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(54) Title: VARIABLE VALVE ACTUATION APPARATUS, SYSTEM, AND METHOD

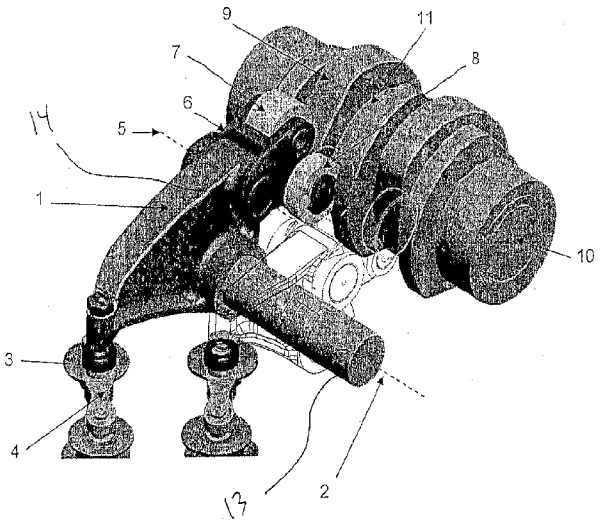


Fig. 1

(57) Abstract: A variable valve actuation system is disclosed. In one form a rocker is disclosed coupled with a valve stem at one end and a cam follower at the other end. The rocker is operable to rotate about a fixed axis. In one form the cam follower includes a set of lower rollers operable to follow one cam lobe and an upper roller operable to follow another cam lobe. A leaf spring can be used to couple the cam follower with the rocker. A cam shaft is disclosed having a nested configuration that includes an inner shaft, an intermediate tube, and an outer tube. Cam lobes can be fastened to the cam shaft in one form by fastening through each of the inner shaft, intermediate tube, and outer tube. In another form the cam lobes can be attached by at least two devices inserted from either side of the cam shaft and that are not inserted at least through the inner shaft.

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# VARIABLE VALVE ACTUATION APPARATUS, SYSTEM, AND METHOD

## CROSS REFERENCE TO RELATED APPLICATIONS

The present application claims the benefit of U.S. Provisional Patent Application 61/207,780, filed February 17, 2009, and is incorporated herein by reference.

## TECHNICAL FIELD

The present invention generally relates to internal combustion engines, and more particularly, but not exclusively, to variable valve actuation systems used in internal combustion engines such as diesel engines.

## BACKGROUND

Variable valve actuation (VVA) can improve engine performance by enabling different combustion strategies at different operating conditions, including Miller cycling, internal exhaust gas recirculation (iEGR), thermal management for aftertreatment control, and decompression for engine starting. Both intake and exhaust valves can be variably actuated to enable this combustion strategies, changing the valve's lift and/or duration. Known VVA systems with both intake and exhaust lift and duration flexibility can be grouped into 3 categories: full electric, hydraulic lost motion (partially mechanical), and fully mechanical. One problem with full-functioning, fully mechanical VVA systems is their large physical size. Package space around the valves is classically limited due to height and width constraints and is increasingly limited in

advanced engines due to increasing fuel system space claims. Accordingly, there remains a need for further contributions in this area of technology.

## SUMMARY

One embodiment of the present invention is a unique variable valve actuation device. Other embodiments include apparatuses, systems, devices, hardware, methods, and combinations for providing variable valve actuation. Further embodiments, forms, features, aspects, benefits, and advantages of the present application shall become apparent from the description and figures provided herewith.

## BRIEF DESCRIPTION OF THE FIGURES

Fig. 1 depicts one form of a cam shaft and rocker assembly.

Fig. 2 depicts one form of a cam shaft and rocker assembly.

Fig. 3 depicts one form of a cam shaft and rocker assembly.

Fig. 4 depicts one form of a cam shaft and rocker assembly.

Fig. 5 depicts one form of a cam shaft and rocker assembly.

Fig. 6 depicts one form of a cam shaft and rocker assembly.

Fig. 7 depicts one form of a cam shaft and rocker assembly.

Fig. 8 depicts one form of a cam shaft and rocker assembly.

Fig. 9 depicts one form of a rocker assembly.

Fig. 10 depicts one form of a rocker assembly.

Fig. 11 depicts one form of a rocker assembly.

Fig. 12 depicts one form of a cam shaft.

Fig. 13 depicts one form of a cam shaft.

## DETAILED DESCRIPTION OF THE ILLUSTRATIVE EMBODIMENTS

For the purposes of promoting an understanding of the principles of the invention, reference will now be made to the embodiments illustrated in the drawings and specific language will be used to describe the same. It will nevertheless be understood that no limitation of the scope of the invention is thereby intended. Any alterations and further modifications in the described embodiments, and any further applications of the principles of the invention as described herein are contemplated as would normally occur to one skilled in the art to which the invention relates.

In one non-limiting embodiment the present application utilizes one double-concentric complex cam (sometimes referred to herein as a "double nested cam") to provide both intake and exhaust variable actuation and packages on only one side of the cylinder head. The double nested cam has one center shaft and two tubes including an intermediate tube and an outer tube. In one form non-variable lobes for both intake and exhaust function are attached to the outer tube. In one form one of the variable lobes is attached to the intermediate tube and the other of the variable lobes is attached to the center shaft. However, the present application further contemplates an embodiment wherein both of the intermediate tube and the outer tube have variable lobes.

With reference to Figs. 1-9, a rocker 1 rotates around a fixed axis 2, moving an adjustable e-foot 3 which actuates traditional overhead poppet valves via a crosshead 4. A follower 6 is pivotally coupled to the rocker 1 about an axis 5. The rocker 1 is rotated about the fixed axis 2 through shaft 13 when it receives a force through its input

axis 5, an axis along a pin 14, generated by the movement of the follower 6. The movement of the follower 6 is generated by the geometric constraints of its three axes: its output axis which is coaxial with the first rocker assembly's input axis 5; an axis through an upper roller 7; and an axis through a lower roller 8. The upper roller 7 follows a cam lobe 9 on the cam assembly 10 while the lower roller 8 follows a cam lobe 11 which is also on the cam assembly 10. In one form the lower cam/roller set can be paired with one set on either side of the cam lobe 9 so as to balance the follower 6. The lower cam lobe 11 causes the valve to open while the upper cam lobe 9 allows the valve to close. In an alternative embodiment the lower cam lobe 11 causes the valve to close while the upper cam lobe 9 causes the valve to open. Additional rocker motion is controlled via spring(s) (not illustrated). In one form, the spring(s) influence motion of the follower 6 such that the upper roller 7 disengages from the cam lobe 9 during at least a portion of a revolution of the cam assembly 10. In one form the fixed lobes 11 are attached to the outer tube of the camshaft assembly 10. In one form the cam lobe 9 can be either attached to the intermediate tube (intake) or the inner shaft (exhaust). One embodiment of the cam assembly 10 is discussed further hereinbelow. The inner shaft and inner tube modulation are controlled via a duplex cam phaser (not shown) or two phasers, one on each end of the cam. In other non-limiting embodiments, the modulation can be controlled via a duplex cam phaser 25 disposed toward one end of the cam assembly (having phasers 26 and 27) and another phaser 28 can be disposed toward another end of the cam assembly, as is illustrated in Fig. 5a. Such embodiments may include additional rotating shaft and/or tube, as will be described

further in one-nonlimiting form below. In one form the phaser 28 can be disposed on the drive end of the cam assembly.

Turning now to Figs. 9-11 and with continuing reference to Figs. 1-8, the follower 6 is shown coupled with the rocker 1 using an energy storage device 12. in one form the energy storage device is a leaf spring. The energy storage device 12 biases the follower 6 into the cam lobe. In the illustrative embodiment the energy storage device 12 is attached at one end to the rocker 1 with a fastener but can be attached using other techniques. At the other end the energy storage device 12 engages the follower 6. The energy storage device 12 can engage the follower 6 in any variety of locations.

Turning now to Figs. 12-13, various views are depicted of a cam. The present application is not limited to the following techniques of assembly and can be assembled using other techniques of assembly in addition to those contemplated herein. In the illustrative form the cam assembly 10 includes an inner shaft 15, intermediate tube 16, and outer tube 17, each of which can be capable of being rotated independent of the others. In one embodiment a phaser arrangement such as that depicted in Fig. 5a can be used to manipulate each of the inner shaft 15, intermediate tube 16, and outer tube 17. A cam lobe 21, which can, but need not, represent the intake cam lobe, is coupled to the inner shaft 15 with a pin assembly 18 which can include a pin 19 and a sleeve 20. The pin assembly 18 can use a press fit or an interference fit, among possible other techniques. The cam lobe 21 can be coupled to the intermediate tube 16 and/or outer tube 17 in other embodiments. The intermediate tube 16 and the outer tube 17 include cutouts that allow the intermediate tube 16 and the outer tube 17 to rotate freely of the inner shaft 15. A cam lobe 22, which can represent the exhaust cam lobe, is coupled to

the intermediate tube 16 with a pin assembly 18 which can include a pin 19 and sleeve 20. The cam lobe 22 can be coupled to the inner shaft 15 or the outer tube 17 in other embodiments. The pin assembly 18 used to connect the cam lobe 22 to the intermediate tube 16 is allowed to pass through apertures formed in the inner shaft 15 and outer tube 17. A cutout is formed in the inner shaft 15 to permit adequate range of motion for the cam assembly 10. Though the pin assembly 18 can be used to couple both the cam lobe 21 and cam lobe 22 to the inner shaft 15 and intermediate tube 16, respectively, other embodiments may use different assembly techniques to fasten the cam lobe 21 and cam lobe 22.

Fig. 13 depicts another embodiment of the cam assembly 10. The cam lobe 22 is depicted in this embodiment coupled with the intermediate tube 16 with a pin assembly 18 that includes pins 23 and 24. The outer tube 17 includes apertures that permit the pins 23 and 24 to pass. The pins 23 and 24, furthermore, can take the same form or can be different. The pins 23 and 24 in this embodiment are depicted without a sleeve as in the previous embodiment, but it will be appreciated that the particular fastening technique for either embodiment can be different than that depicted.

While the invention has been illustrated and described in detail in the drawings and foregoing description, the same is to be considered as illustrative and not restrictive in character, it being understood that only the preferred embodiments have been shown and described and that all changes and modifications that come within the spirit of the inventions are desired to be protected. It should be understood that while the use of words such as preferable, preferably, preferred or more preferred utilized in the description above indicate that the feature so described may be more desirable, it

nonetheless may not be necessary and embodiments lacking the same may be contemplated as within the scope of the invention, the scope being defined by the claims that follow. In reading the claims, it is intended that when words such as "a," "an," "at least one," or "at least one portion" are used there is no intention to limit the claim to only one item unless specifically stated to the contrary in the claim. When the language "at least a portion" and/or "a portion" is used the item can include a portion and/or the entire item unless specifically stated to the contrary.

# CLAIMS

WHAT IS CLAIMED IS:

1. An apparatus comprising:

a cam follower operable to be pivotally coupled with a valve rocker arm and having a first rotatable member operable to be engaged with a first cam lobe substantially throughout a revolution of a cam shaft and a second rotatable member operable to be disengaged from a second cam lobe throughout a portion of the revolution.

2. The apparatus of claim 1, wherein the cam follower includes one end that is pivotally coupled with the valve rocker arm and a second end having the first rotatable member and the second rotatable member.

3. The apparatus of claim 2, which further includes an energy member operable to bias the cam follower such that the second rotatable member is disengaged from the second cam lobe.

4. The apparatus of claim 3, wherein the energy member is a spring.

5. The apparatus of claim 4, which further includes the valve rocker arm, wherein the spring is a leaf spring attached to the valve rocker arm and coupled with the cam follower.

6. The apparatus of claim 1, which further includes the valve rocker arm pivotally coupled with the cam follower, the rocker arm operable to be coupled with a shaft fixed relative to an engine block.

7. The apparatus of claim 1, which further includes the cam shaft, the first and second lobes of the cam shaft operable to be independently clocked during operation of an engine.

8. The apparatus of claim 7, which further includes at least two phasers coupled to the cam shaft and operable to independently clock the first and second lobes of the cam shaft.

9. An apparatus comprising:

a cam follower having a pivot aperture structured to be pivotally coupled with a rocker arm, the cam follower having an end that includes a first cam lobe contact member operable to contact a first cam lobe and a second cam lobe contact member operable to contact a second cam lobe.

10. The apparatus of claim 9, wherein the first cam lobe contact member is axially displaced from the second cam lobe contact member a distance along a pivot axis of the pivot aperture

11. The apparatus of claim 9, wherein the first cam lobe contact member is a roller coupled to the cam follower through a bearing.

12. The apparatus of claim 9, wherein the first cam lobe contact member includes two rollers axially displaced on either side of the second cam lobe contact member.

13. The apparatus of claim 9, wherein the cam follower includes a load bearing portion structured to receive a force from an energy member.

14. The apparatus of claim 13, wherein the energy member is a spring.

15. The apparatus of claim 9, wherein the spring is selected from the group consisting of a helical coil spring and a leaf spring.

16. A camshaft for use in an internal combustion engine, the cam shaft comprising:

a camshaft having a first elongate portion and a second elongate portion, the first and second elongate portions operable to be independently clocked about the camshaft;

a first cam lobe coupled with the first elongate portion;

a second cam lobe coupled with the second elongate portion; and

wherein the first cam lobe is operable to be clocked to a rotational position relative to the second cam lobe by virtue of the relative orientation of the first and second elongate portions.

17. The apparatus of claim 16, which further includes two phasers, each capable of clocking one of the first cam lobe and the second cam lobe.

18. The apparatus of claim 16, which further includes a third elongate portion rotatingly coupled with an engine crank shaft.

19. The apparatus of claim 16, which further includes three phasers, each capable of moving one of the first elongate portion, second elongate portion, and third elongate portion.

20. The apparatus of claim 19, wherein the first elongate portion is a shaft, the second elongate portion is an intermediate tube, and the third elongate portion is an outer tube.

21. The apparatus of claim 16, wherein the first cam lobe is coupled to the first elongate portion with a member that traverses from one side of the first elongate portion to an opposite side of the first elongate portion.

22. The apparatus of claim 16, wherein the second cam lobe is coupled to the second elongate portion with a member that traverses from one side of the second elongate portion to an opposite side of the second elongate portion.

23. The apparatus of claim 20, wherein the second cam lobe is coupled to the second elongate portion with a first member and a second member, the first member couples one side of the third elongate member to one side of the second elongate member, the second member couples the other side of the third elongate member to the other side of the second elongate member.

24. The apparatus of claim 16, wherein the first elongate portion is a shaft and the second elongate portion is a tube, the shaft located within the tube.

25. The apparatus of claim 16, wherein the first cam lobe is coupled to the first elongate portion with a coupling member traversing through the second elongate portion.

26. The apparatus of claim 16, wherein the first elongate portion is a shaft and the second elongate portion is a tube, the shaft located within the tube.

27. The apparatus of claim 26, wherein the first cam lobe is coupled to the first elongate portion with a coupling member traversing through the second elongate portion.

28. An apparatus comprising:

a cam shaft having a reference elongate member driven by an engine crank shaft, the cam shaft having a first lobe and a second lobe structured to be

independently clocked relative to the reference elongate member when the cam shaft is in operation.

29. The apparatus of claim 28, wherein the first lobe is coupled with a shaft and the second lobe is coupled with a tube.

30. The apparatus of claim 29, wherein the second lobe is coupled to the tube with an elongate member that traverses through the tube.

31. The apparatus of claim 29, wherein the second lobe is coupled to the tube with a first member and a second member, the shaft prohibiting the first member or the second member from passing from one side of the shaft to the other side of the shaft

32. The apparatus of claim 29, wherein the cam shaft further includes a shaft, a first tube, and a second tube, the shaft and first tube within the second tube.

33. The apparatus of claim 32, wherein the second lobe is coupled to rotate with the second tube.

34. The apparatus of claim 33, wherein the second lobe is pinned to the second tube through the shaft

35. The apparatus of claim 33, wherein the second lobe is coupled to the second tube with a first pin and a second pin, the first pin prohibited from passing through the shaft.

36. An apparatus comprising:

a cam shaft having a portion rotatingly coupled with a crankshaft, the cam shaft further having first lobe and a second lobe structured to be independently clocked relative to the crankshaft; and

means for coupling the first lobe and second lobe to the cam shaft.

37. A method comprising:

coupling a double nested camshaft with a crankshaft of an internal combustion engine;

engaging a first cam follower member of a cam follower with a first cam lobe and a second cam follower member with a second cam lobe; and

fastening one end of a rocker arm to the cam follower.

38. The method of claim 37, which further includes assembling the cam follower by rotatingly mounting the first cam follower member to the cam follower.

39. The method of claim 38, wherein the rotatingly mounting includes contacting a surface of the first cam follower with a bearing.

40. The method of claim 38, which further includes spring loading the cam follower such that the first cam follower disengages the first cam lobe over a portion of a revolution of the double nested camshaft.

41. The method of claim 38, wherein the spring loading includes attaching a spring between the rocker arm and the cam follower.

42. The method of claim 38, wherein the spring loading includes fastening a spring between the cam follower and a relatively fixed location of the internal combustion engine.

43. An apparatus comprising:

a rocker arm operable to be used in a variable valve actuation engine;

a cam shaft having a variable first lobe and a variable second lobe; and

means for following the variable first lobe and the variable second lobe, the means coupled to an end of the rocker arm.

44. A method comprising:

rotating a cam shaft having an independently variable first lobe and an independently variable second lobe;

periodically engaging the variable first lobe with a first member of a cam follower;

substantially engaging the variable second lobe with a second member of the cam follower;

pivoting the cam follower about a rocker; and

rocking the rocker to actuate a valve.

45. The method of claim 44 includes biasing the cam follower with an energy device.

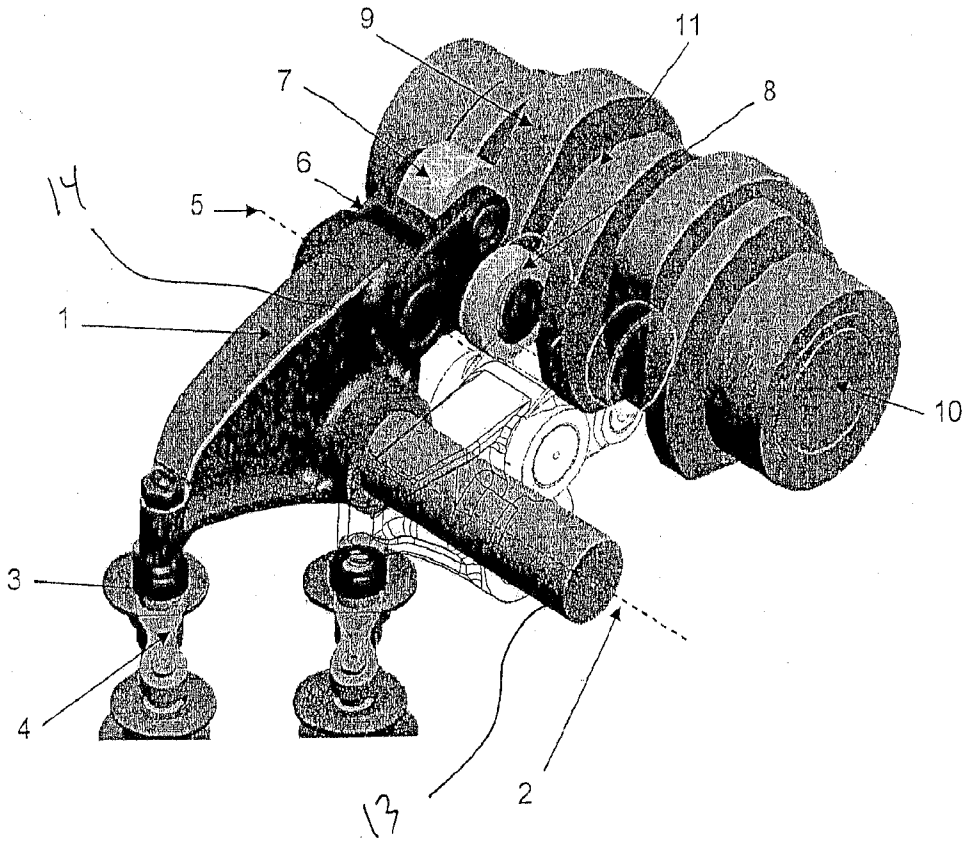


Fig. 1

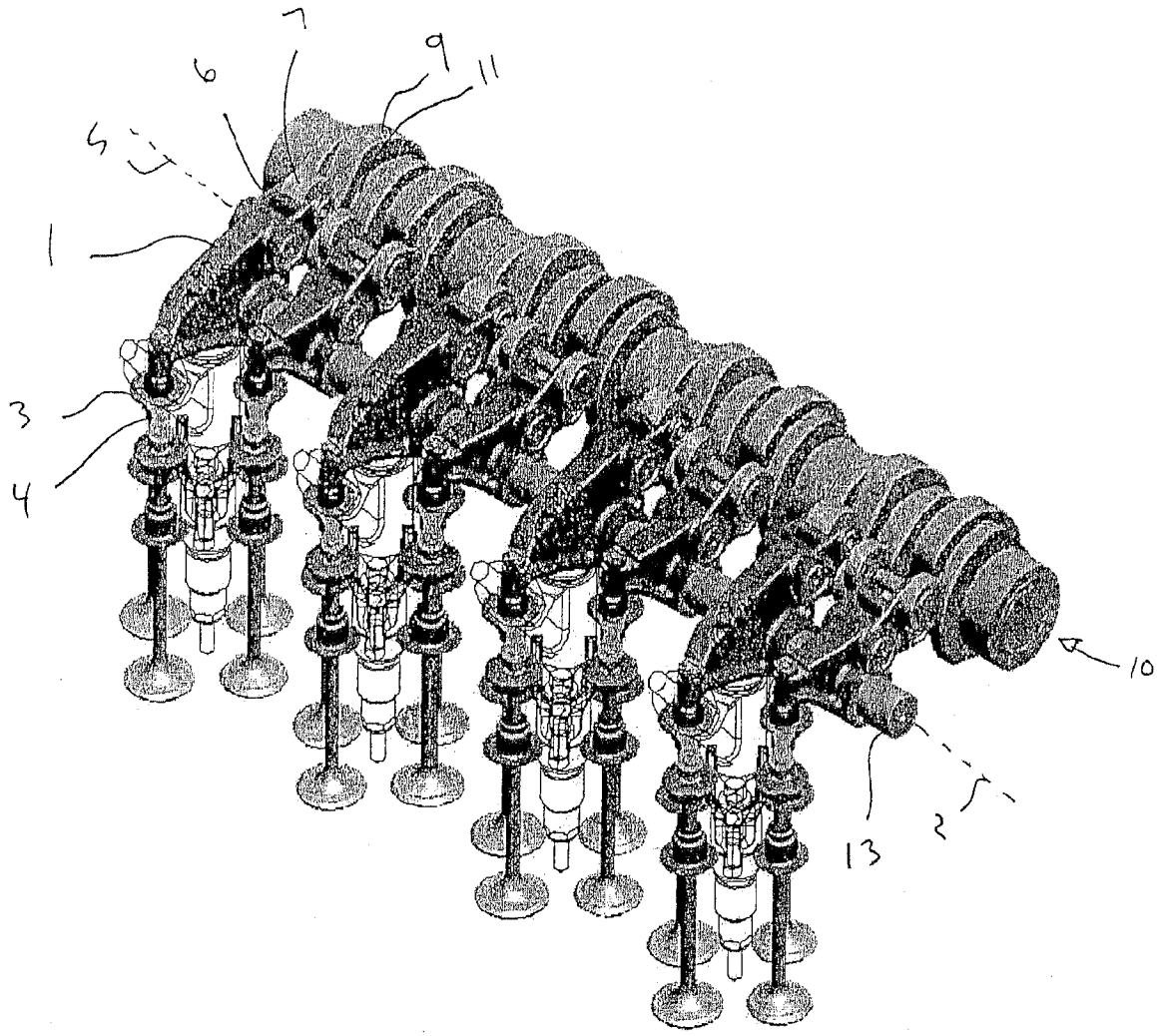


Fig. 2

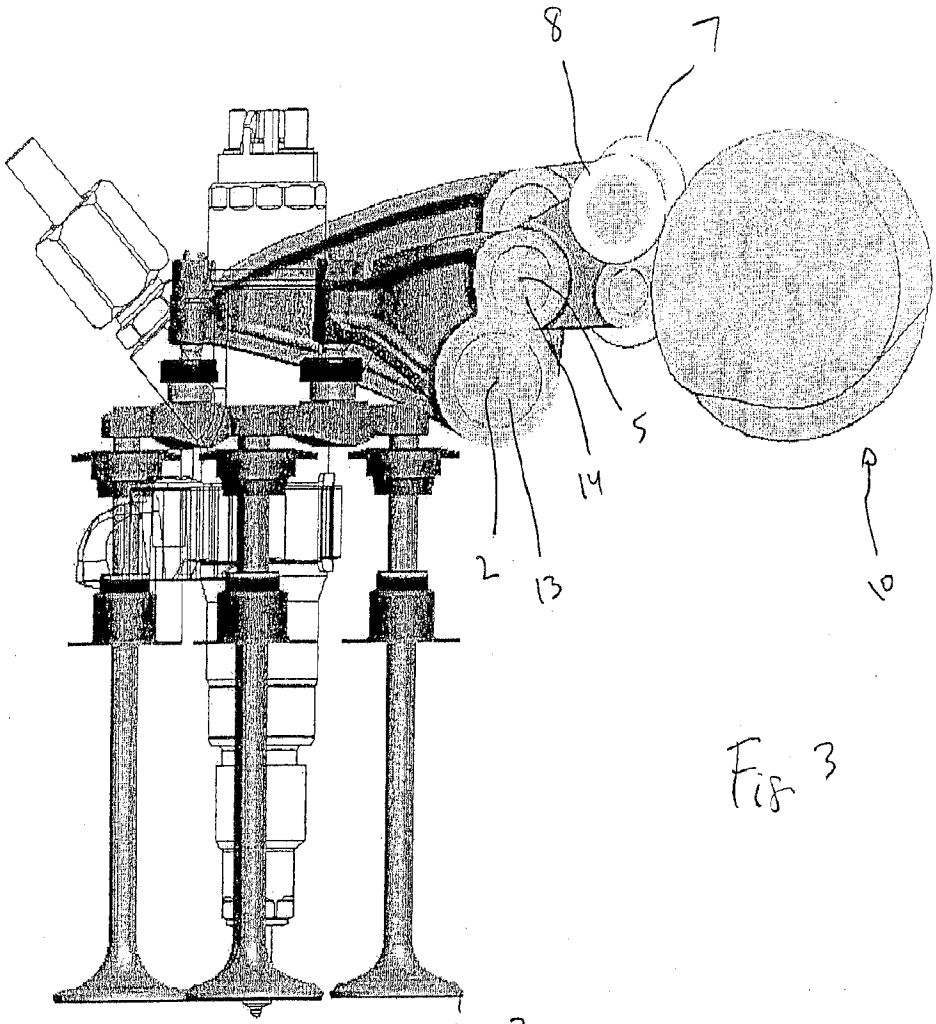


Fig 3

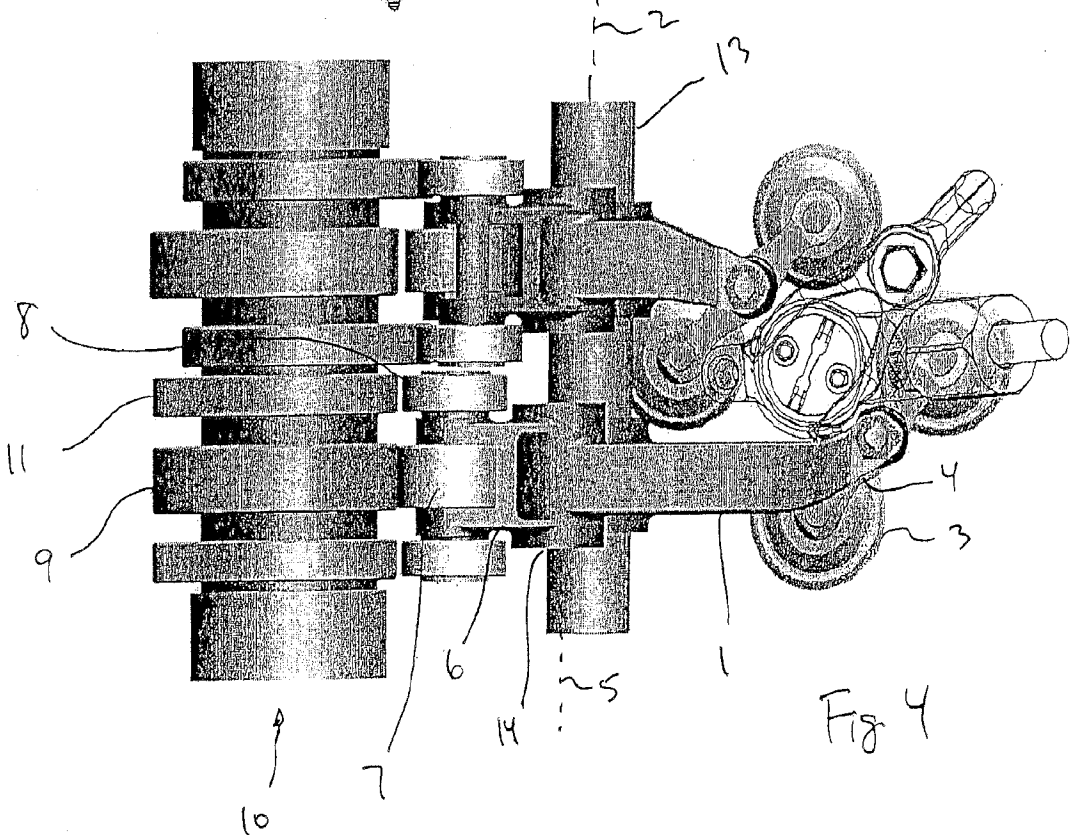


Fig 4

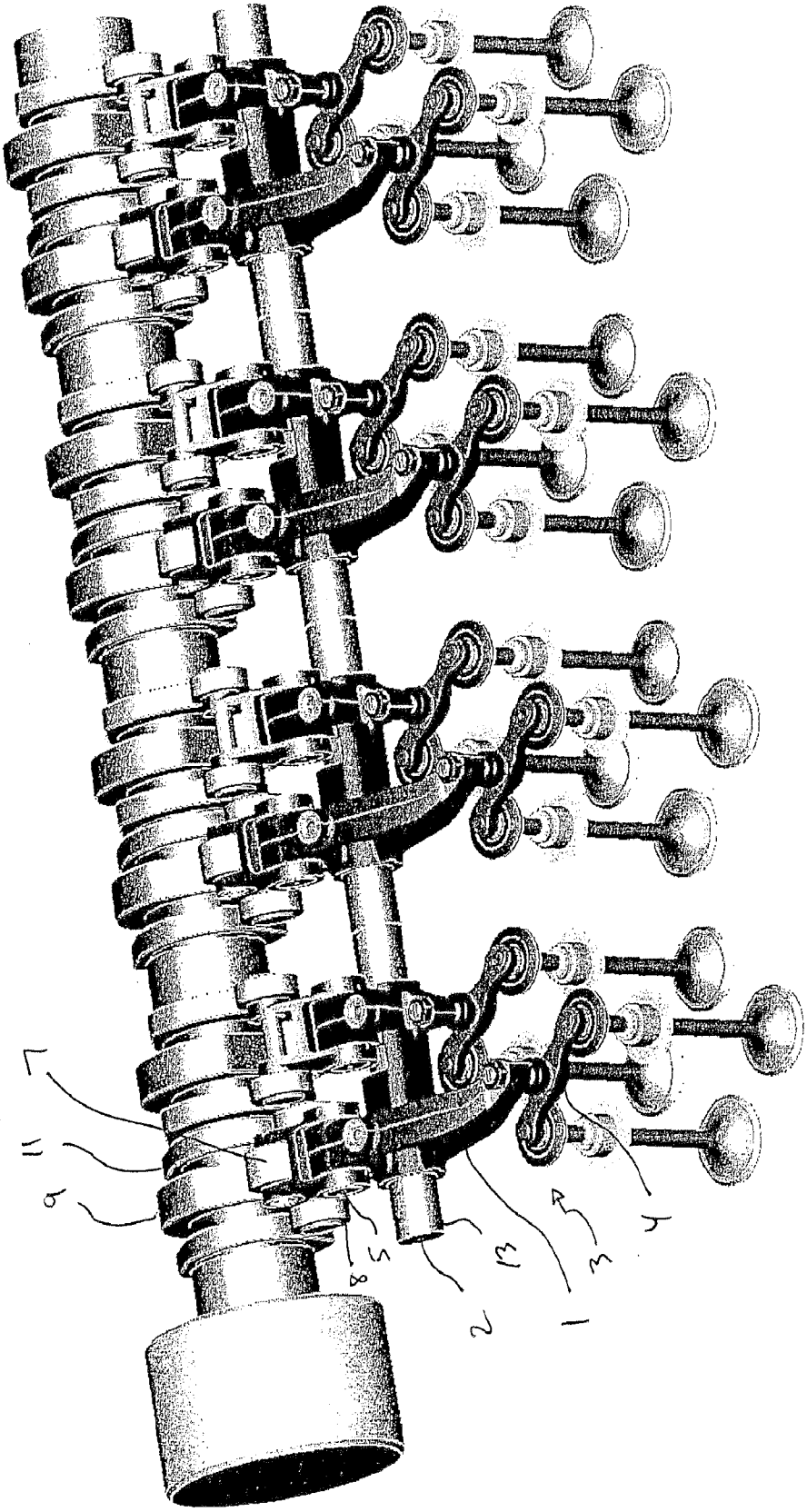


Fig. 5

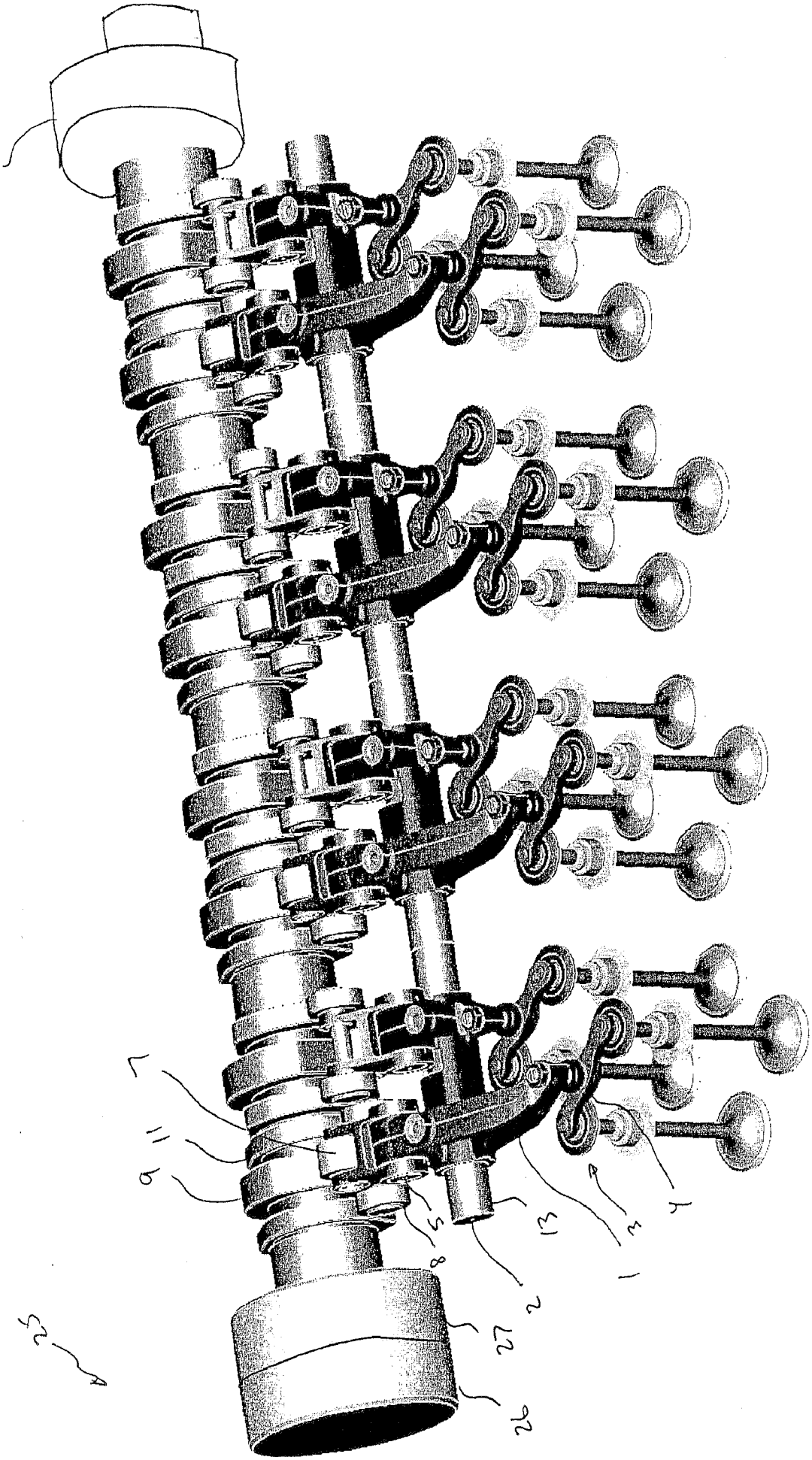


Fig. 5a

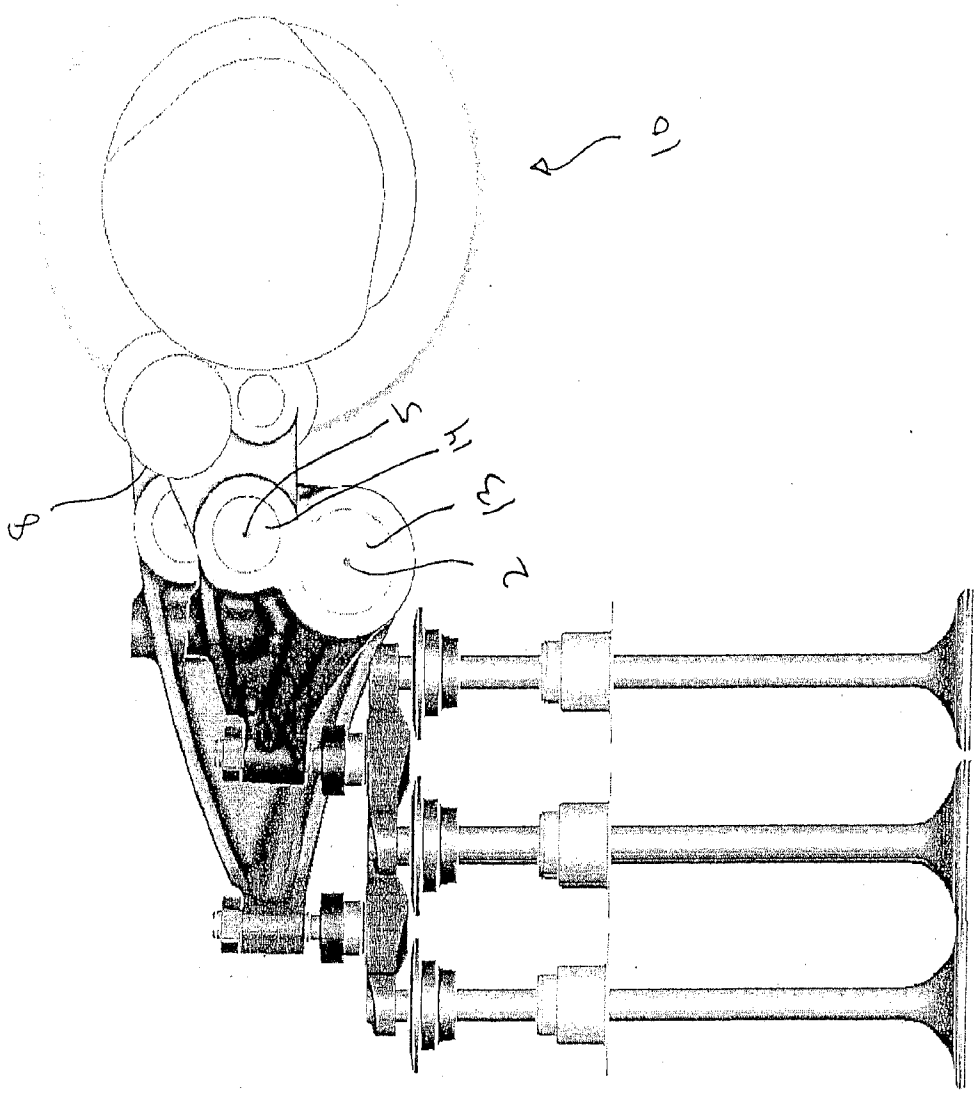


Fig. 6

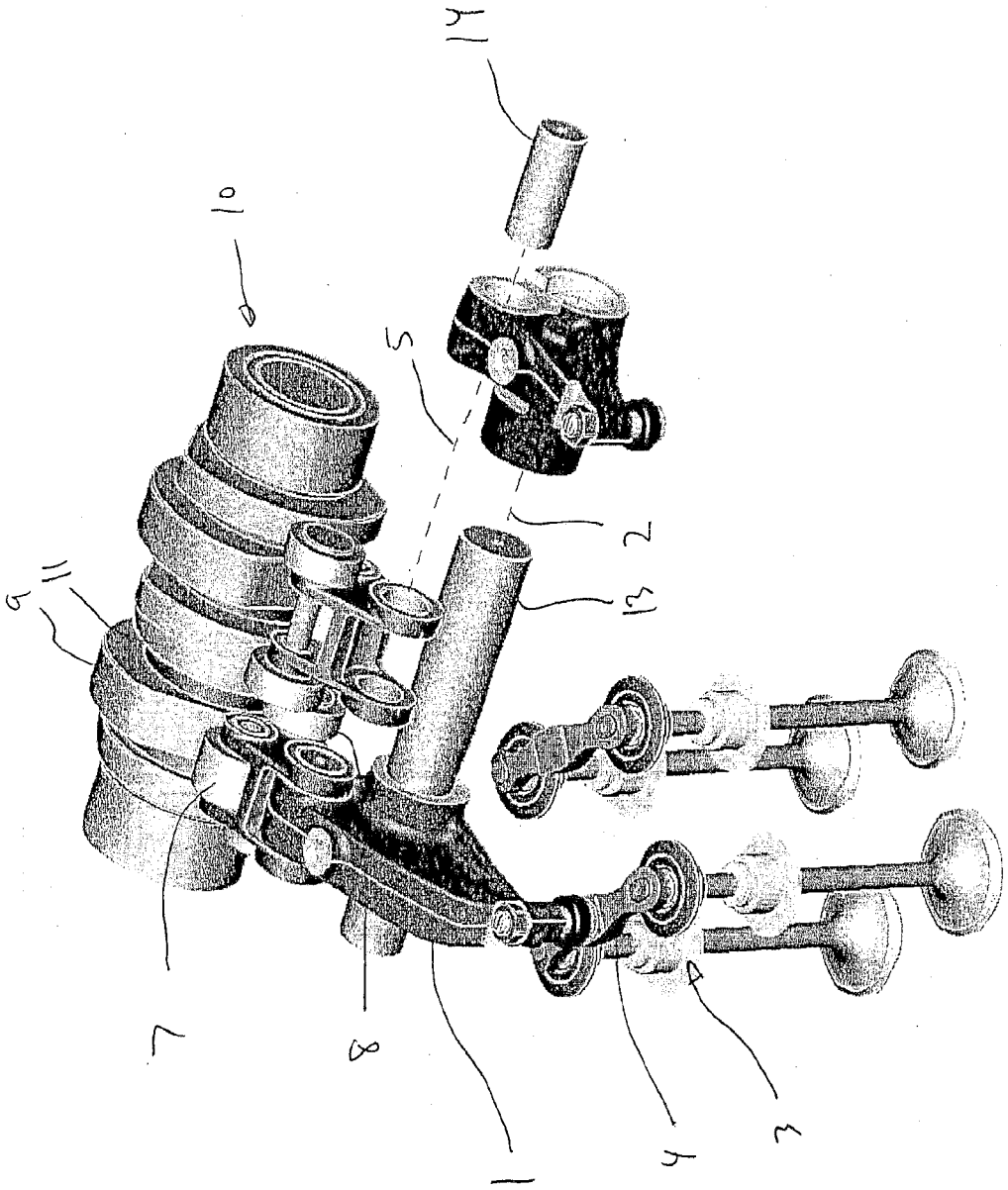


Fig. 7

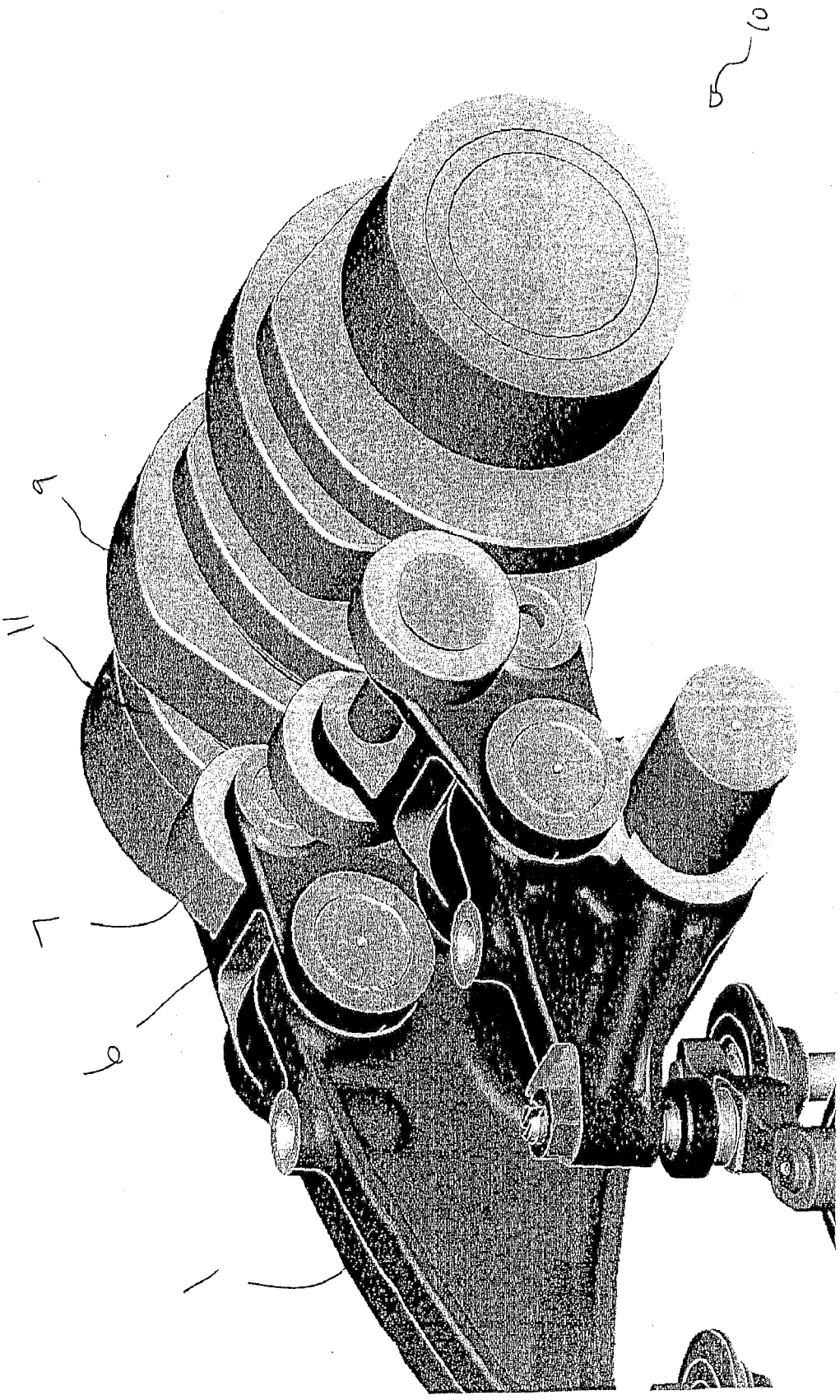


Fig. 8

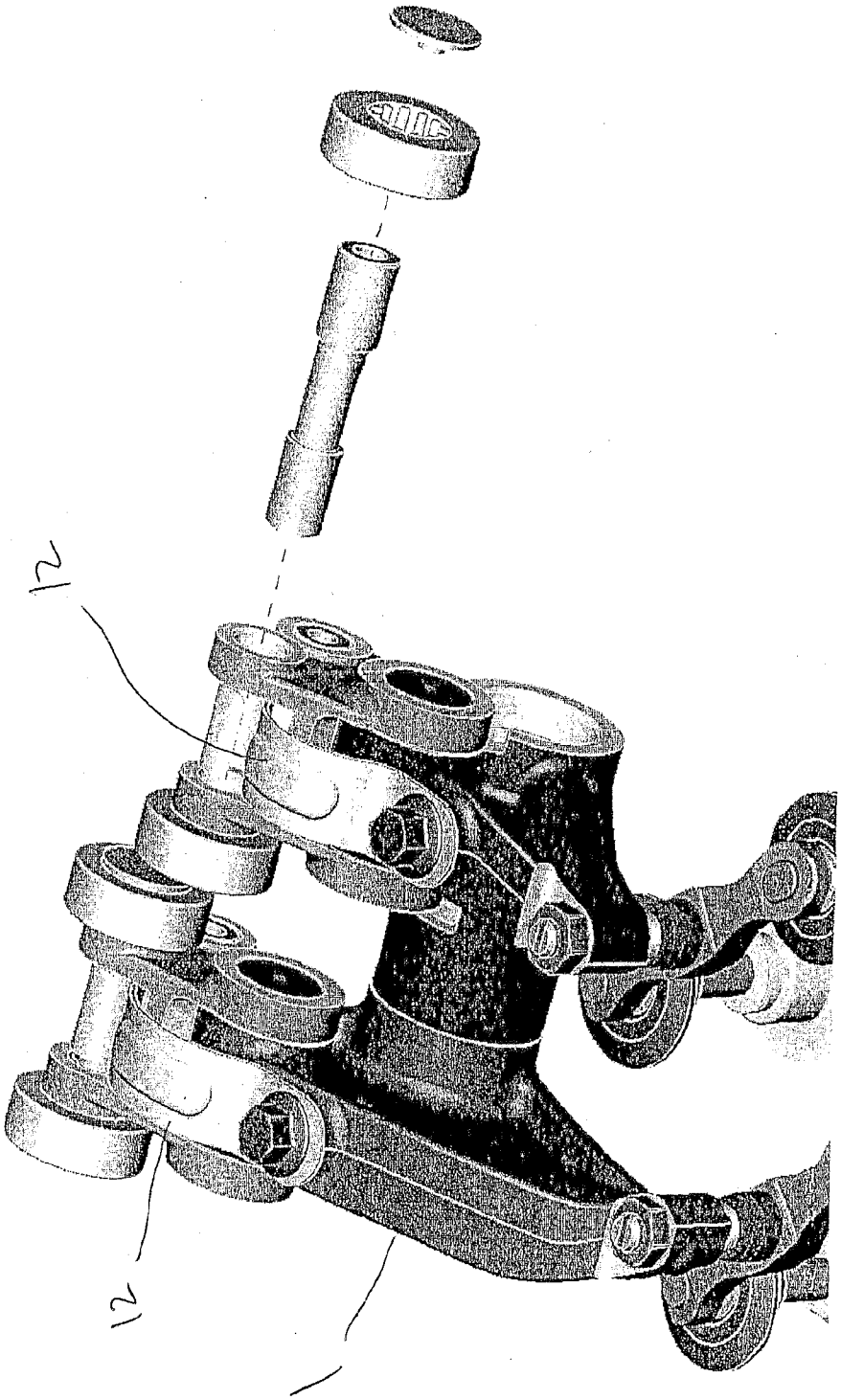


Fig. 9

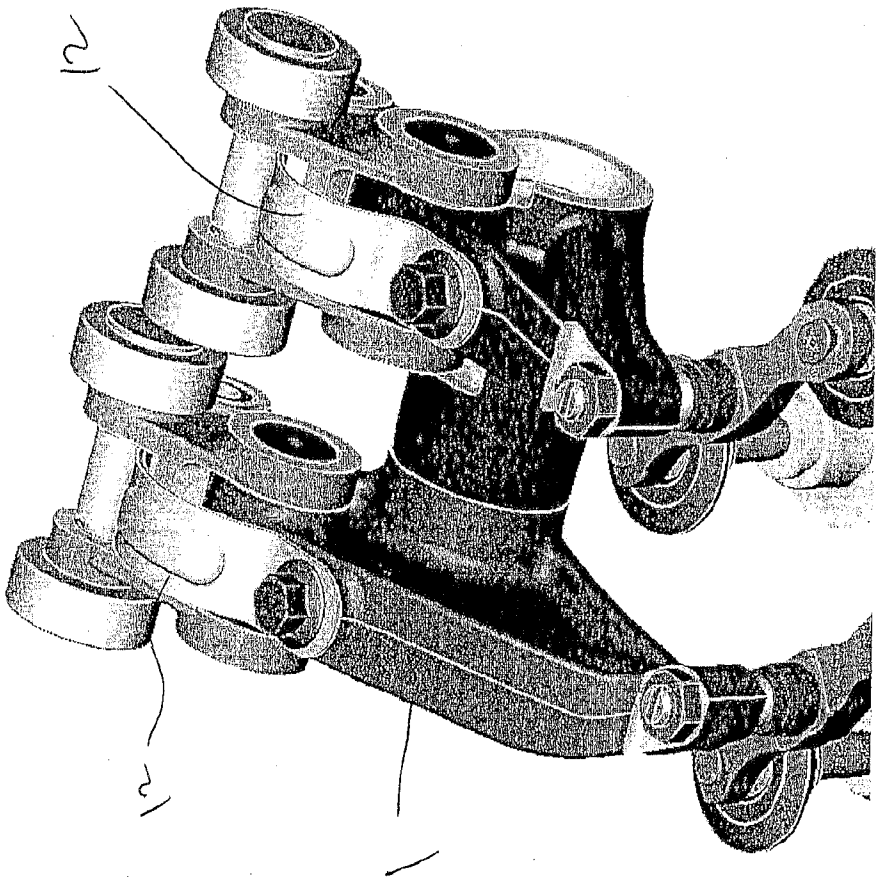


Fig. 1b

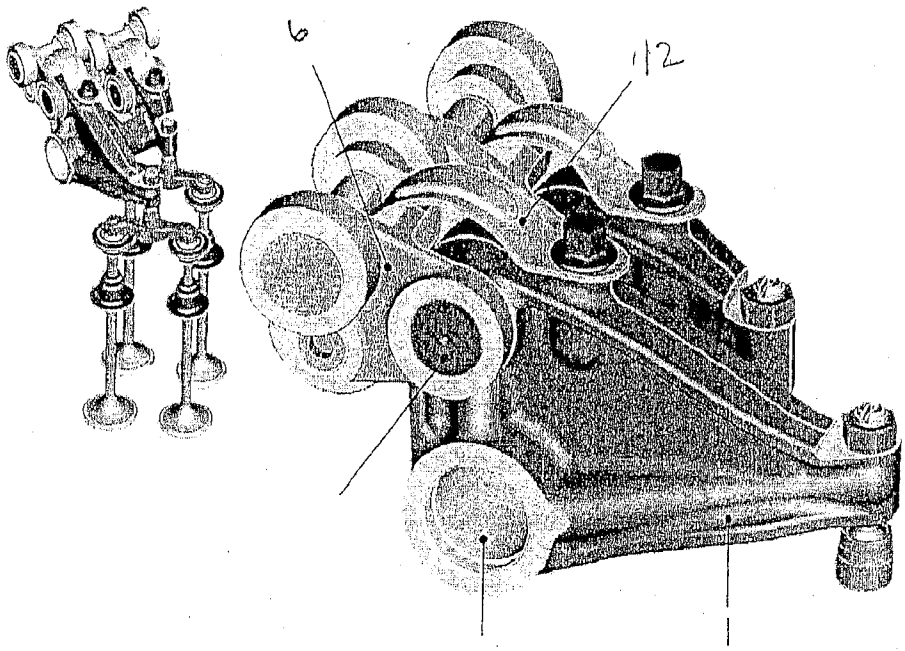


Fig. 11

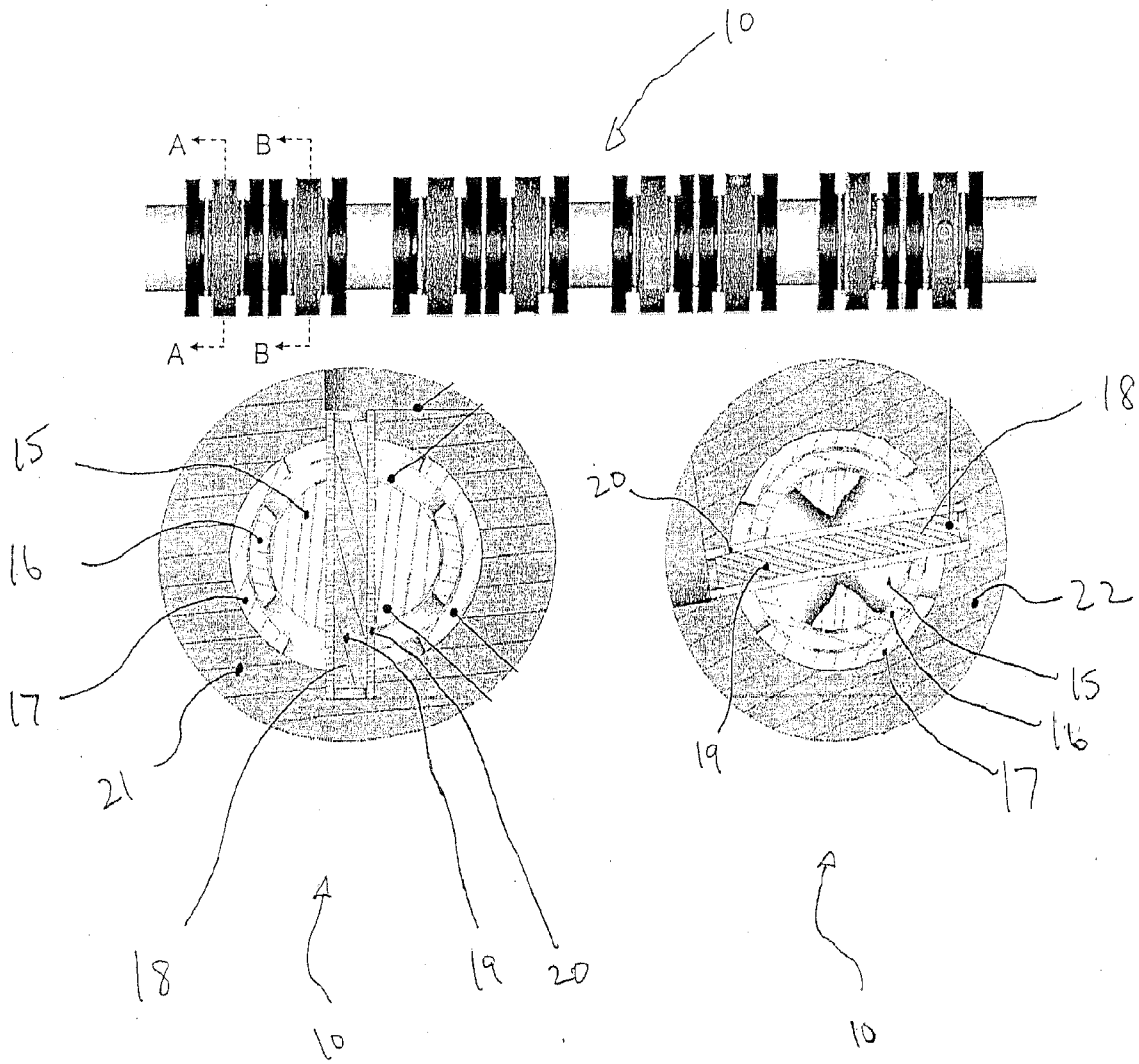


Fig. 12

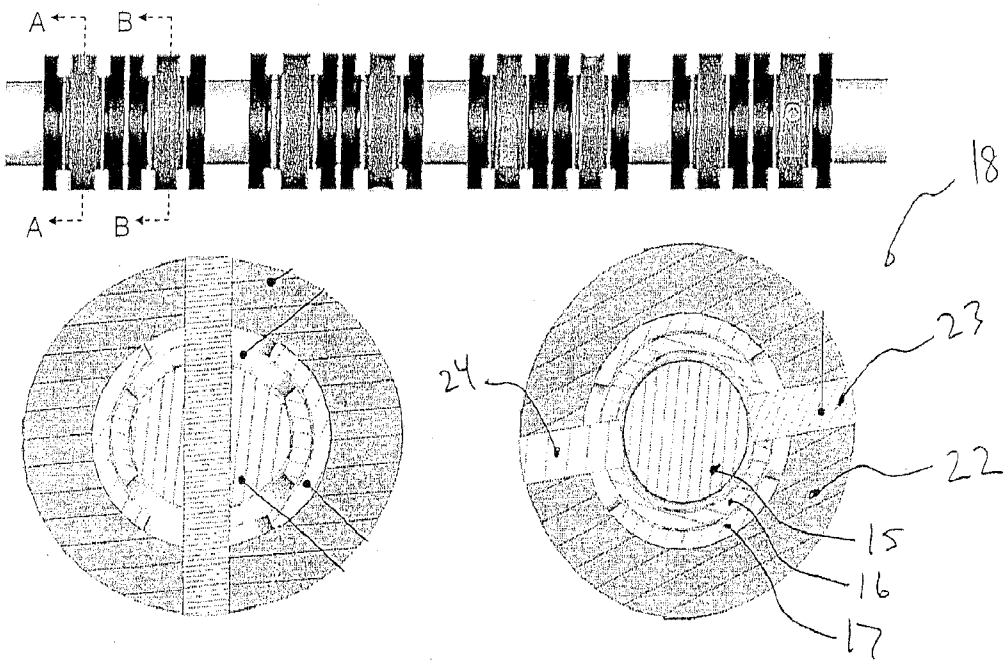


Fig. 13