Experimental Investigation ofElectromechanical Relay under Mechanical Shock and Vibration

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***Abstract*—Mechanical design of electromechanical relay (EMR) is of most importance though the component functions electrically. Mechanical shock and vibration are two critically important factors which are responsible for operation failure of relay. As this relay is used mainly for passenger vehicles it is subjected to severe shocks and vibrations.This paper concentrates on the study ofbehaviour of newly designed relay under these conditions. The objective of the test is to check he endurance against mechanical shock and vibration. The vibration test is conducted as per JIS D1601 and the shock test is carried out as per TATA motors specifications.The tests are carried out on two different electro-dynamic shaker machines. The component passed both the tests.**

Index Terms-- **Electromechanical relay design, Failure reasons of automotive relay,Importance of mechanical design in relay, Mechanical testing of relay.**

I.INTRODUCTION

Electromechanical relay is a basic component of automotive and control systems. It is widely used for communication purpose in railways and space crafts. The function of EMR is switching of high voltage electrical power supply. Basically, EMR assembly contains sixteen mechanical and two electrical components. Some of which are shown in figure 1.

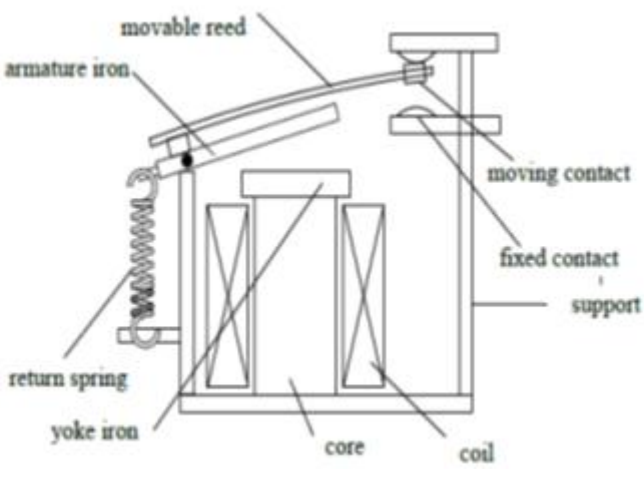

Fig. 1 Mechanical construction of EMR [1]

The current relay is designed as per IS 2077:1996 which is equivalent to all international standards. Relays are subjected to continuous vibration and shocks because of vehicle vibrations andunevenness of roadsurface. The severe shocks can cause cracks in to mechanical parts and can damage the ability to develop magnetic field of the whole system.Almost all the mechanical parts are made of sheet metal and assembled together by riveting process. Assembling all eighteen components is quite tedious job. This complicated process causes dimensional error which ultimately effects on the product quality and its functioning. Electromagnetic force is the driving force of the mechanism but the amount of force generated is such small that it can't activate the mechanism even if a very small physical property of the component is changed. EMR includes two important parts, actuating mechanism and electromagnetic mechanism. Electromagnetic mechanism produces necessary driving force that pickups the armature changing the electrical input into mechanical work[2]. After eliminating or reducing the electrical input the armature is pulled pack to its original position by the help of spring. A small extension spring is used for holding the armature at its specified position and also used for pulling the armature. Spring plays a critical role into pulling of armature. Proper care should be taken while designing the spring as the time of pulling back the armature is critical.

Normally, structural dynamics methods are preferred for the analysis of relay [1].Therefore, it is necessary to keep the process in control and maintain its capability.While designing the EMR it is important to choose materials which are easily formable and have good magnetic and electrical properties. Many of the components are manufactured by wire cutting as they have very complex profile. Extra deep drawing process is used for armature manufacturing. All metallic parts are assembled in to one plastic base, which is designed as per IS 2077. The design of base must be done as per this standard which is universal. No other design standard can be used to develop an EMR for any purpose.

In this paper, the effect of continuous vibration and severe mechanical shock on EMR is given. The purpose of investigating the relay experimentally was to ensure the reliability and durability of the product under harsh operating conditions. This also provides the practical capability of the component to withstand against shock loads and vibrations,the test was also conducted beyond the limiting values given in the testing standard manual.

A. Abbreviations

Sr. No.	Abbreviation	Meaning
1	g_C	Component Acceleration, m/s^2
2	g_T	Table Acceleration, m/s^2
3	A_C	Component Amplitude, mm
4	ms	Milliseconds
5	T	Time
6	D_C	Component displacement

II. EXPERIMENTAL TEST CONDITIONS

A. Vibration Test

Test was conducted as specified in JIS D1601. The type of component was considered as type 1 which is generally used for passenger cars. Class of component was chosen as Class B which indicates that the component is going to be part of engine room. Frequency division range used is 50. Period is of 10 minutes with acceleration 4.5 m/s^2 with maximum amplitude of 0.4 mm. The duration of the endurance test is as follows:

TABLE I
DURATION FOR VIBRATION TEST ON EACH AXIS

Axis	Time (Hours)
X	2
Y	2
Z	4

EMR to be mounted as per vehicle part fitment drawing and suitable fixture plates to be made for fixing it on shaker machine.

The electrodymanic shaker must fulfil following conditions:

i. The tolerance value for amplitude must within 5% for the stipulated frequency range.
ii. The maximum amplitude should be within 25% perpendicular to the stipulated direction of vibration.
iii. Vibration frequency should be 50, tolerance is within 2%.

B. Mechanical Shock Test

Shock test was conducted as specified in ISO 16750-3. The test conditions are as follows:

TABLE II
MECHANICAL SHOCK TEST SPECIFICATIONS

Maximum Acceleration (m/s^2)	Average Duration of one shock (ms)	Shocks per Axis	Total Number of Shocks
50	11	20 (10 positive and 10 negative)	60

Mounting of EMR should be as done for vibration test.Suitable modifications to be done in the fixture to conduct the test on X and Y axis.

III. TEST CATEGORIES

The vibration test includes following three tests.

i. Detection of resonance point
ii. Vibration endurance test
iii. Sweep vibration endurance test

IV. EXPERIMENTAL MEASUREMENTS

A) Vibration Test

(i)Detection of Resonance Frequency on X axis

Resonance frequency can be obtained by uniformly increasing and decreasing the frequency at constant rate within specified frequency range. Following data given in the table gives the idea about the resonance values of EMR on each axis.

Fig. 2 Vibration test of EMR along X-axis
(Courtesy- TML, Pimpri, Pune)

TABLE III
RESONANCE FREQUENCY ON X-AXIS

g_C (m/s^2)	Resonance Frequency(Hz)	A_C (mm)	g_T (m/s^2)
4.5	97.6	8.4	4.5

(ii) Vibration Endurance Test on X-axis

To check the durability of the automotive component this test should be conducted against the vibration of constant frequency.

TABLE IV
VIBRATION ENDURANCE TEST (NORMAL)

Frequency(Hz)	g_C (m/s^2)	T (hrs)	D_C(mm)	D_Y(mm)	g_T (m/s^2)
33	4.5	2	1.655	2.057	3.6

TABLE V
VIBRATION ENDURANCE TEST (WORST CASE)

Frequency(Hz)	g_C (m/s^2)	T (hrs)	D_C(mm)	D_Y(mm)	g_T (m/s^2)
67	4.5	1.5	0.249	0.501	2.2

There was no resonance found on Y and Z axis. Therefore, as per standard the component should undergo vibration endurance test at 33Hz (normal) or 67 Hz (worst case). The stage 5 of JIS D1601 specifications are used to conduct the endurance test.

(iii) Vibration Endurance Test on Y-axis

Fig. 3 Vibration test of EMR along Y-axis
(Courtesy- TML, Pimpri, Pune)

TABLE VI
VIBRATION ENDURANCE TEST (NORMAL)

Frequency(Hz)	g_C (m/s^2)	T (hrs)	D_C(mm)	D_Y(mm)	g_T (m/s^2)
33	4.5	2	1.91	2.06	4.1

TABLE VII
VIBRATION ENDURANCE TEST (WORST CASE)

Frequency(Hz)	g_C (m/s^2)	T (hrs)	D_C(mm)	D_Y(mm)	g_T (m/s^2)
67	4.5	4	0.485	0.5	4.3

iv.Vibration Endurance Test along Z-axis

Fig. 4 Vibration test of EMR along Z-axis
(Courtesy- TML, Pimpri, Pune)

TABLE VIII
VIBRATION ENDURANCE TEST (NORMAL)

Frequency(Hz)	g_C (m/s^2)	T (hrs)	D_C(mm)	D_Y(mm)	g_T (m/s^2)
33	4.5	2	2.134	2.062	4.6

TABLE IX
VIBRATION ENDURANCE TEST (WORST CASE)

Frequency(Hz)	g_C (m/s^2)	T (hrs)	D_C(mm)	D_Y(mm)	g_T (m/s^2)
67	4.5	4	0.485	0.5	4.3

B) Mechanical Shock Test

Half sine pulse was selected to conduct this test. Twenty shocks per axis (ten negative and ten positive) were given. Total sixty shocks were applied on the component. The following settings were done before starting the test.

TABLE X
LIMITING PARAMETERS FOR ELECTRODYNAMIC SHAKER

Description	Shaker
Maximum Force	12000 N
Maximum Positive Disp.	20 mm
Maximum Negative Disp.	-20 mm
Maximum Velocity	1.75 m/s
Maximum Acceleration	50 g
Minimum Freq.	10.00 Hz
Maximum Freq.	2000 Hz
Moving Coil Mass	20 kg

TABLE XI
CONTROL PAAMETERS OF MECHANICAL SHOCK TEST

Pulse Interval	1.5 s
Sampling Freq.	10240 Hz
Response Level Goal	10 %

After conducting the test as per ISO 16750-3 no considerable change was observed. To check the actual capacity of the component the frequency was increased by decreasing the period of shock. The period was reduced to 7ms from 11ms. Following profile parameters were decided for conducting test.

TABLE XII
PROFILE PARAMETERS

Shock Type	Half Sine
Amplitude	50 g
Pulse Duration	7 ms
Pre Pulse Height	3%
Post Pulse Height	15%
Pre Pulse Delay	30%
Post Pulse Delay	0%
Left Width Check	100%
Right Width Check	100%
Main Pulse High Limit	15 %
Main Pulse Low Limit	-15%
Pre Pulse High Limit	5%
Pre Pulse Low Limit	-5%
Post Pulse High Limit	20%
Post Pulse Low Limit	-30%

Following are the test parameters
Shock type used: Half Sine
Amplitude : 50g
Shock duration : 7 ms
Number of shocks: 20 per axis

A piezoelectric accelerometer was selected for this test. Normally, for lower frequency shock pulse it is standard process to select a piezoelectric accelerometer. The reason behind selecting half sine shock is it has very low amount of error(3.4%) as compared to other shock types.This error is the difference between actual and theoretical ratio of time constant to pulse duration [6].

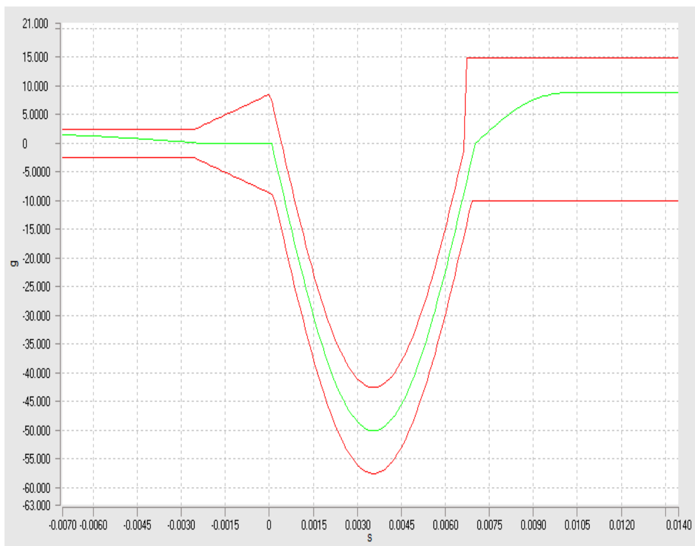

Fig. 5 Half sine shock wave profile

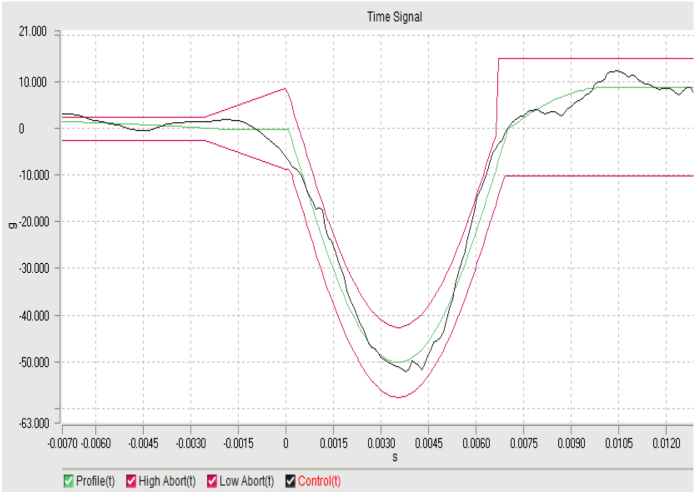

Fig. 6 Time signal profile of mechanical shock

While conducting this test along X-axis, due to consecutive and sudden shock the EMR started to loosen its grip and it jumped outside. Along Y and Z-axis there was no impact of shock on the component. Due to use of higher frequency of shocks the housing of EMR got cracked.

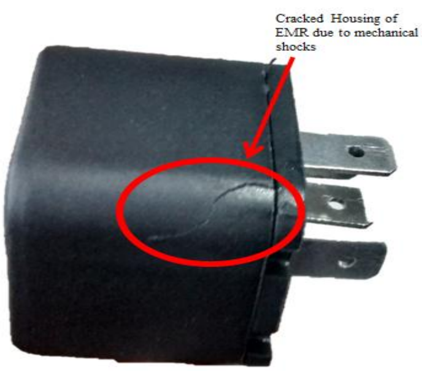

Fig. 7 Cracked housing of EMR due to mechanical shock

V. RESULTS AND ANALYSIS

A.Vibration Test

The component has resonance only along X-direction and the value of resonance frequency is 97.6 Hz with amplitude of 8.4 mm.There was no resonance along Y and Z-direction. The component sustained during severe vibration endurance along all three directions.

The reason behind the resonance along X-axis is the motion of armature. The armature which is bound by extension spring has rotary motion. It has certain amount of torque. The torque at which the armature moves is given by T_m,

$$T_m = I\frac{d^2\theta}{dt^2} + T_k + T_f \qquad (1)$$

Where, I = Armature inertia, θ = Armature rotation angle T_k= Torque due to spring force, T_f= Friction torque [3].

The resonance frequency can be easily avoided by either increasing or decreasing the spring tension and hence the torque value.

The value of bending stress in spring hook is determined by,

$$\sigma_b = K_b\frac{16DF}{\pi d^3} + \frac{4F}{\pi d^2}$$

Where,

$$\text{Stress concentration factor, } K_b = \frac{4C_1^2 - C_1 - 1}{4C_1(C_1 - 1)}$$

$$C_1 = \frac{2r_m}{d}$$

The torsional stress is given by,

$$\tau = K_w\frac{8DF}{\pi d^3}$$

Where,

$$\text{Wahl Factor, } K_w = \frac{4C_2 - 1}{4C_2 - 4}$$

$$C_2 = \frac{2r_i}{d}$$

Spring correction factor is given by, [4-7]

$$K = \frac{r_m}{r_i}$$

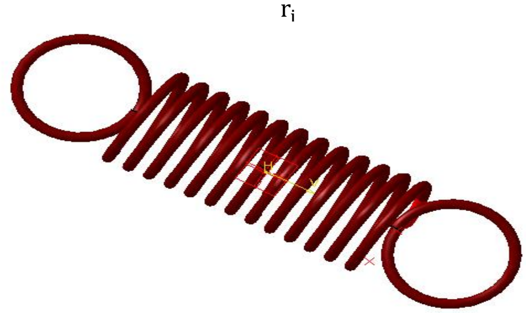

Fig. 8 3D model of extension spring used in EMR

Spring rate is given by,

$$R = \frac{d^4 G}{8D^3 N_a}$$

No issue found in all the 18 components after worst case vibration endurance.

B. Mechanical Shock Test

When the component undergone mechanical shocks as per standard, it remained unaffected. But, it was observed during test that component loses its grip during Z negative direction, which is a concern. But overall there was no change in the parts of EMR.

Decision was taken to go for more severe testing conditions. Frequency of shocks was increased by decreasing the shock period keeping the interval same. Shock period was reduced to 7 ms from 11 ms for achieving higher shock force. This resulted into failure of component. The housing got cracked (fig. 7).

VI. CONCLUSION

The EMR design from mechanical point of view is found be reliable as it passed both test successfully. All eighteen parts were subjected to severe vibration and mechanical shocks, all parts remained unaltered. Even, the electrical properties remained satisfactory. The issue of resonance along X-axis has been tackled successfully. The endurance test was carried out to check the capacity of riveting done during assembly process. All rivets found unchanged. The strong plastic base made up of Polyamide 6, 30% Glass-filled material holds all other parts of relay. There is a chance of cracking of relay base during severe shocks; to avoid this strong holding base(fuse box) should be used.

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