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(54) **CAMSHAFT AND FOLLOWER GEOMETRY**

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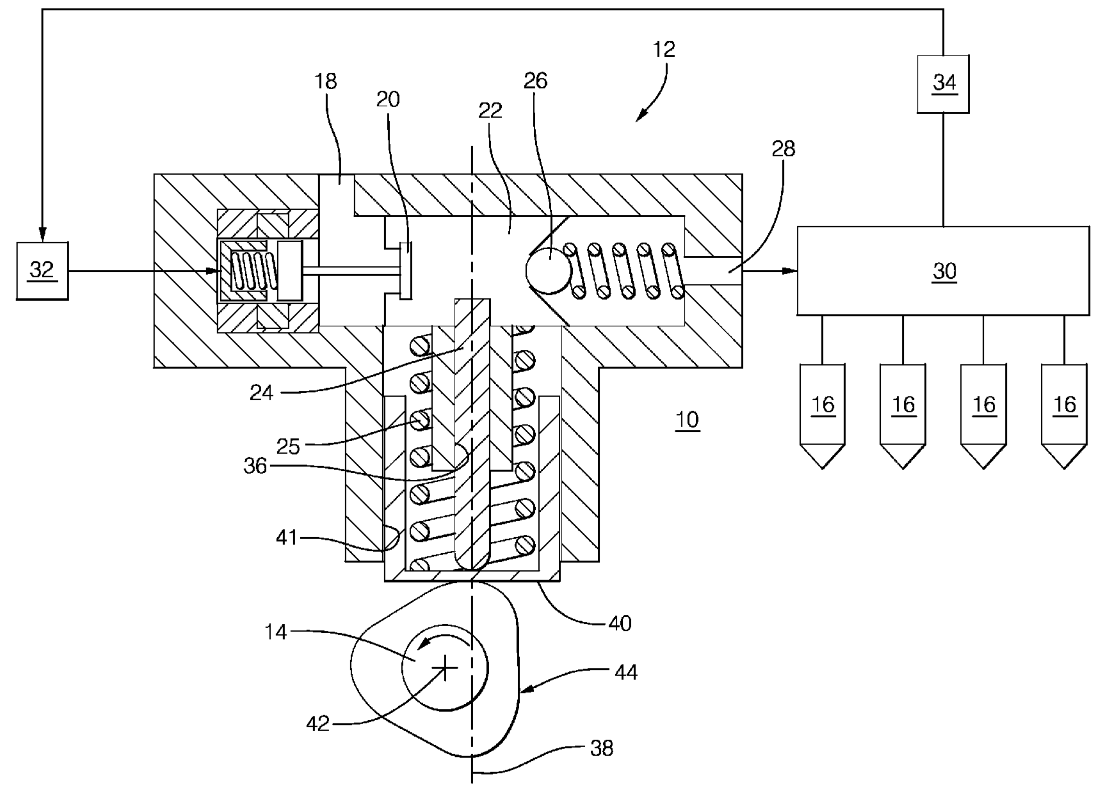
(57) **ABSTRACT**

An internal combustion engine includes a camshaft with a lobe rotatable about a camshaft axis and a follower and which follows the lobe and is reciprocated along a follower axis by the lobe. A contact force is generated between the lobe and the follower such that the contact force is cyclic between a minimum contact force and a maximum contact force. The follower axis is offset from the camshaft axis such that the lobe contacts the follower at a contact point that is substantially aligned with the follower axis when the maximum contact force is generated between the lobe and the follower. In this way, the side load on the follower is minimized.



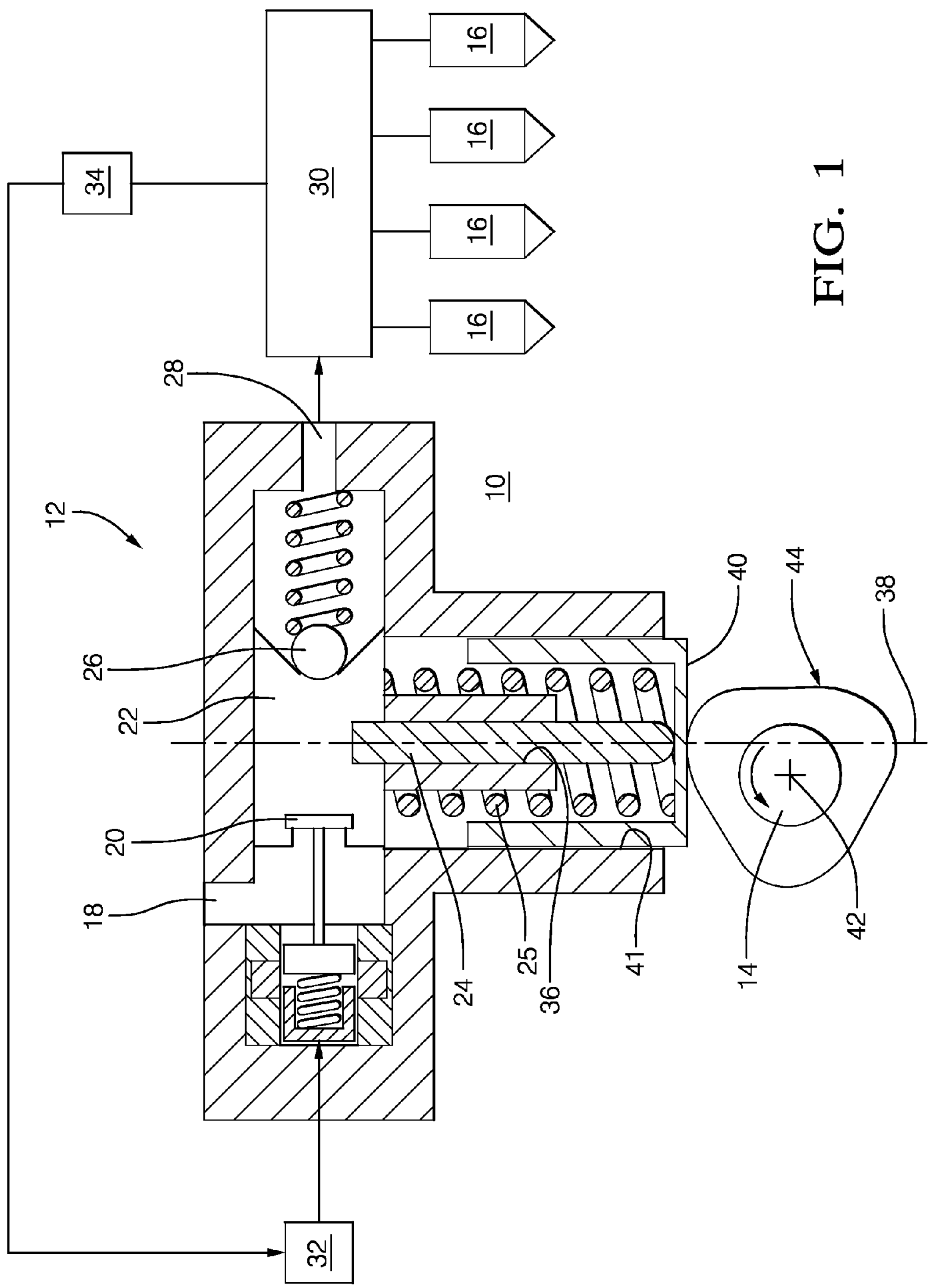


FIG. 1

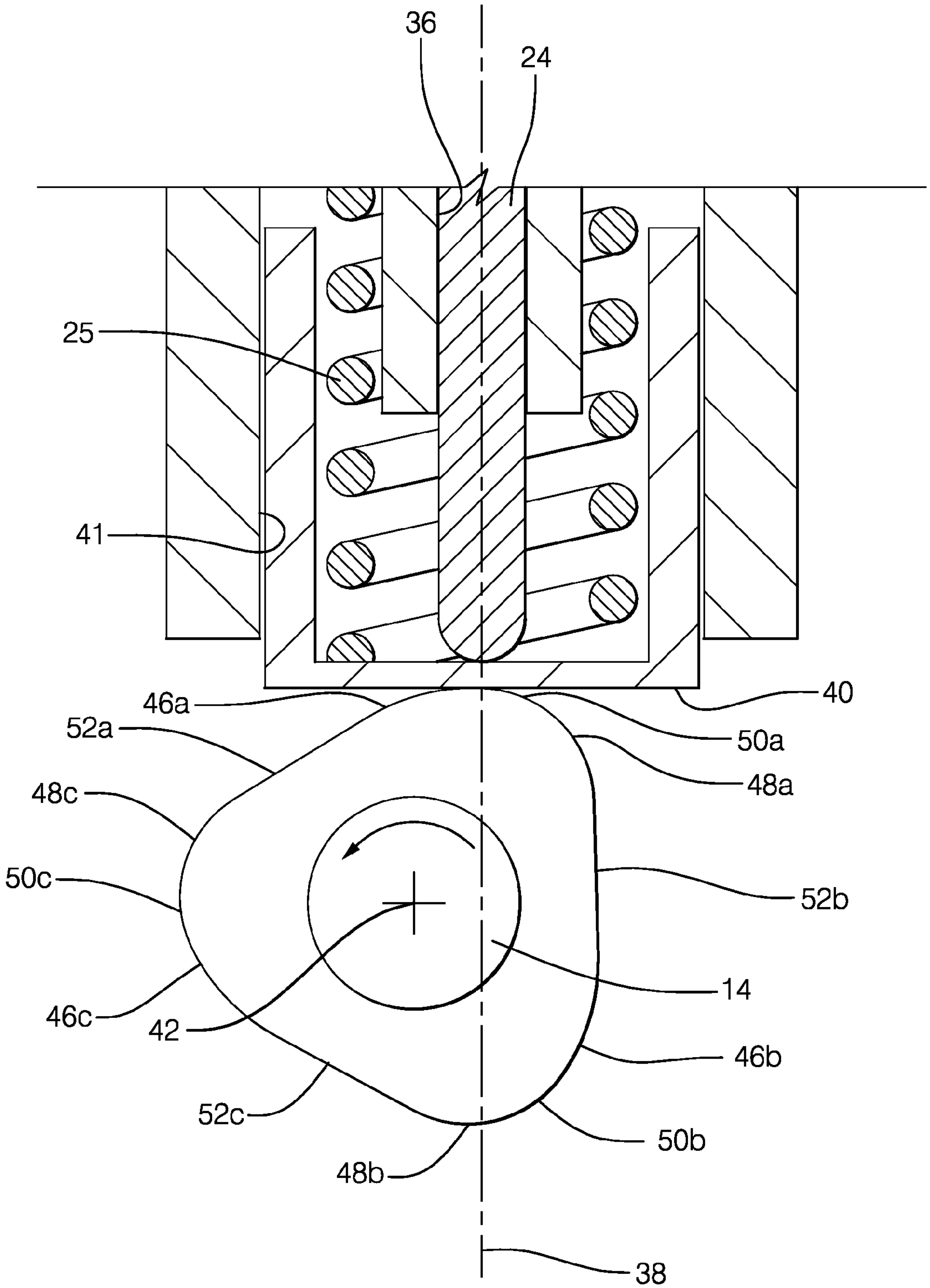

36
24
25
41
40
46a
52a
50a
48a
48c
50c
52b
14
46c
42
46b
52c
50b
48b
38

FIG. 2

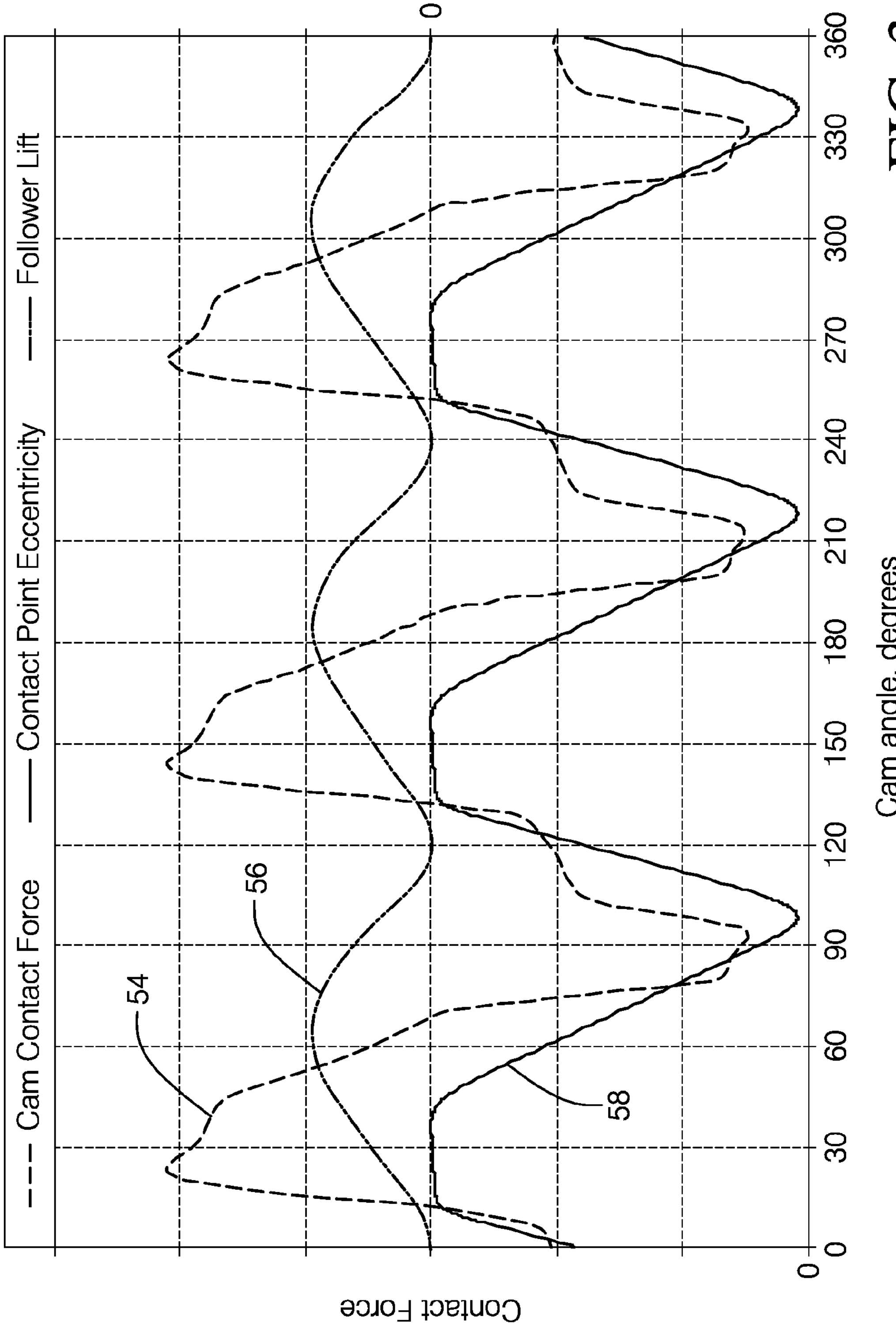

Cam Contact Force
Contact Point Eccentricity
Follower Lift
Contact Force
Cam angle, degrees
0
30
60
90
120
150
180
210
240
270
300
330
360
0
0
54
56
58

FIG. 3

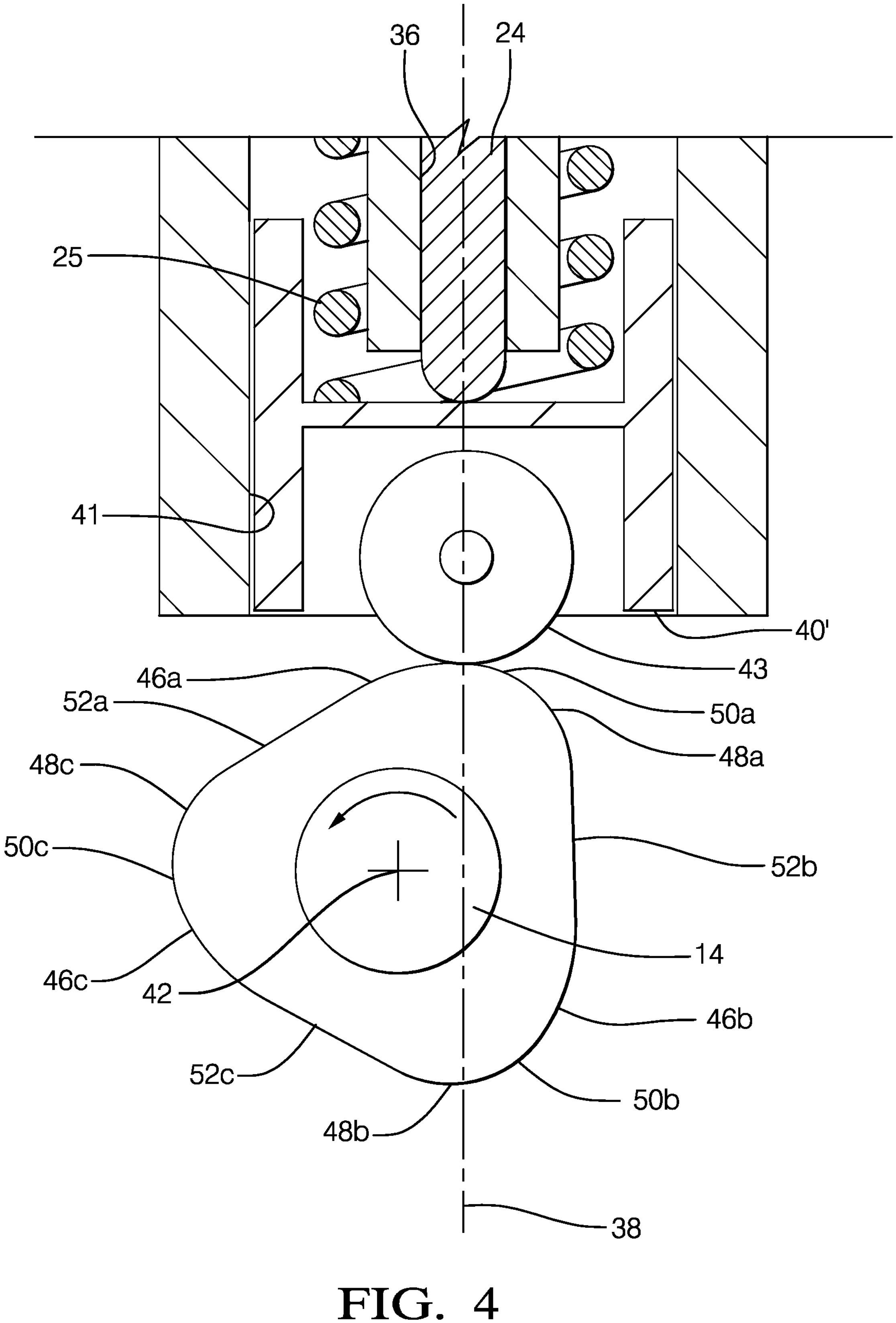

36
24
25
41
40'
43
46a
52a
50a
48a
48c
50c
52b
14
46c
42
46b
52c
50b
48b
38

FIG. 4

CAMSHAFT AND FOLLOWER GEOMETRY

TECHNICAL FIELD OF INVENTION

[0001] The present invention relates to an internal combustion engine with a camshaft having a lobe and a follower which follows the lobe; more particularly to such an internal combustion engine in which the follower imparts a pumping stroke on a pumping plunger of a fuel pump; and more particularly to such an internal combustion engine which minimizes tipping forces imparted on the follower.

BACKGROUND OF INVENTION

[0002] It is known in art of internal combustion engines to provide a fuel pump which is driven by a camshaft which rotates about a camshaft axis. U.S. Pat. No. 7,568,469 to Tokuo et al. shows an example of such an arrangement. The camshaft includes a lobe which is followed by a follower of the fuel pump and which reciprocates about a follower axis which is typically perpendicular to and aligned with the camshaft axis. The lobe reciprocates the follower through one or more pumping strokes for each rotation of the camshaft, thereby reciprocating a pumping plunger of the fuel pump to pressurize the fuel. Due to geometry of the lobe, the point of contact between the lobe and the follower varies in a cyclic patter from being aligned with the follower axis to being eccentric to the follower axis. A contact force between the follower and the lobe is generated which also varies in a cyclic pattern as a function of the rotational position of the lobe such that the highest contact force occurs when the contact point is not aligned with the follower axis which results in a side load being applied to the follower. This side load may result in reduced durability and may require followers which are manufactured with increased strength to be capable of accommodating the side load, thereby increasing manufacturing costs.

[0003] What is needed is an internal combustion engine which minimizes or eliminates one or more of the shortcomings as set forth above.

SUMMARY OF THE INVENTION

[0004] Briefly described, an internal combustion engine includes a camshaft with a lobe rotatable about a camshaft axis and a follower which follows the lobe and which is reciprocated along a follower axis by the lobe. A contact force is generated between the lobe and the follower such that the contact force is cyclic between a minimum contact force and a maximum contact force. The follower axis is offset from the camshaft axis such that the lobe contacts the follower at a contact point that is substantially aligned with the follower axis when the maximum contact force is generated between the lobe and the follower. In this way, the side load on the follower is minimized.

[0005] Further features and advantages of the invention will appear more clearly on a reading of the following detailed description of the preferred embodiment of the invention, which is given by way of non-limiting example only and with reference to the accompanying drawings.

BRIEF DESCRIPTION OF DRAWINGS

[0006] This invention will be further described with reference to the accompanying drawings in which:

[0007] FIG. **1** is a schematic drawing of an internal combustion engine in accordance with the invention;

[0008] FIG. **2** is an enlarged portion of FIG. **1** showing a lobe of a camshaft and a follower which follows the lobe;

[0009] FIG. **3** is a graph showing lift of the follower vs. angle of rotation of the lobe, contact force between the follower and the lobe vs. angle of rotation of the lobe, and contact point eccentricity relative to follower axis vs. angle of rotation of the lobe; and

[0010] FIG. **4** is the enlarged portion of FIG. **2** now showing an alternative follower.

DETAILED DESCRIPTION OF INVENTION

[0011] In accordance with a preferred embodiment of this invention and referring to FIGS. **1** and **2**, an internal combustion engine **10** is shown. Internal combustion engine **10** includes a fuel pump **12** which is driven by a camshaft **14** of internal combustion engine **10**. Fuel pump **12** is used to deliver pressurized fuel to one or more fuel injectors **16**, which may, for example only, inject the pressurized fuel directly into combustion chambers (not shown) of internal combustion engine **10**.

[0012] Fuel pump **12** generally includes a fuel inlet **18**, an inlet valve **20**, a pressure chamber **22**, a pumping plunger **24**, a return spring **25**, an outlet valve **26**, and a fuel outlet **28** which may be in fluid communication with a fuel rail **30** to which fuel injectors **16** are connected and receive pressurized fuel from. Fuel inlet **18** receives fuel from a fuel source, for example a fuel tank (not shown) with a lift pump (not shown) at a relatively low pressure. Inlet valve **20** may be, for example, a solenoid operated valve which is controlled by a controller **32**. Controller **32** may receive input from a pressure sensor **34** which supplies a signal indicative of the pressure of the fuel being supplied to fuel injectors **16**. While pressure sensor **34** is shown arranged to read the fuel pressure within fuel rail **30**, it should be understood that pressure sensor **34** may be positioned at other locations that are indicative of the pressure of the fuel being supplied to fuel injectors **16**. Controller **32** sends signals to inlet valve **20** to open and close inlet valve **20** as necessary to achieve a desired fuel pressure at pressure sensor **34** as may be determined by current and anticipated engine operating demands. When inlet valve **20** is opened, fuel from fuel inlet **18** is allowed to flow into pressure chamber **22**.

[0013] Pumping plunger **24** is slidably received within a plunger bore **36** that is in fluid communication with pressure chamber **22**. Pumping plunger **24** is reciprocated within plunger bore **36** along a plunger axis **38** by camshaft **14** and return spring **25** as will be described later. Pumping plunger **24** includes a follower **40** at an axial end thereof that is distal from pressure chamber **22** for following camshaft **14** as will also be described later. Follower **40** reciprocates within a follower bore **41** which may be, for example only, a bore in the engine block, intake manifold, or cylinder head of internal combustion engine **10** or may alternatively be a bore in a separate housing of fuel pump **12**. Follower **40** is guided by follower bore **41** which is substantially coaxial with plunger bore **36**. After inlet valve **20** has been closed, reciprocation of pumping plunger **24** toward pressure chamber **22** causes the fuel within pressure chamber **22** to be compressed. The pressurized fuel causes outlet valve **26** to open, thereby allowing pressurized fuel to be expelled from fuel outlet **28** to fuel rail **30** and fuel injectors **16**.

[0014] Camshaft **14** rotates about a camshaft axis **42** and includes a lobe **44** which is followed by follower **40** of pumping plunger **24**. As shown in FIGS. **1** and **2**, follower **40** forms a sliding interface with lobe **44**; however, as shown in FIG. **4**, follower **40** may include a roller **43** which forms a rolling interface with lobe **44**. Camshaft axis **42** is arranged to be substantially at a 90° angle relative to plunger axis **38**; however, plunger axis **38** is offset relative to camshaft axis **42** such that plunger axis **38** does not intersect camshaft axis **42** as will be described later in greater detail. One rotation of lobe **44** causes pumping plunger **24** to complete three pumping cycles, i.e. pumping plunger **24** is reciprocated from a minimum displacement to a maximum displacement (pumping stroke) and back again to minimum displacement (refill stroke) in one pumping cycle. Lobe **44** includes three compression flanks **46***a*, **46***b*, **46***c* which each move pumping plunger **24** from the minimum displacement toward the maximum displacement, three refill flanks **48***a*, **48***b*, **48***c* which each move pumping plunger **24** from the maximum displacement toward the minimum displacement, and three noses **50***a*, **50***b*, **50***c* between respective compression flanks **46***a*, **46***b*, **46***c* and refill flanks **48***a*, **48***b*, **48***c* which each provide maximum displacement to pumping plunger **24**. Base portions **52***a*, **52***b*, **52***c* separate adjacent respective compression flanks **46***a*, **46***b*, **46***c* and refill flanks **48***a*, **48***b*, **48***c*. Base portions **52***a*, **52***b*, **52***c* provide minimum displacement to pumping plunger **24** and may define the point at which the direction of movement of pumping plunger **24** reverses. While camshaft **14** has been illustrated as having three compression flanks **46***a*, **46***b*, **46***c*, three refill flanks **48***a*, **48***b*, **48***c*, and three noses **50***a*, **50***b*, **50***c*, it should be understood that a lesser or greater number may be provided, thereby decreasing or increasing the number of pumping cycles that are completed during one rotation of camshaft **14**.

[0015] A description of the rotation of camshaft **14** will now be given. For this description, rotation positions will be assigned as follows: 0° is the center of base portion **52***a*, 63° is nose **50***a*, 120° is the center of base portion **52***b*, 183° is nose **50***b*, 240° is the center of base portion **52***c*, and 303° is nose **50***c*; however, it should be understood that these values are exemplary only. A contact force is generated between lobe **44** and follower **40** as a result of return spring **25** urging follower **40** into contact with lobe **44** and also as a result of the pressure being elevated within pressure chamber **22** during the pumping stroke. This contact force is cyclic between a minimum contact force and a maximum contact force and varies as a function of the rotational position of camshaft **14**. As shown by contact force trace **54** in FIG. **3**, the maximum contact force occurs at about 22°, 142°, and 262° with elevated contact forces surrounding the points of maximum contact force between about 15° and about 45°, between about 135° and about 165°, and between about 255° and about 285° respectively. Consequently, the maximum contact force and the elevated contact forces occur during about a range of 30° on each compression flank **46***a*, **46***b*, **46***c*. Also as can be seen in FIG. **3**, the maximum contact forces do not coincide with the maximum lifts of follower **40** which occur when noses **50***a*, **50***b*, **50***c* contact follower **40** as illustrated by lift trace **56**. The contact point between follower **40** and lobe **44** is also cyclic and varies as a function of the rotational position of camshaft **14** as illustrated by contact point eccentricity trace **58**. When camshaft **14** is rotated to 0°, 120°, or 240°, lobe **44** contacts follower **40** at a point of contact that is offset from plunger axis **38** a magnitude that is substantially equal to the magnitude of offset of plunger axis **38** relative to camshaft axis **42**. Since the point of contact between follower **40** and lobe **44** is offset from plunger axis **38**, a tipping force is generated which tries to tip follower **40**, thereby applying a side load to follower **40** within follower bore **41**; however, since the contact force is relatively low, the tipping force and side load is also relatively low. As camshaft **14** is rotated counterclockwise, as viewed in the drawings, from 0°, 120°, or 240°, the point of contact between follower **40** and lobe **44** moves toward plunger axis **38**, i.e. the eccentricity becomes smaller. When camshaft **14** is rotated to generate the maximum contact force between follower **40** and lobe **44**, the point of contact between follower **40** and lobe **44** is substantially aligned with plunger axis **38**. Since the point of contact between follower **40** and lobe **44** is substantially aligned with plunger axis **38**, there is substantially no tipping force generated which tries to tip follower **40**, thereby minimizing the side load placed on follower **40** within follower bore **41**. As used herein, substantially aligned is understood to be within about ±5% of the total eccentricity of plunger axis **38** and the point of contact between follower **40** and lobe **44**.

[0016] While an exemplary lobe **44** has been described herein, it should be understood that other lobe geometries are contemplated. For example only, the location, duration, lift properties, and quantities of compression flanks **46***a*, **46***b*, **46***c*; refill flanks **48***a*, **48***b*, **48***c*; noses **50***a*, **50***b*, **50***c*; and base portions **52***a*, **52***b*, **52***c* may be altered in order to obtain desired operating performance of fuel pump **12**.

[0017] While this invention has been described in terms of preferred embodiments thereof, it is not intended to be so limited, but rather only to the extent set forth in the claims that follow.

We claim:

1. An internal combustion engine comprising:

a camshaft having a lobe rotatable about a camshaft axis; and

a follower which follows said lobe and is reciprocated along a follower axis by said lobe whereby a contact force is generated between said lobe and said follower such that said contact force is cyclic between a minimum contact force and a maximum contact force;

wherein said follower axis is offset from said camshaft axis such that said lobe contacts said follower at a contact point that is substantially aligned with said follower axis when said maximum contact force is generated between said lobe and said follower, thereby minimizing side load on said follower.

2. An internal combustion engine as in claim **1** wherein said follower reciprocates within and is guided by a follower bore.

3. An internal combustion engine as in claim **1** wherein reciprocating motion of said follower is translated to a pumping plunger which reciprocates within a plunger bore.

4. An internal combustion engine as in claim **3** wherein said plunger bore is in fluid communication with a pumping chamber and reciprocation of said pumping plunger pressurizes fuel within said pumping chamber.

5. An internal combustion engine as in claim **4** wherein said follower reciprocates within and is guided by a follower bore.

6. An internal combustion engine as in claim **5** wherein said follower bore is coaxial with said plunger bore.

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