

Modelling and control of Base Plate Loading subsystem for The Motorized Adjustable Vertical Platform

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Abstract. Malaysia National Space Agency, ANGKASA is an organization that intensively undergoes many researches especially on space. On 2011, ANGKASA had built Satellite Assembly, Integration and Test Centre (AITC) for spacecraft development and test. Satellite will undergo numerous tests and one of it is Thermal test in Thermal Vacuum Chamber (TVC). In fact, TVC is located in cleanroom and on a platform. The only available facilities for loading and unloading the satellite is overhead crane. By utilizing the overhead crane can jeopardize the safety of the satellite. Therefore, Motorized vertical platform (MAVeP) for transferring the satellite into the TVC with capability to operate under cleanroom condition and limited space is proposed to facilitate the test. MAVEP is the combination of several mechanisms to produce horizontal and vertical motions with the ability to transfer the satellite from loading bay into TVC. The integration of both motions to elevate and transfer heavy loads with high precision capability will deliver major contributions in various industries such as aerospace and automotive. Base plate subsystem is capable to translate the horizontal motion by converting the angular motion from motor to linear motion by using rack and pinion mechanism. Generally a system can be modelled by performing physical modelling from schematic diagram or through system identification techniques. Both techniques are time consuming and required comprehensive understanding about the system, which may expose to error prone especially for complex mechanism. Therefore, a 3D virtual modelling technique has been implemented to represent the system in real world environment i.e. gravity to simulate control performance. The main purpose of this technique is to provide better model to analyse the system performance and capable to evaluate the dynamic behaviour of the system with visualization of the system performance, where a 3D prototype was designed and assembled in Solidworks. From the Solidwork, the model was translated to Simmechanics with the system coordinate and specification i.e mass and inertia and actuator model was designed by using Simpower for simulating the system. Then, the system was integrated with controller by using conventional Proportional-Derivative (PD) controller with 0% steady state error, (ess) and 22.4% overshoot, (P.O) as the results.

1. Introduction

Satellite is an artificial body placed in an orbit round the earth or another planet used for collecting information and communication according to Oxford Dictionaries. Satellite will be orbiting around the outer space of the world to provide high efficiency on communication system and data interchange from one place to even the rural area. Malaysia has launched two satellites since 2000 named TiungSAT-1 (2001) and RazakSAT (2009), [1]. ANGKASA is the responsible agency in the space research in Malaysia, has taken another step by building up the Satellite Assembly, Integration and Test Centre (AITC). All operations such as assembly, integration works and launch and environmental testing now can be done in AITC.

Many types of chambers with specific function have been installed in the AITC. Thermal Vacuum Chamber (TVC) is the one of the chamber that is used for thermal vacuum test, which is critical test for satellite. It is located in the one of the ANGKASA's clean room, [2]. The MAVeP was proposed to be one of the facilities at the TVC for transferring satellite from the loading bay into the TVC. As the chamber is located in clean room that has a platform with limitation in space, the precision and accuracy of all mechanisms is important to maximize the safety of the satellite. The Figure 1 shows the overview of the TVC and the space available for the system to operate.

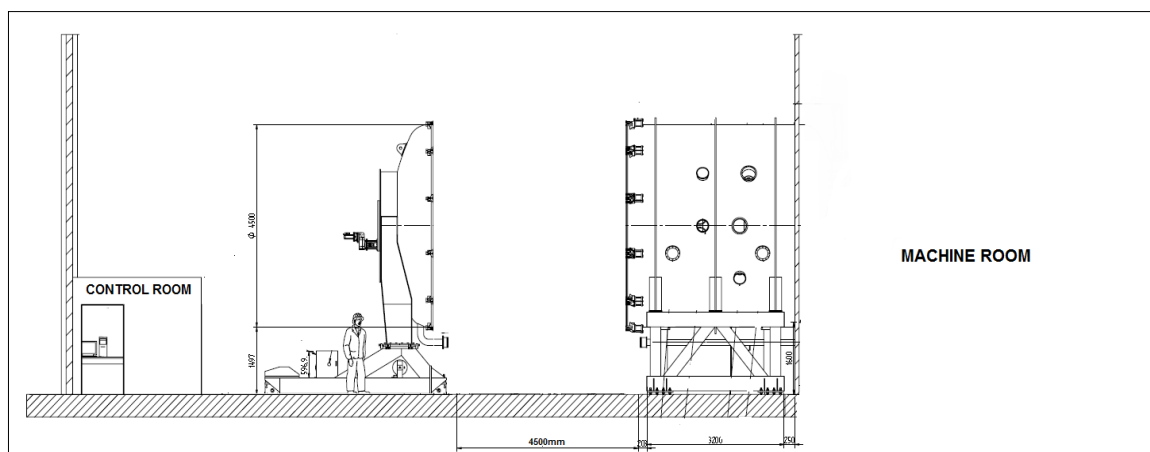


Figure 1. The TVC dimension and overview, [1].

Many subsystems are involved to transfer the satellite such as Mobility, Elevation, Locking and Base plate horizontal loading subsystems. After the satellite is fabricated, the satellite will be placed at the loading bay. The satellite will be transferred by MAVeP from the loading bay into the clean room by Mobility subsystem. After it has safely parked in front of TVC, the platform, which is at stowed position will elevate the satellite to the height where the rails of the TVC is to be reached and the beam will be extended to join the existing rail in the TVC for load transfer. By utilizing the Base plate Horizontal loading Mechanism, the satellite will be transferred from the MAVeP into the TVC to undergo the extreme thermal and pressure tests. Figure 2 visualizes the overview of MAVeP in 3D software.

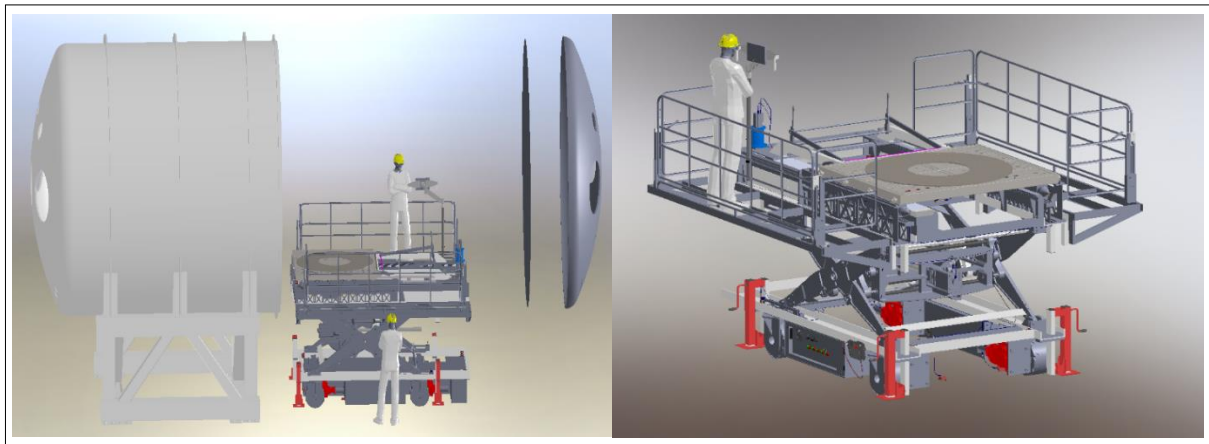


Figure 2. Visual overview of MAVeP in 3D software.

The Base plate subsystem needs to produce horizontal motion. The additional mechanical attachment is required to convert the angular motion produce by motor to the horizontal motion. Table 1 summarizes the common mechanical attachments that have been considered to demonstrate the motion. The Base plate Subsystem motion will have 0.25 to 0.5 metre per minute (m/min) velocity with maximum 3 meters travel distance as its specification requirements. For the motorized platform for satellite test, low velocity is preferred as the operators will be on the platform during the process (loading and unloading). In [3, 4] the researchers stated that, high velocity can cause vibration and long settling time. In order to prevent vibration, velocity profile is used to control the acceleration and reduce the vibration. The Based on the table, the rack and pinion is the most suitable and meets the system specification.

Table 1. Summary of the Common Mechanical Attachment.

	Rigid Chain, [5, 6].	Ball Screw, [7].	Rack Pinion, [8].
Price	High	Medium	Low
Availability	Mostly at United State	Local & Oversea	Local & Oversea
Accuracy	Medium	0.03 mm	0.05 mm (Total travel)
Advantages	Used for lifting the stage Suitable for short distance	Used for Z-axis motion Suitable for short distance Low speed travel	Used for horizontal motion Suitable for long distance (>3m) Less backlash Low maintenance cost High speed travel
Disadvantages	Product availability High maintenance cost	Fast motion can produce vibration Easy to have high backlash	Travel depends on the rail guide

System identification needs the actual plant to obtain the system input and output data, which currently is not available. By implementing the physical modelling technique, the extensive knowledge about the dynamic behaviour of plant is crucial, [9]. The technique will represent the system with mathematical modelling by utilizing the theory such as Kirchhoff's Laws (KCL and KVL) and Newton's Laws, [9, 10]. In order to avoid un-modelled dynamics behaviour and uncertainty

of the system by using physical model and reduce the time consumption to fabricate the system, 3D virtual model is the best method as it is very flexible and easy to construct, [10, 11]. Besides, the Proportional-Integration-Derivative (PID) control was implemented in the plant to enhance the elevation performance of the Base plate Subsystem. Figure 3 shows the control system architecture to reduce the positional error. A PD controller is commonly adopted in various types of system to produce an accurate positional system i.e. Robot Arm and actuator, [12,13]. The controller is capable to reduce the overshoot and manipulate the rise time. Yet, it will increase the steady state error in the system, [14]. The problem can be solved by adding an additional controller.

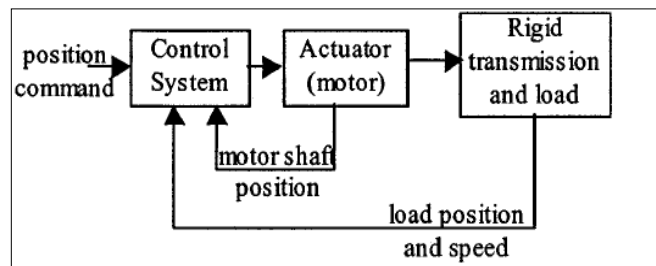
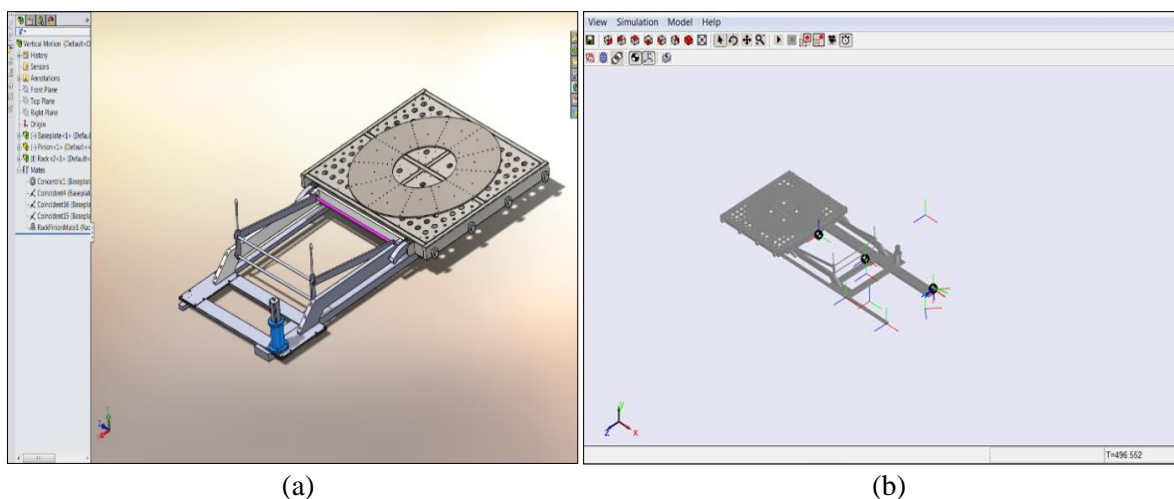


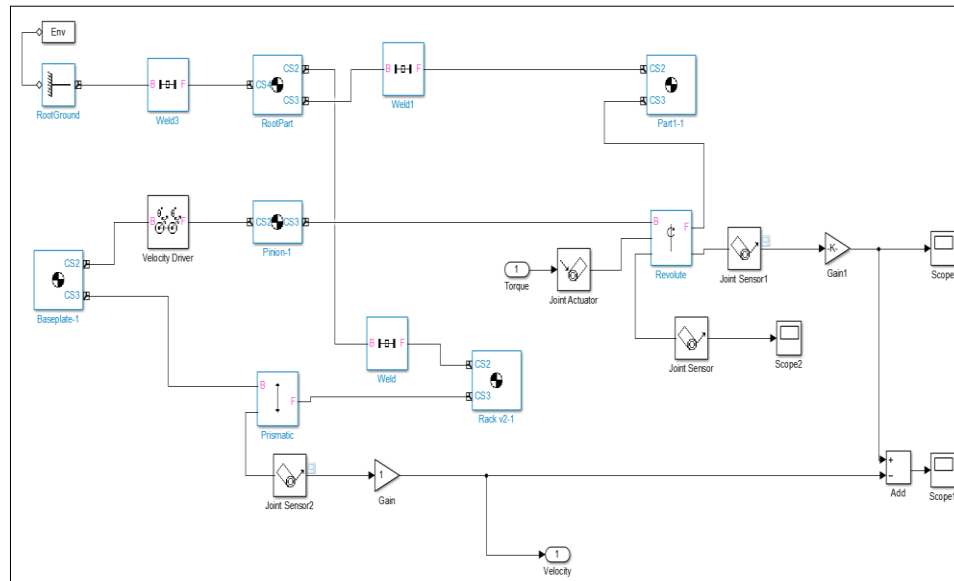
Figure 3. Control system architecture for precision position, [15].

2. Horizontal Base plate Loading Mechanism

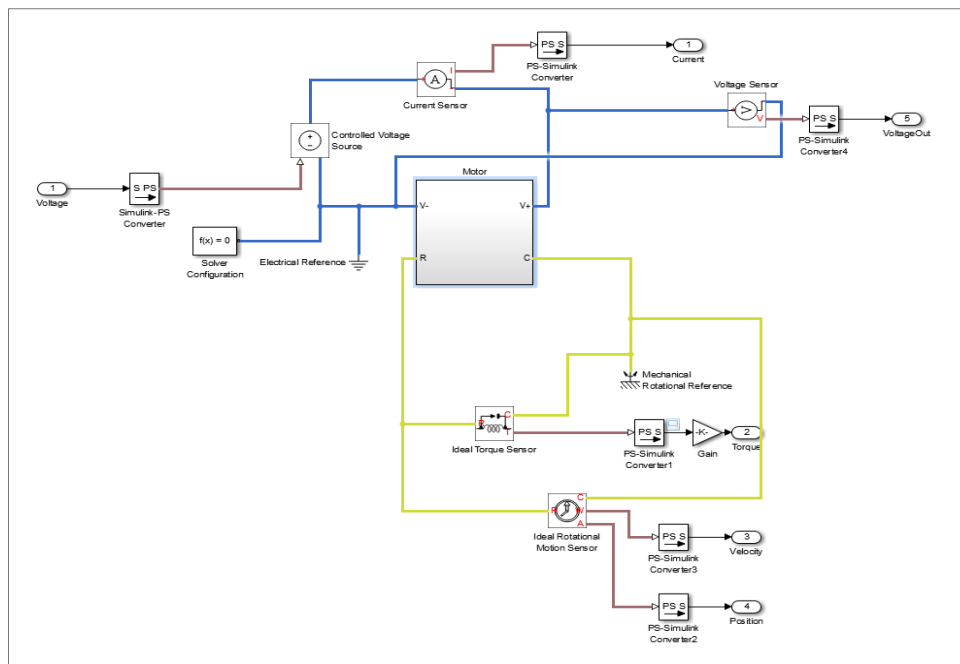
2.1. Modelling of Base plate Subsystem

The common techniques to represent the system for control are system identification and physical modelling. Both techniques are time consuming and required extensive understanding about the dynamical behaviour of the system. By using 3D virtual, the system can be represented as close as to the actual system with visualization. Figure 4 shows the system model with dimension of 2.0 m width and 3.5 m length together with load and base plate mass approximately 1000 kg by using Solidworks and SimMechanics inspired from [16].





(c)



(d)

Figure 4. (a) Modelling the system by Solidworks; (b) Converted model from Solidwork to Sim Mechanics; (c) Translated model in SimMechanics; (d) Motor Model in SimPower.

The most crucial step is to set up both softwares where the Solidwork is to be linked with the Matlab software by command prompt in Matlab workspace. Secondly, all elements; base plate, rack, pinion and slider were assembled in Solidwork software and all *mates* in Solidwork should be compatible with Simmechanics as the software will translate the system based on configuration in Solidwork. The *mate* configuration is available on Matlab website. After the assembly process has been done, the system should be saved as .xml. Some of advanced *mates* such as rack and pinion and *cam* are incapable to be translated directly from Solidwork. Therefore, such *mates* can be set-up in

Simmechanics. Then, open the file by command prompt (*mech_import*) in Matlab workspace. All system configurations such as joints, actuators and sensors can be checked and modified in Simmechanics i.e system coordinate and components' mass. Based on coordinate, Simmechanics will run the model by using equation of motion by referring the coordination motion. Motor model was designed in Simulink and all motor parameters such as rated torque and rated speed for motor are based on Sanyo Denki motor R2AA08020F specifications.

2.2. Control of Horizontal Motion of Baseplate Subsystem

The conventional Proportional-Derivative (PD) control was first designed to simulate the model developed in SimMechanics. The PID equations can be represented as in equation (1).

$$u(t) = K_p e(t) + K_i \int_0^t e(\tau) d\tau + K_d \frac{de(t)}{dt} \quad (1)$$

Table 2 describes the gain parameters used for the controller. The gains that were tuned heuristically by using Ziegler-Nichols (ZN) method and followed by fine-tuning (FT), where critical gain value, K_{cr} and critical time, P_{cr} are 20 and 1200 seconds respectively, have produced satisfactorily system response for position of base plate horizontal loading. ZN technique is only feasible to be conducted if experimental data is available. In this paper, ZN technique is used to provide a good educated guess the starting point for tuning the controller parameter rather than trial and error.

Table 2. Gains Parameters.

Gain	K_p	K_i	K_d
ZN	12	0	1800
FT	8	0	1800

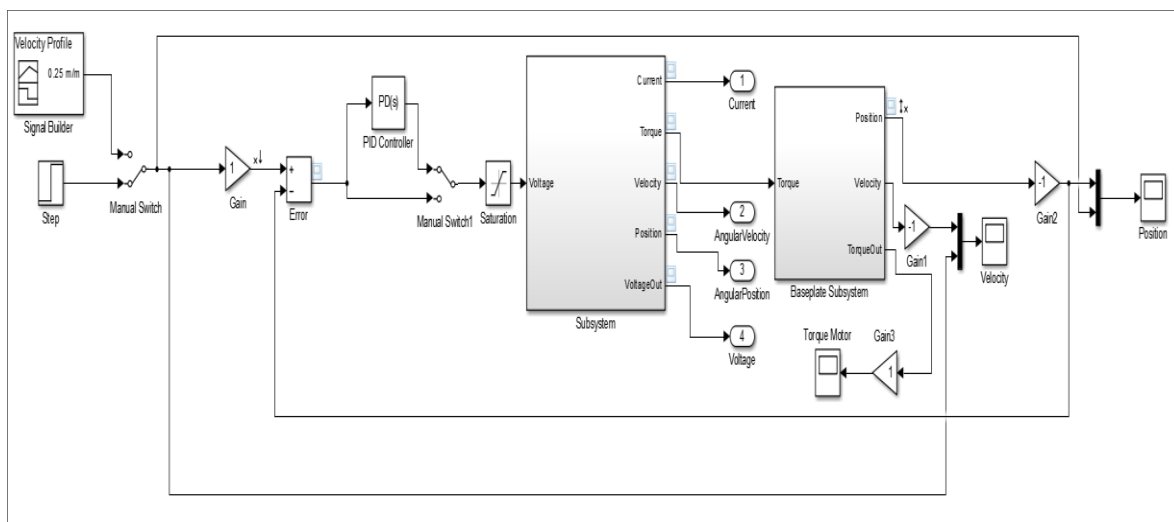
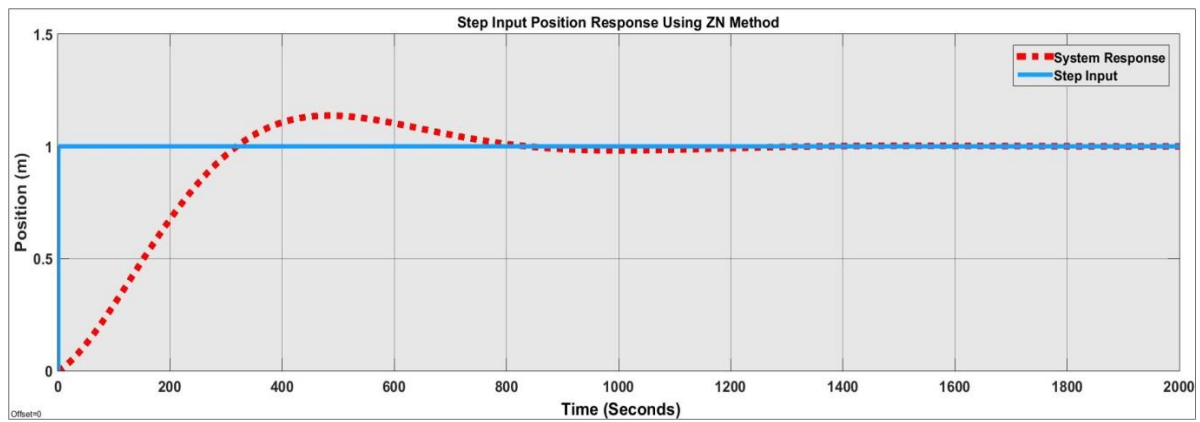


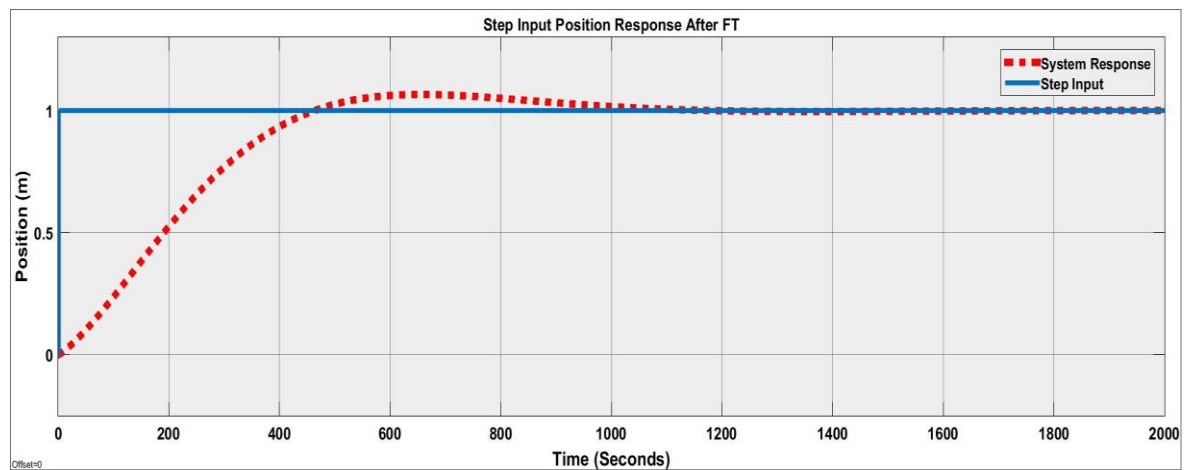
Figure 5. The Proportional-Derivative Control for Base plate Subsystem.

Based on Figure 5, the control was designed to improve the accuracy of the horizontal loading system. The control will compare the actual position with the desired position and compute the error. The error occurs will be manipulated by controller to force the system to perform as the desired performance. As the satellite has countless of sensitive electrical and electronics board, any vibration or jerk occurs must be minimized. Therefore, the control should have less steady state error than 1.0 mm, percentage of overshoot should be less than 50% and appropriate rise time.

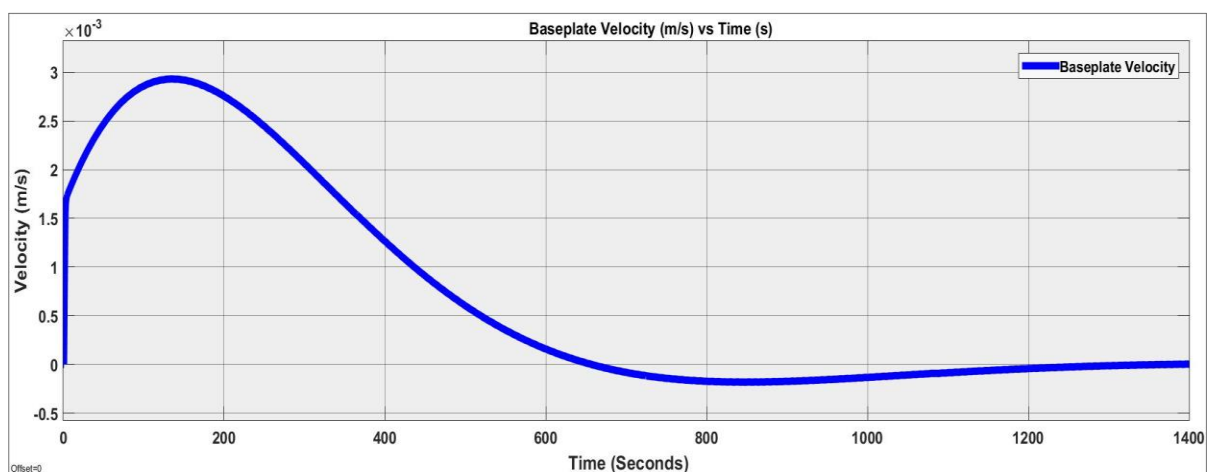
3. Results and Discussion



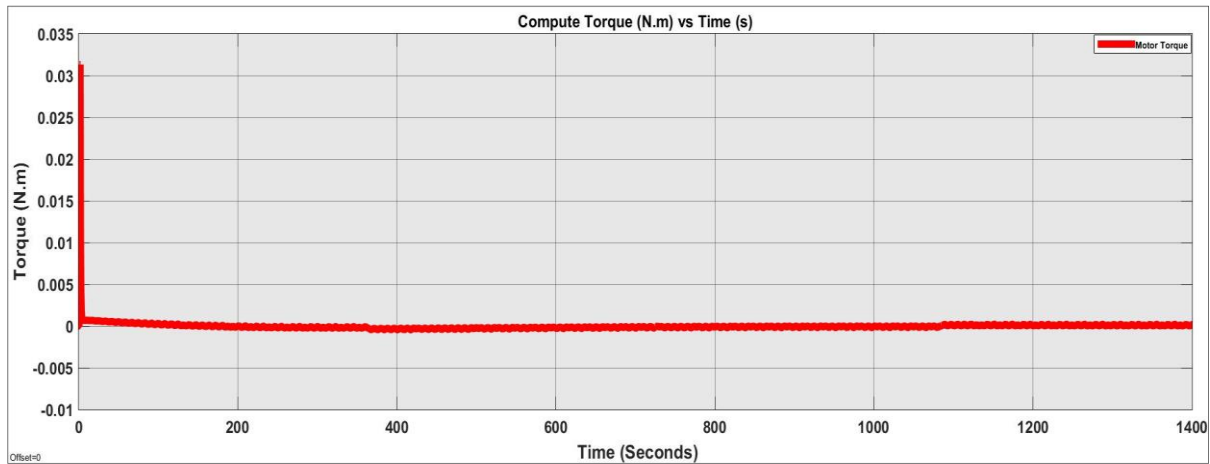
(a)



(b)



(c)



(d)

Figure 6. (a) Step Input Position Response Using ZN Gain; (b) Step Input Position Response After Fine-Tuning; (c) Baseplate Velocity (m/s); (d) Motor Torque (N.m).

Figure 6 (a) shows that the time travel to achieve the desired destination is approximately 1400 seconds for 1 meter travel distance with 27.8% of overshoot and 0 % steady state error. The system rise and settling time are 128 seconds and 1020 seconds respectively after the system was tuned by ZN method. After Fine-Tuning, the system overshoot, rise time and settling time are reduced to 22.4%, 147 seconds and 820 seconds respectively while steady state error remains constant. The integral gain is neglected as the gain has increased the system overshoot during Fine-Tuning process and PD controller has computed 0% steady state error even without integral gain. Meanwhile the Figure 6 (c) and (d), the motor needs 0.031 N.m torque to produce 0.0029 m/s linear velocity of the baseplate. The initial torque is high and then the torque is approaching to zero.

4. Conclusion

In summary, the model of the MAVeP system that represents the Base plate horizontal loading subsystem has been successfully modelled with 3D model technique using Solidworks and Simscape capability. The main challenge is to model the system in the software as close as possible to the actual system and to determine the system validity and parameters. The modelled system has been tested with PD control to evaluate the system performance. Based on the result, the system has 0% steady state error with 22.4% overshoot. The control system performance can be improved by computational method such as Genetic Algorithm to optimize control parameter. In future, the control will be integrated into the real system to evaluate the actual control performance. As the initial torque is high and step input can produce vibration, therefore, the velocity profile will be included to reduce initial torque and vibration in the system.

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References

- [1] Agensi Angkasa Negara 2015 *Design and Development of Motorised Adjustable Vertical Platform for Satellite Assembly, Integration and Test Facility* (Banting: ANGKASA)

- [2] Woo L L, M Ismail and M D Subari 2009 *Setting-up the Assembly, Integration and Test Centre in Malaysia* (Istanbul:IEEE)
- [3] H Li, M D Le and W Lin 2009 *Motion Profile Design to Reduce Vibration of High-Positioning Stages* (Singapore:IEEE)
- [4] X Li 2010 *Optimizing S-Curve Velocity for Motion Control* (Alabama:ResearchGate)
- [5] G Hengeveld, N Idsardi and B Witjes 2015 *Airstacking Machine* (Twente:University of Twente)
- [6] Information on <http://www.serapid.com/en/rigid-chains-can-lift-push-and-pull-loads>.
- [7] Enkon Pro 2011 *Hercules* (Canada: Enkon Information Systems)
- [8] Information on <http://www.camaster.com/wp-content/uploads/2013/09/Rack-and-Pinion%20or%20Screw%20Driven%20System.pdf>.
- [9] S F Toha 2014 *Basic Concepts of Physical Modelling and System Identification* (Gombak:IIUM)
- [10] M T Islam, C Yin, S Jian and L. Rolland 2014 *Dynamic Analysis of Scissor Lift Mechanism Trough Bond Graph Modelling* (Canada: IEEE)
- [11] S Shamsulkamar 2014 *Modelling and Control of 6-DOF of Industrial Robot by Using Neuro-Fuzzy Controller* (Johor: Universiti Tun Hussein Onn Malaysia)
- [12] M A Azman, A A M Faudzi, C C Kai and etc. al. 2013 *P-Adaptive Nuero-Fuzzy and PD-Fuzzy Controller Design for Positional Control of a Modified Single Acting Pneumatic Cylinder* (NSW: IEEE)
- [13] C Murrugarra, G Fernandez and O De Castro 2008 *Design of a PD Position Control Based on the Lyapunov Theory for a Robot Manipulator Flexible-Link* (Kunming: IEEE)
- [14] Y Y Tan, A Irwan & M M Alam 2015 *PD-FLC with Admittance Control for Hexapod Robot's Lef Positioning in Seabed* (Kota Kinabalu:IEEE)
- [15] A S Kulkarni and M A El-Sharkawi 2002 *Intelligent Precision Position Control of Elastic Drive Systems* (Canada:IEEE).
- [16] Information on <http://www.mathworks.com/company/newsletters/articles/modeling-machine-constraints-in-simmechanics-and-simulink.html#rackpinion>

