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Functions and Evaluation of Damper Agent for Optical Pickups

Introduction

For years, optical devices such as CDs, MDs, and DVDs have been incorporated in home electrical appliances, PCs, games, and car navigation systems. The production of these general-storage devices in 1999 was over 0.3 billion.

The core of such a device, an optical pickup lens, reads laser ray reflected from a disk surface. To immediately suppress the vibration caused inside or outside of the device and the counteraction of the servo function, a damper agent that absorbs vibration is used.

This issue focuses on a damper agent developed in 1998, introducing its purpose, its required properties, and the method by which it has been evaluated.

Contents

1. The function of damper agents

An OPD is a device that plays back (or records) information by detecting bumps or pits formed on a disk. The distance between pits for CDs is 1.6 μm, equivalent to 30 tracks within the width of a single strand of human hair. Since a CD contains approximately a billion pits, the pits are extremely densely distributed. The focus of the laser (with a wavelength of 0.78 μm) on the disk is precise. Reading a signal requires positioning resolution within a margin of error of $\pm 1 \mu$m. The CD control consists of a rotary servo, a focus servo, and a tracking servo[1]. The rotary servo adjusts the number of revolutions for the inner and outer radius of the disk to read the pits arranged along a spiral track with constant linear density. The focus servo moves the pickup up and down to focus the laser beam. The tracking servo adjusts the lateral motion of the laser to track the pit train. To ensure the accuracy of the pickup unit, the damper agent constantly absorbs the vibrations and stresses generated by the three servos (the vibration from motor rotation and the reaction in position correction by focus and tracking servos) as well as external vibrations.

There are four main techniques for reducing vibration: (1) isolation, (2) damping, (3) dynamic damping, and (4) shock absorption[2]. (1) Vibration isolation minimizes the transmission of incoming and outgoing vibration. (2) Vibration damping reduces vibration by converting vibrational energy into thermal energy using materials of high internal damping directly attached to the vibration transfer path. (3) Dynamic damping transfers vibrational energy in the main vibration system to a dynamic damper attached to the vibration source with mass (m), spring constant (k), and viscous damping coefficient (c). The damper absorbs and damps the vibration of a specific frequency. (4) Shock absorption reduces the impact force when shock is applied to a unit. The shock absorber converts shock energy into heat via internal damping and reduces rebound energy. Among these, the damper agents for pickup systems must provide functions (1) and (4).

Recent trends in pickup system structures have been to support the pickup lens with 4 thin wires. The damper agent is deployed near the base of the wires. Damper agents are categorized roughly into solid and liquid types, of which the liquid types are applied and then cured. Ultraviolet-curing resins are popular for bonding around the pickup mechanism. Three Bond provides the market with both heat-curing and ultraviolet-curing resins as damper agents.

Resonance frequencies are important vibrational characteristics for the pickup actuator, particularly the first resonance frequency (F0) and its peak height, referred to as the Q value (Figure 2).

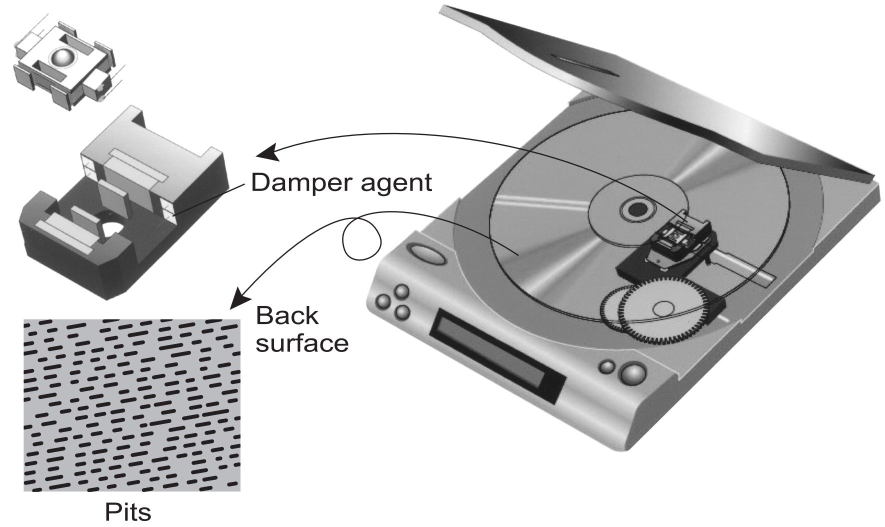


Figure 1: Pits and central part of pickup

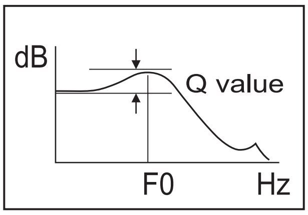
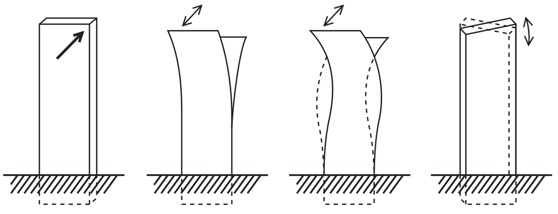


Figure 2: F0 and Q value of the actuator

Here, we will briefly discuss the first resonance. Figure 3 shows a fixed metal plate with a single degree of freedom (indicated by the arrow). When the metal plate is hammered (i.e., when vibration is induced), the metal plate oscillates. The oscillation is divided into the sum of components (1), (2), (3), etc[3]. Figure 4 shows the frequency response curve for the metal plate oscillations. The first peak marked as (1) is referred to as the first resonance. Generally in the low frequency region, the first resonance has large amplitude and tends to generate large-scale mechanical effects.



(1) First bending (2) Second bending (3) First torsion

Figure 3: Metal plate oscillation

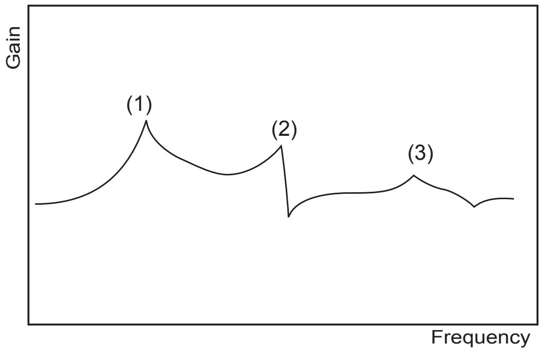


Figure 4: Frequency response curve

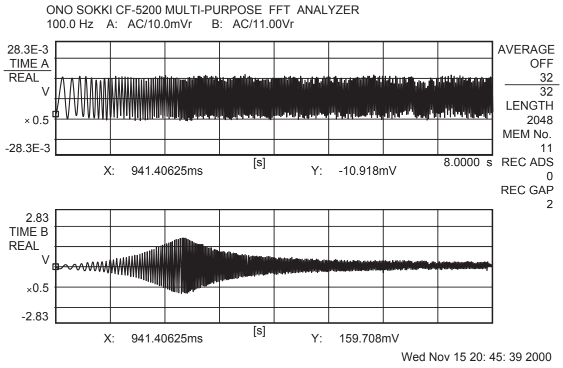
We will now provide a similarly brief overview of pickup systems. Figure 5 shows the frequency response curve for a pickup system. From top to bottom, the figures indicate the input signal (a sweep sine wave), the output signal, the gain characteristic of the frequency response function, and the phase characteristic of the frequency response function. The gain characteristic shows how the amplitude changes as the signal passes through the system. The x-axis corresponds to frequency while the y-axis corresponds to the output/input amplitude ratio (dB). The phase characteristic indicates the advance or delay of the phase of the output signal relative to the input signal. The x-axis indicates frequency, while the y-axis indicates the phase shift in degrees or radians.

Since the first resonance oscillation generates large-scale mechanical effects if applied to the pickup continuously, the system is designed to block this resonance frequency. Thus, F0 (generally 30 Hz to 50 Hz) must remain constant at the initial value after the endurance test, and the Q value must be at or below 10 dB (ideally 5 dB to 10 dB), since vibrations are absorbed faster if the Q value is smaller, and to suppress first resonance amplitude.

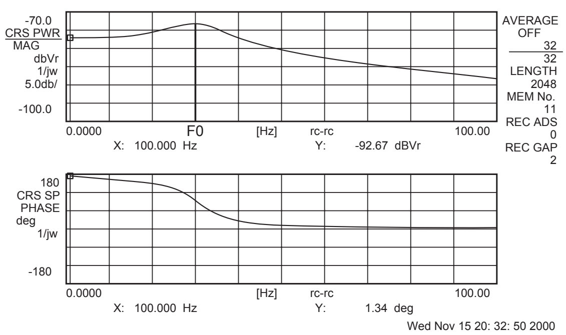
Having two degrees of freedom, the actuator shown in Figure 1 is known as a biaxial actuator. It can be modeled as a wire spring with a single degree of freedom, fixed at one end and supporting the lens at the other. F0 can be theoretically calculated from the mass of support (m), Young's modulus (E), diameter (d), and length (l). The Q value is known to be inversely proportional to the damping ratio (ζ) and proportional to the loss factor ($\tan\delta$) of the material.

$$F0 = \frac{1}{2\pi}\sqrt{\frac{36\pi E\cdot d^4}{m\cdot l^3}} \quad \cdots\cdots(1)$$

$$Q \approx \frac{1}{2\zeta} \qquad Q = \frac{1}{2}\tan\delta \quad \cdots\cdot(2)$$



Input signal (upper) and output signal (lower)



Gain (upper) and phase (lower)

Figure 5: Actuator characteristics

The vibrational characteristics of a gel material, a viscoelastic body, depend largely on its molecular structure, average molecular weight, and polar structure, as well as the shape, diameter, and surface structure of the filler particles added. When stress and strain are applied to the gel, friction between the molecules or between the molecules and the filler arising from macro-Brownian motion of the main chain and the micro-Brownian motion of the side chains converts vibrational energy into thermal energy, absorbing vibration.

The design of damper agents is based on this theoretical underpinning. The major factors are not only to soften the damper agents with increasing dilution oil but to control the oligomer structure, to adjust crosslinking density, and to optimize filler content, particle shape, dilution oil molecular weight, and its polarity.

2. Features of Three Bond's damper agents

Damper agents are resins consisting of silicone-based pre-polymers. Various materials are used to absorb vibrations. Among them, silicone is notable for its low temperature dependence with respect to elasticity and viscosity compared to other polymer materials. While silicone is generally regarded as a rubber material, the silicone used in damper agents has the special properties of forming gels after they are cured. This morphology increases vibration absorption at the frequency at which damping is required. Improved vibration absorption depends on both the elasticity of the rubber and the viscosity of the liquid. The specifics of elasticity and viscosity are discussed later.

Three Bond produces two different types of resins: heat-curing and ultraviolet-curing types. Both types exhibit extremely small changes in characteristics (particularly damping characteristics), and cure rapidly in curing media. The heat-curing types cure through reactions known as addition reactions (also known as hydrosilylation reactions). Heat-curing resins are available as one-part or two-part resins. One-part resins are easier to handle and can be applied as is. On the other hand, they must be stored at lower temperatures than two-part resins. Two-part resins cure at a certain temperature when mixed at a 1:1 ratio. The curing rate is similar to that of one-part resins, but the shelf life is longer, since they do not cure until mixed.

Ultraviolet-curing resins cure through the radical polymerization induced by ultraviolet irradiation. (Please refer to Technical News No. 10 for specifics of the reaction mechanism.) Depending on the working environment of optical pickup production, we recommend ultraviolet-curing resins for automated lines, and heat-curing resins for batch processes when ultraviolet irradiators cannot be installed due to line equipment restrictions.

Two heat-curing resins, TB1230H (two-part resin) and TB1238 (one-part resin), and an ultraviolet-curing resin, TB3168, were released in 1999. Their properties are given below.

TB1230H and TB1238 characteristics:

(1) A major component is a heat-curing silicone resin

The major component is a heat-curing silicone resin cured by addition reactions.

(2) Low curing temperature

TB1238 cures at lower temperatures and more quickly than conventional one-part addition-curing silicone.

- Caution:

  Hydrosilylation reactions involve highly active metal catalysts. Do not mix or allow the resin to contact sulfur, phosphor, nitrogen compounds, or organic metal salts, or it may affect the effectiveness of the catalysts, impairing curing.

TB3168 characteristics

(1) A major component is an ultraviolet-curing silicone resin

TB3168 is a prepolymer consisting of UV reactive groups added to a silicone resin that offers the same flexibility across a wide temperature range.

(2) Fast curing and stable characteristics under excessive UV exposure

Because gels have a small number of reactive groups that form crosslinking points, they tend to cure slowly under UV irradiation. Three Bond achieves fast curing via catalysts that offer superior photo-curing characteristics and structural formation.

(3) High durability

Reducing unreacted component content by fast curing and effective reinforcement with fillers reduce variations in durability testing.

(4) High reliability

The rheological properties (discussed later) of each lot of the gel are assessed to minimize variations.

- Caution:
  The filler components in the resin tend to form sediments. Stir well before use.

Table 1: Properties

Product name		ThreeBond 1230H	ThreeBond 1238	ThreeBond 3168
Color and appearance		Colorless	Colorless	White liquid
Curing method		Two-part heat-curing	One-part heat-curing	Ultraviolet-curing
Viscosity	Pa•s (P)	0.44 (4.4) for both A and B agents	0.52 (5.2)	15 (150)
Specific gravity		0.97 for both A and B agents	0.97	1.01
Penetration * (Curing conditions)		90 (80°C x 60 minutes)	80 (100°C x 60 minutes)	100 ($3\ kJ/m^2$)
G * (30Hz)	Pa	6100	5500	6000
tanδ(30Hz)		1.1	1	0.9
Volume resistivity	Ω•m	1.13×10^{13}	3.30×10^{13}	2.74×10^{12}
Surface resistivity	Ω	2.7×10^{14}	9.45×10^{14}	5.40×10^{13}
Dielectric constant		2.39	2.01	2.31
Dielectric loss tangent		-	-	0.0032

*1/4 cone with 9.38 g loading

3. Evaluation methods

Three Bond uses the three methods outlined below to assess the characteristics discussed in the previous section. As essential elements of the resin design process, these three methods measure the degree of cure and the reliability of the damper agents.

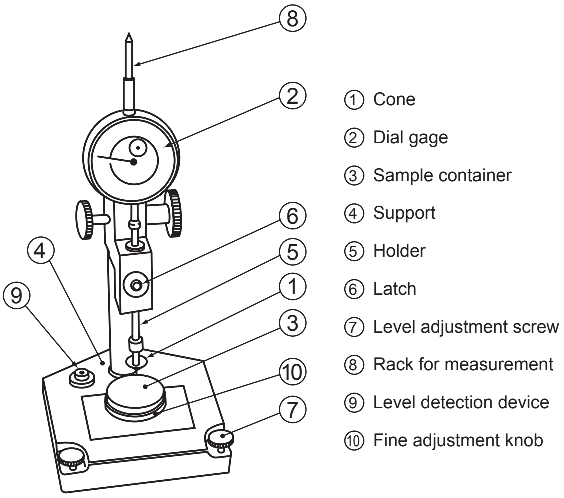


Figure 6: Penetrameter

(1) Penetration

Penetration is a typical method used to measure the hardness of the resin itself. We use a method that conforms to JIS K 2220: A cone is inserted into the cured object, and hardness is expressed in terms of penetration depth in millimeters multiplied by 10 (mm x 10). For example, if the cone penetrates 5 mm into the material, the penetration is given as 50. We use two types of cones, weighing 9.38 g and 50 g.

(2) Laser Doppler vibrometer

The Laser Doppler vibrometer measures the frequency characteristics (the F0 and the Q value discussed earlier) of the pickup system by generating oscillations electronically. The actuator is offered by the manufacturer. This test requires manufacturers to provide actuators. The equipment measures the frequency and velocity of the oscillator via FFT and calculates displacement and acceleration by use of differentials and integrals4).

Measurement using actual products offers benefits, since it is the same evaluation method used by manufacturers. On the other hand, the data will also include various factors inherent in the actuator tested, making these special tests that differ from evaluations of the resin itself. Naturally, the test cannot be performed if the design of the actuator is in the early stage of development and in flux, or if the actuator cannot be provided due to security concerns. Security agreements are concluded in certain cases when actuators are provided. (See Figure 5.)

(3) Rheometer

Rheometers were originally designed to measure the viscosity and viscoelasticity of fluids in the uncured state. The viscosity of fluids differs depending on various conditions: whether the fluid is thixotropic, during coating (under stress) or at rest, and the temperature of the resin. Coating methods include screen printing, dispense coating, and transcription. Viscosity must be designed and adjusted to match the coating method used. Rheometers provide more information than conventional rotational viscometers and are used to evaluate the coating performance of liquids. They are also used to evaluate damper agents, which have a typical viscoelastic behavior, for resin design, product improvement, and inspections.

The measurement detects the stress (strain) generated when mechanical strain (stress) is applied to the sample as a function of time. These quantities can be used to express viscosity and viscoelasticity. The elastic modulus of the polymer material itself that makes up the damper agent (known as the storage elastic modulus and expressed as G') and the viscosity that relaxes the elasticity (known as the loss elastic modulus and expressed as G'') significantly affect vibration absorption characteristics. The ratio of G'' to G' is the loss tangent (expressed as tan δ)5)), which provides a guide value when designing damper agents. These parameters are used in measuring the degree of curing of the resin, changes before and after the reliability test, and optimum ultraviolet exposure.

Compared to the evaluation of damper agents with a Laser Doppler vibrometer, rheometer measurements are simpler and provide more evaluation items to evaluate more details of the resin's intrinsic properties.

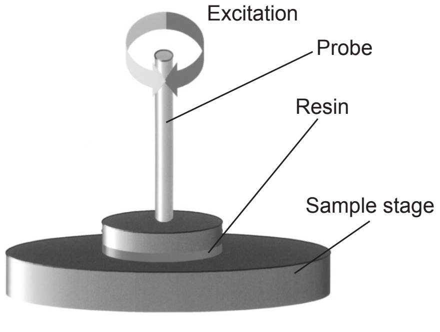
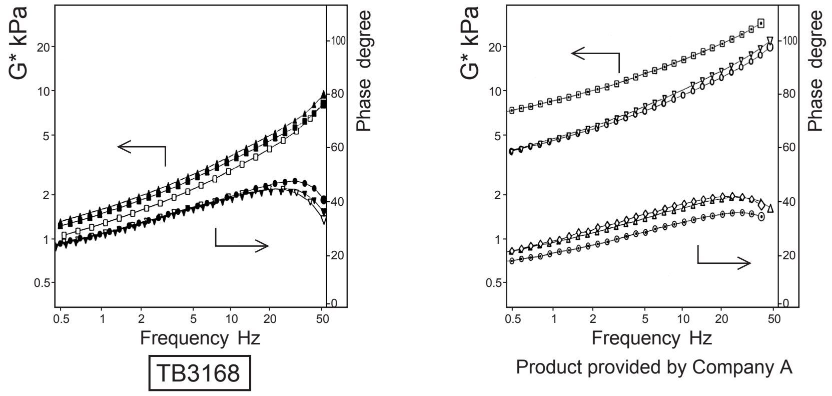


Figure 7: Rheometer probe

Example of resistance measurement with rheometer
Before and after 80°C × 1.2 W



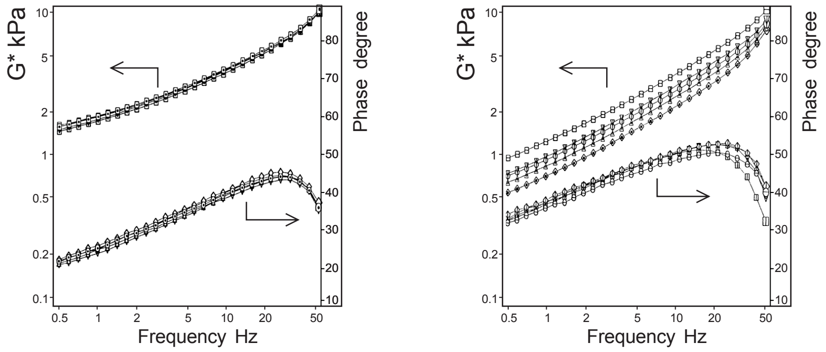
Change in viscoelasticity before and after test at 80°C × 1.2 W
Figure 8: Resistance data at 80°C

Measurement conditions
Equipment: REOLOGICA DAR-100
Measurement mode: Oscillation strain control
Geometry: P25 Gap: 1.00 mm
Frequency: 0.5-50 Hz
Measurement temperature: 25°C
Strain: 0.007

Figure 8 shows the change in G* (complex elastic modulus: discussed later) and the Phase degree (phase angle in degree, δ: discussed later) before and after an environmental test measured with a rheometer. TB3168's viscoelastic characteristics change less during testing than the product provided by Company A, indicating that TB3168 is highly heat-resistant. This characteristic is naturally reflected in performance when used as a damper agent for pickup systems.

Figure 9 shows the degree of ultraviolet-curing measured with the rheometer. The charts superpose the measured graphs for 4 samples with varied ultraviolet exposures ranging up to 15 J/cm^2, where the unit exposure is 3 J/cm^2. For TB3168, the curves for 3 J/cm^2 through 15 J/cm^2 virtually overlap, indicating that rheological characteristics remain constant through accumulated exposure. On the other hand, the curves for the product provided by Company B (especially G* curve) spread widely across a band, indicating that this product cures slowly under ultraviolet exposure and that rheological characteristics do not stabilize even after exposure at 15 J/cm^2.

Example 2 of resistance measurement with rheometer



TB3168

Product provided by Company B

Change in viscoelasticity after ultraviolet exposures of 3, 6, 9, and 15 J/cm^2

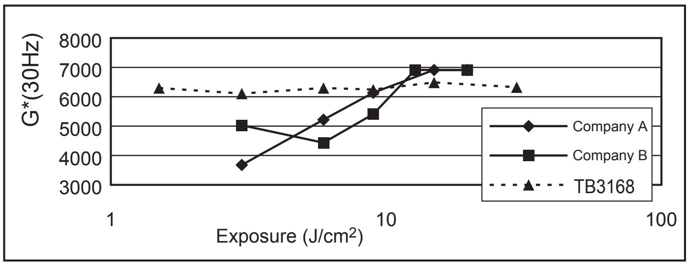


Figure 9: Degree of ultraviolet curing and overexposure resistance

The basic formula for dynamic viscoelasticity is $\sigma = G^*\gamma$ (stress = (complex elastic modulus) × strain). More simply, this expresses the same relationship as Hooke's law, $F = k\chi$ (force = (spring constant) × (displacement)). Rheometers measure G* under constant stress or strain, after which parameters including G' and G'' are calculated. The relationship between G*, G' and G'' is given by:

$$G^* = G' + iG'' \qquad \cdots\cdots(3)$$

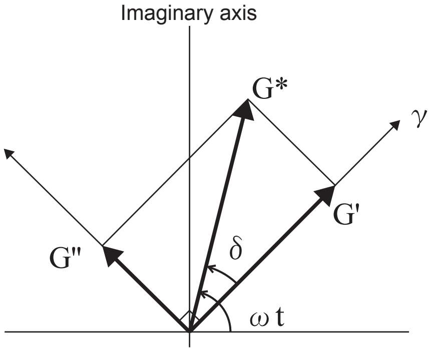


Figure 10: Relationship between G*, G', and G''

The delay in response when stress is applied to a viscoelastic body such as a polymer material is expressed in terms of the phase (the phase degree = δ), where δ ranges between 0 and $\pi/2$. The characteristics of a material change at G' = G'', $\delta = \pi/4$, and $\tan\delta = 1$, with the material being solid for G' > G'' and liquid for G' < G''.

$$F0 = \frac{1}{2\pi}\sqrt{\frac{k}{m}} \qquad \cdots\cdots(4)$$

We are currently undertaking a comprehensive investigation of the correlation between data measured with a rheometer and data measured by other methods, including the F0 and the Q value measured with the actuator and the low frequency sensitivity. F0 is currently believed to correlate with G*, which corresponds to the spring constant for a gel, since F0 is proportional to spring constant k, as indicated in Equation (4). The Q value is considered proportional to tan δ (as discussed earlier). However, these quantities may eventually prove not to be correlated, and further data is urgently required.

Summary

A number of optical pickup manufactures have selected resins released by Three Bond in 1999, resins that now represent our standard-grade products. Products of all grades offer excellent curing and resistance properties, as demonstrated by the fact that the products have passed the reliability tests of our customers. Building on these achievements, we continue to pursue further developments in damper agents offering even better damping properties, particularly vibration absorption (reduced Q value), as well as optimized optical pickup characteristics for each manufacturer's products.

We also plan to pursue applications of resins for vibration prevention, sound insulation, and shock absorption in devices other than OPDs.

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