

ANALYSIS RESULTS OF EXPERIMENTAL VERIFICATION OF THE UNIVERSAL SWITCH IN THE POWER SUPPLY OF THE ELECTRODYNAMIC ACTUATOR

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Abstract – This paper presents the analysis results of experimental research of bidirectional switches based on thyristor SCR and transistor IGBT in a coil circuit of the electrodynamic actuator. A broader scope of application of the IGBT due to an oscillating frequency of the coil current has been shown because at small-capacitance of capacitor bank switching difficulties have arisen in the application of the SCR.

Keywords: actuator, hybrid breaker, controlled switch.

1. INTRODUCTION

Electrodynamic actuators (EA) are used in so-called hybrid circuit breakers in which an essential problem is to move contacts apart in a very short time [1],[3]. EA diagram can be divided into two parts called the primary and secondary. Part of the coil power supply system from the capacitor bank is the primary part. Secondary part is a well-conductive disc (usually aluminium). ED schematic diagram shown in Fig.1. The operation of this actuator is based on the Thomson phenomenon. After closing coil circuit a very dynamic discharge of capacitor banks occurs resulting in magnetic field pulse in a coil being generated. In turn magnetic field induces eddy currents in the aluminium disk. Due to the electrodynamic interaction the force which pushes disc away is created. The advantage of using this kind of actuators is not only the fact of achieving very high accelerations. Important is also the response time of such an actuator from moment of obtaining information by shorting indicator. Therefore a switch closing coil circuit must be controlled element (Fig.1). So far, in most circuits of this kind a SCR thyristor has been used in the unidirectional switch system (sometimes with freewheeling diode) or bidirectional system (with parallel diode) (Fig.7). Up to now these systems worked well with large capacity of the capacitor bank. It should be stressed that the effective operation of actuator is subject to a large value of the initial energy of the battery. Development of non-electrolytical (bidirectional) capacitors meant that sufficient initial energy can be achieved thanks to a possible higher voltage to which the capacitor can be charged nowadays. This means the

possibility of lowering the battery capacity, which results in an increase in the frequency of the oscillating coil current. This increased dynamics of the current waveform has created commutation difficulties when using a bidirectional switch based on the SCR thyristor.

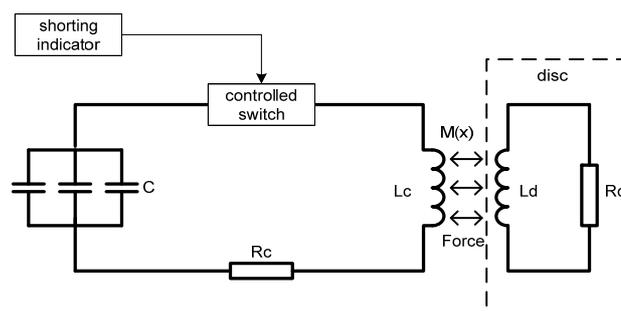


Fig. 1. System of Electrodynamic Actuator – EA.

Therefore the authors have attempted to use faster controlled switches such as IGBT transistors allowing for proper operation of the EA. This paper presents the analysis results of research aimed at selecting the right connector for coil circuit of EA allowing its correct performance in a wide frequency range of current.

2. SIMPLIFIED EA MODEL

Prior to experimental research it was decided to build a simplified model of the drive in Matlab-Simulink. The model was based on the scheme from Fig.1 with some particular parameters such as mutual inductance between the disc and coil and also disc resistance and RL parameters of coil circuit were determined on the basis of the waveforms obtained from the measurement system Fig.7. It should be noted that in the real system due to the disk movement the mutual inductance between the coil and the disc the changes. However, experimental studies show that noticeable disc displacement occurs after the first pulse of current

(Fig.11,12). Therefore, this simplification seems to be justified especially if we are interested in the maximum value and the time of the first pulse current. The parameters, which are used in the model, were experimentally determined for initial disc position relative to the coil, and they are shown in Table1.

Table 1. EA parameters

Parameter	Symbol	Magnitude
Coil inductance	L_c	94.5 [μH]
Disc inductance	L_d	0.2 [μH]
Mutual inductance	M	3.62 [μH]
Capacitance	C	100-1000 [μF]
Disc resistance	R_d	0.3 [$\text{m}\Omega$]
Coil resistance	R_c	25 [$\text{m}\Omega$]

Figure 2 shows the screen of model built in Simulink environments, and Fig.4 shows the sample coil current. The advantage of this environment is the ease of changes made to the model, and especially the ability to adapt ready-made elements such as a transistor or thyristor. The program also allows for the introduction of certain parameters such as resistance of the diode switches. Unfortunately, it does not allow for the introduction of real time switching.

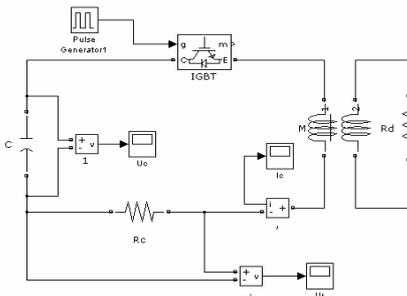


Fig. 2. Screen of EA model in Matlab-Simulink with IGBT transistor and diode .

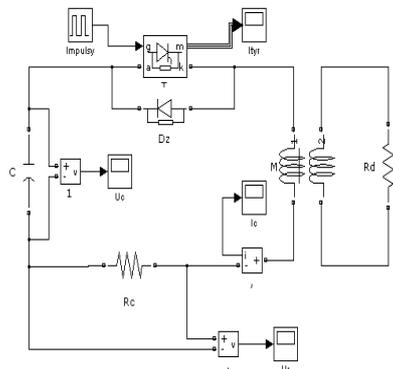


Fig. 3. Screen of EA model in Matlab-Simulink with SCR thyristor and diode .

The results of coil current and the capacitor voltage (Fig.4, Fig.5) were identical for both modeled cases, i.e. IGBT module with diode (Fig.2) and SCR with diode Fig.3.

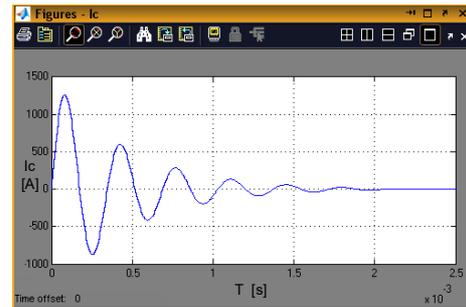


Fig. 4. Simulation of coil current from EA model

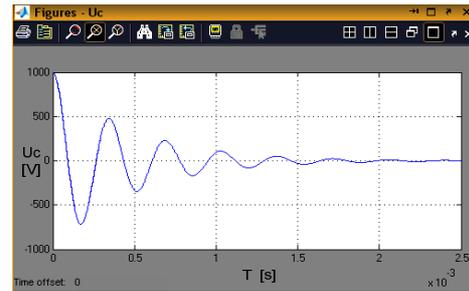


Fig. 5. Simulation of capacitor current from EA model

Realized simplified model was used to carry out a series of simulations for 10 different battery capacity capacitors from 100 μF -1000 μF . For better illustration of simulation results the five selected cases have been shown in Fig.6. Thanks to this a number of initial voltage values was determined for which the maximum current does not exceed the limit value (1300A) prepared a research of the IGBT. Simulations with a connector SCR with diode obviously gave identical results

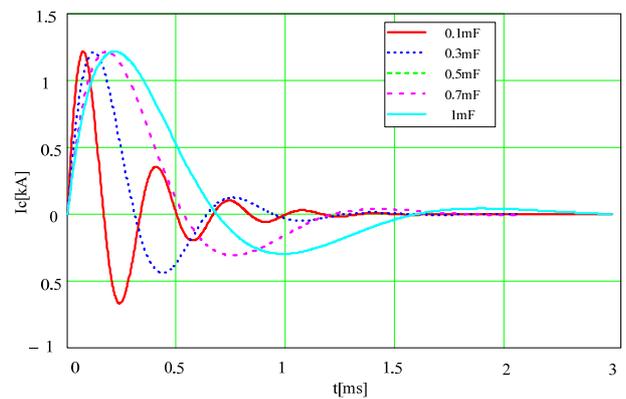


Fig.6. Simulation of coil currents for different capacitance.

3. EXPERIMENTAL MEASUREMENTS

Experimental studies were carried out in the existing measurement system, whose scheme is shown in Fig.7. The system allows for recording current in the coil circuit and recording displacement using an optical sensor (Fig.8),[2].

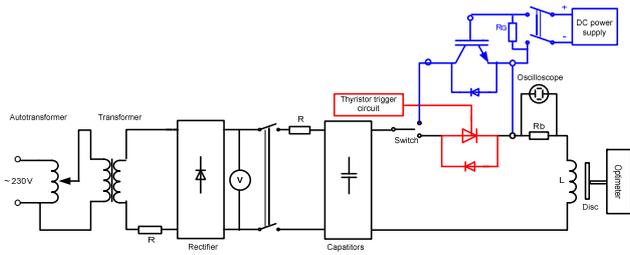


Fig. 7. Scheme of measurement system.

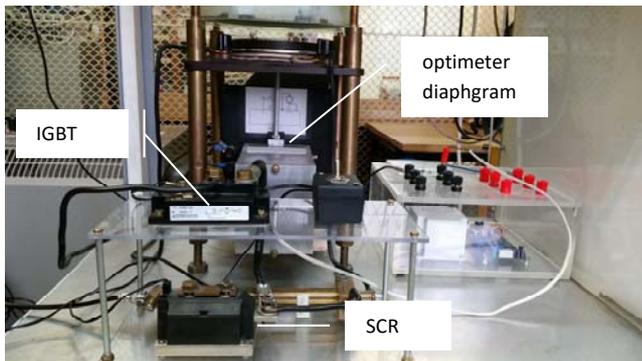


Fig. 8. EA measurement system.

The basic part of the measurement system used in the optical sensor is a light sensitive area, which is a system of parallel photo-elements. The resultant photo-element is supplied by 12V DC voltage source in the photodiode system Fig.9.

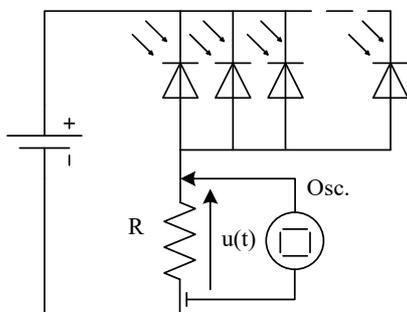


Fig. 9. Power supply system of photoelements.

Because the diaphragm of optimizer is connected to moving disc, during the movement it reveals a photosensitive surface. The signal measured across the resistance is in a certain range nearly proportional to the disc displacement. Fig.10 shows the static characteristics of the optimizer which was measured for load $R = 40k\Omega$ and which provides linearity in a satisfactory range and a good sensitivity [2]. The beginning of the sensor characteristics is at the point which voltage coordinate equals to 2.03V because, despite a complete obturation, a small amount of light from the LED lamp (the light source of optimizer) reaches the surface of the sensor. Using the sensor one should pay attention to the knee of characteristic in the vicinity of the point for which voltage equals to 12V.

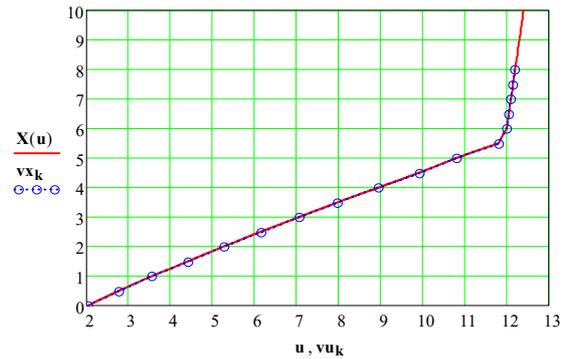


Fig. 10. EA system

In the existing EA system the capacitor battery consists of 10 modules $100\mu F$ each. Every module can be supplied by a maximum voltage up to 1000V. Research so far conducted due to the need of large capacitor energy used the battery with a capacity of no less than $500\mu F$. For such capacity range the system with a thyristor and diode behaved correctly. Fig.11 shows the oscilloscope screen presenting the coil current and the disc displacement at the capacity $C=1000\mu F$. Because nowadays there exist capacitors that can be charged to higher voltages, there is a tendency for the EA operation to take place at lower capacities. It should be noted that the decrease in capacity through series connection of modules is not a satisfactory solution due to the too large size of the battery.

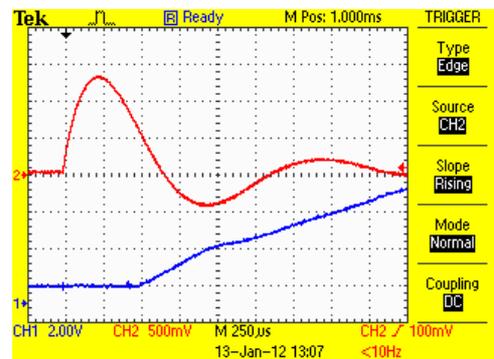


Fig. 11. Coil current (CH2) and disc displacement (CH1)- in system with SCR modules :initial capacitor voltage:350[V], capacitance:1000[μF],.

Initially carried out registration with smaller capacities with SCR and diode revealed problems related to commutation difficulties in the further part of waveform. Fig. 12 shows the screen of the oscilloscope with waveforms of coil current and displacement for $C = 100\mu F$. Then, the test recording was carried out using IGBT and diode switch where the gate circuit was closed using conventional contactor. Unfortunately, very often, but stochastically the noise appeared as shown in Fig.13. For this reason it was decided to use in the existing measuring system the SCR thyristor as switch closing circuit of IGBT gate. This time repeatable result of the coil current waveform was obtained. As can be seen from Fig.14 IGBT-diode switch is so rapid that there exist no commutation problems.

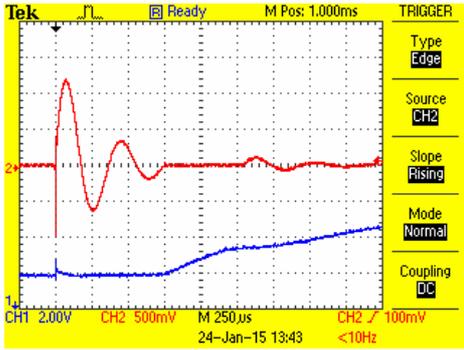


Fig. 12. Coil current (CH2) and disc displacement (CH1)- in system with SCR modules :initial capacitor voltage:800[V], capacitance:100[µF].

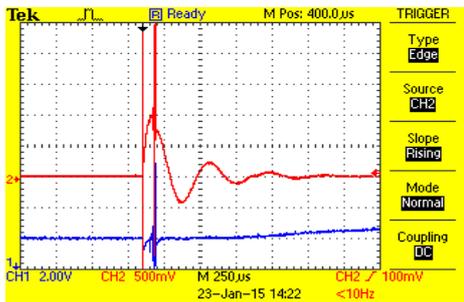


Fig. 13. Coil current with noise (CH2) and disc displacement (CH1)- in system with IGBT modules :initial capacitor voltage:800[V], capacitance:100[µF].

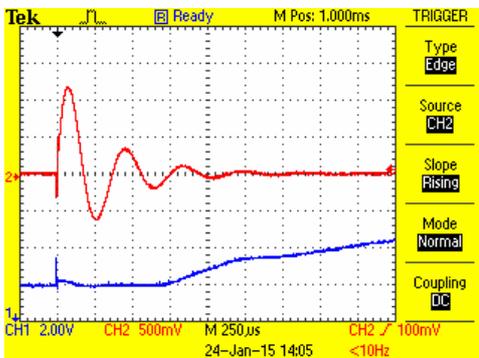


Fig. 14. Coil current (CH2) and disc displacement (CH1)- in system with IGBT modules :initial capacitor voltage:800[V], capacitance:100[µF].

4. APPROXIMATION OF RESULTS

In order to convert to the physical value and compare the received waveforms their results were exported to Mathcad application. The procedure performing conversion of signal generated by the optical sensor and registered by the oscilloscope for displacement waveform with use of the sensor characteristics (Fig.10) was built in Mathcad. Additionally, these results were processed using the filter approximation procedures of Mathcad environment (Fig.17,20). A block diagram of this operation is shown in Fig.15.

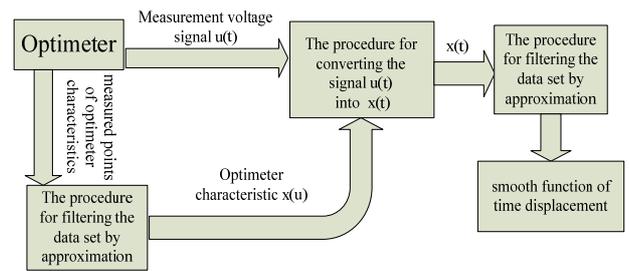


Fig. 15. Block diagram of signal processing

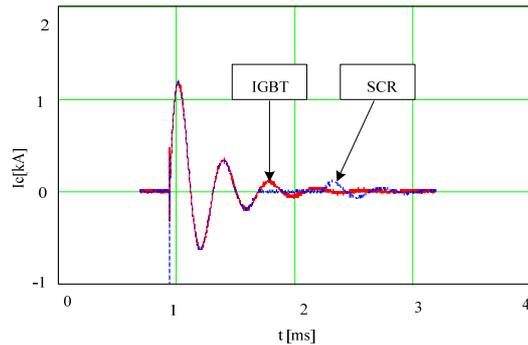


Fig. 16. Imported data of coil currents.

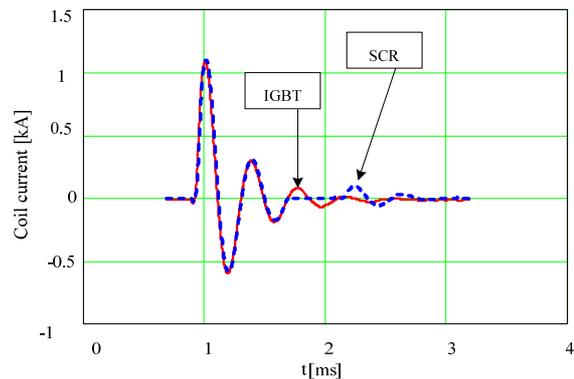


Fig. 17. Approximated coil currents.

As can be seen from the comparison of waveforms of the coil currents in Fig.17 they are identical in value. You can see clearly that the thyristor for 3-th positive current pulse went off with delay. Fig.20 presents together, after the approximation and conversion, the displacement waveforms obtained from the measurement with SCR and with the IGBT and also current waveform in the coil circuit obtained from system with SCR. It turns out that the displacement waveforms start to slightly bifurcate. It is surprising that at the end of the displacement waveform which was obtained from system with SCR gained a slight advantage. However, the result of this measurement may be affected by disturbance, which was induced during the triggering in circuit of optimizer. For example, a test in the system with SCR for a slightly lower voltage of capacitor shows another character of the displacement function (Fig.21, Fig.22).

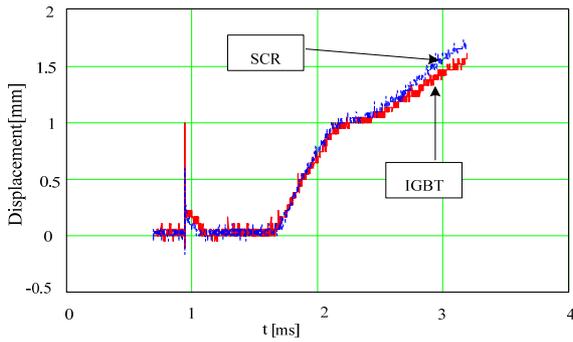


Fig. 18. Imported data of disc displacement.

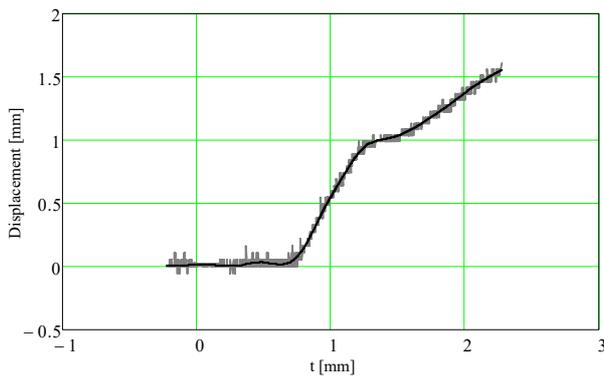


Fig. 19. Imported data of disc displacements and approximation.

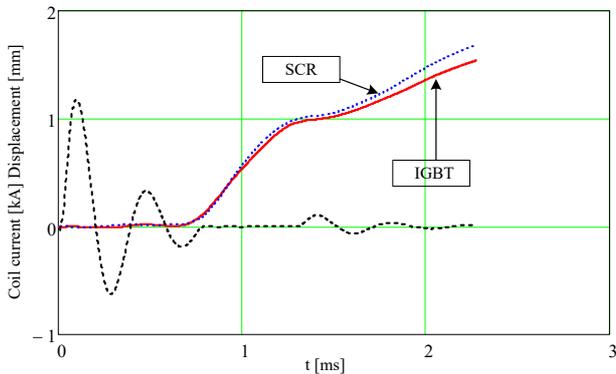


Fig. 20. Comparing displacement from system with SCR and IGBT modules with coil current.

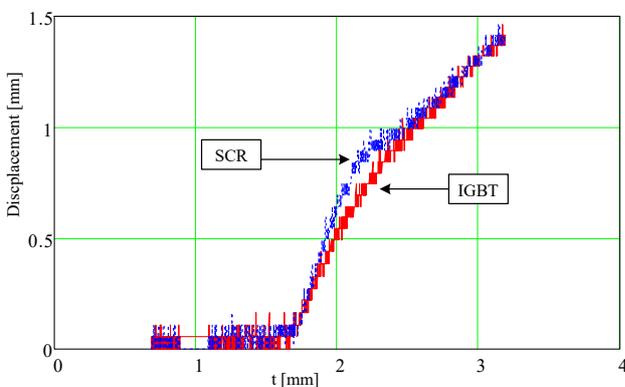


Fig. 21. Imported data of disc displacements

Although the maximum displacement of the disc in the system with the SCR seems to be not less, however, the fact that the defective behavior of this system is the stochastic one causes that the SCR cannot be used for the dynamic cases because the displacement function must be repeatable due to the synchronous work of EA in a hybrid circuit breaker.

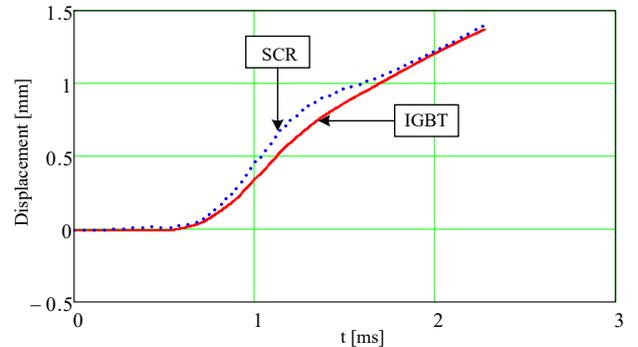


Fig. 22. Imported data of disc displacements

4. CONCLUSIONS

The results of the research presented in the article show the correct operation of SCR with diode switch in the EA system but especially at low capacities of capacitors battery. Studies were also performed with all modules in turn. In all these cases, the switch based on IGBT behaved correctly. Provisionally the cause of malfunctioning of the system with SCR is explained by much higher value of the parameter defining the switching time that for the SCR is $t_{on} = 25\mu s$ and for IGBT $t_{on} = 0.25\mu s$. It should be pointed out that thyristor modules which were widely available until recently generally had a higher allowable maximum value of instantaneous current than the for IGBTs. However, the fast development of semiconductor devices indicates that for such dynamic systems as EA, the switch based on IGBT will be more willingly used and versatile because of its speed.

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