Design of Torsion-typed Smooth Picture Actuator for DLP Projection TV

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Abstract

Smooth picture module is operated by vibration to tilt the light from the DMD (digital micro mirror device) of DLP projection TV, which makes the screen of the TV smoother and DMD chip cost lower.

To satisfy the vibration characteristics of smooth picture module, it is designed by optimizing moment of inertia, spring constant and damping coefficient, using structural and fluid dynamic simulation that showed a good agreement with experimental data. To reduce the material cost and moment of inertia, engineering plastic is used and the reliability is estimated.

A VCM (voice coil motor) type actuator for smooth picture has to satisfy performance requirements such as higher driving force, lower power consumption, and lower cost. The initial design and optimization for VCM was performed using FE analysis. It allowed us to optimize the design of magnetic circuit of the proposed actuator to obtain higher force while maintaining a lower cost.

1. Introduction

Large screen size TV market can be divided into projection TV, PDP, and LCD TV. The larger TV is, the larger market is occupied by projection TV, since projection TV is cheaper than PDP or LCD TV as screen size is increasing, as shown in Figure 1[10]. There are CRT Projection, LCD Projection, and DLP Projection in projection TV. DLP projection TV is clearer in color and quality of the screen is much better than other kind of projection TV. And DLP projection TV has a lot of benefit like eliminating screen door, smooth pictures, no convergence problem, supurb video performance, picture reality, and no burn-in comparing with PDP or LCD TV.

To increase market share, DLP projection should reduce the cost because PDP and LCD TV price is decreasing and larger screen size TV is developed rapidly in PDP and LCD TV. In DLP projection TV, DMD (Digital Micromirror Device) is one of the most expensive parts. So TI (Texas Instruments) suggested if smooth picture module is applied to DLP projection TV, the price of DMD chip could be reduced.

Using smooth picture module that is located between DMD and screen (or other mirror), mirror is oscillated by 1/2 pixel pitch and it makes the boundary line between pixels disappeared as shown in Figure 3. When the mirror of smooth picture module is tilted rapidly, vibration of mirror brings overshoot and rising time at tilting angle according to time that makes the screen of TV rough as shown in Figure 4.

In this paper to reduce the rising time and overshoot, structural dynamic analysis performed, and fluid dynamic analysis is done to design damping system and the reliability is estimated. Using magnetostatic simulation driving force VCM (voice coil motor) is obtained and efficiency of the VCM is increased.

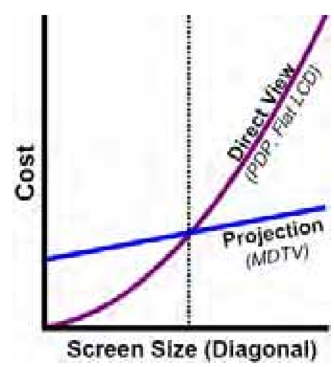


Figure 1. Screen size-cost relations [10]

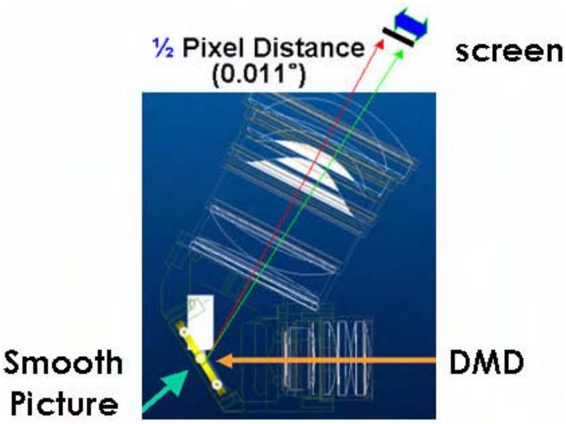
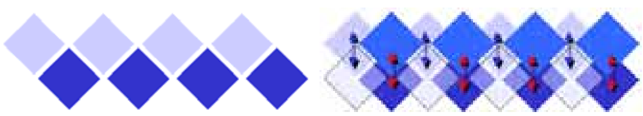
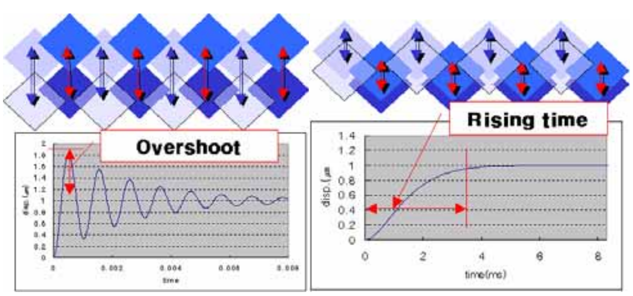


Figure 2. Change of light path by tilting mirror in smooth picture module.



(a) Smooth picture is not applied (b) applied

Figure 3. Pixel of TV.



(a) (b)

Figure 4. pixel of projection TV ((a) when overshoot of smooth picture module is too large (b) when rising time of smooth picture module is too long)

2. Design of smooth picture module

2.1.Dynamic System Design

Dynamic system of smooth picture can be described like Figure 5 and it can be expressed in Eq. (1). J is moment of inertia from weight of titled part (mirror and mirror holder). K is the spring constant when the torsional deformation at mirror holder is occurred by driving force of VCM. To reduced the overshoot from oscillation by the inertia and spring constant, c(damping constant) is required. From this dynamic system that is expressed by Eq.(1), rotation angle(Θ) according to time can be acquired like Eq. (2) by solving the 2nd order differential Eq. (1).

$$J\ddot{\Theta} + c\dot{\Theta} + k\Theta = M(t) \qquad (1)$$

where

$M(t)$: external moment

J :moment of inertia

c:damping constant

k:spring constant

θ:rotation angle

$\dot{\Theta}$:angular velocity

$\ddot{\Theta}$:angular acceleration

$$\theta = e^{-at/2}(y_o \cos \omega t + a\, y_o /(2\omega) \sin \omega t) \qquad (2)$$

Where $\omega = \sqrt{b - a^2/4}$

$(a = c/J,\ b = k/J,\ M(t) = 0)$

Torsion spring of Figure 5 can be designed in two types (hinge and torsion type). Hinge type is designed to get the spring constant by bending cantilever beam like Figure 6(a). And torsion type is designed to get the spring constant by torsional deformation of torsion bar like Figure 6(b).

The purpose of this dynamic system is to reduce the rising time and overshoot. For this purpose, moment of inertia, spring constant, damping coefficient should be designed. At first the smaller the moment of inertia is, the better the dynamic system is for the purpose. The moment of inertia at mirror, mirror holder, and coil is larger than that at other parts. So we should reduce the weight of these parts and if the center of weight is close to center of rotation, moment of inertia can be reduced. Torsion type smooth picture is chosen as a new design because it has less moment of inertia than hinge type and PPS (Polyphenylene Sulfide; engineering plastic) is used because its density is less than steel or aluminum.

After reducing the moment of inertia, spring system should be designed. Figure 6(b) shows deformed shape of mirror holder (torsion type) at smooth picture module when mirror is tilted. Spring constant can be calculated from the following Eq.(3) for torsion bar that has rectangular section of Figure 7.[9] or Finite element structural analysis can be used to calculate spring constant.

$$k = \frac{M_t}{\varphi} = \frac{G}{\ell} I_t \qquad (3)$$

k : torsional spring constant
M_t : torsional moment
φ : rotation angle
G : shear modulus
ℓ : length
I_t : torsional moment

Where $I_t = c_1 h b^3$

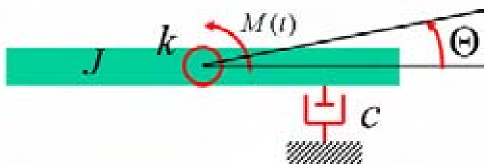
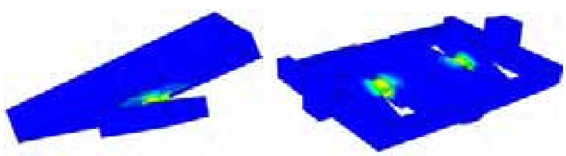


Figure 5. Torsional vibration system of smooth picture.



(a) Conventional design(hinge) (b) New design(torsion)

Figure 6. Mirror holder deformed shape and stress distribution of smooth picture module when mirror is tilted.

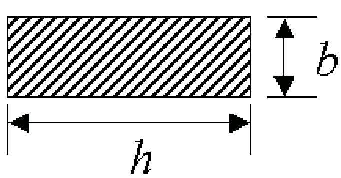


Figure 7. Cross section of torsion bar

2.2. Getting Damping Coefficient by CFD

It is important to determine a proper damping coefficient, since response time and overshoot depend on damping coefficient as shown in Figure 4. To obtain the proper damping coefficient, the factors that affect damping coefficient should be analyzed and optimized.

From Figure 5 and Eq. (1), damping coefficient can be expressed the force per unit angular velocity. As seen in Figure 9, damping coefficient can be calculated with the force (shear force + pressure force) calculated from CFD (computational fluid dynamics) using multi-phase (damping fluid and air) flow field simulation and the real speed of mirror holder.

Major factors that affect damping coefficient are the viscosity of fluid, the gap in which fluid is inserted, and the amount of fluid. Apparent viscosity according to temperature was measured by viscometer because it is important for thermal reliability of product. And damping coefficient according to viscosity is calculated from fluid dynamics simulation and the results showed he damping coefficient is directly proportional to viscosity.

So we should choose the damping fluid that has less viscosity change according to temperature and should not be spilled out. UV-cured silicon shows a best performance for this purpose.

Using UV-cured silicon, Figure 11 shows the change of damping coefficient according to amount of damping fluid and gap where damping fluid is inserted. To obtain the optimal damping coefficient, proper amount of fluid and gap is chosen.

As a result of this analysis, the product of smooth picture module shows overshoot is less than 3% (spec.: less than 10%), rising time is under 0.8ms (spec.: under 1ms), and quality shows 6 sigma-level.

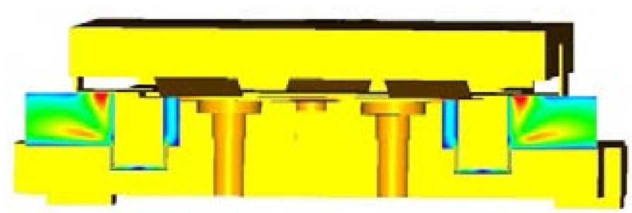


Figure 8. Velocity vector plot of damper as a result of CFD

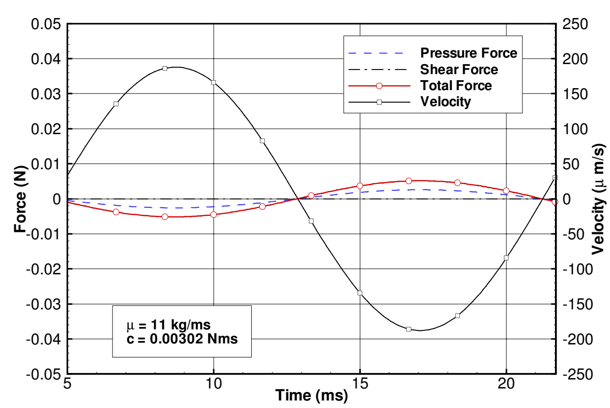


Figure 9 Time-force(shear + pressure) relations(CFD results)

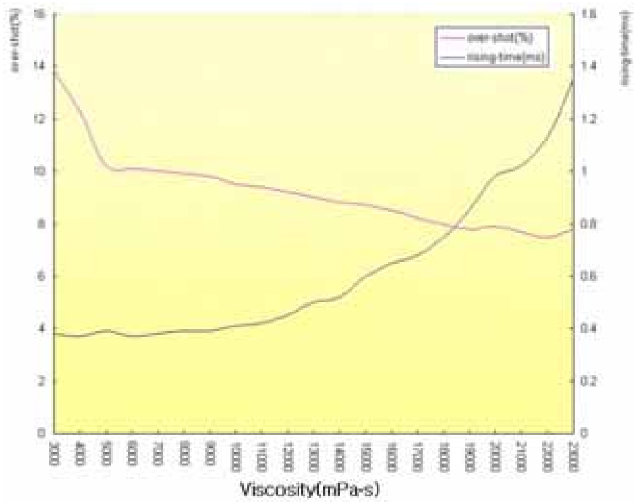


Figure 10. Relations of viscosity-overshoot and rising time (experiment)

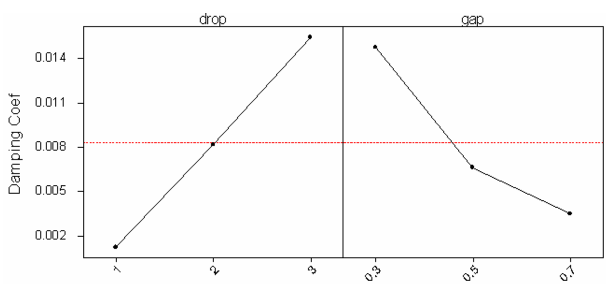
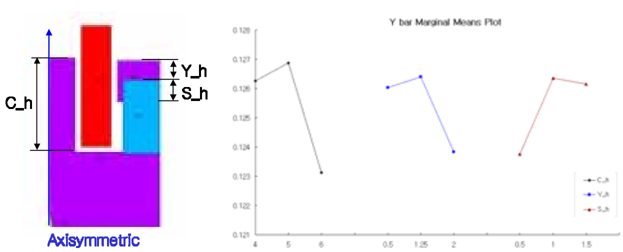


Figure 11. Main effect plot of damping coefficient (CFD results)

2.3. Design of VCM

To reduce a production cost, magnet height reduced in half and then we optimized the other parameter in the magnetic circuit in order to obtain a higher driving force. The candidate design parameters for a magnetic circuit were selected, as shown in Figure 12 (a). Figure 12(b) shows the mean plot of design parameter which expresses the sensitivity of each factor.



(a) (b)

Figure 12. Design parameter and Marginal mean plot ((a) Axisymmetric model (b) Marginal Mean Plot)

The response surface design was used to optimize the dimension of the magnetic circuit. To approximate the object function of the design area, an array for the experiments was constructed using a 3level-3factors central composite design (CCD). When the optimized design was simulated using commercial FEM software, the Lorentz force of this actuator was 0.128N. Finally, we can obtain driving force increased 13% in comparison with initial design. Figure 25 shows an optimized structure and simulated flux distribution at this time.

2.4.Reliability

Smooth picture module is made by PPS (engineering plastic) injection molding instead of aluminum die casting to reduce material cost and moment of inertia. So we should consider high temperature reliability and life time.

3. SUMMARY and CONCLUSION

Smooth picture module is expressed torsional vibration system. To satisfy the vibration characteristics of smooth picture module, it is designed by optimizing inertia, spring constant and damping coefficient from structural dynamic simulation. To get spring constant, torsion bar type smooth picture structure was suggested. And PPS (engineering plastic) is used for reducing material cost and the moment of inertia.

Proper spring constant and damping coefficient is obtained by analytical solution of torsional vibration system of smooth picture module. By structural analysis of torsion bar to get determined spring constant, torsion bar is designed. CFD analysis shows damping coefficient is directly proportional to viscosity and amount of fluid, and reversely proportional to the size of gap in which the fluid is inserted. So we designed these factors using DOE to get the damping coefficient which is determined by torsional vibration system analysis.

Cylinder type VCM is used to get driving force of smooth picture module and optimized using magnetostatic FE analysis and higher force was obtained by 13% while maintaining a lower cost by reducing magnet size.

To assure reliability of the designed smooth picture module, some test and analysis is performed. Young's modulus of PPS at high temperature is almost same as that at room temperature. Thermal expansion measurement for aluminum and PPS shows no problem in use. 20 minutes annealing at 150℃ is enough to remove the residual stress at each part that is made by injection molding of PPS. And fatigue life is almost infinite because the stress at torsionally deformed part is much lower than fatigue limit. Unwanted vibration did not occur because natural frequency is not near the operation frequency.

References

[1] J. Oh, S. Poh, M. Ruzzene, A. Baz, " Vibration Control of Beams Using Electro-Magnetic Compressional Damping Treatment", Journal of Vibration and Acoustics, , Vol.122, pp. 235-243, 2000

[2] Haeng-Soo Lee, Young-Hoon Kim, Tae-Yeon Hwang, Cheol-Soon Kim, "VCM Design to Improve Dynamic Performance of an Actuator in a Disk Drive", IEEE Transactions on Magnetics, vol.41, No.2, pp. 774-778, 2005.

[3] Dong-Ju Lee, Ki-Suk Woo, No-Cheol Park, and Young-Pil Park, "Design and Optimization of a Linear Actuator for Subminiature Optical Storage Devices," IEEE Trans. Magn., vol. 41, pp. 1055-1057, Feb. 2005

[4] H. A. Leupold, "Approaches to permanent magnet circuit design," IEEE Trans. Magn., vol. 35, pp .2341-2346, Nov. 1993.

[5] ABAQUS User's Manual

[6] ANSYS User's Guide

[7] CFD-ACE User's Manual

[8] Maxwell User's Manual

[9] W. Beitz, *Handbook of Mechanical Engineering", Springger-Verlag*, 1994.

[10] John Van Scoter, "CSFB Annual Technology Conference", at http://www.ti.com