# Simulation and Analysis of Support Assistance Body Weighing Systems

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***Abstract*— The main purpose of this study is concerned with the design of a control system for Partial Body Weight Support System using LabVIEW for gait rehabilitation. The system is composed of a counterbalance lead screw mechanism to take over the main unloading force which consists of an active closed-loop controlled electric motor used in conjunction with a linear actuator, and a strain gauge based load cell hooked to the top of the counterbalance system to measure the unloading force.**

***Index Terms*— Body weight support, gait rehabilitation, unloading force, and calibration.**

## I. INTRODUCTION

Body weight support is a mechatronic system devised especially for the gait stroke patients to aid them relearn gait patterns and perform other motion activities of adaily life by supporting or reducing some of the total weight from the subject's body. Now-a-days, these systems are increasingly being used to assist the therapists in gait training of patients with neurological disorders. Impairment in the leg muscles often prevents the patients from supporting their own body weight during normal walking. Reducing the gravitational forces and the pressure of the whole body weight acting on the lower limbs with the help of a Body Weight Supported (BWS) system would reduce the load that needs to be overcome by the patient and facilitates stepping movements [1],[2]. In addition, the BWS system ensures safety and stability of the patient and appends a realistic feeling of walking thus motivating the patient to invest more efforts in the training.

In this paper, a new approach towards Partial Body Weight Supported (PBWS) gait training using an actively controlled linear motor is introduced. In the control system, the force measured by the force transducer is fed into the controller which sends command to the actuator to generate the desired force set by the therapist [3]. The motor drive will stop automatically as soon as the desired unloading is reached.

The PBWS system comprises of a linear electric motor actuated by the lead screw mechanism, a stiff and rigid counterbalance metallic frame and a harness in addition with a polyester rope worn by the patient to help lifting the subject (patient)

In this paper, firstly the linear motor is modeled mathematically and then the support assistance system is analyzed using LabVIEW to measure the desired unloading thus leading to a comparative study between the pre-determined set point and the measured unloading force by the force transducer located between the overhead suspension and the harness.

## II. MECHANICAL SETUP OF PBWS

### A. Linear motor

The PBWS uses a brushless DC (HIWIN LAN5) motor. It is used in conjunction with an electric actuator which expands or compresses its shaft whenever the motor is powered. As a result of which, the subject gets hoisted thus supporting a part of the subject's total weight and similarly, gets lowered down after the training session. Table1 shows the various parameter values of the linear motor

### B. Mathematical model of linear motor

TABLE I: LINEAR MOTOR PARAMETERS

| Parameter | Value |
|---|---|
| Power rating | 24V, 8A |
| Standard" Stroke | 250mm |
| Thrust Max. | 6000N |
| Pulling Max. | 4000N |
| Holding Max. | 5000N |
| Max. Speed (Load=Max. /Load=0) | 7/9mm/s |
| Duty cycle | 10% |

Fig.1 shows a schematic circuit diagram of a linear electric motor with rotational load [4].

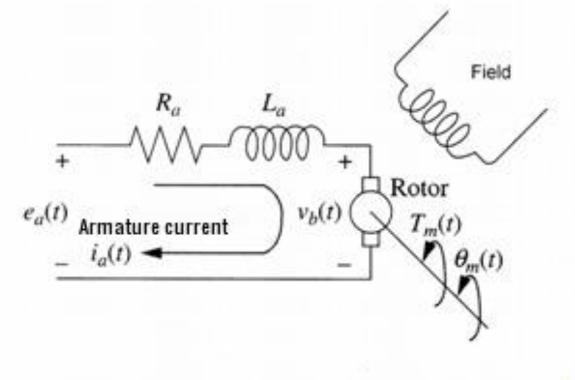


Fig. 1 Circuit diagram of linear motor

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The relationship among the armature currenti_a (t), applied armature voltagee_a (t)and the electromotive force 〖 v〗_b (t)can be obtained by applying mesh equations from Fig.1 as follows:

$$R_a i_a(t) + L_a \frac{di_a(t)}{dt} + v_b(t) = e_a(t) \quad (1)$$

An electromotive force is also generated stated as:

$$v_b(t) = k_b \frac{d\theta_m(t)}{dt} \quad (2)$$

Where, k_bis the back emf constant and
$d\theta_m\ (t))\ /\ dt = \omega_m(t)$ is the angular speed of the motor.
Replacing "(2)" in "(1)", we get

$$R_a i_a(t) + L_a \frac{di_a(t)}{dt} + k_b \frac{d\theta_m(t)}{dt} = e_a(t) \quad (3)$$

Also, the torque produced is:

$$T_m(t) = k_t i_a(t) \quad (4)$$

Where, $k_t$ is the proportionality constant for torque. Generally, $k_t = k_b$

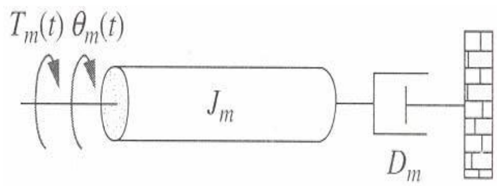


Fig.2 Motor with a mechanical load

From Fig.2, $Tm(t)$ can be obtained as:

$$T_m(t) = J_m \frac{d^2\theta_m(t)}{dt} + D_m \frac{d\theta_m(t)}{dt} \quad (5)$$

Replacing "(5)" in "(4)", we get

$$J_m \frac{d^2\theta_m(t)}{dt} + D_m \frac{d\theta_m(t)}{dt} = k_t i_a(t) \quad (6)$$

The transfer function is obtained from "(3)" and "(6)" by applying Laplace transformation:

$$\frac{\theta_m(s)}{E_a(s)} = \frac{k_t}{(J_m s^2 + D_m s)(R_a + L_a s) + k_t k_b s} \quad (7)$$

Now, relation between Angular and Linear movement:

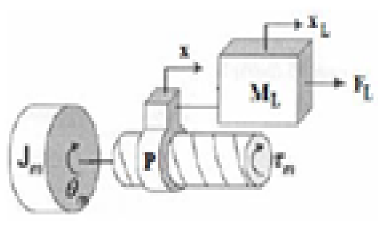


Fig.3 Free body diagram of linear actuator

From the above Fig.

$$x(t) = \frac{l}{2\pi}\theta_m(t) \quad (8)$$

Where, *x(t)* is the linear displacement, *l* is the lead step, *θm(t)* is the angular displacement produced by the motor

Now, let P = 2π/*l*and replace in "(8)". Hence,

$$\theta_m(t) = Px(t) \quad (9)$$

Replacing "(9)" in "(7)" and applying Laplace transform, we get

$$\frac{X(s)}{E_a(s)} = \frac{k_t}{P[(J_m s^2 + D_m s)(R_a + L_a s) + k_t k_b s]} \quad (10)$$

The above equation can also be represented as state variables:

$$\begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 \\ 0 & -\dfrac{D_m}{J_m} & \dfrac{Pk_t}{J_m} \\ 0 & -\dfrac{k_b}{Pk_b} & -\dfrac{R_a}{L_a} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ \dfrac{1}{L_a} \end{bmatrix} u$$

$$y = \begin{bmatrix} 1 & 0 & 0 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} \quad (11)$$

Now, "(11)" can be analyzed in the LabVIEW which would command the linear electric motor to work accordingly.

### *C. Load cell*

A load cell is a transducer which creates an electrical signal whose magnitude is directly proportional to the force being measured. It is deployed to measure the force that is generated by unloading the subject. This measured force is then compared with the reference signal which is the predefined percentage of patient's body weight that should be supported set by the medical personnel.

As all sensors get degraded with the passage of time, therefore load cell need to be calibrated in the first place so as to avoid any pseudo final outcomes while the training therapy is in progression [5].

## III. Results

### *A. Mathematical model of linear electric motor*

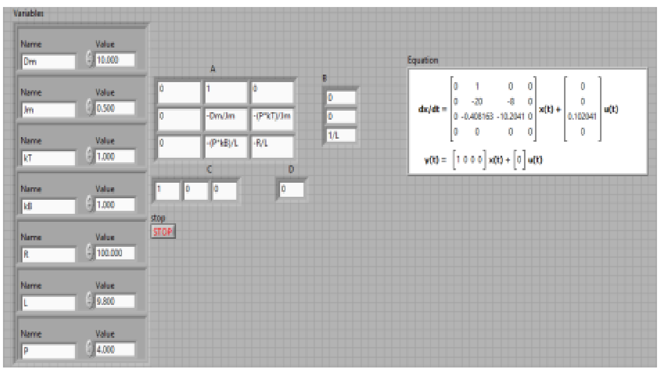

Fig.4 State space model of linear electric motor in LabVIEW.

### *B. The measured and the expected values deviated by approx. "4N"*

TABLE II: THE LOAD CELL WAS CALIBRATED WITH DIFFERENT WEIGHTS. HERE, IT WAS CALIBRATED UP TO "50KG". VARYING OUTPUT FROM THE LOAD CELL WAS AVERAGED FOR EACH WEIGHT AND THEN COMPARED WITH THE EXPECTED FORCE. RESULTS SHOW THAT THE TWO FORCES DIFFERED BY AN APPROXIMATION OF "4N".

| Mass (Kg) | Measured Average Force (N) | Expected Force (N) | Deviation (N) | Error (%) |
|---|---|---|---|---|
| 5 | 52.8 | 50 | 2.8 | 5.6 |
| 10 | 103.75 | 100 | 3.75 | 3.75 |
| 15 | 153.875 | 150 | 3.875 | 2.58 |
| 20 | 203.149 | 200 | 3.149 | 1.57 |
| 30 | 303.85 | 300 | 3.85 | 1.28 |
| 35 | 352.71 | 350 | 2.7 | 0.77 |
| **45** | **456.682** | **450** | **6.682** | **1.48** |
| 50 | 503.15 | 500 | 3.15 | 0.63 |
| | | Mean | 3.7445 N | 2.21 % |

Fig.5 is a graphical representation of the mean deviation calculated using Table II:

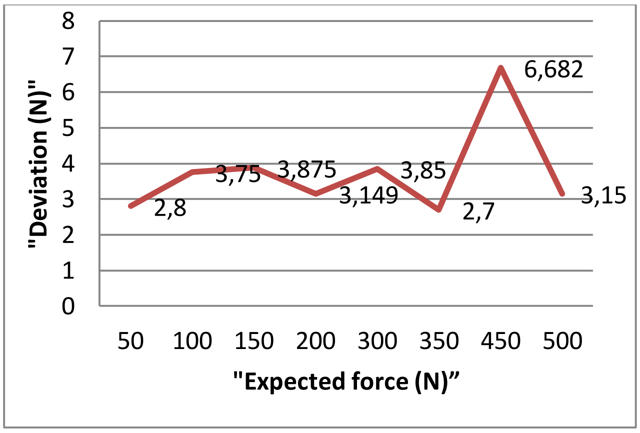


Fig.5 Deviation caused by the load cell at different expected forces

### *C. Results from the LabVIEW simulation; Motor is shown to be switched ON thus indicating the difference between the measured and the desired unloading.*

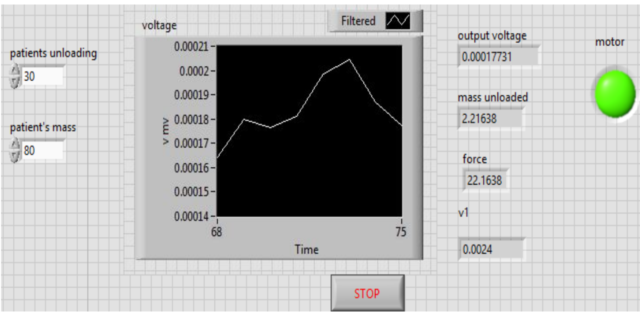


Fig.6 Graph showing the variation in the load cell output, patient's unloading (%) (i.e. required), mass and force unloaded by the load cell

## IV. CONCLUSION

The purpose of this study was to analyze the working of Body weight support system with the help of the lead screw mechanism. This study was designed to investigate to what extent of support is provided by this particular body weight support system which basically focused on the capability of this system to constantly maintain the proper targeted body weight support level and to understand the idea of unloading force.

The results of this study support the idea that the body weight system does not maintain the targeted body weight support (TBWS). As all sensors get degraded in some way or the other, similarly load cells are subjected to deterioration due to mistreatment, drift or ageing. Hence, calibration of such instruments needs to be carried out at regular intervals to improve the system accuracy. Results provide evidence that the sensor seems to be more or less linear as the error percentage drops if we go on increasing the load on the load cell. As an exception, it shows an abrupt rise in error when the experiment is carried out with "45kg" weight. This may be due to the human error for not properly hanging the weight or may be the readings were noted before the weight achieved its equilibrium or in other words a stable position. Hence, minimal deviations can be easily analyzed and corrected with respect to time by repeated calibrations with increasing load or by replacing the particular sensor.

The main goal of the PBWS is to teach the patient to relearn locomotor activities thus leading the subject to head towards early recovery. This system proves to be an effective interactive session that could restore and maintain some degree of ambulatory capacity among gait impaired individuals.

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