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# Finite Element Analysis of Ball-Joint Boots under Environmental and Endurance Tests

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***Abstract*—**Ball joints support and guide certain automotive parts that move relative to the frame of the vehicle. Such ball joints are covered and protected from dust, mud, and other interfering materials by ball-joint boots made of rubber—a flexible and near-incompressible material. The boots may experience twisting and bending deformations because of the motion of the joint arm. Thus, environmental and endurance tests of ball-joint boots apply both bending and twisting deformations. In this study, environmental and endurance testing was simulated via the finite element method performed by using a commercial software package. The ranges of principal stress and principal strain values that are known to directly affect the fatigue lives of the parts were sought. By defining these ranges, the number of iterative tests and modifications of the materials and dimensions of the boot can be decreased. Therefore, instead of performing actual part tests, manufacturers can perform standard fatigue tests in trials of different materials by applying only the defined range of stress or strain values.

***Keywords*—**Boot, endurance tests, rubber, FEA.

## I. Introduction

RUBBER is a kind of hyperelastic material that is flexible, near incompressible, and damping capable elastomer. It is applied to many fields of industry and domestic appliances to take advantage of the distinctive characteristics. One can find its applications at many parts of automotive vehicles, such as; hoses, dampers, boots, gaskets, seals, and tires. The important boots in the automobiles may be raised as the boot at constant-velocity (C.V.) joint, ball joint, and transmission joint. The role of ball-joint boots is to cover and protect the joint from dust, mud, and contamination of the contained grease. The ball joints in automobiles support and guide some moving parts with respect to the frame of the vehicles. On account of the motion of the moving arm, the boots may experience twisting and bending deformations.

Boots covering the ball joint are subject to a repeated loading intermittently to make up so many cycles of times. The repeated loading eventually causes a fatigue failure. The failed boot loses the capability of protecting the ball joint to deteriorate it through the loose of grease, overheat, and wear. To confirm the long term responses of the boots, environmental and endurance tests are required by the auto makers. However, it is a very cost-consuming work to prepare the boot specimen through the crosslinking process in several trial dies, in order to confirm the adequacy of the material and dimension. Moreover, the testing machine [1] of the environmental and endurance tests is not much easily available as the standard fatigue testers.

The major aim of this study is to get the range of stresses or strains of the boot under the environmental and endurance tests, through the finite element method (FEM) simulation [2]. Once the range of stress or strain of the boot is evaluated, we do not need many iterative tests modifying the materials and dimensions of the boot, and therefore making many dies for crosslinking process. Instead of actual part test, one can perform standard fatigue tests trying for different materials only applying the sought ranges of stress or strain. Then, only the final validation test of the boot part under environmental and endurance tests are necessary. The FEM simulation will be performed by using a commercial package modeling the boot part under environmental and endurance tests. The ranges of principal stress and principal strain will be sought that are known as to affect directly to the fatigue lives of the parts.

## II. The Environmental and Endurance Tests of the Ball-joint Boots

In this study, we refer to an Environmental and Endurance Tests demanded by an automobile company in Korea. The Environmental and Endurance Tests of the Ball-joint Boots for the automobile company in Korea is three depending on the temperature. The Environmental and Endurance Tests is as follows [3];

- -30 ºC x bending angle ±15º x twisting angle ±30º x 180 ccpm x 500,000 times (sprinkle muddy water for 1 minute per 10 minutes)
- +60 ºC x bending angle ±15º x twisting angle ±30º x 180 cpm x 500,000 times (sprinkle muddy water for 1 minute per 10 minutes)
- Room Temperature x bending angle ±15º x twisting angle ±30º x 180 cpm x 500,000 times (sprinkle muddy water for 1 minute per 10 minutes)

## III. FEM Analyses of the Endurance Tests of the Ball-Joint Boots

In this study, finite element analysis of the Endurance Tests of the Ball-joint Boots is carried out by using ABAQUS [4]. The modeling of boot part is designed referring to an item [5] which is now selling on market in as shown in Fig. 1.

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According to the Section II, twisting angle 30º and bending angle 15º are applied on boots model by using boundary condition. In this analysis, the material property of rubber boot has Young's modulus of 50.58 MPa and Poisson's ratio of 0.49. The results of FEM analysis are as show in Figs. 2 and 3.

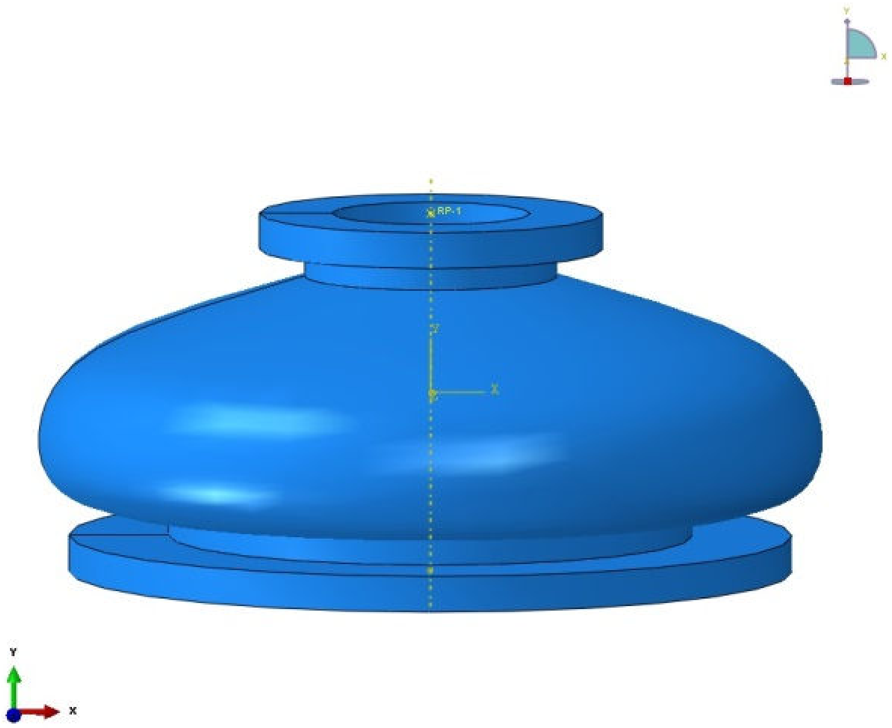
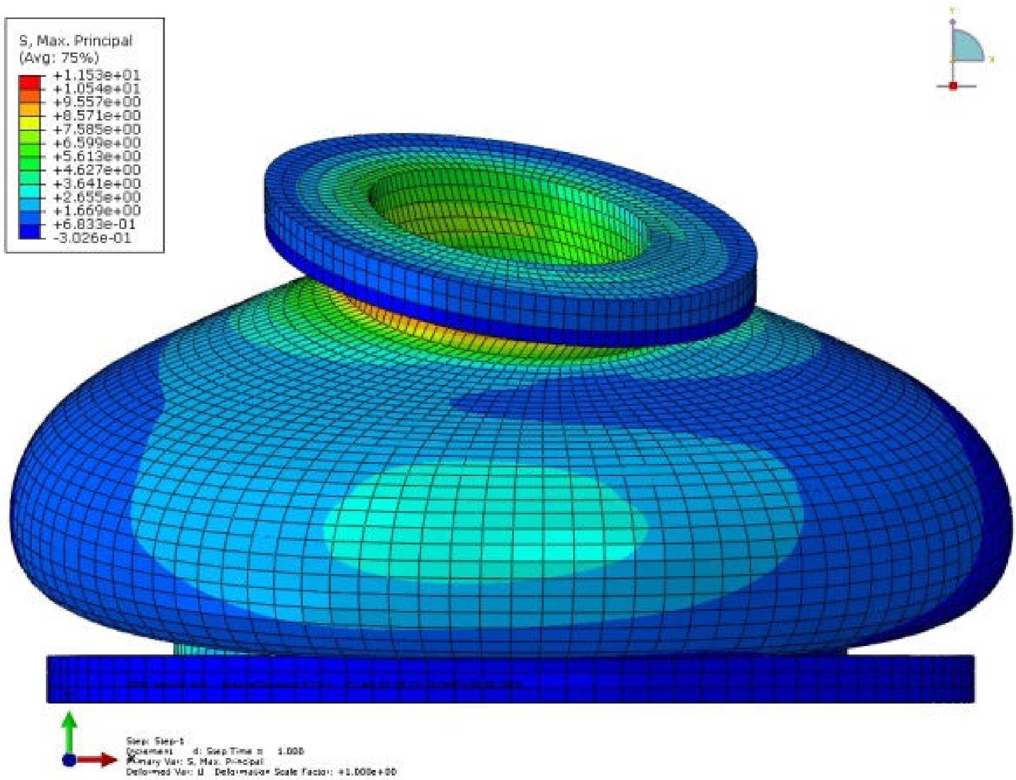
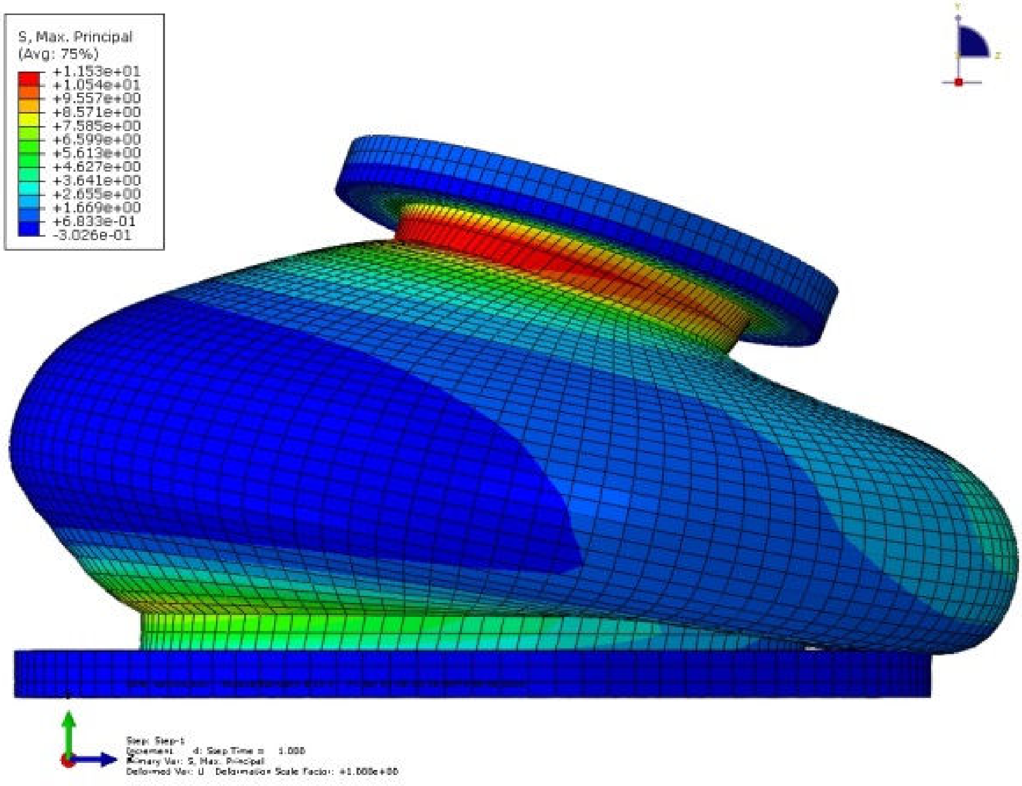


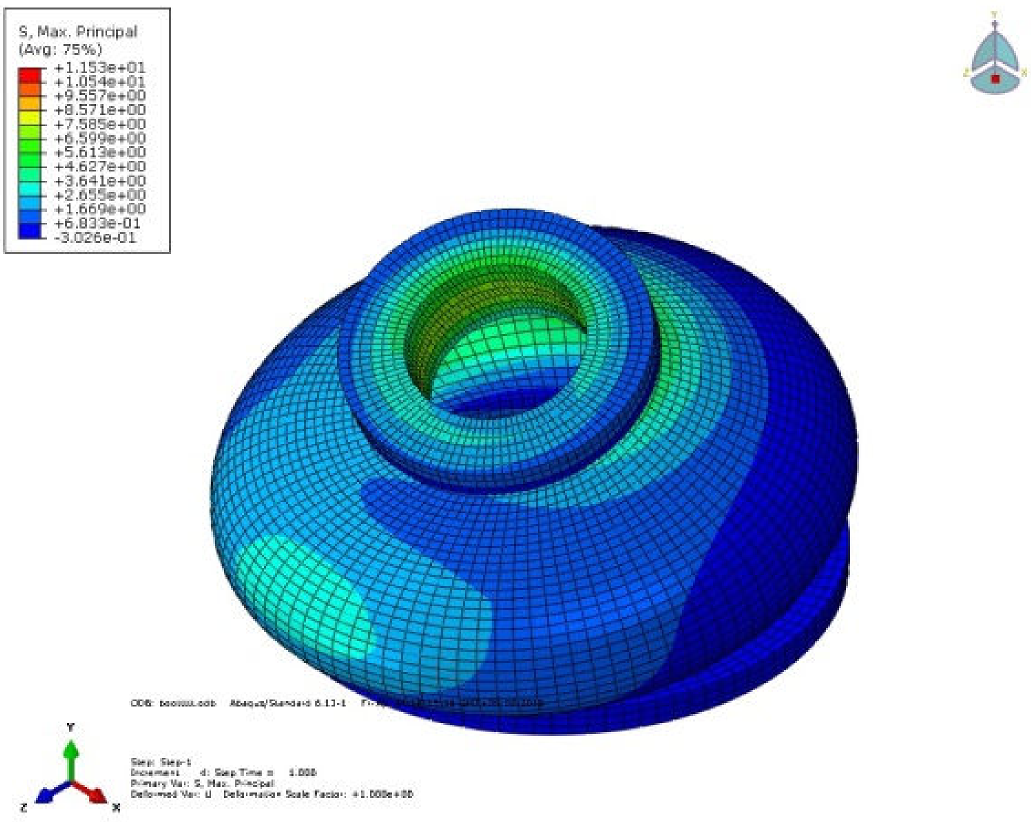

Fig. 1 FEM modeling of boot under environmental and endurance test




(a)

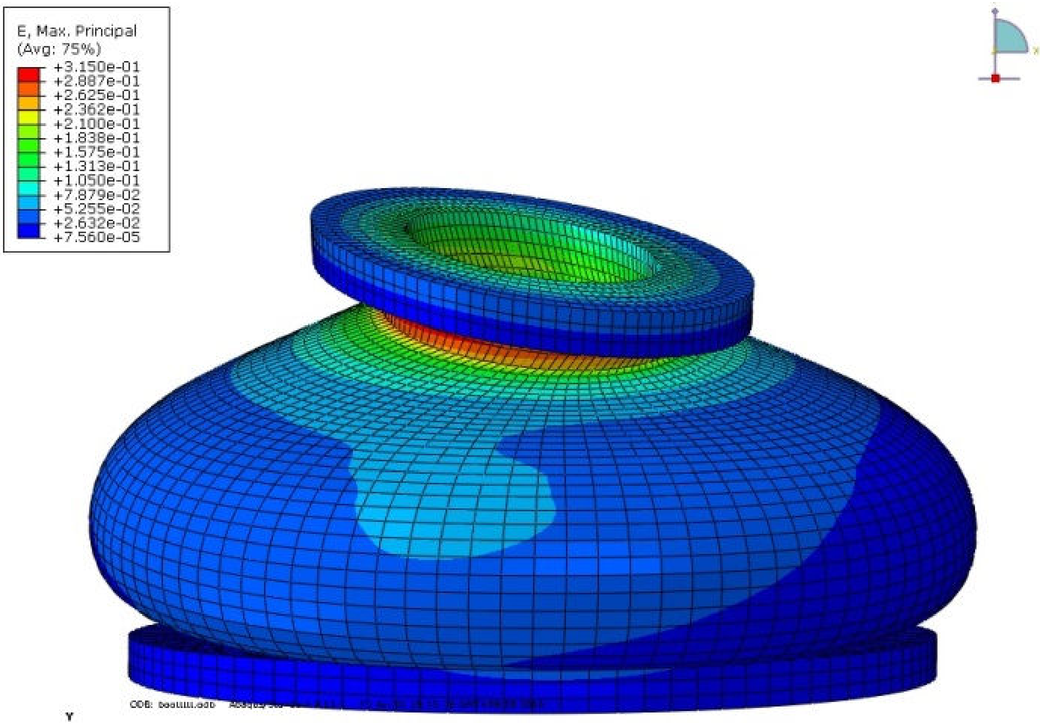



(b)




(c)

Fig. 2 Result of the 1st principal stress of FEM [xy-plane (a), yz-plane (b), isometric view(c)]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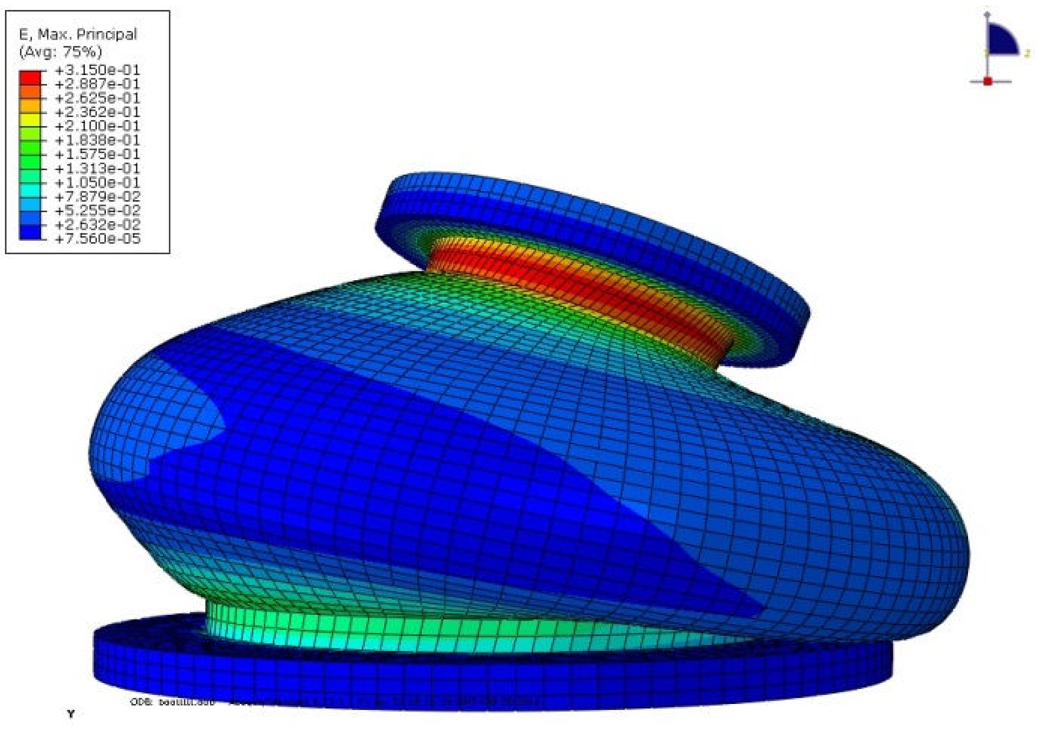
+2.887e-01
+2.625e-01
+2.362e-01
+2.100e-01
+1.838e-01
+1.575e-01
+1.313e-01
+1.050e-01
+7.879e-02
+5.255e-02
+2.632e-02
+7.560e-05

(a)


E, Max. Principal
(Avg: 75%)
+3.150e-01
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+2.625e-01
+2.362e-01
+2.100e-01
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+1.575e-01
+1.313e-01
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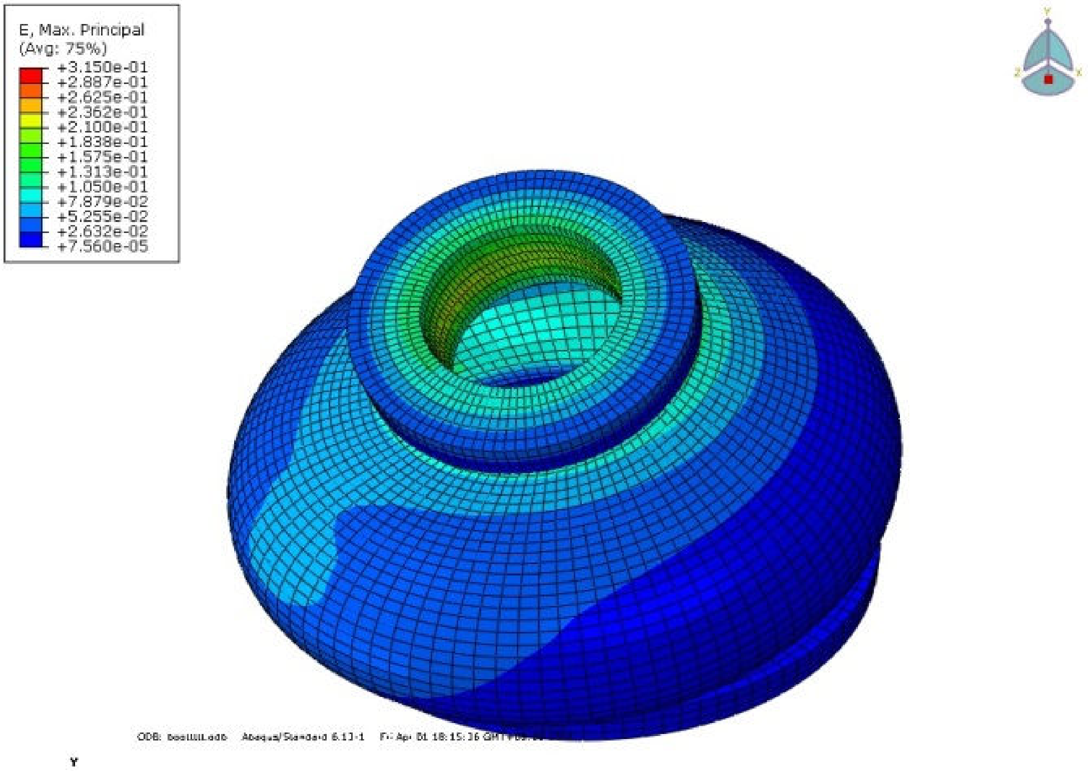
+2.632e-02
+7.560e-05

(b)




(c)

Fig. 3 Result of the 1st principal strain of FEM [xy-plane (a), yz-plane (b), isometric view (c)]

Fig. 2 shows us the contour diagrams of the 1st principal stress of the boot. The maximum principal stress is 11.53 MPa occurring at upper neck part. On the other hand, Fig. 3 shows the contour diagrams of the 1st principal strain of the boot. The maximum principal strain is 0.32 occurring at upper neck part.

## IV. Discussions of the Results

The maximum principal stress and strain are located at the upper neck part. However, except the upper neck, the next maximum principal stress and strain are on surface inside of bending portion. The results of FEM analysis are summarized in Table I.

TABLE I
THE SUMMARY OF RESULTS

| | location of the maximum value | the maximum value |
|---|---|---|
| $\sigma_1$(max. principal stress) | upper neck part | 11.53 MPa |
| $\varepsilon_1$(max. principal strain) | | 0.32 |

The next maximum principal stress and strain are located at the same location on the surface to exhibit 3.06 MPa and 0.05. As a result, we could obtain the range of principal stress and strain by using FEA, which can be applied in standard fatigue test [6]. This FEM simulation result makes us predict the endurance test result approximately before the actual part test. Moreover, if the FEM result is not good enough, one can improve the result by trial and error method or by the method of design optimization.

## V. Conclusion

Rubber boots are used in many fields of industry to protect the joint from dust, mud, and contamination of the contained grease. Among them, the ball-joint boot is analyzed by the FEM to seek the ranges of principal stress and principal strain. These ranges may be used in fatigue tests of standard specimen of different materials. Some findings of the study are summarized as follows.

1. A simplified procedure replacing most of the environmental and endurance tests of ball-joint boot is suggested.
2. Range of the principal stress/strain under the environmental and endurance test could be sought through the FEM simulation by using a commercial package which can be improved before it is adopted in the test.
3. Standard fatigue tests referring the range of principal strain may precede the part tests to reduce the number of latter significantly, or the cost and time for them would be tremendous.

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