch pin **28** in a complementary manner to the forces from the solenoid assembly **500**. With the additive force from the compliance spring **68**, the coil **51** of the solenoid can be smaller and less powerful. This leads to energy, heat, and space savings. With the valve on lift, the force on the latch pin **28** is initially too great to disengage the latch end **280** from the inner arm ledge **24**, but as the cam **60** rotates to base circle **56** from the lift portion **58**, the force on the roller **23** and inner arm **20** reduces and the latch pin **28** can slide in the latch bore **281** as the paddle **455** of actuation lever **400** acts on latch lever **30** to pivot the latch lever **30**. A pivot pin **102** or stake can be used to mount latch lever **30** to the rocker arm **10** in a pivoting relationship.

[0031] The solenoid assembly can be an electromechanical solenoid and can comprise an armature **54** biased by at least one compliance spring **67**, **65**, **68**, **69** out of the solenoid assembly **500**. The actuation lever **40**, **400** extending between the solenoid assembly **500** and the switching rocker arm **10** can alternatively or additionally comprise a linkage between the armature **53**, **54** and the actuation lever **40**, **400** comprising a pin **101**, **103** in a slot **45**, **87**, **403**, **403**. The slot can be tailored to control actuation forces for moving the actuation lever **40**, **400** and the latch pin **28**. The slot can vary between an oblong "pill" shape and a curved shape such as a crescent, as shown in FIG. **5**A.

[0032] The compliance springs **65**, **67**, **68**, **69** can perform several functions, including biasing the armature out of the solenoid to ensure normal operation is always available as a default mode; reduction of assembly stack up as by creating a nominal contact gap between he actuation lever **40**, **400** and the latch pin assembly; assisting with setting a precise contact gap as by a feeler gauge; setting the triggering timing as by providing a consistent gap for the extent that the armature extends from the solenoid assembly; storing energy used for pulling the latch pin **28** out of the rocker arm **10**.

[0033] Actuation lever **400** can comprise a first actuation arm **401** and a second actuation arm **450**. First actuation arm **401** can comprise the slot **403**, **87** for interfacing the linkage end **55** of the armature and linkage pin **103**. The second actuation arm **450** is designed to move as a spring-loaded hinge. So, a second linkage pin **104** can join a pivot point **402** of the first actuation arm **401** with a pivot point **453** of the second actuation arm **450** with the compliance spring **68** coiled or otherwise seated in cup **405**. When the compliance spring **68** is a torsion spring, it can be coiled around the second linkage pin **104**. Other springs like leaf springs can be appropriately mounted. Compliance spring **68** has a spring end **682** pressing against first actuation arm **401** and a spring end **681** pressing against second actuation arm **450**; compliance spring **68** can maintain minimum contacts therebetween. Spring end **681** can pass through a window **452** in second actuation arm **450**. A torsional spring or leaf spring or the like can be used and arranged to bias the second actuation arm **450**. A pressure point formed at stake **451** and seat **406** yields a hinge location. Linkage end **454** of second actuation arm **450** is positioned relative to pivot point **453** and stake **451** in seat **406**. Paddle end **455** of second actuation arm **450** swings as the solenoid assembly **500** draws the armature **54** or releases the armature. When there is a gap **92** or **94**, the paddle end **455** receives no pressure other than the spring pressure from spring end **682**. But when the paddle end **455** contacts the latch lever **30**, the second actuation arm **450** can hinge and put pressure on the compliance spring **68**, which stores energy in the compliance spring **68** for moving the latch pin **28**. As disclosed, one technique for moving the latch pin is to trigger the solenoid when the valve is on lift, which yields a situation where the latch pin **28** is receiving too much force to move. So if the paddle pushes against the latch lever **30**, it causes a hinging force and loading of the compliance spring **68**. The force stored in the spring can be released to act on the latch pin **28** when the valve comes off lift as detailed herein.

[0034] While the actuation lever **400** comprises two actuation arms and two pivot points (linkage and hinge), the actuation lever **40** is a contiguous piece that comprises two pivot points. The actuation lever **40** comprises a controlled slot **45** that can be shaped as oblong **87** or crescent **403** as in FIG. **5**A among variations of the examples to impact the moment of the actuation lever **40** as the solenoid assembly **500** moved the armature **52**. Extension **53** of the armature **52** can comprise a hook, a post or the like to constitute pin **101**, or a pin in a port can constitute pin **101**. A sheath, plug or other fixture can set the compliance spring **66** relative to the extension **53**. A second pivot point formed by material **43** around at pin **100** can trajectory the actuation arm **40**. First arm portion **44** spans between first and second pivot points. Second arm portion **42** extends from the second pivot point to contact latch lever **30** or form gaps like gaps **92**, **94**. A paddle **46** can also be formed at the extrema of second arm portion **42** so that more than one switching rocker arm **10** can be actuated by a single solenoid assembly **500**. Or, the paddle **46** can be limited to act on only one rocker arm in a one-to-one relationship.

[0035] With reference to FIG. **3**, an exemplary switching rocker arm constructed in accordance to one example of the present disclosure is shown and generally identified at reference **10**. The switching rocker arm **10** is shown as part of an electro-mechanical variable valve actuation valvetrain system **12** such as a cylinder deactivation system. The switching rocker arm **10** has an inner arm **20** and an outer arm **22**. A latch **28** is movable between an engaged position (FIG. **3**) and a retracted position (similar to FIGS. **2**F & **2**G). A spring **26** normally biases the latch **28** into the latched position. The rocker arm **10** is switchable between a high-lift mode and a low-lift mode. In the high-lift mode, the outer arm **12** is latched to the inner arm **20**. In a low-lift mode, the latch **28** is urged along a latch bore **281** in a direction rightward out of engagement with the inner arm **22**. Movement of the rocker arm **10** causes translation of a valve **29**.

[0036] A latch pin lever **30** extends from the latch **28** and is arranged to be engaged by an actuation lever **40**. A solenoid coil **50** energizes causing an armature **52** to move to close a gap **90**. That is, the armature **52** is drawn into the solenoid assembly **500** when the coil **50** is energized, which lifts the actuation lever **40** and cants the actuation lever to press the paddle **42** into contact with the latch lever **30**. As will become appreciated from the following discussion, the solenoid coil **50** is energized while the valve **29** is on lift (corresponding to cam lobe or lift portion **56** on cam **60**). By switching on valve lift (rather than on the base circle **58** of the cam **60**), mechanical resistance on the solenoid assembly is minimized. The compliance springs **67**, **66** and latch spring **26** are reducing the available force provided by the solenoid assembly, but the actuation lever **40** is designed to increase the available force. The solenoid coil **50** has the highest force when the motion of the armature **52** is complete (such as **50**N for example) as compared to **15**N when the solenoid coil **50** is first energized.

[0037] Turning now to FIG. **5**B, additional features will be described. In area A, the initial spring force pulling the solenoid down is present when the solenoid air gap **90** is largest. To begin closing the gap **90**, the force from the solenoid assembly is needed. The solenoid coil **50** is initially energized in area B. As the cam **60** rotates from lift portion **56** in contact with roller **23** to base circle **58** in contact with roller **23**, the latch pin **28** travels and forces reach area C. Compliance spring forces then contribute to close the latch **28** (move latch **28** to the second position from the first position) and forces are in area D. Area E represents force needed to reset the armature. The current solenoid line is directed to the maximum force that the solenoid coil **50** can provide, and it can be seen that the latch motion can be achieved within the limitations of the solenoid coil **50**. The system is reliable. The bold line versus the x-dashed line illustrate tradeoffs between linkage designs of FIG. **5**A. Having play, or the ability of linkage pin **103** to move in slot **45**, **403** of the actuation lever **40**, **400** adjusts the forces needed to move the latch pin **28**. The slot **45**, **403** controls the moment of the first arm **401** of the actuation lever **400** and the moment of arm **44** of actuation lever **40** as the arms pivot when the solenoid actuates. An oblong or pill shaped slot **87** gives linear play to the linkage pin **103** while a curved slot, such as crescent shaped slot **403**, gives non-linear play to the linkage pin. Controlling the slot **45**, **403** can help reduce stackup and control the gap between the actuation lever **40**, **400** and the latch lever **30**. Linkage pin **53** can be mounted in linkage end **55** of armature **52**, **54**. An armature extension **53** can protrude from the armature **52** to adjust the forces to linkage.

[0038] Returning now to FIGS. **2**A-**2**C, the rocker arm **10** is in lift mode. As the camshaft rotates and the solenoid coil **50** is not energized there is a gap **90** at the armature **52**. On base circle, a gap **94** also exists between the actuation lever **40** and the latch lever **30**. Because there is no contact, nothing is moving the latch pin **28**. When on lift (lobe **56** of the cam **60** is engaging the rocker arm roller **23**), a gap **92** exists between the actuation lever **40** and latch lever **30**. The gap **92** is bigger than the gap **94**. According to the present disclosure, this is the time the solenoid coil **50**, **51** is energized. In this regard, all of the solenoid/armature motion is completed while this large gap **92** exists. No resistance exists at the actuation lever **40** due to the gap **92**.

[0039] The latch **28** is moved to the retracted position such as to transition from lift to cylinder deactivation. Turning to FIGS. **2**E & **2**G, on base circle following the triggering of the solenoid assembly **500**, no gap exists between the actuation lever **40** and the latch lever **30**. The solenoid coil **50** is energized and the armature gap **90** is 0. As the armature **52** is moving up, the actuation lever **40** is moving (pivoting around pin **100**) toward the cam **60**. The actuation lever **40**, **400** rotates clockwise to contact with the latch lever **30** and pull the latch pin **28** into the latch bore **281** and out of contact with the inner arm ledge **24**. As the cam rotates to the lift portion **56**, lost motion can be achieved (FIGS. **2**D & **2**F). When the desired extent of lost motion has been achieved, the power to the solenoid coil **50**, **51** can be discontinued. Then, when the cam **60** returns again to base circle **58** after de-energizing the solenoid assembly, there is no actuation lever **40**, **400** forcing the latch lever **30** to rotate counterclockwise around a pin **102** to pull the latch **28** out of engagement with the inner arm **20**. The latch spring **26** is biased in the latch bore **281** to push the latch pin **28** to the second position away from the first position to project the latch end **280** to catch under the inner arm edge **24**. The lost motion spring **27** can bias the inner arm **20** so that the inner arm edge **24** is above the latch end **280** when base circle **58** is near the roller **23**. The present disclosure minimizes the mechanical resistance to latch pin motion such that the solenoid assembly **500** has minimal force to overcome. This advantage, according to the present disclosure, the solenoid coil **50**, **51** is energized when there is a maximum gap between the latch pin lever **30** and the actuation lever **40** (gap **92**).

[0040] The instant disclosure further provides a method for triggering the solenoid coil **50**, **51** in an electro-mechanical cylinder deactivation valvetrain system or other variable valve actuation valvetrain at a variable time within the engine cycle as a function of temperature, voltage, and engine speed. The method maximizes the available force in the solenoid assembly **500** and allows for switching in a consistent manner regardless of solenoid response time. In general, the force available in an electro-mechanical solenoid depends on temperature and voltage. This has a significant effect on both the solenoid's ability to successfully perform the intended function as well as the response time it takes to complete that function.

[0041] Since the force available in the solenoid assembly **500** varies, there are certain combinations of temperature and voltage that require the solenoid motion to occur while the valve **29** is "on lift" because the rocker arm **10** moves out of the way at this point in the cycle, allowing the actuation mechanism **40**, **400** to move with very little mechanical resistance. Such cases also require early pre-triggering of the solenoid **50** to begin building force before the valve **29** goes on lift in order to successfully complete its motion. However, for other combinations of temperature and voltage where the available force is significantly higher, triggering this early may result in unintended movement or partial disengagement of the rocker arm latch **24**, which could result in mis-shifting or critical shifting between cylinder activated and deactivated modes. In this regard, the resistance in the solenoid assembly **500** changes as a function of temperature, and as a function of changes of voltage (e.g., battery in the vehicle). As the resistance varies, the amount of force the solenoid assembly is able to generate also varies. As a result, the timing of solenoid triggering is a function of temperature and voltage. Furthermore, engine speed will impact proper timing of the solenoid triggering.

[0042] As will become appreciated herein, the present teachings provide methods for triggering the solenoid coil **50**, **51** at a variable point in the engine cycle such that it completes its motion at the appropriate time. The triggering timing is determined by way of analytical simulations (and physical testing) of the actuation system. The response time of the solenoid assembly **500** at various operating points is predicted. Further, the methods determine whether switching "on lift" would be required to successfully complete actuation. A series of maps of triggering timings are generated. The maps can be further adjusted as a function of engine speed to match up time with crank angle position.

[0043] Plots can be created and correlated to lookup tables to algorithmically correlate solenoid force versus temperature and voltage. Such can be correlated to the size of the solenoid air gap. And discrepancy between minimum and maximum force and air gap sized can be accounted for in the control system. Force changes to close various sized gaps can be programmed in the control system with corresponding methods for implementations so that as temperature and voltage change, the air gap can be closed while the valve is on lift.

[0044] Trigger timings can be established. FIG. **7** illustrates a constant trigger or on-time WA strategy. The solenoid assembly **500** is triggered at time **110** just before a first lift event **120**. At time **122**, the latch pin **24** needs to complete its motion, which is just before the third lift event **130**. It is possible to implement algorithms to trigger the solenoid at the same place in the valve lift cycle when the variable valve actuation technique is desired so that when the solenoid assembly is triggered at location **110** of the valve lift profile, just before lift event **120** caused by lift profile **56**, the latch pin **28** can complete its motion of unlatching and re-latching by the location **122** before third lift event **130**. When the engine speed varies, the timings for the valve lift events **120**, **130** will change (in seconds) and so the triggering timing will correspondingly adjust. In this WA strategy, the control system algorithmically adjusts the trigger timing for engine speed (and also for temperature and voltage) so that triggering occurs relative to the valve lift in a consistent manner.

[0045] However, as discussed above, it is possible to have variability in the WA techniques. By triggering the solenoid assembly **500** at different timings, different valve lift techniques can be achieved. For example, at first engine speed, an early exhaust valve opening can be implemented and at a second engine speed, an earlier or later exhaust valve opening can be implemented relative to the first early exhaust valve opening. So, the triggering timing can be thought of as a range **140**, as shown in FIG. **8**. Then, the latch pin motion can also occur in a range X.

[0046] By mapping latch pin motion versus time at various voltage/temperature combinations, the triggering timing can be established. Switching the rocker arm **10** ideally occurs before the second lift event **134** of FIG. **8** or after the second lift event **134**. If switching happens during the second lift event **134**, there is a risk of mis-shift or critical shift. Such unfavorable conditions can occur when the latch pin **28** is half way in or half way out, or generally not all the way extended or not all the way retracted.

[0047] Mapping valve displacement lift versus time can also be mapped to establish triggering timing. A trigger window **140** (range) for triggering the solenoid assembly **50**, **500** can be established. The trigger window **140** can yield latch pin motion at a time "x" before a third lift **150**. According to the present teachings, a plurality of variable trigger timing maps are determined and stored in an engine control unit for a plurality of engine speeds.

[0048] Variable trigger timing can result in instances where switching occurs during the second lift event **134**, or instances where the switching occurs subsequent to the second lift event **134**. No "in between" cases of significant partial un-latching events occur when the solenoid assembly is triggered on lift just prior to a cam cycle requiring the latch pin in the first position. As a result, the risk of mis-shifts and critical shifts are minimized.

[0049] The methods disclosed herein select the timing of the triggering of the solenoid assembly as a function of system response time such that triggering consistently occurs at an optimal time regardless of operating conditions.

[0050] A control system can be implemented for operating an electro-mechanical valvetrain system in a variable valve actuation technique such as cylinder deactivation, among others. The control system can comprise a switching rocker arm such as a triple roller rocker arm, a slider type rocker arm, a roller finger follower, among other rocker arms. As illustrated the rocker arm has at least an inner arm, an outer arm and a latch pin selectively movable between a first position where the latch pin does not contact the inner arm, and a second position wherein the latch pin contacts the inner arm. A solenoid assembly connected to the control system can be triggered by the control system, resulting in selective actuation of the latch pin. A controller such as ECU **220** determines a timing of the triggering of the solenoid assembly **500** based on a temperature T on line **222** and a voltage V on line **224** of the electro-mechanical WA valvetrain system. The Temperature T, Voltage V, Engine Speed ES can be measured by sensors or solved for. But, ECU **220**

collects necessary inputs on lines **222**, **224**, **226**. A processor in ECU **220** can process collected data algorithmically using stored programming.

[0051] The control system of FIG. **6** FIG. **6** can include the engine control unit (ECU) **220** that monitors temperature T and voltage V inputs **222** and **224** respectively. The ECU **220** determines an optimal timing for the triggering of the solenoid **500** and outputs a signal **230** indicative of when to trigger the solenoid assembly **500**. Again, the optimal timing of triggering of the solenoid **500** can vary based on temperature T and voltage V as described above. The ECU **220** commands the solenoid assembly **500** to trigger such that it will finish moving at the same time regardless of temperature T and voltage V. In some examples, the ECU **220** can also determine the optimal timing based also on an engine speed ES.

[0052] Other implementations will be apparent to those skilled in the art from consideration of the specification and practice of the examples disclosed herein.

1. A switching rocker arm assembly, comprising:
- a switching rocker arm configured to engage a valve, the switching rocker arm movable by contact with a cam having a lift portion and a base circle, the switching rocker arm comprising:
  - an inner arm;
  - an outer arm pivotably secured to the inner arm and having a latch bore; and
  - a latch pin selectively movable between a first position where the latch pin does not contact the inner arm, and a second position wherein the latch pin contacts the inner arm; and
- a solenoid assembly configured to energize while the rocker arm is in contact with the lift portion of the cam.

2. The switching rocker arm assembly of claim **1**, further comprising a latch lever extending from the latch pin

3. The switching rocker arm assembly of claim **2**, further comprising an actuation lever that is selectively movable into contact with the latch lever, the latch lever configured to urge the latch pin into the second position when the actuation lever contacts the latch lever.

4. The switching rocker arm assembly of claim **3**, wherein the actuation lever comprises a spring-loaded hinge, and wherein energizing the solenoid while the rocker arm is in contact with the lift portion of the cam results in the spring-loaded hinge being pre-loaded so that the actuation lever acts on the latch lever to urge the latch pin into the second position as the cam rotates from the lift portion to base circle.

5. The switching rocker arm assembly of claim **1**, wherein the solenoid assembly is an electromechanical solenoid.

6. The switching rocker arm assembly of claim **5**, wherein the solenoid assembly comprises an armature biased by at least one compliance spring out of the solenoid assembly.

7. The switching rocker arm assembly of claim **6**, comprising an actuation lever extending between the solenoid assembly and the switching rocker arm, wherein a linkage between the armature and the actuation lever comprises a pin in a slot, and wherein the slot controls actuation forces for moving the actuation lever and the latch pin.

8. The switching rocker arm assembly of claim **7**, wherein the slot is a crescent shape.

9. A method for switching a switchable rocker arm assembly, the switchable rocker arm assembly comprising:
- a switching rocker arm configured to engage a valve, the switching rocker arm movable by contact with a cam having a lift portion and a base circle, the switching rocker arm comprising:
  - an inner arm;
  - an outer arm pivotably secured to the inner arm and having a latch bore; and
  - a latch pin selectively movable between a first position where the latch pin does not contact the inner arm, and a second position wherein the latch pin contacts the inner arm; and
- the method comprising energizing a solenoid assembly while the rocker arm is in contact with the lift portion of the cam.

10. The method of claim **9**, further comprising processing engine speed data to select a timing of triggering for the solenoid assembly to energize, and adjusting the timing of triggering of the solenoid assembly as the engine speed data indicates a change in engine speed.

11. The method of claim **9**, further comprising
- determining an operating temperature of the system;
- determining a voltage available to the solenoid in the system;
- determining a timing of triggering of the solenoid based on the determined temperature and voltage; and
- commanding the solenoid to trigger based on the determined timing.

12. The method of claim **10** wherein determining the timing comprises determining a preferred timing of triggering based on a look-up table that corresponds to a given engine speed.

13. The method of claim **10** wherein timing of triggering is determined relative to a sequence of a first, a second and a third lift event, and wherein determining the timing comprises determining a preferred timing such that switching of a rocker arm associated with the solenoid concludes subsequent to the second lift event.

14. The method of claim **9** wherein the switching of the switchable rocker arm occurs on base circle such that the latch pin moves to the first position where the latch pin does not contact the inner arm.

15. A control system for operating an electro-mechanical valvetrain cylinder deactivation system, the control system comprising:
- a switching rocker arm having an inner arm, an outer arm and a latch pin selectively movable between a first position where the latch pin does not contact the inner arm, and a second position wherein the latch pin contacts the inner arm;
- a solenoid assembly configured to trigger to result in selective actuation of the latch pin; and
- a controller that determines a timing of the triggering of the solenoid assembly based on a temperature and a voltage of the electro-mechanical valvetrain cylinder deactivation system.

16. A switching rocker arm assembly, comprising:
- a switching rocker arm configured to engage a valve, the switching rocker arm comprising:
  - a latch bore; and
  - a latch pin selectively movable in the latch bore between an extended first position and a retracted second position; and

a solenoid assembly comprising an armature biased by at least one compliance spring out of the solenoid assembly.

17. The switching rocker arm assembly of claim **16**, comprising an actuation lever extending between the solenoid assembly and the switching rocker arm, wherein a linkage between the armature and the actuation lever comprises a pin in a slot, and wherein the slot controls actuation forces for moving the actuation lever and the latch pin.

18. The switching rocker arm assembly of claim **17**, wherein the slot is a crescent shape.

19. A switching rocker arm assembly, comprising:

a switching rocker arm configured to engage a valve, the switching rocker arm comprising:

a latch bore; and

a latch pin selectively movable in the latch bore between an extended first position and a retracted second position; and

a solenoid assembly configured to trigger to result in selective actuation of the latch pin, the solenoid assembly comprising an armature; and

an actuation lever extending between the solenoid assembly and the switching rocker arm, wherein a linkage between the armature and the actuation lever comprises a pin in a slot.

20. A switching rocker arm assembly, comprising:

a switching rocker arm configured to engage a valve, the switching rocker arm movable by contact with a cam having a lift portion and a base circle, the switching rocker arm comprising:

an inner arm;

an outer arm pivotably secured to the inner arm and having a latch bore; and

a latch pin selectively movable between a first position where the latch pin does not contact the inner arm, and a second position wherein the latch pin contacts the inner arm; and

a solenoid assembly configured to energized always and only while the rocker arm is in contact with the lift portion of the cam.

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