March 8, 1966 D. L. KLASS 3,239,041

APPARATUS AND METHOD OF VARYING BULK MODULUS OF ELECTROVISCOUS FLUID

Filed April 13, 1962 3 Sheets-Sheet 1

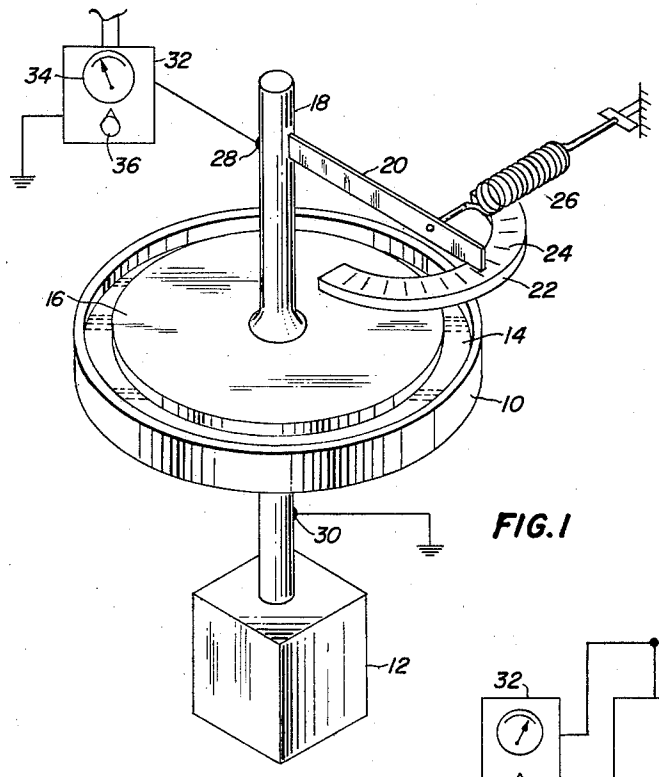


FIG. 1

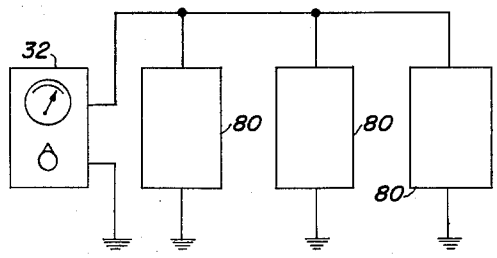


FIG. 3

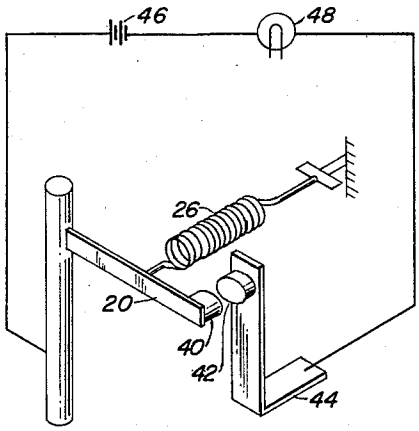


FIG. 2

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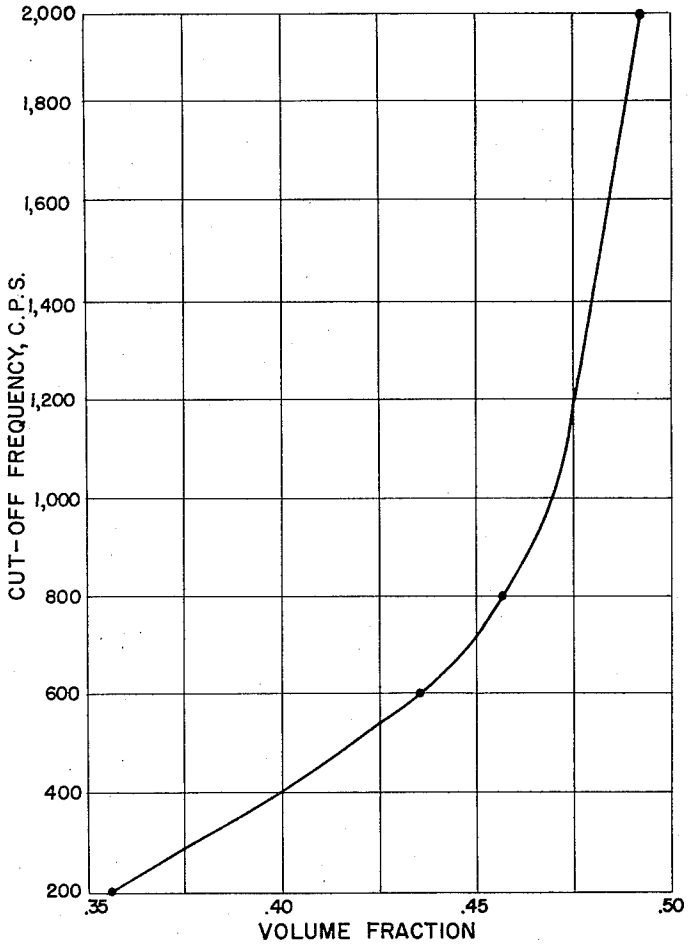


FIG. 4c

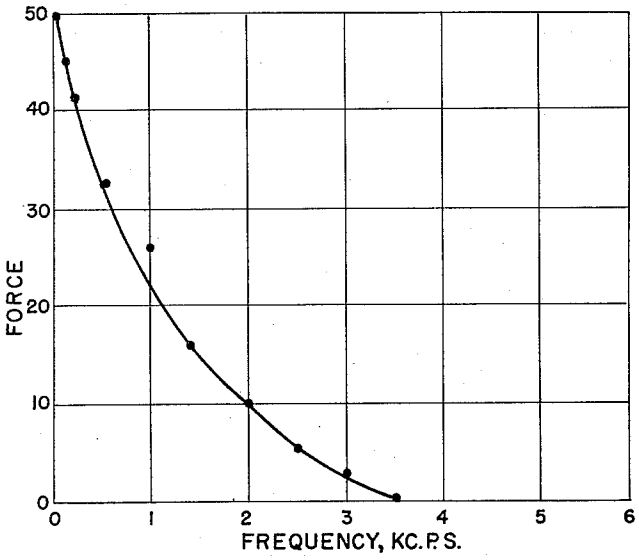


FIG. 4a

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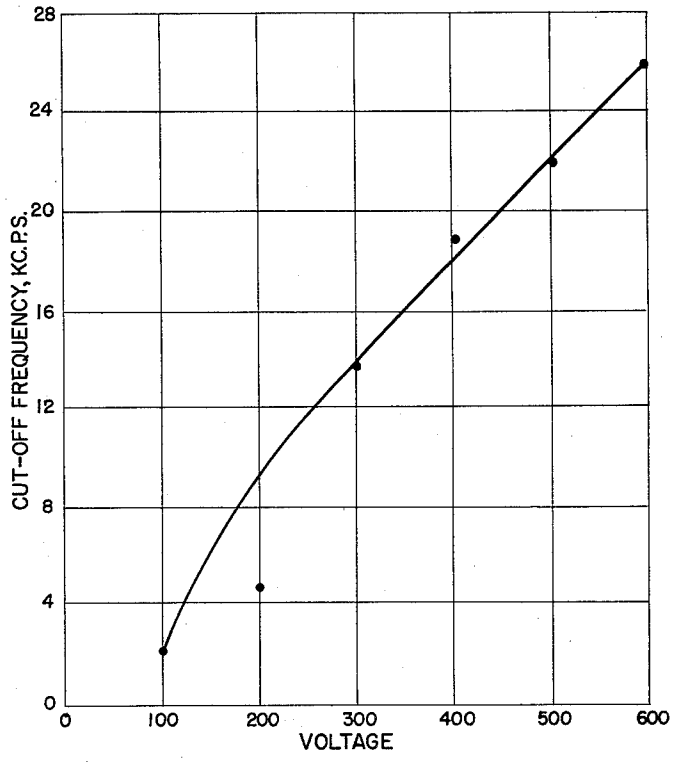


FIG. 4d

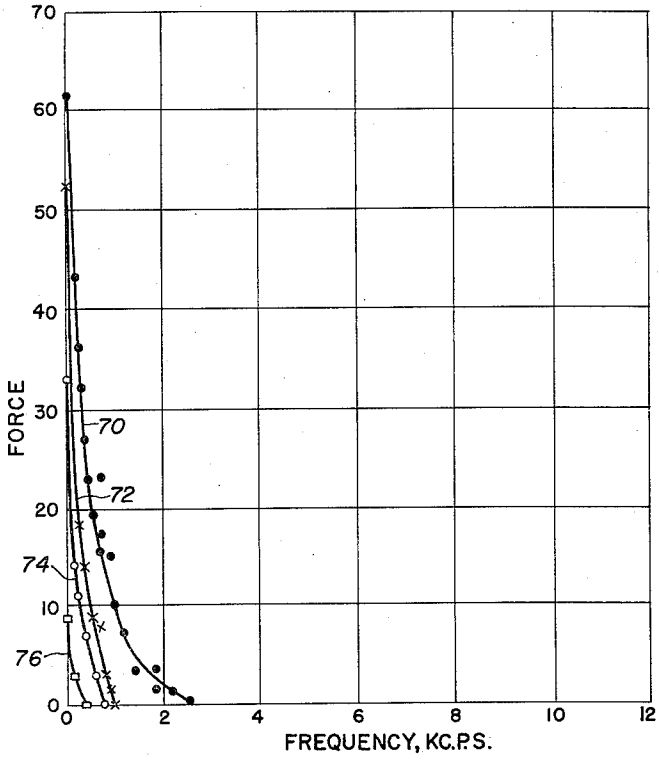


FIG. 4b

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United States Patent Office 3,239,041 Patented Mar. 8, 1966

3,239,041

APPARATUS AND METHOD OF VARYING BULK MODULUS OF ELECTROVISCOUS FLUID

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Filed Apr. 13, 1962, Ser. No. 187,368
7 Claims. (Cl. 192—21.5)

This invention relates to a method for controlling the force transmitted by an electroviscous fluid coupling. In another aspect, the invention relates to a method and apparatus, based on the use of an electroviscous fluid coupling, for determining the frequency of an alternating current.

The operation of electroviscous fluid couplings is described in various patents to W. M. Winslow, such as U.S. Patent No. 2,417,850. Briefly an electroviscous fluid coupling comprises two relatively movable members having adjacent surfaces which are separated by a thin film of electroviscous fluid. The electroviscous fluid which is normally of low viscosity, displays a dramatic change in bulk modulus when energized by the application of an electric field. The energized electroviscous fluid serves to transmit force from one moving coupling member to the other.

Electroviscous fluid couplings can be energized by applying an electric potential across the two conducting coupling members, as described in the afore-mentioned patent to Winslow. Electroviscous fluid couplings can also be energized by applying an alternating potential between a plurality of electrodes set in one of the coupling members, as described in patent application Serial No. 73,326 by Martinek et al., filed December 2, 1960. This invention is based upon the discovery that the force transmitted through electroviscous fluid film energized by an alternating potential varies in response to change in the frequency of the applied alternating potential.

It is therefore an object of this invention to provide a novel method for controlling the force transmitted by an electroviscous fluid coupling. Another object of this invention is to provide a novel method for measuring the frequency of an alternating electric potential. Another object of this invention is to provide an apparatus by which the frequency of an alternating electric potential can be determined.

It has been observed that the electroviscous effect in electroviscous fluids under the influence of an alternating potential is dependent upon the frequency of the potential, the composition of the fluid, the solids content of the fluid, and the applied voltage. Thus, the force characteristics of an electroviscous fluid decrease with increasing frequency under a given set of conditions.

The invention is best described with reference to the drawings, of which,

FIGURE 1 is a view of a simple electroviscous fluid coupling useful in the method of this invention,

FIGURE 2 is a fragmentary view of a modification of the device of FIGURE 1,

FIGURE 3 is a schematic diagram of a combination of electroviscous fluid couplings, and,

FIGURES 4A to 4D are graphs illustrating the effect of the frequency of an applied potential upon an electroviscous fluid coupling.

Referring to FIGURE 1, a simple electroviscous fluid coupling is shown. Cup-shaped coupling member **10** is supported and rotatively driven by means of motor **12**. Disposed within cup-shaped coupling member **10** and in contact with electroviscous fluid layer **14** is disk-shaped coupling member **16**, which connects to output shaft **18**. Thus coupling member **10** serves as the input or drive

member of the coupling, and coupling member **16** serves as the output or driven member of the coupling. Attached to shaft **18** is pointer arm **20**, adapted to move in an arc adjacent to arcuate indicia **22**, which is calibrated by a suitable scale **24**. Rotation of pointer arm **20** is yieldably restrained by means of spring **26**. Potential is applied to energize the coupling by means of brushes **28** and **30**. It will be understood that each of the coupling members **10** and **16**, are fabricated of steel, or other conductive material. The electric potential is applied by means of variable amplifier **32** which includes an output potential meter **34** and a control knob **36**. The input potential to the variable amplifier may be increased to any desired amplitude as indicated by meter **34**, the output being applied to brushes **28** and **30**.

FIGURE 2 shows a modification of pointer arm **20** to include a relay contact **40**. Also provided is relay contact **42** which is supported by arm **44**. Battery **46** and light **48** serve to signal the opening or closing of the contacts **40** and **42**.

In operation, the electroviscous fluid coupling of FIGURE 1 is driven at any desired speed by motor **12**. When an electric potential is applied between coupling members **10** and **16**, the force transmitted through the coupling increases instantaneously to some value much greater than that small force caused by the residual viscosity of the electroviscous fluid. Arm **20**, spring **26**, and indicia **22** provides means for measuring the output torque of the coupling. By varying the frequency of the alternating electric potential which energizes the coupling, the output torque can be varied. Thus a new means for controlling an electroviscous fluid coupling which may be operated at constant potential, is provided. If the device is to be used as a frequency meter, the couping will be driven at some predetermined low speed, preferably about 5 r.p.m., and an alternating electric potential applied to the input of amplifier **32**. Amplifier **32** provides means for adjusting the amplitude of the output potential to any desired value, such as 100 volts, which can be maintained uniform throughout the test. The coupling may be calibrated for frequency using any given electroviscous fluid as the power transfer medium by employing a conventional signal generator to provide a variable frequency input to amplifier **32**. When potentials of uniform amplitudes, but differing frequency, are applied to the coupling, the torque outputs at various frequencies can be plotted to provide a curve characteristic of the coupling and electroviscous fluid, when operated at that potential. Such a curve is shown in FIGURE 4A. By using different electroviscous fluids, different curves will be obtained. FIGURE 4B shows the family of curves provided by four related, but differing electroviscous fluids All of these electroviscous fluids were compounded using silica as the solid material and a mineral oil vehicle. Curve **70** was produced using the electroviscous fluid when compounded to having a silica volume fraction of 0.49. Curves **72**, **74**, and **76** were obtained by diluting the electroviscous fluid with additional mineral oil to provide fluids having solids volume fractions of 0.455, 0.435, and 0.355, respectively.

It will be noted that the electroviscous fluids of different dilution provide dissimilar curves each of which has a "cut-off" frequency above which no force is transmitted through the electroviscous fluid, other than that due to the residual viscosity of the fluid. As the electroviscous fluid is diluted to a greater extent, the cut-off frequency drops, as illustrated by FIGURE 4B. FIGURE 4C is a plot of cut-off frequencies of silica-base electrolviscous fluids as a function of the volume fraction, or dilution, of the electroviscous fluid. This plot was obtained using an applied potential of 175 kilo-

volts per inch. FIGURE 4D shows a plot of cut-off frequency against voltage. This curve illustrates the importance of maintaining uniform voltage input to a coupling during any one series of experiments. The electroviscous fluid was the same as that employed to obtain curve **70** of FIGURE 4B. The spacing between the driving and driven members was the same as that for FIGURE 4B.

The frequency of an electric potential can be determined by means of the cut-off frequency of an electroviscous fluid. To accomplish this, the electroviscous fluid coupling is modified as shown in FIGURE 2, so that the first torque output of the coupling, above that provided by the residual viscosity of the fluid, which is counteracted by spring **26**, will cause contacts **40** and **42** to separate. Thus the first occurence of the electroviscous effect is signaled by the extinguishing of light **48**. In operation, an unknown frequency is fed to amplifier **32**, and thus to the electroviscous fluid coupling. The amplitude of the applied potential, that is, the output voltage of the amplifier, as measured by meter **34**, is slowly increased until the light **48** is extinguished. The frequency of the potential can then be determined by reference to a curve characteristic of the electroviscous fluid coupling when operated with that particular electroviscous fluid. Such a curve is shown in FIGURE 4D.

As described, the unknown frequency of an electric potential can be ascertained by means of an electroviscous fluid coupling. Once the characteristics of that coupling with a given electroviscous fluid have been determined, the frequency can be determined by applying the electric potential at a predetermined amplitude or voltage, measuring the torque output of the coupling, and correlating this output with frequency by means of a curve such as that of FIGURE 4A. Alternatively, the amplitude or voltage of the potential of unknown frequency may be increased gradually and the first movement of the output member of the coupling detected, as by the device of FIGURE 2. The voltage at which the first movement of the output member occurs can then be correlated with the frequency of the energizing potential by means of a curve characteristic of that coupling and electroviscous fluid, as shown in FIGURE 4D. It will readily be apparent to those skilled in the art that the indicia **24** could be calibrated in terms of frequency, rather than force, and by this expedient reference to prepared curves or tables rendered unnecessary. Also, the meter **34** can be calibrated in terms of frequency, rather than voltage, for any given electroviscous fluid coupling system. In this way, when the cut-off potential method of determining frequency is applied, the frequency can be determined directly by reading the scale of meter **34**.

The frequency can also be determined, within preestablished brackets, by employing the cut-off frequency principle and using a plurality of separate electroviscous fluid couplings, such as couplings **80** of FIGURE 3, all of which are connected to the output of amplifier **32**. Any desired number of couplings **80** may be employed, each coupling being provided with an electroviscous fluid having a different cut-off frequency. Each coupling may further be provided with a torque-signalling system as shown in FIGURE 2. When a test signal of unknown frequency is applied to such a system, the signalling lights associated with all of the couplings having a cut-off frequency above that of the unknown potential will remain lit, whereas those having a cut-off frequency less than that of the test signal will be extinguished. Thus the unknown frequency is immediately seen to be between that of the adjacent couplings, one of which is actuated to extinguish the light, and one of which is not actuated. It will be evident that any desired number of couplings can be employed, and that the cut-off frequencies of the electroviscous fluid employed with such couplings may be adjusted as desired by diluting the electroviscous fluid to the desired particle volume fraction, as illustrated in FIGURE 4B.

As a specific example of the determination of frequency in accordance with this invention, an electroviscous fluid coupling, as shown in FIGURE 1, is operated at a potential of 175 kilo-volts per inch, with a spacing of 0.02 inch between the input and output members of the coupling. A signal generator is employed to energize the coupling over a range of known frequencies, and the output torque of the coupling at each frequency is measured. From the information thus obtained, a curve such as that of FIGURE 4A is plotted. A test signal of unknown frequency, but of the same amplitude as that employed in the calibration of the electroviscous fluid, is then used to energize the coupling. An output force having a value of 20 is indicated under these conditions. By referring to FIGURE 4A, it is seen that this force corresponds to a frequency of one kilocycle per second, which is the frequency of the test signal.

As another example of the method of this invention, an electroviscous fluid coupling, as shown in FIGURE 1, is equipped with means for signalling a first movement of the driven member, as shown in FIGURE 2. Potentials of known frequency, provided by a signal generator, are used to calibrate the coupling. This is done by applying signals of differing frequency to the coupling, gradually increasing the amplitude of the signals until the first movement of the driven member of the coupling is detected. The amplitude or voltage of the signal at which this first movement occurs is recorded in each case, and a curve such as that shown in FIGURE 4D is plotted. A signal of unknown frequency is then applied to the coupling, and the amplitude of this signal is gradually increased until the first movement of the driven member of the coupling is signalled. The voltage, as indicated by meter **34**, at which this occurs is noted. The voltage is seen to be 500 volts, and referring to the curve of FIGURE 4D, this is seen to correspond with the cut-off frequency of 20 kilocycles per second, which is the frequency of the test signal.

As another example of the method of determining frequency in accordance with this invention, a group of five electroviscous fluid couplings are connected as shown in FIGURE 3. The couplings are provided with electroviscous fluids having cut-off frequencies of 1, 2, 3, 4, and 5 kilocycles, respectively. These cut-off frequencies occur at a potential of 100 volts, so a potential of 100 volts but of unknown frequency is applied to the system. The first three couplings immediately signal movement of the driven member, whereas the other three couplings show no such movement of the driven member. It is therefore ascertained that the frequency of the test signal is between 3 and 4 kilocycles.

While the invention has been described with reference to a simple, rotary, electroviscous fluid coupling, in which the potential is applied between the driving and driven members of the coupling, it will be evident that the invention can be practiced using numerous other electroviscous fluid devices which in some way indicate the extent of electroviscous effect in an electroviscous fluid. The use of electroviscous fluid devices as disclosed in U.S. application Serial No. 121,491, of Donald Klass and Vincent Brozowski, is specifically contemplated. The frequencies of the applied alternating potential will be in the range of 0.01 to 25 kilocycles and dependent only upon the formulation of the specific electroviscous fluid employed.

The embodiments of the invention which an exclusive property or privilege is claimed are defined as follows:

1. In the operation of an electroviscous fluid device wherein an alternating electric potential is applied to a body of electroviscous fluid forming part of said device, the step of varying the frequency of the applied alternating potential in the range from below the cut-off frequency

of the fluid to above the cut-off frequency of the fluid, thereby varying the apparent bulk modulus of said fluid.

2. The method in accordance with claim 1 wherein the frequency is varied within the range of 0.01 to 25 kilocycles per second.

3. In the method of varying the apparent bulk modulus of a thin layer of electroviscous fluid across which an alternating current is applied the step of varying the frequency of said current in the range from below the cut-off frequency of the fluid to above the cut-off frequency of the fluid.

4. In the method of varying the force transmitted between spaced coupling members of a coupling the members of which are separated by an electroviscous fluid film and across which an alternating current is applied transversely to the film, the step of varying the frequency of said current in the range from below the cut-off frequency of the fluid to above the cut-off frequency of the fluid.

5. Method in accordance with claim 4 in which the frequency is varied within the range of 0.01 to 25 kilocycles per second.

6. The method in accordance with claim 4 in which the coupling members are adapted for relative movement in fixed space relationship.

7. An electroviscous fluid device comprising a pair of spaced conductive elements, a film of electroviscous fluid

in contact with said pair of conductive elements, said elements being connected to a source of alternating current and means for changing the frequency of said alternating current across said film of electroviscous fluid, from a frequency below the cut-off frequency of said fluid to a frequency above the cut-off frequency of said fluid.

References Cited by the Examiner

UNITED STATES PATENTS

1,402,025	1/1922	Tesla	324—78
1,933,086	10/1933	Battegay	324—78
2,663,809	12/1953	Winslow	192—21.5
2,708,018	5/1955	Dudley	192—58
2,733,794	2/1956	Reid	192—58
2,806,533	9/1957	Fleck	192—21.5
2,995,705	8/1961	Walker et al.	324—70
2,996,267	8/1961	Warren	192—21.5
3,005,155	10/1961	Faria	324—70
3,150,678	9/1964	Nuber	192—21.5

OTHER REFERENCES

Winslow: "Induced Fibration of Suspensions," Journal of Applied Physics, volume 20, December 1949, pp. 1137–1140.

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