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DEVELOPMENT OF A LOW PRESSURE WATER HYDRAULIC ACTUATOR WITH SELF RECIPROCATING MOTION

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ABSTRACT

This paper concerns a newly designed water hydraulic actuator to make reciprocating linear motion without any directional control valves outside. It works with only supply of low pressure water, such as from tap water network. The object of this paper is to introduce the idea of construction and working principle of the actuator and to present some experimental results gained by prototypes. Two different prototypes, with a short stroke (approx. 20 mm) and a long stroke (approx. 200 mm), are produced. Fundamental performances were tested for the two types and good results were gained. Main piston's displacement, speed, force, and supply flow rate and pressure were measured under steady working conditions. The experimental results are presented and some considerations to improve the characteristics of them are also discussed.

KEY WORDS

Water Hydraulics, Actuator, Self Reciprocating Motion, Low Pressure

INTRODUCTION

Water hydraulic system which uses pure tap water as pressure medium has been paid attention for ten years more as a new environmental friendly drive system. It has advantages besides the environmental safety; cleanness, non-flammability, easiness of obtaining and disposing pressure medium, high power density, high stiffness and good controllability, etc.[1],[2].

The water hydraulic system has a great potential in the field of low-pressure level as well as the middle- and high-pressure levels. When the pressure level is low, the cost of the components becomes lower. A lot of research has been carried out in the field of low-pressure water hydraulics. The aim of them is to realize the water hydraulic systems with low price of pneumatics and high power density and good controllability of oil hydraulics [3],[4].

Many applications of water hydraulics are found in industries, especially such as food processing industry where the machine and systems are required to have high tolerance to water cleaning and high hygienic standards [5]. The low-pressure water hydraulics has applications also in the field of nursing equipments to be used for caring handicapped or elder persons in institutions, and also it may be used for some domestic applications at homes when it can be driven by the low pressure water from household tap water network.

Concerning the water hydraulic components, there are less commercialized components in the low-pressure level rather than the middle- and high-pressure levels. Especially, actuator is needed to be developed further more in order to make the field of application of low pressure water hydraulics expand.

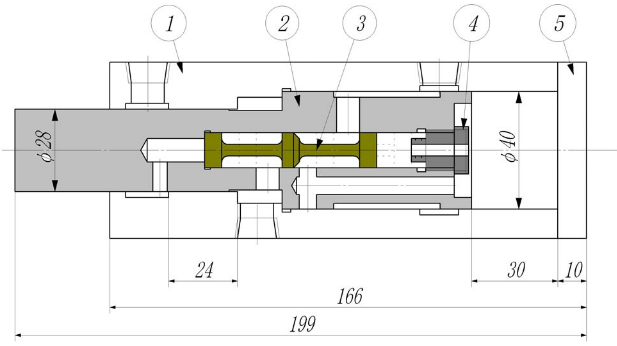
Commonly, the basic motions to drive machines are rotational and linear reciprocating motions. The rotation is generated by motors. A low-pressure water hydraulic motor with the maximum working pressure 2.0 MPa has been developed and in market [6]. Another motor driven by the pressure of tap water network is now under developing [7]. On the other hand, the linear reciprocating motion is generated by a water hydraulic cylinder, with usually using electro-magnetic directional control valves to switch the flow direction of water. But, the electro-magnetic valves tend to cause troubles when they are used at the places where will be wet and sometime under water. There are, however, practical applications in such situations to need just a simple reciprocating motion with a constant cycle time and a constant stroke, for example, the shaking equipments used in food processing and the feeder of a shower nozzles used in paper machines, etc.

This paper proposes a new type of a water hydraulic actuator which has possible applications in the situations mentioned above. It makes self reciprocating linear motion without any directional control valves outside. It works by only supply of low pressure water from a tap water network. It has advantages; easy usage, high stiffness and no danger of electric leakage. Two different prototypes, with a short stroke (approx. 20 mm) and a long stroke (approx. 200 mm), are produced. The construction of their important part, which switches the flow direction inside the main piston, is designed on the same concept. At first, the structure and working principle of the actuator is introduced and then the experimental results gained by the tests with each prototype are presented. Some considerations to improve the characteristics of them are also discussed.

STRUCTURE AND WORKING PRINCIPLE

Figure 1 shows the practical structure of the short stroke type. It consists of only five parts except for bolts. It has no sealing between the piston and the bore in the body to minimize friction. A small amount of leakage appeared to the outside through the clearance between the piston and the bore. At least, the sealing to prevent the leakage to the outside is absolutely necessary when it will be manufactured as a commercialized product. The material of the piston, spool and plug is stainless steel and the body and the end cover is brass.

The piston has two diameters, the bigger is 40 mm and



(1: Body, 2: Piston, 3: Spool, 4: Plug, 5: End cover)

Figure 1 Assembly drawing of the short stroke type

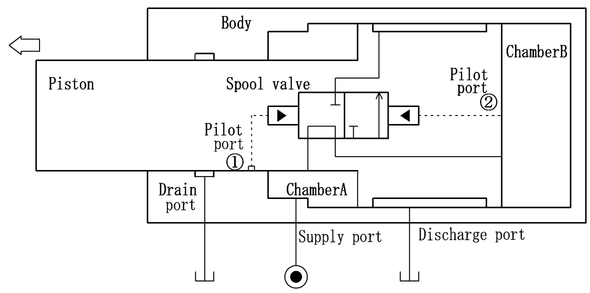
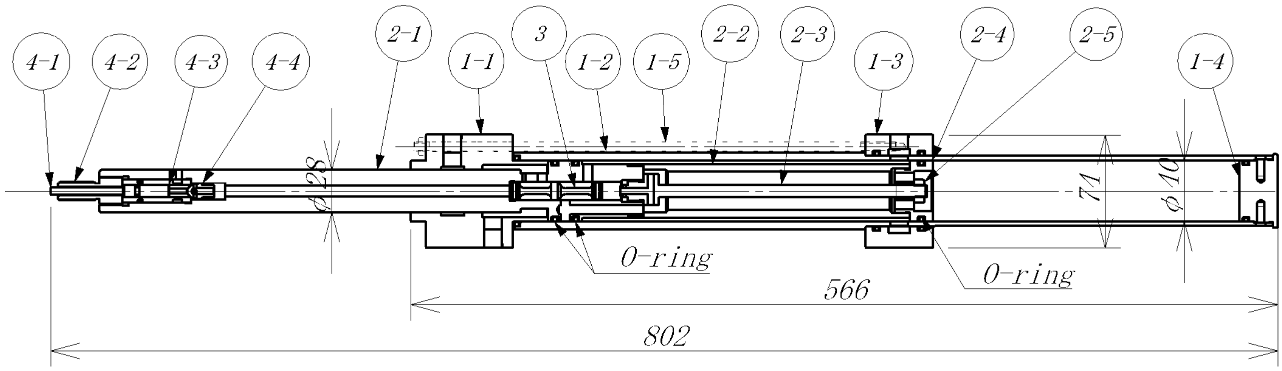


Figure 2 Schematic structure of the short stroke type

the smaller is 28 mm. It has, therefore, the two areas pressure acts on. One is 1,257 mm^2 on the right end of the piston and another is 641 mm^2 of the annular area at around the middle. Their ratio is almost 2:1.

A spool is installed in the piston and it makes a function of 3 way-2 position directional control valve as shown in Figure 2. It operates by difference of pressures act on its both the ends through the pilot ports 1 and 2. It switches the direction of the flow to and from the chamber B. When the position of the valve is as same as shown in Figure 2, the supply pressure comes to the chamber B as well as the chamber A and the piston moves to the left. On the other hand, when it is at another position, the camber B connects to the discharge port and the piston moves to the right.

The position of the spool valve is determined by the position of the pilot port 1. When the pilot port 1 connects to the chamber A while the piston moves to the right, the position of the valve switches to the position as same as shown in Figure 2. Therefore, the piston changes the direction of its movement to the left. When the pilot port 1 connects to the drain port while the piston moves to the left, the spool valve switches to another position and the piston, therefore, changes the direction of its movement to the right. It is continuously repeated and the self reciprocating motion of the piston continues.



(1-1 to 1-5: Body, 2-1 to 2-5: Piston, 3: Spool, 4-1 to 4-4: Pilot valve)

Figure 3 Assembly drawing of the long stroke type

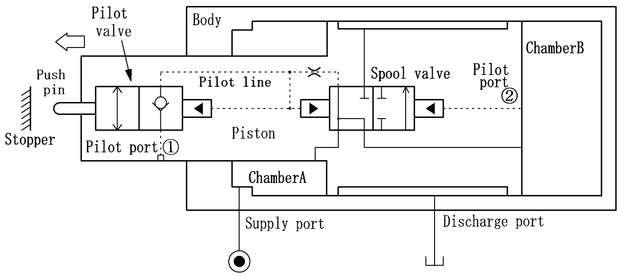


Figure 4 Schematic structure of the long stroke type

Figure 3 shows the structure of the long stroke type. The body consists of five parts; No.1-1 to 1-5. The No.1-2 is made of a stainless-steel pipe of which inner surface is finished by honing. The piston consists of five parts of No.2-1 to 2-5. The No.2-2 is also made of a stainless-steel pipe. The piston has two diameters, the larger is 40 mm and the smaller is 28 mm as same as the short stroke type. The piston has three O-rings on the larger diameter area. Grease is put on the O-rings to decrease the friction with the inner surface of the pipe of the body in which the piston slides. A spool is installed in the piston as same as the short stroke type. The major difference from the short stroke type is that the long stroke type has a pilot valve on a top of the piston, which consists of the four parts of No.4-1 to No.4-4. Due to the difficulty in producing, the same structure as the short stroke type was not available for the long stroke type. The material of the most parts is stainless-steel. The parts of No.1-1, 1-3 and 4-3 are made of brass.

The spool makes a function of 4 way- 2 position directional control valve as shown in Figure 4. It operates basically as same as in the short stroke type. The different point is that the pilot valve is installed on the pilot line connected to the pilot port 1. When the position of the valves are as shown in Figure 4, the supply pressure comes to the chamber B as well as the chamber A. The piston moves to the left. The left end of the piston reaches the stopper and the push pin of the pilot valve is pushed in, the pilot valve switches the position and the pilot line is connected to the pilot port 1. The pressure in the pilot line decreases to the atmospheric pressure. The spool valve, therefore, switches its position to another position and the piston changes the direction of its movement to the right because the chamber B connects to the discharge port. When the pilot port 1 connects to the chamber A while the piston moves to the right, supply pressure comes through the pilot valve into the pilot line. It switches the positions of the spool valve and also the pilot valve. Then, it becomes the same situation as shown in Figure 4. The piston changes the direction of its movement to the left. As these steps are continuously repeated, the self reciprocating motion of the piston continues.

EXPERIMENTAL METHOD

Fundamental characteristics of the motion were tested for the both of the short stroke and the long stroke types. The piston's displacement, speed, force, and the supply flow rate and pressure were measured under steady working conditions.

The tests were carried out under the two kinds of load; inertia mass and constant force loads. As shown in Figure 5, the constant force load is given by using a magnetic brake (see (a)), and the inertia mass load was given by stacking iron plates on a plate with wheels (see (b)). The mass of each iron plate is 2 kg.

The water is supplied to the actuator through a common nylon tube of 5 m length from a tap water network. The maximum pressure at the tap is about 0.4 MPa. The flow rate is detected by a turbine flow meter, the supply pressure is by a strain gauge type pressure transducer, the displacement of the piston is by a magnetic displacement detector and the force is by a load cell to be available for the both of tension and compression. All the data is

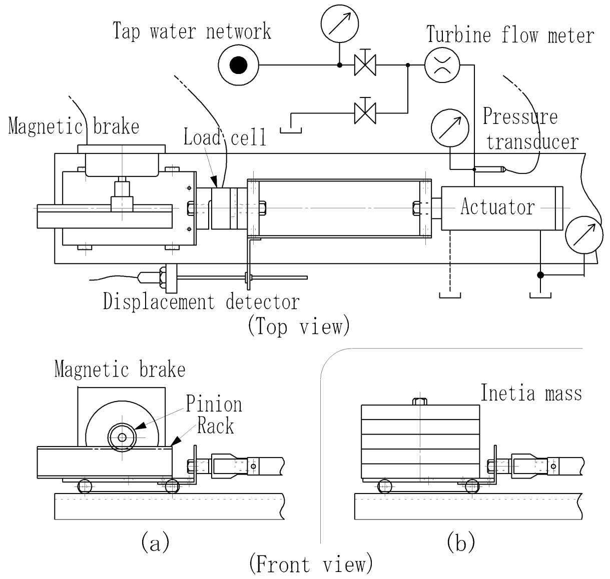


Figure 5 Test system

acquired by a computer with 1 ms and shorter sampling time.

EXPERIMENTAL RESULTS

Short Stroke Type

Figure 6 shows the displacement of the piston of the short stroke type when no inertia mass is loaded, and figure 7 shows that when the inertia mass is 10 kg. Supply water pressure is 0.28 MPa for the both cases. It is found that the good reciprocating motions are obtained in the both cases. The frequency of the reciprocating motion becomes larger as the inertia mass is smaller and the pressure is higher as shown in figure 8. The stroke of the piston changes with the change in pressure and inertia mass as shown in figure 9. The actuator does not work when the pressure is lower than 0.02 MPa.

Figure 10 shows the displacement of the piston of short stroke type when a force load is 50 N. Figure 11 shows the force detected by a load cell simultaneously with the data of displacement in figure 10. It is found that the actuator works well under such load condition. The critical force load is shown at each pressure in figure 12. The piston dose not reciprocate when the force load is larger than the critical value. The stroke of the piston changes with the change in force load and pressure as shown in figure 13. The stroke becomes smaller as the force load is larger. It dose not work when the pressure becomes lower so that the stroke becomes smaller than 0.0184 m.

Long Stroke Type

Figure 14 shows the displacement of the piston of the long stroke type when the inertia mass is 10 kg and the

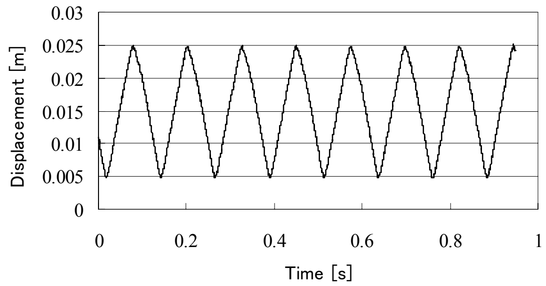


Figure 6 Displacement of piston in short stroke type (no inertia mass, at 0.28 MPa)

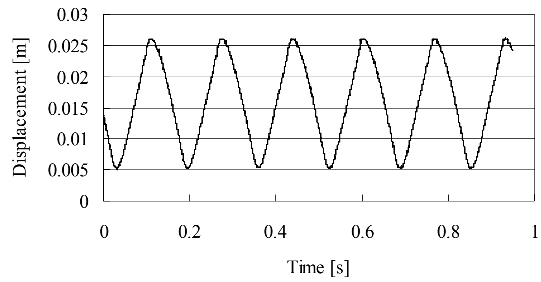


Figure 7 Displacement of piston in short stroke type (with 10 kg inertia mass, at 0.28 MPa)

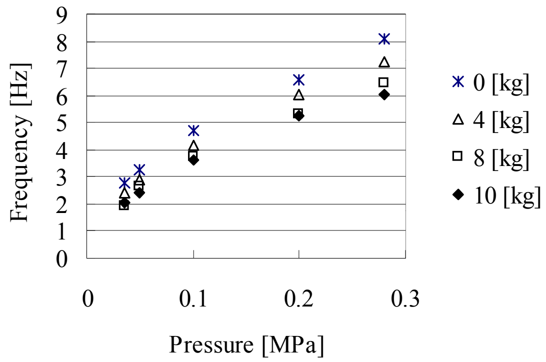


Figure 8 Frequency of the motion with change in pressure and inertia mass (short stroke type)

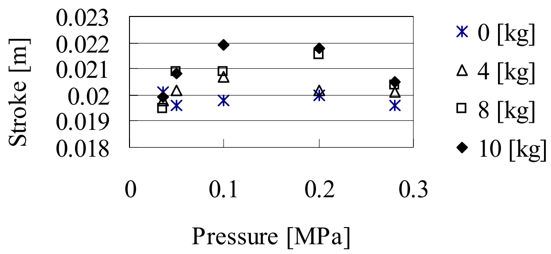


Figure 9 Stroke of the piston with change in pressure and inertia mass (short stroke type)

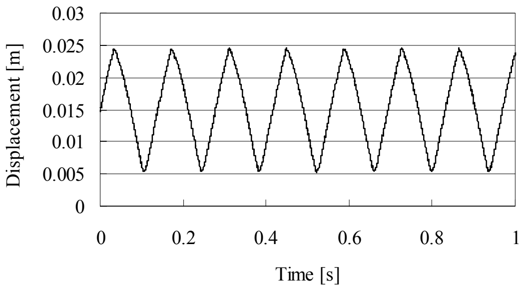


Figure 10 Displacement of the piston in short stroke type (with 50 N force load, at 0.28 MPa)

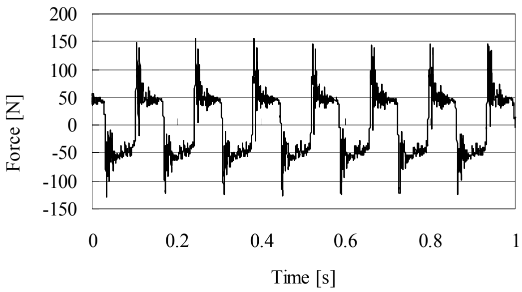


Figure 11 Detected force in the short stroke type (with 50 N force load, at 0.28 MPa)

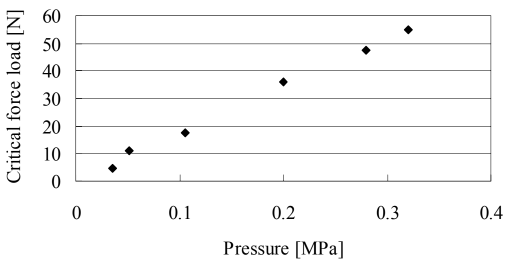


Figure 12 Critical force load in the short stroke type

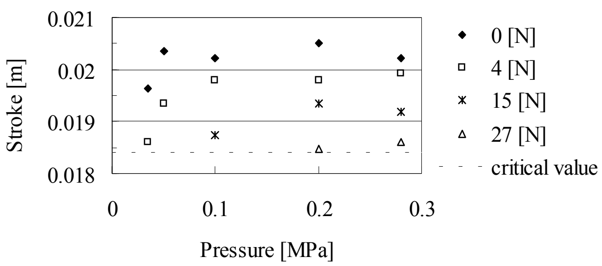


Figure 13 Stroke of the piston with change in pressure and load force (short stroke type)

pressure is 0.3 MPa. The stopper is located at the place to get the stroke 0.18 m. It is found that the reciprocating motion is continuously obtained, but the piston speed is slightly different between the forward and the backward movements. The stroke of the piston shows the two different values as shown in figure 15; 0.18 m when the pressure is high and around 0.142 m when it's low. Due to the drain from the pilot port 1 while the piston moves backward, the piston changes the direction of movement from backward to forward before the pilot port 1 reaches the chamber A. When the pilot port 1 is covered with the bore of the body, the pressure in the pilot line rises and it makes the spool valve switch. It causes the shorter stroke. The frequency of the reciprocating motion becomes larger as the inertia mass is smaller and the pressure is higher as shown in figure 16.

Figure 17 shows the displacement of the piston of the long stroke type when a force load is 50 N. Figure 18 shows the force detected by a load cell simultaneously with the data of displacement in figure 17. It is clearly

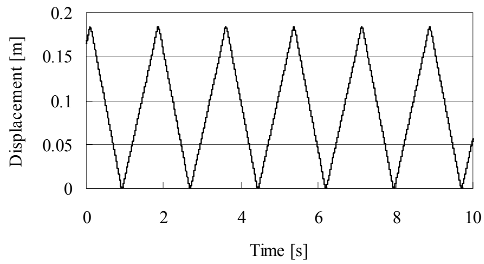


Figure 14 Displacement of piston in long stroke type (with 10 kg inertia mass, at 0.3 MPa)

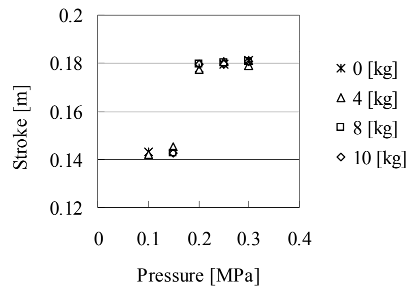


Figure 15 Stroke of the piston with change in pressure and inertia mass (long stroke type)

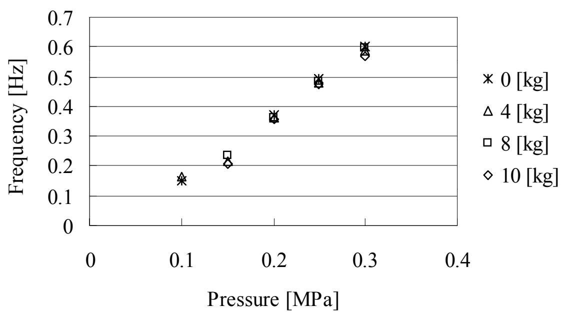


Figure 16 Frequency of the motion with change in pressure and inertia mass (long stroke type)

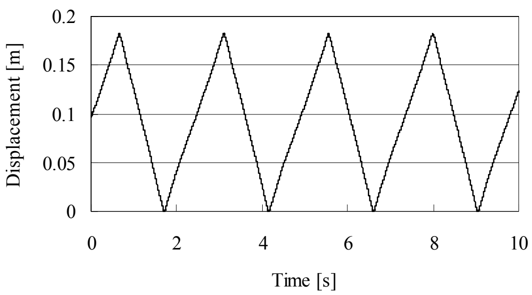


Figure 17 Displacement of the piston in long stroke type (with 50 N force load, at 0.3 MPa)

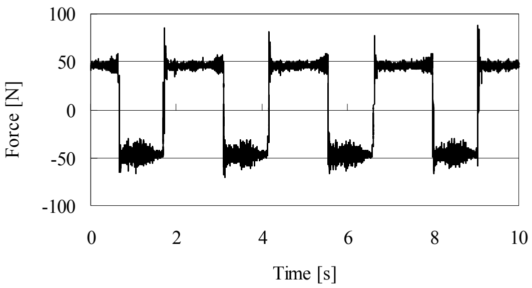


Figure 18 Detected force in the long stroke type (with 50 N force load, at 0.3 MPa)

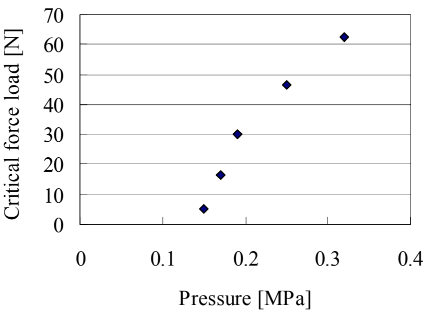


Figure 19 Critical force load in the long stroke type

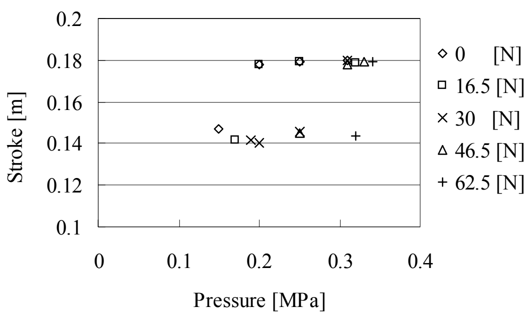


Figure 20 Stroke of the piston with change in pressure and load force (long stroke type)

found that the piston speed when moving forward is lower than backward. The critical force load is shown at in figure 19. Comparing with the result in figure 12, the critical value becomes extremely smaller as the pressure is lower. It is considered to be caused by the friction between the piston and the bore because the piston has O-rings. The stroke changes with the change in force load and pressure as shown in figure 20. The stroke gets the smaller value around 0.142 m when the pressure is lower and the force load is larger. As mentioned previously, the leakage thorough the pilot port 1 causes this.

It was found that the long stroke type still needs to be improved and it was important to decrease the friction between the piston and the bore and to make the leakage thorough the pilot port 1 close to zero when the piston is moving backward.

CONCLUSION

The low pressure water hydraulic actuator which makes self reciprocating linear motion with only supply of the low pressure water from tap water network is developed. Two different prototypes, a short stroke type and a long stroke type, were produced and tested. They showed good fundamental performances. But, especially, the long stroke type still needs to be improved.

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