From https://www.rapp-instruments.de/index6.htm (Google translated from German)

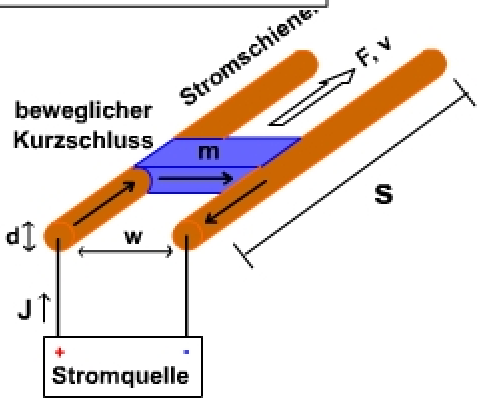
the principle of the railgun is very simple. A moving short circuit between two current-carrying rails is accelerated by the force of the resulting magnetic field and serves as a projectile or projectile carrier. The formulas show the force generated by a certain current and the muzzle velocity that can be achieved with this force, a certain rail length and a projectile mass. Influences such as friction, air resistance, etc. are not taken into account.

$$F = \frac{\mu_0 J^2}{\pi} \ln\left(1 + \frac{2w}{d}\right) \quad (1)$$

$$v = \sqrt{\frac{2Fs}{m}} \quad (2)$$

J = Schienenstrom
w = Schienenabstand
d = Schienendurchmesser
F = beschleunigende Kraft
s = Beschleunigungslänge
m = beschleunigte Masse
v = Endgeschwindigkeit

J= rail current
w= rail spacing
d = rail diameter
f = accelerating force
s = acceleration length
m=accelerated mass
v = final speed

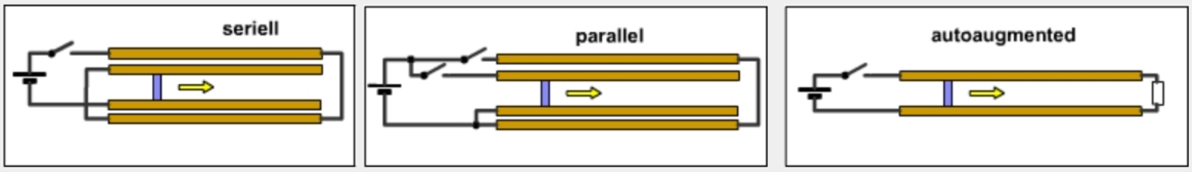


Mass m = 1g	Rail length s=1m
Speed v = 1000m/2	Rail spacing w = 1cm
	Rail diameter d=1cm
	Current J=34kA
Force F = 500N	Time t=2ms

In order to achieve high accelerations and thus high speeds, very high currents flow in the circuit and thus also through the sliding contact. This leads to strong contact wear at the transition resistance between the rails and the sliding piece. At the same time, however, the contact pressure should not be too high in order to keep the friction of the sliding piece low.

One way to keep the currents through the sliding contact low and still achieve great acceleration is the principle of the "augmented railgun". The magnetic field is increased by additional coils or permanent magnets without the current through the sliding contact having to be increased. There are two circuit options for implementing the coil-supported railgun: serial and parallel. In the serial circuit, the coil (busbar->sliding piece->busbar) is supplemented by one or more windings, in the parallel circuit, the coil(s) are connected parallel to the rails.

A variation of the parallel connection is the "autoaugmented" railgun, where the mouth of the rails is connected to a shunt resistor so that only part of the current flows through the sliding contact. This of course requires a precise coordination between the shunt resistor and the contact resistance of the sliding piece.

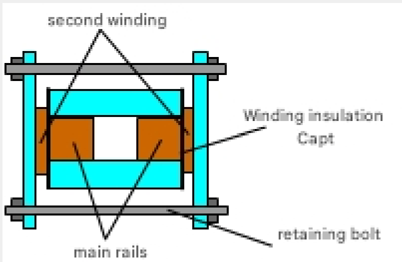


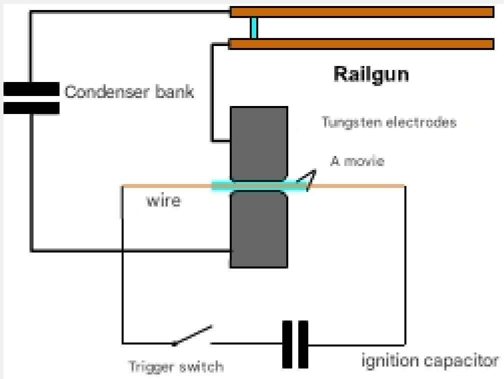
Construction:

Capacitor bank: For the hobbyist, only a capacitor bank is suitable as a power source. Other sources such as homopolar generators, compulsators or generators operated by explosives (flux compressors) are certainly out of the question. As can be seen from the calculation example above, the current must also flow for a relatively long time (2 ms). A high-capacity bank with medium voltage would be advantageous. For the tests, a bank consisting of 10 individual capacitors of 6800uF/350V each was available. According to the data sheet (Epcos), these capacitors have an impedance of 25mOhm and a self-inductance of 25nH. The energy at 350V charging voltage is 4 kJ. Charged capacitors of this capacity are not entirely harmless - not only the risk of an electric shock, but also the purely mechanical effect of the discharge, which at least corresponds to that of about 1g of TNT, can be devastating.

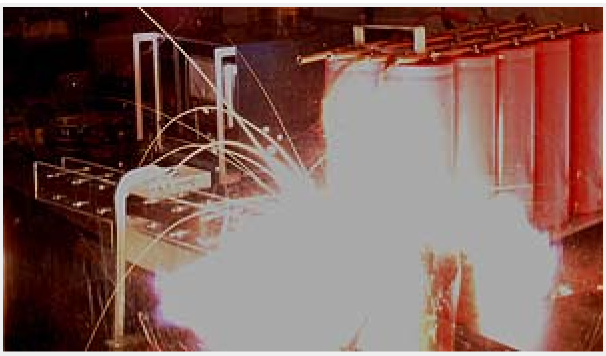
Switch: the necessary high-current switch is a problem. Attempts to use the short-circuit slider itself as a switch failed due to the strong sparking. A spark gap is also not very useful at voltages around 400V. The best solution would be thyristors or IGBTs, but these were not available in sufficient power.

The dielectric switch, Two electrodes are only separated by a thin insulating layer. To trigger the switching process, this insulating layer is destroyed and the switch is closed. The long repetition time of the switch - the insulating layer has to be renewed again and again - is not important in this case, as the railgun is not intended to be used as a repeating rifle. The switch is made of two solid tungsten electrodes (from an old flash lamp), with a thin wire insulated with sticky tape between them. If the wire is now caused to explode by a capacitor discharge, the resulting plasma cloud closes the switch. The trigger switch can be a simple thyristor, as only relatively small currents (a few hundred amps) are necessary to evaporate the wire.



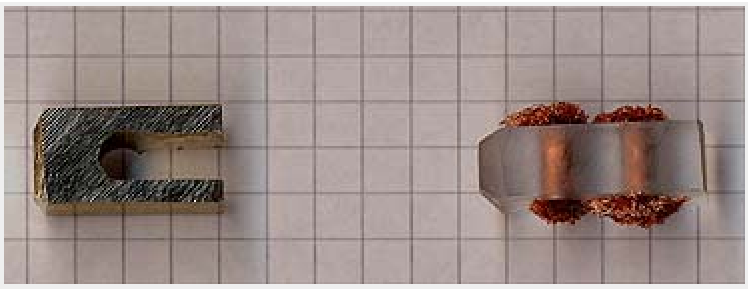


Railgun: the railgun was built as a serially supported version, in the hope that the higher impedance would compensate for the somewhat low capacity of the capacitor bank of 68mF. The 50cm long accelerator is made of copper rails and plexiglass.
The **projectile** is, as usual, filed from a slotted brass block and fits tightly between the rails. The original idea of using a graphite projectile had to be discarded because the rails could not be adjusted parallel enough and graphite unfortunately does not have any spring properties

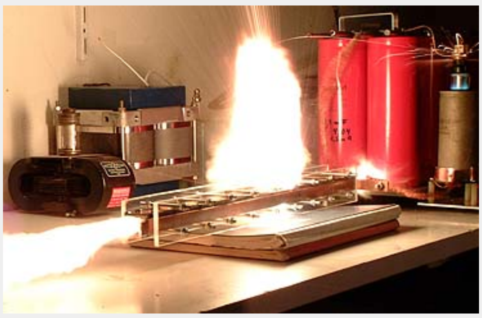
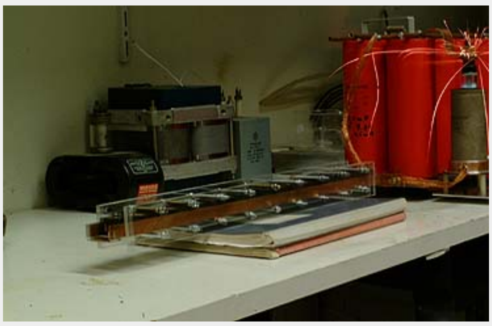


The first test shot was quite disappointing. The projectile only moved about 2 mm between the rails, but fragments of the switch flew quite quickly and far. The switch therefore had to be redesigned; the insulator (PVC) must not be subjected to tension but to pressure. There was also a breakdown between one of the outer auxiliary rails

and a main rail. The copper strands used are also too weak and are severely deformed by the magnetic field.
Ignitron: An ignitron is now used as a switch for the further tests. An ignitron is a switching tube, similar to a thyratron, except that the cathode of the ignitron is not heated but consists of a mercury pool that can deliver very high emission currents. A semiconductor ignition pin immersed in the mercury ignites a local arc that spreads very quickly (microseconds) to the main anode. The type used, **>** **GL-7171** **<,** is well suited to our purposes.

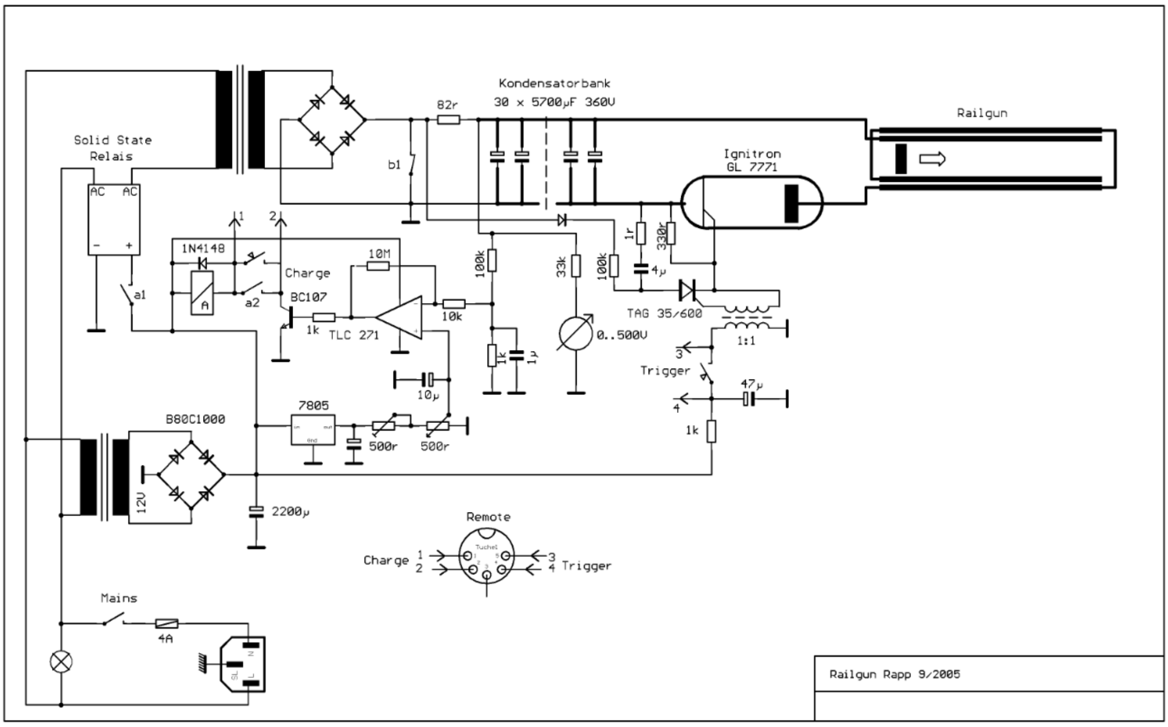


Another projectile was also used, copied from the **>professionals<** , a Plexiglas projectile with pressed-in brushes made of fine copper wire is now used. These brushes compensate for unevenness and deviations in the rails with a spring mechanism, making it possible to fire the railgun with full power without visible sparks and arc discharges and the associated severe erosion of the rails. The picture shows the projectile after firing!

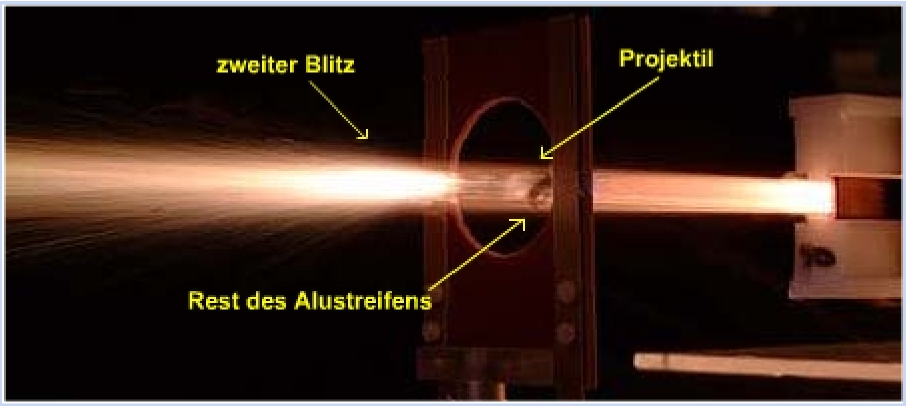
The success of the new projectile can be clearly seen in the above pictures. While in the left picture flames are shooting out of the rails, accompanied by a deafening bang, nothing can be seen in the right picture with the new projectile. The projectile in the left picture is probably driven by the plasma armature that is created; the much larger jet flame at the muzzle than at the rear end is an indication of this. The jet flame upwards comes through a crack in the upper plexiglass cover. The energy and the projectile speed (approx. 100m/s) are the same in both cases. The sparks on the anode of the ignitron come from a bad screw contact.

After the successful preliminary tests, a new railgun was built with a slightly different design. The use of press contacts allows the inner rails to be easily changed. A new capacitor bank was also built, consisting of 30 x 5700F electrolytic capacitors, which store an energy of 12kJ at a maximum charging voltage of 370V. The capacitor bank, ignitron, charging and trigger circuit were built together with the railgun to form a compact unit.



View of the device from the right side. The large mains transformer on the right and the ignitron to the left are striking. All connections in the discharge circuit must be made carefully, as the electro-magnetic pulling forces can reach very high values. Where possible, solder connections should be additionally screwed or brazed. The mechanical stress must be absorbed, particularly at the anode connection of the ignitron, to prevent damage to the glass feedthrough.

At higher charging voltages and the resulting currents, a transition to an arc discharge cannot always be avoided despite brush contact, so that the projectile is accompanied by a brightly glowing plasma jet

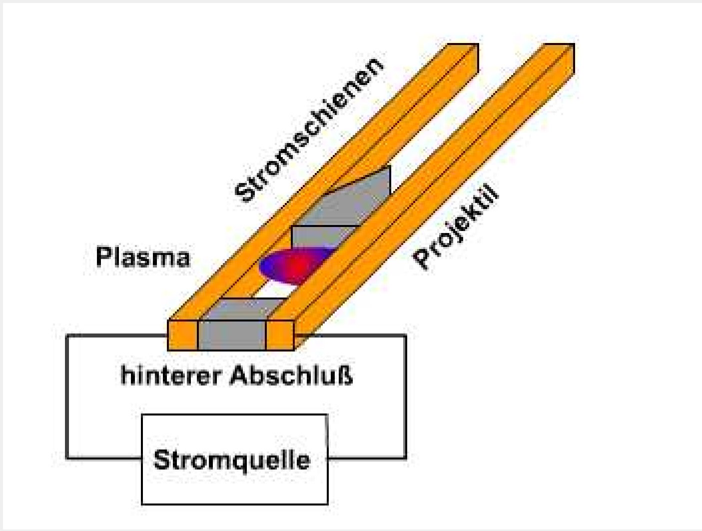


This picture shows some interesting details. A strip of aluminum foil was used to trigger the flash, and cutting it triggers the flash. It seems that the aluminum strip is already destroyed before the projectile reaches it. The reason is probably the gas jet, which apparently overtakes the projectile. A second flash can also be seen, which probably comes from the aluminum strip being ignited by the hot gas jet.

The sound barrier has been broken!!!

Plasma Railgun

One way to get around the sliding contact problems described in the first >> Railgun << is to use a plasma fitting. In this case, the moving short circuit consists of a conductive plasma cloud. Like a metal short circuit piece, this plasma is accelerated by the magnetic fields and driven towards the muzzle at increasing speed. The pressure of the plasma also accelerates the non-conductive projectile and it leaves the rails at high speed. In contrast to the picture on the right, the rails are closed at the top and bottom with insulating plates. If the rear end of the barrel formed by the rails is also closed, the projectile is accelerated further by the pressure of the hot, expanding gas. Of course, with this method, the rails are heavily corroded and damaged by the plasma.



Structure:

The picture shows the test structure of the plasma railgun. The 30cm long rails are 10x10mm copper rods which are connected to stable 5mm glass fiber epoxy plates. Two plastic brackets cover the outside of the railgun, as despite the screw connection, discharge flames find their way out and interfere with the photographic recordings. The shots are extremely loud. To dampen the bang a little, the railgun was built into a large plexiglass tube. Nevertheless, the use of hearing protection is strongly recommended. At the back left is the capacitor bank, of which only five of the ten capacitors are used. The 5 x 6800 µF are charged to 300V, which corresponds to an energy of 1530 joules. At the front is the ignitron switch with the associated trigger electronics.