This invention relates to engines of the floating piston type and provides improved operating means for such engines especially in connection with starting, regulation, and synchronization between the pistons of such engines, Its general object is to provide such means which will fulfill ~~verious~~ various practical requirements more completely than the means heretofore available.

The invention provides an arrangement for use with a floating-piston engine, which comprises at least one magnetic element rigidly connected with a piston of said engine, a magnetic circuit relatively to which said element is movable on reciprocation of the piston to modify the reluctance of said magnetic circuit, and energizable electric winding means inductively associated with said magnetic circuit and connected with an electric circuit, whereby a mutually coupled relationship is present between the variations in the kinetic energy of reciprocation of said element and piston, and variations in the electrical energy in said electric circuit, so that energy can be selectively transferred from said engine to said electric circuit and vice versa.

The arrangement is operable as a starting device for floating-piston engines, and in that case one or preferably a series of electric voltage pulses are applied to the electric windings, preferably alternately in one and the other of two windings associated with respective legs of a multi-legged core forming said magnetic circuit, each of said legs having a gap in which an associated movable magnetic element movable is movable, both movable elements being coupled for bodily reciprocation, with the engine piston and being so associated with said respective legs of the magnetic circuit that the application of said pulses alternately to the two related windings will cause a bodily reciprocation of said movable elements and hence the piston coupled thereto, thereby starting the engine.

Where the invention is applied to the feed regulation of the floating piston engine, variations in an electrical characteristics of the current induced in one or more windings associated with the magnetic circuit may be used to operate a suitable relay device, such as a solenoid relay, which in turn may produce a mechanical displacement of a regulator control element such as an air or fuel intake valve. In connection with such a regulating system, the arrangement of the invention is able to provide a servo-loop or feedback action of extremely efficient and advantageous character, as will be made apparent from the detailed disclosure hereinafter.

Where the invention is applied to the synchronization of a pair of conjugate floating pistons in a common cylinder of an engine, each piston may have an associated movable magnetic element mechanically connected with it each element cooperating with a respective magnetic circuit, and means are provided for coupling both circuits in synchronizing relationship. Thus, the winding means associated with the respective magnetic circuits can be cross-connected into a balanded circuit such that in case of a lack of synchronization between the reciprocation of the two elements, energy will be transferred in one or the other sense over said balanced circuit to exert magnetic forces on said elements which will restore them to accurate synchronism.

Exemplary embodiments will now be described in detail by way of illustration but not of limitation and with reference to the accompanying drawings wherein :

Fig. 1 is a diagrammatic sectional view of one embodiment of the invention which is more particularly operable as a starting device for a free-floating piston engine;

Fig. 2 is a view on line II-II of Fig. 1 ;

Fig. 3 is a diagrammatic view of one embodiment of part of a throttle regulating device according to the invention;

Fig. 4 is a similar view of an automatic injection regulating device according to an embodiment of the invention ; and

Fig. 5 is a diagrammatic sectional view of one embodiment of the invention as applied to the synchronizing of a pair of conjugate floating pistons.

The present invention will first be described with particular reference to its operation as a starting device as illustrated in Figs. 1 and 2. As there shown the motor comprises a cylinder 1 having a single floating piston reciprocable therein but it will be understood that a single piston is shown only for the purpose of simplifying the disclosure.

Associated with the cylinder 1 are a spark plug or igniter 2, an intake port 3 (fig.1), and exhaust port 4 (fig. 2) and a transfer or by-pass duct 5. It will be understood that the engine would normally comprise such fuel supply equipment as a carburettor or an injector, not shown.

The engine here shown is a two-stroke engine and its piston 6 is accordingly formed with a transfer or by-pass port 7. As is characteristic for free-floating piston engine, the piston rod 8 has no connecting rod coupled with it for the transmission of movement.

Rigidly connected with the free end of piston rod 8 are a pair of spaced non-magnetic bar members 9a and 9b (Fig. 2) which are rigidly interconnected at their ends to provide a frame. Secured to the end of said frame remote from the piston is a device for ensuring a positive return of the piston 6 at its outer dead centre position. Such device is conventional and is here shown as comprising a piston 10 reciprocating in a chamber 21 constituting an auto-compressor device.

The electromagnetic section of the system in the illustrated embodiment comprises a magnetic circuit in the form of a core having two side legs 11a and 11b and a central leg 12, all three legs being interconnected by transverse end legs 13a and 13b. The centre leg 12 is here shown solid but it will be understood that the present invention may advantageously be combined with a system according to the Applicants' Canadian Patent No. 568,019 wherein an electromagnetic system somewhat similar to that of the present application is used for converting the reciprocation of a floating piston engine to a rotational movement, and in such case the core leg 12 may include a cutout in it for receiving a rotatable armature of a repulsion type motor therein, the ends of said leg directed towards the armature serving as magnetic pole pieces for the repulsion type motor.

In the embodiment now being described the side legs 11a and 11b are formed with aligned transverse cuts which provide relatively wide airgaps in each side leg, so that such airgaps insert high reluctances into the associated branches of the magnetic circuit, the increase in reluctance being of at least 100% its initial value, and preferably exceeding said initial value by a factor of about from 5 to 20.

Freely reciprocable in said airgaps with just enough clearance to avoid friction are a pair of movable magnetic elements 14a and 14b which are preferably vaneshaped and of such dimensions transversely to the legs 11a and 11b as substantially to fill the airgaps. The spaced vanes 14a and 14b are secured within the frame formed by the non-magnetic members 9a and 9b at positions such that when one of the vanes is inserted in its airgap in registering relation with the respective side legs 11a or 11b the other vane is completely clear of the airgap in the other side leg and is positioned outside the magnetic core.

Wound about each of the side legs 11a and 11b is a coil 15a, 15b. Depending on the particular use to which the system is to be put, the windings 15a and 15b are arranged to be energized from a d-c source 16 one at a time, or to be energized simultaneously from the source 16, in series or in parallel. For the purpose of selectivity disconnecting and connecting the windings 15a, 15b from and to each other there may as shown be provided a jack or other type of coupler device schematically indicated at 16c and having its terminals connected with the source terminals. A double-pole double-throw switch 16c makes it possible, in the open-circuit condition of the coupler, selectively to energize one or the other of the two windings, as will be readily understood from the connections shown, which include lines 16e connecting the source to the coupler and the switch, and the lines 16a and 16b connecting the windings 15a and 16b to the opposite switch terminals.

In the instant embodiment the windings 15a and 15b are wound with such polarities that they tend to generate, when energized, magnetic fluxes of suitable polarities in the central core leg 12 as will presently appear.

The electro-magnetic section now being described with reference to Fig. 1 and 2 is applicable, according to the invention, to purposes other than the starting of the engine, e.g. to such purposes as the automatic regulation of air and/or fuel supply and the synchronization of the pistons in a twin-piston engine. While the latter applications will be more specifically described hereinafter with reference to the further figures, it may be noted at this point that in connection with the regulation and synchronization functions the windings 15a and 15b would be so wound as to generate magnetic fluxes of opposed polarities through the center leg 12. Further, for certain applications an additional winding 17 would be provided on the center leg as will later appear, but this winding is not used in the engine-starting function of the system.

The electro-magnetic section including core and windings thereon is shown enclosed in a casing 19 being secured therein by suitable bolts or cross members at 20.

The system described is operated as follows for starting a floating-piston engine. Assuming that a current pulse of suitable polarity is supplied to one of the windings say 15a, a magnetic flux is created in the associated side leg 11a developing an attractive force which causes the movable element 14a to be drawn inwards of its airgap, thereby causing a rightward bodily displacement of the rigid assembly including piston rod 8, piston 6, and the other core element 9a. Thereafter, another current pulse supplied to the winding 15b will shift the other element 14b leftward and cause a leftward bodily displacement of the assembly including the piston. Hence the delivery of a current pulse to one of the windings 15a, 15b and preferably an alternate application of pulses to both windings 15a, 15b, will result in reciprocating the piston 6 in the cylinder thereby providing a means of starting the engine. Advantageously the rate alternate application of voltage pulses to the windings 15a and 15b is initially slow and is gradually increased while the duration of the pulses may be decreased, through any convenient means not illustrated, while thereby providing a highly efficient, and reliable starting action; it will be understood that means (not shown) would be provided for injection the fuel and/or igniting the fuel-air mixture at the proper times in correlation with the rate of application of the electric voltage pulses to the windings.

The timing of application of the pulses to the alternate windings may be determined in any of various ways. Thus a simple switch such as that shown at 16d may be used, or contacts having an equivalent effect. Preferably delay means, not shown, are interposed in the circuits of the windings and the delay time may be made automatically adjustable to provide an optimum timing of the alternate pulses, particularly the gradually increasing rate of pulse delivery mentioned above. The actual duration of time lapse between the pulses and the amplitude thereof would naturally depend on the characteristics of the engine, such as nominal power output and speed and length of piston stroke. The source 16 may be provided by a storage battery or other convenient generator.

We shall now describe an embodiment of our invention as applied specifically to the fuel supply regulation of floating-piston engines. The problem here is, that of automatically controlling the setting of some control such as a valve, which acts e.g. on the rate of supply of combustible mixture to the cylinder or cylinders, in response to some operating factor of the engine such as the engine speed or load, and this is accomplished according to the invention by operating said control in response to variations in the electrical energy put out by a part of the electro-magnetic circuit. It is especially advantageous to combine this application of the present invention with the electro-magnetic drive system of Applicants' aforementioned patent for converting the reciprocating of floating pistons into rotary motion, including means for varying the drive ratio.

Whereas in the first embodiment of this invention relating to the starting of an engine voltage was alternately supplied to each of two windings of the system in order to reciprocate the pair of magnetic elements connected with the engine piston, in the application of the invention to an engine regulator system, use is made of the electric output induced in a winding of the electromagnetic system in response to the reciprocation of said movable magnetic elements. Excitation means must therefore be provided and these may assume any of various ways. However, in view of the desirability of combining this system both with the drive system disclosed in the afore-mentioned patent and/or with the starting device described herein with reference to Figs. 1 and 2, it is convenient to use the afore-mentioned windings 15a, 15b of the system of Figs. 1 and 2 as excitation windings, said windings in that case being preferably coupled together by means of coupler 16c. Thus, after first having started the engine with coupler 16c in open-circuit condition, the coupler would then be moved to close condition (while switch 16d is held open) so that the same system thereafter performs the regulating function.

In using the system of the invention to regulate the operation of the engine the fuel or/and air supply to the engine may be regulated in response to any desired electrical characteristic of the output electrical energy, including the frequency, voltage, current or phase condition.

In one form, wherein the frequency of the output energy is used, the engine supply may be regulated in a manner to maintain the reciprocation rate, and hence the mean effective velocity, of the piston, substantially constant, while the engine torque is allowed to vary over the full range from zero to a prescribed nominal load. For this purpose an air or fuel intake control valve may be operated by way of a suitable electromechanical relay device in response to the frequency variations in the output voltage, so that any departure of the frequency from a prescribed value will result in altering the setting of the valve in such a sense as to return the engine velocity to normal, i.e. increase the fuel supply in case of a drop in piston velocity and output voltage frequency, and reduce the supply in case of a rise in piston velocity and voltage frequency. The auxiliary electro-mechanical relay device may comprise a conventional sliding-core solenoid device energized by way of frequency sensitive circuit.

In another form of regulating system according to the invention the engine supply is varied in such a manner as to maintain the torque of the engine constant under varying resistent torque or load. In such a type of system there is generally provided in addition to the energizing or primary winding or windings, one or more secondary windings, in which the induced current will vary as a function of the load. The secondary winding may constitute the winding 17 shown in Fig. 1 and the electromagnetic system will then operate somewhat in the manner of a "static alternator" producing an a-c output across the pair of terminals 18 (Fig. 1). Alternatively, the secondary winding means may comprise the winding of a rotor operated as an electric motor in the manner disclosed in our aforementioned Canadian Patent No. 568,019. In any case the varying voltage from the secondary winding may be used to energize a sliding core solenoid relay device of the type above referred to for operating an intake valve or other control.

In yet a third form of the regulating aspect of the invention metters may be so arranged that the engine velocity increases slightly with increase in load. For this purpose the fuel supply to the engine may be controlled in response to a voltage which is hel substantially constant within a predetermined narrow range, as induced in an auxiliary winding such as winding 17 of Fig. 1, but in this case so arranged that the voltage induced therein is proportional both to the reciprocation frequency of the magnetic cores 14a - 14b and to the magnetic flux. Thus, when said flux is reduced simultaneously with a reduction in the load, the reciprocation frequency is increased in order to maintain the voltage in said auxiliary winding substantially constant.

The approximately constant voltage delivered by the auxiliary winding can, additionally, be used for such purposes as to charge a storage battery which, incidentally, may serve as the d-c source in a system according to the invention, such as source 16 of Fig. 1.

Figs. 3 and 4 schematically illustrate two exemplary embodiments of the electro-magnetic portion of a regulating system according to the last-mentioned form of the invention i. e. that wherein a substantially constant voltage is put out by an auxiliary winding such as, or equivalent to, the winding 17 in Fig. 1. Referring first to Fig. 3, a

.ottle valve 21 is shown in a carburettor air intake conduit 22 which forms part of a fuel supply circuit for a floating-piston engine, not shown. Valve 21 is connected by way of pivotal linkage 27-26 with the sliding magnetic core 25 of a solenoid device, having winding supply terminals 23. The core 25 has a flange 29 which is biassed into engagement with an abutment 30 corresponding to the fully-open position of valve 21, by the action of a spring 28 so calibrated that the core is maintained in its leftward abutted position so long as the voltage applied to the solenoid terminals 23 does not exceed a prescribed value. The solenoid terminals 23 are connected to the output terminals 18a of an electromagnetic system which may be similar to that shown in Fig. 1, in which case the terminals 18a would be identical with the terminals 18 shown in that figure as providing the output from auxiliary winding 17. Should the voltage output from winding 17 exceed the prescribed value the solenoid core 25 is moved rightward of Fig. 3 thereby partly closing the throttle and reducing the engine speed by such an amount that the voltage across 18 is restored to the prescribed range.

Referring to Fig. 4, the regulating system is shown as applied to a fuel injector for a floating-piston engine of the direct injection type. The injector assembly is positioned in the wall 1b of the engine cylinder. Injector chamber 31 is maintained filled with fuel under pressure but the fuel is prevented from flowing out of the chamber into the cylinder through injection orifice 33, by means of a needle valve member 32 normally seated on the inner end of said orifice. The valve member 32 can be lifted off its seat a variable amount by the action of an electromagnet 34 acting on a magnetic armature secured to the rear end of valve member 32. The winding of electromegnet 34 is gized with voltage pulses delivered from a suitable variable pulse generator 35, which may be of any appropriate electronic type, operated to generate a voltage pulse of predetermined duration at each reciprocation of the engine. Control terminals of the variable pulse generator 35 are connected to the terminals 18a which may be similar to the terminals 18 of Fig. 1, and the generator is so constructed, in a manner that will be apparent to those familiar with the art, that when the voltage applied to it from terminals 18a exceeds a precribed value, the duration of the generated pulses is correspondingly reduced. The open periods of the injection valve are reduced accordingly and so is the rate of fuel supply to the engine. The engine operates at a slower rate until the voltage across terminals 18a has been restored to its prescribed range.

It will be understood that in the general showing of Fig. 1 the block C may indicate any intermediate electromechanical relay device such as the solenoid device of Fig. 3 or that of Fig. 4, which relay device in turn controls the operation of the engine as indicated by the connection D in Fig. 1.

An embodiment of the invention will now be described in its application to the synchronization of a pair of floating pistons. In its most desirable form a floating-piston engine comprises one or more cylinders each containing a pair of symmetrically operating pistons reciprocating in opposition to each other, and which may be termed conjugate pistons. In operation the desired accurate opposition between the reciprocations of the two conjugate pistons tends to be disturbed by various factors which introduce phase displacements between the respective operating cycles and the correct operation of the engine requires the provision of some synchronizing means for maintaining the desired opposed relationship between the pistons at all times. Conventional synchronizing systems for floating-piston engines have generally been mechanical in character, involving the provision of symmetrical linkages connected with the respective pistons and with each other by way of suitable kinematic transmission. The linkages are subjected in operation to very high accelerations and consequent stresses, and have constituted a limitation to the operating speeds achievable with engines of this type. Moreover such linkages are generally objectionable in that they destroy the truly free-floating characteristic which constitutes the fundamental advantage of such engines.

Other known types of synchronizing systems for floating-piston engines are pneumatical rather than mechanical and operate by way of the usual air cushions normally present in such engines. Such pneumatic synchronizing systems can be controlled electrically or mechanically.

In the systems of the present invention synchronism is achieved between the operation of conjugate pistons in a floating-piston engine by associating with each piston one or more movable magnetic elements such as 14a and 14b of Figs. 1 and 2, cooperating with a pair of electromagnetic systems each of which may be of the same general character as shown in those figures which systems are so coupled with each other (electrically or magnetically), that, in case of a disturbance in the synchronism (or a phase displacement) between the reciprocations of the two magnetic elements (or sets thereof), electromagnetic forces are set up which act upon said elements to restore them to synchronism.

The electro-magnetic systems associated with the two pistons are preferably coupled together electrically to cause an interchange of electric power between the two systems in case the reciprocations of the magnetic elements thereof tend to fall out of step, so that power is transferred from one to the other of the systems and applies to one or each magnetic element a force acting to restore it into synchronism with the other element. For this purpose, the circuits of windings such as 15a and 15b in Fig. 1 may be connected in opposition to provide a balanced circuit, e.g. by connecting midpoints of the respective windings, or/and connecting the ends of both windings in parallel across a further winding provided on the third arms of both electromagnetic systems.

Fig. 5 illustrates such an embodiment of the invention wherein a cylinder 36 has two floating pistons 37 and 38 reciprocating therein, and normally adapted to be positioned in opposition to each other on either side of the transverse midplane of the cylinder. The cylinder is shown as including a pair of intake ports 39 and a pair of transfer or bypass conduits 40. The exhaust ports lie outside the plane of the drawing and cannot hence be seen. Secured to each piston 37 or 38 is a rigid transmission 41 or 42 which serves to drive load mechanism, not shown, such as a compressor or converter of mechanical energy. The load mechanism forms no part of the present invention and is not illustrated but can be assumed to be interposed in the broken sections 41a or 41b shown in each of the transmission rods 41 or 42.

Each transmission rod further has interposed on it an air-cushioning device, of the general type shown as 10-21 in Fig. 1, and serving to provide for a smooth reversal of movement of the pistons at each outer dead center position. Said air cushioning devices are here shown as comprising pistons 45 and 46 respectively, secured on the ends of rods

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41 and 42 and operating in cylinders 43 and 44.

Each transmission rod 41, 42 carries intermediate its length a magnetic section 47, 48 each cooperating with an electromagnetic assembly of a somewhat modified construction from that shown in Fig. 1. The two assemblies being identical only the left hand one as shown on Fig. 5 will be described, the components of the other system being designated with the same reference numerals followed by suffix b instead of a.

Said electromagnetic assembly comprises a three-legged magnetic core having the side legs 49a and 51a and center leg 50a and enclosed in a casing 61a. Legs 49a and 50a are cut away in their midpart to provide wide airgaps within which the magnetic element 47 secured to piston 37 is reciprocable. The leg 51a is not cut away and it will be noted that in case the said third leg 51a is positioned in the longitudinal center plane of the system as illustrated, the piston rods 41 and 42 would have to include two pronged sections surrounding said third legs 51a and 51b in order to permit unimpeded reciprocation. The side leg 49a carries an energizing winding 53a (which may include one or more separate winding sections), and leg 50a carries a winding 52a. Windings 52a and windings 53a are connected in series relation and with a d-c source 54a by leads 55a and 56a. While separate d-c sources 54a and 54b are shown, a common source may desirably be used.

The windings 52a and 53a are so wound and connected that the windings tend to create magnetic fluxes of reverse sign in the third core leg 51a. In view of the cyclic variations in reluctance produced in legs 49a and 50a by the reciprocation of the element 47, an alternating magnetic flux is generated in the third, fluxed-reluctance leg 51a, since the resultant flux in the latter corresponds to the algebraic sum of the fluxes generated by the two windings.

Furthermore, as a result of the cyclic variation in reluctance in the legs 49a and 50a electromotive forces are induced in the windings 52a and 53a. It will readily be understood that if the electromagnetic system associated with the right-hand piston 38 presents accurately similar characteristics to those of the system associated with the left-hand piston, then by providing cross connections between one or more symmetrically disposed points of the two circuits associated with the respective systems there will be obtained a balanced output circuit in which no current will flow so long as the reciprocations of the movable magnetic elements 47 and 48 are effected in strict phase opposition with one another, but there will be current flow in one or the other sense over said cross connection or connections should a phase displacement tend to occur between the reciprocation of the two elements. Electrical energy is thus transferred from that system in which the movable element is in leading relationship to the system in which the movable element is lagging, and the electrical energy thus transferred generates a magnetic force which imparts to the lagging element 47 or 48 the requisite surplus of kinetic energy for bringing it back into synchronous relationship with the other element. The force thus acting to restore synchronism between the two movable elements and hence the pistons respectively connected thereto, increases at a very rapid rate with the degree of phase displacement between the two elements. Thus, the differential voltage appearing across the ends of the synchronizing connection such as 57 in Fig. 5, for a linear phase displacement between elements 47 and 48 as low as 1/100 the reciprocation amplitude of each element, can be many times the value of excitation voltage, applied at 54a and 54b. Moreover it will be noted that the large forces thus developped are axial forces applied exclusively to the simple, rugged magnetic elements 47 and 48 integrally connected and bodily with the pistons, rather than being applied to complex pivotal linkages as in conventional mechanical synchronizing devices.

The cross connection or connections between the two symmetrical circuits can be variously arranged to provide the balanced synchronizing circuit, a simple arrangement being that wherein the synchronizing cross connection 57 connects midpoints between the pair of windings 52a-53a, and 52b-53b, as shown in Fig. 5. Alternatively, a balanced synchronizing circuit may be obtained by providing on each core additional windings such as the windings 58a, 58b shown encircling the third core legs 51a and 51b respectively, and connecting such windings in parallel as shown by the connexions 59 and 60. While the resulting circuit might be used for the purpose of synchronization just described, it is here shown as serving to provide an additional output at terminals 18a which may be used for regulating purposes in a manner generally similar to what was described in connection with the remaining embodiments.

Thus it will be seen that the invention provides highly advantageous arrangements for the operation and regulation of engines of the floating-piston type, particularly with respect to the starting, supply-regulation and synchronization of such engines. The regulation provided by the invention is of a very accurate and flexible character, and has a low response time, and is especially advantageous in connection with floating-piston type engines since in such engines the reciprocatory operation does not tend to be regularized by associated mechanical couplings such as connecting rods and crankshafts as in more conventional reciprocating engines. The synchronizing function provided by the invention also is considerably more advantageous than the means heretofore provided for a similar purpose. A further advantage of the invention is the readiness with which the various arrangements thereof can be combined with one another, as mentioned at various points throughout the specification, and also combined with the Applicants' prior electromagnetic systems such as the variable-drive movements-conversion systems for floating-piston engines described in Applicants' Canadian Patent No. 568,019 already referred to.

As previously mentioned the embodiments illustrated herein should not be construed as restricting the invention since various modifications may be made in the constructions illustrated and also in the applications explicity mentioned, without departing from the scope of the invention. Thus, among the many possible structural modifications, it should especially be noted that the magnetic circuit means may assume a variety of forms other than that of a three-legged (or "EI-type") core. Multi-legged cores are well known in the art for more or less conventional various purposes, e.g. magnetic transformers, and are known to admit of a very wide range of variations in shape and in the disposition and connection of windings thereon, and similar variations will be readily conceivable regards the magnetic systems utilized in the invention. The arrangements of the airgaps in the core in which the movable magnetic element or elements is or are slidable can also vary considerably. As one example of a modification, the solid core legs 51a and 51b in the embodiment of Fig. 5

may be arranged outside the plane of the other legs of the core (i. e. outside the plane of figure) thereby reducing the lengths of the magnetic systems in the directions parallel to the reciprocation of the pistons.
