June 25, 1968 W. D. LION ET AL 3,389,596

VISCOSITY MEASUREMENT

Filed April 29, 1965 3 Sheets-Sheet 1

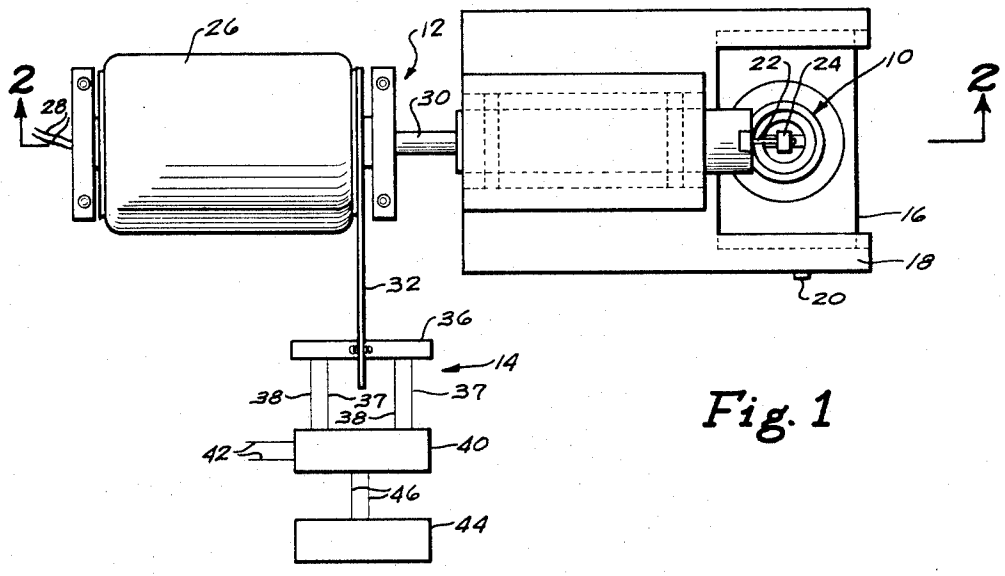


Fig. 1

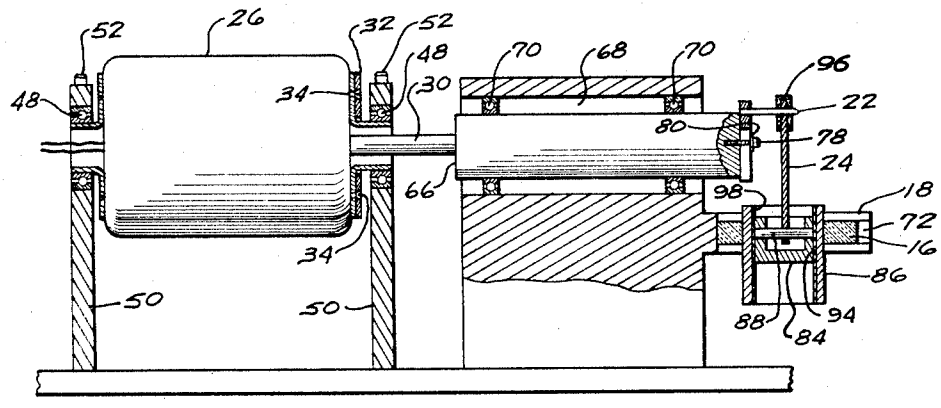


Fig. 2

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VISCOSITY MEASUREMENT

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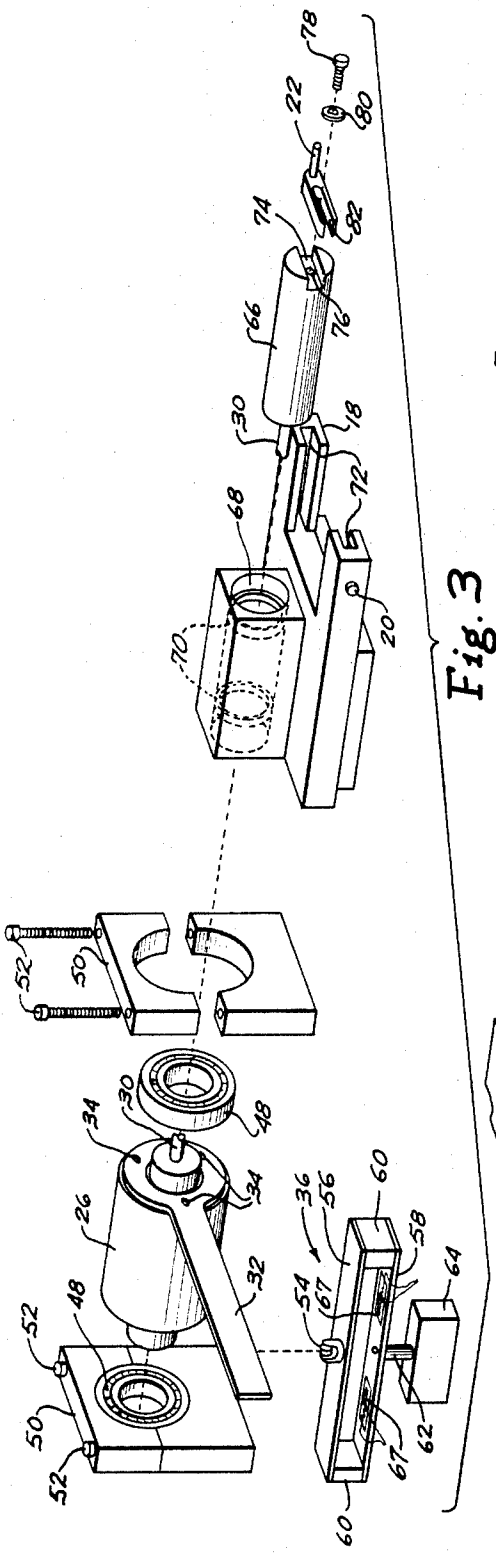


Fig. 3

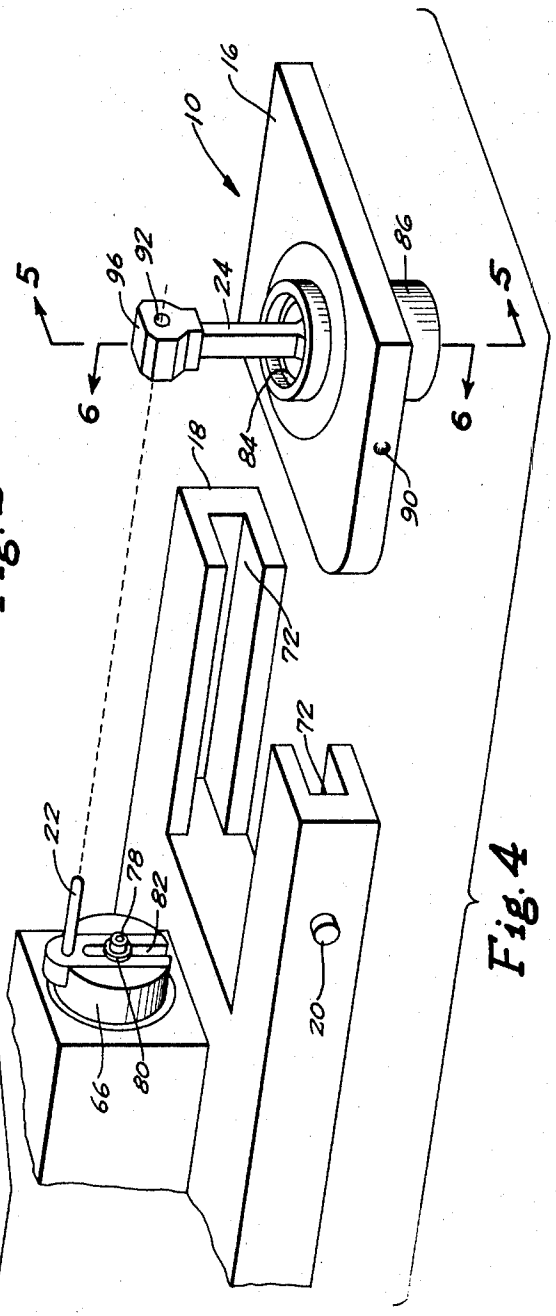


Fig. 4

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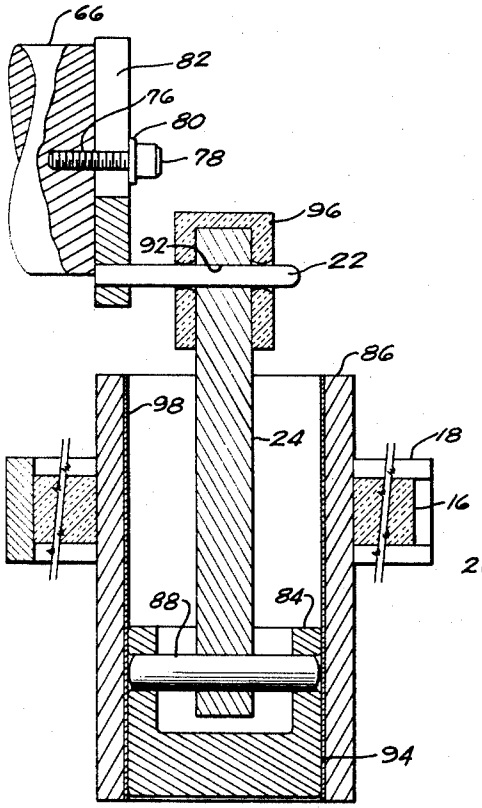


Fig. 5

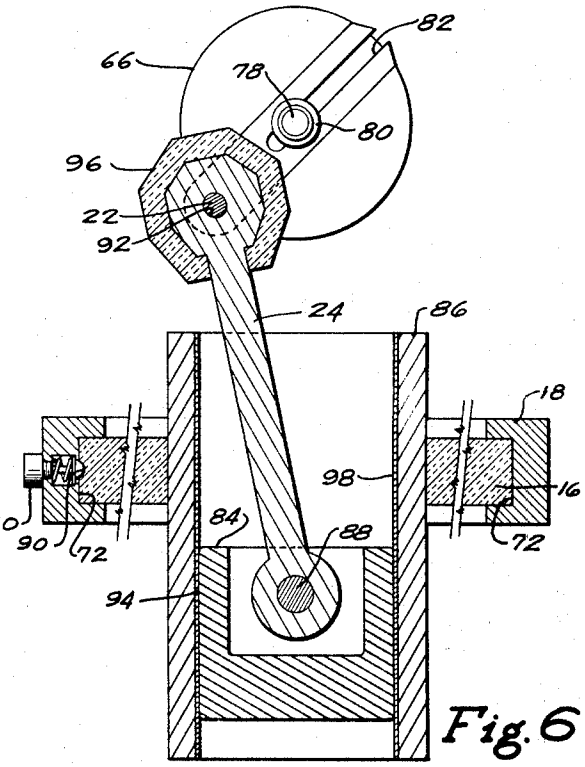


Fig. 6

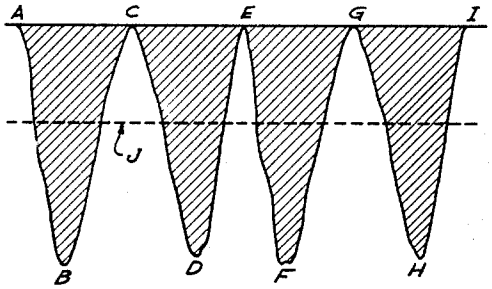


Fig. 8

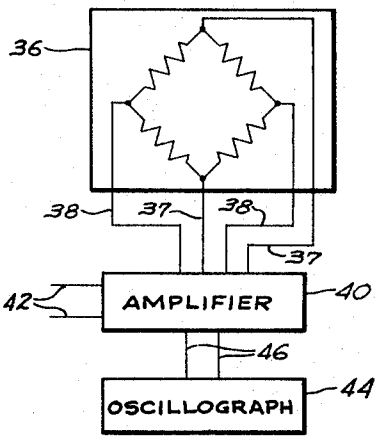


Fig. 7

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3,389,596

VISCOSITY MEASUREMENT

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10 Claims. (Cl. 73—60)

ABSTRACT OF THE DISCLOSURE

Oil viscosities are measured under low temperature conditions and the measurements correlate to a high degree with the cranking properties of internal combustion engines under low temperature conditions. The viscometer utilizes as a sensing assembly a cylinder secured in a fixed position and a moveable piston with a small annular space therebetween. A film of the test oil is applied to the annular space. Constant speed motor means reciprocates the piston within the cylinder. The resistance of the test oil to the reciprocating action is determined by measuring the reaction to said resistance at the motor.

This invention relates to process and apparatus for the determination of viscosity of a liquid, such as a lubricating oil. The process and apparatus of this invention determines viscosity by shearing a liquid film by the reciprocating action of a piston in a cylinder. Low temperature lubricating oil viscosities determined by the method and apparatus of this invention correlate to a high degree with the cranking properties of internal combustion engines under low temperature conditions.

Lubricating oil in an internal combustion engine is subjected to shearing action between engine components which move relative to one another in two different ways. The first type of relative movement is rotation of engine components relative to one another and the second type of relative movement is the reciprocation of engine components relative to one another. During cranking of an engine the resistance offered by an oil between reciprocating parts is substantially greater than the resistance offered by the oil between parts which rotate relative to each other. When an internal combustion engine is cranked the principal resistance to engine cranking is the residual oil film between the piston and cylinder. This invention determines viscosity by measuring the resistance to reciprocating shearing action of a film of lubricating oil while excluding substantially all rotary shear stress from the measurement. The measurement of the resistance to reciprocating shearing action of a lubricating oil maintained at a low temperature in accordance with this invention was found to be an accurate prediction of the low temperature cranking properties of the test lubricating oil in an internal combustion engine.

The apparatus of this invention comprises a viscometer apparatus having a detachable viscosity sensing assembly, said detachable assembly comprising a cylinder and a piston, the diameter of said piston being slightly smaller than the diameter of said cylinder to provide a small annular space therebetween for the application of a film of the test oil, piston rod means attached to said piston for transmitting reciprocating motion to said piston, said piston being freely removable from said cylinder when said assembly is detached from said viscometer to permit uniform application of a film of lubricant to the piston and to the cylinder wall along the entire length thereof, the apparatus to which said viscosity sensing assembly is attached comprising motor means, shaft means actuated by said motor means, mounting means in the region of said shaft means adapted to receive said detachable viscosity sensing means, connecting means adapted to connect said piston rod means to said shaft means whereby

said motor means motivates the reciprocation of said piston within said cylinder, and measuring means connected to said apparatus for measuring the resistance offered by the oil film to reciprocation of said piston.

In terms of process the present invention comprises the application of a film of lubricating oil to fill a small annular space between a piston and a cylinder, reciprocating said piston within said cylinder, the speed and number of reciprocations being sufficiently low to avoid inducing any substantial increase in temperature in said oil film and corresponding generally to the low cranking speeds imparted to an engine by a starter motor, the annular space between said piston and cylinder permitting substantially free movement of said piston relative to said cylinder except for said oil film so that substantially the only resistance against free reciprocation is the film of oil in said annular space, maintaining said film of oil at a constant temperature and measuring the resistance to reciprocation offered by said film of oil.

This invention will become more apparent by reference to the accompanying drawings in which

FIGURE 1 is a top view of an apparatus of the invention,

FIGURE 2 is a view taken through the section **2—2** of FIGURE 1,

FIGURE 3 is an exploded view of a viscometer apparatus excluding the detachable viscosity sensing element,

FIGURE 4 is a view of a viscosity sensing element and a segment of the apparatus of FIGURE 3 to illustrate the mode of attachment of the sensing element to the drive means,

FIGURE 5 is a view taken through the section **5—5** of FIGURE 4, including connecting elements,

FIGURE 6 is a view taken through the section **6—6** of FIGURE 4, including connecting elements,

FIGURE 7 is a schematic electrical diagram of the torque measuring apparatus, and

FIGURE 8 is a tracing of an actual oscillograph chart produced during a viscosity measurement with an apparatus of this invention.

Referring to FIGURE 1, three major components of the viscometer apparatus are shown including the viscosity sensing assembly **10**, the cranking apparatus **12**, and the measuring apparatus **14**. The viscosity sensing assembly is provided with a flange **16** so that it can be mounted in a slotted cradle **18** of the cranking apparatus. Flange **16** is fabricated of a heat insulating material such as a glass fibre, so that the cylinder can be handled when cold without body heat being transferred to the oiled surfaces within viscosity sensing assembly **10**. Spring loaded pin **20** holds flange **16** securely in place in cradle **18**. When flange **16** is inserted into slotted cradle **18**, crankpin **22** slips into a corresponding opening in piston rod **24** to complete the assembly. The assembly is driven by synchronous motor **26** which receives power through leads **28** and which drives shaft **30**. Motor **26** operates at a constant low speed of from about 2 to 200 revolutions per minute. The speed of motor **26** is constant regardless of viscosity. The preferred speed is from about 50 to 75 revolutions per minute. Because motor **26** operates at a constant speed the apparatus imparts a uniform shear rate to a liquid under test and permits correlation between the resistance offered by the liquid and its viscosity. Measuring assembly **14** is connected to the cranking apparatus by means of torque arm **32** which is bolted to motor **26** by means of bolts **34**, shown in FIGURE 2. The free end of torque arm **32** rests on a strain gauge **36**. Wires **37** and **38** extend between the strain gauge **36** and amplifier **40**. Amplifier **40** receives power through lines **42**. The output of the amplifier is fed to oscillograph **44** through wires **46**.

Details of the cranking assembly **12** will become more apparent by referring to FIGURES 2 and 3. Motor **26** is

shown in these figures to be mounted on a pair of lubricant-free ball bearings 48 with the outer race of each bearing 48 being secured tightly within a pair of pedestal supports 50 by means of bolts 52. The casing of motor 26 is free to rotate in bearings 48. Torque arm 32 is secured to the casing of motor 26 by means of bolts 34 and the free end of torque arm 32 rests on a small roller 54 which is secured to strain gauge 36. Strain gauge 36 comprises upper flat spring 56 and lower flat spring 58 which are secured to each other at the ends thereof by means blocks 60. Lower flat spring 58 is secured to a central pivot 62 which is attached to a base 64. Lower flat spring 58 is also provided with a pair of strain gauge wire assemblies 67 having wires extending therefrom for connection to an amplifier.

Rotatable shaft 30 has an enlarged portion 66 which extends through passageway 68 in the superstructure of slotted cradle 18. Passageway 68 is provided with a pair of lubricant-free ball bearings 70 for the support of shaft portion 66. Cradle 18 is provided with a pair of slots 72 for snugly receiving flange 16 of viscosity sensing assembly 10. The terminus of shaft portion 66 is provided with a transverse slot 74 for snugly receiving the base of crankpin 22. Slot 74 is provided with threaded hole 76 so that crankpin 22 can be secured at slot 74 by means of bolt 78 and washer 80. The base of crankpin 22 is provided with its own slot 82 so that the distance of crankpin 22 from the axis of shaft portion 66 can be adjusted. As will be made apparent below, an increase or decrease in the distance of crankpin 22 from the axis of shaft portion 66 provides a corresponding increase or decrease, respectively, in the length of stroke in the viscosity sensing element.

The mode of attachment of detachable viscosity sensing assembly 10 to the cranking apparatus is shown clearly in FIGURE 4. Flange 16 of viscosity sensing assembly 10 is nearly as thick as corresponding slots 72 in the cranking apparatus. Before flange 16 is inserted into slots 72 and before piston rod 24 is connected to crankpin 22, piston rod 24 is free so that piston rod 24 and piston 84 which is attached thereto can be freely removed from and returned to the interior of cylinder 86. As is shown in FIGURES 5 and 6, piston rod 24 is attached to piston 84 by means of wrist pin 88 which extends through both the lower end of piston rod 24 and the walls of piston 84. When flange 16 is inserted into slots 72 spring loaded pin 20 is forced to protrude outwardly from the side of cradle 18 until it comes into register with depression 90 in the side of flange 16 whereupon it springs into depression 90 and secures flange 16 against further sliding within slots 72. The sliding of flange 16 into slots 72 permits crankpin 22 to slide through opening 92 in piston rod 24.

There is an annular space 94 between piston 84 and cylinder 86 which can vary within substantial limits depending upon the liquid being tested but is advantageously between 0.0001 and 0.0004 inch. Piston 84 is free of piston rings which would scrape against the wall of cylinder 86 during reciprocation. A temperature insulating material 96 is provided at the top of piston rod 24 to assist temperature control during a test by preventing body heat from traveling to a film of lubricant 98 applied to the walls of cylinder 86 and piston 84 during manual insertion of viscosity sensing unit 10 into cradle 18.

The operation of the apparatus is as follows. Before beginning a test, viscosity sensing element 10 is removed from slots 72 and piston 84 is then lifted out of cylinder 86. The piston and the cylinder are carefully washed in a suitable solvent to remove from piston and cylinder surfaces all traces of oil used in the previous test. The piston and cylinder are then dried of solvent. Thereupon, oil to be tested is applied by any suitable method such as with a hypodermic syringe and needle to the outer surface of piston 84 and the inner surface of cylinder 86. The oil is applied as a very thin film over the entire length of the piston and cylinder and the piston is then reciprocated a few times manually to cause the film to assume a uniform thickness equal to the width of annulus 94. Since annulus 94 is only between about 0.0001 to 0.0004 inch thick the layer of oil is so thin that it will not flow. Flange 16 is then inserted into slots 72 so that crankpin 22 is received by opening 92 of piston rod 24. Sensing unit 10 is locked into position when spring loaded pin 20 is received by depression 90. The assembled apparatus including viscosity sensing unit 10 with oil applied thereto, cranking apparatus 12, and measuring apparatus 14 is kept in an environment maintained at a constant temperature until the entire apparatus, particularly viscosity sensing unit 10 and the oil film contained thereon, reaches the temperature of the environment. The environmental temperature is the temperature at which the viscosity measurement is desired. The test is then performed in the controlled temperature environment in order to maintain the oil film at a constant temperature throughout the test procedure.

Power is applied to synchronous motor 26 which imparts rotation to shaft 30. The test requires very few revolutions of the motor for the measurement to be completed and it is advantageous to utilize a timer in conjunction with the motor to open the circuit to the motor after about only 6 or 7 revolutions. Before sensing element 10 is attached to cranking unit 12, the assembly consists of the structure shown in FIGURE 3. This structure provides substantially no load upon the motor. When motor 26 operates cranking unit 12 without sensing element 10 attached thereto, the reaction torque of the motor is so small as to be unmeasurable with the torque measuring equipment used to measure the reaction torque of the motor during a viscosity test with sensing unit 10 attached to the cranking unit. The load on motor 26 in the absence of sensing unit 10 is negligible because the shaft-supporting ball bearings 70 are dry of lubricant and the speed of rotation is low. With the sensing unit attached to the cranking unit the additional load on the motor consists of the friction of crankpin 22 and wrist pin 88 within piston rod 24 and the resistance to shearing action of the oil in the clearance space 94. The crankpin and wrist pin bearing surfaces are free of lubricant and the crankpin and wrist pin are both advantageously of steel construction while piston rod 24 is advantageously of aluminum construction. Since contacting steel and aluminum parts constitute low friction bearings, the contribution of crankpin 22 and wrist pin 88 to the load on the motor is negligible. The motor load, therefore, and the resulting reaction torque on the strain gauge 36 is a direct measure of the viscosity of the oil within the clearance space 94, all other resistance in the apparatus constituting less than 1 percent of the measured torque.

Motor 26 causes shaft 30, shaft portion 66, and crankpin 22 to rotate and in turn to reciprocate piston rod 24 and piston 84 within cylinder 86. Reciprocation of piston 84 relative to cylinder 86 creates a reciprocating shear stress upon oil film 98. The absence of piston rings around the exterior of piston 84 insures that no scraping of oil film 98 will occur during the reciprocating motion of the piston 84. Substantially the entire load carried by motor 26 is contributed by the shear stress in oil film 98. The rotational speed of motor 26 is constant and is sufficiently low and the number of revolutions required for a test is sufficiently low that the temperature of oil film 98 does not rise due to work upon the oil film during the test. Substantially constant viscosity readings are produced during successive reciprocations of piston 84 within cylinder 86.

There are several ways to vary the shear rate or the shear stress of a given oil with the apparatus of this invention. First, a motor of different speed can be utilized. Secondly, with a given motor, crankpin 22 can be adjusted outwardly or inwardly to increase or decrease, respectively, the shear rate within viscosity sensing assembly 10. Movement of crankpin 22 is permitted by loosening bolt 78. Thirdly, a different sensing assembly 10 can be utilized

in which a different clearance **94** is provided between piston **84** and cylinder **86**.

Motor **26** is suspended on the pair of bearings **48** and is free to rotate within the bearings **48** because it is not secured by bolts or other means to prevent rotation thereof. When motor **26** is operated without viscosity sensing unit **10** attached there is a negligible load upon motor **26** so that the casing of motor **26** does not tend to significantly rotate in bearings **48**. However, when sensing unit **10** is attached to the cranking unit, the shearing action in the test oil film **98** imparts a significant load to motor **26** and in reaction to this load the motor casing tends to rotate in a direction opposite to the direction of rotation of shaft **30**. Since motor **26** is mounted on bearings **48**, the only obstruction to reactive rotation of the casing of motor **26** is the impingement of torque arm **32** upon strain gauge spring roller **54**. As the shear stress in the test oil increases, the tendency of the motor **26** to rotate in reaction will correspondingly increase, and the pressure of torque arm **32** upon roller **54** will similarly increase. Pressure on roller **54** causes flexure in flat springs **56** and **58** whereby flat springs **56** and **58** are transformed from flat surfaces to curved surfaces. Strain gauge wire assemblies **67** detect the strain in spring **58** occasioned by this flexure. Each strain gauge wire assembly **67** contains two wires, the first disposed so as to be distended by the flexure of spring **58** and the second disposed transversely to the first so as to be unaffected by said flexure but to act as a temperature correcting element to render the readings in measuring apparatus **14** immune to changes in temperature.

Referring to FIGURE 7, the pair of springs **56** and **58** and the pair of strain gauge wire assemblies **67** are schematically indicated at **36**. Two of the resistances within the Wheatstone bridge of element **36** are responsive to mechanical strain in spring **58** while the other two resistances are immune to mechanical strain and are responsive to temperature changes only, thereby tending to correct the measurement for changes in temperature. The power input to the Wheatstone bridge flows through leads **37** while the output from the Wheatstone bridge flows through leads **38**. Power is supplied to amplifier **40** through leads **42** and the output of amplifier **40** is supplied to oscillograph **44** through leads **46**. Oscillograph **44** provides an indication or record of the shear stress of the oil in viscosity sensing unit **10**.

FIGURE 8 is a tracing of an actual oscillograph chart produced during a viscosity determination with the apparatus of this invention. The shaded portion of the tracing indicates two full revolutions of piston **84** within cylinder **86**. Position A on the tracing denotes zero torque and corresponds to a top dead center position of piston **84** within cylinder **86**. Position B denotes a maximum torque such as occurs when the angle between the crankpin base and the piston rod **24** is 90 degrees and the piston **84** is near the middle of cylinder **86**, whereupon its velocity is a maximum and the shear rate is also a maximum. At position C, the piston is at bottom dead center of cylinder **86**, whereat its velocity is zero and the shear rate is therefore also zero. Position D on the chart corresponds to an angle between the crankpin base and the piston rod **24** of 90 degrees and a position of piston **84** near the center of cylinder **86** with the piston moving upwardly and its velocity being a maximum once again. Position E on the chart denotes the return of piston **84** to top dead center in the cylinder. The curve EFGHI denotes a second revolution substantially identical to the first. The dashed line J on the chart indicates substantially the average torque for the two revolutions. It is noted that substantially reproducible torque curves are achieved during sequential reciprocations. The torque achieved with a given viscosity sensing unit **10** can easily be correlated with viscosity by calibration with oil of known viscosity and the torque readings obtained in the oscillograph can thereby readily be converted to viscosity units.

A wide range of dimensions can be utilized in viscosity sensing unit **10**. For example, the bore of the cylinder can vary between about 0.5 and 1.25 inches and the length of the piston stroke can vary between about 0.25 and 1.25 inches. Shear rates measured with reciprocating viscometers of this invention can vary within a wide range, for example, between 100 and 100,000 seconds^{-1} by varying the bore of the cylinder, the stroke of the piston, the piston-to-cylinder clearance or the rotational speed.

Various changes and modifications can be made without departing from the spirit of this invention or the scope thereof as defined in the following claims.

We claim:

1. A viscometer apparatus having a viscosity sensing assembly, said viscosity sensing assembly comprising cylinder means secured in a fixed position and piston means, the diameter of said piston means being slightly smaller than the diameter of said cylinder means for providing a small annular space therebetween to receive a film of oil, piston rod means attached to said piston means for transmitting reciprocating motion to said piston means, said piston means being freely moveable within said cylinder in the absence of said film of oil, constant speed motor means, shaft means actuated by said motor means, connecting means adapted to connect said piston rod means to said shaft means whereby said motor means motivates the reciprocation of said piston means within said cylinder means, and measuring means for measuring the reaction at said motor means to the resistance of the oil film against reciprocation of said piston means.

2. The apparatus of claim **1** wherein said viscosity sensing assembly in detachable from said apparatus.

3. The apparatus of claim **1** wherein said annular space is between about 0.0001 and 0.0004 inch.

4. The apparatus of claim **1** wherein the casing of said motor means is rotatable in reaction to the resistance of said oil film, including torque measuring means for measuring the torque imparted by the reactive rotation of the casing of said motor means.

5. The apparatus of claim **1** wherein substantially the only load upon said motor means is contributed by said oil film.

6. A viscometer having a detachable viscosity sensing assembly, said viscosity sensing assembly comprising cylinder means secured in a fixed position and piston means, the diameter of said piston means being slightly smaller than the diameter of said cylinder means for providing a small annular space therebetween to receive a film of oil, piston rod means attached to said piston means for transmitting reciprocating motion to said piston means, said piston means being freely removable from said cylinder means when said viscosity sensing assembly is detached from said viscometer for application of lubricant to the piston wall along substantially the entire length thereof, the apparatus to which said viscosity sensing assembly is attached comprising constant speed motor means, shaft means actuated by said motor means, mounting means in the region of said shaft means adapted to receive said detachable viscosity sensing means, connecting means adapted to connect said piston rod means to said shaft means whereby said motor means motivates the reciprocation of said piston means within said cylinder means, and measuring means for measuring the reaction at said motor means to the resistance of the oil film against reciprocation of said piston means.

7. The apparatus of claim **6** wherein there is substantially no load on said motor means in the absence of said oil film.

8. A process comprising applying a film of lubricating oil to fill a small annular space between a cylinder secured in a fixed position and a piston, reciprocating with constant speed motor means, said piston within said cylinder at a speed which is sufficiently low that there is no substantial increase in the temperature of said oil film as a result of said reciprocation, maintaining said oil film at

substantially a constant temperature, said piston being freely moveable within said cylinder except for said oil film so that substantially the only resistance against free reciprocation is contributed by the film of oil in said annular space, and measuring the reaction at the motor means to the resistance against reciprocation offered by said film of oil.

9. The process of claim **1** wherein the speed of reciprocation is constant regardless of the resistance of said oil film.

10. A process comprising applying a film of viscous liquid to fill a small annular space between a cylinder secured in a fixed position and a piston, reciprocating with constant speed motor means, said piston within said cylinder at a speed which is sufficiently low that there is no substantial increase in the temperature of said liquid film as a result of said reciprocation, maintaining said liquid film at substantially a constant temperature, said piston being freely moveable within said cylinder except for said

liquid film so that substantially the only resistance against free reciprocation is contributed by the liquid film in said annular space, and measuring the reaction at the motor means to the resistance against reciprocation of said liquid film.

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