Fig. 1

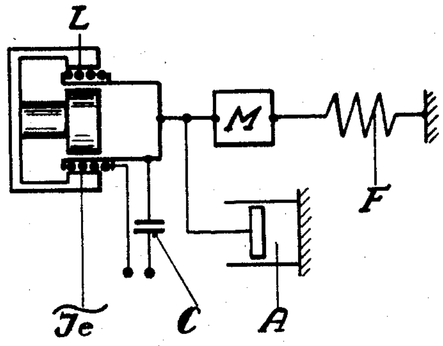


Fig. 2

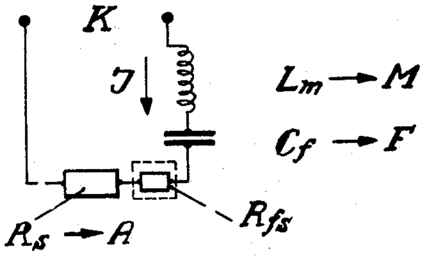
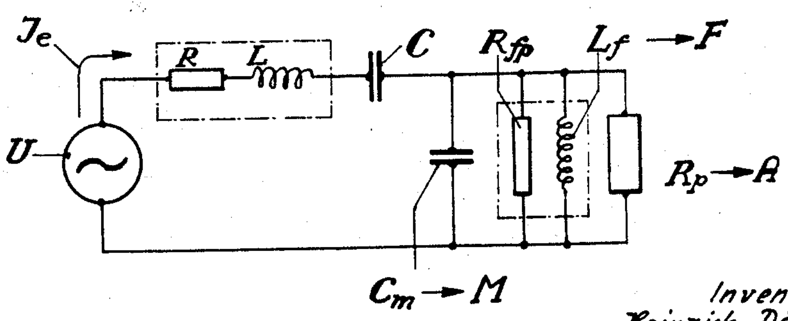


Fig. 3



Inventor
Heinrich Dölz
By
Ag't

April 5, 1960 H. DÖLZ **2,931,925**

OSCILLATORY DRIVES MORE PARTICULARLY FOR
SMALL REFRIGERATING MACHINES

Filed July 24, 1953 4 Sheets-Sheet 2

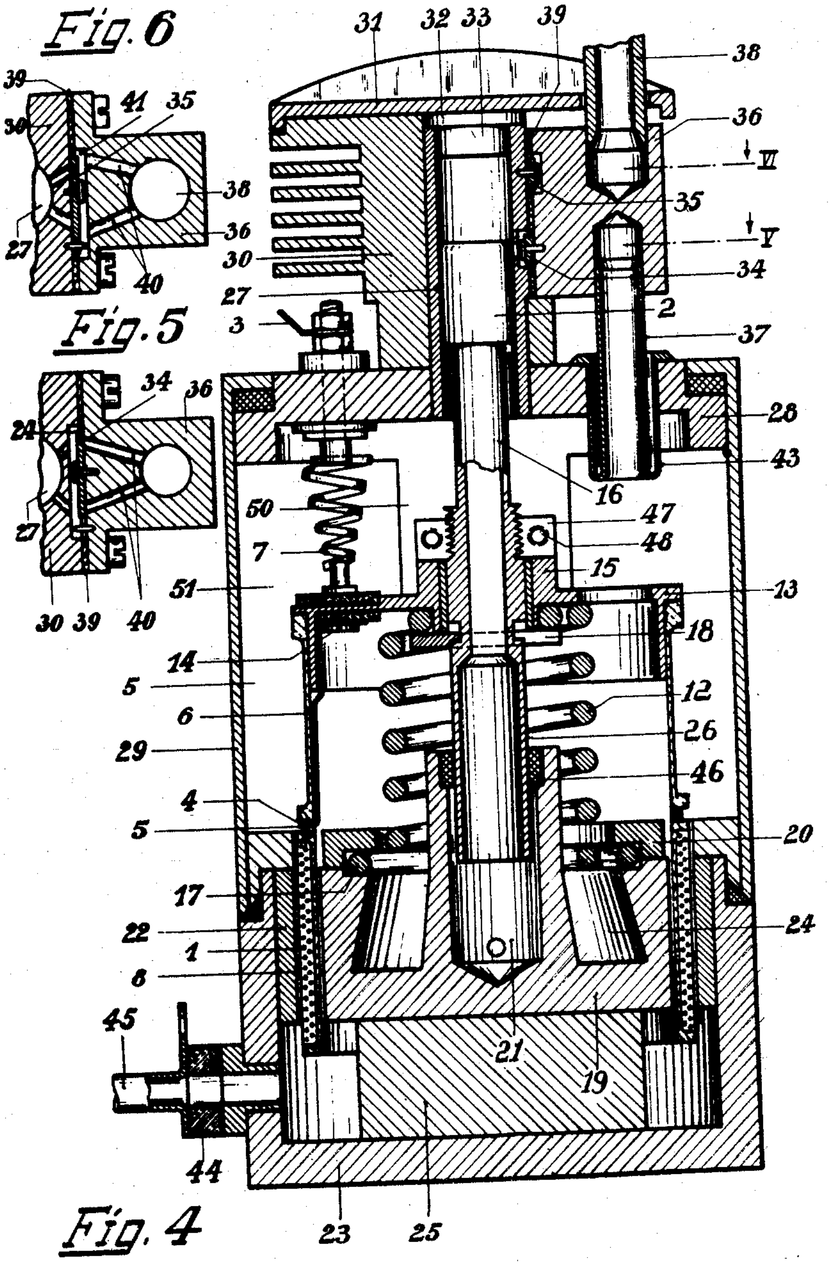


Fig. 6

Fig. 5

Fig. 4

Inventor
Heinrich Dölz
By
Ag't

Fig. 7

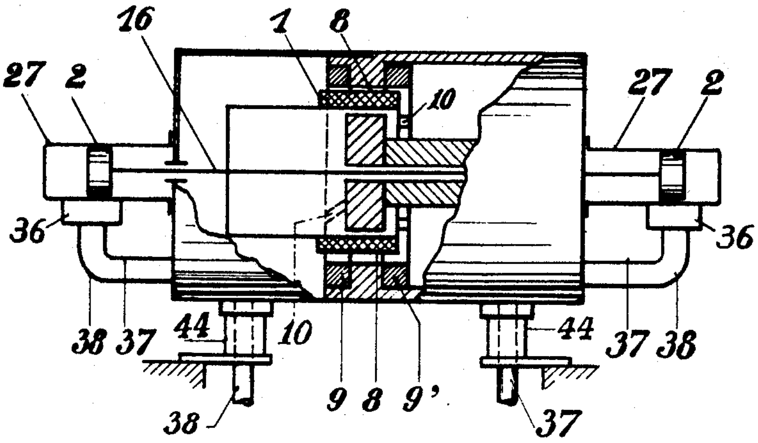


Fig. 8

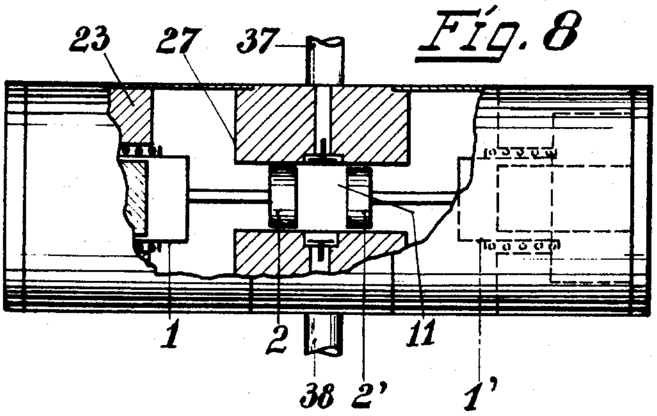
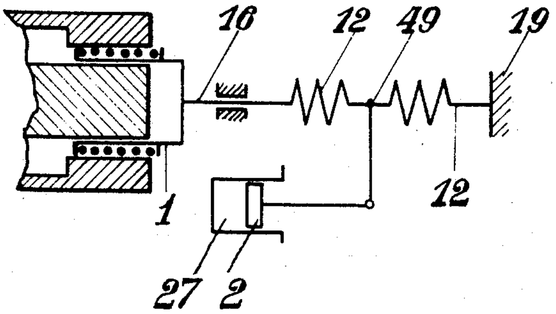


Fig. 9



Inventor
Heinrich Dölz
By Richard Low
Ag't

April 5, 1960

H. DÖLZ

2,931,925

OSCILLATORY DRIVES MORE PARTICULARLY FOR SMALL REFRIGERATING MACHINES

Filed July 24, 1953

4 Sheets-Sheet 4

Fig. 10

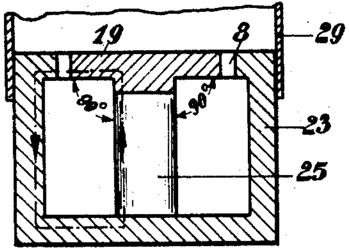


Fig. 11

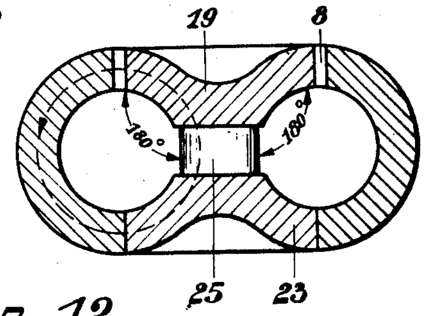
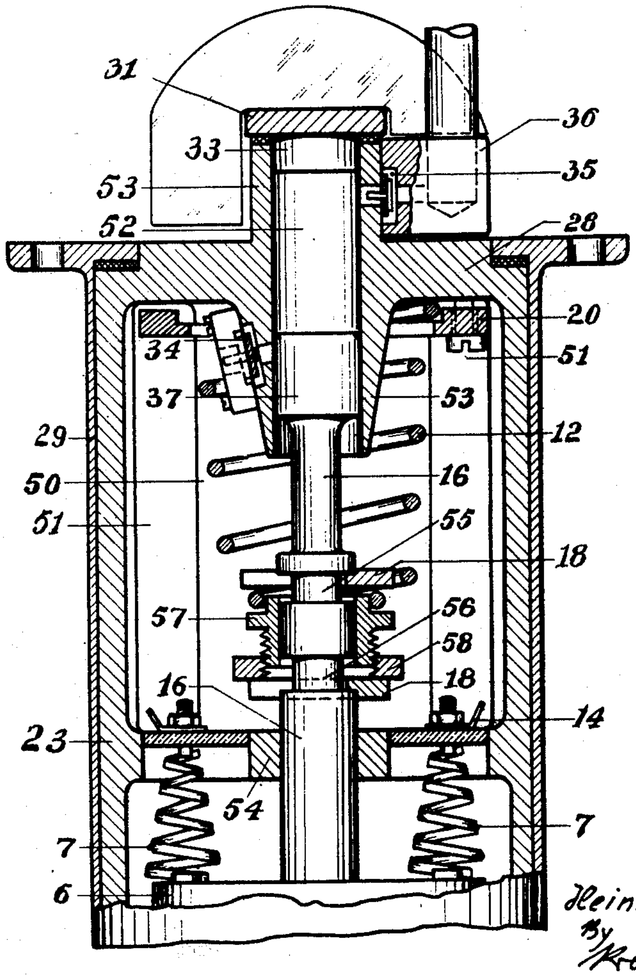


Fig. 12



Inventor
Heinrich Dölz
By
Richard Low
Ag't

United States Patent Office

2,931,925

Patented Apr. 5, 1960

2,931,925

OSCILLATORY DRIVES MORE PARTICULARLY FOR SMALL REFRIGERATING MACHINES

Heinrich Dölz, Stuttgart-Mohringen, Germany, assignor to Sofix A.G., Vaduz, Liechtenstein, a corporation of Liechtenstein

Application July 24, 1953, Serial No. 370,068

Claims priority, application Switzerland July 26, 1952

22 Claims. (Cl. 310—27)

This invention relates to a reciprocating drive, which is particularly suitable for small refrigerating machines, and wherein a reciprocating electrically driven part operates in resonance, or nearly in resonance, with the excitation frequency of the parts to be driven. Preferably, the invention relates to the electric construction of electro-dynamic reciprocating drives consisting of an iron-free air coil, which may be mounted on a supporting member of electrically insulating material, and operates in the air gap of a permanent constant magnetic field.

As a rule, existing devices of the described character use springs for producing the required conditions of resonance for the reciprocating movement of the mechanical part. These springs constitute together with the masses participating in the reciprocating movement, a mechanical oscillatory system, the natural frequency of which is equal or nearly equal to the exciting frequency of the supply circuit in the case of polarised electro-dynamic, oscillatory drives, or double or nearly double that of the exciting supply frequency in the case of non-polarised magnetic, oscillatory drives.

In order that the operation of such drives may not be disturbed, it is necessary that the total mass of the springs shall not be greater than about ¼ the total mass of the masses participating in the reciprocating movement. If the mass of the springs is greater than the aforementioned value then, as the same increases, instabilities, non-harmonic oscillations, upper harmonics, stationary waves, or other irregularities arise in the reciprocations. These irregularities cause the output of the devices to fluctuate greatly, quite apart from the unpleasant noises which are produced. Moreover, the work required for spring deformation increases with increases in the mass of the springs, and thus has a very great detrimental effect upon the efficiency of such devices. In addition thereto, such irregularities substantially reduce the life of the springs.

In view of the fact that, as much as possible, the total mass of the springs shall not be greater than ¼ of the oscillatory mass, and considering the maximum admissible stressing of the material of the springs, the attainable stroke in such devices is usually limited to a maximum of 1.5 cm. total stroke, and such limitation on the length of stroke naturally greatly limits the possible applications of such devices and affects their output. If in spite of the foregoing it is necessary to increase the output, the constructional dimensions, particularly of elements of the magnetic circuit, have to be such that they cannot be economically employed in practice.

In the case of reciprocating drives upon which great demands are made as regards life and reliability of operation, the spring is a source of defects and possible failure which renders difficult the practical introduction of these devices, especially in refrigerating machines. Apart from the possibility of failure, fatigue of the material of the springs results in a deterioration of the efficiency.

Further, in such existing devices the gravity forces which have to be continuously overcome are large compared with the useful forces to be produced, so that the resonance curve of the mechanical reciproacting system is very sharp, and, consequently, disturbances are produced upon the slightest fluctuations in the excitation frequency. Since the natural frequency of the mechanical reciprocating system is not constant, but is influenced by temperature, changes in the useful forces and the like, the sharp resonance curve can result in disturbances or a complete falling out-of-step, even when the excitation frequency remains constant.

It has been found, that economical reciprocating drives having a good efficiency, great reliability of operation and reasonable dimensions, are possible only if the spring masses are within the order of about ¼ of the total of the reciprocating masses, and if the resonance curve of the mechanical reciprocating system has a generally flat characteristic.

The object of the invention is to provide a reciprocating drive preferably based on the electro-dynamic principle, and wherein the reactive power produced by the gravity forces is reduced, or completely compensated, without employing highly stressed springs, while the mechanical reciprocating system is brought more or less in resonance with the supply frequency, as in the existing devices.

Further, in accordance with the invention the spring forces are reduced as much as possible or eliminated altogether in order substantially to increase the reliability of operation, the efficiency, and the loads that can be driven for the same dimensions of the elements of the magnetic circuit. A further object is to simplify, or completely eliminate the special condenser connections in the electric circuit, which are usually used for effecting the compensation of the reactance of the inductance of the excitation winding, especially in the case of electro-magnetic drives.

In order to reduce or compensate the gravity forces in the mechanical part of the reciprocating drive, and also the reactive power in the electrical part, due to the inductance of the excitation winding, it is proposed, in accordance with this invention, to use the electrically effective capacity resulting from the oscillating masses, the magnetic inductance, and the length of the excitation winding in determining the condition of resonance. This electrically effective capacity is so dimensioned by a suitable selection of the conductor length, the oscillating mass and the inductance of the magnetic field, that gravity forces and electrical reactive power are greatly compensated, and that either no spring at all or, at most, only a small mechanical spring, and/or a small electrical reactance, are required. This electrical reactance is mostly a condenser. However, occasion may arise in which the reactance is an electrical choke. Finally, in accordance with the invention use may be made of a transformer coupling between the excitation winding and the exciting source of voltage. For the sake of simplicity, however, reference will hereinafter be made continuously to an electric condenser, but the above described and other similar possibilities are not thereby excluded.

In an electrical reciprocating drive operating in resonance or approximately in resonance with the excitation frequency in accordance with this invention, and which is particularly useful for the drive of small refrigerating machines, the inductance of the excitation winding which is supplied with the periodically alternating excitation current, and the electrically acting capacity, which is the electrical equivalent of the reciprocating masses and is determined from the magnetic inductance, the value of the reciprocating masses, and conductor length of the excitation winding, are so tuned to each other and relatively dimensioned that the natural frequency of the system is at least approximately equal to the frequency of the excitation current.

The inductance of the excitation winding and the electrical effective capacity which is the electrical equivalent of the reciprocating masses may be tuned to each other and dimensioned by the use of a mechanical spring or a condenser. The tuning is preferably effected in such a way that in the case of a no-load drive (idle running) the natural frequency f_0 is greater than the excitation frequency f_e, and in the case of a theoretical load the natural frequency f_0 is approximately equal to the excitation frequency f_e.

The last mentioned tuning keeps the stroke constant with variable useful work. By selecting a flat resonance characteristic, it is possible to ensure that the stroke between idle running and the theoretical load is practically constant. In those cases in which it is advantageous to operate on a definite portion of the resonance characteristic, the resonance point may lie within, or close above or below, the working range.

The great importance to be attributed to a small drop in the work required to deform the spring or springs of the reciprocating system can be appreciated from the following: If it is assumed that a drop in the deformation work of the spring from 5 to 3% is obtained for 3 kg. of useful force, when there is a very small resonance sharpness of only 1:6, below which it can hardly drop, then about 18 kg. of spring forces is obtained, and the pure deformation force would drop from 0.9 kg. at 5% to 0.54 kg. at 3%. At first, this may not appear decisive. However, the values change substantially, since these losses have to be referred back to the existing useful force of 3 kg., so that, the losses amount, in the case of 5%, to 30%, and, in the case of 3%, only to 18% of the losses.

The accompanying drawings illustrate examples of construction according to the invention.

Figures 1 and 2 are diagrammatic illustrations of known arrangements;

Figure 3 is a diagrammatic representation of one embodiment of this invention;

Figure 4 is a longitudinal sectional view of a compressor having a reciprocating drive or motor embodying this invention;

Figures 5 and 6 are fragmentary sections through the valve arrangement shown in Figure 4 and taken along the lines V—V and VI—VI, respectively, of the latter;

Figure 7 is a diagrammatic longitudinal section of another embodiment of the invention;

Figure 8 is a diagrammatic longitudinal section of still another embodiment of the invention;

Figure 9 is a diagrammatic representation of a special transformation means;

Figures 10 and 11 respectively show two magnet constructions for use in reciprocating drives embodying the invention; and

Figure 12 is a sectional view of a further embodiment of the invention.

Figure 1 shows diagrammatically the conditions of a known electro-dynamic reciprocating drive, comprising an iron-free moving coil, that is, an air-coil, which may be mounted on a supporting member of electrically insulating material. L is the inductance of the moving coil which is supplied with an alternating current I_e either directly or through a condenser C. The natural frequency of this electric system is equal to the excitation frequency. The parts to be driven, that is, the piston of a compressor, the suspension, the springs, and the like, are secured to the coil.

All the masses which participate in the reciprocation, including the moving coil and the co-oscillating part of the spring are indicated by M. The return forces, that is spring forces, are indicated by F, while the useful work to be delivered, represented by a damping, is indicated by A. This mechanical system is so tuned, that the mechanical natural frequency of the system F, M, is equal or approximately equal to the excitation frequency. Such drives work electrically as well as mechanically in resonance with the excitation frequency, that is, it has been endeavoured to compensate as much as possible the reactance components, and a further increase in efficiency is no longer possible, more particularly in view of the unavoidably substantial work required for deformation of the powerful spring F.

These considerations do not change even when it is endeavoured to transform this mechanical reciprocating system into a corresponding electrical substitute for the driven parts by using electrical symbols, in order to make some progress in the direction of improving efficiency, at least as regards dimensions.

The situation resulting from the substitution of electrical symbols for mechanical parts is shown in Figure 2, wherein the force K, produced by the moving coil, drives, as a source of voltage, a series-resonance circuit, which is represented by replacing the mass M with an inductance L_m, while the spring F is replaced by the capacity C_f, and the useful work A is replaced by the resistance R_s. The reciprocating speed of the parts to be driven could then be represented in this circuit by the current I. It will be seen therefrom, that actually the reciprocating speed is a maximum when the resistance of the series L_m—C_f becomes zero, that is, when the conditions of resonance are present. Since hitherto the work required for deformation of the spring F was not taken into consideration, this should now be included and is represented by a further resistance R_{fs}. From this it can easily be seen that one cannot in any way dispense with the complicated springs hitherto used. If the springs were not taken into consideration or were dispensed with altogether, the result would be merely an increase in the reactive component, and the force K would no longer be in a position to provide the theoretical work, as in a pure mass oscillator.

Figure 3, which diagrammatically illustrates the invention, represents the reciprocating drive by a purely electrical substitute. U is the source of voltage producing the excitation current I_e. The circuit includes the reciprocating coil with its inductance L and resistance R and the auxiliary condenser C. The useful work is represented by the resistance R_p. The spring, which is now represented electrically, is connected parallel to the resistance R_p representing the useful work, and is represented by an inductance L_f rather than as a condenser, as in Fig. 2, the work required to deform the spring being represented at R_{fp} as a resistance. All the masses to be accelerated are considered as a condenser C_m connected in parallel with the electrical representations of the spring and useful work, since the masses to be accelerated operate as a condenser, and not as an inductance L_m, as in Figure 2 wherein they were considered mechanically.

The condenser C and the parallel connection L_f—R_{fp}, that is, the electrical equivalent of the spring, can be completely disregarded or entirely left out, when the inductance of the reciprocating coil L and the condenser C_m are so tuned to each other, or dimensioned, that the natural frequency of this system is equal or approximately equal to the supply frequency U. Such elimination of the springs avoids the defects resulting from the latter in previous devices and further eliminates the deformation work, that is, the pure running losses, since R_{fp} decreases or completely disappears with the reduction or absence of the spring. Thus, it can be seen that now it is possible to produce a pure resonance reciprocating drive, which is also devoid of any spring, and which operates without any spring forces.

By taking into consideration purely electrical conditions, means can be provided in the arrangement shown in Figure 3, which, when transformed back into the mechanical equivalents, changes the device described in one sense or another. For instance, if it is mechanically desirable, there may be inserted, between the movable coil and the machine to be driven, change speed means, in the form of levers or special coupling springs, or gears, in which case, by bearing in mind the purely electrical conditions, the most favourable dimensions can be determined to avoid any detrimental effect upon the efficiency.

In many applications of the invention, one may entirely dispense with a spring and/or an auxiliary condenser, if there is accurate tuning of the corresponding factors in the electro-mechanical part. Even when the device includes a spring or springs, the invention makes it possible to employ a ratio of mass of the springs to the total reciprocated mass that is no greater than 1:4, so that the device is subjected to totally different continuous stresses and can operate with much greater reliability.

According to a further modification of the invention it is possible to substantially increase the total stroke, hitherto limited by the properties of the springs to a maximum of 1.5 cm., so that, in the case of reciprocating drives for compressors, a substantial increase in the output of the compressor can be obtained while maintaining the same dimensions of the device, since the power increases according to the square of the stroke. This possibility of increasing the total stroke beyond 1.5 cm. is also an essential feature of the invention.

Further, it has been found that, in reciprocating drives embodying this invention, a current density may be used in the excitation winding of the air coils which is higher than 6 amp./mm.^{2}, even up to 60 amp./mm.^{2}, without encountering excessive heating of the coil, and a further increase in the mechanical output of the devices may be obtained by providing special means for effecting cooling of the reciprocating coil.

In the case of compressor drives it is advisable, in order to maintain an exact central position of the moving coil during operation, to provide two opposed compressors on a common connecting member with the moving coil at the center of the latter.

In the example of construction shown in Figure 4 the reciprocating drive is illustrated in connection with a small refrigerating machine. In this example, the mechanical reciprocating part of the device and the electrical part are suitably dimensioned and a weak spring in the form of a helical spring is provided in the device.

The moving coil **1** in this example consists of an iron-free winding mounted on a coil support **6**. The winding receives the current through terminals or contacts **3**, **14** and a conically wound contact spring **7** therebetween, the cross-section of the spring being larger in the axial direction than in the radial direction, in order to obtain a small axial moment of inertia while permitting the passage of a large current. If the return connection is not to be effected through the mass of the device, the above arrangement of terminals and a contact spring is repeated.

The coil support **6** is preferably slid over and secured to a cover **13** and it is formed from an electrically insulating material. A recess **5** provided in the coil support **6** serves to accommodate special contact rings **4**, to which are connected the electric leads and the beginning of the coil winding. The object of these contact rings is to increase the cross-section available for passage of the current at these connecting points, so that there is no unnecessary high load at the soldered connections. The moving coil **1** fills up the air gap **8** of the permanent magnetic field and is longitudinally displaceable therein without touching the walls, being mounted in a special guide. Such guide may be formed by a bore **21** in an iron core **19** accommodating a bushing **46** of bearing material which slidably receives a rod **16**. The bushing **46** may be formed of a pressed synthetic material with suitable admixtures of an antifriction material, for example, graphite.

Further, an annular recess **24** may be provided in the iron core **19**, with the diameter of the recess preferably increasing towards the bottom. This recess is shaped to reduce the eddy current losses, and if desired, the same objective may be achieved by also providing radial slots. The outer closure of the magnetic field is effected by a casing **23** having an annular part **22**, which is integral with the casing **23** or is fitted therein and secured. The casing **23** may be a single forged piece or a pipe section, the bottom of which is subsequently inserted. A magnet **25** is inserted between the bottom of the casing **23** and the iron core **19** and is in the form of a closed body. This magnet is clamped against corresponding flat surfaces only by means of separate screws, so that it may be replaced without having to provide any openings or the like for that purpose.

As shown in Figs. 10 and 11, the efficiency of the magnet **25** may be still further increased, for example, to obtain an efficiency up to about 80%, the parts of the device may be arranged so that peripheral surfaces of the iron parts adjacent the limiting edge of the outlet surface of the lines of force never lie far behind the edge but form everywhere an angle of maximum 180° with the peripheral surface of the magnet **25**, iron being excluded from the space included within such angle. In this way all of the magnetic flux acts directly in the annular gap **8** without any stray losses. In Figure 10 the magnet **25** is so arranged in the iron casing **23** that it and the adjacent iron parts everywhere enclose an angle of 90°, that is, a total angle of 180°, and the iron part **19** is so constructed that the air gap **8** is formed between the iron parts **19** and **23**, as is also apparent in Figure 4. According to a further modification, as shown in Figure 11, the iron part **19** and the casing part **23** are formed so that, considered together, they are of approximately circular cross-section, whereby angles greater than 180° are enclosed between the magnet **25** and the iron part **19** and the magnetic flux is circular to avoid losses. An annular magnet gap **8** is disposed within the circular or torroidal cross-section. The outer surface of the annular gap **8** which forms a portion of the annular casing **23**, **19** runs in the same axial direction as the magnet **25**, so that it is possible to ensure the maximum utilization of the magnet, since the lines of force run entirely symmetrically with respect to the annular gap.

Referring again to Fig. 4, it will be seen that the coil support **6** with its cover **13** is secured on the driving rod **16** by means of a collar **15**, which is supported on an annular slotted attachment **18** inserted into a corresponding recess in the rod **16**. A divided screw-threaded member **47** engages threads on rod **16** and secures the collar **15** in position, and the divided parts of member **47** are held together by a screw connection **48** and locked with respect to the rod **16**.

A spring **12** is preferably mounted within the hollow space of the coil support **6** and may be in the form of a helical spring, with the turns thereof, more particularly the last turn, increasing in diameter in the direction of the magnetic field. The object of this increase in the diameter particularly of the last turn **17** of the spring, is to secure the spring **12** in the iron core **19**, at least over a portion of the periphery of the turns of the spring, by means of a roof-like cover **20**.

Projections **50** secure the flange **28** to the casing **23** and are integral therewith. Window-like openings **51** in the periphery of the casing permit assembly of the parts therein and observation of the driving parts and such window-like openings normally are closed, by a sleeve **29** slidable over the casing. The driven part of the assembly is secured to the flange **28**, and the driven part, in the embodiment of Fig. 4, is a one-stage piston compressor. The described reciprocating drive with piston compressor is especially suitable for small encased refrigerating plants.

The driven compressor part consists of a compressor cylinder **27**, for example, in the form of a sleeve surrounded by a casing **30** provided with cooling ribs. The casing 30 and the sleeve 27 may be formed integrally, preferably as a die or pressure casting. A piston 2 is guided in the sleeve 27, and is preferably integral with the rod 16. In the illustrated embodiment, the diameter of piston 2 is equal to the diameter of the guided portion 26 of rod 16 so that a single machining process can be used for the guide and the piston. In order to reduce the value of the reciprocated masses the piston 2 and the guide 26 are made hollow. On the casing 30 there is machined a surface 39, which can be seen in Figures 5 and 6 and to which there is secured a special valve casing 36, with packing means therebetween. The valve casing 36 is provided with inlet and outlet conduits 37, 38, which preferably extend in the longitudinal direction of the piston. In the valve casing 36 there is provided a recess 41 for an outlet valve 35, preferably in the form of a disc valve, and the casing 30 is provided with a similar recess 42 for an inlet valve 34 which opens in the opposite direction. The surface of valve casing 36 abutting against surface 39 is preferably larger than the diameter of compressor cylinder 27, and the valve casing 36 and the casing 30 are provided with a plurality of registering inlet and outlet channels 40 opening into the recesses 42 and 41, respectively, in order greatly to reduce the flow losses. These inlet channels and outlet channels are jointly controlled by any suitable valve arrangements, as can be seen from the examples shown in Figures 5 and 6.

According to the invention, the valves 34, 35, in the compressor, are arranged with respect to the piston stroke so that, when running on no-load, an air cushion is produced in the compressor cylinder which acts as a brake. This action can be obtained by displacement of the outlet valve 35 towards the bottom. Further, in order to reduce the losses in the rate of delivery, the inlet valve 34 is displaced towards the bottom, to a position about at the middle of the total stroke. As a result thereof, when the piston moves downwards, the medium which has been compressed in the cylinder 27 is expanded to about suction pressure when the channels 40 leading to the inlet valve are uncovered, so that it is possible to obtain an increase in the efficiency.

The casing 30 has a flange-like securing surface at the top to which a cylinder head 31 is secured, and this head may be used to effect the closure of the compressor cylinder 27. In the illustrated construction, closure of the compressor cylinder 27 is effected by a special insertion 32, which has a cylinder-like extension 33 engaging more or less deeply in the compressor cylinder. By means of these exchangeable insertions 32, it is always possible to influence the compression ratio, while displacement of the outlet valve 35 with respect to the upper edge of the piston influences the air cushion and the particular position of the moving coil, more particularly if, according to the invention, a spring is to be eliminated.

Of course, the position of the extension 33 may be made adjustable within definite limits with a single insertion 32 and suitable auxiliary control means (not shown). Resilient means (not shown) may also be provided between the head 31 and the insertion 32 and the extension 33 may then be longitudinally displaceable in the cylinder 27. By adopting these measures it is possible within certain limits, owing to the additional damping of the movable and resiliently loaded attachment 33, to compensate for changes in the amplitudes of reciprocation of the moving coil 1, due to fluctuations in the current supply or changes in the load, so that there is practically no dead space in the compressor cylinder.

The inlet conduit 37 to the valve casing 36 is connected to the flange 28 of the casing 23, and the connection should, as much as possible, have a certain elasticity. This elastic connection may be provided by forming the conduit 37 with an inverted tubular member 43 which has a larger diameter and is joined to the conduit 37 at the lower end of the latter. The tubular member 43 is secured, at its upper end, to the flange 28 so that the lower end of conduit 37 can deflect.

The medium to be compressed is introduced into casing 23 through a duct 45, and the whole arrangement is made so tight that the medium to be compressed is sucked from the duct 45 through the interior of the reciprocating drive along the air gap 8 so as to cool the latter before entering the compressor part by the conduit 37. The duct 45 supplying the medium and the outlet conduit 38 are preferably connected with the casing 23 and the valve casing 36 by way of elastic parts 44, which may be made of a mass of synthetic material subjected to pressure or injection molding, or of rubber compounds for instance "perbunan," and to which the usual pipes are connected. These resilient parts 44 are secured to the related ducts and casings by sticking or adhesion to provide absolutely gas-tight connections and, if the elastic cross-sections of parts 44 are properly dimensioned, the latter can serve at the same time as an elastic suspension and mounting. Thus, these elastic intermediate parts 44 may also be provided with the mounting lugs of the device.

In order to compensate for axial displacement between the cylinder 27 and the guide 26, recesses may be provided in the central part of the rod 16, to permit elastic deformation of the rod.

The magnetic circuit, consisting of the iron core 19, the magnet 25 and the casing 23, may be magnetised in the following manner: First of all, the device is assembled with all its essential parts and its electrical connections. The device is now properly cleaned and, since all the parts 25, 23, 19 are not yet magnetized such cleaning is comparatively easy.

After cleaning, the device has applied to the winding of the moving coil 1 a direct current voltage of suitable strength for a short period of time and in this way the magnetisation of the magnet 25 is effected directly only through the moving coil. Owing to the construction of the moving coil 1 made by its long stroke, it surrounds practically the whole of the magnetic circuit, and in this way it is possible to carry out the entire magnetisation of the magnet 25 without danger by a suitable choice of the direct current voltage and temporary actions thereon. This is a very important advantage of the device according to the invention.

It has already been mentioned above that the current density in the reciprocating moving coil 1 is greater than 6 amp./mm.^{2}. This is a subsantially greater load than one generally may use in electric drives of the described chracter, but it can be used in drives embodying the invention since the admissible heating limit is then about 60 amp./mm.^{2}. This is justified mainly by the fact that, owing to the good cooling of the air coil and the pump-like action of the carrier 6 of the coil, which may even be formed to efficiently perform the pumping function, a completely adequate cooling is ensured, the cooling medium being sucked through the magnet gap. Thus, it is possible to reduce the cross-section of the wire of the air coil 1, which leads to a more favorable utilization of the winding space and to a reduction in weight. Moreover, it is possible to assist the cooling effect, as is more particularly shown in Figure 7. In this case, a ring 9 of good heat conducting and non-magnetic material, for instance, aluminum or copper, or arranged on both sides of the air gap 8 for dissipating the heat. This ring 9 may also be provided with special cooling ribs and may be interrupted at one or more locations, for instance by slits 10, in order to avoid the formation of any eddy currents.

Further, in this embodiment of the invention, all springs acting on the moving coil are eliminated, and in order to maintain the moving coil 1 in an exact central position, the rod 16 is connected at each end with a compressor 2, which is constructed according to the example shown in Figure 4, and which provide suitable air cushions by the selection and positioning of the valves 36.

Further, two independent driving units may be mounted within one casing 23, as shown in Figure 8, so that the pistons 2, 2′ driven by moving coils 1, 1′, work in a common central compressor cylinder 27 in a counteracting arrangement. The cylinder is provided with an inlet 37 and an outlet 38 and with corresponding valve chambers.

Of course, mechanical speed changing means, which may be in the form of coupling springs, coupling gears or lever arrangements, may be provided between the driven piston 2 and the moving coil 1. The embodiment of the invention shown in Figure 9 has its moving coil 1 connected, by way of rod 16, with a spring 12 which is secured to the iron core 19. The spring 12 is divided into two sections and the part to be driven, that is, the compressor piston 2, is connected only to one of the sections of spring 12, as at 49. By suitably choosing the connection 49 and tuning the particular spring length, it is possible to obtain any desired gear ratio, and in addition thereto, to maintain the amplitude of the reciprocations of the moving coil as large as possible, preferably with a total stroke of more than 1.5 cm. This has the advantage of increasing the efficiency of such a drive, so that, for a drive developing a predetermined amount of power, a relatively smaller magnet can be used.

The device shown in Figure 12 corresponds, so far as its magnetic construction is concerned, substantially to the construction shown in Figures 4 and 10. However, in the device of Figure 12, the casing 23 and the flange 28 constitute an integral unit which is diametrically divided and held together by special clamping screws. The flange 28 is provided with two axial projections 53 having a bore 52 to define the compressor cylinder in which the piston 37 is reciprocable. Preferably, in the central region of the casing 23 there is provided a wall 54 serving as a central guide for the piston rod 16, and this wall 54 can also be used to carry the terminals 14 for the contact spring 7.

In the projection 53 within casing 23, there is mounted the inlet valve 34, and on the external projection 53 there is mounted the outlet valve 35 and the valve casing 36, with a number of valve ducts being provided, as at 40 in Figs. 5 and 6. As in the embodiment of Fig. 4, the upper end of the bore defining the compressor cylinder 52 is closed by an insert 33.

The spring 12 is disposed in the space between wall 54 and flange 28 and the relatively large turn of spring 12, at the upper end of the latter, is secured by a cover 20. The spring 12 is secured to rod 16 by means of two slotted projections 18 and 18′ which are received in recesses 55 and 56, respectively, formed in the rod 16. Special clamping means are provided on the rod 16 between the projections 18, 18′ to press the spring firmly against the projection 18.

As seen in Fig. 12, such clamping means may be constructed in the form of a sleeve with an outwardly directed flange 57 which slides over the piston rod. The sleeve is provided with a screw-threaded member 58, which can be adjusted to abut against projection 18′ and thereby clamp the lower turn of spring 12 between flange 57 and projection 18. When the devices shown in Figures 4 and 12 are used for refrigerating machines, it is advisable that the mounting be effected at right angles to the direction of the piston rod 16, that the magnet constitute the lower part of the device, and that the inlet of the cooling means be provided in the lower part and the outlet in the outer part. At the same time, the space between the magnet 25 and the casing 23 may be used as an oil collecting space so that lubrication of the upper part of the device is effected by the oil particles which have been dragged along together with the cooling means.

Where silent operation is of great importance, the suspension of the device may also be effected by surrounding it with a more or less elastic casing which is secured to the device in the region of the center of gravity.

I claim:

1. In an electrical reciprocating motor, particularly adapted for driving the compressors of small refrigerating machines and the like, which works substantially in resonance with the frequency of the alternating excitation current therefor, and having means producing a magnetic field, and a reciprocating mass that includes exciter windings and moves through the magnetic field; the magnitude of said mass being such that a capacitance which is the electrical equivalent thereof, and which is represented by the value of the mass divided by the square of the product of the induction of the magnetic field and the length of said exciter windings, taken together with the inductance of the exciter windings forms an electric resonant circuit having a natural frequency that is at least approximately equal to said frequency of the alternating excitation current.

2. In an electrical reciprocating motor as in claim 1; a mechanical spring acting on said reciprocating mass and assisting in tuning said capacitance which is the electrical equivalent of the reciprocating mass with respect to said inductance of the exciter windings to form said electric resonant circuit.

3. In an electrical reciprocating motor as in claim 1; an electric condenser tuning and adjusting relative to each other said inductance of the exciter windings and said capacitance which is the electrical equivalent of the reciprocating mass.

4. In an electrical reciprocating motor as in claim 1; a mechanical spring acting on said reciprocating mass and an electric condenser in the circuit feeding the excitation current to said exciter windings for tuning and adjusting relative to each other said inductance of the excitor windings and said capacitance which is the electrical equivalent of the reciprocating mass.

5. In an electrical reciprocating motor as in claim 1; an electric condenser in series with said exciter windings in the circuit feeding the alternating current to said windings, and mechanical spring means acting against said reciprocating mass, said mass and spring means forming a mechanical system which operates in resonance, said capacitance, which is the electrical equivalent of the reciprocating mass, and the force applied by said spring means for achieving resonant operation of said mechanical system being tuned and adjusted relative to each other in relation to a single electric oscillating system in which a series resonant circuit, representing the electrical elements of the motor, is connected in series with a parallel resonant circuit which represents the electrical equivalent of said mechanical system, to result in at least a reduction in the values of the force of said spring means and said electric condenser.

6. In an electric reciprocating motor as in claim 1; wherein said exciter windings are iron-free and work on the electro-dynamic principle so as to be adapted for driving two opposed compressors in order to maintain said windings in an exact central position during operation of the motor.

7. In an electric reciprocating motor as in claim 6; a rod having said exciter windings mounted thereon and adapted, at its opposite ends, to drive two opposed compressors.

8. In an electric reciprocating motor as in claim 1; wherein said exciter windings are dimensioned in relation to the alternating excitation current so as to have a periodic current density therein greater than 6 amp./mm.^{2}.

9. In an electric reciprocating motor as in claim 1; means for feeding the alternating excitation current from a lead-in terminal to said exciter windings and having increased cross-sections substantially greater than that of said windings.

10. In an electric reciprocating motor as in claim 9; a coil support carrying said exciter windings, and divided contact rings, said coil support having recesses receiving

said contact rings with the latter defining said increased cross-sections of said feeding means.

11. In an electric reciprocating motor as in claim 1; helical contact springs having small mechanical resistance and turns that engage conically within each other, said contact springs being included in means for feeding the excitation current to said exciter windings.

12. In an electric reciprocating motor as in claim 11; each of said turns of the helical contact springs having a cross-section that is smaller in the radial direction than in the axial direction so as to have a small axial moment of inertia when the excitation current is large.

13. In an electric reciprocating motor as in claim 1; said means producing a magnetic field including a permanent magnet defining a gap through which said windings move, and ribbed rings of a good heat conducting material which is non-magnetic, said rings being disposed on the opposite sides of said gap for the dissipation of heat.

14. In an electric reciprocating motor as in claim 13; each of said rings being interrupted at least once to avoid the production of eddy currents.

15. In an electric reciprocating motor as in claim 14; said rings having slots therein to define the interruptions thereof.

16. In an electric reciprocating motor as in claim 1; the total stroke of said windings being at least 1.5 cm.

17. In an electric reciprocating motor as in claim 1; mechanical change speed means driven by movement of said windings and adapted for driving a compressor.

18. In an electric reciprocating motor as in claim 17; said change speed means including coupling springs.

19. In an electric reciprocating motor as in claim 1; a return spring connected to said windings and being divided so that only one section of said divided return spring can be connected to a compressor for driving the latter.

20. In an electric reciprocating motor as in claim 1; adjustable means for connecting said winding to a compressor to be driven by the latter.

21. In an electric reciprocating motor as in claim 1; a tubular supporting member of electrically insulating material having a recess in which said windings are disposed, and a cover over which said supporting member is slidably disposed and to which said supporting member is secured.

22. In an electrical reciprocating motor, particularly adapted for driving the compressors of small refrigerating machines and the like, which works substantially in resonance with the frequency of the alternating excitation current therefor, and having means producing a magnetic field, and a reciprocating mass that includes exciter windings and moves through the magnetic field; the magnitude of said mass being such that a capacitance which is the electrical equivalent thereof and which is equal to

$$\frac{M}{(B.1)^2}$$

wherein M is the value of the reciprocating mass, B is the induction of the magnetic field and 1 is the length of conductor of the exciter windings, when taken together with the inductance of the exciter windings, forms an electric resonant circuit having a natural frequency that is at least approximately equal to said frequency of the alternating excitation current.

References Cited in the file of this patent

UNITED STATES PATENTS

2,040,677	Suits	May 12, 1936
2,040,763	Summers	May 12, 1936
2,194,535	Von Delden	Mar. 26, 1940
2,669,937	Presentey	Feb. 23, 1954

FOREIGN PATENTS

475,758	Italy	Nov. 14, 1952