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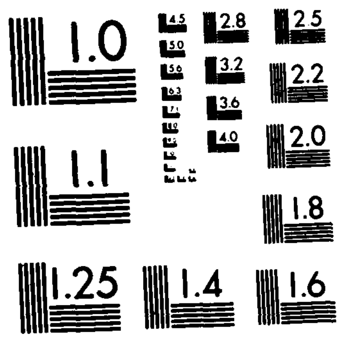

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FOREIGN TECHNOLOGY DIVISION

AIR FORCE SYSTEMS COMMAND

LONG-RANGE ELECTRICAL GUN

Equipment and Supplies of the Red Army

by

A. L. Korol'kov

FOREIGN TECHNOLOGY DIVISION

EDITED TRANSLATION

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Block	Italic	Transliteration	Block	Italic	Transliteration
А а	*А а*	A, a	Р р	*Р р*	R, r
Б б	*Б б*	B, b	С с	*С с*	S, s
В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
Й й	*Й й*	Y, y	Щ щ	*Щ щ*	Shch, shch
К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*ye initially, after vowels, and after ъ, ь; e elsewhere.
When written as ё in Russian, transliterate as yё or ё.

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	$\sinh^{-1}$
cos	cos	ch	cosh	arc ch	$\cosh^{-1}$
tg	tan	th	tanh	arc th	$\tanh^{-1}$
ctg	cot	cth	coth	arc cth	$\coth^{-1}$
sec	sec	sch	sech	arc sch	sech^{-1}
cosec	csc	csch	csch	arc csch	csch^{-1}

Russian	English
rot	curl
lg	log

GRAPHICS DISCLAIMER

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LONG-RANGE ELECTRICAL GUN

Equipment and Supplies of the Red Army

During the World War, the inventors of all the countries, in attemting to improve the ordnances of war, gave many new ideas, part of which was realized and gave the war that terrifying nature which it acquired. However, along with the inventions that were realized, an even greater number of them died during the designing stages due to their fantastic nature or not having been sufficiently thought out.

Among the number of such designs, a very enlighting and an interesting one is that of the Fachon-Villeplee's electrical gun published in the brochure "Cannons Electriques systeme Fachon-Villeplee" in 1920.

The design was presented to the commission on inventions in France in June of 1916 but was rejected. Then the inventor constructed a small experimental model at his own expense in order to prove the feasibility of his project.

The model was tested in 1917 and 1918; the current was supplied by a dynamo or batteries. As a result of these tests, the director of the commission on inventions proposed that the inventors construct a small experimental 30—50-mm caliber cannon.

Figures 1, 2, and 3 show the general appearance of such a gun (model), its projectile in the form of an arrow, and a wooden block punctured by this projectile.

However, due to the end of war and high cost of the experiments, this proposal was dropped.

Then the author of the design published his calculations, drawings, and the details of the design in the brochure mentioned above.

This design was discussed in Russia by the committee on artillery, in German, American, French, and Italian special literature and was found to have no merits.

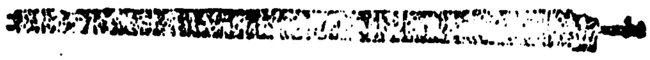

Fig. 1.

In the following lines I will present the content of the brochure and then the reasons which force one to reject the design, in general, one which has been thought through quite well.

Many of these reasons pertain to any electrical ordnance no matter what the design features and principles are at the base of the gun design - this is the reason why this analysis has a significance, in general, for any designs of electrical ordnances utilizing both the dc and ac currents.

I. The Principle of the Electrical Gun Designed by Fachon-Villeplee.

This gun utilizes direct current. Inside a long electromagnet (2 m in length in a small model, 30 m in a gun for 100-kg shells with the initial velocity of 1600 m/s, and 120 m in length for the initial velocity of 3000 m/s) are longitudinal slots, in which the wings of a projectile lying inside the electromagnet slide. The magnetic force lines in the slots are perpendicular to the axis of the gun and the plane of wings; electrical current passes through the winding of the electromagnet, through the wings of the projectile, and the projectile itself.

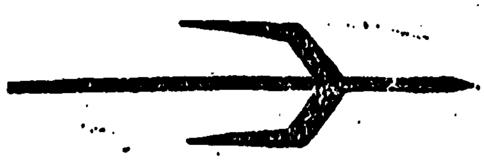

Fig. 2.

The interaction between the magnetic field and the current passing through the wings of the projectile and the projectile pushes out the latter from the gun with a force, which is proportional the strength of the field, force of the current, and length of the moving current. The wings of the projectile slide in the slot over strips.

Large guns can be provided with 4 slots and wings and more. The wings can be replaced by the projections on a projectile, sliding in the grooves of the electromagnet, and with spiral cutting of grooves the projectile obtains rotation for stability in flight. Without the spiral grooves, it is presumed that the stability of flight can be achieved by means of an appropriate shape of the wings and of the projectile itself.

Fig. 3.

The brochure shows an elementary calculation of a model for a projectile weighing 50 g, initial velocity of 200 m/s, and the length of the channel at 2 m. Then calculation is given for a gun using 100-kg shells with the initial velocity at 1600 m/s and length of the gun at 30 m. The calculations were performed generally in an elementary way without taking into account certain conditions indicated below.

II. Calculating the Power Required for an Electrical Gun.

In order to give ourselves an account with regard to the properties of an electrical gun, let us go through, in accordance with the author of the design, the calculation of the power required to eject a shell from a large gun, which has the following data:

Weight of the shell	100 kg.
Initial velocity	1600 m/s.
Length of the gun	30 m.
Number of poles	4.
Magnetic-flux width intersected by wings	20 cm.

The magnetic-field strength in the slot is assumed to be 30,000 units C. G. S.

When a conductor with length l moves through a magnetic field of H gauss at a velocity v cm per second, provided that l, H, and v are mutually perpendicular, an electromotive force E is induced in the conductor which equals

$$E = \frac{l.H.v}{10^8} \text{ volts.}$$

For this case l=20 cm, H=30,000 G, and v=160,000 cm/s.

Thus,

$$E = \frac{20 \times 30000 \times 160000}{10^8} = 960 \text{ volts.}$$

The kinetic energy of the projectile equals

$$T = \frac{Mv^2}{2} = \frac{P}{g}\frac{v^2}{2}$$

P=100 kg, g=9.82 m/s, and v=1600 m/s.

Now instead of 9.82 we will take 10 m, then

$$T = \frac{100}{10} \times \frac{1600^2}{2} = 12800000 \text{ kgf-m.}$$

Assuming that the average velocity of the projectile is 800 m/s, we will determine the time t in which the projectile passes through the channel of the gun

$$t = \frac{30}{800} = \frac{3}{80} \text{ s.}$$

Thus, the work done per second or the required power W equals T:t

$$W = T{:}t = \frac{12800000 \times 80}{3} = 340 \text{ million kgf-m.}$$

Assuming that 1 kgf-m equals 10 W (9.82), we obtain

$$W = 340000000 \times 10 = 3400 \text{ million watts.}$$

The force of the current I equals W:E. Therefore

$$I = \frac{3,400,000,000}{960} \text{ or } 3,550,000 \text{ A.}$$

In the brief time of firing ($\frac{3}{80}$ s) almost 3.4 million kilowatts of power are expended and the current passing is at 3.55 million amperes.

Nevertheless, these fantastic figures become attainable thanks to the following method.

The dynamos is equipped with a large flywheel, whose speed is increased continually for 10 or 20 min thus storing a considerable reserve of mechanical energy. Then by short-circuiting the current, the stored energy of the flywheel and the energy of the motor make it possible to use up this energy in a brief period of time ($\frac{3}{80}$ s) and develop the required power.

The author assumes the efficiency of the gun to be at 35%, while that of the dynamo-flywheel at 75%; in general, the recoil will be

$$35 \times 75 = 26.2\%,$$

i.e., about 25%.

Thus, the power calculated earlier at 12,800,000 kg/m has to increased by 4 times:

$$T = 12{,}800{,}000 \times 4 = 51{,}200{,}000 \text{ kgf-m}.$$

If this power is to be stored in 20 min, the motor required will be the one which produces the following amount of power in a second:

$$\frac{51{,}200{,}000}{1200} = 42{,}600 \text{ kgf-m}$$

or 426,000 watts or 426 kilowatts, rounded off to 450 kilowatts. Nine hundred kilowatts will be required to fire the gun every 10 min.

It can be seen from this basic calculation that the firing of an electrical gun will require a powerful electrical station with dynamos, with flywheels, and with corresponding high-capacity thermal engines (450–900 kW in this case, according to author's calculation).

But this calculation is completely erroneous. He presumes that the current attains the required magnitude instantaneously (3,550,000 A) and lasts all of $\frac{3}{80}$ s at this level. Actually, current I starts from zero and increases relatively slowly according to the following law:

$$I = I_0 [1 - e^{-\frac{rt}{L}}].$$

Here I_0 is the maximum limiting current, L - self-induction, and r - resistance of the circuit.

As a result of current attenuation due to self-induction, the intensity of the magnetic field and the current forces in the moving conductor diminish, and the velocity of the projectile decreases; the time it takes the projectile to move through the channel increases. If the self-induction and resistance r will such that $\frac{r}{L}=0.7$ (which is quite possible for such a large steel mass), then for t=1 s

$$e^{-0.7} = \frac{1}{2} \text{ and } I = I_0\left(1 - \frac{1}{2}\right) = \frac{1}{2} \cdot I_0.$$

i.e., the current will attain half of the limiting value in 1 s. But in order to attain a velocity of 1600 m/s in a channel 30 m long, the time cannot be over $\frac{3}{80}$ s. Thus, only a small portion of the current can be utilized in such a short period during the self-induction of the circuit. It is necessary to increase the power of the station by tens of times.

The station required for such a large gun must have the capacity of of ten thousand kilowatts and more and, in this case, the rate of fire will be once every 20 min.

Herein lies the main reason why it is difficult to use electrical ordnances.

Each electrical gun will require an electrical station with an enormous capacity with all its accessories - dynamos, thermal engines, distributing and regulating attachments, supply of fuel and lubricants, etc.

In this case the ordinary central stations cannot be used, since the latter are not designed for the surge experienced by the dynamo of the electrical gun as a result of short-circuiting during firing. The flywheels can fly apart into pieces, the axels and parts of all machines can bend, etc.

Fochon-Villeplee designs special dynamos - single-pole with a massive armature which plays the role of a flywheel.

For the gun indicated above (1600 m/s, 100 kg projectiles), one would have to have 14 of such machines weighing 25–30 t each.

I will not perform further calculations due to the fact that the initial calculations presented above are erroneous. I will present the calculation results obtained by the author.

Weight of the gun	150 t
Heating of buses	$4^{\circ}.5$
Current density in projectile's body	180 A/mm^2
Heating of the projectile	$33^{\circ}.1$
Current density in sliding contacts	36 A/mm^2
Recoil	35%
Recoil losses due to self-induction	25%
Voltage	1350 V
Weight of the dynamo flywheels	400 t
Weight of thermal engines	20 t.

According to the calculation of the author, one gun will require

10 cars.

An electrical locomotive can be powered by the gun's dynamos and motors on the train.

III. The Most Important Dependences Between the Required Initial Velocity and the Size of the Electrical Gun.

Certain dependences derived by the authors are of interest, for example:

1. The voltage is proportional to the initial velocity of the projectile.

2. The force of the current is proportional to the square of the velocity and inversely proportional to the length of the gun.

Thus, in order to double the initial velocity at the same current strength, it is necessary to double the voltage and increase the length of the gun by four times.

3. The temperature of the conductors in the winding of the electromagnets (copper strips) is inversely proportional to the velocity of the projectile and directly proportional to the length of the gun and to the square of the current strength.

4. The recoil of the gun is proportional to the square of the velocity of the projectile and inversely proportional to the length of the gun.

Thus, in order to double the projectile's velocity without increasing the recoil, it is necessary to quadruple the length of the gun.

5. In order to double the projectile's velocity, it is necessary to quadruple the mass of the dynamo and the mean capacity of the generator.

It can be seen from these dependences that, in general, increasing the velocity of the projectile requires an increase in the weight of the gun, its length, and the weight of all the accessories to a greater extent than the increase in velocity.

IV. Advantages of Electrical Guns.

In the opinion of the author, electrical guns have the following advantages:

1. Electrical gun fires without smoke and virtually without noise; the flash of the spark can be easily concealed.

Actually, the spark resulting from breaking of the current, which is in millions of amperes and having the power in millions of kilowatts, will produce a crack and light, which can neither be eliminated nor concealed. Incidentally, the author points out horn-type devices which accelerate extinction of the spark just as in horn-type lightning rods. However, the acceleration of extinction does not weaken the spark. All the conventional methods for diminishing the spark (electrical and magnetic blowing out, increasing the capacitance) are palliatives with the power being considered.

2. The electrical guns are constructed from inexpensive materials, from an ordinary cast steel and other easily obtainable materials. Their construction is very simple since the work can be carried out in parts and does not require cumbersome machines. Thus, they can be constructed very quickly and attain enormous dimensions.

The advantage pointed out by the author is not entirely correct since steel, as was indicated above, must have a magnetic permeability of 30,000, which requires a special high-quality steel. The copper for the winding strips must also be of high quality. Thus, the low cost of such guns is very doubtful. It is also doubtful that it will be possible to avoid large machine tools in the machining of such large masses weighing 150 t and more.

3. Electrical guns do not wear out. They are not subjected to breaking stresses, high temperatures and pressures which damage the barrel and rifling and limit the life of the gun to a hundred shots. Electrical guns operate just like ordinary machines and can utilize lubrication in sliding contacts.

This advantage, which is true for the electrical guns operating on alternating current without sliding contacts, is totally nonexistent for the Fochon-Villeplee guns with sliding contacts. It is impossible to avoid sparks at such a high velocity (1600 m/s) and such high current. It is known how difficult it is to avoid sparks even for the brushes of dynamos.

The buses in the gun will burn up after several shots, requiring maintenance.

The major inconvenience of sparks in the sliding contact consists in the fact that they will be the reason for fluctuations in the current strength, hence there will be considerable variability in the velocities of the projectile. A gun with a constant current cannot be accurate.

4. Their efficiency is considerably higher than that of the conventional guns using explosives, since in the latter all the energy of

gasses leaving the gun is lost entirely.

This energy gain is compensated by the losses in the electrical gun due to heating of of the conductors, magnetization of iron, and sparks. According to the calculations of the author himself, these losses are not any less than in conventional guns.

5. Electrical guns use fuel (petroleum, kerosene, etc.) which, at equal weight, possesses greater energy than an explosive and it is less expensive.

During combustion a kilogram of petroleum produces 10,000 calories, while a kilogram of powder - from 1000 to 2000 calories.

In this case, consideration was not given to the fact that the fuel on the thermal engine cannot convert all of its energy to work. In better machines, hardly 1/5 of the energy is converted to work. Thus, of the 10,000 calories hardly 2000 are expended on rotation of the dynamo, which again themselves absorb about 20% of the obtained mechanical energy, which is why hardly 1500 caloroes out of a kilogram of fuel remains for the gun. Therefore the weight of the fuel transported with the gun will be approximately the same as that of the powder. There is not advantage in weight. The only advantage remaining is that in the cost of the powder and fuel.

6. The force ejecting the projectile in the electrical gun is applied along the entire projectile and not only to its buttom, as is the case with a conventional gun. Thus, it is advantageous to increase the length and volume of the projectile.

This advantage of the electrical guns is indisputable.

7. Since the gun heats up very little and there is no need to waste time on the opening and closing of the breechblock, an electrical gun can be fired more often than a conventional one.

This convenience is purely ephemeral, since the frequency of fire from an electrical gun is determined by the time (10 or 20 min) necessary for storing energy by the flywheel.

8. The recoil during the firing of an electrical gun is less than that of the conventional gun due to the fact that the powder gases, which comprise sometimes 1/4 of the weight of the shell in case of a long-range gun, are not ejected.

9. Controlling the range and the velocity of the projectile can be accomplished by varying the voltage without changing the angle of elevation.

This is a considerable advantage of electrical guns.

10. There is no charge in electrical guns and there cannot be a premature explosion in the gun's channel.

This is true.

11. The power of electrical guns can be increased extremely - it depends only on the instantaneous energy of the electrical source.

We saw above that the power of an electric-energy generator for an electrical gun must be exceedingly high and, consequently, the maximum power of the gun is determined essentially by the power of the generator.

Of the number of listed qualities of electrical guns, two (spark during breaking of current and burning out of sliding contacts) pertain exclusively to the guns operating on a direct current - of the Fochon-Villeplee type. The rest pertain to all types of electrical guns.

V. Arrangement of the Fochon-Villeplee's Electrical Gun.

The drawing (draw. 4) shows the side view of the Fochon-Villeplee gun. The scale of the drawing is based on a gun 30 m long.

The gun proper (a steel electromagnet with a winding consisting of copper strips) is placed inside a steel latticed frame (2) and is connected to the latter by means of springs which absorb the shock during firing.

The frame has journals (3), by means of which it can attain various angles of elevation. The lifting mechanism consists of a toothed arc (7), along which gear (9) connected with the frame can travel, having been brought into rotation by a special electrical motor. The ends of the beds (5–10) in the mobile system rests on the platforms (11) standing on the rails. In stationary arrangements the carriage rests on rollers. Form the description given by Fochon-Villeplee, one cannot see how laying for direction is made. Apparently, in the mobile systems, this was to be achieved by curving the tracks. In a stationary arrangement, the carriage can rotate on a pedestal.

Of course this drawing, in case of actual construction, will require a very serious and detailed elaboration from the mechanical, electrical, and artillery standpoints.

The schematic of the electrical equipment can be seen in draw. 5.

Here bb' and cc' depict the body of the gun, in whose channel the projectile f is sliding along the bus. The letters ee' and dd' designate copper strips carrying the current, which magnetizes the electrical magnet of the gun.

Letters A, B, and C designate 3 special flywheel dynamos with an independent excitation of inductors A', B', and C'.

A small dc generator l, used to excite the inductors, is brought into rotation by the thermal engine m. The excitation of the inductors can be controlled by means of the rheostat n or by varying the rotational speed of the engine.

Another thermal engine p brings into motion the dynamo O, which activates the flywheel dynamos A, B, and C. The rheostat q serves to activate the dynamo A. A series of contacts - r, s, t, u, and v - are connected with the dynamos and the be' buses of the gun. The lever of the switch x, sliding through sector y, makes it possible to connect the contacts r, s, and t consecutively with the sector y, or connect the contacts u and v.

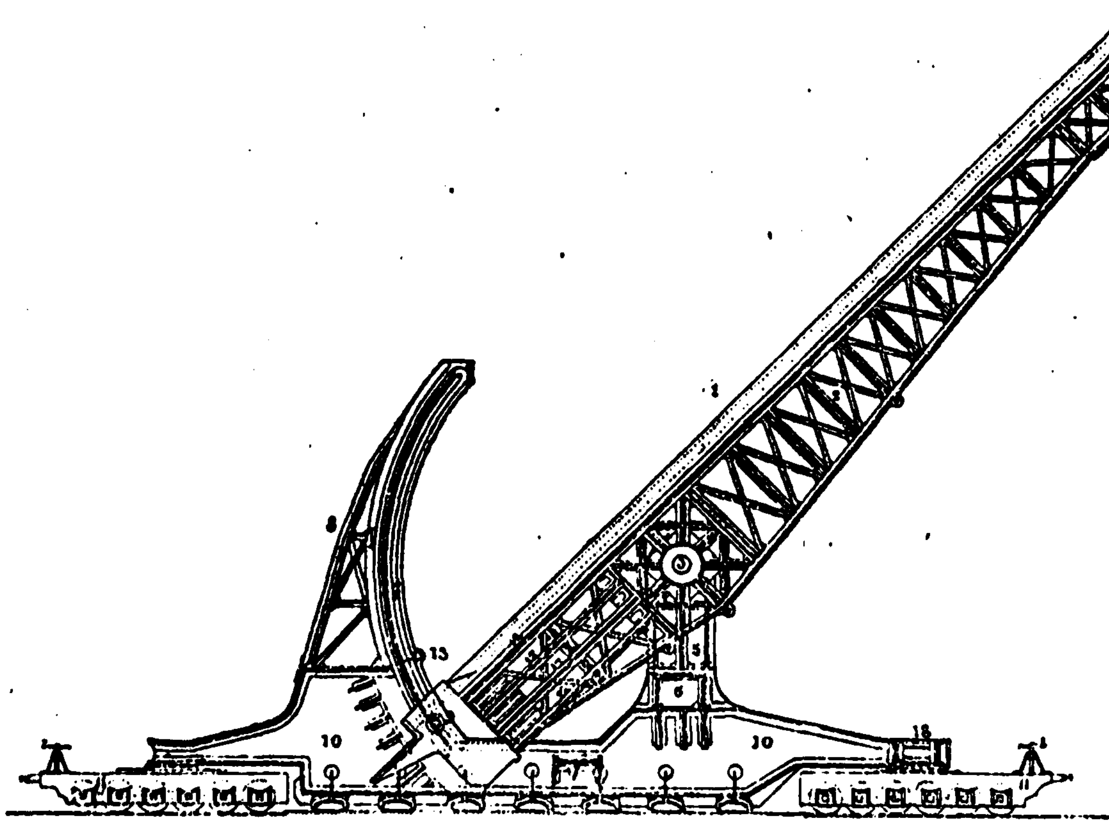

Fig. 4.

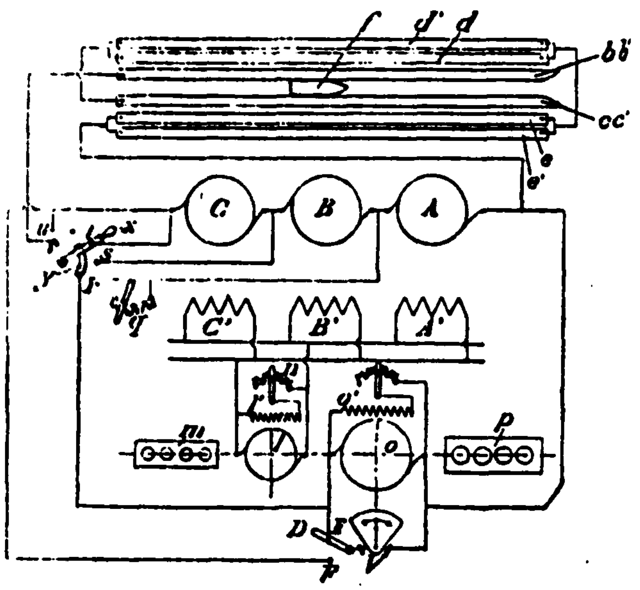

Fig. 5.

In order to fire, first the engine m with the generator l is started and the inductors of the flywheel dynamos A, B, and C are excited.

Then the engine p with the generator O is started. Varying the speed of the engine p and the excitation of the generator O supply the voltage to the latter which is necessary for the operation of the dynamo A.

When this voltage is obtained, the lever x is set at the contact r in order to pass the current to the flywheel dynamo A which will bring it into motion, as an electrical motor. Now the starting rheostat q controls the start of operation.

Then the lever x is switched to the contact s to activate the flywheel dynamo B, increasing the speed of the engine p and excitation of the generator O at the same time.

The dynamo C is brought into rotation by switching the lever x to the contact t.

Having brought the flywheel dynamos A, B, C into the appropriate level of rotation, whose speed is indicated by the voltmeter V, we can now fire the gun by switching the lever x to the contacts u and v.

In this case the machines A, B, and C functions as generators. From them the current passes through the bus bb', projectile f, bus cc', the winding of the electromagnets dd' and cc', and the entire dynamo. This current ejects the projectile and brakes the flywheel dynamos A, B, and C.

For another shot, the speed of the machines A, B, and C is increased by means of the generator O, ... [page missing] ... at 600 km. It would have been possible to shell London, Berlin, and Rome from France.

The realization of such designs will become possible with further development in technology, if the following problems are satisfied:

It is necessary to replace the storing of energy by heavy flywheels to its storing in an electrical form by means of capacitors or storage batteries of special, nonexistent at the present time, type, which are light and which are capable of releasing the stored energy without damage during the brief period of firing and accumulate it again.

It is necessary to have the thermal engines which are lighter and more efficient.

In particular, it is necessary to await the possibility of converting the energy of the fuel to electrical energy without resorting to mechanical engines which, theoretically, cannot be more efficient than the known limit.

VII. Conclusion.

At the present state of electrical engineering, the problem of constructing an electrical long-range gun is entirely solvable in various ways.

Practical application of such guns is hampered by the fact that the gun has to have an electrical station, which is of special design, of enormous capacity, very heavy and complex.

Further progress in the technology of thermal engines, and especially in the ways of obtaining and storing of electrical energy directly from fuel, will put the problem of electrical guns on solid ground.

Prof. A. L. Korol'kov.