CALCULATION AND MEASUREMENT OF THERMOSTATIC BIMETAL DEFLECTION IN MOLDED CASE CIRCUIT BREAKER

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Abstract: This paper deals with a thermal overload trip unit in automatically operated electrical switching devices. The first part describes an application of thermostatic bimetal in thermal overload trip unit. The main part is devoted to analytical calculation and measurement of specific thermostatic bimetal type contained in thermal trip unit of molded case circuit breaker. It is measurement of deflection depending on temperature change using photoelectric laser sensor. The analytical results are compared with the measured results at the end of the paper.

Keywords: thermostatic bimetal, molded case circuit breaker, measurement

1. INTRODUCTION

Overcurrents generate excessive heat, leading to the risk of damage to electrical equipment. There are many components in automatically operated electrical switching devices used for scanning and evaluating overcurrents. Currently, the most common such component is a thermostatic bimetal, electromagnet and electronic evaluation of overcurrent using the current transformer and Rogowski coil. Thermostatic bimetal is a classic element mainly used for detection of small overcurrents caused by overloads. It is the main structural component of the thermal overload trip unit and thermal overload relays. In general, overcurrent trip unit is the main functional element of automaticly operated switching devices. It scans and evaluates the current flowing through the device (circuit breakers, motor starters) and instructs the device to trip acting directly on its switching mechanism.

2. THERMOSTATIC BIMETAL IN ELECTRICAL SWITCHING DEVICES

Thermostatic bimetal is made of two different metals bonded together. The two metals have different thermal expansion coefficients, so the bimetal bends when heated. Therefore, the basic thermostatic bimetal characteristics is an ability to change its shape due to a temperature change. In electrical switching devices this ability is used in thermal trip unit for a protection against overloads. If an obstacle (a tripping latch in circuit breaker) prevents the deformation of bimetallic strip as an opposite force to the internal forces causing the deformation, these internal forces can do a mechanical work on the track of deflection, release the latch of tripping mechanism and trip the circuit breaker. [2]

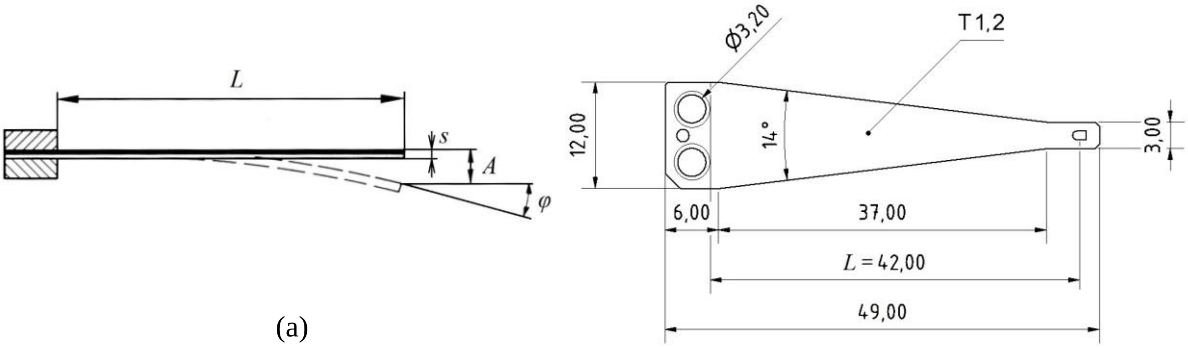
Thermal trip unit works on the principle of thermal effect of the current. The greater current, the hotter the bimetallic strip becomes, and the more it bends. Heat generated by the strip is converted to the force releasing the latch of the tripping mechanism. A tripping characteristic of thermal trip unit is time dependent. The greater the overcurrent through the breaker, the shorter the time it takes to interrupt the current. If the overcurrent of certain value passes for a certain time (depending on the tripping characteristic of the breaker), the bimetallic strip heats up and bends. After bending a predetermined distance, the strip makes contact with the tripper bar activating the tripping mechanism. Then, a power contacts of the breaker are automaticly disconnected using an energy stored in the switching mechanism springs. [5]

In the switching devices the bimetal element is most often shaped into straight, rectangular or trapezoidal cantilever. It is heated directly by passing current through itself or indirectly by a heating strip or winding with a defined resistance. Another possibility is a combined heating of the bimetal using the two previous methods. [5]

3. CALCULATION OF THERMOSTATIC BIMETAL DEFLECTION

Knowledge of the temperature dependence of deflection, a heating characteristic and a temperature dependence of force developed by the bimetallic strip (for partially or fully restrained deflection caused by the tripping mechanism) is important to determine the time needed to release the tripping latch by the strip (for the certain overcurrent). Deflection is not dependent on a width (shape) of the strip.

The calculation is performed for the bimetal used in overcurrent trip unit of a Sentron 3VA12 molded case circuit breaker with a nominal current of 250 A, intended for a line protection against overload and short circuit. The breaker is equipped with a thermal-magnetic overcurrent trip unit, which is a separate removable block. The trip unit consists of a thermal trip unit for protecting against overload, and a magnetic trip unit for protecting against short circuits. The both trip unit components are series-connected [3]. In the each pole of the thermal trip unit a straight trapezoidal bimetallic strip with an interlayer of copper is used. Its dimensions are shown in **Figure 1** (b). It is heated indirectly by a parallel current path to which is fixed.



(a) (b)

Figure 1: Deflection of straight thermostatic bimetal cantilever strip (a) and dimensions of the strip in trip unit (b)

Deflection of straight thermostatic bimetal cantilever strip for the temperature change is calculated according to [1] by following equation:

$$A_s = \frac{a \Delta T L^2}{s} = \frac{0{,}53 k \Delta T L^2}{s} \quad (1)$$

Where A_s is deflection [mm], a is specific thermal deflection [K^{-1}], k is specific thermal curvature [K^{-1}], ΔT is temperature change [K], L is active length [mm] and s is thickness [mm].

The deflection of the strip was calculated using equation (1). The specific thermal curvature according to the manufacturer [1] is $k \pm 5$ %. The calculation considers an active strip length of $L = 42$ mm, because of a measurement method. The calculated deflection A_s for temperature change $\Delta T = (0 \div 160)$ K considering $k \pm 5$ % is shown in **Table 1:** and a graphical dependence is shown in **Figure 3**.

Temperature change [K]	Deflection [mm]		
	k	*k* - 5%	*k* + 5%
0	0,00	0,00	0,00
20	0,58	0,55	0,61
40	1,15	1,10	1,21
60	1,73	1,64	1,82
80	2,31	2,19	2,42
100	2,88	2,74	3,03
120	3,46	3,29	3,63
140	4,04	3,83	4,24
160	4,61	4,38	4,84

Table 1: Calculated values of bimetallic strip deflection depending on temperature change

4. MEASUREMENT OF THERMOSTATIC BIMETAL DEFLECTION

4.1. MEASUREMENT METHOD

The aim of the measurement was to verify the calculated bimetallic strip deflection depending on temperature change. The measurement was performed in a Professor List Technology Park FEEC BUT.

A hole for sensing the position of the bimetallic strip free end was drilled into the 3VA12 circuit breaker plastic cover. The strip deflection was measured using a special extension piece with a free-hanging plastic tube and a measuring disc. It was mounted directly on a plastic cap of the strip free end. To the strip passive layer, two thermocouples for the temperature measurement were fastened. The first was fastened to the free end, another to the fixed end. The both thermocouples for the bimetal temperature measurement and also a thermocouple for an ambient temperature measurement were connected to an universal multi-channel logger.

For the deflection measurement, the tripping mechanism of the breaker was removed. The breaker was mounted to a vertical stand in a classic working position and a pole, in which the strip temperature and deflection was measured, was connected to a current source. For the disc position measurement a photoelectric laser sensor was fastened below the breaker and the sensor beam was aimed precisely to the center of the disc. In this measurement method, it can be considered that the measured disc deflection corresponds to the true strip deflection in the trip unit. The laser sensor was powered by a laboratory source. The analog laser output representing the detected distance in its operational measurement range was measured by a digital multimeter. The current flowing through the breaker was measured by a current transformer and digital multimeter. Scheme of the strip deflection measurement is shown in **Figure 2**.

The temperature dependence of the strip deflection was measured for heating by current of 262.5 A and 325 A and subsequent cooling. These are the values of conventional non-tripping and tripping current of molded case circuit breaker tripping characteristic. According to [5] conventional non-tripping current (I_{nt} = 1.05 x I_n = 262,5 A) is a specified value of current which the thermal unit can carry for a specified time (2 hours) without operating. Conventional tripping current (I_t = 1.3 x I_n = 325 A) is a specified value of current which causes the thermal unit to operate within a specified time (2 hours).

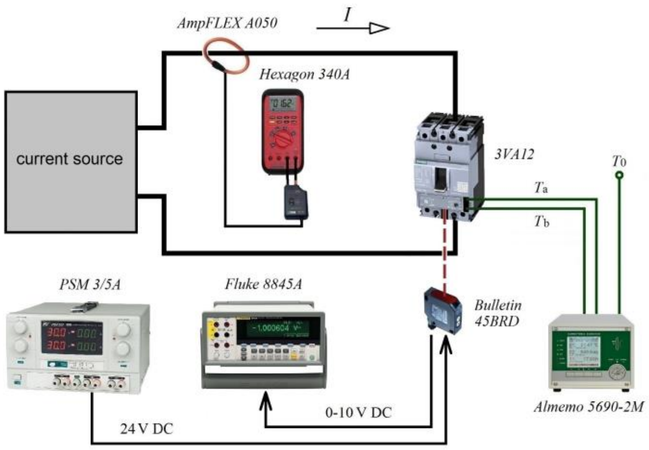


Figure 2: Measurement of thermostatic bimetal deflection

The measured values of the laser sensor DC output were converted to the corresponding distance of the disc in the sensor measuring range. Instantaneous strip temperature T is the mean temperature of the free end T_a and fixed end T_b of the strip. Instantaneous temperature change of the strip is:

$$\Delta T = T - T_i \qquad \text{[K]} \qquad (2)$$

where T_i is measured initial mean temperature of the strip. Deflection of the strip (disc) is:

$$A_m = l_i - l \qquad \text{[mm]} \qquad (3)$$

where l_i is measured initial distance of the disc in the sensor measuring range. Absolute error of the deflection meaurement is:

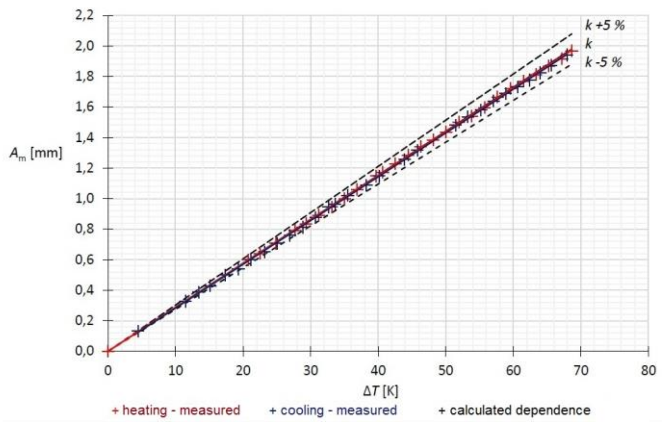
$$\Delta_A = |A_m - A_s| \qquad \text{[mm]} \qquad (4)$$

and relative error:

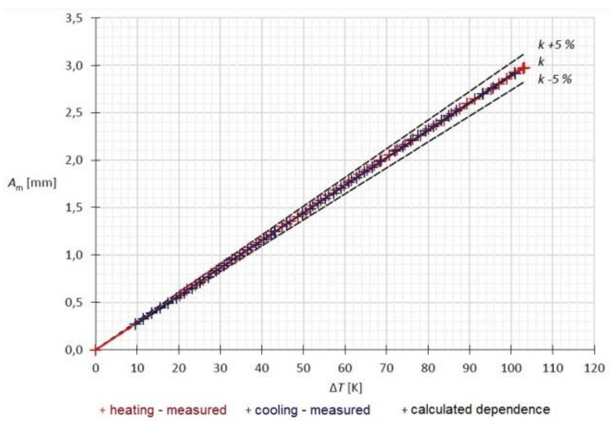
$$\delta_A = \frac{\Delta_A}{A_s} \cdot 100 \qquad [\%] \qquad (5)$$

where A_s is the calculated deflection.

4.2. MEASURED DATA



(a)



(b)

Figure 3: Measured bimetallic strip deflection depending on temperature change for heating by current of 262,5 A (a) and 325 A (b)

5. CONCLUSION

As can be seen in **Figure 3** for heating by the both currents 262.5 A and 325 A and subsequent cooling the bimetallic strip deflection is directly proportional to the temperature change. A whole range of the measured values is within a linearity range (-20 ÷ 200) °C given by the strip manufacturer in [1]. According to [1], the linearity range is the temperature range within which the strip deflection does not vary more than ± 5% from the deflection as calculated from the specific thermal curvature and the thickness.

The measured deflection for heating by current 262.5 A and subsequent cooling does not vary more than 2.9 % from the calculated deflection. The steady state temperature change of 68.7 K corresponds to the deflection of 1.97 mm. In the case of heating by currnet 325 A and subsequent cooling the measured deflection does not vary more than 2.7 % from the calculated deflection. The steady state temperature change of 103.2 K corresponds to the deflection of 2.98 mm. The measured dependence $A_m = f(\Delta T)$ therefore corresponds to the calculated dependence $A_s = f(\Delta T)$ when considering the active strip length of 42 mm. However, the measurement was affected by the following measurement errors:

- The measurement method. In the whole measurement range it is considered that the measured disc deflection corresponds to the true strip deflection.
- Uneven distribution of temperature when heating by the current. It is contemplated that the strip temperature is the mean value of the free and fixed end of the strip.
- According to the manufacturer the strip is straight at the temperature of 20°C. There is no deflection at this temperature. In this measurement it is contemplated that the strip is straight at the initial temperature T_i before heating.
- Instruments error.

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