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(54) **ELECTRO-HYDRAULIC HYBRID CAMSHAFT PHASER**

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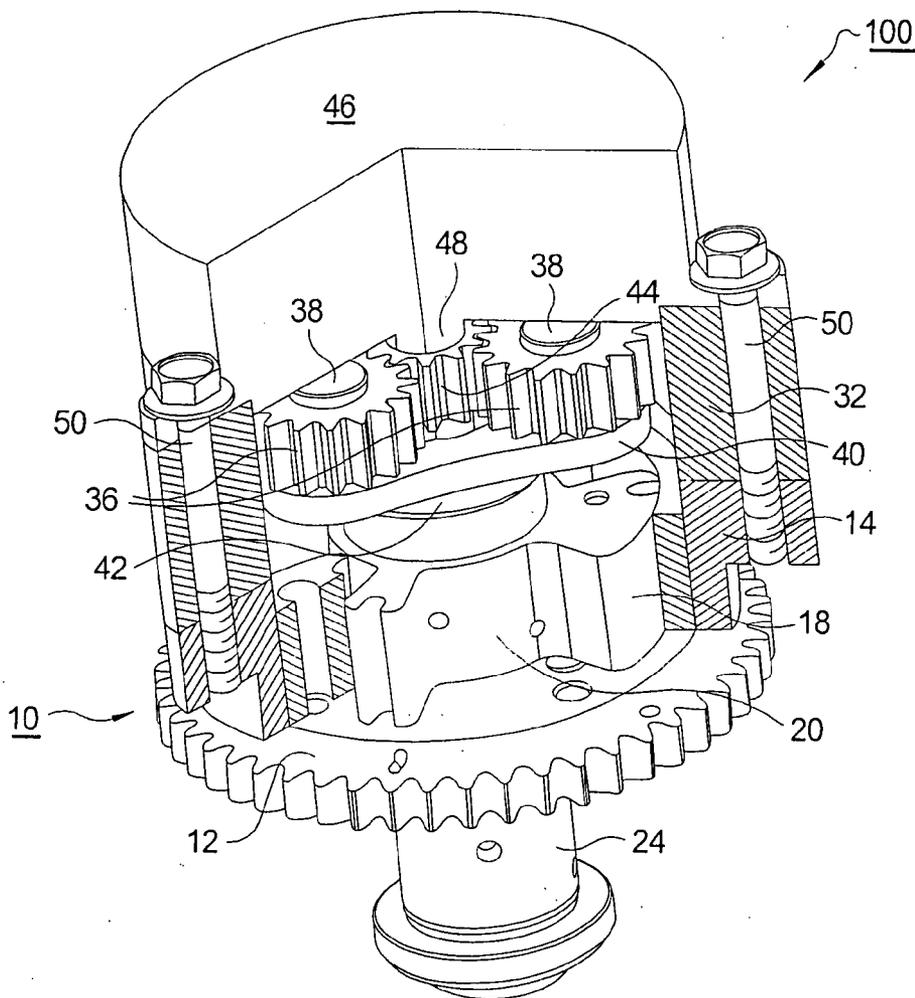
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(57) **ABSTRACT**  
A hybrid camshaft phaser comprising a conventional vane-type hydraulically-actuated phaser to which is coupled an electric motor and gear transmission. The transmission output shaft is coupled to the phaser rotor, optionally via an intermediate clutch mechanism. Under engine operating conditions in which the response of a hydraulic phaser is poor, the electric motor operates to augment the hydraulic actuation. Such conditions include at least low ambient temperatures at which oil viscosities are high, and high ambient temperatures and/or low engine speeds at which oil pressures are low. Preferably, at engine speeds above about 1500 rpm, the electric motor is de-energized.

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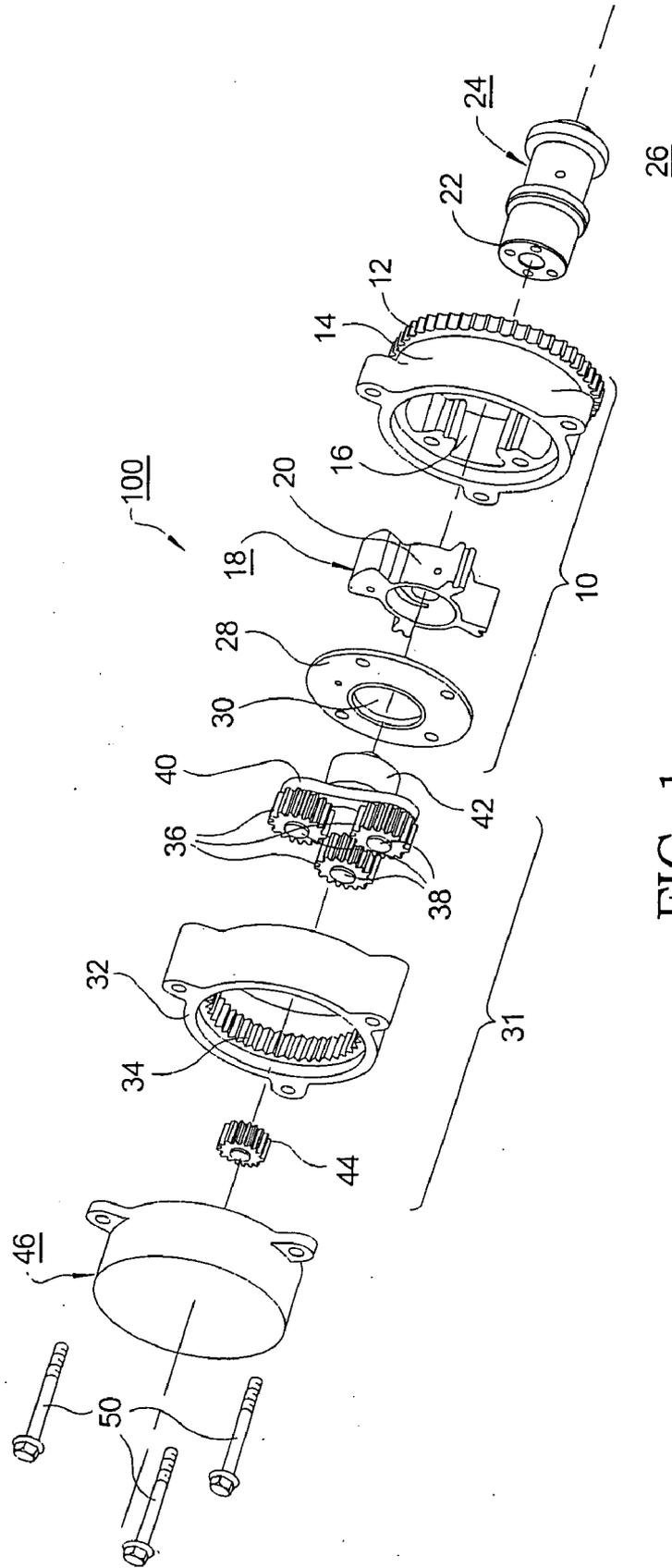


FIG. 1.

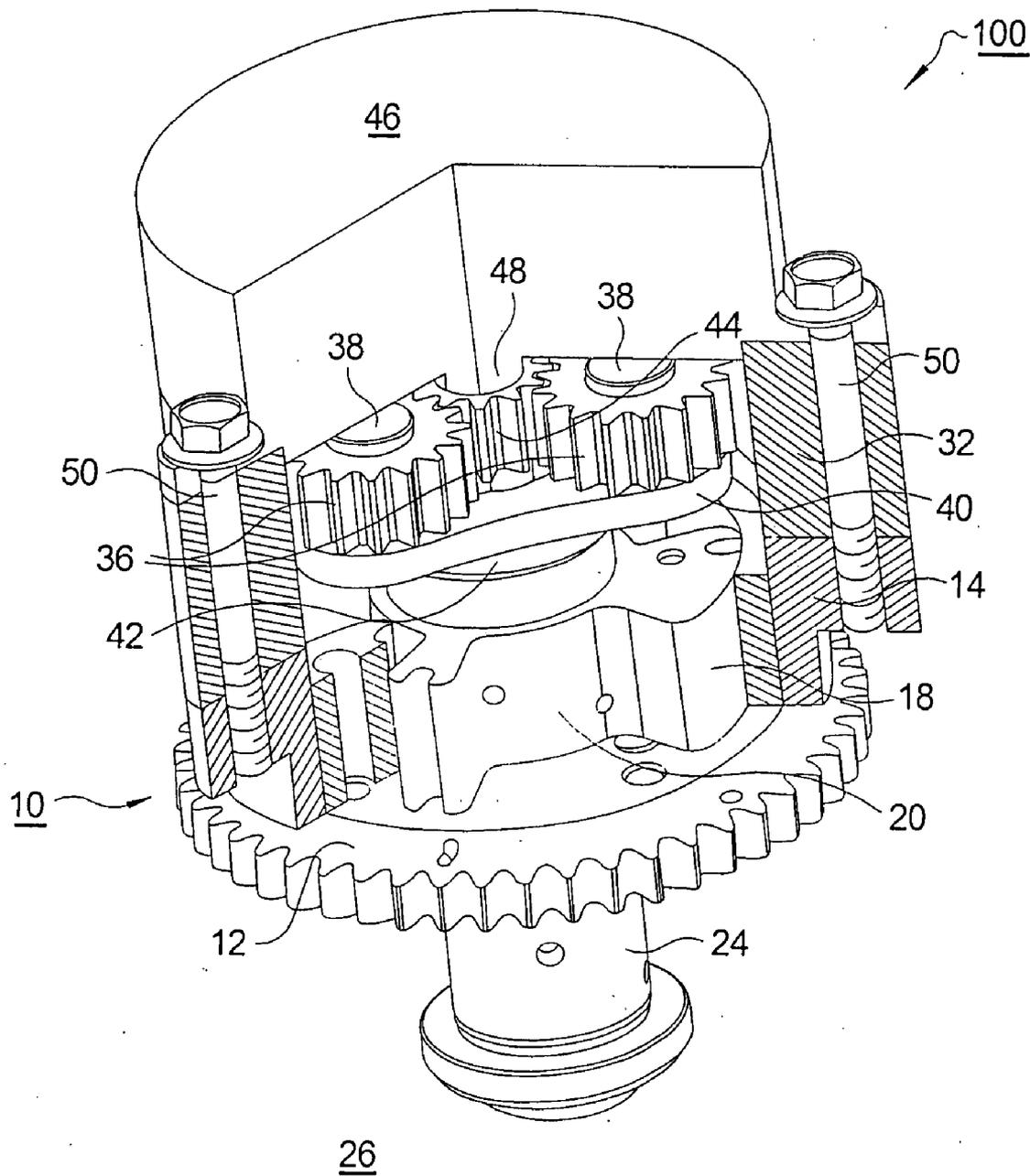


FIG. 2.

**ELECTRO-HYDRAULIC HYBRID  
CAMSHAFT PHASER**

**RELATIONSHIP TO GOVERNMENT  
CONTRACTS**

**[0001]** The present invention was supported in part by a U.S. Government Contract, No. DE-FC26-05NT42483. The United States Government may have rights in the present invention.

**TECHNICAL FIELD**

**[0002]** The present invention relates to camshaft phasers for varying the phase relationship between crankshafts and camshafts in internal combustion engines; more particularly, to such phasers wherein the rotor is actuated either hydraulically or electrically; and most particularly, to a hybrid camshaft phaser (HCP) wherein hydraulic rotor actuation torque is selectively supplemented by electrical actuation torque to improve the speed of response under operating conditions that are borderline for hydraulic actuation alone.

**BACKGROUND OF THE INVENTION**

**[0003]** Camshaft phasers for varying the phase relationship between the crankshaft and a camshaft of an internal combustion engine are well known.

**[0004]** A prior art hydraulically actuated camshaft phaser typically comprises a plurality of outwardly-extending vanes on a rotor interspersed with a plurality of inwardly-extending lobes on a stator, forming alternating advance and retard chambers between the vanes and lobes. Engine oil pressurized by the engine's oil pump is supplied via a multiport oil control valve (OCV) directed by an engine control module (ECM) to either the advance chambers or the retard chambers as required to meet current or anticipated engine operating conditions.

**[0005]** A prior art electrically actuated camshaft phaser typically comprises a DC electric motor coupled through a gearbox transmission to a phaser rotor attached to the engine camshaft. The rotor is disposed within a stator driven conventionally by the engine crankshaft and supportive of the motor and gearbox. Operation of the motor serves to vary the phase relationship of the rotor to the stator.

**[0006]** Some benefits of a typical hydraulic phaser are that it requires relatively little electric current from the engine's electrical system, generally less than about 5 amps; it is hydraulically self-locking of the rotor within the stator at any position; it is capable of defaulting to a specific rotor angle; and it is low in cost.

**[0007]** Weaknesses are that it is slow to respond under conditions of high oil viscosity (low temperatures, as at startup in some climates) or low oil pressure (low engine speed or hot engine oil); has a limited rotational range of authority; and has delayed phasing operation after engine startup due to time required to fill and stabilize the phaser system.

**[0008]** Some benefits of a typical electric phaser are very fast cam phasing, if sufficient current is supplied; a wide range of phasing operating temperatures (relative insensitivity to oil or coolant temperatures); prompt phasing, even at engine startup; and insensitivity to oil contamination, a significant problem when using hydraulic phasers on diesel engines.

**[0009]** Weaknesses are that it is expensive to manufacture, costing several times the cost of a comparable hydraulic

phaser; requires high current, typically in the range of 10-15 amps, requiring a separate driver box and complex EMS system; has no inherent default position capability; and requires use of a gearbox transmission having poor efficiency to provide self-locking, resulting in high current demand with a large DC motor.

**[0010]** Increasingly strict engine emissions requirements and advanced engine technologies can both benefit from a camshaft phaser having improved speed of response and greater range of temperature and engine speed operation.

**[0011]** What is needed is a camshaft phaser having the mechanical properties of a hydraulic phaser and the response times and operating range of an electric phaser.

**[0012]** It is a principal object of the present invention to increase the speed of response and the operating range of a camshaft phaser.

**SUMMARY OF THE INVENTION**

**[0013]** Briefly described, a hybrid camshaft phaser in accordance with the invention comprises a conventional vane-type hydraulically-actuated phaser to which is coupled an electric motor and gearbox. The gearbox output shaft is coupled to the phaser rotor. Under engine operating conditions in which the speed and/or torque response of a hydraulic phaser is poor, the electric motor augments the hydraulic actuation. Such conditions include at least low ambient temperatures at which oil viscosities are high, and high ambient temperatures and/or low engine speeds at which oil pressures are low.

**BRIEF DESCRIPTION OF THE DRAWINGS**

**[0014]** The present invention will now be described, by way of example, with reference to the accompanying drawings, in which:

**[0015]** FIG. 1 is an exploded isometric view of an electro-hydraulic hybrid camshaft phaser in accordance with the invention; and

**[0016]** FIG. 2 is an assembled isometric view in cutaway of the hybrid phaser shown in FIG. 1.

**DESCRIPTION OF THE PREFERRED  
EMBODIMENTS**

**[0017]** Referring now to FIGS. 1 and 2, a first embodiment 100 of an electro-hydraulic hybrid camshaft phaser in accordance with the invention includes a vane-type camshaft phaser 10 comprising a pulley or sprocket 12 for engaging a timing chain or belt (not shown) operated by an engine crankshaft (not shown). A stator 14 is disposed against and rotates with pulley/sprocket 12. Stator 14 is provided with a central chamber 16 for receiving a rotor 18 having a hub 20. Hub 20 is provided with a recess coaxial with a central bore in sprocket 12, allowing access of an end 22 of engine camshaft 24 into rotor hub 20 during mounting of phaser 10 onto an internal combustion engine 26 during assembly thereof. Central chamber 16 is closed by a cover plate 28 (omitted from FIG. 2 for clarity) having a central opening 30, forming advance and retard chambers between the rotor and the stator in chamber 16.

**[0018]** A power transmission 31 comprises a planetary gear transmission box 32 having an internal ring gear 34 mounted to stator 12 and containing a plurality of planet gears 36 rotationally mounted on fixed shafts 38 to an output plate 40 having a central output shaft 42 engaged into rotor hub 20.

Optionally, a friction or electromagnetic clutch (not shown) may be disposed between output shaft 42 and rotor hub 20. A sun gear 44 is disposed in mesh with planet gears 36.

[0019] An electric motor drive 46, shown here generically, has an output shaft 48 to which sun gear 44 is mounted. The entire assembly 100 is held together by a plurality of binder screws 50 engaged into threaded bores in stator 14.

[0020] Power transmission 31 is shown here preferentially as a planetary gear system, although it should be understood that any type of reduction gear transmission is fully contemplated by the invention. Examples of contemplated alternate gear arrangements are spur, helical, harmonic, and cycloidal, which may be single stage or multiple stage.

[0021] Further, a preferred motor arrangement for electric motor drive 46 is a small size pancake DC motor disposed axially or inline, although other motor types and arrangements such as a standard radial or transverse DC motor are fully contemplated by the invention. The motor may include brushes or may be brushless.

[0022] In operation, electro-hydraulic camshaft phaser 100 is operated like a conventional hydraulic camshaft phaser. As is well known in the prior art, hydraulic fluid (not shown), typically in the form of pressurized engine lubricating oil, is supplied to the advance and retard chambers within the phaser to cause the rotor to change rotational phase with the stator, thus changing the rotational phase of the camshaft with respect to the engine crankshaft to achieve desired engine operating characteristics. Selective oil flow is typically provided by a spool valve (not shown) controlled by an Engine Control Module (ECM) (not shown).

[0023] In addition, the ECM selectively controls the energizing of electric motor drive 46 and also any optional electromagnetic clutch. When energized, electric motor drive 46 provides added torque to rotor 18 that complements the available hydraulic torque also applied.

[0024] In a presently preferred operating algorithm, electric motor drive 46 is energized whenever engine 26 is started, to eliminate the phasing lag characteristic of a hydraulic phaser.

[0025] If the ambient operating temperature of the engine oil is below a predetermined value, for example -7° C., at which temperature oil viscosity may be too high for properly responsive phasing, the electric motor assist is operative.

[0026] Similarly, under conditions of low engine speed and/or high oil temperature wherein engine oil pressure may be too low for responsive phasing, the electric motor assist is also operative.

[0027] Thus, the operating range of thermal conditions and engine speeds is significantly greater for an electro-hydraulic hybrid phaser in accordance with the present invention than for a prior art hydraulic phaser alone. Preferably, the electric motor assist is de-energized during other engine operating conditions, although full-time or other scheduled energizing of the electric-motor assist is fully contemplated by the invention.

[0028] While the invention has been described by reference to various specific embodiments, it should be understood that numerous changes may be made within the spirit and scope of

the inventive concepts described. Accordingly, it is intended that the invention not be limited to the described embodiments, but will have full scope defined by the language of the following claims.

1. A hybrid camshaft phaser, comprising:

a) a hydraulic camshaft phaser having a stator and a rotor disposed for rotation within said stator, said hybrid phaser being actuatable by injection of a hydraulic fluid into chambers formed between said rotor and said stator; and

b) an electric motor drive operatively connected to said rotor for selectively augmenting actuating torque of said hydraulic camshaft phaser.

2. A hybrid camshaft phaser in accordance with claim 1 wherein said electric motor drive comprises an electric motor and a gear transmission.

3. A hybrid camshaft phaser in accordance with claim 2 wherein said electric motor is selected from the group consisting of axial motor, radial motor, brush, brushless, and combinations thereof.

4. A hybrid camshaft phaser in accordance with claim 2 wherein said gear transmission is selected from the group consisting of spur, helical, planetary, harmonic, and cycloidal.

5. A hybrid camshaft phaser in accordance with claim 2 wherein said gear transmission is selected from the group consisting of single stage and multiple stage.

6. A hybrid camshaft phaser in accordance with claim 1 further comprising a clutch disposed between said electric motor drive and said rotor.

7. A hybrid camshaft phaser in accordance with claim 6 wherein said clutch is selected from the group consisting of friction clutch and electromagnetic clutch.

8. An internal combustion engine including a camshaft and a crankshaft wherein a hybrid camshaft phaser is interposed between said crankshaft and said camshaft, wherein said hybrid camshaft phaser includes

a hydraulic camshaft phaser having a stator driven by said crankshaft and a rotor disposed for rotation within said, stator and attached to said camshaft, said hydraulic camshaft phaser being actuatable by injection of a hydraulic fluid into chambers formed between said rotor and said stator, and

an electric motor drive coupled to said rotor for selectively augmenting actuating torque of said hydraulic camshaft phaser.

9. A hybrid electro-hydraulic phaser, for shifting the angular phase of a first shaft relative to a second shaft comprising:

a) a stator rotatable by one of said first and second shafts;

b) a rotor disposed for rotation within said stator and rotatable with the other of said first and second shafts, said hybrid phaser being actuatable by injection of a hydraulic fluid into chambers formed between said rotor and said stator; and

c) an electric motor drive operatively connected to one of said rotor and said stator for selectively augmenting actuating torque of said phaser.

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