

[72] Inventor **Richard T. Race**
Chicago, Ill.
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[73] Assignee **Motorola, Inc.**
Franklin Park, Ill.

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Primary Examiner—D. F. Duggan
Assistant Examiner—B. A. Reynolds
Attorney—Mueller, Aichele & Rauner

[54] **RECIPROCATING MOTOR WITH EXCURSION MULTIPLICATION**
18 Claims, 6 Drawing Figs.

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[51] Int. Cl. **H02k 33/04**

[50] Field of Search 310/18, 15,
17, 27, 28, 29, 30, 33, 25, 8.1, 8.5, 8.6, 8.3, 8.2;
103/53; 230/55

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ABSTRACT: A reciprocating motor for a refrigerator compressor operates in response to alternating current signals applied either to an electromagnet or to a bilayer piezoelectric crystal mounted within the motor housing. The armature of the electromagnet and a plate driven by the bilayer crystal are arranged for limited excursions in an amount which normally would be insufficient to provide sufficient output to the piston of a compressor. The armature or the plate, however, are connected to a compressor piston through a power drive spring which is caused to have a resonant frequency of vibration equal to the frequency at which the armature or the crystal is driven. The drive spring then amplifies the movement of the armature or plate to cause the piston driven thereby to have a substantially greater excursion of reciprocation than the driving armature or crystal, thereby providing sufficient physical piston displacement to operate the compressor.

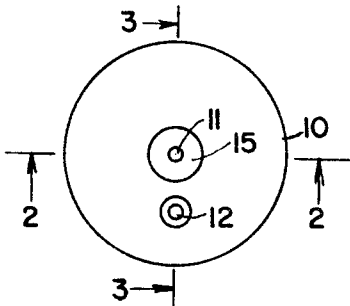


FIG. 2

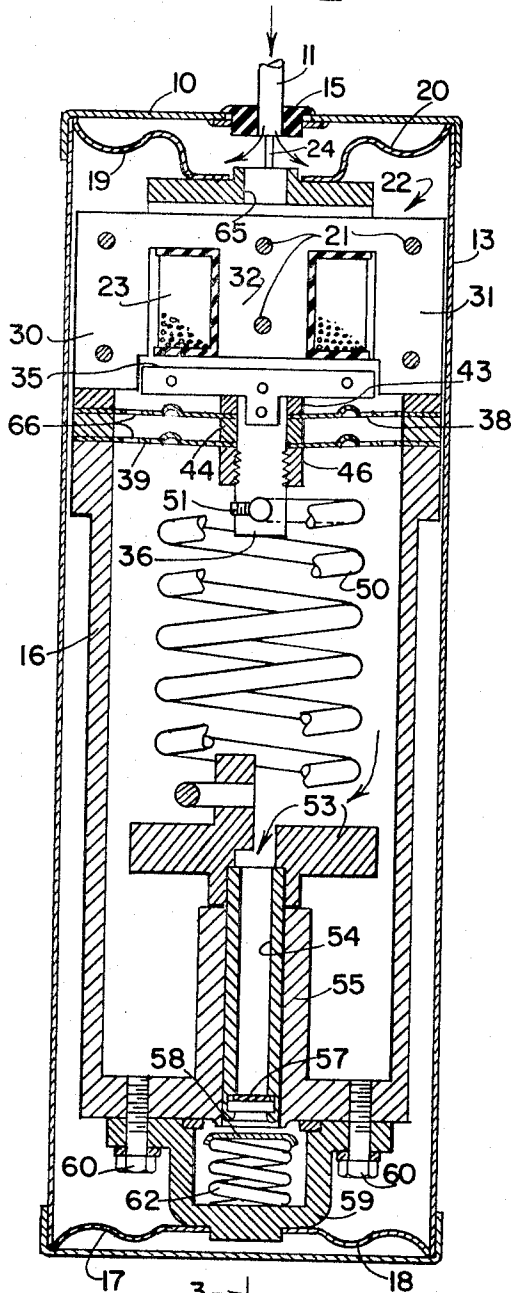


FIG. 3

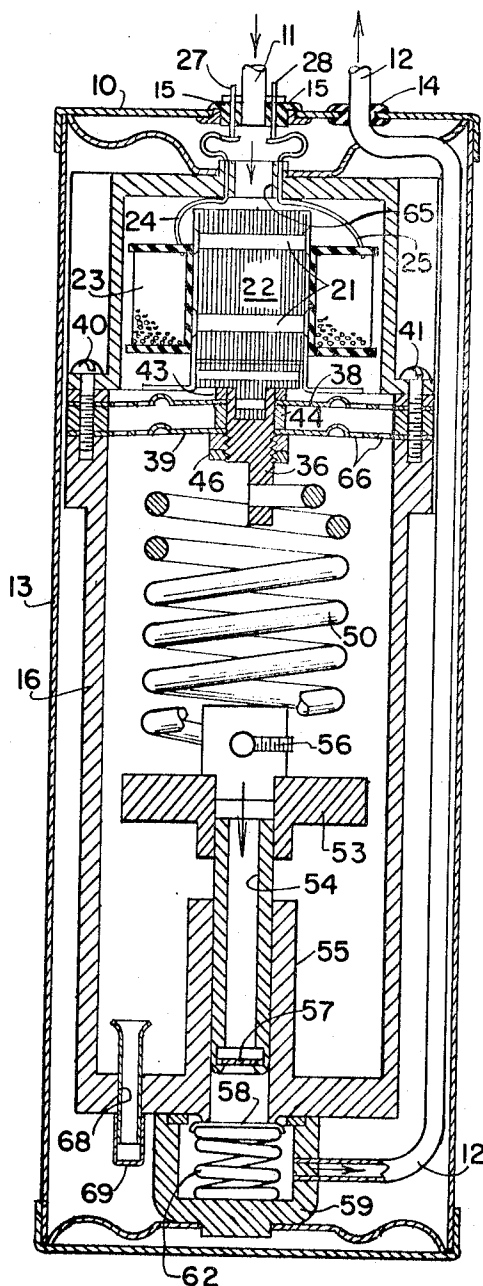
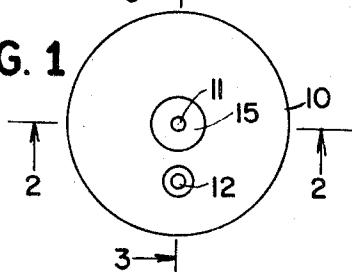
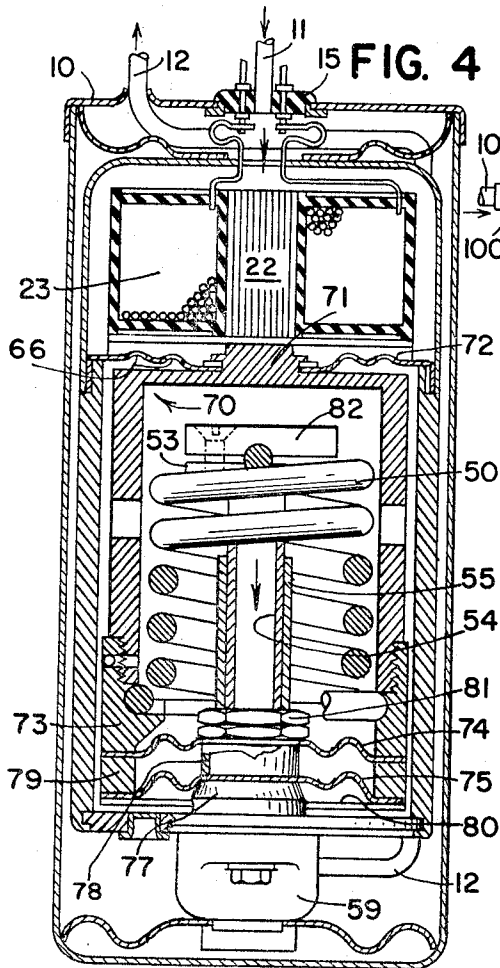
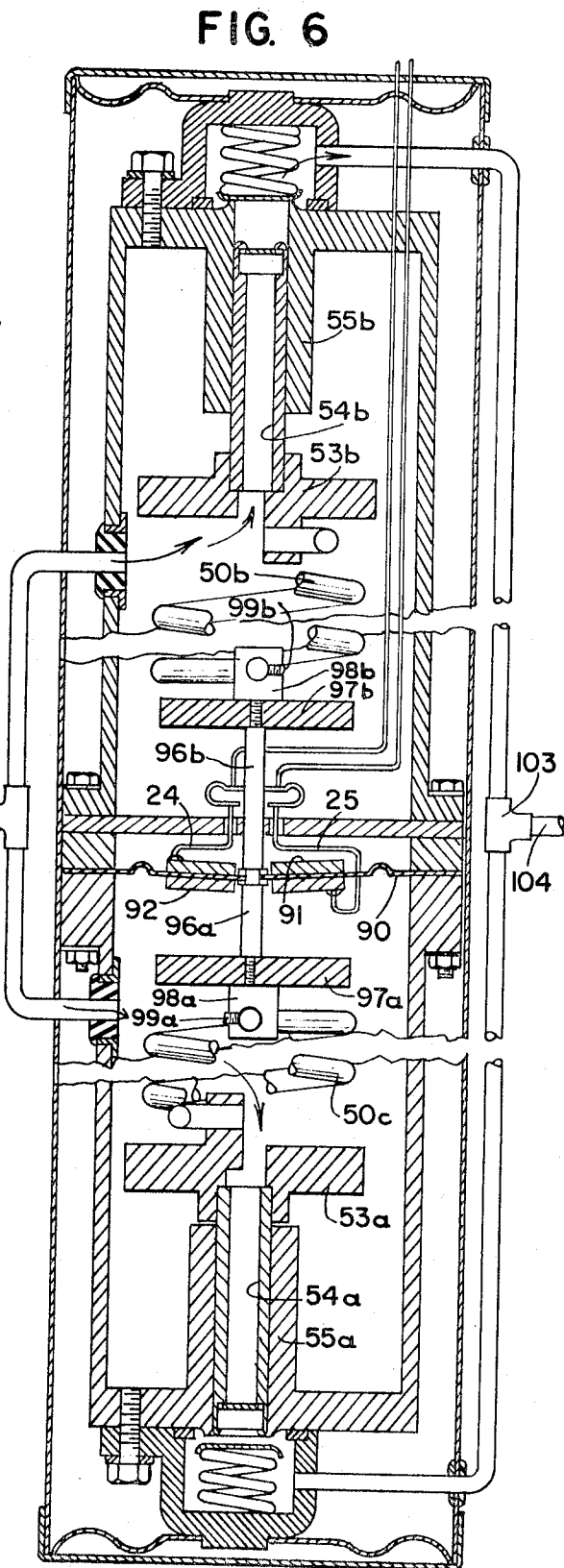
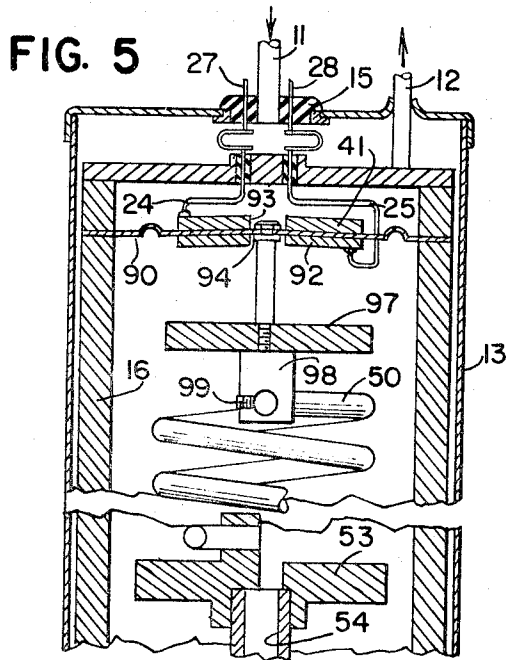


FIG. 1



INVENTOR
RICHARD T. RACE
BY
Mueller, Aichele & Ranner

ATTYS.



RECIPROCATING MOTOR WITH EXCURSION MULTIPLICATION

BACKGROUND OF THE INVENTION

It is a common practice to drive a reciprocating piston mechanism by means of the rotary motion of an induction motor. With such a drive mechanism, it is necessary to convert the rotary motion of the motor to a reciprocating motion by some mechanical means, resulting in a mechanism having a number of friction points between contacting parts. Motors of this type often are used to power refrigeration compressors, causing the compressors to be relatively complicated and somewhat expensive devices. In addition, the current drawn by an induction motor for such compressors is relatively high, so that operation of such motors from a DC source through an inverter powered by a battery generally is not feasible.

In order to overcome the disadvantages inherent in transforming the rotary motion of an induction motor into the reciprocating motion of the piston, attempts have been made to effect the electrical drive by means of a magnetic armature which is drawn into the magnetic field of a coil and withdrawn by a restoring spring in synchronism with the frequency of an AC signal applied to the coil. The armature then is directly connected to the compressor piston providing a direct reciprocating motion in response to the application of AC signals to the coil. A motor of this type, however, also has disadvantages, inasmuch that the armature must be moved the full length of the stroke of the piston and must be of comparatively large mass in order to cause sufficient power to be transmitted to the piston. Because of the large air gaps required and because of the large mass of the armature, such a motor is relatively inefficient.

Another type of reciprocating motor has been provided in the form of a moving coil motor, in which the moving coil is connected directly through a shaft to the reciprocating piston of the compressor. Alternating current is passed through the coil which is placed in the air gap of a permanent magnet, causing the coil and piston to reciprocate at the frequency of the AC signal applied to it. Such motors generally include a restoring spring which is provided merely to center the coil in the air gap of the magnet. In addition, provisions have been made for an additional spring connected to the piston-coil combination and caused to resonate at the frequency of the AC signals applied to the coil in order to improve the efficiency of the motor. This type of a system is well known in dynamic loudspeakers and is comparable to the drive used in such loudspeakers. Such a system, however, still is relatively inefficient due to the fact that the coil must move in a relatively large air gap, since the excursions of movement of the coil are the same as the excursions of movement of the piston. In addition, motors of this type are heavy because of the relatively large magnet required; and the magnet also is expensive.

SUMMARY OF THE INVENTION

Accordingly it is an object of this invention to provide an improved reciprocating motor.

It is an additional object of this invention to drive the piston of a reciprocating motor through relatively large excursions from a reciprocating drive input operating through relatively small excursions.

It is an object of this invention to drive the piston of a reciprocating motor through relatively large excursions by coupling the piston through a resonant spring system to a driving member driven through relatively small excursions.

In accordance with a preferred embodiment of this invention, a first reciprocating driven member is driven through a predetermined excursion, and a second reciprocating driven member is interconnected to the first member through a resilient coupling to form a resonant system having a predetermined resonant frequency of vibration corresponding to the frequency at which the first member is driven. The second reciprocating member then is caused to be driven through excursions which are substantially greater than the predeter-

mined excursion of the first driven member by the multiplication effect caused by the resonant resilient coupling means.

In different embodiments of this invention, the first reciprocating driven member constitutes either the armature of an electromagnet or a member driven by a bilayer piezoelectric crystal. In either case, the driven member is caused to move through very limited excursions compared to the excursions through which the piston or second reciprocating driven member is moved; so that a relatively high efficiency is achieved due to the fact that when using an electromagnetic device to drive the armature, only a small air gap need be employed, and when using a piezoelectric crystal device, the high efficiencies present in operating such devices may be utilized to their fullest extent.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a top view of a motor housing used with a preferred embodiment of this invention;

FIG. 2 is a cutaway side view of the motor shown in FIG. 1, with the section taken along line 2-2 of FIG. 1;

FIG. 3 is a cutaway side view of the motor of FIG. 1, taken along the line 3-3 of FIG. 1;

FIG. 4 is a sectionalized side view of another embodiment of a motor in accordance with this invention;

FIG. 5 is a partial sectionalized view of another embodiment of this invention; and

FIG. 6 is another embodiment showing a different version of a motor of the type shown in FIG. 5.

DETAILED DESCRIPTION

Throughout the several views of the drawing, the same reference numerals are used to designate the same or similar components in order to aid in an understanding of the embodiments shown in the different FIGS.

Referring now to FIGS. 1, 2 and 3, there is shown a reciprocating compressor motor made in accordance with one embodiment of this invention. As shown in FIG. 1, such a motor may be enclosed in an outer housing 13 of a hollow cylindrical cross section and having a cover 10 mounted over the end of the housing. An intake tube 11 is provided for admitting gases to the compressor and an exhaust tube 12 (FIGS. 1 and 3) for permitting the egress of gases compressed by the motor is mounted within the housing 13. The housing 13 is gastight, with the tubes 11 and 12 passing into the housing through openings in the cover 10 and passing through grommets or hermetic seals 14 and 15 in order to prevent the leakage of gases from the housing 13.

A compressor motor constructed in accordance with a preferred embodiment of this invention then is mounted in a second or inner housing or frame 16, which is supported at its lower and upper ends within the outer housing 13 by pairs of resilient damper springs 17 and 18 and 19 and 20 respectively. These damper springs permit the inner housing 16 to float with respect to the outer housing 13 and act to isolate vibrations between the motor and the outer housing 13. As shown in FIG. 1 and 2, the motor is an electromagnetically driven motor having a laminated E core structure 22 mounted in the inner housing 16 at the upper end by clamping the outer legs of the E core structure to the inner housing 16. The laminations of the core 22 are held together by rivets 21, with a laminated core being used in order to minimize the heat produced within the core structure. In order to drive the motor, a winding 23 is placed around the inner leg 32 of the core and is provided with AC signals over a pair of leads 24 and 25 connected to a pair of terminals 27 and 28 which pass through the grommet 15. The terminals 27 and 28 may be connected to any suitable source of AC voltage (not shown), such as the ordinary 60 cycle, 120 volt house current, or the AC signals can be derived from a suitable battery-operated inverter.

As is most clearly shown in FIG. 2, the outer legs 30 and 31 of the E core structure 22 are extended beyond the length of the middle leg 32 in order to cause the number of working air

gaps of the electromagnet to be reduced from the normal three gaps to a single gap present at the middle leg 32. A laminated armature 35 is placed in this gap below the middle leg 32 and extends substantially across the width of the space between the legs 30 and 31 in order to provide a close coupled magnetic path during the operation of the electromagnet. The armature 35 also includes an extension 36 at its center, so that the complete armature assembly is a T-shaped assembly. The extension 36 is supported and centered within the inner housing 16 by a pair of relatively stiff, spaced diaphragm springs 38 and 39 which are clamped into spaced locations in the inner housing 16 by a pair of clamping screws 40 and 41 (FIG. 3). In addition, the springs 38 and 39 are located and clamped onto the extension 36 by means of a pair of spacer sleeves 43 and 44 which are locked into position by means of a pair of lock nuts 46 threadedly engaging the extension 36. The diaphragm springs 38 and 39 have a combined spring rate of approximately 150 pounds for a 0.040-inch movement of the armature 35, and in their relaxed condition cause the armature 35 to be located at a position midway between the two positions shown in FIGS. 2 and 3. The free resonance of the driving mechanism including the diaphragm springs 38 and 39 is approximately 250 Hz.

This armature-driving mechanism then is connected to one end of a resonant power coil spring 50 which is locked into position at the end of the extension 36 by means of a conventional locking screw 51. The other end of the power coil spring 50 is connected to an extension on a piston coupler 53 by means of a lock screw 56 and the piston coupler 53 is welded to or braised to a hollow piston 54 which is slidably mounted within a cylinder 55, formed as part of the inner housing 16.

The characteristics of the coil spring 50 are chosen in accordance with the mass of the piston coupler 53 and piston 54 to form a resonant system which resonates at 120 Hz. Since the armature 35 is attracted and released from the electromagnet at 120 Hz, when a 60 Hz. AC signal is applied to the coil 23 (the armature is attracted and released for each half-cycle of the AC signal), the motion imparted to the armature 35 by the electromagnet causes the spring 50 and the piston 54 to reciprocate at 120 cycles per second. Because the resonance of the system including the spring 50 is carefully selected to match the frequency at which the armature 35 is driven, a mechanical impedance match is achieved between the armature 35 and the piston 54, causing a multiplication of the excursions of the armature 35 in order to drive the piston 54 through relatively wide excursions compared to the excursions of the armature 35. For example, it is possible to drive the piston 54 through excursions which are approximately 12 times the excursions of the armature 35.

The springs 38 and 39 serve a number of functions in the operation of the motor shown in FIGS. 2 and 3. These springs provide mechanical support and alignment for the entire moving system as has been described previously. In addition, the springs 38 and 39 store the unilateral mechanical energy developed by the armature 35 and convert this energy into bilateral sinusoidal mechanical drive power for the resonant coupling spring 50 and piston assembly 53, 54. By providing a stiff drive source for the resonant coupling spring 50, the springs 38 and 39 prevent the system from being influenced by the 90° phase lag which exists between the two mechanical halves of the moving system under dynamic conditions.

The hollow piston 54 reciprocates within the cylinder 55 in a conventional manner for a refrigerator compressor and is shown in FIG. 2 at the position of its bottommost compression stroke, in which position an intake valve 57 at the end of the piston 54 is closed and an exhaust valve 58 located in the end of the cylinder 55 is open. A pressure chamber 59 is provided at the bottom of the inner housing 16 and is fastened thereto by a suitable fastening means such as bolts 60. Compressed gas is expelled from the cylinder 55 through the open exhaust valve 58, into the pressure chamber 59 and out the exhaust tube 12 (most clearly shown in FIG. 3). To provide the desired pressure, the valve 58 is opened against a relatively stiff valve

spring 62, the parameters of which are chosen to provide this pressure. The construction of the compression chamber 59, the piston 54 and the cylinder 55 may be of the type conventionally used in refrigerator compressor motors.

It should be noted that the gas returning to the compressor motor through the intake tube 11 also passes through an opening 65 located in the top of the inner housing 16 directly above the electromagnet core 22 and above the winding 23. This returning gas passes downwardly over the winding and core to provide cooling for these components, as is best seen in FIG. 3 where it is apparent that the gas may pass between the coil 23 and the edge of the housing 16 at both the left-hand and right-hand edges of the coil. The diaphragm springs 38 and 39 are provided with openings 66 therein to permit the gas to pass through these springs into the larger portion of the chamber occupied by the resonant power spring 50. In this chamber the gas then passes into the upper open end of the hollow piston 54; and during the return stroke of the piston as shown in FIG. 3, the intake valve 57 is open permitting the gas to pass through the piston 54 into the chamber of the cylinder between the end of the piston 54 and the now closed exhaust valve 58.

Also shown in FIG. 3 is an additional intake port 68, providing an opening between the interior of the inner housing 16 and the space between the inner housing 16 and the outer housing 13. The end of the intake port 68 extending into this space between the two housings is provided with a filter screen 69 and also may include a wick saturated with a lubricant; so that air passing between the two housings passes upwardly through the filter 69 and into the intake port 68, carrying with it some lubricant for the piston 54. The provision of such a lubrication intake port for a compressor motor is standard and lubricant for the intake port may be obtained from a reservoir of lubricant introduced into the space between the housings 13 and 16 and located at the bottom of the housings as viewed in FIGS. 2 and 3.

In FIG. 2, the piston 54 and the armature 35 both are shown in their lowermost positions, and in FIG. 3, the piston 54 and the armature 35 both are shown in their uppermost positions in order to best provide a comparison of the relative excursions of both of these elements. It should be noted, however, that in actual practice, a 90° phase lag exists between the excursions of these two components, so that at no time during the dynamic operation of the device will both the armature 35 and the piston 54 occupy simultaneously the upper and lower extremes of their travel.

Referring now to FIG. 4 there is shown another embodiment of an electromagnetically driven compressor motor of the type described above in FIGS. 1, 2 and 3. For the most part, the motor shown in FIG. 4 is substantially the same as that shown in FIG. 2, with the exception that a different configuration of the armature assembly 35 is employed. As a consequence, the operation of those portions of the motor shown in FIG. 4 which are the same as the motor shown in FIGS. 2 and 3 will not be repeated, since the description already made in conjunction with FIGS. 2 and 3 applies equally as well to the embodiment shown in FIG. 4.

The armature of the motor shown in FIG. 4, however, is in the form of a hollow cylinder 70 formed of magnetic material and having an upper portion 71 of a configuration substantially to mate with the center leg 32 of the electromagnet in a manner similar to the armature 35 of FIGS. 2 and 3. This upper end 71 of the cylinder 70 also is mechanically supported by a stiff diaphragm spring 72 which is generally of the same type as the springs 38 and 39 used in the motor shown in FIGS. 2 and 3. The sides of the armature cylinder 70 then extend downwardly and surround the spring 50 which is attached to the armature cylinder 70 at its lower end by clamping the lower convolution of the spring 50 between the lower end of the armature cylinder 70 and a clamping member 73 which is threaded onto the lower end of the armature 70.

The lower end of the armature cylinder 70 and the clamping member 73 are supported from the cylinder 55 of the pump by

an additional pair of stiff diaphragm springs 74 and 75 which are positioned on the outside of the cylinder by a pair of spacer sleeves 77 and 78 and are spaced from one another by a spacer 79 at their outer extremity. A clamping ring 80 holds the assembly together at the bottom end; and a pair of lock nuts 81, threaded onto the exterior of the cylinder 55, clamp the spacers and the springs 74 and 75 between the lock nuts and the clamping ring 80. Thus, the three diaphragm springs 72, 74 and 75 are fastened to the inner housing 16 to support and center the cylindrical armature assembly 70. The upper end of the spring 50 shown in FIG. 4 then is attached to the top of the piston 54 by means of a piston clamp 82 which is attached to the piston coupler 53 by means of suitable fastening devices such as screws or the like. The piston 54 is free to move within the cylinder 55 in the same manner described previously in conjunction with FIGS. 2 and 3.

It will be noted that the configuration of FIG. 4, however, provides for a much more compact motor than the motor shown in FIGS. 2 and 3 since the spring 50 surrounds the cylinder and piston assembly, due to the fact that it is coupled to the armature assembly at its bottom end, with the armature assembly 70 surrounding the spring 50.

In both of the embodiments shown in FIG. 4 or in FIGS. 1, 2 and 3, the armature mass and the diaphragm springs are selected to store several orders of magnitude more mechanical energy than is required to drive the resonant pump assembly including the spring 50 and the piston 54. This insures minimal change in the resonant frequency under the conditions of varying head pressure encountered in the operation of the compressor motor.

Referring now to FIG. 5, there is shown another embodiment of the resonant amplitude magnification motor of the type shown in FIGS. 2 and 3. Once again, in FIG. 5 the same reference numerals used in FIGS. 2 and 3 will be used to designate the same parts, with different reference numerals being employed only to designate parts which differ from those shown in FIGS. 2 and 3. In the embodiment of FIG. 5, the electromagnetic assembly has been replaced by a piezoelectric crystal drive assembly in the form of an invar metal drive plate 90 which is mounted in and clamped to the inner housing 16 in a manner similar to the manner in which the diaphragm guide springs 38, 39 or 72, 74 and 75 are connected to the inner housing. This plate is in the form of a circular disc, and a pair of nickel-plated bilayer piezoelectric ceramic discs 91 and 92 are cemented to the plate, with the disc 91 being located on the upper surface of the plate 90 and the disc 92 being located on the lower surface thereof. The leads 24 and 25 are connected to the piezoelectric discs in a conventional manner so that AC driving signals may be applied to the bilayer drive assembly.

In order to provide clearance for connecting a driving link 96 to the center of the invar plate 90, holes 93 and 94 are formed in the centers of the discs 91 and 92. The driving link 96 may be connected in any suitable manner such as by welding or causing it to be threaded with lock nuts clamping it to the plate 90. The other end of the driving link 96 is threaded into a spring coupler plate 97 having an extension 98 to which the spring 50 is connected by means of a set screw 99. The remainder of the compressor motor shown in FIG. 5 is the same as that shown in FIGS. 2 and 3, and for this reason no further details of this remaining portion of the motor have been shown in FIG. 5.

When a 60 Hz. AC drive voltage is supplied to the bilayer discs 91 and 92 over the leads 24 and 25 in the proper phase, the diameter of the discs change. The discs are so phased and selected that one disc is increasing in diameter while the other disc is decreasing in diameter for one half-cycle of the applied AC signal. During the other half-cycle of the AC signal, the disc which increased in diameter for the previous half-cycle decreases in diameter, while the disc which decreased in diameter for the preceding half-cycle increases in diameter to cause an "oil can" effect or movement to be applied to the drive plate 90.

This movement at the center of the drive plate 90 is approximately 30 to 40 mils; and when it is coupled to the drive spring 50, which is chosen in conjunction with the piston 54, to resonate at the 60 Hz. driving signal frequency, the piston 54 reciprocates. Since the resonance of the system including the spring 50 and piston 54 is matched to this 60 Hz. frequency, a mechanical impedance match is achieved between the bilayer driver and the piston, resulting in a mechanical advantage of the order of 12 to 1 being achieved. As a consequence, it is possible to translate the limited motion of the piezoelectric bilayer driver into a usable reciprocating excursion which can be employed in a refrigerator compressor motor.

Referring now to FIG. 6, there is shown a piezoelectric bilayer crystal driver of the type shown in FIG. 5 but being utilized to drive two pistons simultaneously in a push-pull relationship, so that with each half-cycle of oscillation or reciprocation of the bilayer crystal device, a compression stroke is achieved by one or the other of the two pistons. Each half of the motor shown in FIG. 6 is substantially the same as the motor shown in FIG. 5, utilizing a coupling spring 50 between the bilayer driver and the piston of the type shown in FIGS. 2 and 3. For this reason, no additional explanation of the operation of each of the two halves of the motor will be made, with the components of each half, however, being designated as *a* and *b* in order to distinguish between them.

In modifying the motor of FIG. 5 to provide a two-cylinder balanced compressor of the type shown in FIG. 6, all that is necessary is to provide an additional coupling link 96*b* connected to the center of the invar drive plate 90 diametrically opposite the coupling link 96*a* previously described in conjunction with FIG. 5. The resonant frequency of the driver spring 50 and piston 54 assemblies of each of the halves of the motor shown in FIG. 6 is chosen to be the same and to be the frequency at which the bilayer discs drive the invar plate 90. The intake ports for each half of the motor are connected in common through a T-coupling device 100 to a common intake tube 101, and the exhaust tubes for each half of the motor are connected in common through a T-coupler 103 to a common exhaust tube 104. The operation of each half of the motor shown in FIG. 6 is the same as the operation of the motor shown in FIG. 5, with the halves being operated 180° out of phase with one another.

The motors described above utilize a resonant amplitude magnification coupling system for efficiently coupling low displacement drive mechanisms such as the bimorph crystal drivers or the small dynamic air gap electromagnetic driver, while achieving high efficiency with a relatively long stroke at the piston being driven by the motor. In the electromagnetic motor, the use of the very small dynamic air gap results in a high electromechanical efficiency, so that only a low power input is required. In both of the devices, either the piezoelectric crystal device or the electromagnetic device, the power input is low enough that the devices can be efficiently operated from a DC source through an inverter, thus lending themselves to use in portable refrigeration units such as could be employed in campers, motor vehicles and the like.

The diaphragm springs used in the electromagnetic motors to align and support the armature assembly can be designed with a nonlinear characteristic in order to better match the force/distance curve of the electromagnet 22.

Because it is not necessary to employ a large, expensive and heavy electromagnet in the motors described above, the cost of the motors is substantially reduced, and a smaller physical size for the same capacity achieved by other reciprocating motors is realized. Since the only friction points in this motor are between the piston and the cylinder, it may be possible to employ Teflon piston rings or a Teflon coating on the piston to permit the construction of a "dry" refrigeration or air compressor with no oil in the system. This would be an advantage especially for a portable unit.

Although the foregoing description has been concerned primarily with a refrigerator compressor motor, it should be

noted that the motor shown in the drawings also could be utilized as a low-cost air compressor for pneumatic control systems, or to pump liquids and the like. In addition, this motor could be employed in other situations where a reciprocating motion is desired having a relatively large excursion in order to efficiently utilize the limited excursions of the armature in the electromagnet embodiment or of the invar plate in the piezoelectric embodiment. The frequencies used in the description of operation were chosen for purposes of illustration only, and are not to be considered limiting.

I claim:

1. A reciprocating motor comprising in combination:

a frame;

a first reciprocating driven member for movement relative to the frame having a predetermined excursion;

a second reciprocating driven member for movement having a second predetermined excursion substantially greater than said first predetermined excursion of the first driven member;

resilient coupling means interconnecting the first and second reciprocating driven members to form a resonant system having a predetermined resonant frequency of vibration; and

means mounted on the frame for driving the first reciprocating driven member at said resonant frequency, so that the excursion of the first reciprocating member is multiplied by the resilient coupling means to cause the second reciprocating member to reciprocate through said second predetermined excursion.

2. The combination according to claim 1 wherein the resilient coupling means is a coil spring.

3. The combination according to claim 1 wherein the means for driving the first reciprocating driven member is an electromagnet armature placed in an alternating electromagnetic field for reciprocation at said resonant frequency.

4. The combination according to claim 1 further including a cylinder wherein the second driven member is a piston movable within the cylinder.

5. The combination according to claim 4 wherein the motor is a compressor pump and wherein the piston is hollow, having an intake valve located therein and wherein the cylinder has an exhaust valve located therein.

6. The combination according to claim 1 including a third reciprocating driven member for movement at said second predetermined excursion and including a second resilient coupling means interconnecting the first reciprocating member and the third reciprocating member to form a second resonant system having said predetermined resonant frequency of vibration and the third reciprocating driven member being driven at said second predetermined excursion by the second resilient coupling means.

7. The combination according to claim 6 wherein the second and third reciprocating members and the first and second resilient coupling means are located respectively on opposite sides of the first reciprocating driven member.

8. The combination according to claim 1 wherein the means for driving the first reciprocating driven member is a piezoelectric crystal device excited for vibration at said resonant frequency.

9. The combination according to claim 8 wherein the first reciprocating driven member includes a flexible plate and wherein the driving means includes a bimorph piezoelectric crystal fastened to the plate, the material of the crystal being such that when an AC signal is applied thereto the crystal causes movement at the center of said plate in an amount equal to said first predetermined excursion, and further including means for applying an AC signal to the piezoelectric crystal.

10. The combination according to claim 9 wherein the flexible plate is of substantially circular configuration having a coupling shaft connecting the plate to the resilient coupling means and wherein the bimorphic piezoelectric crystal in-

cludes a first crystal mounted on one side of the plate and a second crystal mounted on the other side of the plate, the first and second crystals being in the form of discs and having characteristics such that when an AC signal voltage is applied to the discs, the diameters of the discs change, with the diameter of the first disc increasing while the diameter of the second disc decreases and vice versa to cause reciprocating movement of the flexible plate and the coupling means attached thereto.

11. An electric reciprocating motor comprising in combination:

a frame;

an electromagnet mounted on the frame having a core and a coil for connection to a source of AC signals;

an armature;

means for resiliently supporting the armature on the frame in close proximity to the core of the electromagnet;

a reciprocating driven member for movement having a first predetermined excursion;

a spring member interconnecting the armature and the reciprocating driven member to form a resonant system having a predetermined resonant frequency of vibration; and

the application of AC signals to the winding of the electromagnet driving the armature at said resonant frequency through a second predetermined excursion with the excursion of the armature being multiplied by the spring member to cause the reciprocating member to reciprocate through said first predetermined excursion, said first predetermined excursion being substantially greater than said second predetermined excursion.

12. The combination according to claim 11 wherein the reciprocating driven member is a piston and the spring member is located between and interconnects the armature and the piston.

13. The combination according to claim 11 further including a cylinder and wherein the reciprocating driven member is a piston movable within the cylinder, and the spring member is located between and interconnects the piston and the armature and is further mounted to surround the cylinder in which the piston moves.

14. The combination according to claim 11 further including a housing in which the electromagnet and the armature are mounted, wherein the resilient support for the armature is provided by at least one diaphragm spring locating the armature in a predetermined position with respect to the electromagnet in the housing.

15. The combination according to claim 14 wherein the piston is a hollow piston having an intake valve located therein and wherein the cylinder has an exhaust valve located therein so that reciprocation of the piston causes gas to be alternately drawn into and expelled from the cylinder.

16. The combination according to claim 11 wherein the driven member is piston and the reciprocating motor comprises a compressor pump further including a cylinder and a housing for said pump in which the cylinder, electromagnet, armature and piston are mounted, with the cylinder and electromagnet being attached to the housing; the armature being resiliently attached to the housing by a diaphragm spring, causing the armature to be aligned with the electromagnet core; and the piston being slidably mounted within the cylinder.

17. The combination according to claim 16 wherein the spring member is a coil spring connected between the armature and one end of the piston.

18. The combination according to claim 17 wherein the armature comprises a first hollow cylindrical member surrounding the cylinder, with the spring surrounding the cylinder and being connected to the end of the armature remote from the electromagnet, and with the other end of the spring being connected to the piston such that the piston reciprocates within the spring member.