Feb. 2, 1960 C. J. FITCH 2,923,390

ELECTROSTATIC CLUTCH

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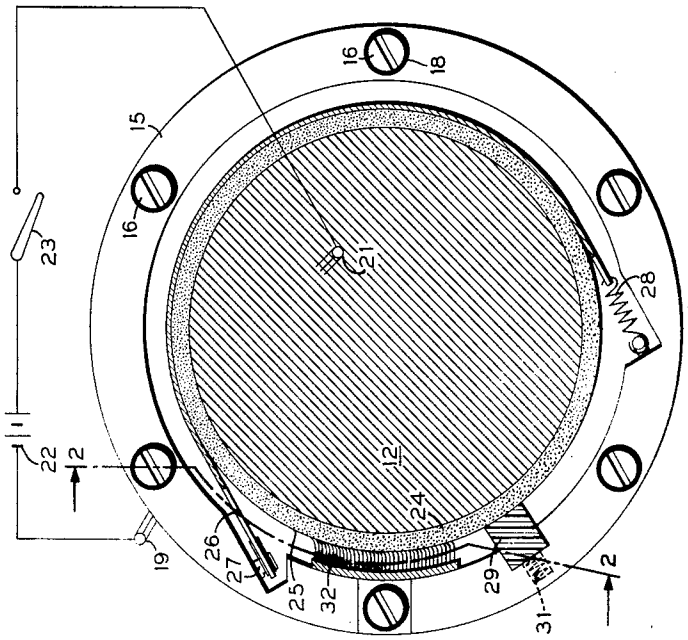

FIG. 1

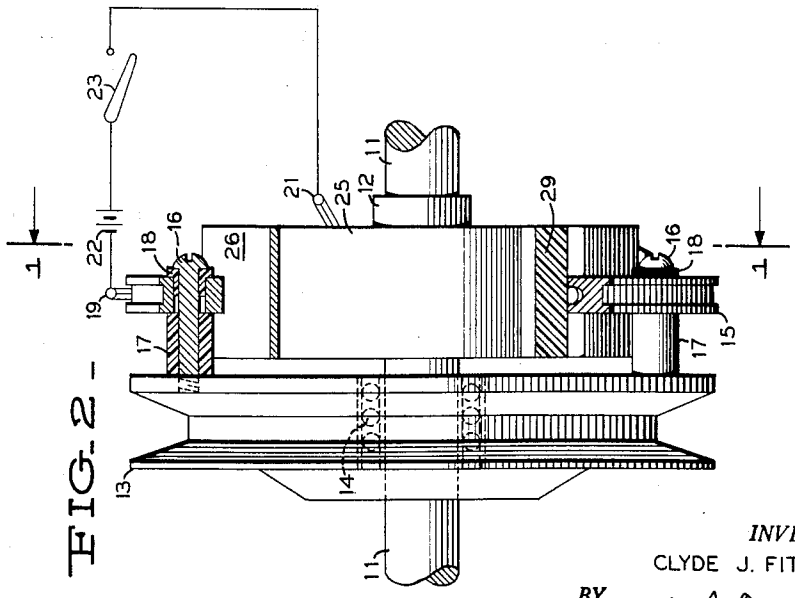

FIG. 2

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ELECTROSTATIC CLUTCH

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This invention relates to electrostatic devices wherein the operation depends upon the electro-adhesive forces between a conductive member and a cooperating semi-conductive member.

More particularly, this invention is directed to electrostatic clutches wherein a driven member is clutched to a driving member by electro-adhesive forces.

The electro-adhesive effect between conductors and semi-conductors is well known in the art and there are hundreds of materials that will exhibit electro-adhesion under some conditions. In this art, a number of improvements and modifications have been made in efforts to obtain reliable devices. Early in these attempts to obtain a usable electrostatic or electro-adhesive device, an agate or similar stone cylinder was used as a clutch wheel. Moisture from an electrolyte within the porous cylinder rendered it what has been termed a "semi-conductor." As used hereinafter, a "semi-conductor" will be defined as a resistance material having a resistivity within the general range of 10^6 to 10^7 ohms per cubic centimeter. Among the defects in these early devices were the following: electrolysis (ionic conduction) and eventual erosion of the clutch surfaces, resulting from the use of an electrolyte; variations in resistance and torque caused by evaporation; and nonuniform torque around the periphery because of the anistropic characteristics of natural stone. From this point, the use of alternating current was partially successful in avoiding electrochemical alterations in the device, and a synthetic stone, fabricated of materials such as powdered flint bonded together with conductive material such as water glass, was isotropic but remained hygroscopic. However, even with these improvements, only devices of erratic operation, particularly at high operating speeds, were possible. In further attempts to produce a reliable electro-adhesive device, semi-conductive materials of electronic conduction were fabricated from mixtures such as magnesium and titanium oxides. But these and all the prior attempts resulted in unstable electro-adhesive devices, particularly unreliable at high operating speeds.

In addition to the above defects, amplified wear of the clutching surfaces was caused by dust particles acting as an abrasive between the surfaces. These dust particles were produced by wear, due to surface friction, and erosion, due to making and breaking electrical current passing through the surface contact. This amplified wear resulted in alterations of the quality of the clutching surfaces, i.e., smoothness and shape, and produced unstable and unreliable operation. In attempts to prevent this amplified wear, brushes were used as wipers to remove the abrasive particles. However, the brushes became saturated with the abrasive dust particles and ceased to function.

Even though a primary advantage of an electro-adhesive clutch over other similar devices is rapid electrical response time (of the order of microseconds), this advantage has not, in practice, been available for most

applications because of erratic operation and unreliability. In addition to rapid response time, an electro-adhesive clutch has many other potential advantages not found in similar devices. Low operating current (of the order of milliampere at 200 volts), non-inductive circuit operation, low manufacturing cost, and small size in relation to torque output are examples of these advantages.

The present invention, therefore, is directed to an electrostatic clutch employing novel electro-adhesive material, operable under severe frictional conditions, capable of withstanding relatively high operating temperatures and having constant stability under a wide range of operating conditions. Furthermore, the concept of operation of the present invention is based on electronic conductivity through the semi-conductor in order to eliminate adverse electrochemical effects, rather than on ionic conductivity. The present invention also contemplates a novel electro-adhesive material comprising heterogeneous deposits of conductive or semi-conductive particles bonded together in an insulating binder. Materials of this nature may comprise carbon particles in a rubber or phenolic binder, molded to shape, and cured, or carbon particles and/or metal oxides in a clay or ceramic binder, die pressed to shape and fired. Finally, the present invention contemplates a novel electro-adhesive clutch wherein a permanent surface condition is maintained. This is accomplished by the use of an agent acting as a lubricant and scavenger in the clutch to lubricate and collect abrasive dust particles resulting from wear.

A primary object of this invention is to provide a stable and reliable electro-adhesive device.

Another object is to provide a reliable electro-adhesive clutch capable of operating at relatively high speeds.

A more particular object is to provide an improved electro-adhesive material.

Another object is to provide an improved electro-adhesive clutch wherein a substantially permanent surface condition is maintained.

A further object is to provide an electro-adhesive clutch with an improved semi-conductor.

Still another object is to provide an improved electro-adhesive clutch wherein the abrasive effect of particles of wear is eliminated.

Another object is to provide an improved semi-conductive clutch element wherein the electrical conductivity therethrough is electronic.

Another object of this invention is to provide an improved and lubricated electro-adhesive device.

Another object of this invention is to provide an electro-adhesive clutch reliable under a wide range of operating conditions.

Other objects of the invention will be pointed out in the following description and claims and illustrated in the accompanying drawings, which disclose, by way of examples, the principle of the invention and the best mode, which has been contemplated, of applying that principle.

In the drawings:

Fig. 1 is a transverse vertical sectional view, partly diagrammatic, of an electro-adhesive clutch constructed in accordance with the present invention and taken along the line 1—1 of Fig. 2.

Fig. 2 is a partial sectional view taken along line 2—2 of Fig. 1.

Referring to the drawings, a shaft 11 has a conductive hub 12, preferably of brass, secured thereto and has a pulley 13 mounted, by a bearing 14, to rotate freely thereon. Pulley 13 has a metal ring 15 secured thereto by bolts 16, insulating sleeves 17 and insulating plugs 18. Thus ring 15 may be electrically isolated from hub 12.

Ring 15 has a contact brush 19 riding thereon and hub 12 has contact brush 21 riding thereon. Brush 19 is connected to the negative terminal of a source of potential shown as a battery 22, and brush 21 is connected through a switch 23 to the positive terminal of the source. An electro-adhesive material 24, described in more detail below, is bonded to hub 12 and forms a clutching surface 25. A conductive band 26, preferably of stainless steel, is secured at one end to ring 15 by a member 27, so as to make electrical contact with ring 15. The other end of band 26 is attached to one end of spring 28. The other end of spring 28 is attached to ring 15 so that spring 28 urges band 26 into contact with the surface 25. A block of material 29, tetrafluorethylene resin, for example, the function of which will be described more fully below, is held against surface 25 by spring 31. The block 29 and the spring 31 are carried by ring 15. A brush 32, of mohair or the like, is carried by ring 15 to wipe the surface 25.

In operation, either the shaft 11 or the pulley 13 may be externally driven as desired by a motor, or the like, not shown. With switch 23 open, the surface 25 and the band 26 slide over one another. When switch 23 is closed, the potential of battery 22 is applied between band 26 and material 24, and the resulting electro-adhesive force between surface 25 and band 26 will clutch pulley 13 to shaft 11. It should be pointed out that the clutch operates at either polarity; however, it is preferable that the band be the negative electrode and the semi-conductive material be the positive electrode. The clutch also operates satisfactorily with an alternating current source. Thus, if shaft 11 is externally driven, hub 12, with material 24 bonded thereon, acts as the driving member of the clutch, and band 26 acts as the driven member. If pulley 13 is externally driven, the opposite functions prevail as to driving and driven members.

According to the present invention, the electro-adhesive material 24 is a semi-conductor comprised of conductive particles in an insulating binder. One preferred material includes natural or synthetic rubber, phenolic, asbestos and carbon. A material found to be quite satisfactory may be fabricated from the following proportions by weight of ingredients: 162 parts rubber, 200 parts phenolic resin, 240 parts asbestos, 6 parts zinc oxide, 6 parts sulphur, 3 parts stearic acid, 3 parts zinc stearate, 3 parts antioxidant, 1.5 parts mercaptobenzothiazole, .3 parts zinc dimethyl dithiocarbamate and 166 parts carbon black. With such a material bonded to hub 11 the surface 25 will contain many conductive particles, some of which are in contact with band 26. When switch 23 is closed, current passes between material 24 and band 25. Arcing, caused by the imperfect sliding contact, acting in an atmosphere containing oxygen, burns out the conductive particles contacting band 26. With the conductive particles burned back below the surface of the semi-conductor, a high surface contact resistance is presented and a large proportion of the voltage drop appears across the contact between band 26 and the semi-conductor. As the semi-conductor wears, this process continues to maintain the high surface contact resistance. Since electrostatic attraction appears between the band 26 and the surface 25 in accordance with the formula:

$$f=\frac{1.59KAE^2}{d^2\times 10^{11}}$$

where f is the force in ounces, K the dielectric constant (1 for air), A the area in square inches, d the distance of separation in inches and E the applied voltage (i. e., the voltage across the contact), the above-described process is highly desirable.

The above formula also indicates that the distance of separation should be as small as possible. Even with very smooth surfaces, the band touches the semi-conductor only at isolated points. Thus, in order to maintain the average distance of separation as small as possible, a smooth surface is indicated. In order that a smooth surface and one of proper shape may be maintained, the action of the abrasive dust particles, mentioned earlier, produced by wear and erosion, must be eliminated. According to the present invention, a solid lubricating agent of high electrical resistance, also acting as a scavenger, is placed to contact a clutching surface. The agent wears and deposits a thin film on the clutching surface. Particles of the agent cling together and attract surface dust particles, possibly by triboelectric action, to thus eliminate the abrasive action of the dust particles. A block of tetrafluorethylene resin has been found to be quite satisfactory as a lubricating and scavenger agent. In the drawings, a block of tetrafluorethylene resin 29 is carried by ring 15 and urged against surface 25 by spring 31. With this arrangement, wear of the semi-conductor is controlled. A brush 32 is also provided, though not necessary, to remove any large accumulations of the tetrafluoroethylene resin.

With the above-described electro-adhesive material and the lubricating agent, it has been found that an electro-adhesive clutch may be given a long life of stable and reliable operation, even at high speeds. Such a clutch is well suited to many high speed clutching needs not before satisfied. This clutch also has a relatively high torque at zero slip speed, thus enabling synchronous operation through the clutch.

In summary, according to the teachings of the present invention, electro-adhesion is a surface phenomenon, and maintenance of proper surface conditions in an electro-adhesive clutch is of vital importance in securing reliable operation. Proper surface conditions may be maintained in a clutch comprising the above-described material and lubricating agent.

While there have been shown and described and pointed out the fundamental novel features of the invention as applied to a preferred embodiment, it will be understood that various omissions and substitutions and changes in the form and details of the device illustrated and in its operation may be made by those skilled in the art, without departing from the spirit of the invention. It is the intention, therefore, to be limited only as indicated by the scope of the following claims.

What is claimed is:

1. An electro-adhesive device, comprising in combination, a conductive member having a first surface, a semi-conductive member formed of a heterogeneous mixture comprised of rubber, phenolic, asbestos and carbon and having a second surface disposed to slidably contact said first surface, means for moving said members relatively to each other along their contacting surfaces, a body of tetrafluorethylene resin disposed to slidably contact one of said surfaces, and means for applying an electrical potential difference between said surfaces.

2. An electro-adhesive clutch, comprising in combination, a rotatable semi-conductive body comprised of electrically conductive particles bound together by an electrically insulating binding agent and having a first surface, an electrically conductive body having a second surface disposed to slideably contact said first surface, and means for applying an electrical potential difference between said surfaces.

3. Apparatus according to claim 2 wherein said semi-conductive body is a heterogeneous mixture comprised of rubber, phenolic, asbestos and carbon.

4. An electro-adhesive clutch, comprising in combination, a first rotatable member comprised of a body of semi-conductive material formed of a heterogeneous mixture comprised of rubber, phenolic, asbestos and carbon and having a first surface, a second rotatable member comprised of an electrically conductive body having a second surface disposed to slidably contact said first surface, a body comprised of a lubricating agent carried by one of said members and disposed to slidably contact the cooperating surface of the other, and means for ap-

plying an electrical potential difference between said surfaces.

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