Vibration suppression of bilateral control system

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***Abstract*—This paper proposes a novel concept of vibration suppression of bilateral control system by first order low pass filters. This will be a huge step of improvement of the transparency of conventional bilateral control system. In a master slave manipulating system, master gives command to the slave and according to the slave responses master commands are varying. So that slave response should always come up without unwanted vibrations. Therefore vibration suppression is more important in motion control. Conventional bilateral control system is suppressed the vibration up to some certain level. The suppressing frequency bandwidth have been pointed out by bode diagrams. Further suppression has been done by placing low pass filter on different places of the conventional block. Then the system block was modified by adding a filter. The results of the disturbance observer filter effects are illustrated by the simulation graphs. The proposed method of additional filter effect is validated by simulation and practical results.**

Keywords—bilateral control; vibration suppression

I. INTRODUCTION

Vibration suppression is a major subject of robotics and motion control. There are several types of vibrations. Free vibration, force vibration and damped vibrations are some of them. Various concepts have been developed by researchers to suppress the vibrations of mechanical systems. Resonance ratio control has used to suppress the vibrations of two mass resonant system and three mass resonant systems. In there, reaction torque occurred in the shaft have used to suppress the vibrations without using any position sensors [1].

Bilateral control systems are controlled according to the tactile sense or the sense of touch. This tactile information has included both action and reaction. In a bilateral control system both master and slave are controlled simultaneously. Master is the one who operates the system and slave is the one who face to the environment. Always slave act according to the master command, the slave force and position responses are given as an input to the master. Transparency and the operationality of the bilateral control system should be always considered. How well the force and position information feels to both master and slave is called the transparency which is the main tasks of the authors in this paper [2].Therefore the responses of master and slave should always be perfect, with the wanted vibrations. If the responses include any vibration which can be confused the master, then the system will not run properly and the slave vibrations are disturbed to the master operator.

Vibration suppression strategy is more useful in industrial applications. In a manually controlled ground mining systems vibration feedback are transferred to the operator. So that the operators can be threatened by the irritated vibrations. It will be a big health issue to the operator as well. In applications like minimal invasive surgeries, the surgeon should feel the reactions occur during a surgery [3]. In a master slave manipulator system, the surgery is done by a slave manipulator. So that, the master manipulator, where is operated by the surgeon should be well known with the movements of the slave side. It will be a risked condition if those motions include any unknown vibrations which can be a nuisance to the master. Therefore vibration suppression is required by the system. Most of the robot arms have a light weight therefore the tip is vibrating frequently. In such a manner resonant ratio control is applied [4].As well as in space applications the slave environment reactions are required by astronomers. And those environments are unknown and assumed by the scientist. Bilateral control theories have already applied to such kind of applications but still the unknown vibrations are a big issue in the technology.

Always good transparency of the system means, the reflection of both force and position feedbacks from slave to master and master to slave [5]. In this paper, the new concept of vibration suppression of bilateral control system by using low pass filters was introduced. Even though, large number of researchers published on vibration suppression, still a less amount of research has done on vibration suppression of conventional bilateral control. Through "frequency response analysis of bilateral control system", researchers have proved bilateral control system has the ability to suppress the vibration itself. This paper is based on further suppression by adding filters to the system and it has been proved by analytically and practically.

II. BILATERAL CONTROL

The action of the master and the reaction of the slave is the main aspect of bilateral control. The master is directly contacted with the operator and the slave is contacted with the environment. Always slave is run by master command. Fig.1 shows the bilateral control system with a vibration environment which is handled by four players [6]. f_m and f_s are the action of the master and the reaction of the slave respectively. X_m and X_s represent the master slave positions. Unwanted vibrations are illustrated in the slave environment

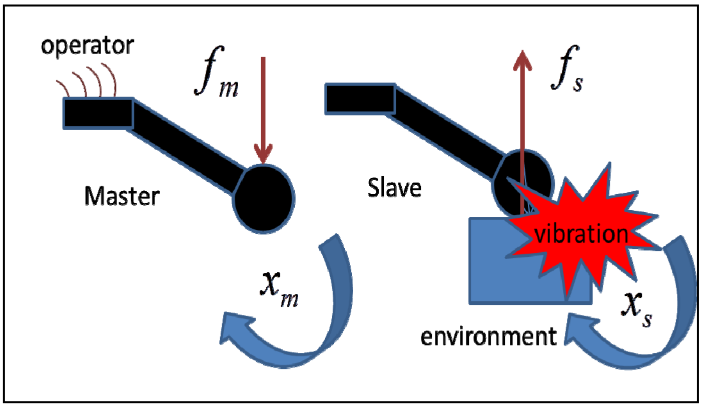

Fig.1. Bilateral control with vibration on slave environment

as shown in fig.1, in a bilateral control system both position and force control have to be considered [7]. So that the equation (1) and equation (2) can be derived.

$$f_m + f_s = 0 \tag{1}$$

$$x_m - x_s = 0 \tag{2}$$

Modified block diagram of bilateral control system is illustrated in fig.2. Two identical dc motors have used as both master and slave manipulators. Always the PD controller input is difference between master and slave position outputs. For the simulation constant force is applied to the master and the slave manipulator hits an object which has a spring constant K_x. Different vibrations are given to the slave environment as a force input with the reaction torque. The given vibrations of the slave environment are reflected to the master operator. Vibration is transferred by both position and force responses of the slave. Therefore force and position filters are required by the system. Both force and position equations are transformed to equation (3) and (4). But both conditions cannot be satisfied at same time.

$$f_m - f_s\left(\frac{a_1}{s+g_1}\right) = 0 \tag{3}$$

$$x_m + x_s\left(\frac{a_2}{s+g_2}\right) = 0 \tag{4}$$

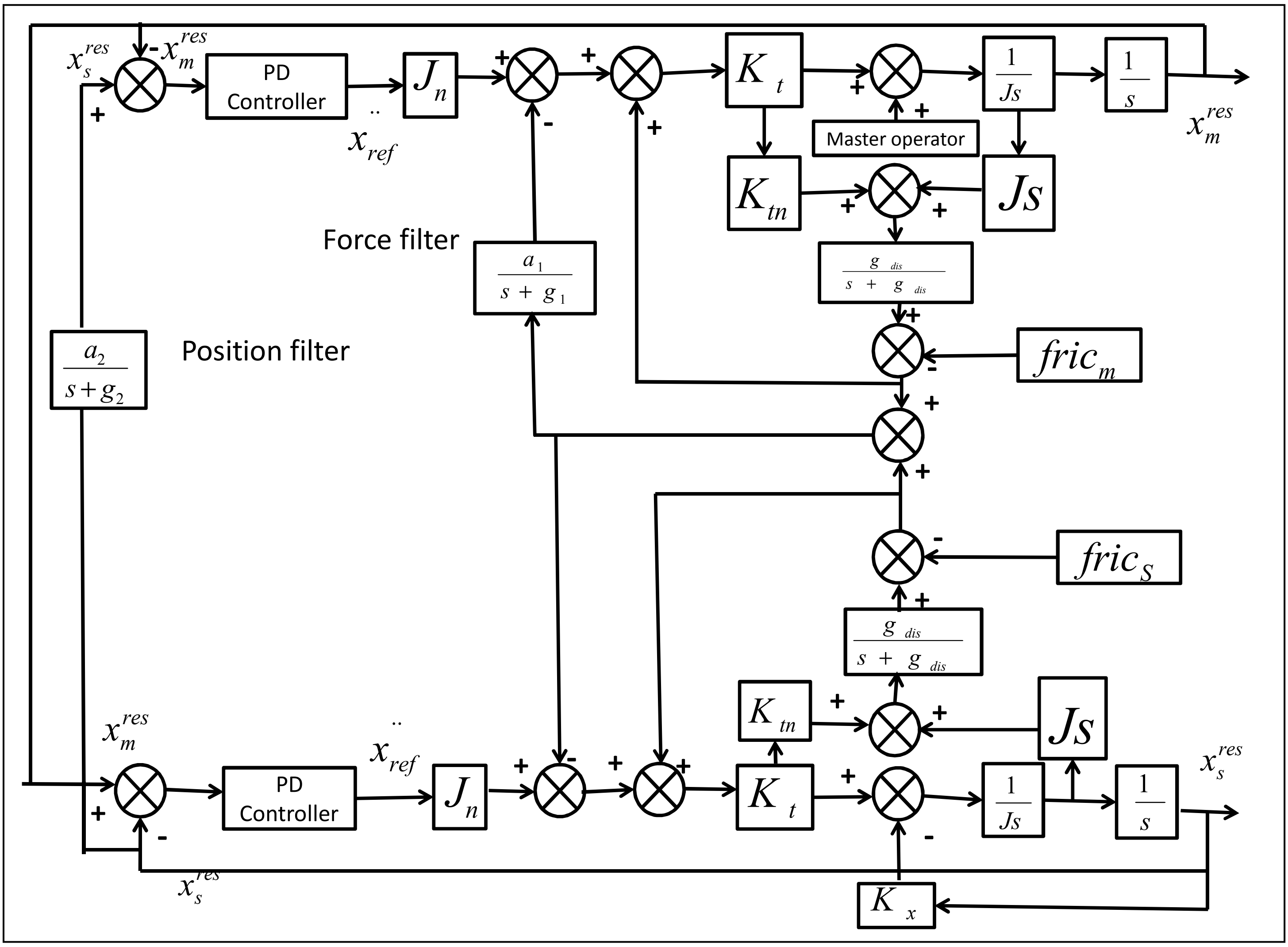

Fig.2. Modified block diagram of bilateral control block

Therefore the position filter is added to slave position output which is fed back to the master and testing was done, then force filter is added in between point A and point B as mentioned in fig.2. Without scaling both a_1 and a_2 values should be kept as one. But for some systems scaling is required and it is varied from system to system. For this system $a_1=g_1$ and $a_2=g_2$, for keep the same magnitude in both master slave position and force outputs. Simulation results and practically verified that the force filter is more powerful than position filter.

III. DISTURBANC OBSERVER

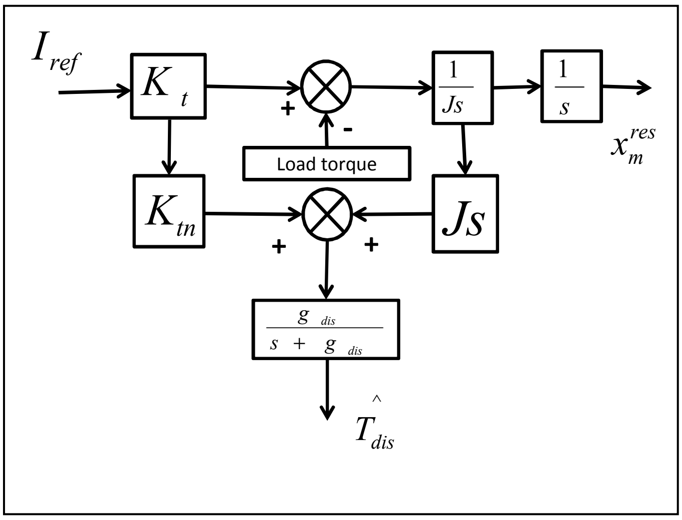

Fig.3. Disturbance observer block diagram

Disturbance observer not only compensate the disturbance but also used as a reaction torque estimator [8]. Disturbance observers are highly useful when the system requires higher bandwidth because most of the torque sensors have a lower bandwidth [9]. Fig.3 shows the block diagram of the disturbance observer. Where;

J: motor inertia
J_n: nominal motor inertia
K_t: torque constant
K_{tn}: nominal torque constant

Disturbance observer model is included a differentiator which can make noises. Those noises are removed by a low pass filter. This low pass filter is an important part in vibration suppression simulation. Because internal and some external vibrations are suppressed by this low pass filter. Systems transient period is depended on the g_{dis} value of low pass filter.

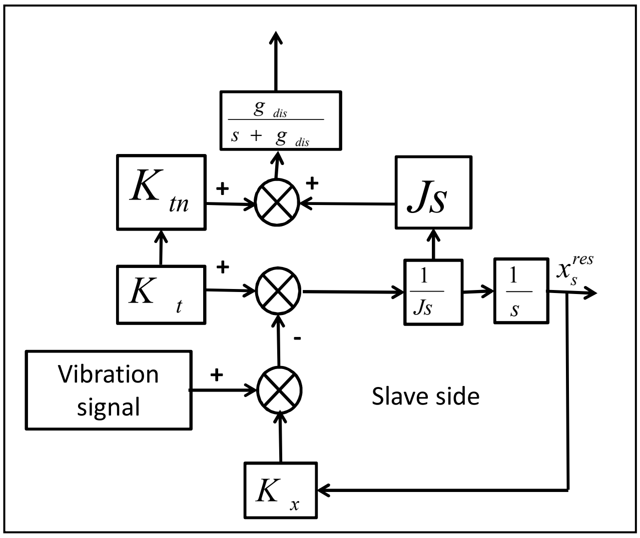

Fig.4. Vibration signals with disturbance observer

As shown in fig.4 external vibrations were applied to the system with the slave side reaction force. High and low frequency signals were given to the system as a vibration signal. And the vibrations are given as a force input with the reaction force. Both position and force out puts were checked for the conventional bilateral control system for the given vibrations and finally with modified system by using the simulation.

IV. SIMULATION RESULTS

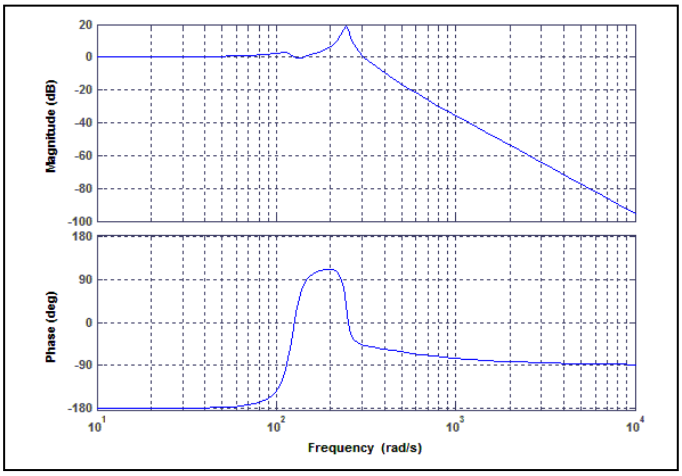

Fig.5. Bode plot for the conventional bilateral control block

Fig.5 shows the bode plot of the conventional bilateral control block [10]. Master force is selected as the input point and the slave disturbance observer (DOB) output is selected as the output point. Vibrations which have the frequencies higher than 100rad/s are suppressed by the system. The bode plot illustrate a zero magnitude and -180 degree phase shift at the frequency range of 10-100rad/s. The accuracy of bode plot is tested by the simulation with a given high frequencies. So that the modifications are required by the system to suppress the vibrations which have the frequencies lesser than 100rad/s. Simulation block is modified by adding first order low pass filters as a position and frequency ranges are checked. Fig.6 shows the bode diagram of the system with a position filter.

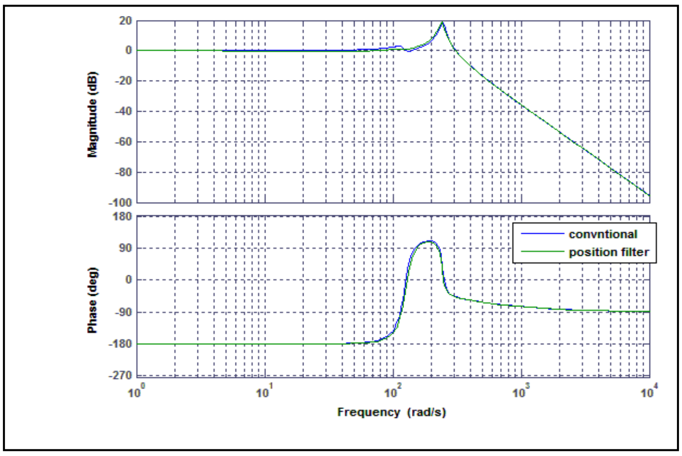

Fig.6. Bode plot for the conventional bilateral control with position filter

According to the graph cutoff frequencies are not varied with the position filter. Force filter effect is illustrated in fig.7. The cutoff frequency has been shifted to the left side. It has been proved that, vibrations can be suppressed by using a force filters.

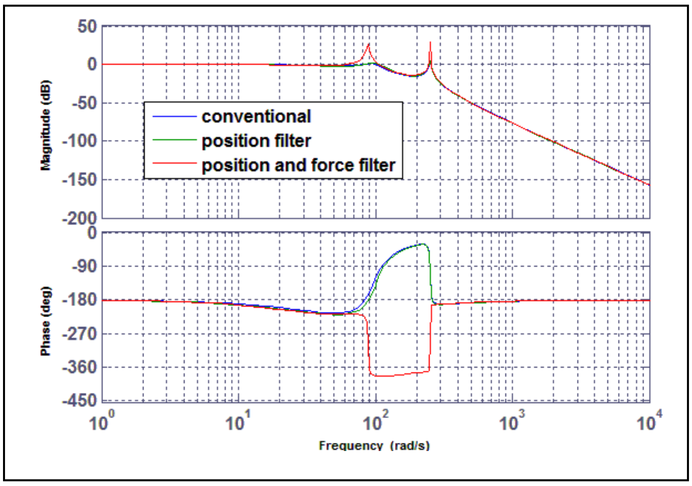

Fig.7. Bode plot for the conventional bilateral control with force and position filter

In the modified system, force and position outputs are compared with the conventional system outputs. It has proved that the vibrations are suppressed by the filters. Table 1 shows the required parameter values for the above simulation.

TABLE I

Simulation and practical parameters

Parameters	Symbol	Value	Units
Motor inertia	J_n	0.000091	$Kgcm^2$
Torque coefficient	K_t	13.5	Ncm/A
Spring constant	K_x	5.0	N/cm
Proportional constant	K_p	1000.0	Rad/s
Derivative constant	K_d	80.0	Rad/s
Cut-off frequency of low pass filter	g_{dis}	300.0	Hz

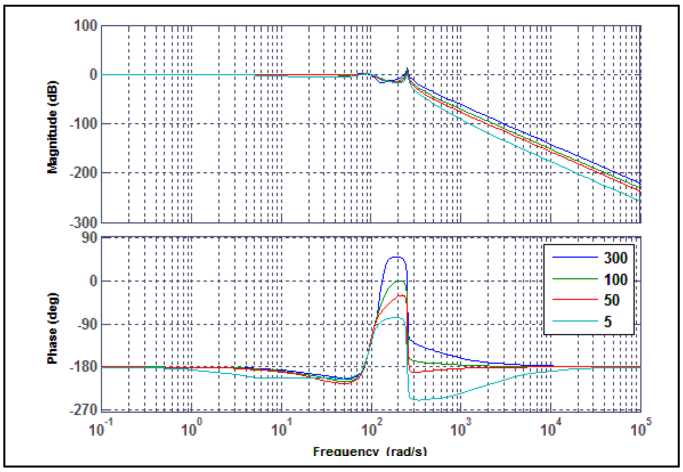

Fig.8. Bode plot for the conventional bilateral control with different filter values on master side DOB

Fig.8 shows the changes of the bode plot for different g_{dis} values of slave disturbance observer. In here master disturbance observer g_{dis} value has been kept as a constant value of 50 and the slave value has been varied. According to the graph when g_{dis}=5 gives the lowest bandwidth. It has proved that the vibration suppression is controlled by the g_{dis} value up to some certain level.

Conventional block of the bilateral control system has already included a low pass filter which suppress the noises occurs in the system. Due to that, system required some extra filters which suppress the vibrations below its lower bandwidth. But it will be important because this vibration suppression is going to be applied to low frequency controlled unit. As discussed earlier, position filter has a less chance of effect so that the force filter effect was checked by varying the filter constant. The results are illustrated in fig.9.

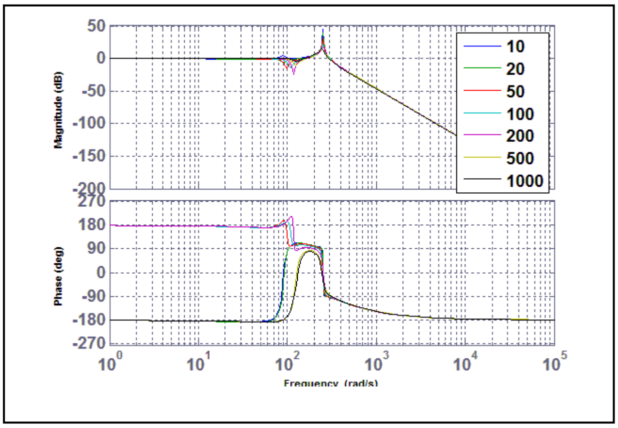

Fig.9. Bode plot with force filter coefficient effect

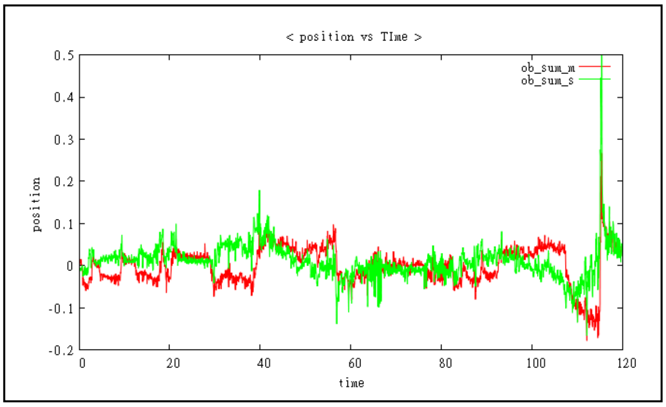

Fig.11. Slave and master force responses with position filter

According to the graph the task of this paper has been fulfilled. Cutoff frequency point can be change by varying the force filter constant.

V. PRACTICAL RESULTS

Then the concept was applied to a hardware unit which is controlled by embed microcontrollers. It has been included a master unit and a slave unit. The vibration signals are given to the slave side by using a vibrating motor. The practical data was collected for a given vibration. By using GNU plot position and force response were plotted.

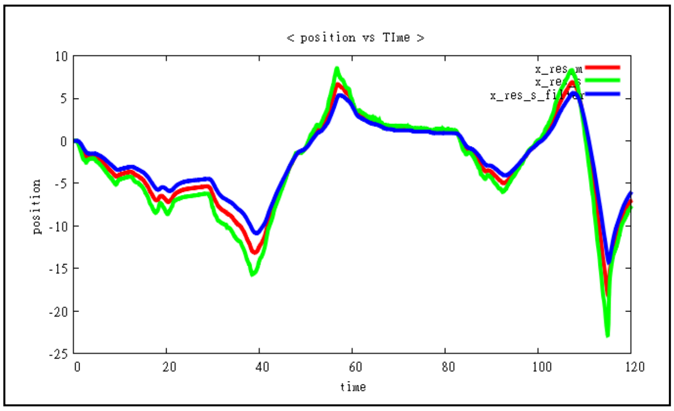

Fig.10. Slave and master position responses with position filter

Fig.10 shows the data of position responses with position filter. According to graph the master position, slave position and filtered slave position are not changed. The vibration signals were given to the slave side and position filter was added to the system.

Force outputs with position filter is illustrated in Fig.11. Master and slave force responses are same with vibrations. Both position and force graphs have proved that the vibrations cannot be suppressed by using a position filter. So that, the force filter was added to the system.

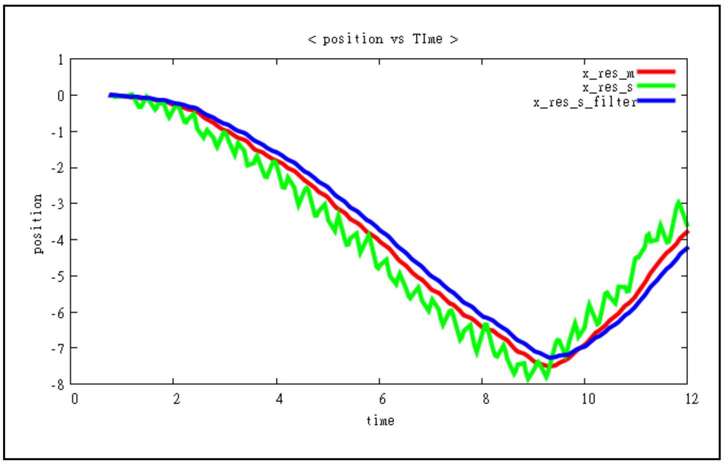

Fig.12. Slave and master position responses with force filter

Fig.12 and Fig.13 have illustrated the position and force outputs with force filters. According to the Fig.12, Green colored line represent the vibrating slave position output, blue colored line represent filtered slave position output and red colored line represent filtered master position output. As illustrated in fig.13 green colored line represent the vibrating force output and the red colored line represent filtered force output. All the above practical data has proved that the vibration can be suppressed with force filter.

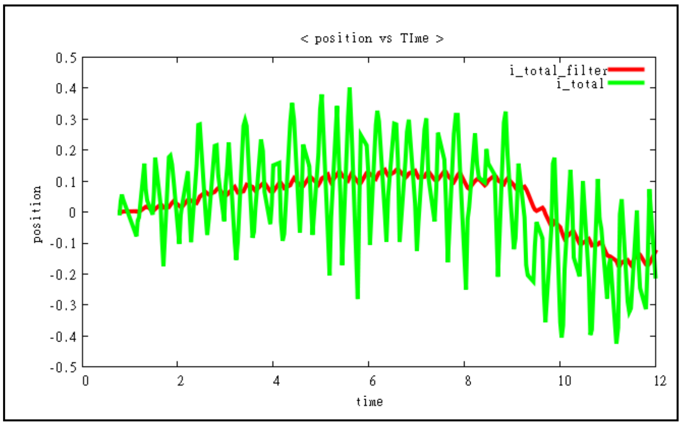

Fig.13. Slave and master force responses with force filter

VI. CONCLUSION

In this paper, vibration suppression of the bilateral control system was proposed and modeled in matlab Simulink. Disturbance observer filter effect was analyzed by using bode diagrams and was found the most suitable filter for the available system. Vibration suppression of the system was analyzed and extra filters were added to the system for further suppression. Vibrations of the system were suppressed by using low pass filter as a force filter.

VII. REFERENCES

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