

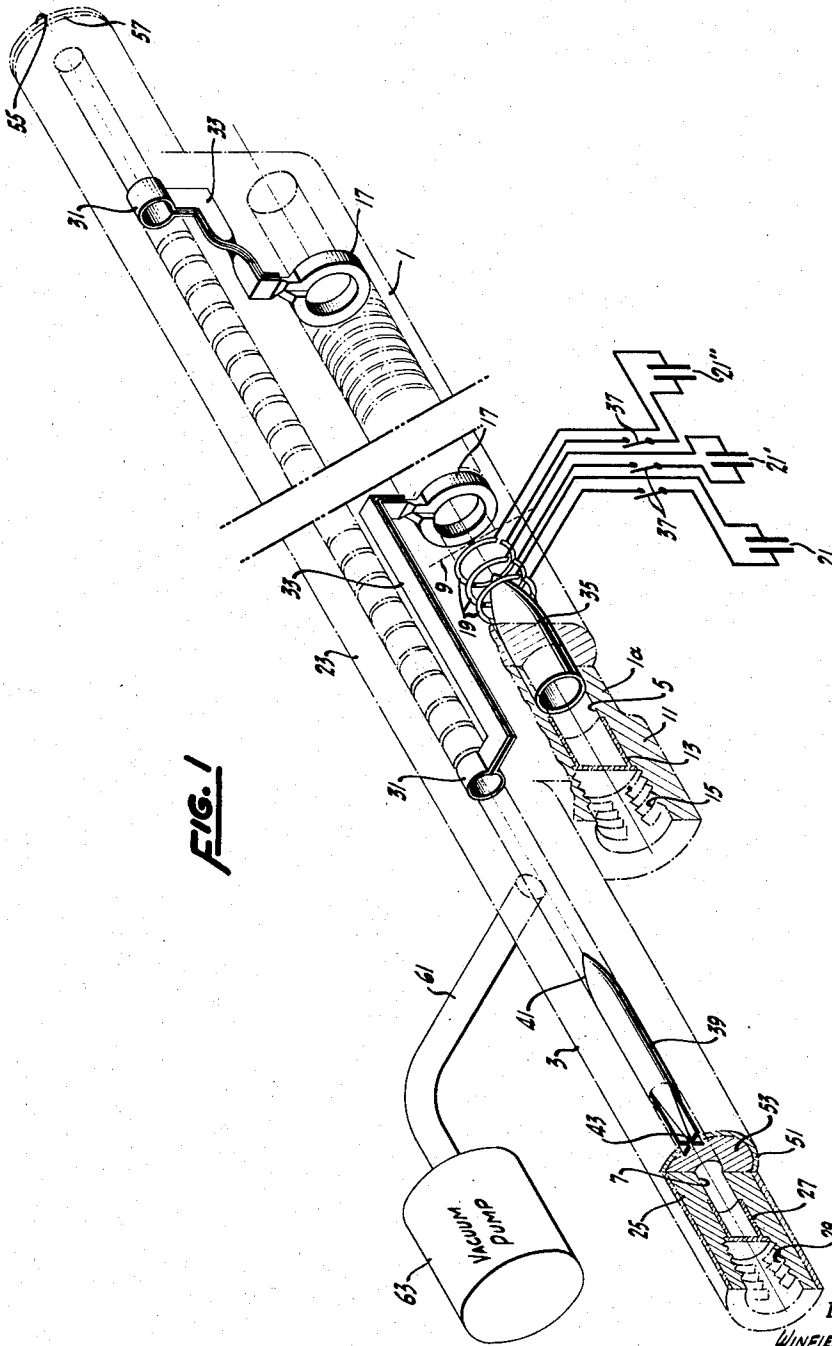
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W. W. SALISBURY
ACCELERATION AMPLIFIER

2,870,675

Filed Nov. 15, 1954

3 Sheets-Sheet 1



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3 Sheets-Sheet 2

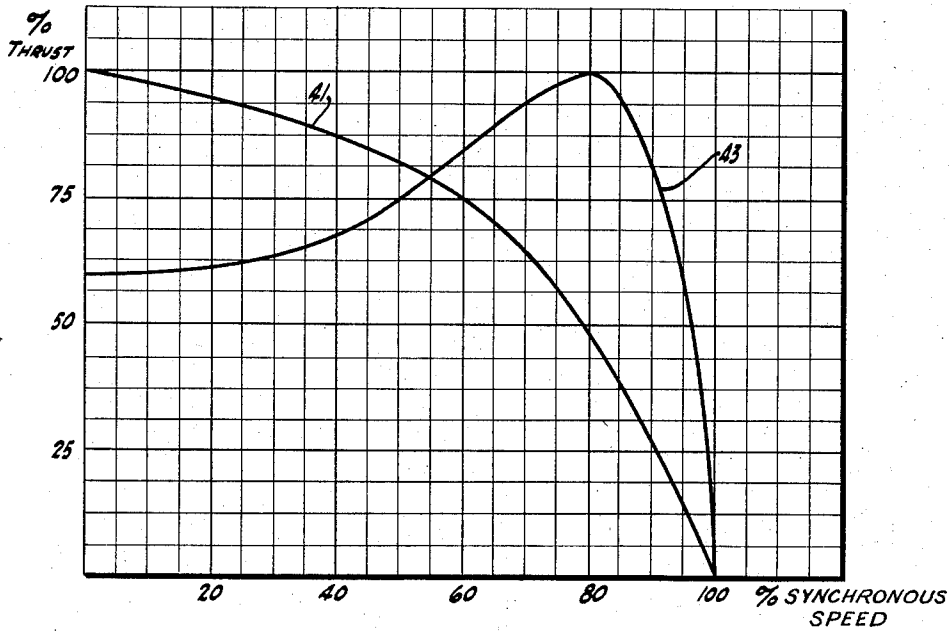


FIG. 2

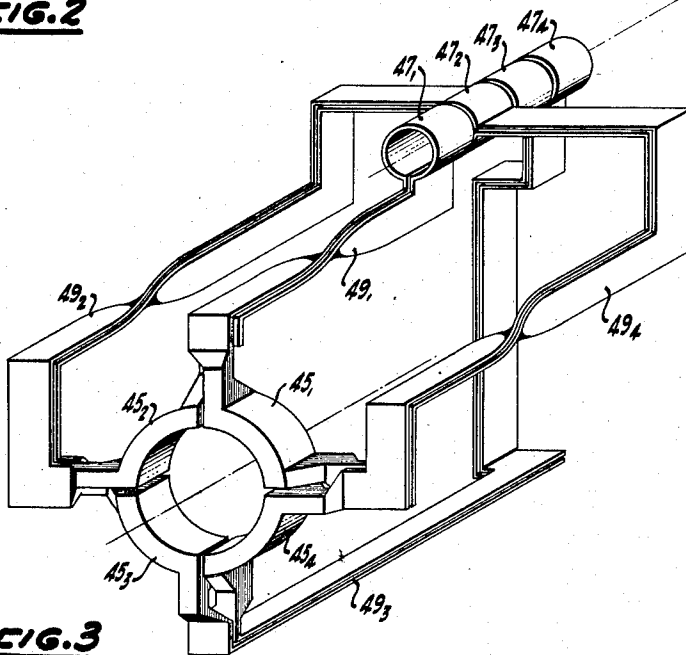


FIG. 3

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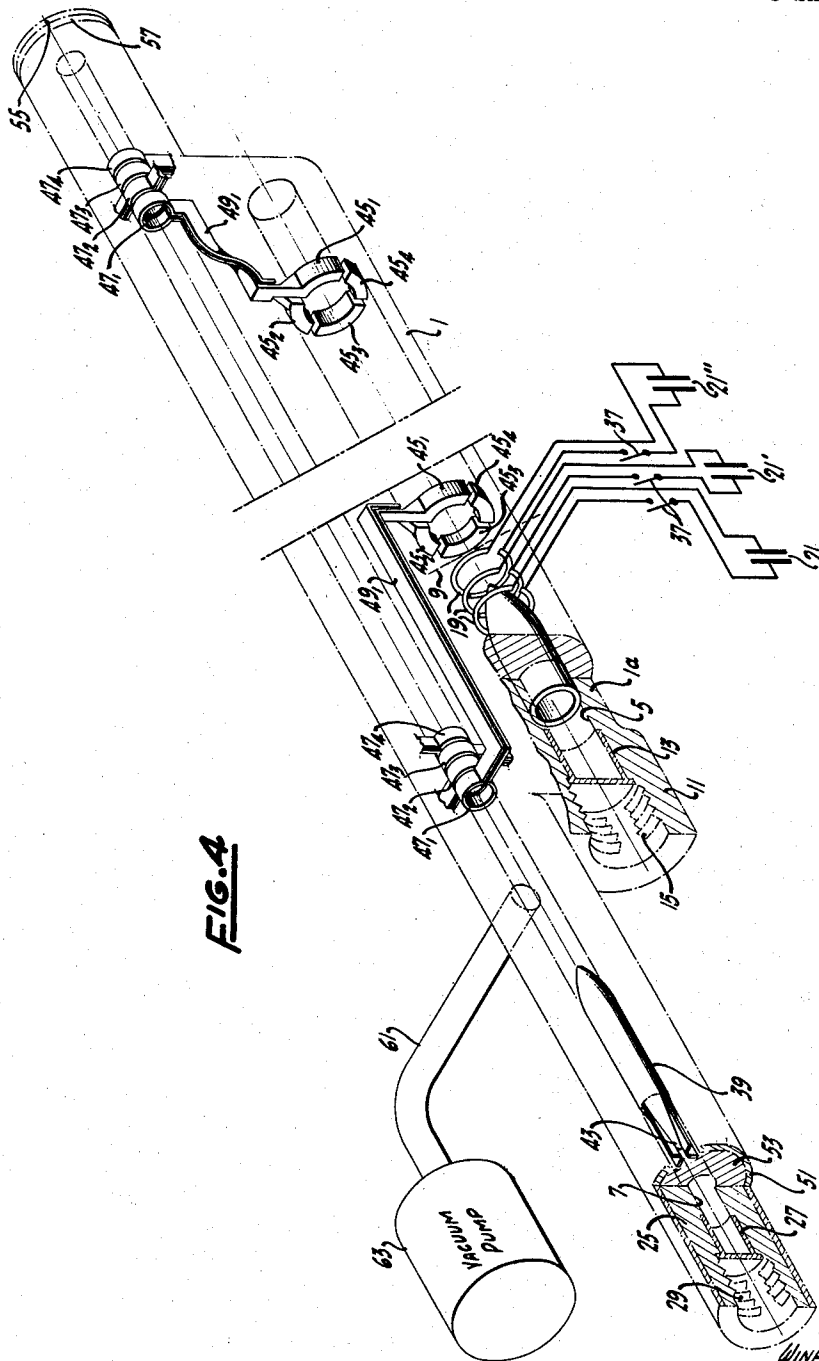
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ACCELERATION AMPLIFIER

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Application November 15, 1954, Serial No. 468,696

14 Claims. (Cl. 89—1)

This invention relates to means for producing higher accelerations and higher ultimate velocities than can be achieved by conventional methods. Specifically, it relates to means for giving to projectiles, not self-propelled, higher velocities than are attainable by the direct use of explosive charges.

The advent of aircraft capable of flying at supersonic speeds and of flying at extremely high altitudes has brought forth the need for new weapons and particularly for ground weapons capable of combatting them. The present-day types of artillery are ineffective against such craft which can fly at or above the extreme range of the artillery where air resistance and the decelerating effect of gravity have reduced the velocity of the projectile, if not to the vanishing point, at least to the point where evasive action is possible. To be effective, the velocity of the projectile should be of an order of magnitude greater than that of its target.

The maximum velocity which can be imparted to a projectile fired by explosive charges cannot exceed the maximum velocity of a shock wave in the propelling gas. This theoretical limit is in the neighborhood of 6000 feet per second; thus far the maximum velocities attainable in practice have been in the neighborhood of 4000 feet per second in spite of the utmost efforts to raise this value. What is actually needed is not a mere addition to the velocities now attainable but an actual multiplication thereof. Multiplication by a factor of 2 would be of enormous advantage; multiplication by a factor of 10 would be of inestimable value, particularly when coupled with the automatic gun laying and position predicting devices which have been developed during the period beginning with World War II.

The primary object of the present invention is to provide a means for imparting accelerations to and hence developing velocities of projectiles exceeding those that can be produced by explosive charges. Other objects of the invention are to provide means for producing such accelerations which are physically realizable in apparatus of reasonable size and mobility; to provide a means for effectively amplifying the acceleration and hence the velocity produced as a result of an explosive charge by a definite and predeterminable factor; to provide a device of the character described which has a relatively high efficiency, and will therefore not destroy itself through losses associated with the very high energy which must be imparted to give accelerations of the magnitude herein contemplated; and to provide a device of the character described which is capable of being built in a wide variety of sizes in order to meet the requirements of different offensive or defensive conditions.

An acceleration amplifier constructed in accordance with the present invention includes a first multiplicity of coils successively spaced one after another to define a bore of predetermined length; these coils form a linear induction motor stator through which an armature such as a projectile is movable. A generator stator includes a second multiplicity of coils similarly positioned to define

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a second bore of substantially less length. Means are provided for developing a magnetic field traveling the length of the generator bore in a predetermined time interval. The generator and motor stators are intercoupled so that a magnetic field travels the length of the motor stator in substantial time-correspondence with the generator traveling field. The motor armature is pulled through the motor stator coils by induction from the magnetic field traversing the motor stator. Preferably, the generator traveling field is developed by propelling a projectile-like armature through the generator stator; this armature emanates a magnetic field linking the generator coils whereby the generator traveling field is developed. Since the motor stator is substantially longer than the generator stator while at the same time the motor field must traverse its stator in substantially the same time interval as for generator field traversal, a substantial acceleration gain is realized, its magnitude depending principally upon the difference in physical lengths involved. It is usually preferable that the coils be equally spaced along the stators although in certain instances it may be desirable to vary this relationship in order to provide uniform acceleration of the projectile which forms the motor armature. While the generator armature may be driven in a variety of ways, it is preferred to utilize an explosive charge in a manner similar to that employed in conventional artillery.

The motor armature or projectile can be a simple conductive shell, which can contain the same type of explosive charge, fuse mechanism, or the like, as the projectile fired from a conventional gun. It is possible to provide means for setting up in the motor armature magnetic fields fixed with relation to the armature structure, in which case the motor becomes, in effect, of the synchronous type. The preferred type of armature, comprising the simple conductive shell, converts the device into an induction motor, wherein the propulsive force is derived from the interaction of the stator fields with the fields produced by currents induced in the shell as the result of slip. The generator armature can also take various forms. Like the motor armature, it may be provided with means for establishing magnetic fields which are substantially constant in value and in position with respect to the armature itself, or it also may be a conductive shell and the fields therein may be initially established by circulating currents, which, interacting with the stator coils, induce currents in the latter in accordance with the same general principles as in the motor but with the slip in this case negative so that the device acts as an induction generator.

It will be apparent that both of the armatures must be of sufficient length to span several coils of their respective stators, the coils spanned being relatively few in comparison to the total number of coils disposed on both structures. Either or both of the stators may include ferro-magnetic cores. Under certain conditions the use of such cores will increase energy transfer from generator to motor. Where the highest possible velocities and accelerations are desired, however, best results are obtained where no ferro-magnetic material is utilized in the core.

The broad concept of electro-magnetic guns is not new. Many such guns have been proposed and a few have been actually constructed and tested in the past, including one which is reported to have been built and tested by the Germans during World War II and one tested by the Japanese during the same period. Such prior proposals have failed for many reasons. The rate at which energy must be liberated during the brief interval of acceleration of a projectile is enormous, even with a small gun and a small projectile. Past proposals have in general utilized conventional energy sources. In order to enable these

sources to deliver the power required, various expedients have been used, such as motor generators provided with large fly-wheels in which energy could be stored in kinetic form to be withdrawn at the instant of firing, condensers which could be charged and discharged successively to provide the magnetic fields for accelerating the projectile, or batteries of various types, the latter having been reported to have been used in the German gun above mentioned. When expedients of the types mentioned are employed, the size and weight of the generating equipment has been so large as to make it unwieldy and impractical. A second difficulty lies in the very large inductance of the coils and their leads, together with the necessity of using very steep wave-fronts in order to move the field through the stator at the necessary rate; this inductance has been a factor which has limited the terminal velocities to an impractical degree.

Still another factor of major importance is Kelvin's law of magnetic force which states that, in a system which uses a constant current to produce motion by means of magnetic force, half the energy imparted to the system by the current must be stored in the magnetic field and half the energy will be acquired as kinetic energy by the moving part of the system. In addition to the inevitable losses in an electric circuit, therefore, about one-half of the available energy is lost. In the German gun mentioned previously the projectile is reported to have been a moving short circuit between a pair of parallel rails and to have been accelerated to a velocity of 2000 meters per second. This is about 6,500 feet per second, an increase of about 65% over the highest velocities attained by explosive means. It can be shown, however, that to provide such an acceleration, at the instant the projectile left the rails the battery must have been producing one million amperes at 2400 volts. This amounts to nearly two and a half million kilowatts at the instant of discharge. Stored energy in the magnetic field would be dissipated in an enormous arc, dwarfing in magnitude and brilliance the flash from the most powerful cannon, even assuming that the battery could be so disconnected as to add nothing to the stored energy maintaining the arc.

The present invention avoids all of these three major difficulties. The energy utilized preferably is stored in an explosive, in chemical form, which is the most readily available method of getting large instantaneous powers for very brief intervals; in effect the energy which would suffice to derive a large shell at presently available velocities is made applicable to drive a smaller shell at higher velocities. The inductance problem is met by the use of single turn coils which are, in effect, provided with short-circuited turns comprising the armatures themselves, and the structure of the leads reduces their inductance to a very small value so that the steep wavefronts required can be effectively applied. The use of the induction motor largely avoids the difficulties described in connection with the German device. Kelvin's law is satisfied during a portion of each cycle during which force is imparted to the projectile, but this energy is returned to the system at later phases of the cycle and only the energy stored in the final cycle is lost.

All of the above will be more clearly understood by reference to the detailed descriptions of a preferred form of the device and certain modifications thereof which follow, in connection with the drawings wherein:

Fig. 1 is a schematic drawing of a preferred form of the invention;

Fig. 2 comprises curves illustrating performance characteristics of the inventive apparatus;

Fig. 3 is an isometric drawing of generator and motor windings of a somewhat modified form; and

Fig. 4 is a drawing similar to Fig. 1, illustrating the positioning of windings of the type illustrated in Fig. 3.

Fig. 1 of the drawing is a schematic isometric view, partly in section, partly broken away, and partly in phantom, of a gun embodying the present invention. Although

shown in the present instance as a unitary structure, fundamentally the device comprises two distinct portions which could, if desired, be entirely separate; these are a generator stator 1 and a motor stator 3. Each of the stators is tubular, having linear bores 5 and 7, respectively, through which the respective projectiles are adapted to be propelled. The motor stator 3 is several times the length of the generator stator, but is materially smaller in internal diameter. The generator stator proper terminates, at the breech end, approximately at the position indicated by the dotted line 9. It is provided, however, with a rearward extension 1a, preferably integral with the stator proper and having a bore of like diameter, the extension being broken away in the drawing and its position indicated by dotted lines. The extension 1a terminates in a breech 11 which may be chambered to receive a cartridge case 13 of substantially conventional form. The breech is provided with the usual interrupted screw 15 for receiving the conventional breech block and closing mechanism, which are not shown since such structures are well known. The extension 1a is actually a gun barrel, and can be constructed as such. It is in this portion of the structure that the generator armature receives its initial acceleration.

Disposed along the length of the generator stator 1 are a plurality or multiplicity of single-turn stator coils 17. All but two of these coils are shown in phantom; each coil consists of a massive copper ring, and the coils are disposed as closely adjacent to each other as is feasible. These coils correspond to the windings of a conventional, rotary-type generator in purpose, and like such coils they are insulated from each other and the surrounding material, preferably by mica. Collectively, the insides of these coils define the bore of a gun barrel the coils being successively spaced one after another along the projectile path. Accordingly, they must be accurately aligned and closely spaced. The manner of retaining them in position will be discussed hereinafter.

In addition to the stator coils 17, there are also provided three additional single turn coils 19. Leads to each of these latter coils are brought out through the stator structure and are adapted for connection, in the present instance, to condensers 21, through switches 37 schematically illustrated in the drawing.

Except for dimension, the motor stator 23 is substantially similar to the generator stator. Like the latter, it is provided with a rearward extension forming a breech 25 chambered to receive a cartridge case 27 and provided with an interrupted screw 29 for receiving a breech block. Like the generator stator, it is provided with single turn coils 31 which are mutually insulated and preferably are positioned closely adjacent to each other. Beside being smaller in diameter than the generator coils, they are axially longer so that cumulatively they occupy substantially the entire length of the stator. Because of their greater length, they may be of thinner material and yet provide the same current carrying capacity. These band-shaped coils produce greater efficiencies since in operation they carry sheet-like currents which substantially confine the magnetic fields linking the coils to the armature.

The motor coils 31 are equal in number to the generator coils 17, and the motor and generator coils are connected together permanently in 1:1 relationship, in numerical order from breech to muzzle of the two stators, by leads 33. The form of the connections is important for the operativeness of the device; the conductors forming the connections are formed of a flat strip, wide in comparison to its thickness. The two conductors forming the connection are superimposed, face-to-face, a minimum thickness of insulation between them. For reasons which will become apparent hereinafter, it is advisable that the generator portion of the device be positioned closer to the muzzle of the motor than to the breech, so that there is a minimized length of lead at this point. The lead structure specified provides circuits of very low

inductance; the reasons for this are fully disclosed in the copending application of the present inventor, Serial No. 324,199, filed December 5, 1952, now Patent No. 2,785,265. The low inductance is accompanied by relatively high shunt capacity between the leads, but since the resistance of each individual circuit is very low and the voltage necessary to initiate even very large currents is correspondingly low, the losses incident to the high shunt capacity are small in comparison with the drop in transfer constant between generator and motor coils that would be involved with leads of higher inductance. Because the armatures of both generator and motor are being constantly accelerated as they travel through the stator structures, the frequencies developed as the generator armature progresses through the coils are also constantly increasing. The susceptance of the circuit as represented by the interlead capacity increases in direct proportion to frequency, and therefore it is desirable, as a general proposition, to make this capacity smallest where the frequency is greatest; i. e., at the muzzle end of the device. Accordingly, the generator stator is positioned with respect to the motor stator to render the connecting leads nearest the muzzle end shortest.

In the particular embodiment of the invention herein shown, the generator armature 35 may be a simple hollow shell of highly conductive material, preferably copper. Because it is unnecessary, and in fact undesirable, that the momentum of this shell be great, it is preferably not solid; it may, in fact, contain all or part of the driving explosive, acquiring a portion of its energy by rocket action which tends to maintain its acceleration throughout the length of the stator. The rocket action becomes more effective as the shell velocity approaches the speed of sound in the burning gases. The initial drive is derived from the pressure developed by a portion of the charge contained in the cartridge case; the latter portion of the drive is effective during the first part of the armature travel at lower speeds where the rocket action is least efficient.

Means, embodied as switches 37, are provided for closing the circuits between the condensers 21 and the auxiliary coils 19 as the generator armature enters these coils, the coils being excited as the armature enters within them. The current surges resulting from the excitation of the coils 19 persist as circulating currents in the armature shell, inducing EMFs in the generator coils 17 which react on the armature to maintain these currents. The action is that of an induction generator which is well understood including the emanation of a magnetic field from the armature that links the coils to induce current therein. In accordance with Kelvin's law, a portion of the energy is stored in the inductance of the system; this becomes the magnetizing current, which, as it is returned to the system, provides continuous excitation and maintains the circulating currents in the armature as its travel continues, the characteristics being those of an induction motor with a negative slip. The remainder of the energy is available for driving the projectile.

Considered as an armature, the projectile 39 may also comprise a hollow copper shell. In accordance with standard aerodynamic practice, it will normally be provided with a pointed nose 41 which may contain a fuse, detonating mechanism, or the like. It is also preferably provided with stabilizing fins 43, and its body will normally contain an explosive, incendiary, or other type of destructive charge. Since the device is essentially an induction motor, although of unconventional form since the armature is a free-body unconnected mechanically or electrically but only magnetically to the other structure, the general principles of induction motor design apply such as the principle that the air gap should be small whereby in this instance the armature diameter is only slightly less than that of the bore. If the "winding" (in this case the shell itself) is of relatively high resistance, the starting forces will be high and the "running" ef-

iciency and thrust low, while low resistance results in reverse characteristics. It is therefore desirable that the breach and starting explosive charge be provided, so that as the armature enters the fields induced in the motor stator coils it is travelling at a velocity which represents a relatively small slip in comparison with the velocity of the travelling magnetic field generated in the coils 31 in response to and in substantial time-correspondence with the traveling magnetic field developed in the generator stator by movement of the generator armature therethrough. Once within this field, the conditions common to induction motors obtain, the thrust becoming proportional to the slip. The frequency, it is true, increases constantly as the armature progresses through the stator. While this is unusual in induction motor practice, it is not unheard of; actually, the efficiency increases somewhat with the frequency and there is no necessity for frequency stabilization in this particular application of the principles.

Because of the slip, positive with respect to the motor and negative with respect to the generator, both armatures should be long enough to span more than the two coils theoretically necessary to constitute a continuous travelling wave. In the generator portion of the device, the voltage will lead the current, whereas in the motor portion the reverse is true. If the transfer constants are properly computed, the phase relationships remain substantially constant. The armatures should each span coils representing at least a full cycle, and preferably somewhat more, in order that the energy returned to the system as the projectiles pass may be effectively to excite the coils in advance; this excitation current is wasted as the two projectiles leave the muzzles of the gun.

The slip-thrust relationship is illustrated in Fig. 2. In this figure, curve 41 shows the relationship in the case of a high resistance motor-projectile, whereas curve 43 shows the relationship with a minimum resistance projectile. Intermediate values of resistance would, of course, give intermediate curves, but the effect observed can be sufficiently deduced from the two curves shown. In each case, the thrust is shown in terms of the percent of maximum. It would obviously be possible to start the projectile from rest, but in this case the thrust imparted to it by the field would fall off as it gains speed relative to the speed of the generator projectile. "Relative speed" as here used is in terms of coils per unit time traversed by the two projectiles. If the motor-projectile is traveling at nearly the same relative speed as is the generator projectile, the low-resistance projectile will operate on the descending branch of curve 43. The efficiency at this point will be high and a decrease in relative speed of the motor projectile with respect to that of the generator projectile will result in an increased thrust and a tendency to "catch up." As it does catch up, it reduces the current flowing in the coils of both motor and generator portions of the device and therefore reduces the portion of the energy which is stored in the magnetic field. The necessity for getting rid of large amounts of stored energy after the projectile leaves the gun is therefore to a large extent eliminated; there is no sudden generation of unduly high voltages which might result in flash-overs and possible destruction of the equipment.

Although emphasis has been laid upon efficiency in the foregoing, particularly as efficiency is limited by Kelvin's law, the ultimate desideratum is to transfer to the motor-projectile the maximum available energy, and it is well known that maximum energy transfer occurs when the impedance of the source of power is equal to that of the "sink," i. e., when the impedances of the driving and driven elements are matched. The impedance looking into the individual motor coils has both resistive and reactive components. Owing to the coil construction, the ohmic resistance of the circuit can be made very small so that the resistive component is due almost entirely to the mechanical energy imparted to the motor

projectile. The inductive reactance of the motor coils is reduced owing to the fact that the projectile lies within them, as a short circuited turn. The total reactance of the circuit, however, is increased by the presence of the capacitance between the leads connecting the generator and motor windings, although this capacitance increases the power-factor. The use of complete coils for the generator windings, as shown in Fig. 1, therefore may result in a much higher effective impedance in the generator branch of the circuit than is desirable. Fig. 3 shows a coil configuration which permits improved matching of the motor and generator coil impedances, a single generator coil and its accompanying motor coil being indicated in this figure.

In the embodiment of Figure 3, the generator coil is divided into four sectors, although the same effect could be secured to a greater or less degree by the use of two, three, or more sectors for the generator coil. The four sectors of the generator coil are designated as 45₁ to 45₄, inclusive. Each sector is connected to two single-turn motor coils, designated as 47₁ to 47₄ inclusive. Tracing the circuit, counterclockwise from generator-coil sector 45₁, the upper terminal of this sector connects through the upper of a pair of leads 49₁ to coil 47₁, returning through the lower of leads 49₁ to the upper terminal of sector 45₂. The lateral terminal of sector 45₂ is connected similarly to coil 47₃, returning to the left-hand terminals of sector 45₃. The circuit continues in this manner through the remaining sectors and the leads as distinguished by their appropriate subscripts back to sector 45₁ through the lower lead of the pair 49₄ from coil 47₂. In effect, therefore there is a single generator turn 45 connected with four motor turns in series. From a circuit constant point of view, this is preferable to the more obvious arrangement of a single pair of leads from the generator coil to a group of series connected motor coils, giving better current distribution in the coils themselves and, for certain designs, a better balance between interlead capacity and inductance of the circuit as a whole. The interlead capacity, between a pair of leads connecting a generator coil and a motor coil separated by a given actual distance, will be substantially the same whether they connect to a complete generator turn or only a sector thereof. By dividing the generator coil, as illustrated, only one-fourth of the total voltage drop is effective between any pairs of leads; the four capacities are effectively in series, and the circuit capacitance is therefore only one-fourth of what it would be with the more obvious construction. One advantage of this construction is that it enables an arrangement of motor coils taking up the full length of the motor stator, without gaps, and is conducive to the design of the two stators in their desired length-ratio without requiring gaps between the coils while, at the same time, maintaining the desired impedance relationship.

The manner in which such coils may be embodied in a gun of the same general type as that shown in Fig. 1 is illustrated in Fig. 4. The structures common to the two figures are designated by the same reference characters, the coils in Fig. 4, however, bearing the same notation as those illustrated in Fig. 3.

It will be recognized that effectively each generator coil, as shown in Figs. 3 and 4, represents a separate phase of the circuit, and that the four coils of the motor stator represent a corresponding phase in the latter structure. It will also be seen that because of the structure of the motor coils, each being a complete turn which is fed radially, there is no skewing of the magnetic field to give a lateral thrust or wobble to the projectile. The four coils comprise what is essentially a current sheet insofar as that particular phase is concerned.

It will also be recognized that only those coils within which the generator projectile is moving are energized, and that as long as the motor projectile lies within the corresponding motor coils it will receive a major portion

of the energy from the generator coils and continue to accelerate. The progress of the projectiles through the individual coils of the two stators causes the projectiles to excite them or be excited by them in succession.

The currents in any two successive coils will be of nearly the same phase at the instant the nose of the projectile enters the coil, the phases in the generator coils gradually advancing along the stator as a result of negative slip. The progress of the projectile through the stator causes the successive excitation of the coils, and since the projectile spans a number of coils the result will be polyphase fields, the number of phases being dependent upon the number of coils spanned by the respective projectiles. Because of this, one of the greatest advantages of the inventive structure exists; the only portion of the structure which is excited is that which is actually doing work. So far as is known, the various structures shown by the prior art excite the entire motor stator and thereby waste most of the available power or else encounter destructive, high-current arcs. The structure here described applies energy only where it is actually useful and without arc-producing current switching.

Thus far the description of the invention has dealt primarily with the electrical considerations involved in the invention, but it will be obvious that there are several mechanical features which are of very great importance. Not the least of these is the fact that the construction of the gun barrels does not require that they be resistant to explosive forces from within, such as will be generated by both the generator charge and the charge giving the initial impulse to the motor projectile. In constructing the device, it is quite clear that the coils must be accurately aligned; they may, for example, be assembled on a mandrel and there be affixed to their various leads, the generator and motor mandrels being held in their proper relative positions by suitable jigs or fixtures. Fortunately, although the currents involved are very high most of the voltages are low, and only minimum amounts of insulation need be used. The rearward extensions of the two stators, including the breach mechanisms, must be carefully aligned with the coils and the mandrels on which they are assembled. These portions can be of ordinary gun-construction except for the fact that no rifling is necessary and, in fact, any spin of the projectiles is to be avoided rather than encouraged.

Once the motor projectile has entered the stator and begins to be accelerated by induction from the stator fields, the pressure in the gun barrel proper will drop; actually the projectile will run away from the pressure wave which gives it its initial start. This is not necessarily true of the generator armature, although it may be true in part if only a small charge is used to give the latter its original impulse and its major acceleration is derived by rocket action, as has already been described.

The problem of mechanical construction can be met by encasing both motor and generator portions of the device in an outer tube 51 of high tensile strength material and by filling the space between the latter tube and the coils with material 53 which is high in compressional strength but which is a poor conductor. Owing to the relatively low voltages employed, however, the filling material 53 need not be a particularly good insulator. Since the stresses are ultimately carried by the high tensile strength casing 51, it is satisfactory if the filling material be strong only in compression. For this reason, it is possible to use, as the filler 53, a dense, fine grain Portland cement concrete. As is well known, this has a very high compressive strength although it is weak in tension. Although it is not a good insulator, its resistance is sufficiently high so that very little energy is dissipated by induced currents therein. The outer shell 51 is very loosely coupled to either the motor or generator coils and, moreover, the fields due to these coils as viewed from the outer casing are substantially neutralized by the counter fields due to the circulating

currents in the respective shells. The outward loss of energy is therefore very small.

Actually, a more serious difficulty is presented by the air pressure wave which builds up in front of the motor projectile as its speed approaches and eventually exceeds mach 1, the speed of sound. The loss of energy to the shock wave thus developed can be minimized by providing the muzzle of the motor barrel with a cover plate 55, provided with a gasket of rubber or like material 57. The cover plate 55 may be made of metal or even of light plastic; it must have sufficient strength to withstand atmospheric pressure over the area of the bore of the gun. Communicating with some convenient portion of the bore, preferably, although not necessarily, adjacent to the breech end of the stator proper, is a conduit 61 leading to a vacuum pump 63. With the cover plate 57 and its gasket in place, and with the breech sealed by the breech block and cartridge case, the barrel is exhausted by vacuum pump 63. The evacuation avoids build up of terrific pressures ahead of the projectile as it is accelerated. Momentum, corresponding to the projectile velocity, must be imparted to the gas remaining in the barrel of the gun, but with only a fairly good vacuum produced in the barrel the pressures generated are not excessively large. The cover plate will, of course, be blown away as, or shortly before, the projectile reaches it.

Alternatively, and slightly less effectively, the stator portion of the barrel can be vented at short intervals to permit the gas to escape laterally instead of removing it beforehand.

It should be evident that it is not necessary that the initial impulse be given to the motor projectile by an explosive charge, or, in fact, that it be given any initial impulse although this is preferred. The primary drive can be imparted by compressed air, for example, or if an evacuated barrel is used, and a sealing ring is employed on the projectile, atmospheric pressure will give it a start. If no initial impulse is given, however, the stator coils near the breech should be spaced more closely than those farther along in order that a given amount of electrical slip in the breech portion may not correspond with two great a lagging-behind of the magnetic fields. When an initial impulse is applied it may be desirable to vary the spacing of either the motor or generator stator coils in order to maintain a substantially constant degree of acceleration from breech to muzzle of the device. If the generator armature is given a constant acceleration, uniform spacing of both sets of coils is desirable, but if the rate of acceleration of the generator armature varies, a compensating variation in coil spacing in either motor stator, generator stator, or both, improves the performance.

It has already been mentioned that the switch 37 of Figs. 1 and 4 is shown purely schematically. A mechanical switch is possible. In order to reduce the size of the equipment and at the same time to generate a large circulating current in the generator armature it is desirable to charge the condensers 21 to relatively high voltages, to make their leads to the coils 19 of low inductance like the leads to the coils 17, and to make the closure of the switch as rapid as possible. In order to accomplish this, the switch 37 may be in the form of a triggered spark gap, such as is used in radar apparatus to initiate high voltage pulses. Various such triggered spark gaps are well known in the art and it is therefore unnecessary to describe any particular type here. The simple condensers shown can, of course, be replaced by pulse forming networks of any of the types used in radar apparatus, but the simple condenser is practically as effective. If the resistance of the armature 35 is low, substantially all of the energy of the condenser discharge will be absorbed in setting up the circulatory currents within it, and the condenser discharge can be made substantially non-oscillatory.

It has already been pointed out that the frequency generated in the various coils increases as the two armatures travel from breech to muzzle of the device. Other than making it advisable that the connections between the muzzle coils should be shorter than those between the breech coils, so as to reduce both inductance and capacitance effect as the frequency increases, this change in frequency is of no particular moment. The consequent currents and fields adjust themselves so as to produce the proper induced armature currents in the proper phase. The circulation of the currents in both motor and generator armatures will be such that, considered around any circumference, an alternating current will exist, these currents varying in phase from nose to butt of the projectile. In the stators, the current will lead the voltage in the generator portion of the circuit and lag in the motor portion. In the generator, energy is imparted by the armature to the circuit as the armature enters the coil and is returned as magnetizing current later in the cycle. In the motor portion, energy is imparted to the armature as it approaches and returns from the armature to the circuit later in the cycle, the returned energy being represented as magnetizing current in the generator. It may be noted that more than one cycle can occur during the passage of the armature as a whole through any one coil.

While the use of an induction type generator leads to what is now believed to be the simplest form of design, it is not the only type that can be used for the generator portion of the apparatus. It should be quite evident that the stator of any type of rotating field A. C. generator can be developed into linear form. It is further apparent that individual windings in such a developed stator or armature structure can be connected to individual coils of the motor to produce a traveling field in the motor stator structure corresponding to that developed in the generator coils. Among the many types of generator structure that might be used is the inductor type in which both field and armature windings are on the stator and cooperated with a ferro-magnetic inductor that effectively switches the field between the stator pole pieces. This inductor type is typified by the well known, although now little used, "Stanley" generator. Other types of well known generator apparatus in which a magnetic field of a continuously magnetized armature passes through the stator coils can also be employed if desired.

All of these various types of generators, although usable, possess the disadvantage that they require a heavier generator armature or projectile than does the induction-generator type. With the latter type, the entire mass of the generator projectile can be the "winding" or conducting portion of the projectile. None of the energy of the charge therefore need be wasted in accelerating a heavy magnetic core. The result is that as the generator projectile leaves the muzzle it has much less kinetic energy than the heavier device would have and therefore greater energy is imparted to the projectile itself.

Any of the types of generators that have been suggested, however, possess the characteristic which has been considered to be that which gives to this invention its greatest value; i. e., all of the energy generated and transferred to the motor portion is concentrated, without the need for high-current switches, in the region where it is immediately effective upon the projectile. Of the electromagnetic guns which have been suggested in the past, some have been of the induction motor type. So far as is known to the present inventor, however, all of these have required that the entire stator structure be excited. They have used rotating alternators to generate the requisite current, speeding up these alternators and using the momentum of their rotating parts to store kinetic energy which could be drawn upon at the instant of discharge of the gun. Of the

energy transferred to the stator structure, only that which develops the fields immediately surrounding the projectile is of any actual effect, but in these former structures the energy must be stored in the magnetic field and the whole structure excited in order to obtain the desired action. Furthermore, the frequency drops as energy is taken from that stored as kinetic energy in the fly wheels and this imposes a definite limit upon the velocity imparted to the projectiles.

In the particular forms of the device which have been illustrated, it will be noted that no ferro-magnetic material has been used in either the motor or generator stator structures. A ferro-magnetic field or core structure can be used if desired. At lower frequencies and muzzle velocities, the use of ferro-magnetic structures is permissible and may be of advantage. In general, however, computations indicate that non-ferro-magnetic structures are more efficient. While the high projectile velocities for which the present invention is primarily intended, the frequencies generated in the coils become very high, particularly toward the muzzle, and with increasing frequencies the advantage to be gained from the use of ferro-magnetic material in the cores falls off rapidly. At higher frequencies, the inductance of the coils rises, increasing the required voltage per coil. The capacitance of the leads then begins to assume greater importance and may involve serious losses. Therefore, although the use of ferro-magnetic core structures is considered to be within the scope of the invention here presented, the preferred form of the device dispenses with the use of ferro-magnetic materials.

As has been indicated, the details of structures in which the present invention may be embodied vary widely. The particular types described herein are therefore not intended as limitations, all limitation intended being specifically expressed in the following claims.

What is claimed is:

1. An acceleration amplifier comprising a linear induction motor stator and a shorter linear generator stator, said stators including an equal multiplicity of cylindrical coils disposed end to end to form respective tubular bores therealong, rigid connections from each generator coil to the motor coil positioned in corresponding order on said motor stator, a generator armature adapted for movement through the generator stator and of such length as to span a few of the coils thereon, means for exciting in said armature magnetic fields linking the coils spanned thereby to induce therein phase-displaced currents when moved with relation to the coils so spanned, a motor armature comprising a conductive projectile moveable within the coils of said motor stator and of such length as to span a plurality thereof, and means including means for accelerating said generator armature through said generator coils to induce in said projectile from said motor coils a localized field traversing said motor stator to support said projectile and to move the latter through said motor coils at a greater acceleration than that of said generator armature, said localized field constituting the sole support of said projectile during said acceleration.

2. An acceleration amplifier comprising a linear induction motor stator and a shorter linear generator stator, said stators including an equal multiplicity of coils disposed therealong, permanent connections from each generator coil to the coil positioned in corresponding order on said motor stator, a generator armature adapted for movement through the generator stator and of such length as to span a few of the coils thereon, means for exciting in said armature magnetic fields linking the coils spanned thereby to induce therein phase-displaced currents when moved with relation to the coils so spanned, a motor armature comprising a conductive body moveable within the coils of said motor stator and of such length as to span a plurality thereof, and a breech chamber aligned with said generator stator and connected therewith

and adapted to contain an explosive charge for driving said generator armature therethrough at an accelerating rate.

3. An acceleration amplifier comprising a linear induction motor stator and a shorter linear generator stator, said stators including an equal multiplicity of coils disposed therealong, permanent connections from each generator coil to the coil positioned in corresponding order on said motor stator, a generator armature adapted for movement through the generator stator and of such length as to span a few of the coils thereon, means for exciting in said armature magnetic fields linking the coils spanned thereby to induce therein phase-displaced currents when moved with relation to the coils so spanned, a motor armature comprising a conductive body moveable within the coils of said motor stator and of such length as to span a plurality thereof, means including a breech chamber aligned with said generator stator and connected therewith and adapted to contain an explosive charge for driving said generator armature therethrough at an accelerating rate, and means for giving an initial velocity to said motor armature concurrently with the firing of such explosive charge.

4. An acceleration amplifier comprising an elongated tubular induction motor stator, a plurality of coils disposed end to end therealong to form a tubular bore, each coil comprising a single turn of strap conductor forming a band of predetermined diameter, a tubular generator stator of materially smaller length and large internal diameter mounted closely adjacent to said motor stator, single turn cylindrical coils equal in number to said motor coils disposed end to end along said generator stator to form a second tubular bore, connections from each of said generator coils to the coil in the like numerical order on said motor stator, means for inducing currents in a conductive projectile movable through said generator coils, means for driving such a conductive projectile through said generator coils thereby to induce therein currents producing a localized magnetic field travelling along said motor stator, and a conductive free-body projectile of a diameter only slightly less than said predetermined diameter movable through said motor stator coils by induction from the field traveling therealong.

5. An acceleration amplifier as defined in claim 4 wherein the connections between each of said generator coils and the motor coil corresponding thereto comprise flat strips wide in comparison to their thickness, the outgoing and return leads comprising each connection being closely apposed and separated only by a thin layer of insulation.

6. An acceleration amplifier comprising an elongated tubular induction motor stator, a plurality of cylindrical coils disposed end to end therealong to form a bore, each coil comprising a single turn of strap conductor, a tubular generator stator of materially smaller length and larger internal diameter mounted closely adjacent to said motor stator and comprising single turn cylindrical coils disposed end to end to form a bore and equal in number to the coils on said motor stator, connections from each of said generator coils to the coil in like numerical order on said motor stator, a group of additional coils positioned at one end of said generator stator in alignment with said generator coils, means for passing electrical energy through each of said additional coils to induce electric currents in a conductive projectile encompassed thereby, and means for driving such a conductive projectile through said additional coils and said first-mentioned generator coils in succession to constitute an induction generator developing a magnetic field in said motor coils advancing proportionally and at a higher rate in said motor stator.

7. An acceleration amplifier comprising an elongated tubular induction motor stator, a plurality of coils disposed therealong, each coil comprising a single turn of strap conductor, a tubular generator stator of materially

smaller length and larger internal diameter mounted closely adjacent said motor stator, single-turn coils equal in number to said motor coils disposed along said generator stator, connections from each of said generator coils to the coils in like numerical order on said motor stator, means for inducing currents in a conducting body within said generator stator, and means, including a breech chamber coaxial with said generator stator and adapted to contain an explosive charge, for driving such a conducting body through said generator stator thereby to induce in the coils thereon currents producing a traveling magnetic field in said motor stator.

8. An acceleration amplifier comprising an elongated tubular induction motor stator, a plurality of coils disposed therealong, each coil comprising a single turn of strap conductor, a tubular generator stator of materially smaller length and larger internal diameter mounted closely adjacent said motor stator, single-turn coils equal in number to said motor coils disposed along said generator stator, connections from each of said generator coils to the coil in like numerical order on said motor stator, means for inducing currents in a conducting body within said generator stator, means, including a breech chamber coaxial with said generator stator and adapted to contain an explosive charge, for driving such a conducting body through said generator stator thereby to induce in the coils thereon currents producing a traveling magnetic field in said motor stator, and means aligned with said motor stator for impelling a conducting armature thereinto concurrently with the initiation of a traveling field therein.

9. An acceleration amplifier comprising: a linear induction motor stator including a first multiplicity of cylindrical coils successively spaced end to end one after another to define a first bore; a generator stator including a second multiplicity of cylindrical coils positioned successively end to end one after another to define a second bore of a length shorter than that of said first bore; means for developing a first localized magnetic field traveling the length of said second bore in a predetermined time interval; means, including electrical conductors individually coupling said first and second multiplicities of coils, for developing a second localized magnetic field traveling the length of said first bore in substantial time-correspondence with said first field; and a motor armature comprising a conductive projectile of a length to span a plurality of said first multiplicity of coils and movable through and solely supported within the coils of said first bore by magnetic induction from said second magnetic field.

10. An acceleration amplifier as defined in claim 9 including a housing for said induction motor stator and a vacuum pump coupled to said housing for evacuating the latter.

11. An acceleration amplifier as defined in claim 9 including additional means for imparting an initial velocity to said motor armature.

12. An acceleration amplifier comprising: a linear induction motor stator including a first multiplicity of cylindrical coils successively spaced end to end one after another to define a first bore; an induction generator

stator including a second multiplicity of cylindrical coils positioned successively end to end one after another to define a second bore of a length substantially less than that of said first bore; means, including coupling elements individually coupled between said first and second multiplicities of coils, responsive to a magnetic field traveling the length of said second bore in a predetermined time interval for developing a magnetic field traveling the length of said first bore in substantially the same time interval; a generator armature movable through the coils of said second bore and of a length to span a plurality of the coils thereof; a motor armature comprising a projectile of conductive material movable through the coils of said first bore and of a length to span a plurality of said first multiplicity of coils; means for establishing a magnetic field emanating from said generator armature to link coils spanned thereby and induce therein phase-displaced currents upon relative movement between the armature and the spanned coils; and means for accelerating said generator armature through said generator stator to induce in the latter a localized magnetic field traversing the length thereof and consequently create a similar localized magnetic field traversing the longer motor stator in an equal time interval to accelerate by induction said motor armature through said motor stator coils.

13. An acceleration amplifier as defined in claim 12 in which each of said first multiplicity of coils comprises a strap-like band closely encircling the motor armature path and responsive to coil-current flow to produce sheet-like currents substantially confining the magnetic fields linking the bands and the armature to the space immediately between the bands and the motor armature.

14. An acceleration amplifier comprising: a linear induction motor stator including a multiplicity of cylindrical coils successively spaced end to end one after another to define a motor bore; a generator including a multiplicity of inductive elements positioned successively end to end one after another to define a path of a length substantially less than that of said first bore; means for developing a first localized magnetic field traveling the length of said path in a predetermined time interval; means, including electrical conductors coupled between individual ones of said multiplicities of coils and elements, for developing a second localized magnetic field traveling the length of said motor bore in substantial time-correspondence with said first field; and a motor armature comprising a conductive projectile of a length to span a plurality of said multiplicity of coils and movable through and solely supported within said motor bore by magnetic coupling from said second magnetic field, said projectile beam moved through said bore in substantial time correspondence with said second magnetic field.

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