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Terminal Arcing Forced Failure Test Design

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Terminal Arcing Forced Failure Test Design in Refrigerator Compressors

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ABSTRACT

Arc faults are caused by loose, damaged, or corroded connections of electrical terminals. These faulty terminal connections cause electrical current to spark or arc, between metal contact points. Terminal arcing generates enough heat to break down the wiring insulation and ignite any surrounding flammable material, which ends up with fires. Since it is not possible to detect arc failures at normal working conditions, an accelerated test is needed to simulate Arc Failures, caused by loose/weak terminal contacts in order to catch these faults before sending them to customer. European Fire academy reported that electrical failures including arc faults account for twenty-five percentage of building fires.

The purpose of this study is Simulation of Arc Failures that occurs in the field because of loose contacts of compressor or refrigerator terminals, and Arcing Test Acceleration in order to distinguish good and weak terminal connections in early stage. To this end, the proper stress factors will be defined, both reliable and faulty terminal samples will be prepared and tested, and Reliability Analysis will be performed in order to verify the obtained results.

As a result of this study, a forced failure test will be put into use and it will be possible to catch weak or loose terminal contacts caused by process faults which will emerge in the field. So that a big safety risk will be minimized on household and similar electrical appliances.

Keywords: arc faults, electrical terminal, wiring insulation, accelerated test, reliability, safety, household appliances

1. INTRODUCTION

Product safety is one of the main concerns in household appliances industry. Although it is important to optimize the performance of the electrical product, one should be paying much more attention to the reliability and safety of the product itself. This becomes a vital issue when it comes to household appliances. In this industry, the customer rightfully demands danger-free products, which they can comfortably use in their houses.

It should be noted that safety is considered as an integral part of product quality; therefore, the product quality features and indices can be linked to product safety (Ahmadian *et al*., 2020). Since reducing the product accidents and problems for consumers are our direct goals, every design-trial-test cycle should be carefully examined. Based on this fact, by improving the product safety, the household appliance company would increase its competitive strength, eliminate the warranty expenditures, and prevent the return of goods from the field (Azimian *et al.*, 2016).

One can evaluate the safety of the product according to possible risks and dangers that may encounter during working conditions. In refrigerator compressors for example, one of the most critical components is electrical terminals. Within this part, corroded terminals and loose or damaged wires should be classified as possible risky components which can cause fires on the refrigerator. One of the main reasons to why these parts are classified as dangerous parts is, issues like insulation breakdown and instant ignitions are quite possible if not carefully treated. For instance, fire incidents have occurred at refrigerators in India market due to extension cable usage and loose contacts of terminal groups. The company who owned this field problem proved that arc failures was the main cause for this unfortunate event.

If this incident is evaluated with "physics of failure" perspective, one can see the snowball effect as such:

- Abnormal conditions
  - Process faults on terminal groups,
  - Wrong customer usage,
  - Poor electricity infrastructure of India.
- Beginning of Failure
  - Arcing on loose terminals,
  - Heat increase and short circuits on extension cables,
- Growth of Failure
  - Plastic parts melt
  - Flame spillage arising from arcing
- Final Situation
  - Fires on Refrigerators

Figure 1. Fire Incident in India

The "physics of failure" above proves that if the necessary precautions are not taken, a minor problem can cause unbearable problems at the end of the day. To this end, the paper is going to target the subject incident and provide a reliable test structure to improve the safety of the product. This project came up to fulfill the need of an accelerated arc failure test to catch faulty terminal connections which can end up with arc ignition and fire in the field.

2. MATERIALS AND METHOD

As discussed in the introduction, the main purpose of the test is to simulate the arc failures caused by loose terminal contacts in the field and inflammation and fire starting by arc origin. In addition, for full product safety, simulating the failure will not give an optimal solution; that's why a test acceleration algorithm is used in order to distinguish good and weak terminal connections. With this algorithm, one will be able to catch the process faults of terminal grouping suppliers before sending them to their customers, and thus preventing the arc failures that can occur in the field. The test system can be summarized as below:

1. Electronic Load
2. Shaker
3. Frequency Generator
4. Power Amplifier

To begin with, terminal groups are received from India in order to prepare the test samples with the same conditions as in the India fire accident. The loose contact forced failure test is categorized as below and evaluated based on the duration of the arc failure and duration from arc failure to burning.

Table 1. Categorization of Faulty Test Samples

Test Sample 1	Overlapped touching between Male-Female terminals
Test Sample 2	Mutually touching Male-Female terminals
Test Sample 3	No touching but 0-1mm close Male-Female terminals

For this test design, stress factors are determined in a way to accelerate the arcing on faulty samples in a few minutes. The Reliasoft analysis were also helpful to define the test conditions for each mass production control. The design is studied by 2 Level Stress Factors:

Table 2. First FF Test Conditions

Stress Factors	Used Stress Levels	Accelerated Test Design 1	Accelerated Test Design 2
Temperature (*°C*)	70	a	1,3 a
AC Current (*A*)	0,7	b	2,5 b

By applying the first FF test conditions given at Table 2, arcing occurred on terminals in 90 days. Waiting for 90 days can be acceptable for a typical life test, but it is too long for an accelerated life test. Since test acceleration couldn't be achieved with the test conditions in Table 2, stress factors are changed. Temperature is removed and mechanical vibration that occurs during compressor running is used as a new stress factor together with line current. The defined stress levels are given in Table 3 for the second FF Test.

Table 3. Second FF Test Conditions

Stress Factors	Level 1	Level 2	Level 3	Level 4
Frequency (*Hz*)	c	1,5 c	c	1,5 c
AC Current (*A*)	d	d	1,5 d	1,5 d

By increasing the stress level factors, the test was accelerated to the demanding point. It is also important to state that mechanical vibration that occurs during the compressor running is used as a new stress factor together with the line current. The attempt to accelerate the test was successfully achieved and arcing occurred on faulty samples in minutes.

Arc observation during accelerated test and the darkening occurred on the contact is seen below at Figure 2.

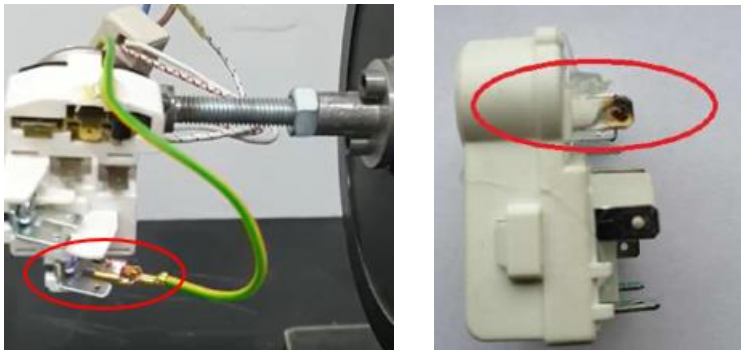

Figure 2. Arcing Occurred on Loose Contacts by Applying High Stress Factors

3. EVALUATION OF THE RESULTS

Both faulty test samples explained at Table 1 and correct test samples are tested according to the test conditions given at Table 3. The obtained test results are given below at Table 4:

Table 4. Results of Accelerated Tests

	Time to First Arcing (*min*)			
Sample Types	**Stress Level 1**	**Stress Level 2**	**Stress Level 3**	**Stress Level 4**
Faulty Sample 1	2,4	0,97	0,7	0,03
Faulty Sample 2	1,2	0,52	0,5	0,13
Faulty Sample 3	0,4	0,18	0,07	0,02
Faulty Sample 4	1,95	0,52	0,12	0,02
Faulty Sample 5	0,32	0,17	0,1	0,02
Faulty Sample 6	0,05	0,03	0,02	0,02
Correct Sample 1	60	60	60	60
Correct Sample 2	60	60	60	60

It is recorded that arcing occurs on the faulty terminals in maximum 3 minutes. Test conditions and passing criteria is selected by evaluating the accelerated test results. The selected test conditions for the FF Test passing criteria is given below at Table 5:

Table 5. Selected Test Conditions & Passing Criteria

Vibration Frequency	c *Hz*
Current Through the Terminal	d *A*
Test Duration	t *min*
# of Samples for Each Lot	6
Passing Criteria	No arcing observed within t *min*

4. VERIFICATION OF THE TEST DESIGN BY RELIASOFT ANALYSIS

For the ALTA results of the acceleration factor of Stress Levels 1 & 2, under new stress levels of a amperes and frequency levels of x and y were examined respectively. For the first level, the acceleration factor turned out to be 2,12. On the other hand, the acceleration factor for the second case turned out to be 2,96 with frequency level of y at the same ampere level. This proved that, by examining the results, one can realize that the acceleration factor begins to rise rapidly as the frequency increases. Yet, an interesting result shows up with the stress levels 3 & 4.

It was obvious that the biggest acceleration factor is seen on the fourth stress level, where the ac line current is b amperes and frequency is y Hertz. With these conditions, the acceleration factor turns out to be 7,1. A better representation is shown on the graphs given at Figure 3:

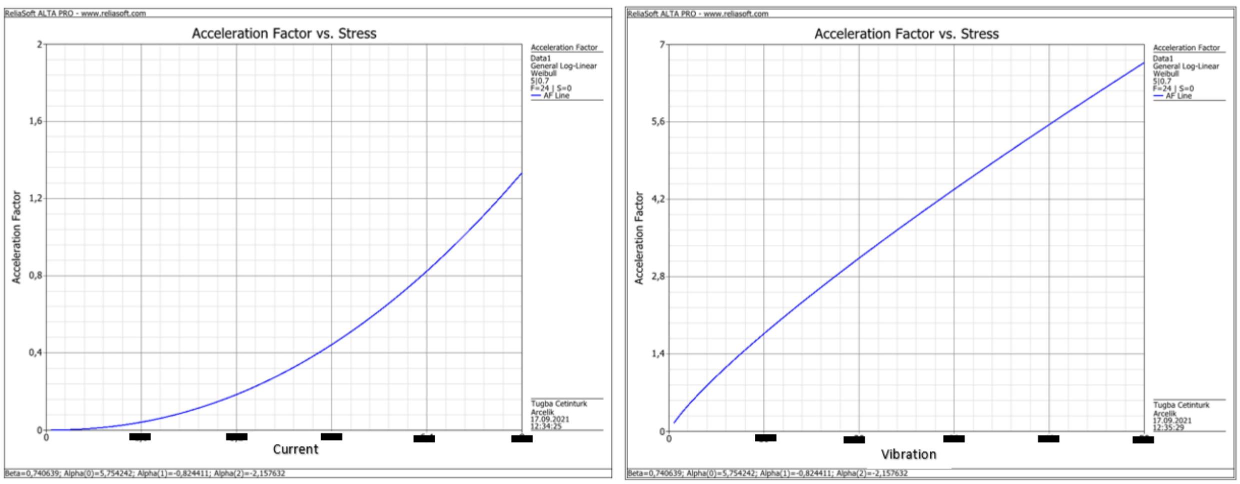

Figure 3. Acceleration Factor vs. Current and Vibration

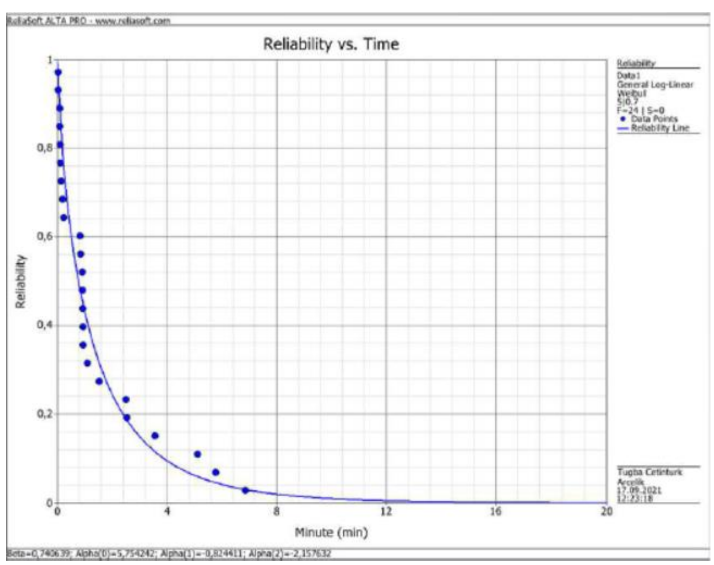

Figure 4. Reliability vs. Time

Last but not least, the graph at Figure 4 shows the behavior of the trend of reliability vs. time. One can observe that the reliability of the system dramatically drops down immediately by applying the forced failure stress factors. This shows that the samples were successfully accelerated to the demanding point, as the test design wanted to fulfill at the beginning.

5. CONCLUSION

In conclusion, simulation of the arc failures on faulty terminals was achieved with this study. An accelerated test method was developed successfully, and ALTA analysis of the test results showed that the simulated failures are not because the product is aged, and loose terminal case is not a design failure. If it can be caught before sending it to the field, it will not affect the reliability of the terminals and provide no risk at normal working conditions. Also, it was verified that the selection of stress factors for rapid aging of loose terminals is correct.

For the business impact of this study, it will be easily possible to catch weak or loose terminal contacts caused by process faults which will emerge in the field. Thus, a big safety risk is minimized. This test not only applies to the products of household appliances, but also relates to other industries. This is directly because of the fact that testing time and the safety risk is decreased significantly with this design.

NOMENCLATURE

Subscript	**Explanation**	**Units**
a	Temperature Level Used in First Test	*(Degree Celsius* - °C*)*
b	AC Current Level Used in First Test	*(Amperes - A)*
c	Frequency Level Used in Second Test	*(Hertz - Hz)*
d	AC Current Level Used in Second Test	*(Amperes - A)*
t	Second Test Duration	*(min)*

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