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Automotive Switch Digital Modelling And Life Prediction

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Abstract: Electro-mechanical switch reliability is a critical issue in the automobile industry. While physical tests are used to evaluate reliability, adequate sample size is a challenge. It is essential to design Reliability model using physical as well as digital simulation data. Such "Phygital Reliability Model" will be useful to improve the overall prediction accuracy and pave the path for fully digital reliability model. The paper presents an experimental study of switch reliability parameters and proposes a "Phygital Reliability model". A methodology used analyses electrical and mechanical parameters of a switch in physical domain and simulated data in digital environment. During this process, the design specifications for Roof lamp Switch are collected, the environmental parameters such as temperature, humidity and vibration are measured, and electrical load analysis is conducted. The switch contact geometry, one of the major parameters that affect contact resistance, has been elaborated holistically. The obtained results are used in statistical model to forecast the switch life. This methodology can be further extended to all electromechanical switches in automotive industry.

Index Terms - Regression, Reliability, FEA.

I. Introduction

Electromechanical switches are an integral part of vehicle architecture in today's scenario as electrical components are constituting major part of current automobiles. Therefore, timely validation of switch performance is one of the key deliverables for meeting project timelines. The conventional way to validate switch reliability is the physical testing of it under different operating conditions. Measurement of electrical parameters at the end of the test and conclusion regarding achievement of target life is sole purpose in this case. It is possible to capture variation in mechanical properties of switch geometry, which will improve robustness of the validation process. While physical validation is comparatively accurate in simulating actual operation scenario, it takes too longer time and become constraint considering cost and time required. In this paper authors are proposing an alternative approach to validate switch performance at digital level. This model will take mechanical and electrical parameters as an input and predict switch reliability parameters as the output. The detailed methodology and proposed workflow are discussed in digital validation segment of this paper.

II. Physical Validation

To predict the life of a switch, endurance test is the general choice for validation. Here in this work, endurance test for simulating switch life is considered. Voltage drop across terminals is selected as parameter to define reliability at the end of the validation. Switches are subjected to three different temperatures during the test and cumulative cycles are noted. Up to 10000 cycles of target life the endurance test is continued. The results are noted and compared to initial values.

Table 1 shows the details of measurement, all these data points are indicative values.

Cumulative Operating	Temperature	Sample	Sample2
Initial Value	27 deg. C	4.10	4.32 mV
5000	27 deg. C	4.2 mV	4.42 mV
7500	50 deg C	4.3 mV	4.5 mV
10000	-10 deg C	3.97	4.27 mV

Table 1: Cycle vs Voltage Drop

During physical endurance testing of switch, the rated voltage 13.5V is considered and supplied through the regulated voltage supply. During on-off cycle the switch was connected to electrical load.

Physical Validation Analysis and Scope:

Physical validation for these switches took around one month and also have limitations on sample sizes (only two in this case). Due to low sample size, it is not often feasible to model the switch parameters vs time which is key to life estimation of the switch. But the physical validation provides very useful insight which can be used in planning digital validation. Voltage drops changes significantly over time; our scope of digital validation is based on voltage drop prediction.

III. Digital Validation

Before modeling in Digital domain, it was necessary to understand different properties that influence the reliability of contact switches. Switch life is affected by mechanical as well as electrical aspects. Hence both mechanical as well as electrical parameters are considered in physical testing as well as Digital simulation. Certain physical phenomena affect the endurance life of a contact switch, those are, contact geometry, contact material, operating force, operating voltage, temp, humidity, vibration, and operating cycles [1,2,3,4,5,6]. Electrical aspects such as voltage & current are major factors leads to degradation of switch life. If current or voltage is higher than specified design value, it results in wear out of the switch contacts and results in reduction in switch life. During simulation the rated voltage (13.5V) of the switch was considered. Deformation of contact area under influence of switch operating force [8] over usage cycles largely affect the contact resistance and subsequently the voltage drops. Reference [6] elaborately described contact resistance calculation based on geometry and mechanical properties of contact material. Reference [1,7] proposed FEA model to predict contact resistance. An increase in contact resistance of the switch over time results in increase in voltage drop across terminals and thus affect the desired performance. Next section describes the simulation of voltage drop across terminals after certain switch on off cycles under given operating force.

IV. Reliability Modeling Approach In Digital Domain

Finite Element Analysis (FEA) platform is used here for digital simulation.
Following is the workflow of voltage drop simulation (refer Fig 1):
1. Created 3D geometry for switch contact area in Pro-E.
2. 3D meshing of the contact surface
3. Selected Electrical stimulation in Flux 3D
4. Chosen Copper alloy as Contact Material for better electrical properties
5. Identified voltage measuring nodes in application circuit
6. Switch operating force profile of 5N over on-off cycles of 25000 is taken as mechanical input. Temperature and vibration based on vehicle operating condition is set at given level.
7. Rated voltage & Current considered during the circuit simulation
8. Voltage drop measured at different cycles of operation and results are summarized.

V. Simulation Result

With the inputs mentioned in the step 6,7 & 8 of previous section, voltage drops across terminals are measured. Operating cycles vs voltage drop is shown in Table 2. The simulation results are considered at temperature 27deg c.

Cumulative	Temperature	FEA output
1000	27 deg C	4.00 mV
5000	27 deg C	4.10 mV
10000	27 deg C	4.12 mV
15000	27 deg C	4.15 mV
20000	27 deg C	4.20 mV
25000	27 deg C	4. 21 mV

Table **2**: Cycle vs Voltage Drop

A regression model is applied to experimental results shown in table 2 to establish a relationship between change in voltage drop over usage cycles. Terminal voltage drop is shown for illustration in Table 3.
For terminal voltage, a linear relationship is estimated as below. Both parameters found to be significant from low p value and model accuracy is approximately 90% (R square value).

Voltage drops at terminal = 4.02+8.03E-06*cycles

We considered increase in voltage drop by 10% from initial value as acceptable limit. With that approximately 4.4mV would be the

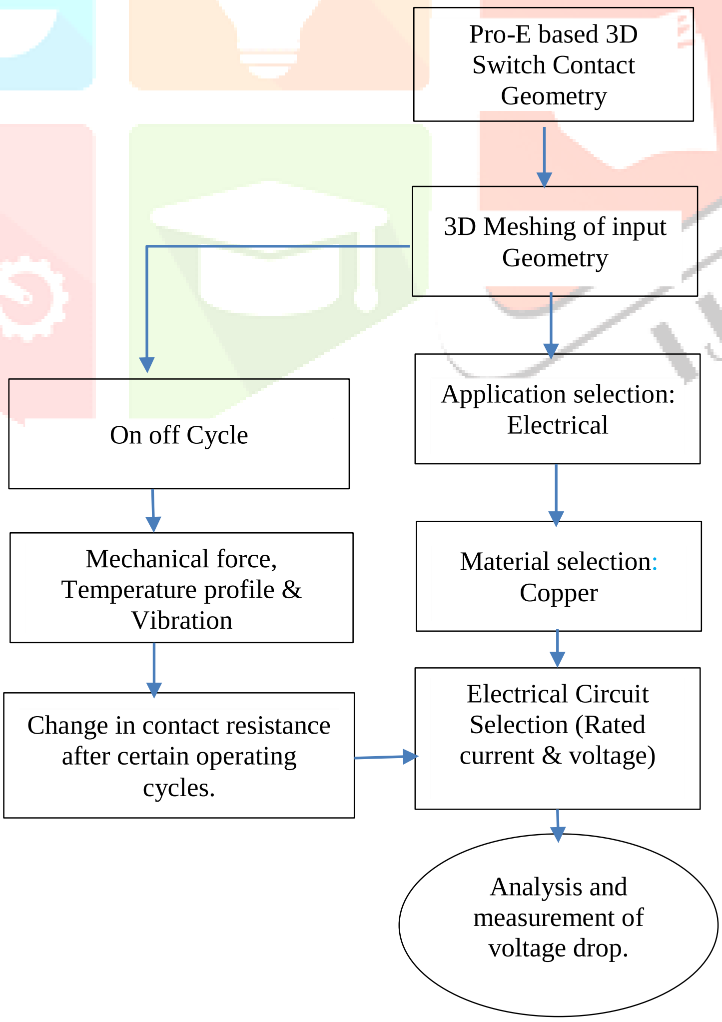

Figure 1: FEA Simulation Flowchart

Regression Statistics	
Multiple R	0.94
R Square	0.90
Adjusted R Square	0.87
Standard Error	0.02
Observations	6

ANOVA	df	SS	MS	F	Significan
Regressio	1	0.026	0.026	36.36	0.0038
Residual	4	0.002	0.000		
Total	5	0.029			

Parameters	Coefficients	Standard E	t Stat	P-value
Intercept	4.028	0.020	199.71	3.77067E-09
X Variable 1	8.03E-06	1.33189E-06	6.03	0.003810515

Table 3: Regression Output for Cycle vs Voltage Drop

limiting value for which operating cycles to be estimated. Based on above equation it would be around 46,000 cycles.

VI. Physical Test And Digital Simulation Correlation

Physical test was carried out on 3 different temperatures. To establish correlation between physical and digital simulation, it was required to simulate the results in same temperature profile as in physical test. To carry out this, FEA model shown in Fig 1 was run for intended temperature profile. Table 4 shows the Voltage Drop data for Physical test and corresponding Digital simulation Output.

Cumulative Operating Cycle	Temperature	Physical Test Output (Average value)	FEA output
Initial	27 deg C	4.21 mV	4.18 mV
5000	27 deg C	4.31 mV	4.25 mV
7500	50 deg C	4.4 mV	4.45 mV
10000	-10 deg C	4.12 mV	4.15 mV

Table 4: Voltage Drop Comparison Physical vs Digital

To evaluate the correlation between Physical and Digital simulation, trend line has been fitted with the data in Table 3. A linear relationship is evident from Fig 2 with R-Square value of 85%.

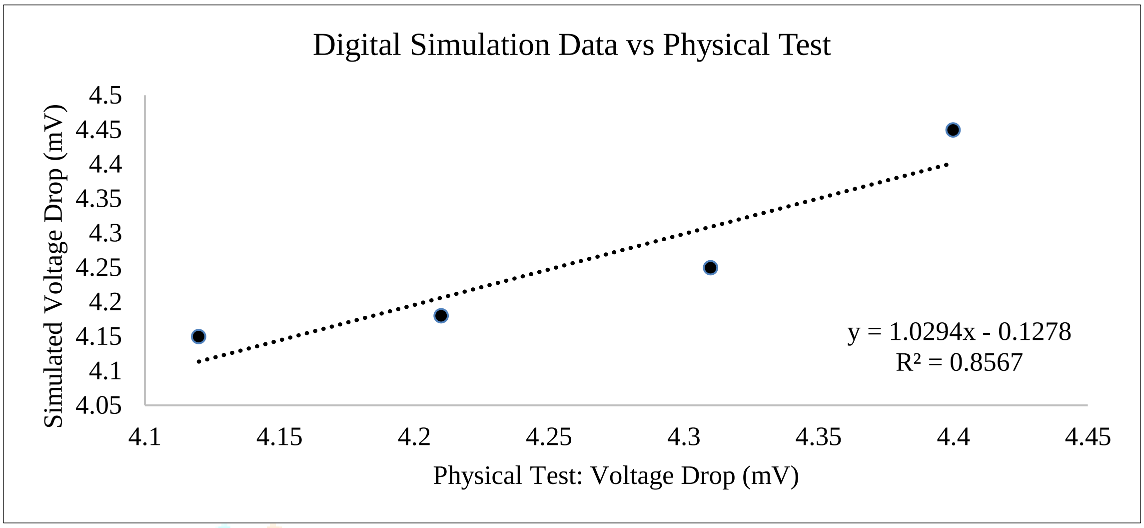

Figure 2: Correlation Study for Physical Vs Digital Simulation

VII. Summary / Conclusion

As discussed in earlier sections Mechanical parameter like contact geometry, operating force and temperature and Electrical parameters like Rated voltage & current are considered as affecting factors for change in contact resistance. Physical data analysis can lead to key parameter to be further considered for digital simulation. In this case voltage drop is derived as that parameter. In this work we are able to put up the statistical model based on digital data and predict the voltage drop at different operating cycles, leading to prediction of switch life. Also, Correlation between Physical and Digital simulation has been established. Contact resistance may also depends on few other factors like, surface roughness, surface contamination and carbon deposition. The limitations of finite element analysis presented in this work has not evaluated these factors. This may lead to difference between Physical test data and Digital test data and has further scope of enriching the model.

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