EFFICIENCY MEASUREMENT OF THE MOTOR OPERATOR

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Abstract: All producers want to develop devices with low power consumption and with high level of reliability. Therefore, the efficiency and power measurement of the motor operators is very important. It is used during the research and development and for the quality assessment of products as well. In this way, it could identify the parts with the highest power losses. This method enables us to look into the motor operator and into the energy balance. It gives the results which can be used for fulfilling the requirements of the market.

Keywords: Efficiency, power consumption, motor operator, circuit breaker

1. INTRODUCTION

Motor operators are used for switching of circuit breakers. They provide safety operation of circuit breaker's system. For the reliable and faultless function all their parts must be designed very well because the motor operator is as strong as the weakest part inside. This is the reason why is necessary to know how these parts of motor operators work in order to find the most critical parts.

The basic function of motor operators is changing electrical energy to mechanical energy, which is needed for switching of the circuit breaker. It is a system of electrical and mechanical parts connected together. At each of these parts there are power losses. One of the many ways how to diagnose the possible critical places is to find out the part with the highest power losses. It means to measure the input and output energy of all parts inside the motor operator. These parts are the power source, the motor, the gear box and the ratchet wheel.

2. FLOWS OF ENERGY

The circuit breaker is switched on and off by means of the control lever driver. The motor operator needs enough force on the lever see *Fig. 1*.

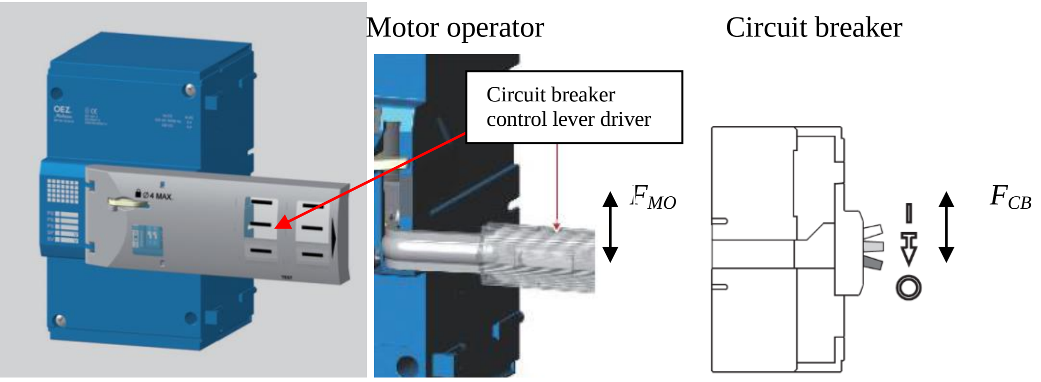

Fig.1 Picture of the motor operator and function with circuit breaker [1]

The force of motor operator must be higher than the maximum force on the lever of circuit breaker:

$$F_{MO} \geq F_{CB} \tag{1}$$

The motor operator moves a distance $S_{OFF\text{-}ON}$ from OFF position to ON position. Therefore, the work done by force F_{MO} on the lever of circuit breaker that travels $S_{OFF\text{-}ON}$ is given by the line integral:

$$W_{MO} = \int_{S_{OFF-ON}} F_{MO} \cdot ds = \int_{OFF}^{ON} F_{MO} \cdot ds \tag{2}$$

And the energy is equal to work:

$$E_{MO} = W_{MO} \tag{3}$$

If efficiency of the motor operator η_{MO} was 100 %, input energy $E_{MO\text{-}in}$ would be equal to output energy E_{MO}. Because the motor operator is not the Perpetuum mobile, the input energy $E_{MO\text{-}in}$ is:

$$E_{MO-in} = \frac{W_{MO}}{\eta_{MO}} \tag{4}$$

Nevertheless, the efficiency of the motor operator is unknown. The input energy is equal to electrical work $W_{MO\text{-}in}$. It is calculated from input voltage and current consumption during switching time *T*.

$$W_{MO-in} = \int_0^T u(t) \cdot i(t) dt \tag{5}$$

For a better calculation motor operator is connected to the DC power source with constant voltage *U*. Therefore, the input energy is calculated from average input power $P_{in\text{-}avg}$ and time of switching *T*.

$$W_{MO-in} = P_{in-avg} \cdot T = U \cdot I_{mean} \cdot T \tag{6}$$

The same result is given if the calculation from electric charge *Q* is used, which is the area below the current curve for time *T*.

$$W_{MO-in} = Q_{in} \cdot U = U \int_0^T i(t) dt \tag{7}$$

At this point, the input energy, the output energy and the energy representing losses of motor operator are known. This energy is redistributed to the parts of motor operator, see *Fig.2*.

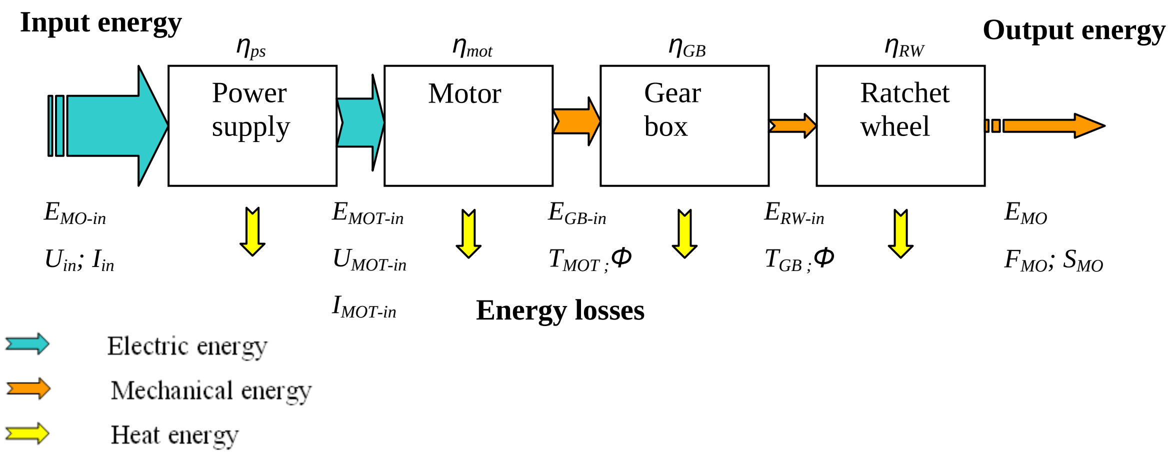

Fig.2 Parts of motor operator and flow of energy.

Energy balance of this system is given:

$$E_{MO-in} - E_{MO} - E_{lost} = 0 \quad (8)$$

$$E_{MO-in} \cdot \eta_{MO} = E_{MO-in} \cdot \eta_{PS} \cdot \eta_{MOT} \cdot \eta_{GB} \cdot \eta_{RW} = E_{MO} \quad (9)$$

Therefore, the efficiency of MO is equal:

$$\eta_{MO} = \eta_{PS} \cdot \eta_{MO} \cdot \eta_{GB} \cdot \eta_{RW} \quad (20)$$

Efficiency of the parts of motor operator can be calculated:

Power source

$$\eta_{PS} = \frac{\int_0^T u_{in}(t) \cdot i_{in}(t)dt}{\int_0^T u_{MOT-in}(t) \cdot i_{MOT-in}(t)dt} \quad (31)$$

Motor

$$\eta_{MOT} = \frac{\int_0^T u_{MOT-in}(t) \cdot i_{MOT-\mathrm{int}}(t)dt}{\int_0^{\Phi} T_{GB}(\phi)d\phi} \quad (42)$$

Gear box

$$\eta_{GB} = \frac{\int_0^{\Phi} T_{GB}(\phi)d\phi}{\int_0^{\Phi} T_{RW}(\phi)d\phi} \quad (53)$$

Ratchet wheel

$$\eta_{RW} = \frac{\int_0^{\Phi} T_{RW}(\phi)d\phi}{\int_{OFF}^{ON} F_{MO} \cdot ds} \quad (64)$$

3. MEASUREMENT

The key condition for the measurement of all parts is using the same circuit breaker which has to be connected to the motor operator. Force and distance of circuit breaker’s lever is measured via the force sensor 200N (accuracy class 0,05) and a distance sensor. The force curve is in the *Fig. 5*.

For voltage and current analyses 4-channel oscilloscope with voltage differential and current probes was used. It can be seen in the *Fig. 2*.

Torque which must be given by the motor was measured via special adapter and motor operator had to be disassembled. It was repeated for torque of ratchet wheel as well. These tests were carried out via torque and angle sensor. The curves are in the *Fig. 3*.

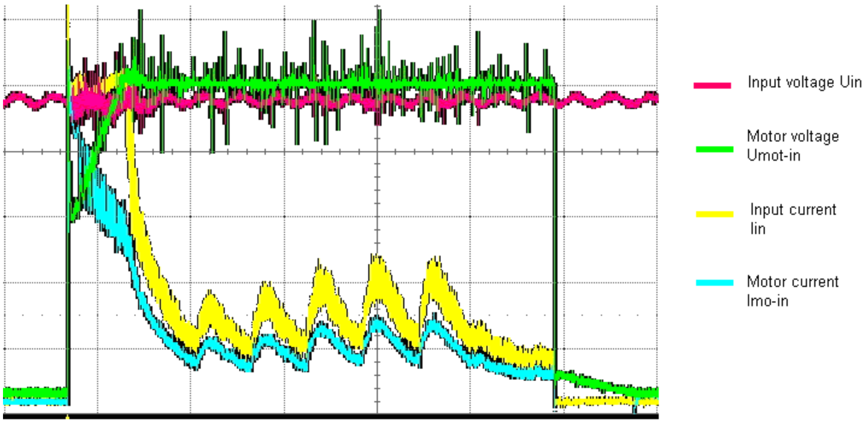

Fig.2 Voltage and current curves on the power source and motor.

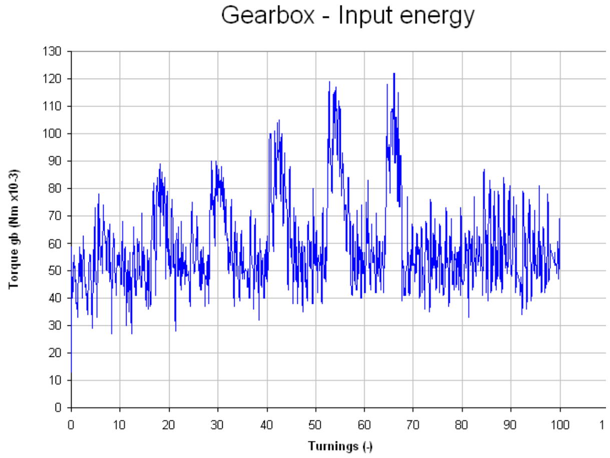

Fig.3 Torque curve on the gerbox.

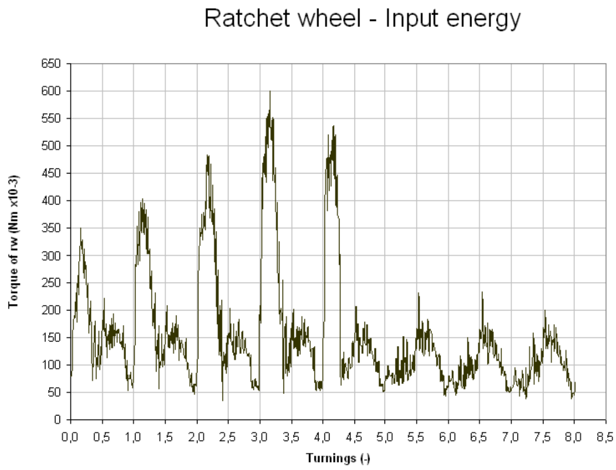

Fig.4 Torque curve on the rathet wheel.

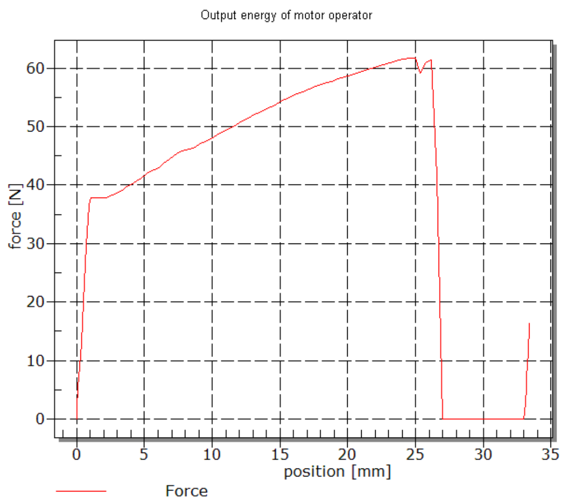

Fig.5 Torque curve of the motor operator.

Motor operator					
#	Part	Measured	Energy [J]	Efficiency	Energy looses
1	Electronic input	Voltage, current, time	22,19		
				85,8%	14,2%
2	Motor input	Voltage, current, time	19,04		
				82,2%	17,8%
3	Gearbox input	Torque, turnings	15,66		
				59,2%	40,8%
4	Ratchet wheel input	Torque, turnings	9,27		
				13,2%	86,8%
5	Circuit breaker	Force, distance	1,22		
					94,50%

Fig.6 Efficiency of motor operator .

4. CONCLUSION

The motor operator is a very complicated device. Energy losses analysis can give us information about the behaviour of each part. As can be seen in *Fig. 6* the efficiency of the motor operator is only 5,50 % and energy losses are 94,50 %. Furthermore, the worst parts of the motor operator in the sense of energy losses can be identified. The current curves on power source and motor reflects the torque on mechanical parts. These tests could be used for:

- Improvement of electronical and mechanical parts of the motor operator,
- comparasion of tests at diferent load of motor operator,
- studying the behavior of parts at different climatic conditions (IEC 60947-1 etc.).

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