AGEING OF MECHANISMS OF CIRCUIT BREAKERS

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ABSTRACT

This article gives the methodology to investigate the behavior of mechanisms for high-current LV and MV circuit-breakers in so-called "sleeping mode" which means that an apparatus performs a few or absolutely no operations during several years.

INTRODUCTION

Nowadays plenty of researches concerning electrical apparatus' reliability have been done. But almost all of them take into account the endurance only. Nevertheless, lots of circuit-breakers, especially for the high current rankings, work in so-called "sleeping mode" which means they perform no operation during several years or just a few operations. In this case there is no longer endurance problem. The reliability of an apparatus is limited not by the number of operations but by the duration of ageing.

Because of corrosion, adhesion, etc. a significant increase of friction coefficient may occur. Difficulties might appear because of increase of the initial force which is necessary to move every joints of the mechanism to perform successful tripping.

It was decided to build a methodology which can predict the behavior of mechanisms in "sleeping mode". A technical action was launched to study ageing of mechanisms for high-current LV and MV equipment. It is necessary to build a verification test which represents the ageing of a mechanism. The test should allow checking the behavior of different solutions to predict their reliability in "sleeping mode". For a new design it is necessary to be able to compare the behavior of possible solutions to choose the best one for the particular application. So, this paper is dedicated to testing and comparing different technologies and solutions but not to testing existing products.

METHODOLOGY

The methodology consists of 4 steps: physical model, experimental model, accelerated ageing test and conclusion and perspectives. The steps are described below.

The methodology is being developed generally for testing future solutions for new-designed equipment. It is necessary to mention that the methodology does not take into account the influence of grease.

There are 3 main reasons not to take grease into account:

- modern materials, surface treatments and coatings give opportunity to develop solutions without grease;
- grease dramatically lose its characteristics in case of "sleeping mode". *Using grease gives very big dispersion in the characteristics of a mechanism during its life and it is impossible to precisely predict the behavior of grease. The best way to keep stable characteristics is to find a solution without grease. This is the most progressive way for investigations in this field;*
- climatic tests in presence of grease often make no sense because ageing of grease during climatic test is not at all the same as ageing in real conditions.

It is possible to conclude that using grease gives difficulties in defining climatic test scheme and interpreting its results, and also it does not give valuable output for the scope of the study. Otherwise, solutions without grease are modern and give more prospects so when building the methodology for the future applications, it is better not to use grease. This methodology will help to check if it is possible to build a mechanism with no grease.

Physical model

Joints in a mechanism are the most impacted by ageing in sleeping mode. Possible fault in this mode is caused by blocking a joint when the friction in it is too high. It is not efficient to investigate all the joints in a mechanism. At the first step it is necessary to choose the most critical joints from the mechanical point of view using the physical model. Also it is necessary to calculate the force in these joints to be able to build a experimental model of them at the next step. So, there are two problems solved by these calculations: "blocking of the mechanism" and "reactions and forces in the mechanism".

From mechanical point of view the most critical moment during tripping in case of blocking a mechanism by friction is the moment of starting right after the mechanism receives a command for switching. The friction force also has the biggest value when mechanism is not moving. That is why it is necessary to calculate the mechanism at the start of motion. As parts do not move yet, static equations can be used. Equations should include friction forces if it is possible. It is necessary to make static calculations of each part sequentially from the first to the last. For each part joints are replaced by their reactions. For the first part, the force which is applied is known (usually it is a force applied to the operation (main) shaft). Knowing this force reactions for joints can be calculated. For the next part in the kinematic chain the reaction of the joint connecting this part with the first one should be taken as an external force. Going like this through all the kinematic chain of the mechanism, all the forces for all the joints can be calculated one by one. Obviously, if a coefficient of friction in the equation is increased, the force which applied to the next part from the previous one will be decreased. By recalculating all the mechanism for different values of the friction coefficient for different joints, it is possible to find which one is more prone to be blocked than the others under the same circumstances. It is the **weak point** in the mechanism in "sleeping mode" from the mechanical point of view. There are several different constructions of joints used in mechanisms of circuit breakers. The most common of them are pin-joint, latch, ball-bearing and slider. It is necessary to choose at least 1 critical joint of each type (pin-joint, latch, etc.) because it is difficult to compare different types together.

Experimental model

In the previous step were chosen the most critical joints in the mechanism to be investigated. But studying the joint using a real mechanism appears to be quite complicated.

Several difficulties are found, which are:

- almost impossible to access the joint for measurements within the mechanism;
- joints are usually hidden deep within the mechanism. *In real application medium inside the apparatus changes very slowly, all airflows are laminar. All the parts are impacted similarly. But during climatic test air in a chamber changes fast. Applying a climatic test to an assembled apparatus causes turbulence inside. Distribution of aggressive medium is not homogeneous within the mechanism, the outside parts are more impacted than the inside ones. This does not correspond to the real case of ageing. But using the experimental model of a single joint can provide similar conditions for all the tested parts;*
- fully-assembled product is expensive, so it is impossible to launch a big batch of tests using real equipment.

This is why the use a experimental model of the particular joint is needed as chosen before.

The model (test bench) has to satisfy the following requirements:

- the bench should allow measurement of joint friction easily and precisely;
- the bench should represent correctly materials, surface quality, stress and geometry of the real joint;
- ageing of the bench itself should not give dispersion into measured parameter of the joint.

Based on those requirements were built two types of test benches: one for pin-joint and one for latch. Construction of the bench allows to investigate different joints for different mechanisms making some minor changes in the part of the bench which directly models the joint. The principles for the bench for pin-joints are shown on Figure 1:

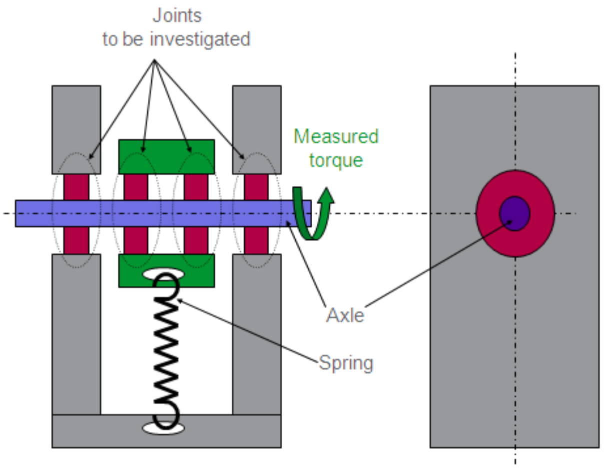


Figure 1. Principles of the test bench for pin-joint.

The force in a pin-joint model is given by a spring. Friction torque in the model is measured by turning the axle using a torque capture. The bench includes 4 samples of the studied pin-joint, i.e. all the connections between the body and the axle are made with models of the investigated pin-joint. It means that only the ageing of these pin-joint models will affect the torque that is measured.

Figure 2 gives the principles of the test bench for half-moon latch:

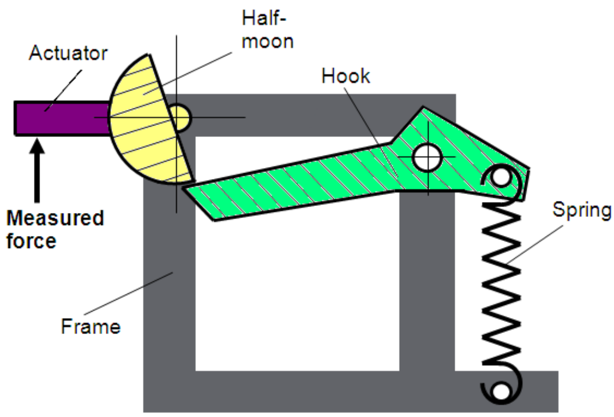


Figure 2. Principles of the test bench for half-moon latch.

Half-moon and hook should be an exact copy of the solution which is being studied. Shape, materials, surface treatment etc. should be the same. The spring gives necessary contact force between half-moon and hook. It is necessary to measure the force which is necessary to move the actuator. If this force is below the threshold (limit) value, everything is OK. Otherwise there may be a problem during tripping. The limit is given by the maximum force which the release in a real product might produce.

Accelerated ageing test

It is necessary to perform accelerated ageing of the test benches to model several years of ageing of the joint. For this purpose was built a cyclic climatic test with salt fog, humidity and high temperature. The test is based on standard climatic tests but it is less severe than standard ones to be able to only model several years of ageing, but not to check the corrosive resistance. Humidity and high temperature level are parameters to be varied within the range. During the test it is necessary to perform some operations and measure the friction force. The idea is to have several points with different durations of ageing and different numbers of operations which have been made before. For example, to test 6 benches with 3 points after 2, 4 and 6 days of ageing, the following method is used: after 2 days only 2 benches are tested. After 4 days it is necessary to test these first 2 and 2 new, which have not been tested before. After 6 days are tested all 6 benches (4 benches have been tested recently, 2 are new). By doing this, "new" bench (the benches which haven't performed any operations after ageing yet) are tested at each point, so results for these "new" benches can be compared with the others which have the same duration of ageing but which made operations previously. It helps to determine the influence of making operations. Also the increase of a friction force as function of time can be determined by comparing the data from the first measurement on different benches with different times of exposure.

The whole test duration varies depending on results. As soon as exceeding the threshold limit of a controlled parameter which was found by physical model, there is no need to continue the test. To give the example, Figure 3 shows a group of diagrams of the tripping force in coordinates "displacement of the actuator, mm – force on the actuator, N" for different time of exposure (different benches) from the tests on latch models:

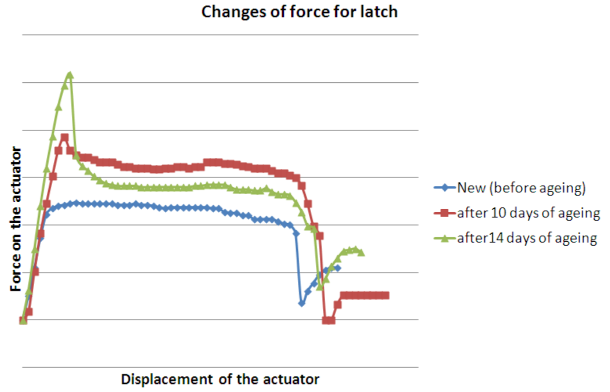


Figure 3. Example of the experimental data.

As expected, the friction has its maximum level near the starting point. The longer is the ageing, the higher is the peak and the higher is the ratio "peak value / low value".

Performing several batches of tests varying one parameter at each time allows collecting statistics of behavior of the tested joint.

For the time being, not all the batches of test are completed. But it is already possible to make some conclusion from the results of the test for latch. The behavior of latch after long-time ageing has been checked. 5 operations after long-time ageing have been performed and the curve "displacement of the actuator, mm – force on the actuator, N" was obtained. It was found that for the current solution, only the first operation gives significant increase of tripping force. The second and the following operations give almost the same curve as this one observed on the new latch [Figure 4] and the values of force for 2nd and the following operations are definitely below the threshold value.

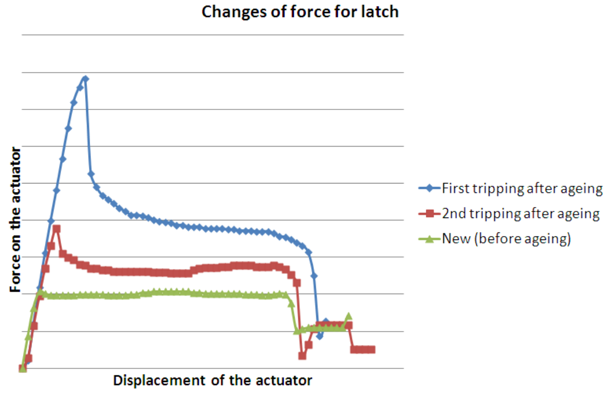
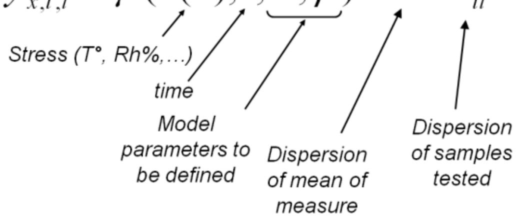


Figure 4. Behavior of latch depending on duration of ageing and number of operations.

The test shows that even after very severe ageing just 1 operation gives significant reduction of tripping force. Also, when putting the bench which performed 5 operations back on climatic test, the ageing goes with a velocity almost the same as for the not-aged bench. As a consequence of this, performing 1 operation is enough to "reset" ageing processes for the investigated solution of half-moon latch.

As a last step, it is necessary to predict the behavior of the joint in real application based on results of accelerated test. To make a correlation between the accelerated test and the reality are used bibliographical study, results of previous investigations and ageing model which is being built in collaboration with a French university. The test is specific because the quantity of data that are possible get from measurements is limited. It happens because the measurement implies the operation. When a measurement is made (operation performed), test conditions are changed. It means that it is only possible to make two measurements on one bench – one before ageing and one after ageing. The next measurement on this bench will be made for different conditions (measurement after 1 operation). To repeat the measurement, it is needed to test another bench. Also, because measurements cannot be repeated, only information about dispersion between measurements for different benches is obtained but it is impossible to evaluate dispersion of measurement for one bench. An ongoing study is aiming to build the model which should explain the behavior of our specimens in accelerated test. For this purpose, an acceleration factor of the test should be specified. The model is based on numerous works made on ADDT (Accelerated Destructive Degradation Tests), see for example [1]. Using Arrhenius law, Coffin-Manson relation and Peck's model and arranging test results for variations of temperature and humidity (test parameters) a model is being built which gives the value for measured characteristic $y_{x,t,i}$ as a function of "stress" which is a combination of characteristics of severe climatic withstand (temperature, humidity, salt fog concentration – the combination of this parameters is shown by 'x' value in the formula (1)), time, model parameters and dispersions (of mean of measure and of benches tested):

$$y_{x,t,i} = \mu(z(x), t; \underbrace{\alpha, \beta}) + \varepsilon + V_{ti} \qquad (1)$$



During the test, parameters and duration of the test are chosen in a way to keep measured values as close as possible to the threshold value (little bit lower or little bit higher of the limit value). Doing this makes the model more precise near the threshold. After building the model it will be possible to find an acceleration factor of the test. For this it is planned to make a long-term test and to use results of previous works and international standards for explaining results. Also, to have a reference, specimen of zinc has been put into the same climatic chamber with the test benches. Electrolytic zinc plating is a well-studied so knowing how the test affects the zinc specimen, it is possible to estimate how severe the test is. Polished metal plate with thin zinc coating is used as a reference specimen. During a climatic test the coating is getting thinner. When the test is finished, the thickness of the coating is measured and an estimation of the severity of the test for different applications is made. There are several different corrosivity categories of environments in international standards and the loss of thickness for zinc is given for each of them (see [2], [3]). For instance, 0,4 μm loss of thickness corresponds approximately to 1 year of ageing in the atmosphere with low corrosivity (class C2), see [2], [3], [2].

Conclusion and perspectives

Using the model of ageing of the joint, it should be possible to make a conclusion about reliability of the studied joint in "sleeping mode" for real applications. If it is the critical joint, it is also possible to estimate the reliability of the whole mechanism in sleeping mode. During designing new products by using this model it is possible to check the behavior of possible solutions in sleeping mode and based on test results to choose the most suitable one. In further steps, using this methodology in combination with endurance testing will allow to make a comparative table for all common solutions to create a design guide to help with the choice of a solution providing the best performance for all working regimes for each particular application. This should provide a way to ensure the performance when designing products operating in "sleeping mode" and to make users confident about all possible working regimes. Another positive effect will be the possibility to increase the maximum allowed duration of staying without operationing the apparatus.

REFERENCES

[1] Escobar L.A., Meeker W.Q., Kugler D.L. and Kramer L.L., 2003, "Accelerated destructive degradation tests: data, models and analysis", *Mathematical and Statistical Methods in Reliability*, World Scientific, 319-337.

[2] EN ISO 9223:2012, "Corrosion of metals and alloys; Corrosivity of atmospheres; Classification, determination and estimation", *European standard*, 3-4.

[3] EN ISO 14713-1:2010, "Zinc coatings; Guidelines and recommendations for the protection against corrosion of iron and steel in structures", *European standard*, 9.

[4] Mikhaylov A.A., Panchenko Yu.M., Igonin T.N., Kovtanyuk V.V., 2013, "Atmospheric corrosion of zinc: mapping of velocity of corrosion for European territory of Russian Federation", *Corrosion: Methods, Materials.*