Electrical equipment of the test bench and safety clutches adjustment

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Abstract. Among the types of safety clutches tests, operational life testing is singled out, which verifies the reliability of the clutch during multiple operations and change of the clutch settings during multiple operations. The task of rational use of electricity by a test bench during operational life testing is of great importance. A rational scheme of the electrical equipment of the test bench for operational life testing and safety clutches adjustment is given. The circuit with return circulation of the load power of the safety clutch is applied in the equipment of the test bench, which saves the energy consumed for the testing. Patterns of adjustment of rotational speed and the load torque of the proposed device are considered. It is of interest for designers of test equipment and specialists in safety clutches adjustment.

1. Introduction
Agricultural machines often have a rather complicated kinematical scheme, where several units of a machine are driven from a single source of mechanical power (motor). An example would be a combine harvester, in which long shafts are often used for transmitting torque to individual nodes, and the nodes themselves have a high probability of overloads over allowable values and other abnormal or emergency situations due to the processing of heterogeneous materials having solid inclusions. To increase the reliability of such devices, safety clutches are widely used. They automatically disconnect the emergency assembly from general kinematics [1, 2]. Safety clutches are among the most critical drive assemblies, and they are located as close as possible to the place of possible emergency jamming or shaft overload. Friction, ball-spring and jaw-spring safety clutches as well as other types of clutches are used in agricultural engineering [3].

Like all products of agricultural engineering, during manufacture the clutches are subject to various types of tests [4]: research (at the development stage of a new design), resource, preliminary and acceptance (for prototypes), operational (installation series), periodic, attestation and typical ones (serial products). For clutches quality control acceptance tests are carried out, which are the final operation of the technological process of their manufacture.

Resource tests are carried out with a rotating clutch. Often such tests are accompanied by control of maximum power loading (transmitted torque) and rotational speed. To achieve this the so-called load devices are being used. They contain the drive units for driving, loading and measuring torque. During tests, different stands with open or closed flow of electrical and mechanical power are being used. In medium-power-clutches test benches as a load device for loading the clutch with mechanical power we often use DC generators of separate or parallel excitation.

The tests of safety clutches for reliability, related to their repeated cyclic loading until actuation with the subsequent reduction of the moment until the restoration of the clutch, require considerable
mechanical power and energy consumption [5–7]. In the test bench equipment power transmitted through the clutch goes through several transformations. In the simplest test device in the rotating clutch mode it is converted from electrical to mechanical (motor) and thermal (mechanical brake) power, while the latter requires its utilization.

The return of part of the energy transmitted through the test clutch to an electrical circuit can significantly reduce the cost of electrical energy for the testing, making energy savings, and allows us to improve the microclimate in the testing laboratory [8].

The principle of operation of most of the known devices for returning electric power to the supply network is based on the conversion of energy from electric to mechanical and vice versa using a generator for loading the tested clutch of the generator operating in parallel with the supply network or as part of a common electrical circuit with a driving motor. The composition and scheme of the return operation devices are diverse. The choice of a rational scheme is determined by the requirements for regulating the rotational speed of the tested clutch and the control range of the load torque.

A variety of return operation schemes is a loading-back circuit of electric machines, where the motor gives mechanical energy, transmitted through the clutch, to the load generator, which in turn generates electrical energy that is transmitted to the specified engine. An influx of energy from the outside is required to cover the energy losses in both electric machines and transfer devices.

2. Methodology

The most rational one for use in test benches is the Potier scheme [9] (that was modernized at Kuban State Agrarian University) the possible implementation of which is presented in Figure 1.

The tested safety clutch Cl connects the shafts of the DC drive motor M of separate excitation and the direct current load generator G. MEW and GEW are excitation winding of a motor and a generator respectively. The motor M and the generator G receive power from the adjustable voltage source VA1 (pins 1 and 2) via a smoothing choke Ch. As an adjuster VA1 and the motor M, it is advisable to use a complete DC electric drive, intended for machinery equipment, with rotational speed control by modifying the armature voltage.

Modern market offers a large selection of such drives. The adjuster VA1 has pins 3 and 4 of stabilized excitation voltage. Resistors R1 and R2 are used to adjust the magnetic fluxes of the motor M and generator G in the process of adjusting the equipment of the stand. The semiconductor voltage adjuster VA2 can be a complete single-phase bridge semi-controlled rectifier (semi-controlled rectifier VS1 ... VD2 on Figure 1), a three-phase controlled rectifier or an unregulated rectifier with a voltage...
adjuster on the AC side (connected between transformer T and rectifier). An obligatory element of the unit is an isolation transformer T, which is necessary for the galvanic isolation of DC and AC circuits.

The change in the moment transmitted through the tested clutch is achieved by changing the voltage on the VA2 regulator. When the clutch actuates (its half-clutches disengage), the electromagnetic torque of the generator G is reset and the torque on the leading half-clutch decreases. In this case the generator current is recorded at the moment of the half-clutches disengagement to control the trigger point. Then the voltage on the rectifier decreases and the clutch engages again. Further the test cycle is repeated many times.

The scheme of electromechanical power conversion has a positive property: the voltage adjustment at the motor armature makes it possible to regulate the rotational speed at a constant value of the torque on the shaft, i.e. the speed and torque of the clutch are regulated as independent variables. This property of the circuit can be illustrated by the equations of the static mode of the “motor-generator” system. From the complete system of equations of the static mode of the motor and the generator \[10\], we select the following:

\[
\begin{align*}
U_a &= E_1 + R_{a1}I_2; \\
U_a &= E_2 - R_{a2}I_4 + U_d; \\
E_1 &= C_1\Phi_1\Omega; \\
E_2 &= C_2\Phi_2\Omega; \\
M &= C_1\Phi_1I_2; \\
M &= C_2\Phi_2I_4,
\end{align*}
\]

where \(U_a\) is the voltage at the armature of the electric motor; \(U_d\) is the voltage on the side of the rectified current of the adjuster VA; \(E_1\) and \(E_2\) - EMF of the armature, respectively, of a motor and a generator; \(I_2\) and \(I_4\) are the armature currents, respectively, of a motor and a generator; \(\Omega\) is the angular frequency of the shaft rotation (the same for both machines); \(M\) - the moment on the shaft; \(\Phi_1\) and \(\Phi_2\) - magnetic flux, respectively, of a motor and a generator; \(C_1\) and \(C_2\) are engine constants, respectively, of a motor and a generator; \(R_{a1}\) and \(R_{a2}\) - armature resistance, respectively, of a motor and a generator.

In the equations of moments of the system \((1)\), an assumption is made about the equality of the electromagnetic moments of the motor and the generator, which is equivalent to neglecting the deceleration moments in the machine design. This assumption does not introduce tangible errors in the calculation results and analysis.

Solving together equations \((1)\) with respect to the moment \(M\) and excluding the currents \(I_2\) and \(I_4\) from the variables, we get:

\[
M = \frac{C_2\Phi_2}{\frac{R_{a2}}{C_2\Phi_2} + \frac{R_{a1}}{C_1\Phi_1}} + \frac{U_d}{\frac{R_{a2}}{C_2\Phi_2} + \frac{R_{a1}}{C_1\Phi_1}},
\]

from which it follows that under the condition

\[
C_2\Phi_2 - C_1\Phi_1 = 0,
\]

the moment \(M\) does not depend on the rotational speed \(\Omega\) of the shaft, since the first term of formula \((2)\) vanishes (becomes zero). The magnitude of the moment is determined by the voltage \(U_d\) of the rectifier:

\[
M = kU_d,
\]
where $k = \frac{1}{\frac{R_{a_2}}{C_2\Phi_2} + \frac{R_{a_1}}{C_1\Phi_4}}$. \hspace{1cm} (5)

For machines of separate excitation the magnetic flux does not depend on the state variables of the armature circuit, therefore the coefficient $k$ is a constant value, and equation (4) represents the linear dependence of the moment on the rectifier voltage. Condition (3) for DC machines of separate excitation of any type can be achieved by controlling the magnetic flux (excitation current) of one or both machines. For motors of series and compound excitation it is practically impossible to achieve condition (3) for different values of speed and load due to the dependence of the magnetic flux on changing regime variables.

The rated maximum voltage of the rectifier bridge $U_b$ must satisfy the condition [11]:

$$U_b \geq (1 - \eta_1\eta_2)U_n,$$

where $U_n$ is the nominal voltage of a motor and a generator (these voltages must be the same or differ by 5%); $\eta_1, \eta_2$ - nominal efficiency of a motor and a generator.

The rated current of the bridge rectifier must not be less than the rated current of the generator.

3. Results
Let us analyze the system of equations (1). When taking into account differences in the magnitude of the electromagnetic moments of the tested motor and the load generator, the conclusion that the excitation adjustment of both machines can achieve independence of the clutch torque from the voltage value $U_a$ at the motor armature is not cancelled. In this case only the value of the coefficient $k$ changes, which is determined by a more complex dependence than in equation (5) and can be chosen experimentally.

4. Discussion
The independence of the torque from the frequency of rotation of the loading machine simplifies the automation of the test stand of the safety clutch, allowing the two variables to be adjusted as independent values.

Since with separate excitation the generator has a stabilized or deterministically modifiable magnetic flux, the measurement of the moment can be determined by the magnitude of the armature current $I_4$, according to the equation $M = C_2\Phi_2I_4$. To do this one should calibrate the ammeter or use the table to convert the current to the value of the moment. To measure the moment the relation (4) can also be used. In this case one should calibrate the voltmeter which measures the rectified voltage on the rectifier.

5. Conclusion
An important advantage of the proposed test bench is a significant reduction in the cost of electricity for testing due to return of electrical power of the generator to the electrical circuit of this power circulation. Simple calculations show that the reduction of power consumed by the stand with a motor and a generator efficiency of 75% constitutes 50%, i.e. the power of the stand is half the power of the drive motor. During long-term testing of the clutch for reliability of significant energy savings are achieved in comparison with the known test benches [12].

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