Effect of ferromagnetic shunt manual armature return polarized electromagnet on electromagnet power performance

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Abstract. Using the FEMM program, models of a neutral electromagnet, a polarized electromagnet without a shunt and a polarized electromagnet with a shunt for manual armature return to the initial position have been developed to study a shunt effect on an electromagnet power characteristics. It has been established that the polarized electromagnet anchor attraction electromagnetic force without a shunt at a critical (initial) working gap is 1.44 times greater than that of a neutral electromagnet. A polarized electromagnet with a shunt armature attraction electromagnetic force with an initial gap is 1.1 times less than that of a polarized electromagnet without a shunt. The shunt initial and final positions influence investigations on the armature attraction electromagnetic force magnitude have been carried out. It is shown that in the armature final position and the shunt initial position, the armature attraction force from the permanent magnet is sufficient to keep the contactor contacts closed. When the shunt is moved to the end position, the force from the permanent magnet is not enough to hold the armature in the pulled position and the condition is provided for opening the contactor contacts. Studies have confirmed that a ferromagnetic shunt, designed to manually return a polarized electromagnet armature to its initial position, the contactor in normal operation leads to a decrease in the drive electromagnet magnetomotive force.

1. Introduction

In papers [1, 2, 3], a polarized electromagnetic drive for a vacuum contactor of the KV-2-250 series [4] is considered. The electromagnet magnetic system appearance and geometrical dimensions are shown in figure 1. Two control coils switched on, are set on both magnetic circuits (not shown in figure 1).

An electromagnet operating cycle in normal mode consists of an on period and an off period. The electromagnet is switched on due to a control signal short-term supply to the switching winding. The electromagnet is switched off by briefly applying a control signal to the switching winding. In normal operation, the shunt 4 is in the initial position when the air gap δ3 between the shunt and the magnetic circuit is maximum. At the same time, there is a magnetic flux minimum removal through the shunt Fsh from the magnetic flux in the system Fconst+Fav.

The need to manually return the solenoid armature arises when the auxiliary power is lost and the contactor main contacts need to be opened. To do this, it is necessary to press the shunt tightly against the magnetic circuit with a special manual return device. In this case, the gap between the shunt and the magnetic circuit becomes minimal, the magnetic fluxes redistribution Fpos and Fsh occurs, and the armature returns to its original state corresponding to the contactor main contacts open states.
2. Methods

This work main objective is to determine the polarizing permanent magnet and ferromagnetic shunt effect degree on the contactor electromagnetic drive power characteristics. The shunt effects degree is considered on the KV2-250 series contactor magnetic system example produced by ChEAZ JSC (Cheboksary) [4]. The analysis was carried out using models built on the FEMM program.

For the KV2-250 series contactor magnetic system with an electromagnetic drive based on a neutral electromagnet, the critical response gap is 6 mm, and the magnetomotive force (MMF) of operation and return, respectively $F_{av}=3000$ A, $F_v=675$ A. When constructing models of drive electromagnets for the MMF winding power characteristics' comparability for all drive options, it was taken equal to $F=3000$ A, and the working gap size was equal to the critical gap $\delta_1=6$ mm. In the constructed models, the multi-turn control winding (figures 2–4) was replaced by solid copper conductors Obm1 and Obm2 with a current density equal to the MMF winding ratio to the winding window area $S_O$: $j=(F/2)/S_O=1500A/448mm^2=\pm3.348 \text{ MA/m}^2$. In an electromagnet model in the windings off state, the latter was replaced by solid copper conductors Obm3 and Obm4 with a current density of $j=0$. The magnetic circuit ferromagnetic parts are made of electrical steel grade 10895, and the permanent magnet is made of high-pressure neodymium-iron-boron grade N35.

3. Results and discussion

The constructed model for studying neutral electromagnet characteristics is shown in figure 2, where the equal magnetic flux tubes obtained using the FEMM program are shown. The magnetic induction in the electromagnet armature middle is 0.892 T. The calculated armature attraction electromagnetic force is $P_e=72.085 \text{ N}$.

By examining a polarized drive electromagnet model (figure 3, a), the magnetic induction value in the electromagnet armature middle part is set equal to 1.054 T. In this case, the armature attraction...
The electromagnetic force is equal to $R_e = 101.654 \, N$. Thus, a polarized electromagnet thrust force is 1.41 times greater than that of a neutral electromagnet, which leads to a decrease in the MMF operation.

![Figure 2](image1.png)

**Figure 2.** A neutral drive electromagnet Model (a) and the equal magnetic flux tubes distribution in the magnetic system (b).

A polarized drive electromagnet with a ferromagnetic shunt model is shown in figure 3, b. The magnetic induction in the electromagnet armature middle is $1,006 \, Tl$. The armature attraction electromagnetic force $R_e = 91.955 \, N$, i.e. the shunt leads to a decrease in the electromagnetic force value by 1.1 times.

![Figure 3](image2.png)

**Figure 3.** A polarized drive electromagnet magnetic system models (a) and a polarized drive electromagnet with a ferromagnetic shunt (b).

The study of a polarized electromagnet with a ferromagnetic shunt armature holding force after its operation and the windings' disconnection from the control voltage source was carried out on the model.
shown in figure 4, a. The electromagnetic armature holding force was 417.395 N, which is sufficient to hold the contactor main contacts closed.

To check the contactor drive correct functioning after pressing the ferromagnetic shunt to the magnetic circuit, a corresponding model is built, shown in figure 4, b.

![Figure 4](image_url)

**Figure 4.** A polarized drive electromagnet with a ferromagnetic shunt magnetic system models after its operation (a) and after pressing the ferromagnetic shunt to the magnetic circuit (b).

The shunt transfer to the final position led to an anchor's electromagnetic gravity reduction by 3.2 times to the value of 130,329 N, which will lead to the contactor main contacts disconnection.

4. Conclusions
Using the FEMM program, models of a neutral electromagnet, a polarized electromagnet without a shunt and a polarized electromagnet with a shunt for manual armature return to the initial position have been developed to study a shunt effect on an electromagnet power characteristics.

The shunt initial and final positions influence investigations on the armature attraction electromagnetic force magnitude have been carried out.

A ferromagnetic shunt, designed to manually return a polarized electromagnet armature to its initial position, the contactor in normal operation leads to a decrease in the drive electromagnet magnetomotive force.

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