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# STARTING SYSTEM OPERATION IN THE STARTER-GENERATOR

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**Abstract-** In this paper the research of process of start-up and system start-up as «the starter, generator, a cranked shaft» is considered mathematically and physically. The basic mathematical parities of the static moments, efforts and inertia are analyzed.

**Keywords:** Starter, Generator, Excitation Winding, Cranked Shaft, Starting Switch, Reducer, Power Block, Internal Combustion Engine.

## I. INTRODUCTION

At development of the world industry the requirement increases by the means, applied to simplification of work, moving, transportation of cargoes etc. The internal combustion engines are started by the starters eating from the unique power supply, the storage battery. Considering that this starter-engine has rather small capacity and for the purpose of fast dispersal, the starting mode is carried out without restrictive resistance in a chain of a current of an anchor.

The starter mode basically has transitive character of a current of process and consequently its research is important for an estimation of electromagnetic. The mechanical action of the starter-generator; in aggregate electromechanical transient is exposed to research basically.

The starter-generator, also as start at modern starters, carry out the start of an internal combustion engine in a straight line as it has advantage of the greatest simplicity of starting equipment and starting operation. During too time low involved voltage gives the chance to realization of direct start-up.

The developed design of the starter-generator [1, 2], carrying out both starter function, and the generator which simultaneously favorable in the ecological relation, is constructed on the basis of the car of a direct current of small capacity, and despite some change in electric connections and two regime works. We will quite apply a mode of direct start-up and start an internal combustion engine.

Switching of electric chains is carried out consistently taking into account two modes, starter and generating, and these modes should be carried out without complications, as concerning electric communications, and mechanical overloads. In transformation of storage electric energy in further mechanical systems in electrical equipment, three windings participate of anchor and two windings of excitation exist.

The basic winding of excitation creates the required magnetic stream and supplies from the storage battery. Inclusion and creation of a magnetic stream occur as at an independent winding of excitation as the magnetic stream joins earlier than the anchor winding joins. In the electric schemes the consecutive winding of excitation with several coils which is projected and pays off on a current of anchor windings are shown.

The anchor winding entering into a design consists of two identical parts, each of which pays off and projected on half of capacity of start-up.

## II. MATHEMATICAL RESEARCH OF PROCESS OF START-UP

Generally, based on the generalized theory of electric cars and according to an action principle it is known that one axis cars with the motionless switching brushes located on a cross-section axis, and the winding of excitation focuses on a longitudinal axis without a gear structure of an anchor which it is possible to write down the equations of the excitation circuit as the following:

$$U_{ab} = R_в i_в + L_в \frac{di_в}{dt} \qquad (1)$$

where $U_{ab}$ is voltage of the storage battery.

The equation of voltage of the circuit of a winding of an anchor:

$$\left.\begin{aligned} U &= C_E \Phi_n + R_{y1} i_{y1} + L_y \frac{di_{y1}}{dt} \\ U &= C_E \Phi_n + R_{y2} i_{y2} + L_y \frac{di_{y2}}{dt} \end{aligned}\right\} \qquad (2)$$

where

$C_E = \frac{PN}{a}$ - factor of electrical driving flux;

$P$ - number of pairs poles;
$N$ - number of conductors of a winding of an anchor;
$a$ - number of parallel circuits;
$n$ - the frequency of rotation expressed in turns in second.

The equation of movement of an anchor:

$$\left.\begin{aligned} C_M \Phi i_{y1} + M_1 = 2\pi J \frac{dn}{dt} \\ C_M \Phi i_{y2} + M_2 = 2\pi J \frac{dn}{dt} \end{aligned}\right\} \qquad (3)$$

where

$C_M = \dfrac{C_E}{2\pi}$ - moment factor;

$R_в$, $R_{y1}$, $R_{y2}$ – resistances;

$L_в$, $L_y$ - inductances

$M_1$ and $M_2$ - the moments on a shaft from currents $i_{y1}$, $i_{y2}$;

$J$ - the moment of inertia of the rotating weights, the led axes of an anchor.

The starter mode basically has transitive character of a current of process and consequently the research is important for an estimation of electromagnetic and mechanical action of the starter-generator which in aggregate the electromechanical transient is basically exposed to that.

Start of an internal combustion engine by the starter-generator, also as at modern starters, carries out the start in a straight line as it has advantage of the greatest simplicity of starting equipment and starting operation. It is reasonable that during too time low involved voltage gives the chance to realization of direct start-up.

To solve the equations of the balanced voltage of circuits of excitation and anchor, the equations of the moments, it is required to define a current and frequency of rotation of an anchor and starter-generator which transfer in a generating mode after start an internal combustion engine which are main points of research taking into account physical analyses. Inclusion process of the shunt excitation windings on voltage $U_в=U_{ab}$ occurs in an idling mode, i.e. at $i_y=0$; by influence of vertical currents in massive parts of the car. The saturation magnetic wires is neglected, as time between inclusion of contacts and rather more than constant time of system of excitation. The action of personnel starting of the internal combustion engine is considered for connecting with its reaction to the restoration voltage of involved network. At normal passage of process of the command on switch inclusion is also given.

Constant time of system of excitation is defined on to the following equation:

$T_B = L_B / R_B$

Designating $i_{B*} = i_B / i_{B0}$ ($i_{B0}$ is the restored value of a current of excitation at idling) and having divided the equation (1) on $U_B = R_{B0} i_{B0}$, we will present it in the dimensionless form of:

$$i_{B*} + T_B \frac{di_{B*}}{dt} = 1 \qquad (4)$$

With accepting the entry condition of $i_{B*}(0) = 0$, the equation (4) will look likes:

$$i_{B*} = 1 - e^{\frac{t}{T_B}} \qquad (5)$$

at $t \geq (3 \div 4)$ the currents values are $i_{B*} \approx 0$ and $i_{B*} \approx i_{B0}$.

As shows in the equation (5), taking into account of time parameters, before giving of voltage of the storage battery on an anchor winding occurs much more time, than $t$. As it is specified above, usually after voltage giving on an involved network (simultaneously on a winding of excitation of the starter-generator) the signal on start-up after a while (it is more than time $t$) is given in two processes of full excitation of the car and the start-up beginning as well as occur freely, i.e. in time pieces independent from each other.

Let's consider the condition of magnetic system before the modes of starting, during starting and generating of starter-generator.

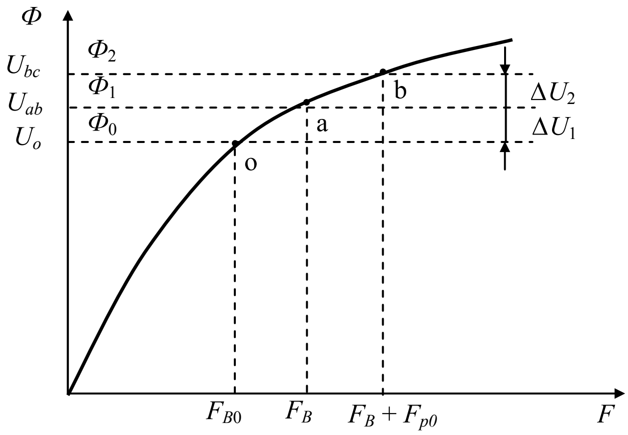


Figure 1. A magnetization curve in the starter-generator

At contact inclusion on an involved network, the voltage of storage battery $U_{ab}$ moves and in an excitation winding a transient and a current is quickly restored. Thus $I_B = I_{B0}$ which is created by a current of excitation $I_{в0}$ magnetic driving force creates magnetic stream $\Phi_1$.

It corresponds to a non saturated condition of magnetic system (point "a" on Figure 1) in car working point value of a generating mode which the magnetic stream increases as well as $I_B$ increase. The involved voltage $U_{bc}$ in generating mode corresponds to the flux $\Phi_2$ in magnetic system. Voltage $U_{bc}$ also should correspond to non strongly stated area of magnetic system of the car (point "b" on Figure 1) because that the voltage regulator normally functioned.

Suppose that an internal combustion engine is started-up by the starter-generator without a consecutive winding of excitation. It would be carried out unreliably and unstably for the reasons of non saturation status of the magnetic system and strongly influenced by a starting current of an anchor based on the size of voltage of the involved network voltage $U_{bc}=U_{ab}$. The voltage would be exposed to fall in limits $\Delta U_1$ ($U_{bc}$ will be equal to $U_0$) and it would lead to reduction of a current of excitation $I_B$ of the starter-generator, and it is in turn connected with reduction of magnetic driving forces (from $F_B$ to $F_{B0}$), leading to fall of a magnetic flux $\Phi_0$.

This process as a whole, is influencing a starting current of an anchor, would promote sharp fall of the moment on a shaft and, finally, it causes stop of start in an internal combustion engine. On the other hand, it would affect on work of various devices, gauges and other kinds of electric equipment of involved system. For this important reason the influence of start-up on a power failure is necessary for considering introduction in excitation system of the consecutive winding and winding of the anchor flowing round by a current.

Except in power failure indemnification $\Delta U_1$, the consecutive winding should lift the value of voltage to the value $U_{bc}$ and therefore, normalize the starting process of internal combustion engine by the starter-generator. It is supported by a generating mode in generating mode $U_{bc}$ with the exact control of a regulator of voltage. The starter-generator will work with the raised moment on a shaft with a consecutive winding which the number of coils should be picked up from the point of view of indemnification $\Delta U_{12}$, i.e.

$\Delta U_{12} = \Delta U_1 + \Delta U_2$

As the point "a" (Figure 1) is in a rectilinear site, the excitation current decreases proportionally to a power failure $\Delta U_1$, i.e. $i_B \equiv \Delta U_1$. At a choice of number of coils in a consecutive winding of excitation, it is necessary to consider that insignificant excess of magnetic driving force, corresponding to a point «b», will not affect negatively in starting process. Therefore, the voltage regulator will join and influences a current of excitation of the starter-generator.

### III. PHYSICAL RESEARCHES START-UP

Process of start-up of starter in the generator taking into account the above stated analytical researches can be analyzed by the following analytical explanations. Considering that capacity of the starter-generator for voltage of an involved network which is not small at mode of estimation and it is necessary to consider both electromagnetic and electromechanical current of the processes. When time of course of electromagnetic processes in the starter-generator are commensurable in due courses of electromechanical processes, it is necessary to consider influence of electromagnetic inertia of the circuit of the anchor.

As it is specified above, the electromagnetic constant of time is defined by inductance of the anchor and resistance of the circuit of the anchor. Process of changing the current of anchor is not so instant, because of its increasing depends on the speed of course of electromagnetic process. Time which the anchor current reaches to the necessary value for creation of the moment will be considerable small in comparison with usual engines which consume from a powerful source. The starter-generator supplies the involved electric network which the unique source is the storage battery with the big internal resistance.

The starter of the generator will influence a starting current of the anchor and the given resistance at start-up of the internal combustion engine. Then, it is physically impossible to equate a starting current at $t$=0 as a current of short circuit (Figure 2). After time reaches to $t_t$ the anchor begins to rotate. It is connected with numerous processes of the electromechanical and electromagnetic phenomena, and one of them strongly can be swinging cranked shaft of internal combustion engine.

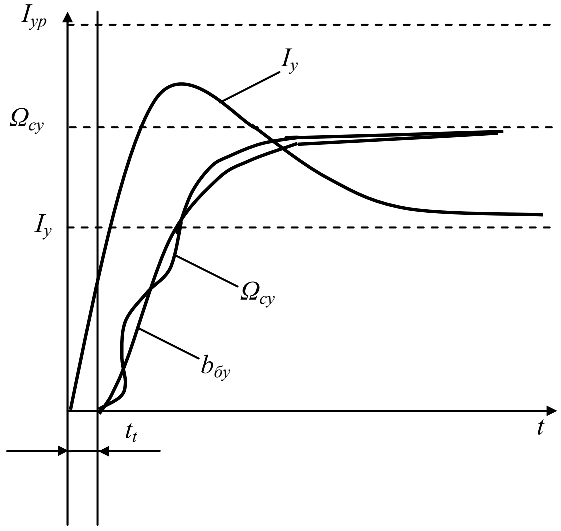


Figure 2. Current changes ($i_y$) and frequencies of rotation ($\Omega_C$) depending on start-up time

$\Omega_{cy}$ – frequency of rotation with the account influences swinging

$\Omega_{by}$ – too, without taking into account

The ignition moments can be actable in the cylinders at small frequency of rotation in a cranked shaft and rather than the time in wide interval frequency of rotation; despite presence on a shaft of a flywheel and belt drive application between flywheel and starter-generator shaft. This instability does not influence almost a current of an anchor because of few amplitudes swinging and its fast repayment in a start of motion sometimes occurs imperceptible swinging frequencies of rotation of an anchor in narrow limits. On the other hand, the great influence does not render an assumption at transitive electromechanical processes in limits (5÷10)% on the calculations and physical analyses, if the processes are defined in time near of seconds.

Transfer a starter of the generator in a generator mode is special operation and should be considered separately as two freely operating electromotive forces (generating and storage) in the system such as an electric network or an involved electrical supply.

### IV. THE EQUATION OF MOVEMENT OF THE ELECTRIC DRIVE AND «THE STARTER, GENERATOR, THE CRANKED SHAFT»

The operating modes of the starter-generator include internal combustion engine start, transition in a generator mode and sharp change of frequency of rotation of cranked shaft in an internal combustion engine. These modes lead to occurrence of dynamic processes in the complex owing to elastic deformation of transfer links for the car direct current in the starter-generator; the starting switch and belt drive [3].

It is known that in any elastic mechanical system with one or several degrees of freedom in unsteady processes, the free and compelled fluctuations take place. The fluctuation in a starter-generator can arises at change of the moment in impellent starter a mode.

Without dynamic oscillatory processes in mechanical system of the starter-generator, it is impossible to design it correctly. This problem still becomes complicated vibration of design as independent objects and can create the resonant phenomena pose threat of integrity of elements and knots.

The given complex concerns mechanisms with consecutive connection of the elastic links working in the conditions of free movement of all elements. Movement of these elements is described by difficult system of the differential equations which decision is inconvenient even by means of mathematical cars.

Let's consider the basic mathematical parities used in calculations of reduction of the static moments and the moments of inertia.

For drawing up the settlement scheme of the mechanism in «the starter, the generator, the cranked shaft» with elastic mechanical communications, the rigidity of links is led to a shaft of the engine of direct current. The kinematics scheme of the mechanism is made on the basis of the connected elastic elements including the engine shaft, the starting switch, the belt drive and cranked shaft of internal combustion engine [4].

The equation of movement rotating system can be described in the generalized angular co-ordinates. In the theory of fluctuations it is accepted to mark moving systems on number of degrees of freedom. So, the settlement system «the starter, generator, cranked shaft» is defined in four generalized co-ordinates ($\alpha_1$, $\alpha_2$, $\alpha_3$, $\alpha_4$) and therefore, it has four degrees of freedom. The conclusion of the equation of movement is carried out using a principle of Dalamber.

Generally, the movement equation in settlement system of the electric drive taking considering the elastic mechanical communications is written as the following:

$$\sum_{i=1}^{n}\left(A_i P^{2i}\alpha_1\right)+\alpha_1=\sum_{i=1}^{n}\left(B_i M_i\right)+ + f\left(M_i,\ldots,M_{n-1}\right) \quad (6)$$

where

$n$ - number of degrees of freedom;

$P$ - a symbol of differentiation which is defined under the formula:

$$P=\frac{d}{dt}$$

Left part of the equation is the sum of even derivatives of required co-ordinate with factor $A_i$, depending on the moments of inertia and rigidity of elastic links and co-ordinate $\alpha_1$. The right part consists of two parts: the first is the sum of all moments operating in system with the factors which also depending on the moments of inertia and rigidity. The second part is function of the sum of even derivative of the operating moments with factors.

Taking into account the generalized equation (6) for system «the starter, generator, the cranked shaft» can be written down as the equation of the following:

$$\begin{aligned} &A_4 p^8\alpha_1 + A_3 p^6\alpha_1 + A_2 p^4\alpha_1 + A_1 p^2\alpha_1 = \\ &= B_3 p^6 M_1 + B_2 p^4 M_1 + B_2 p^2 M_1 + \\ &C_2 p^4 M_2 + C_1 p^2 M_2 + Dp^2 M_3 + \\ &+ M_1 + M_2 + M_3 + M_4 \end{aligned} \quad (7)$$

where $A$, $B$, $C$ and $D$ can be defined on the differential equations, written down for similar systems.

The system of «the starter, generator, the cranked shaft» is the object having design of belt drive between shaft of the starting switch devices and cranked shaft. Processes occurring in a cranked shaft almost are not translated on a shaft of a reducer except the moment of resistance because of the raised elasticity of the belt.

These processes connected with compression of cylinders mix of internal combustion engine by burning, are not constant on frequency of occurrence in system «the cranked shaft, the belt drive». All these high-frequency forces are accounting in mathematical system of the research including varying on amplitude, time, frequency and also short-term work of the starter-generator. The account of these phenomena will not bring the big benefit in any approach of a positive exit.

Besides, all high-frequency of operating moments on the cranked shaft are extinguished by a flywheel rigidly connected with cranked shaft and elasticity of the belt drive. Considering this circumstance, it is possible to come to conclusion about system transfer in two mass.

The operating mode of the starter-generator has short-term frequent character [5]. Actually, it is transitive and varies depending on numerous factors:

1. Pressure fluctuations;
2. Temperatures of windings (the anchor winding and excitation winding in short-term mode);
3. Time of the included condition.

All these modes are investigated by means of receiving above equations as it was already marked, by means of mathematical cars which represent a great difficulty. Therefore, transition from four mass to two mass the input of the additional factors should justify itself considering strengthening of reliability. Then given transient of start-up can not correspond to the second.

Taking into account all these circumstances, it is possible to conduct researches on dynamics of start-up of system «the starter, generator, a cranked shaft».

## V. CONCLUSIONS

Traditional involved networks connected the an electric equipments have usually independent objects of the starter-generator which is carrying out such functions as start of the internal combustion engine which yields maintenance of the involved network with the electric power. It is simple and gives the chance to save great volume of expensive materials in comparison with the existing.

In this paper the mathematical and physical analysis result that all questions are considered taking into account time and dynamics estimation. It is considered in the object of mathematical research for drawing up of the equation of movement in given electric drive «the starter, generator, the cranked shaft».

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## BIOGRAPHIES

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