CHARACTERISTICS OF A 4-PHASE VALVE RELUCTANCE MOTOR WHEN POWERED BY UNCAPACITOR SWITCHBOARD

Purpose. Nowadays more and more in a variety of machines and mechanisms applied switched reluctance motor. When designing these engines solve the problem selection switch. While the switch scheme comprises symmetrical bridge and eight transistors, eight diodes; Miller switch comprises six transistors and six diodes; in company Graseby Controls Ltd switch circuit but four transistors and four diodes includes two capacitors. The aim is to develop a mathematical model, calculation program, a numerical analysis of the characteristics and parameters of the WFD and the characteristics of their work. Methodology. It is assumed that the resistance in the open state transistors and diodes for direct current is zero and the resistance of the transistors in the closed state, and diode reverse voltage is infinity. When feeding a single-phase motor and power at the same time two adjacent phases determined by the flow through the tooth. Results. The motor powered by a switch on the circuit symmetrical bridge power, which provides a maximum permissible winding temperature is 1.665 kW. But at the same time the surge up to 38.8%, resulting in high levels of noise and vibration. Through the installation of switching angles, ensuring reduction of torque ripple and reduce engine power to a level below which there is a decrease in the value of torque ripple, received power of 1,066 kW and a torque ripple value of 21.18 %. For engines with improved vibration acoustic characteristics necessary to use a switch of four transistors and four diodes. Practical value. For motors with improved vibration acoustic characteristics appropriate to apply uncapacitor switch on four transistors and four diodes, which allows you to receive half the value of torque ripple than the lowest value of the motor torque ripple, eating from a switch on the circuit asymmetric bridge. The cost of reluctance motor with uncapacitor switch on the circuit with four transistors and four diodes is more than two times less than the motor with the switch on the circuit asymmetric bridge. References 9, tables 1, figures 10.

Key words: valve reluctance motor, switchboard, flux linkage of phases, rotor angle of rotation, motor power.
The goal of the work is to develop a mathematical model to calculate the electromechanical characteristics of the VRM when powered by a switch with four transistors and four diodes to determine the parameters of the motor windings allowing to improve vibroacoustic characteristics and have strong economic performance.

Development of mathematical model. The magnetic circuit of the motor with windings with the combined phases is shown in Fig. 4.

When the angle of rotation of the rotor $\zeta$ in electrical radians in the range $0 \leq \zeta \leq \pi / 2$, the transistors VT1 and VT2 are open and, if this current in $D$ phases and $C$ are not equal to zero, then phase $D$ through the D1 diode and VT1 transistor being connected parallel to the phase $A$ and phase $C$ through VT2 transistor and a diode D2 is connected in parallel to phase $B$. The transistors VT3 and VT4 locked.

In this interval of the rotor rotation angle phase current, flux and torque of the VRM describes by the system of differential equations (1)

$$
\begin{align*}
    i_A' \cdot r + \frac{d\Psi_A(i_A, \zeta)}{dt} + i_B' \cdot r + \frac{d\Psi_B(i_B, \zeta)}{dt} &= U; \\
    i_C' \cdot r + \frac{d\Psi_C(i_C, \zeta)}{dt} &= -i_B \cdot r - \frac{d\Psi_B(i_B, \zeta)}{dt}; \\
    i_D' \cdot r + \frac{d\Psi_D(i_D, \zeta)}{dt} &= -i_A \cdot r - \frac{d\Psi_A(i_A, \zeta)}{dt}; \\
    i_D &= i_A + i_C - i_B.
\end{align*}
$$

where $i_A$, $i_B$, $i_C$ and $i_D$ are the phase currents, $\Psi_A(i_A, \zeta)$, $\Psi_B(i_B, \zeta)$; $\Psi_C(i_C, \zeta)$, $\Psi_D(i_D, \zeta)$ are the phase flux linkages as a function of the currents and the rotor rotation angle; $r$ is the active phase winding resistance (all values – in SI units).

The fourth equation (1) holds in all bands of the rotor rotation angles.

In the rotor rotation angle range in electric radians $\pi / 2 \leq \zeta \leq \pi$ transistors VT1 and VT4 are opened, and the transistors VT2 and VT3 – locked. In this case, the phase $B$ is connected in parallel with phase $A$ and phase $C$ – in parallel with phase $D$. The initial phase of the parallel system of equations for the angles of rotation of indicated rotor interval may be represented as

$$
\begin{align*}
    i_D' \cdot r + \frac{d\Psi_D(i_D, \zeta)}{dt} + i_A' \cdot r + \frac{d\Psi_A(i_A, \zeta)}{dt} &= U; \\
    i_B' \cdot r + \frac{d\Psi_B(i_C, \zeta)}{dt} &= -i_A \cdot r - \frac{d\Psi_A(i_A, \zeta)}{dt}; \\
    i_C' \cdot r + \frac{d\Psi_C(i_C, \zeta)}{dt} &= -i_A \cdot r - \frac{d\Psi_D(i_D, \zeta)}{dt}.
\end{align*}
$$

In the rotor rotation angle range in electric radians $\pi \leq \zeta \leq 3 \pi / 2$ transistors VT3 and VT4 open phase $A$
through VT4 transistor and a diode D4 connected in parallel D phase and phase B through the diode D3 and transistor VT3 is connected parallel to the phase C. Transistors VT1 and VT2 are locked. Electromagnetic processes in the VRM in the rotor rotation angle range described by the system

\[ i_C \cdot r + \frac{\partial \Psi_C(i_C, \zeta)}{\partial i_C} + i_D \cdot r + \frac{\partial \Psi_D(i_D, \zeta)}{\partial i_D} = U; \]
\[ i_A \cdot r + \frac{d \Psi_A(i_A, \zeta)}{dt} = -i_D \cdot r - \frac{d \Psi_D(i_D, \zeta)}{dt}; \]
\[ i_B \cdot r + \frac{d \Psi_B(i_B, \zeta)}{dt} = -i_C \cdot r - \frac{d \Psi_C(i_C, \zeta)}{dt}. \]

(3)

In the range of angles of rotation of the rotor in electrical radians \(3\pi/2 \leq \zeta \leq 2\pi\) transistors VT3 and VT2 open, and transistors VT1 and VT4 – locked. The VRM equations can be written as

\[ i_B \cdot r + \frac{d \Psi_B(i_B, \zeta)}{dt} + i_C \cdot r + \frac{d \Psi_C(i_C, \zeta)}{dt} = U \]
\[ i_D \cdot r + \frac{\partial \Psi_D(i_D, \zeta)}{\partial i_D} = -i_C \cdot r - \frac{\partial \Psi_C(i_C, \zeta)}{\partial i_C}; \]
\[ i_A \cdot r + \frac{d \Psi_A(i_A, \zeta)}{dt} = i_B \cdot r + \frac{d \Psi_B(i_B, \zeta)}{dt}. \]

(4)

Analytical flux dependences on the current phase and angle of rotation of the rotor are presented in [3].

To solve systems (1-4) by the Runge-Kutta method should be presented as a system of linear algebraic equations for the production of time-phase currents. Given that

\[ \frac{d \Psi (i, \zeta)}{dt} = \frac{\partial \Psi}{\partial i} \cdot \frac{di}{dt} + \omega \cdot \frac{\partial \Psi}{\partial \zeta}; \]
\[ \omega = \frac{d \zeta}{dt}. \]

(5)

Systems of differential equations (1-4), authorized with respect to the first derivatives of currents, in conjunction with the fourth equation of (1), the second equation of (5) and equation (6) allow using Runge-Kutta method, to get depending on the currents, torques and the phase flux linkage on the time and angle of the rotor in the gate, and the speed on time

\[ \frac{d \omega}{dt} = \left\{ \begin{array}{l}
\frac{i_A \partial \Psi_A(i_A, \zeta)}{\partial \zeta} \cdot di_A + \frac{i_B \partial \Psi_B(i_B, \zeta)}{\partial \zeta} \cdot di_B + \\
\frac{i_C \partial \Psi_C(i_C, \zeta)}{\partial \zeta} \cdot di_C + \frac{i_D \partial \Psi_D(i_D, \zeta)}{\partial \zeta} \cdot di_D - M_e \end{array} \right\}/J, \]

(6)

where \(M_e\) is the drag torque on the motor shaft; \(J\) is the moment of inertia of the rotating masses.

In the correspondence with the presented mathematical model the calculation program in the environment MathCAD 2001 is developed.

Fig. 6 shows the torque phase of the angle of rotation of the rotor when powered from a switch on the VRM of Fig. 5 at the maximum power (solid curve), at equal specific losses (dot dashed line) with specific losses when powered by the VRM switch scheme asymmetrical bridge, at least torque ripple (dashed curve).

Fig. 7 shows the resulting moment on the angle of rotation of the rotor when VRM powered from the switch according to Fig. 5

Figures 8, 9 show curves of current change and the phase flux linkages, respectively.

Fig. 8 shows the phase current dependence on the angle of rotation of the rotor when powered from a switch on the VRM of Fig. 5 at the maximum power (solid curve), at equal specific losses (dot dashed line) with specific losses when powered by the VRM switch scheme asymmetrical bridge, at least torque ripple (dashed curve).

Fig. 9 shows the dependence of the phase flux linkage on angle of rotation of the rotor when powered from a switch on the VRM of Fig. 5 at the maximum power (solid curve), at equal specific losses (dot dashed line) with specific losses when powered by the VRM switch scheme asymmetrical bridge, at least torque ripple (dashed curve).
of rotation of the rotor when VRM powered from the switch according to Fig. 5.

Fig. 10 shows the dependence of the phase voltage of the rotor rotation angle. The results of calculation of the time of one phase of the VRM are shown in Fig. 6, the resulting torque – in Fig. 7.

![Graph](image)

**Table 1**

| $P_2$, W | $n$, RPM | $I_{ph}$, A | $\eta$, % | $P_{sw}$, W | $P_{w}$, W | $P_{mech}$, W | $\Delta M$, % | $p_r$, W/cm² | $B$, T | $W_p$ | Switch circuit |
|---------|---------|-------------|----------|------------|----------|-------------|------------|------------|------|-------|----------------|
| 1665    | 6006    | 3.863      | 61.6     | 59.8       | 540      | 114         | 325        | 38.8       | 1.621| 1.121| 130 Asym. bridge (Fig. 1) |
| 1066    | 5997    | 2.67       | 60.7     | 34.56      | 256      | 79          | 322        | 21.18      | 1.07 | 0.772| 143 Asym. bridge (Fig. 1) |
| 1066    | 5937    | 3.464      | 53.2     | 29.61      | 524      | 30.4        | 325        | 12.18      | 1.59 | 1.128| 102 4 diodes, 4 transistors (Fig. 5) |

* Note. Calculation of losses in the steel is carried out by [1].

The motor powered by a switch on the circuit asymmetric bridge (Fig. 1), the power, which provides a maximum permissible winding temperature is 1.665 kW. But at the same time the surge up to 38.8 %, resulting in high levels of noise and vibration. Through the installation of switching angles, to ensuring reduction in torque ripple and reduce engine power to a level below which there is a decrease in the value of torque ripple, received power of 1.066 kW and a torque ripple value of 21.18 %. The same performance is achieved when the engine power switch to it from four transistors and four diodes. At the same time the cost of the switch according to the scheme of the asymmetric bridge to date is 1200 UAH. The pulsations of the engine torque with the switch, as shown in Table 1, almost half that of the smallest torque ripple motor powered by a switch on the circuit asymmetric bridge.

Consequently, for motors with improved vibroacoustic characteristics it is necessary to apply switch according to Fig. 5.

**Conclusions.**

1. For improved vibroacoustic characteristics of the VRM is advisable to apply uncapacitor switch on four transistors and four diodes, which allows you to receive half the amount of torque ripple than the lowest value of the motor torque ripple, eating from a switch on the circuit asymmetric bridge.

2. The cost of the VRM with uncapacitor switch on the circuit with four transistors and four diodes is more than two times less than the engine with the switch on the circuit asymmetric bridge.

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