

Applying Intelligent Fuzzy Control to Reduce Hysteresis Effect of Force Actuator in a SPM

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Abstract: - This research is to use fuzzy controller to eliminate hysteresis effect of a force actuator for a Scanning Probe Microscope (SPM). This improvement has been verified by MATLAB simulation and practical implementation to reduce the hysteresis effect of the force actuator. Comparisons with two previous designs with and without Linear Velocity Transducer (LVT) for inner-loop feedback compensation are also made. Thus the new system design is cheaper and valuable.

Key-Words: - SPM, LVT, LVDT, Fuzzy controller, PI compensator, Force actuator, Hysteresis effect

1 Introduction

The SPMs have been developed rapidly in last three decade [1-10]. Their usages are very extensive, e. g. the measurements of physical distribution and material property such as surface profile, roughness, static charge, magnetic dipole, friction, elasticity, and thermal conductivity. As the block diagrams in Fig.1 of previous researches [11-12], a balance with stylus probe, force actuator (Fig.2), LVDT (Fig.3), load cell (Fig.4), personal computer, and XYZ-stages were integrated into a contact-force-controlled SPM, such that the sample surface would not be destroyed by the contact force produced by stylus probe. The block diagrams of the control system design with and without LVT for inner-loop feedback [11-12] are shown in Figs.5 and 6, respectively.

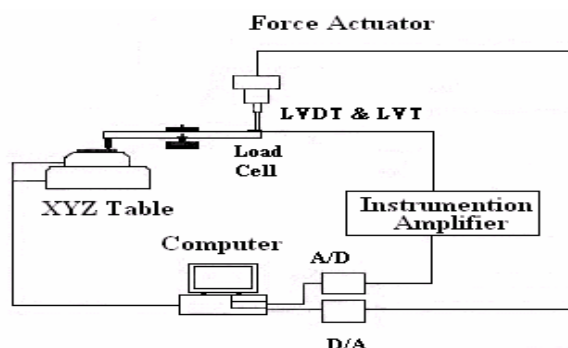


Fig. 1 The system setup of a SPM.

To eliminate hysteresis effect of the force actuator this research in Fig.7 applied an intelligent fuzzy controller [13-20] and without using LVT for

inner-loop feedback system design. This improvement has been verified by MATLAB simulation and practical implementation of a surface profiler. Comparisons with two previous designs with and without LVT for inner-loop feedback are also made. Thus the cost of the new system is cheaper, and the concept is also valuable.

The organization of this paper is as follows: the first section is introduction. The second and the third ones are for the review of previous researches and the proposed fuzzy controller design. The test results and discussions are given in Section 4. The last part is the conclusion.



Fig. 2 Voice coil as the force actuator.



Fig. 3 LVDT.



Fig. 4 Load cell.

2 Review of Previous System Design

The force actuator is consisted of a coil and a spring. As in Fig.8 (a) the rod returns to the initial place when the force actuator de-energized. However, if a voltage is applied across the coil, then there is current in the coil, a force is generated to compress the spring and make the rod pull down as in Fig.8 (b). The relationship of the actuator applied voltage and displacement is shown in Fig.9.

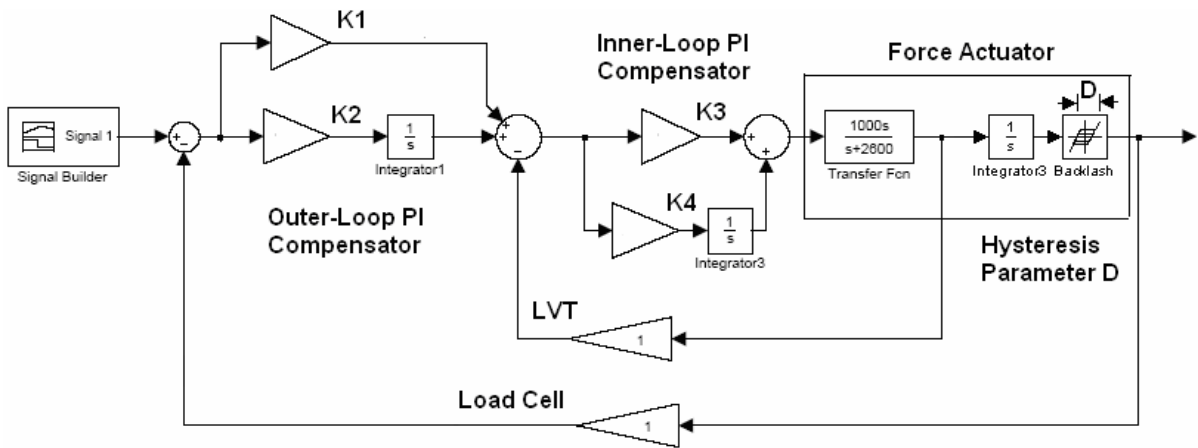


Fig.5 Block diagram of SPM with LVT for inner-loop feedback in the previous research [11].

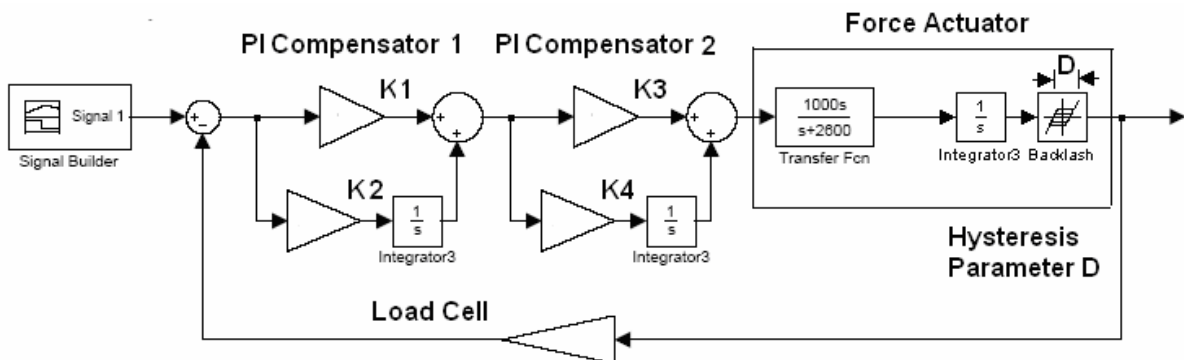


Fig.6 block diagram of SPM without LVT for inner-loop feedback in the previous research [12]

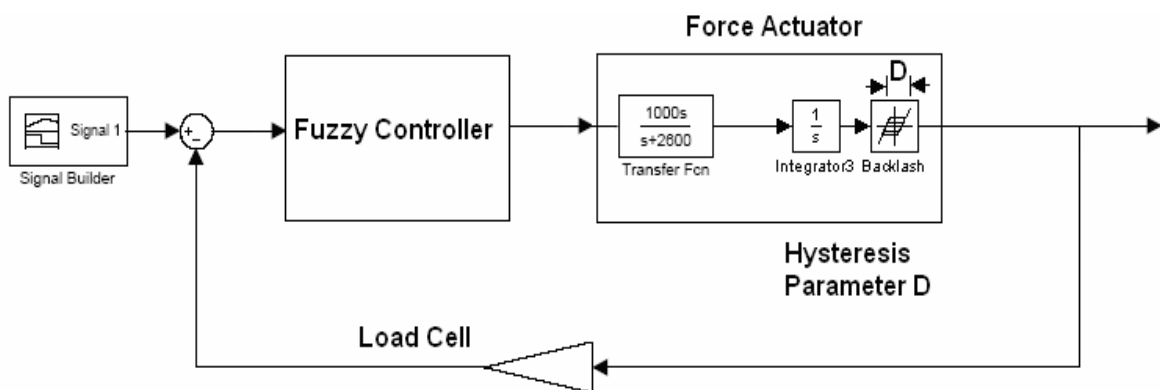


Fig.7 Block diagram of SPM with an intelligent fuzzy controller and without LVT in this research.

To reduce the hysteresis-effect of the force actuator in Fig.9, this research is to use only an intelligent fuzzy controller. The newly system model is shown in Fig.7. Table 1 listed PI compensators for inner and outer loops design (steady state errors are equal to zero for inner and outer loops) results in Fig.5. In addition, the corresponding gain margins, phase margins of the inner (GM1, PM1) and outer (GM2, PM2) loops as well as the phase cross-over frequency ω_c are included. Figs.10-13 are the Bode plots of cases 1, 2, 5 and 6, respectively. The outputs of LVDT for saw tooth shaped input (as in Fig.14) are shown from Figs.15 to 18 for comparison (with hysteresis effect parameter D be 0.3). One can see that the larger the outer-loop phase margin, the lower the hysteresis effect, but all the hysteresis effects are still very dominant. The reason is that ω_c are very large for these cases, and then the time and phase delays produced by the hysteresis effect would be

increased. Thus the stability can even be degraded by adding the hysteresis effect to push the resulted phase margins approaching zero.

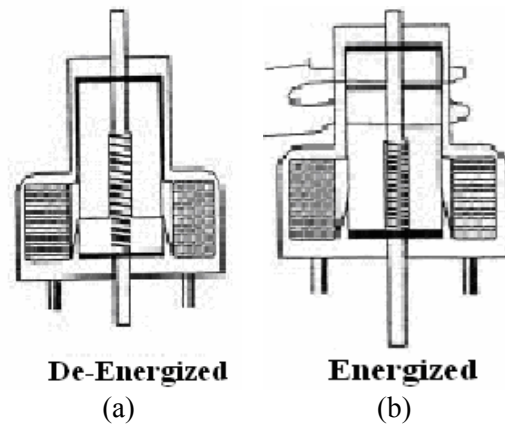


Fig.8 Operation states of actuator.

Table 1 Previous design results of the system defined in Fig 1.

Case	K1	K2	K3	K4	GM1	PM1 (Deg)	GM2	PM2 (Deg)	ω_c (rad/sec)
1	12	120	1	200	∞	73	∞	85	9840
2	10	100	0.8	180	∞	75	∞	70	7500
3	15	100	1.5	200	∞	65	∞	88	20000
4	20	150	2	150	∞	63	∞	89.5	40000
5	8	80	0.5	300	∞	85	∞	60	30000
6	18	200	1.3	220	∞	70	∞	90	30000

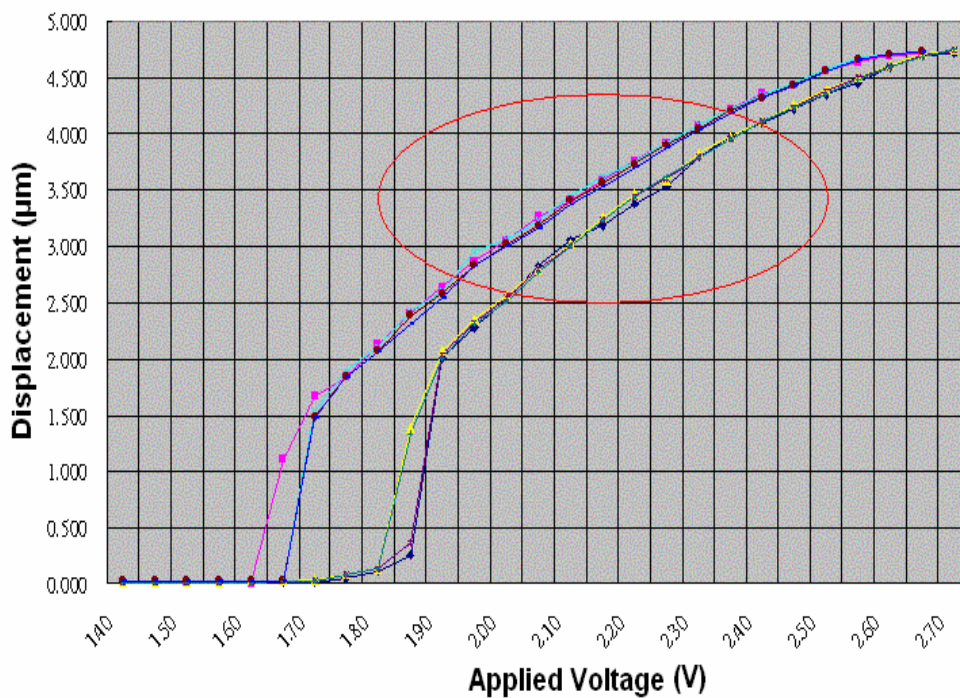


Fig.9 Relationship of actuator applied voltage vs. displacement.

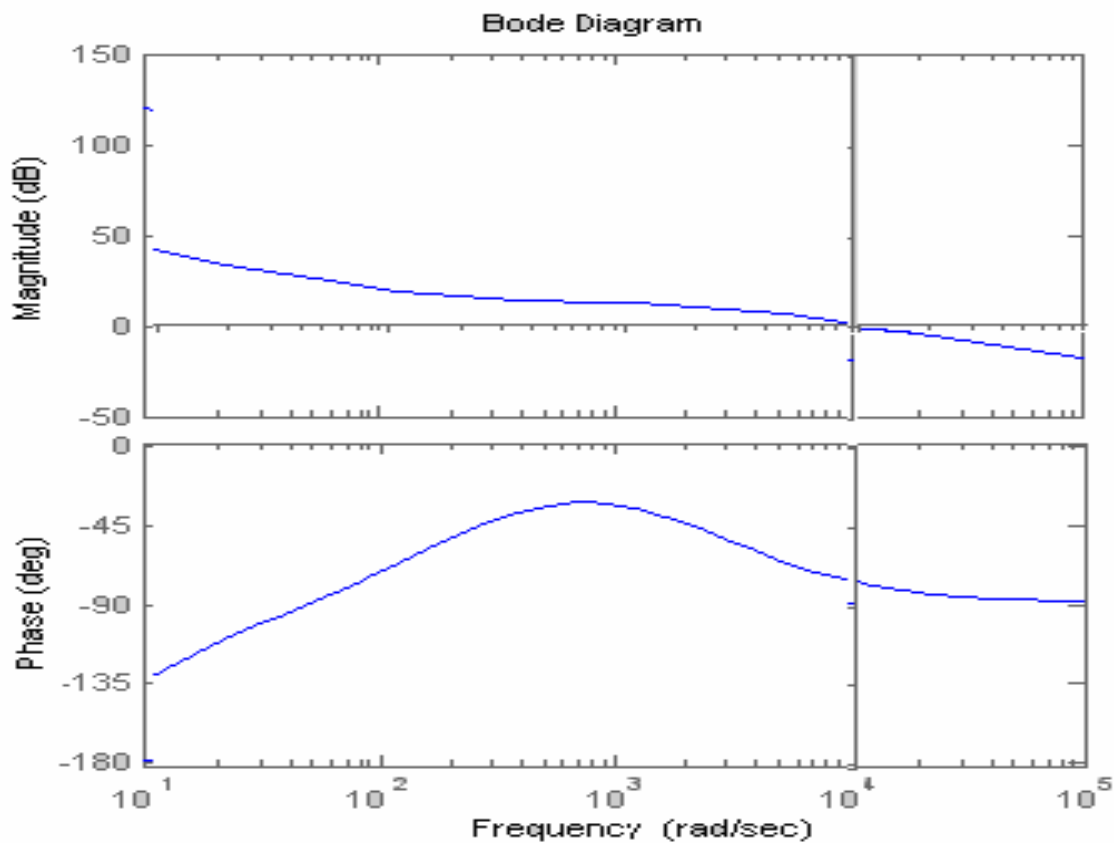


Fig.10 Previous Bode plot of case 1 in Fig. 1.

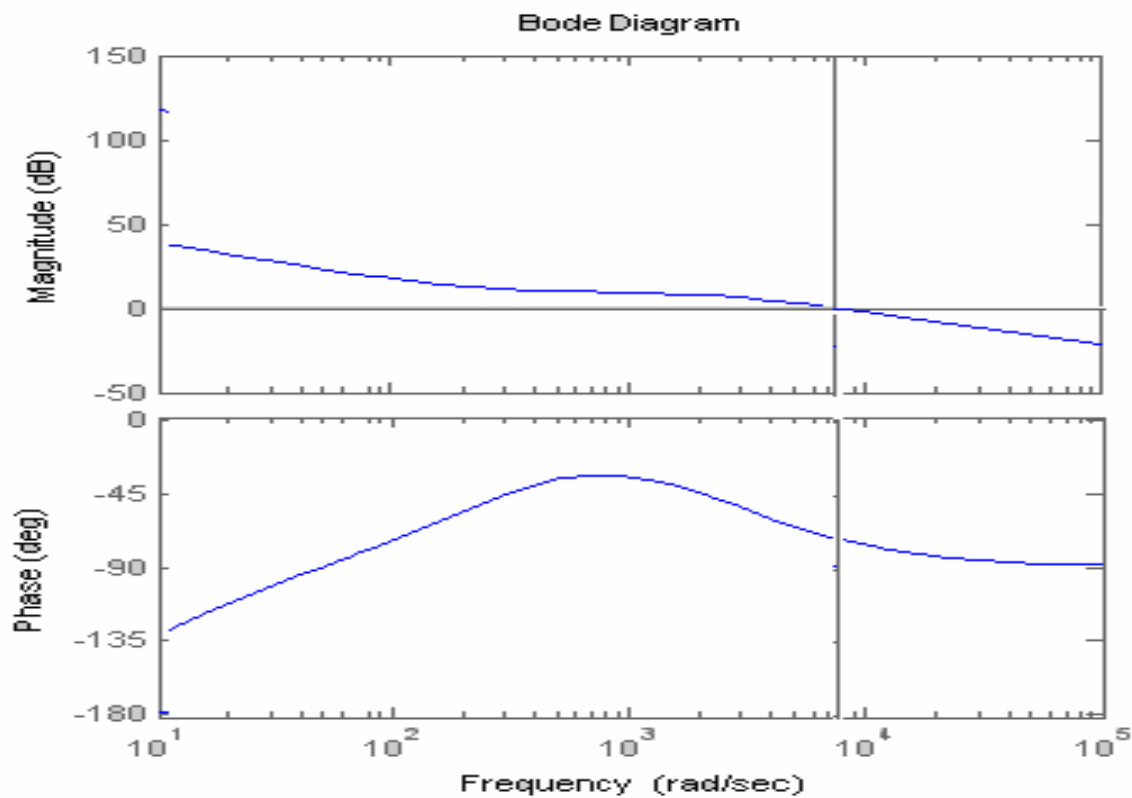


Fig.11 Previous Bode plot of case 2 in Fig. 1.

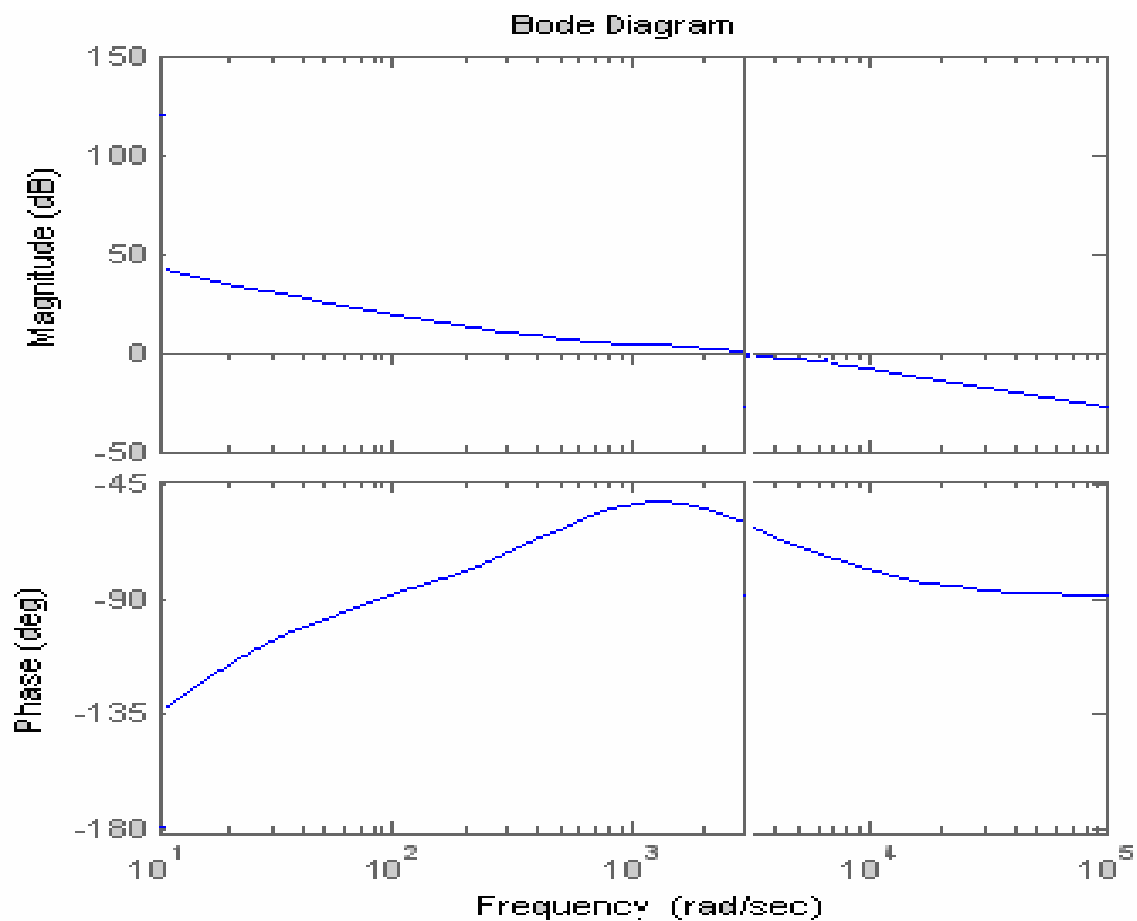


Fig.12 Previous Bode plot of case 5 in Fig. 1.

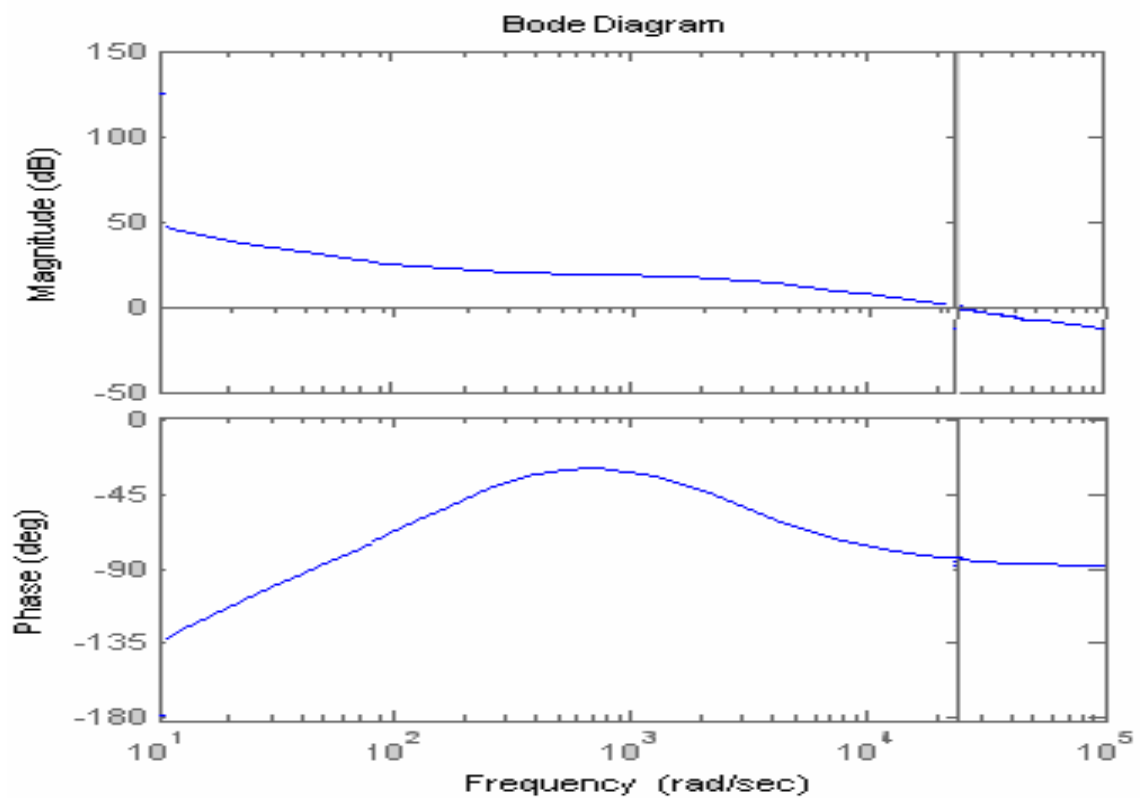


Fig.13 Previous Bode plot of case 6 in Fig. 1.

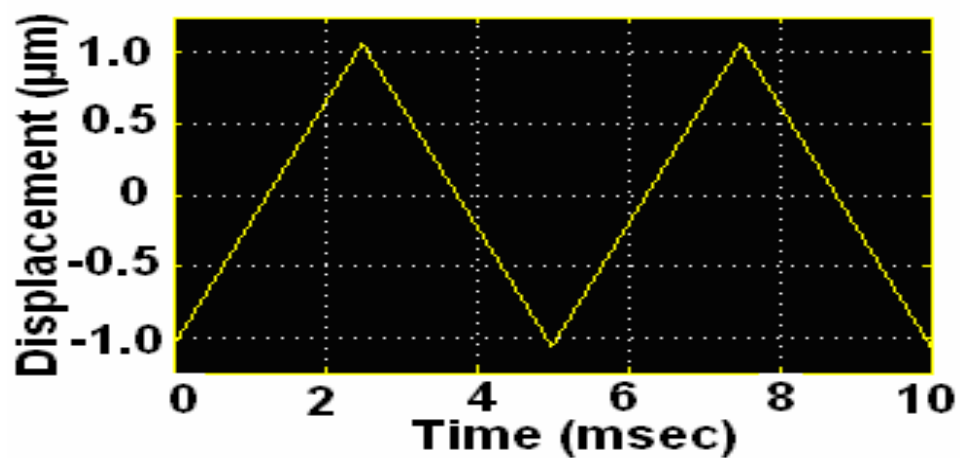


Fig.14 Saw tooth shaped displacement command as input.

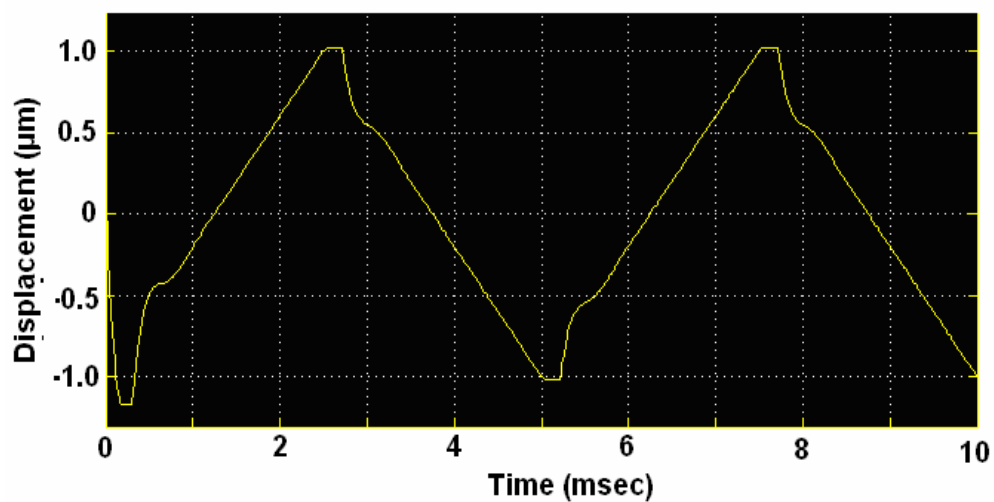


Fig.15 Previous design output of case 1 in Fig. 1.

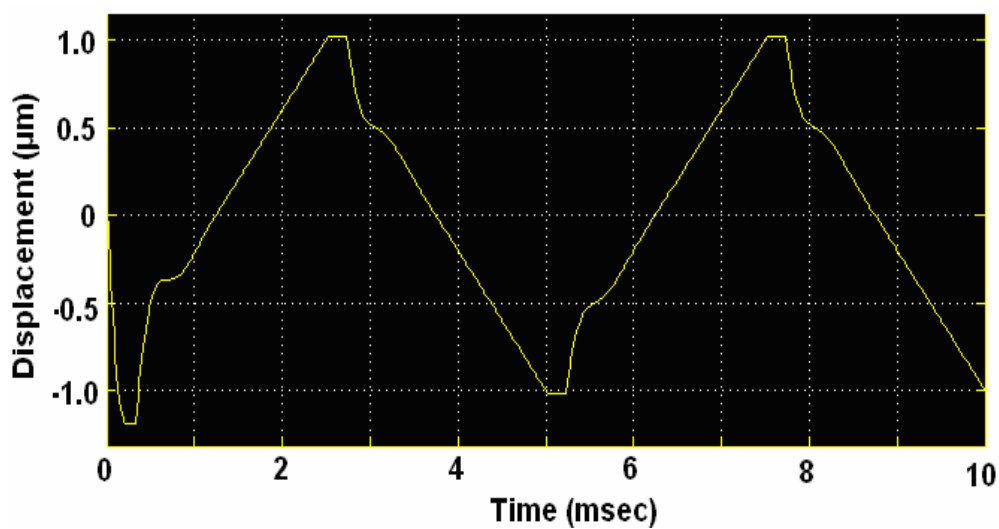


Fig.16 Previous design output of case 2 in Fig. 1.

Now consider the second previous design without LVT for inner-loop feedback in Fig.6. Table 2 also listed the inner and outer loop gains. In addition, the gain margin, phase

margin and ω_c are also included. The Bode plots for cases of 1, 3, 4 and 8 are in Figs.19-22 for comparison. In addition, the outputs for saw tooth-shaped input are in Figs. 23-26 ($D = 0.3$).

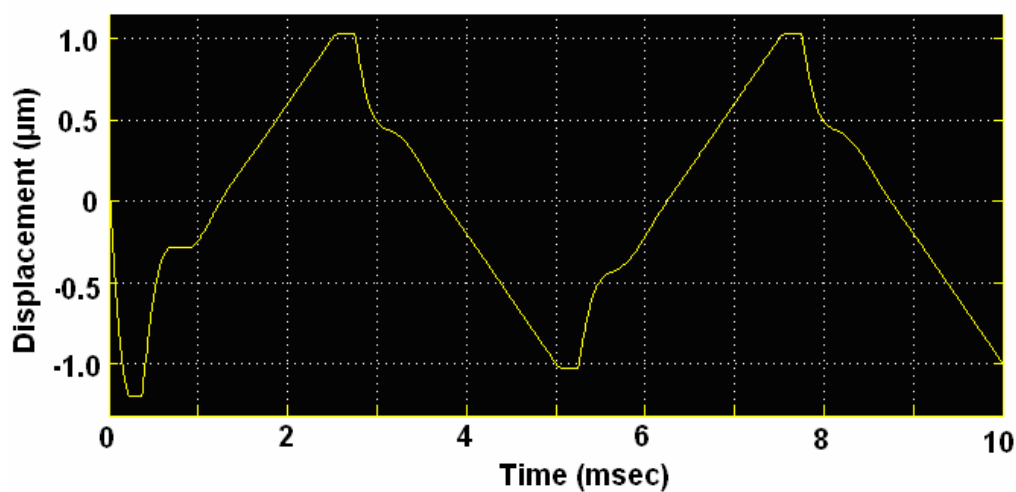


Fig.17 Previous design output of case 5 in Fig.1.

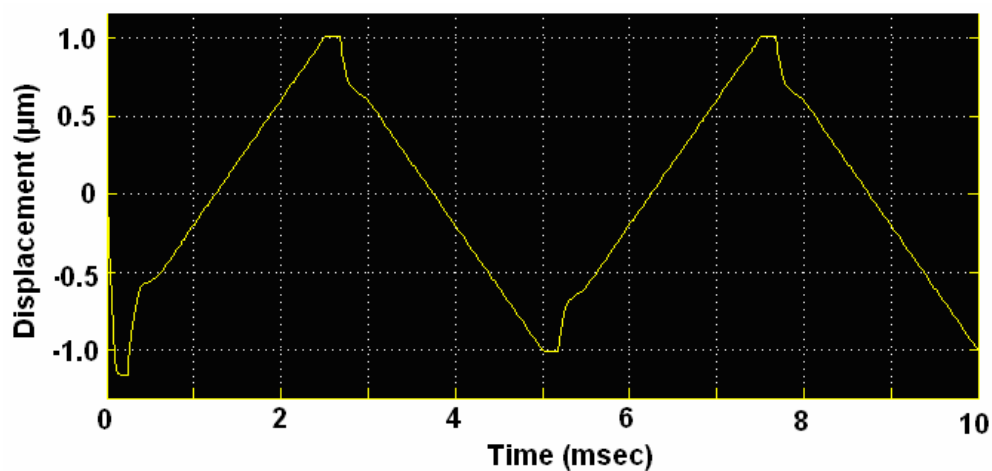


Fig.18 Previous design output of case 6 in Fig.1.

Table 2 The design results of system in Fig.2.

Case	K1	K2	K3	K4	GM	PM (Deg)	ω_c (rad/sec)
1	1	0	1	200	∞	109	80
2	0.5	0	1	200	∞	100	40
3	0.25	0	1	200	∞	98	20
4	0.1	0	1	200	∞	90	8
5	1	0.2	1	200	∞	110	90
6	0.5	0.4	1	200	∞	92	30
7	0.25	0.6	1	200	∞	89	20
8	0.1	0.8	1	200	∞	50	9

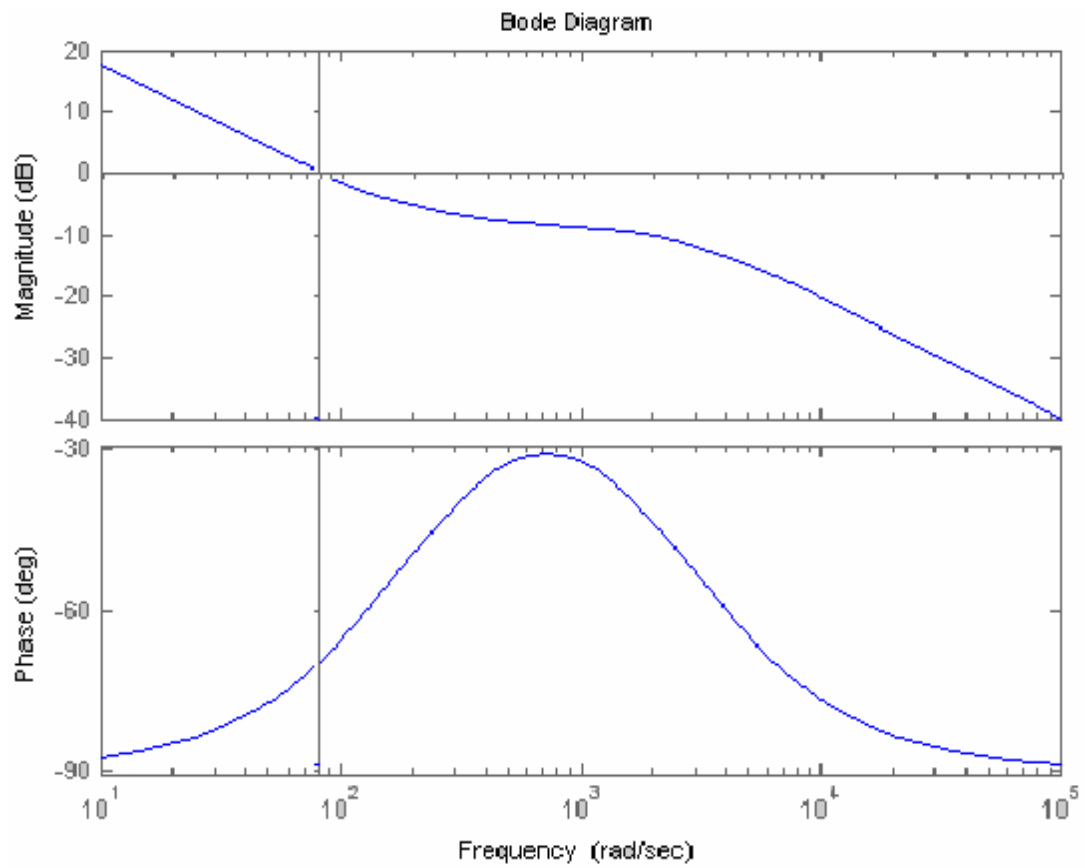


Fig.19 Previous Bode plot of case 1 in Fig.2.

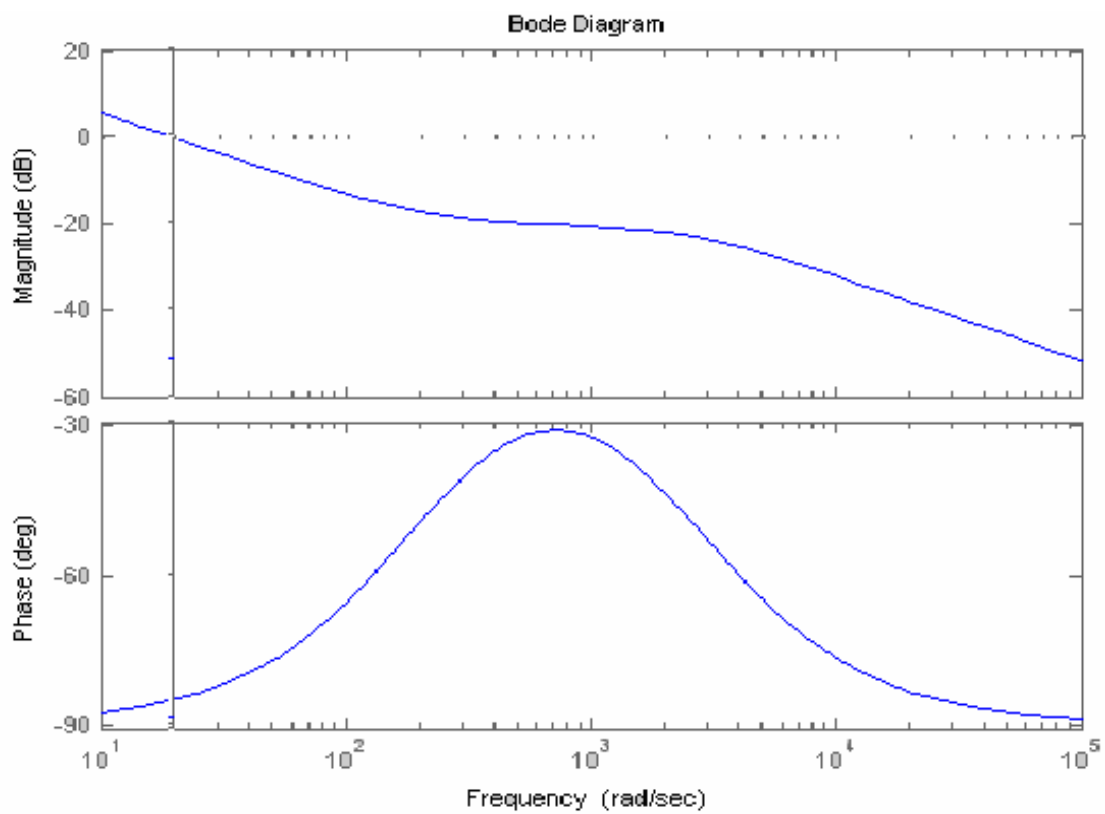


Fig.20 Previous Bode plot of case 3 in Fig.2.

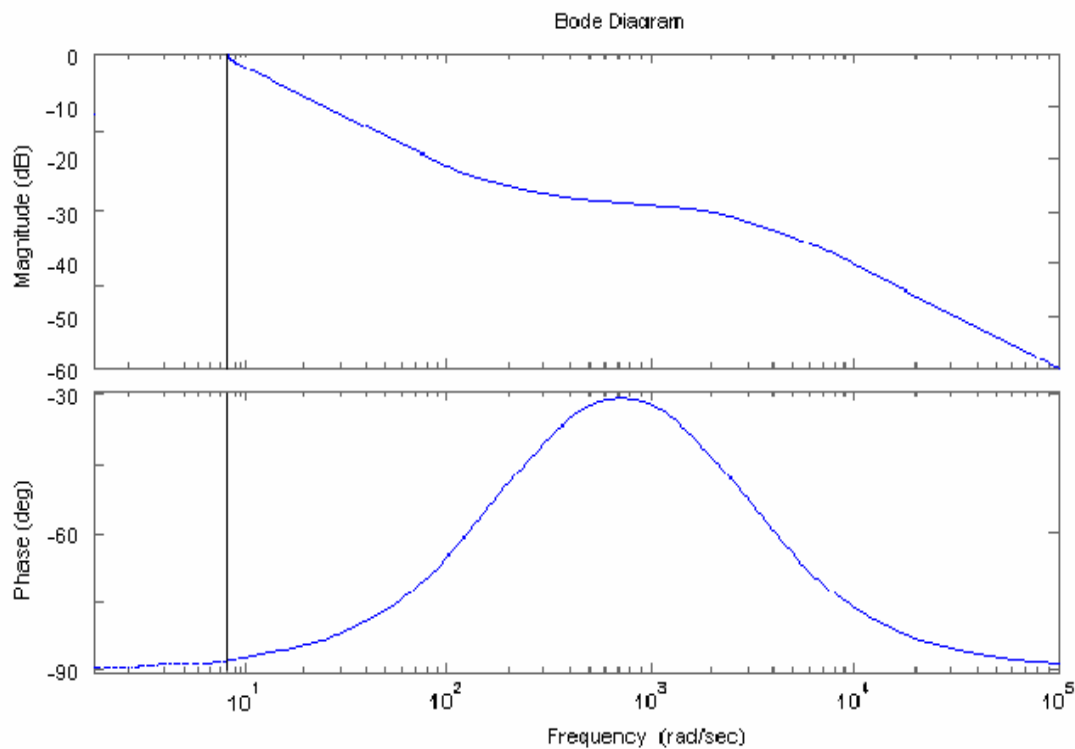


Fig.21 Previous Bode plot of case 4 in Fig.2.

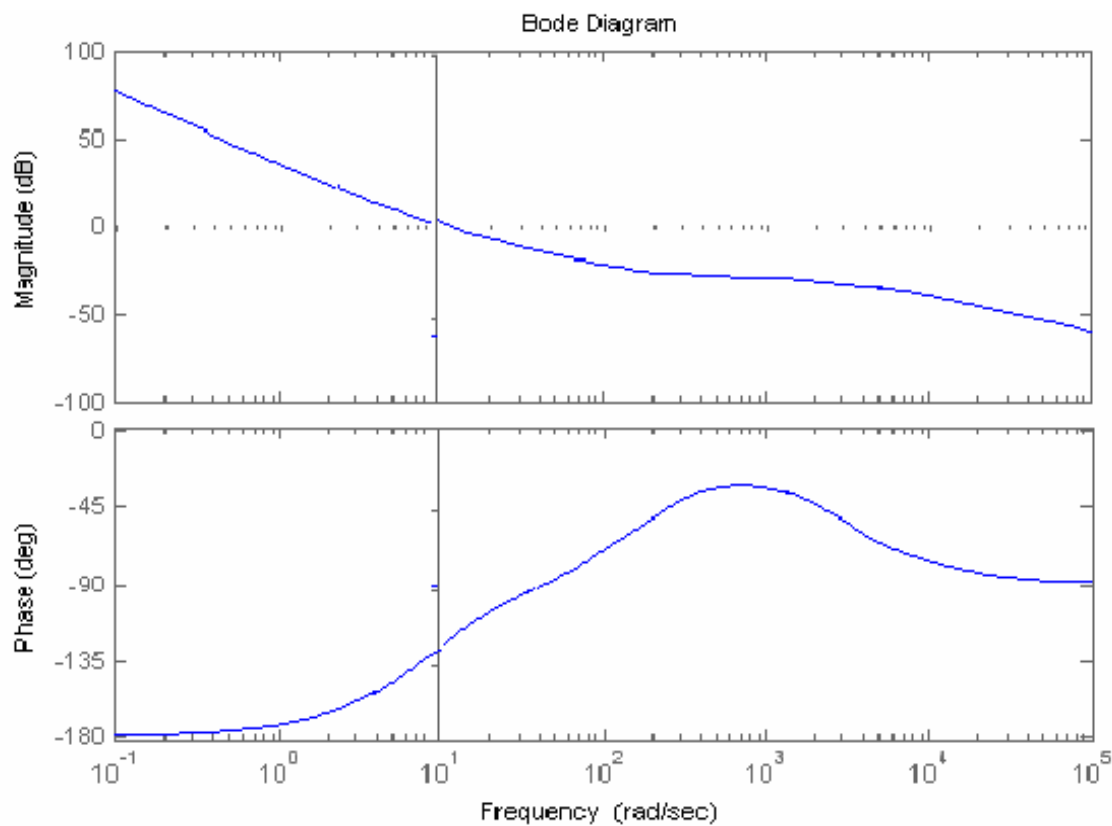


Fig.22 Previous Bode plot of case 8 in Fig.2.

One can see the hysteresis effect is lower for case 1 with larger phase margin, while still bad for cases 3, 4 and 8. The reason is that the phase margins as well as the magnitudes of ω_c are larger for case 1, thus the system responses are quicker, and the dead zone effect and phase delay produced by the hysteresis effect would be smaller as in Fig.23. However, the magnitudes of ω_c as well as the phase margin

are much smaller for cases 3 and 4, thus the hysteresis effects are larger as in Figs.24 and 25. In addition, since the original phase margin as well as the magnitudes of ω_c are too smaller of case 8, thus as Fig.26 shows that the stability can even be degraded by adding the hysteresis effect to push the phase margin approaching zero.

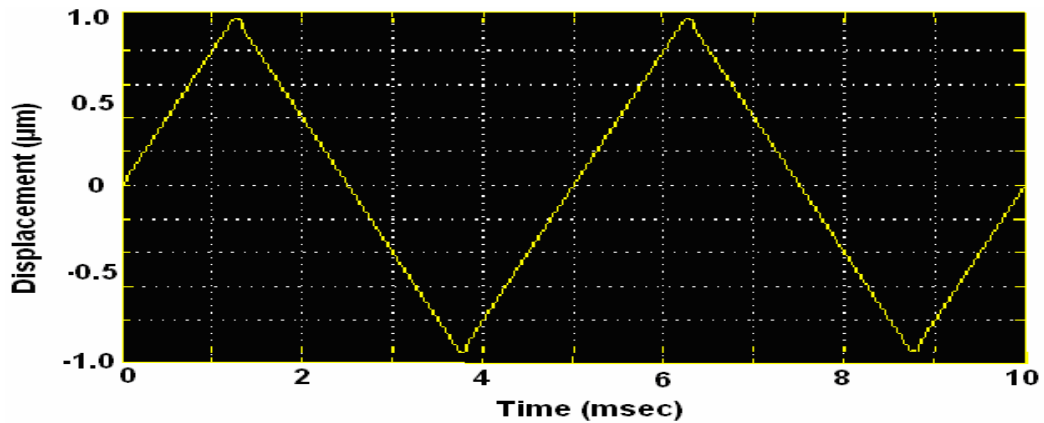


Fig.23 Previous design output of case 1 in Fig.2.

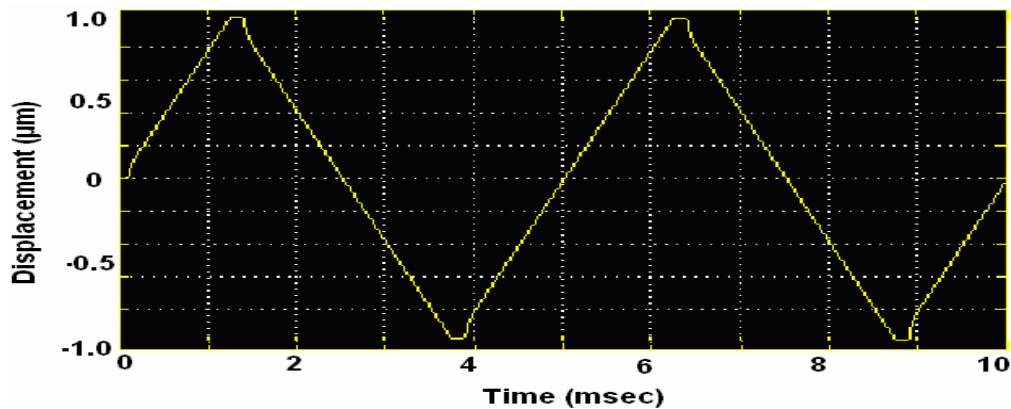


Fig.24 Previous design output of case 3 in Fig.2.

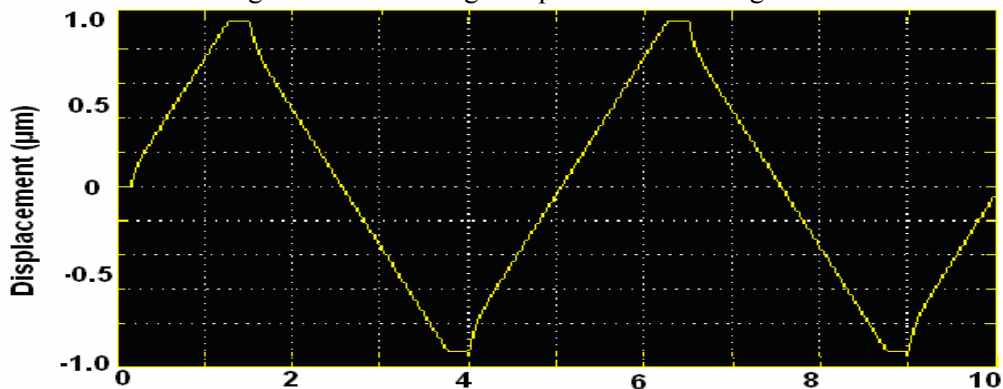


Fig.25 Previous design output of case 4 in Fig.2.

