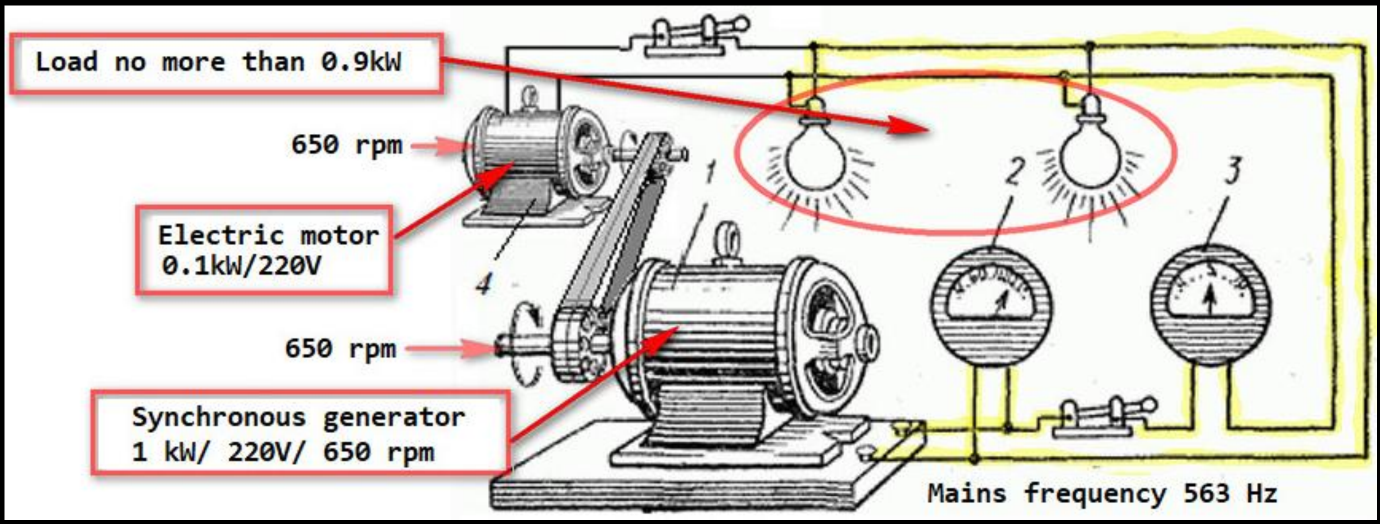


Electromechanical converter COP> 1. Solving a problem in physics

Serge Rakarskiy

Let's get started. A little about the "eternal"!

What the Law of Conservation of Energy tells us is that it is a fundamental law of nature, ***established empirically*** and consisting in the fact that for an isolated physical system a scalar physical quantity can be introduced , which is a function of the parameters of the system and is called energy , which is conserved over time. Since the law of conservation of energy does not refer to specific quantities and phenomena, but reflects a general pattern that is applicable everywhere and always, it can be called not a law, but the principle of conservation of energy

There is a statement by scientific luminaries, confirmed by electrical equipment, that an electric generator cannot have an efficiency factor of more than 100%.
This is a prelude. We are interested in an electromechanical converter, which, according to the traditional opinion of physicists, is impossible with a conversion factor greater than one (**COP> 1**). Well, let's take a quick look at what the conversion factor calculation is based on.

A bit of electrical engineering theory about electrical machine devices (*you can skip it*)

An electromechanical converter in traditional solutions is a device consisting of two components: mechanical (kinetic energy) and electromagnetic * (* in physics there is no concept of electrical energy, there is the concept of electromagnetic field energy). To shorten the term, traditionally the energy of the electromagnetic field is called electrical energy, we will also use this in our story, we will call it electrical (electromagnetic energy) with the designation [***e***], and kinetic energy is mechanical energy with the designation [***k***]. Any energy measured in Joules [***J***]. There is a clear definition of what an electromechanical converter is. It is a device that converts one type of energy into another, an electric motor - electric [***e***] into mechanical [***k***], and an electric generator (alternating current or direct current generator) - mechanical into electrical. This device is an electromechanical machine based on the rotation of a moving part (rotor, armature), relatively stationary, static part (stator). We will not use the concept of energy as such, we will use the concept of power. Power [***P***] is a scalar physical quantity that characterizes the instantaneous rate of transfer of energy from one physical system to another, during its use and, in general, is determined by the ratio of the transferred energy to the transfer time. Measured in watts [***W***]. Watt to joule refers to the ratio of

$$1\ J = 1\ W * s \text{ or } 1\ W = 1\ J / s.$$

Power is the result of the action of various components, let's take a look at our transformable elements.

The force of rotation, expressed by the condition $Pk = M * \omega$, where ***M*** is the moment of force, in Newtons per meter [***Nm***]; ω - angular velocity of rotation, in radians per second [***rad / s***]. The angular velocity can still be expressed as $\omega = 2\pi * n / 60$, where n is the number of revolutions per minute [***rpm***]. We can write down the expression of mechanical force for rotational motion:

$$Pk = M * 2\pi * n / 60.$$

The moment of force [***M***] about a fixed axis is called a scalar value equal to the projection on this axis of the vector of the moment of force relative to any point located on the axis. This moment is equal to the projection of the force vector onto the plane perpendicular to the axis of rotation, [***F***], multiplied by the shoulder of the force [***r***] - the shortest distance from the axis to the line of the circle of action of the force :

$$M = F * r,$$

Where F is the force in Newtons [N], r is the shoulder of the applied force to the axis of rotation, in meters [m]. Next, we write the expression for the mechanical moment of force for rotational motion relative to power: $M = Pk * (60 / 2\pi) / n$, where: $60 / 2\pi = 30/2 * 3.14 = 9.55$, we get the expression

$$M = Pk * 9, 55 / n.$$

If we transform this formula to determine the power from the moment of force, it will take the form:

$$Pk = M * n / 9.55.$$

Traditionally, this formula uses the power value in kilowatts with a coefficient:

$$Pk = M * n / (60 / 2\pi * 1000) = 9550.$$

Electrical power [Pe] is a physical quantity that characterizes the rate of transmission or conversion of electrical energy. The power of the electric current is equal to the product of voltage and current:

$$Pe = U * I$$

Where U is the voltage at the section of the circuit in volts [V]; I is the current in this area, in amperes [A]. The expression for electrical power according to Ohm's law can be written through the resistance to current in the conductor R in ohms [*Ohms*]: $P = U^2 * R; P = I^2 / R$.

For AC circuits, the expression $Pe = U * I * \cos \varphi$ is also used, where $\cos \varphi$ is the power factor.

How do these completely different systems fit together?

Let's start with the first episode, power matching: $1\ W$ [Pk] = $1\ W$ [Pe].

The second episode of reconciliation is “Moments of Power”. An electric motor and an electromechanical generator have such an indicator as the electromagnetic moment of an electric machine.

You can find this expression: The moment of force developed by the electric motor is equal to the electromagnetic power divided by the synchronous rotation speed of the electric drive:

$$M = Pe / \omega.$$

We can freely write in this form $M = Pe * (60 / 2\pi) / n$ or $M = Pe * 9.55 / n$. Logically, if the mechanical and electrical powers are equal, then their Moments of force on the shaft are also equal. For an electromechanical generator, such an expression is conditional, so it will not always be fulfilled.

For a synchronous generator, the following condition is met: $M = F * (d / 2) = F * r$.

For example, for a direct current generator, the expression of the electromagnetic moment is as follows:

$$M = N * F * (d / 2) = (p * N / 2\pi * a) * \Phi * Ic,$$

Where: ***d*** is the diameter of the armature; ***p*** is the number of pole pairs; ***N*** is the number of armature winding conductors; ***a*** - the number of pairs of parallel branches; ***Ic*** - armature current; ***Φ*** is the magnetic flux of the poles.

The electromagnetic power of the electromagnetic moment of the generator can be expressed by the condition:

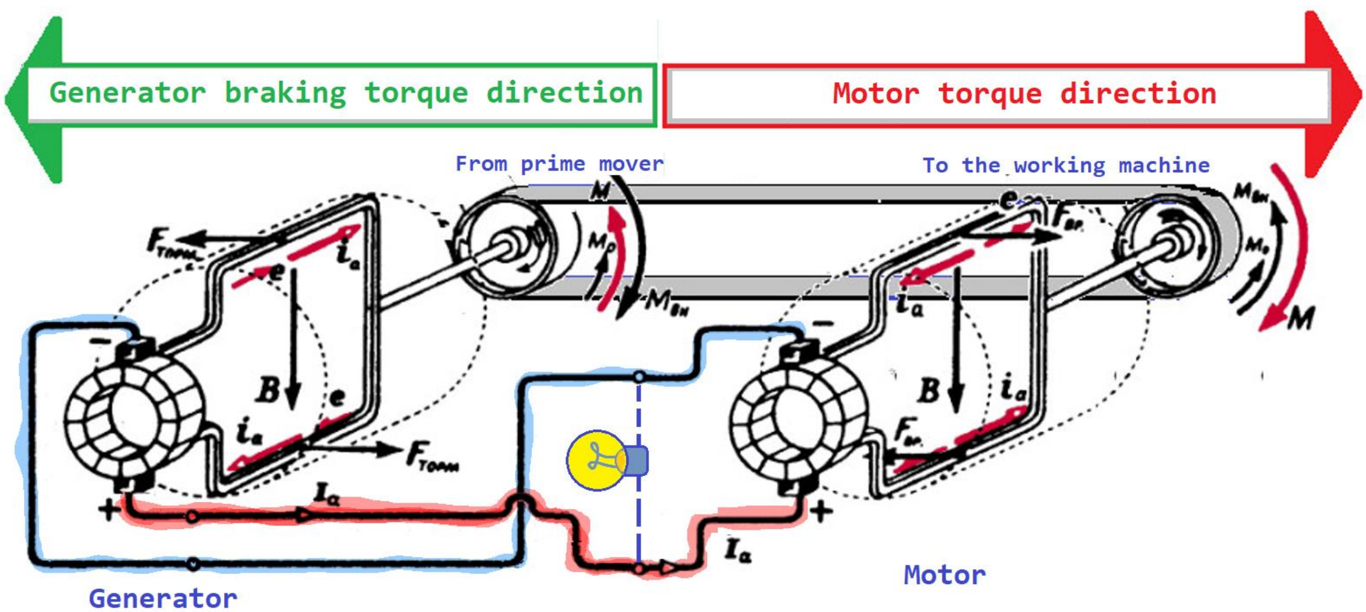
$$Pk = M * \omega \text{ or } Pk = M * n / 9.55$$

The only question remains is whether the equality is fulfilled between the electric power, expressed by the formula ***Pe = U * I***, and the power of the electromagnetic moment, expressed by the formula:

$$Pk = M * n / 9.55$$

A natural question arises about the ratio of the electromagnetic moment and the electric power of the electric motor. Will the equality ***Pk = Pe*** hold.

Let's figure out how an electromagnetic moment arises in a generator and an electric motor. Let's consider all this using the example of a rotating conductor frame in a magnetic field. Here is the image you can see in the tutorials.



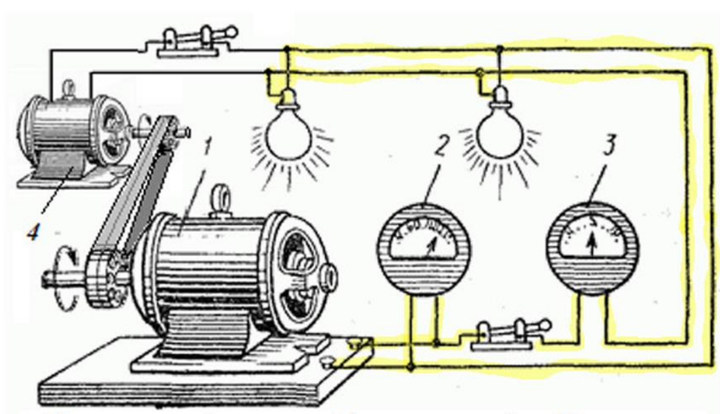
In the picture I have depicted a DC motor housing and a DC generator housing connected by a belt drive to each other. The frames of the electrical conductor are closed with each other through the collector brush. We assume that we will also have a payload.

Electromagnetic force ***Fa*** [*H*] has its own definition formula. For a straight wire in a magnetic field ***Fa = B * I * l***, where ***B*** is the magnetic induction from the wire from the wire to the point of contact with the plane of the magnet pole, in Tesla [***T***]; ***I*** is the current in the wire, in Amperes [***A***]; ***l*** - active wire length, in meters [***m***].

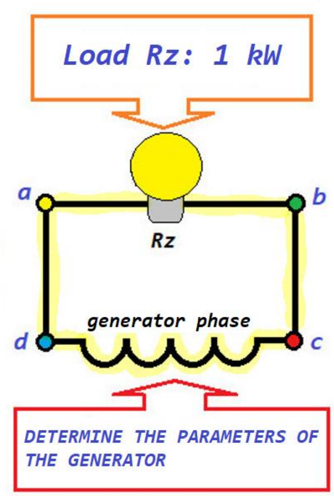
The magnetic induction is determined by the formula: $B = \mu_0 I / 2\pi r$, where μ_0 is the magnetic constant; I is the current in the wire; r is the distance from the wire to the magnet, in meters. The current in the wire is determined by the current formula for the entire circuit $I = E / (R + r)$, where: E is the electromotive force in volts [V], R is the load resistance, and r is the source resistance. , in Ohm [***Ohm***]. The electromotive force in a conductor that crosses the magnetic field is determined by the formula: $E = B * l * v * \sin(a)$, where B is the magnetic induction from the magnetic pole, l is the length of the wire, which depends on the magnetic induction (active wire) , in meters, and v is the rate of change of the magnetic induction in the zone of the wire, in meters per second [m / s], $\sin(a)$ is the sine angle of the magnetic induction vector to the axis of the conductor (*in our case, sin (a) will be = 1, which corresponds to a right angle of* 90^0).

Condition and solution of the problem.

It remains to check whether the condition that the electromagnetic moment of the generator (mechanical power of the resistance) is identical is its electrical power. Let's take a drawing of the simplest electrical circuit with a generator. Generator in the same circuit with incandescent lamps. Suppose incandescent lamps are included in the circuit, with a total power of P_e = **1000 *watts*** (**1 *kW***), at **220 *volts of*** voltage, in the network circuit. It is necessary to calculate the parameters of the generator, and find out the possibility of connecting a motor to the circuit to rotate the generator of the same circuit.



The generator supplies power to the incandescent lamp.
1 - generator; 2 - voltmeter; 3 - ammeter; 4 - motor



First, we need the generator parameters. We will calculate the generator according to the classical scheme of a frame rotating in a magnetic field between two poles.

Solution -1: defining the raw data of the generator:

For the calculation, we already have the initial load data: P_e = **1 *kW*** (**1000 *W***); Mains voltage - ***U* = 220 *V*** ; We determine the load resistance of the formula $Rz = U^2 / P = 220^2 / 1000 = 48.4$ ***ohms*** . Determine the effect of the load current $Iz = P_e / U = 1000/220\ 4.55 = A$.

We choose a wire by cross-section, taking into account the current throughput: [***d***] the diameter of the copper wire in the varnish = **1 *mm*** , $S = 0.79\ mm^2$, with $Ai = 8\ A$ per *square meter. mm* , the capacity of the current will be: $J = Ai / S\ (mm^2) = 8 / 0.79 = 6.28\ A$.

Let's define the following parameters for the generator: angular speed of rotation of the shaft: ***n* = 650 *rpm*** ; the diameter of the armature ***d* = 0.35 *m*** (*in our case, the distance between the active conductors of the frame relative to the center of rotation*); Magnetic induction ***B* = 0.4 *T*** , maximum index ***sin (a)* = 1** , at 90^{0} .

1. We need to calculate the EMF [***E***] and the length of the active wire [***l***]:

1.1 EMF [***E***] is calculated using the current formula for the complete circuit: ***Ii = (E - U) / (R + Rz)***, (where ***R*** is the resistance of the active wire of the generator case). To calculate the EMF, the formula will take the form: ***E = (U + I) * (Rz + R) = (220 + 4.55) * (48.4 +*** [***?***]), - we do not know the resistance of the active wire, the frame. There is another option - to calculate the EMF [***E***] according to the formula: ***E = U * k***, where - ***k*** is the coefficient expressed by the ratio of the mains voltage to the EMF of the phase. The coefficient [***k***] cannot be less than 2. When ***k*** = ***2***, the ideal state is when the resistance of the phase conductor is equal to [***0***]. Let's check: ***E = U + (I * (Rz + R)) = 220 + (4.55) * (48.4 + 0)) = 440 V***;

E = U * k = 220 * 2 = 440 volts.

1.2 Now we need to determine the length of the wire and its resistance. We find its EMF by the formula [***E***] for a linear wire: ***E = B * l * v***, from it we derive the formula for calculating the length of the active wire:

l = E / v / B.

To calculate, we need a speed parameter, a change in the magnetic flux ***v*** (*m / s*). We find it by the formula: ***v = πnD / 60 = 3.14 * 650 * 0.35 / 60 = 11.9 m / s***. We find the length of the wire:

l = E / v / B = 440 / 11.9 / 0.4 = 92.44 meters.

1.3 Determine the resistance of the active phase wire:
R = ***Ri * l*** [where Ri = ρ * (1 / mm²) = 0.017 * (1 / 0.79) = 0.0276 Ohm] = ***92.44 m * 0.0276 Ohm = 2, 55 ohm***.

1.4 We can then calculate the loop current. Mains current Ii (at E = 440 V):

Ii = (E - U) / (Rz + R) = 440 - 220 / 48.4 + 2.55 = 4.32 A.

1.5 We got the difference between the load current and the current current of the power circuit:
4 55 - 4.32 = 0.23 A. We correct our coefficient: ***k = 2 + (1 - Ii / Iz) = 2 + (1 - 4.32 / 4 , 55) = 2.05054945055***.

1.6 We adjust the EMF of our generator: ***E = U * k = 220 * 2.05054945055 = 451 volts***.

1.7 We correct the length of the active wire of the generator frame:

l = E / v / B = 451 / 11.9 / 0.4 = 94.75 meters.

1.8 We check the initial value according to the electromotive force formula:

E = B * l * v = 0.4 * 94.75 * 11.9 = 451 volts.

1.9 We check the value of the current in the circuit:

I = (E-U)/(Rz+R) = 451 - 220/48.4 + 2.55 = 4.55A.

As a result, the load power: ***P e* = 1000 *W*** , with a resistance of **48.4 *Ohm*** , which is provided by the generator phase, the length of the wire of which is: **94.75 *meters*** with a current of **4.55 *A*** ,and the resistance of the active wire of **2.55 *Ohm*** .

Solution - 2: determining the possibility of connecting the motor to a circuit with a generator and load:

We can, according to the classical formula, calculate the electromagnetic moment of the generator: (*provided that* , ***Pe = Pk***):

$$M = Pe * 9.55 / n = 1000 * 9.55 / 650 = 14.69\ Nm\ .$$

It remains to clarify the coefficient of the idle moment of the generator (*what resistance to rotation is provided by the mechanical part of the generator, when rotating at a given speed without including the frame in the circuit with a load*), traditionally they take 20% of 100% of the electromagnetic moment under load. As a result, 100% + 20% = 120% of the electromagnetic moment of the generator generated by the induction of the current: ***k*** **= 1.2**... The electromagnetic moment of the drive motor will be = **1.2 * *M* = *17.63 N * m*** . Define the electrical power of the drive motor:

$$P_e\ motor = 17.63 * 650/9550 = 1.20\ kW\ .$$

We define transform coefficient **COP =** P_e generator / R_e Motor = 1 / 1.2 = **0.83** .

As you can see, everything coincides with the traditional statements. Conversion factor:

COP = 0.83 <1 .

We cannot include an additional drive motor for the generator to the load, proceeding from the condition of equilibrium of the kinetic and electric powers. But that's not all, let's go ahead and calculate the electromagnetic moment of the generator through the ampere force and the radius vector.

Solution - 3: determination of the electromagnetic moment of the generator through the electromagnetic force and the radius vector:

To calculate the electromagnetic moment in terms of the Ampere force, we use the basic formula:

$$M = Fa * (d / 2)$$

Where Fa is the Ampere force in Newtons. Ampere force is calculated by the Formula:

$$Fa = B * In * La$$

Where: magnetic induction: $B = \mu_0 * (In / 2\pi * r)$, in *T*, current in ampere-turns: $In = n * I$, in amperes; and La is the sum of the lengths of the two active sides of the frame, divided by the number of turns:

$La = 2 * l / n$, in meters.

Imagine our frame is extended to its full length:

1/2 active wire length = 94.75 meters / 2 = 47.36 meters.

We get the length of one edge of the frame, which is not really the actual length of the generator. We accept conditionally. that we have such a design of an electromechanical device. We will assume that we have it with a minimum or very high idle torque.

Let's calculate the electromagnetic moment of one frame of an *unreal* generator with a gap between the magnetic pole and a wire of 1 *mm* (0.001 *m*):

$$M = ((\mu_0 * I * n / 2\pi * r) * (I * n) * (La * n) * (d / 2) =$$
$$(0.00000126 * (4.55 * 1/2 * 3.14 * 0.001)) * (4.55 * 1) * (2 * 47.36 * 1) * (0.5 * 0.35) = 0.136\ N * m$$

We got a completely unrealistic small dimensionality of the electromagnetic moment **EMM = 0.136 *N * m*** , versus **EMM = 14.69 *N * m*** , subject to the equilibrium of powers!

That's the result! I double-checked for an error that I did not find. I made a few more calculations: putting the length of the wire in turns and shortening the length of the frame (armature / rotor).Results in the table:

#	Position	Desig.	Measuring	Index				Formula
	Checking the possibilities for calculating the electromagnetic moment of the generator to the drive							
1	Number of turns of the frame	*n*		1	1	107	150	
2	Length of the active wire of the winding frame	*L*	*m*	94,8	94,8	0,89	0,63	*L=l/n*
3	Current strength (sum per turns)	∑*I*	*A*	4,55	4,55	486,85	682,50	∑*I=n*I*
4	Magnetic induction of a wire with a current of 1 mm	*B*	*T*	0,0018	0,0018	0,1941	0,2730	$B=\mu_0*(I/2\pi*r)$
5	THE POWER OF AMPERE, the wires in which the curr	*F*	*N*	0,78	0,78	83,36	117,24	*Fa=B*I*L*
6	Estimated Electromagnetic Moment	*M*	*Nm*	**0,136**	**0,136**	**14,59**	**20,52**	*M=Fa*(d/2)*
7	Idle engine ratio	*k*		*1,25*	*130,0*	*1,25*	*1,10*	
8	Estimated drive motor power	*P(m)*	*kW*	0,012	1,206	1,24	1,75	*P=k*M*n/9550*
			COP	8625%	83%	81%	57%	

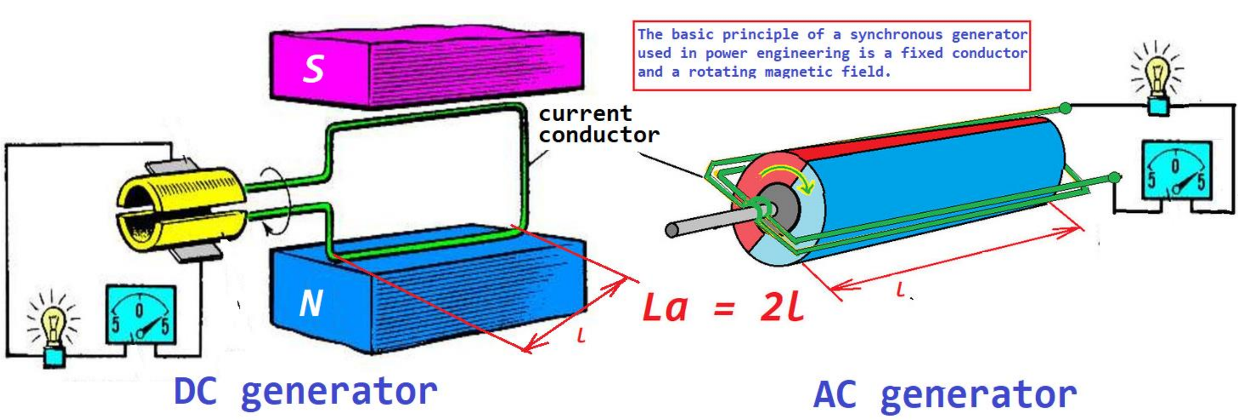
In fact, we have counted the first two columns. With a generator no-load ratio of 1.25, the power of the drive motor will be 0.012 kW (12 W) !!! Achieving parity according to the usual formula (with ***Re*** = ***Pk***) is achieved at idle speed k = 130. Obviously, an anchor with two attachment points of such a length cannot be produced. A rotor with intermediate supports is possible. How great the moment of force will be, we will not take into account the rotation of this rotor at idle speed due to the impossibility of such a design..

We have two more calculations. The wire is laid in several turns (an inactive wire is considered zero resistance and is not taken into account). To achieve parity with the condition P e = P k, we got 107 turns. The length of the frame edge has been reduced from 47 meters to 0.445 meters (which is quite acceptable for the generator's dimensions). It turns out that the current and magnetic induction increased 107 times: current - [486.85 / 4.55 = 107 times]; Magnetic induction - [0.1941 / 0.0018 = 107 times], but the length of the wire or bundle has decreased 107 times: Length - [94.8 / 0.89 = 107 times].

Logically, the length of the rods can be related to the cross-section of the flow, the overall result should not change, but it will. If we compare this to a nozzle through which a jet flows, the smaller the cross section, the higher the speed and actual pressure. If you add more turns and decrease the length, this pressure will increase even more. For a motor this is not bad, but for a generator it is the cost of current induction from the side of the drive motor. It is necessary to look for a solution to the optimal size of the generator with the minimum number of turns for a given wire length.

The main thing is that the default condition, the equality of powers Pk = Pe, is not observed in the simplest generator and, obviously, in the engine. The energy conservation law for the conversion of kinetic energy into electrical energy is unacceptable for the simplest generator.

The solution is in the design of the generator!

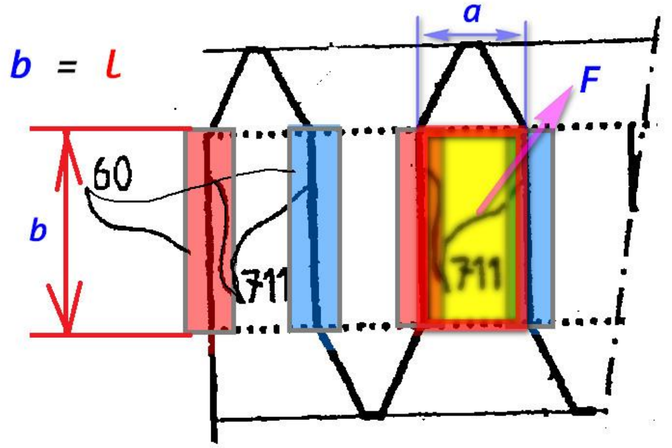


What to do? There is always a solution, especially since physics indicates where to look for this solution.

What you need to do: recalculate the result for 104 meters of active wire. We will have 104/2 = 52 pairs of poles. The rotor length will be 0.5 *m* , the diameter is 0.35 *m* . Lay the entire length of the wire in a wave on these poles. Does it matter if the wire has a straight line or a zigzag, the main thing is that the phase is laid in one wire. We will have a frequency parameter since it will already be an alternator.

Let's calculate the frequency by the formula: $f = p * n / 60$, where: p is the number of pole pairs; n - angular speed, *in rpm* , $f = 52 * 650/60 = 563$ *Hz* .

In this installation option, one more parameter will be added, this is the electromagnetic thrust force arising from the focused magnetic flux of the circuit, which is formed between the wires with a multidirectional current vector. When calculating the final result when laying in one wire, the traction force of the electromagnet does not exceed - ***0.157 N***. Laying the wave wire, our solution. In our case, this is laying on a frame that is neutral to magnetic flux, for example, plastic of a 3D printer. Calculation by formulas:



$$F© = B^2 * S / \mu_o$$

$$B = 1/2\ \mu_o * I * (N/L)$$

$$S = a*b\ (m^2)$$

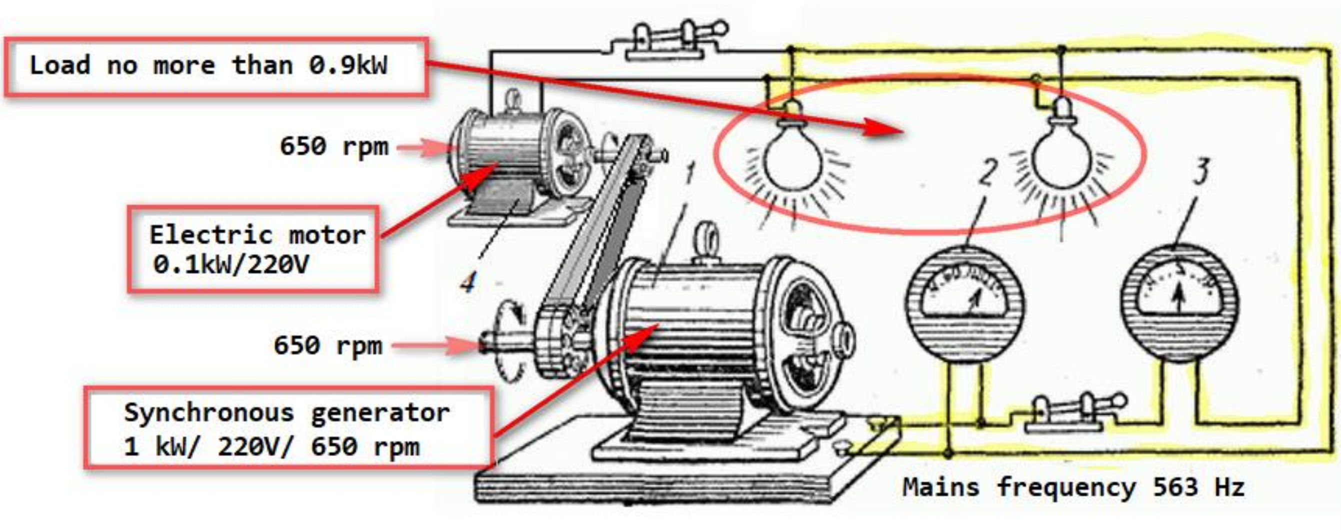
The electromagnetic moment with the sum of the Ampere forces and the electromagnetic traction force, will preliminarily have a value: $M = (0.78 + 0.157 = 0.937) * (0.35 / 2) = 0.163\ N * m$, which will be, in the need for the drive power of the generator motor , taking into account the coefficient 1.2 at idle:

$$P = 1.2\ M * n / 9500 = 0.014 \text{ kW } (14 \text{ W}).$$

It is not difficult to calculate the conversion coefficient

COP = $P_{genator} / P_{motor} = 1 / 0.014 =$ **71.4 (7140%)** .

The figure looks fantastic, this generator is very real. If the drive motor comes out, perform with a minimum power of 100 W, then with self-propelled operation of the electromechanical converter there will be 0.9 kW of free energy. The main thing that we found out is that it is possible to turn on the motor. In our case, according to the condition of the task, we can turn on the engine in the generator circuit with a load, subject to a decrease in the load power, for the power consumption of the engine and the frequency of the network and the engine of ***563 Hz***.



It is easy to solve a physical problem, observing the fundamental foundations of the physics of electrical engineering. Doubt? That's right, you need to check everything yourself. The best test is to solve the problem yourself, take your part, the whole solution is given above. Such a generator is possible, the only thing is that it will be inferior to the traditional ones in terms of watt / kg and material consumption. You need a lot of magnets and they are expensive.

[Introduction to Electrical Engineering - a text book for B Tech Electrical Engineering students]

"Impossible only until the opportunity becomes known."

Yours Serge Rakarski.

If you want to know more, follow the link: **Manual with calculator - purchase. (in Russian)**

http://rakarskiy.narod.ru