Field Reactor transducer

Introduction

The Field Reactor works as a thruster and as a controllable resistance to an external force.

Possible commercial applications include propulsion and attitude control for spacecraft and any other system in which a directed force or a damper or shock absorber is required where there is an advantage to not being limited by the distance over which the device can work. For example, a car's shock absorber can only move a short distance; a thruster on a spacecraft will only produce a force for as long as it has propellant to eject as reaction mass. A Field Reactor will produce a thrust or resist acceleration for as long as it is powered.

The Field Reactor is an active bidirectional transducer. A transducer is any device which converts energy from one type to another. Examples include microphones, loudspeakers, motors and generators. A bidirectional transducer is one which has two modes of operation which are symmetrical in time. For instance, a moving coil microphone will work as a speaker when driven with an audio signal. A moving coil speaker will produce a current when the cone is made to move by a force. The chief difference between the starter motor and the alternator of a car is the speed at which their rotors turn; in terms of the general arrangement of their parts they are similar. An active transducer is one which requires a power supply.

The Field Reactor exploits the same physical principles as any other electric motor, where an electric current in a coil on the rotor creates a magnetic field which exerts a force on a magnetic field from the housing, the stator, which causes the rotor to move relative to the stator. An electric motor can only work because the rotor is free to move relative to the stator.

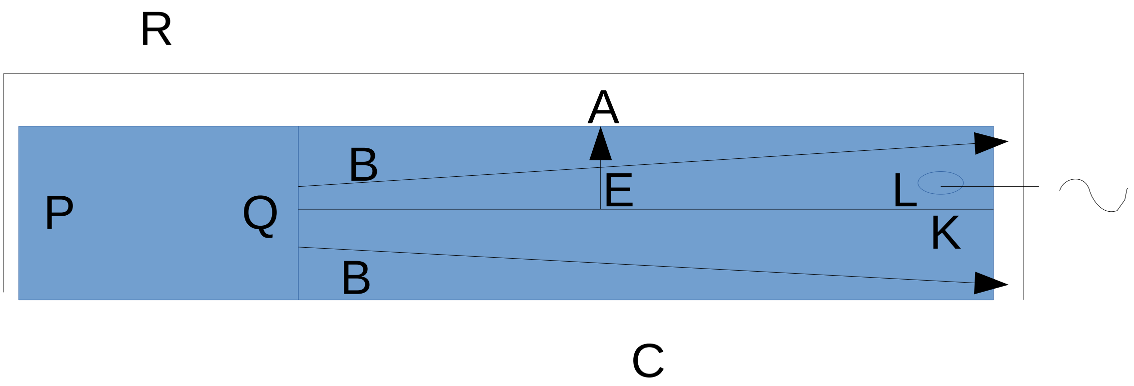
In the Field Reactor the field coil of the rotor is replaced with a space charge, a cloud of electrons, accelerated in a cavity to form a vortex circulating around the axis of the device. Because this cloud and the housing are not mechanically attached they are free to move relative to each other and the magnetic field generated by the motion of the space charge exerts a force on a magnetic field from the stator, just as in any other electric motor, but the arrangement of the parts causes this force to act along the axis rather than around it. The vortex-like flow of the electrons works just like the a current flowing in a coil and the device works like a coil next to a bar magnet.

Newton's second law states that a force is a rate of change of momentum. In an electric motor the momentum of electrons flowing in the field coil of the rotor is transferred to whatever the motor is driving. The drift velocity of an electron flowing in the current of the rotor field coil of a motor is in the order of millimetres per second, 10^{-3} m/s, and the rest mass of an electron is a little under 10^{-30} Kg giving it a mechanical momentum, its mass multiplied by its velocity, of about 10^{-33} Ns. This is vanishingly small and even given the number of electrons in the field coil of a motor their combined momentum cannot explain the force on the rotor. In fact it is the electromagnetic momentum of the moving charge of the electrons, which is equal to the magnetic field made by the current in the coil, which is responsible for the force. This is not taught well in schools.

The action of the Field Reactor as a thruster from first principles

Here are some numbered bullet points to enable you to work through the process step by step to allow you to see how the Field Reactor produces a force and that energy and momentum **(both mechanical and electromagnetic)** are accounted for due to the conservative, symmetrical nature of electromagnetism. This assumes that the device is free to move; so you might consider it to be in free fall in space, for instance. The Field Reactor joins the family of “crossed field” devices which exploit the behaviour of electrons in the presence of electric and magnetic fields with components at right angles to each other.

Fig 1

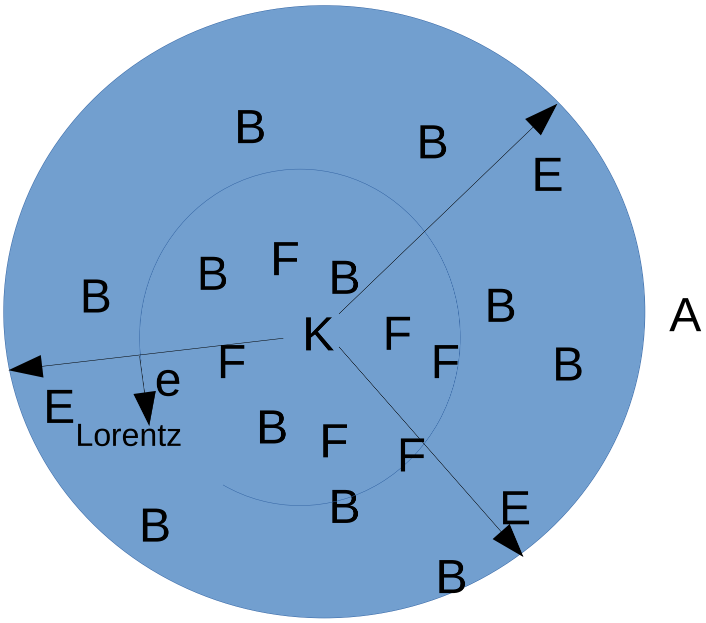


1 Fig. 1 Is a diagram in side elevation of the simplest topology of the Field Reactor, which is similar to the experimental proof-of-principle prototype. A bar magnet (either permanent or electromagnet) with poles P and Q abuts cavity C. The end caps of the cavity are made from a magnetically permeable material such as soft iron and the cavity walls are made from a good conductor (if the walls are to function as the anode) of low magnetic permeability such as copper. Cathode K is mounted in the centre of the cavity and may either be a hot cathode designed to emit electrons by thermionic emission or a cold cathode made of a material which emits electrons readily by field effect. The flux B from pole piece Q threads through the cavity to the opposite end cap. Plate R is made of a magnetically permeable material and acts as a flux return to pole P to complete a magnetic circuit. Loop L serves as an antenna to allow excess electromagnetic energy to radiate from the cavity. In this case the wall A of the cavity is the anode. There is a large potential difference between K and A which gives rise to electric field E; in the prototype it is about 2kV and the hot cathode emits about 0.3 Coulomb of free charge into the cavity each second, giving a power of some 700W and a static thrust of about 0.1N using circuit-bent components in ways they were not designed for.

2 We will now consider the case for a single electron emitted into the cavity by cathode K.

3 Fig. 2 shows the device in plan view looking down the cavity towards pole Q.

Fig 2



4 Flux B is from pole Q and has a strong component along the axis of the cavity (in or out of the page) but the flux lines are somewhat divergent.

5 Electron e with charge q is emitted from the cathode K and is accelerated radially towards the anode A by electric field E and its motion in the direction of E in the presence of B causes it to be acted on by the Lorentz force F=Eq+qvB where v is the instantaneous velocity of e. The Lorentz force causes the electron to accelerate at right angles to E and B.

6 Appropriate flux density of B and field strength of E are selected so that the Lorentz Force is equal to the centripetal force required to compel the electron to go around the cathode in a roughly circular path. This forms the simplest possible current loop which, by Ampere’s circuital law, encloses a flux F of a density which is proportional to the magnetic constant (permeability of free space, Mu) and the beam current made by the motion of the electron. **Flux F may be seen as the relativistic component of the electromagnetic momentum of the moving charge: its density varies with rate of charge flow relative to the observer, magnet PQ. It is this momentum which is transferred to the body of the device by the action of a force.**

7 As more electrons are emitted they follow similar paths around the cathode to form a vortex-like flow around the cathode with each electron adding its own component to flux F. This vortex-like flow of electrons in the cavity is equivalent to a vacuum core solenoid carrying a current which is the sum of all the individual current loops.

8 Due to the Lorentz force law, the direction of induced flux F is the opposite of flux B (flux F and flux B are disconnected) when the cathode is surrounded by the anode.

9 Thus there is a repulsive force between pole Q (flux B) and flux F.

This force causes pole Q to accelerate away from the space charge in the cavity.

As pole Q moves relative to the space charge Faraday's law describes how the intersection of the flux B from pole Q with the paths of the moving electrons exerts an electromotive force (emf) on the space charge just as it would if it were moving relative to a coil carrying a current. Lenz's law describes how the sense of this emf is always such that it will cause a change in F which will tend to oppose the change being made by the relative motion of Q and the space charge. In other words, the acceleration of Q relative to the space charge will decelerate the electrons causing them to fall to the anode under the action of electric field E as the Lorentz force acting on them no longer matches the centripetal force needed to maintain a circular path and Q (and the rest of the housing of the device) will gain a proportion of the **electromagnetic** momentum the electrons lose as it accelerates relative to the space charge. The anode will gain any residual mechanical momentum when the electrons strike it, so there is no net transfer of mechanical momentum in the cavity. All electromagnetic and mechanical momentum is conserved. **The device is mechanically sealed, but electromagnetically and thermodynamically the device is open as charge flows into the cavity via the cathode and flows out via the anode. Energy enters the cavity via the electric field between cathode and anode and exits via the antenna as radio waves and the rest is radiated as infra-red photons of waste heat. The electrons in the cavity are effectively in free space and at the instant they are emitted from the cathode they have a velocity of zero, so all of the momentum they gain is from the force due to the electric field E and they transfer this momentum to the housing via the magnetic field of PQ via the covariant electromotive and magnetomotive forces as described by Faraday's law and Lenz's law.**

Here Lenz's law is playing the role of Newton's third law – the emf acts in the opposite direction to the Lorentz force on the electrons and perpendicular to the force between flux B and flux F. However, electricity and magnetism are not Newtonian but relativistic, so the relationship between energy and electromagnetic momentum of the moving charge varies according to the choice of frame of reference. Thus the emf is opposite but not equal to the Lorentz force as a lot of the energy leaves via the antenna. Electrons are accelerated into the cavity continuously to replace the decelerated electrons which have hit the anode.

10 As the electrons move in the cavity they emit electromagnetic radiation which is an unwanted by-product of the process and needs to be removed from the cavity via loop L and either absorbed by a load (in the prototype this is a block of polymer resin mixed with black copper oxide powder which was chosen for its absorption characteristics) or reclaimed.

11 The Field Reactor works by exploiting the law of conservation of momentum, in common with other propulsion technologies. Most of the energy that goes into the space charge via E comes out via the loop L. In contrast to a magnetron, which, to optimise efficiency, requires symmetry of the design of the resonant lobes machined into its cavity and also of the magnetic field which provides the axial flux to exploit the Lorentz force, this device requires an asymmetric magnetic field in the cavity and the precise geometry of the cavity is less of a concern.

The Field Reactor as a damper or brake

1 We have seen how the Field Reactor works as a thruster by exploiting Faraday's law of induction and Lenz's law (which is really Newton's third law, the law of conservation of energy and momentum, in the context of electricity and magnetism) and that the vortex-like flow of electrons in the cavity is equivalent to a current in a vacuum core solenoid.

2 If the entire device is set in motion by the action of an external force then Faraday's law and Lenz's law again come into play as the relative motion of the magnet PQ and the space charge induces eddy currents and consequent magnetic flux in the space charge which tend to oppose the external force, thus damping or braking the motion. It is like the school experiment where a magnet is dropped down a copper pipe and takes a long time to come out of the bottom because of the braking action of magnetic flux due to eddy currents induced by the motion of the magnet relative to mobile electrons in the copper pipe, whereas a marble dropped down the pipe falls as expected.

3 Even if the potential difference between the cathode and the anode is zero and the space charge is not accelerated by E because E=0 and an external force acts on the device the eddy currents induced by the relative motion of PQ and the space charge will produce a reactionary force and cause the emission of electromagnetic waves via loop L.

4 Anode current will flow when electrons hit the anode as a result of being accelerated by the motion of the magnet relative to the space charge.

5 Thus, in acting as a brake or damper this transducer can harvest energy from whatever it decelerates. This is in line with expectations as a motor is a generator in time-reverse.

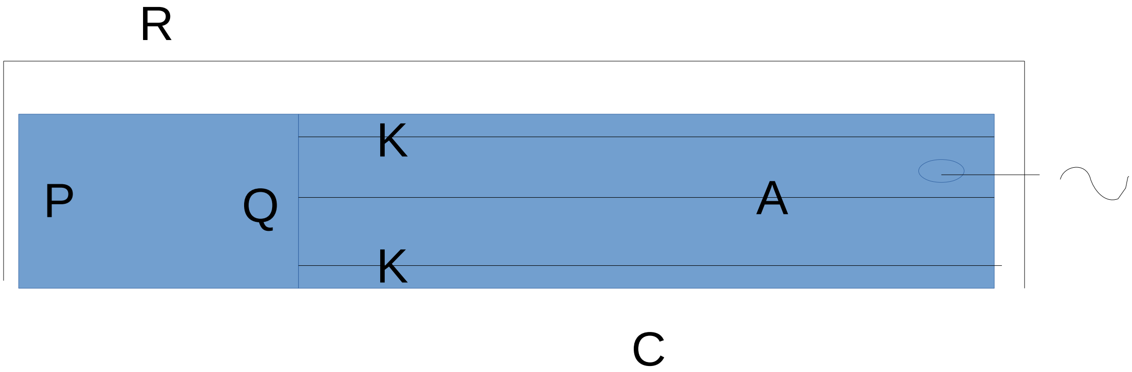
6 By adjusting the flux density of B from magnet PQ (assuming PQ to be an electromagnet) and the potential difference between cathode and anode to vary E the characteristics of the Field Reactor may be tuned to suit specific requirements. It can be used as a thruster and brake simultaneously and this has been verified experimentally with the prototype suspended by a thin monofilament line and set in motion as a pendulum. The amplitude of the swing decreases significantly faster when switched on than when switched off while the thrust component stays as before.

Configurations and considerations

1 It makes no difference if P and Q are North or South poles as with the cathode at the centre of the cavity the Lorentz force law always ensures that the sense of the vortex-like flow of the electrons of the space charge is such that the flux F enclosed by the current loops described by the individual electrons in the space charge is always repulsive to the pole Q.

2 Another arrangement is where the cathode surrounds a central anode in the cavity. In this case, the electrostatic potential of the cavity wall would be held negative with respect to the cathode to force the electrons away from the wall and into the cavity towards the anode. In Fig. 3 we see this arrangement. In this configuration the Lorentz force law ensures that the flux enclosed by the electrons circulating in the cavity is always of the sense that the force between Q and F is attractive and pulls magnet PQ towards the space charge.

Fig 3

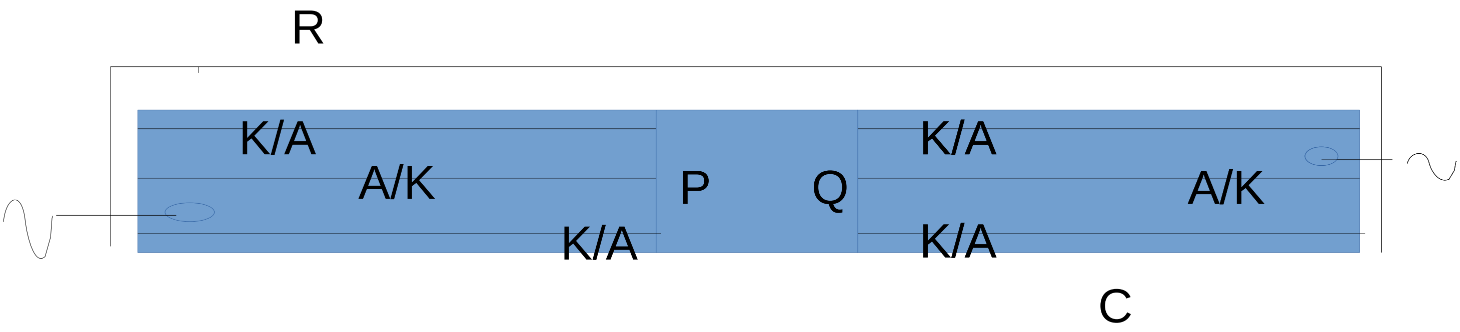


In the prototype, with the cathode at the centre of the cavity, the region where the centripetal force and the electric field match and cause the electrons to circulate is relatively narrow as the flux F and B are disconnected and cancel out further away from PQ and the device works more like a diode and relatively few of the electrons contribute to making a force. With a central anode, however, flux B and F connect to form a magnetic circuit and add up so all of the electrons in the cavity contribute. For this reason, it is expected that production models will be of the central anode configuration and will have thrust to power and thrust to mass ratios orders of magnitude greater than the prototype. In this configuration the cavity could be made longer to produce a greater force. Many cavities may be machined in a single block to form a compact array and many electrodes may be in a single large cavity.

3 Both of the electrodes (anode and cathode) may be made as emitters with swappable roles to alter the characteristics of the device by altering the currents flowing through them and varying their electrostatic potentials.

4 Fig 4 shows a possible configuration where the cavity on one side of the magnet could be used with the central cathode (the “push” or repulsive configuration) and the other with the central anode (the “pull” or attractive configuration). Or they could both be “pull” or both be “push” which would give the effect of controllable inertia. With PQ as an electromagnet its polarity may be chosen at will.

Fig 4



To gain a deeper understanding of the subject please refer to "Classical electricity and magnetism" by Wolfgang Panofsky and Melba Phillips. Panofsky was the first director of the Stanford Linear Accelerator Center and wrote this textbook for graduate students. **It notes that in all of classical electricity and magnetism the only physical reality is Coulomb's law and everything else is mathematics**. The magnetic flux measurable due to the relative motion of an observer and electric charge is the relativistic component of the electromagnetic momentum of the moving charge. Axiomatically, no mechanical momentum can be exchanged in a mechanically sealed unit but in the Field Reactor it is the exchange of electromagnetic momentum via the electromagnetic force which is at work, just as in any other electric motor. Newton and Galileo didn't know about electricity and magnetism so to understand this we need to look to Maxwell's equations, the Lorentz force law, and the Maxwell stress tensor. Then we take the Poynting vector **S=ExH** which tells us which way energy is flowing in the EM field and then taking $E=mc^2$ we divide the Poynting vector by c to give a corresponding electromagnetic momentum density and we use this and a work term to build the electromagnetic stress-energy tensor $T^{\mu\nu}$ in all nine pairings of dimensions x, y and z which has units of pressure, Newtons per square metre when all terms are expressed in S.I. units. This introduces the idea of the vortex of electrons creating a region of relative high (central cathode) or relative low (central anode) pressure, depending on the direction of the vortex flow, pushing or pulling the magnet PQ to try to restore equilibrium. The values of the electric field vectors **E** and **D** and the magnetic field vectors **B** and **H** at each point in the cavity at an instant in time are determined by the electric field between the electrodes K and A, the flux from the magnetic pole piece PQ at the end of the cavity, the emf on the electrons of the space charge, the density and motion of the space charge and the electric and magnetic field vectors of electromagnetic radiation emitted by the moving charge. Computing a precise numerical simulation would be challenging, so it is easiest to assume smooth distributions of energy and charge density and treat the cavity as a solenoid and accept a margin of error.