American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-6, Issue-12, pp-67-73
www.ajer.org
Research Paper Open Access

Performance Improvement of Printer Belt Drive for a Computer System

Njoku Donatus. O.[1],Amaefule I.A.[2], Nwandu C. Ikenna[1],Uka Kanayo Kizito[2]
[1](Department of Computer Science, Federal University of Technology Owerri, Nigeria)
[2](Department of Computer Science, Imo State University, Owerri, Nigeria)
Corresponding Author:

ABSTRACT: *This paper has presented performance improvement of printer belt drive for a computer system.A typical printer for a computer uses a belt-drive mechanism to laterally move a printing device across a printed page. It is required to improve the response performance of a printer so as to achieve efficiency, positioning accuracy, timing, high speed and acceleration. In order to address the poor response performance, mathematical equations representing a belt and pulley dynamics and the rotational dynamics of a DC motor were obtained. A robust system is developed to take care of the problem. The objective of the paper is to design a compensator that will optimally improve printing performance of a printer belt drive system. A hybrid compensator was designed using Matlab software. The designed `compensator was combined with dynamics of a printer belt drive system to form a single input single output (SISO) closed-loop system. Simulation results obtained showed that with the compensator in the loop, the response performance of the system was highly improved.*

Keywords: *Printer belt drive, Dc motor, Positioning, Performance, Hybrid compensator*

Date of Submission: 28-11-2017 Date of acceptance: 08-12-2017

I. INTRODUCTION

A belt can either drive the pulleys normally in one direction or the belt may be crossed, so that the direction of the driven shaft is reversed in a two pulley system. When used as a source of motion, a belt drive is one application where the belt is adapted to continuously carry a load between two points.A belt drive offers smooth transmission of power between shafts at a considerable distance. Belt drives are used as the source of motion to transfer to efficiently transmit power or to track relative movement. Belt drives are widely applied in different fields of human activity to transmit the mechanical energy from the rotating shaft to the objects of the control. Computerized numerical control (CNC) machines in particle cutting machines and 3D- printers is one of the many industrial applications that uses belt drive system [3]. There are many examples of belt drives implementation in our life such as cars, audio and video devices, computer devices, etc [4].Nowadays, belt drives are used in industries for positioning control of objects or material transportation (for example in conveyors) were precision and accuracy are key factors for efficient production process. The application of belt drives for high precision applications has become appropriate because of rapid development of motor and drive technology as well as the implementation of timing belts in belt-driven systems [5].

In recent times, direct current (DC) motors are widely used in many belt drive systems due to precise, wide, simple and continuous control characteristics. Belt drive systems are primarily DC motors driven. A DC motor is an electrical drive that converts electrical energy into mechanical energy. Belt drive systems are primarily DC motors driven. High performance DC motor belt drives are very important in both industrial and other applications. Good dynamic speed command tracking and load regulating response is generally one of the main characteristics of high performance motor drive system.

In most of the of the commonly used low-cost products such as printers, domestic appliances, pumping equipment, heating, ventilation, and air conditioning system, a DC motor belt drive assembly is essentially employed for positioning, speed, and precision performance improvement. In this research, a belt driven printer with a DC motor actuator for a computer is considered in this paper.A typical printer for a computer uses a belt-drive mechanism to laterally move a printing device across a printed page. It is required to improve the response performance of a printer so as to achieve efficiency, positioning accuracy, timing, high speed and acceleration. In order to address the poor response performance, mathematical equations representing a belt and pulley dynamics and the rotational dynamics of a DC motor were obtained. A robust system is developed to take care of the problem. The objective of the paper is to design a compensator that will optimally improve printing performance of a printer belt drive system.

II. RELATED WORKS

Doug [6] presented a paper on control systems challenges in the HP personal ink jet printing application faced by Hewlett-Packard Company in designing competitive ink jet mechanisms for desktop printer and multifunction device market. The process under control was discussed. The performance objectives and the limitations for the control system was provided.Parkkeinen et al [7] presented a paper on motion synchronization of two linear tooth belt drives using cross coupled controller. It implemented and tested a cross-coupled controller with biaxial linear tooth belt drive system for motion synchronization. In order to design the controllers, the quantitative feedback theory was applied due to uncertainty in the system parameters caused by the elastic tooth belt.

Grzegorz [8] presented the results of measurements and analyses gear timing belts used in control systems. It stated that the usefulness of timing belt system is determined by many of its design features. For proper use of such belt in the construction, knowledge of technical parameters is required. Jayawardene et al [9] investigated how belt drives provided freedom to position the motor relative to the load and this phenomenon enabled the reduction of the robot arm inertia. In the paper, accurate positioning of a belt driven mechanism using a feed-forward compensator under maximum acceleration and velocity constraints was proposed. The proposed method plans the desired trajectory and modified it to compensate delay dynamics and vibration. Being an off-line method, the proposed method could be easily and effectively adapted to the existing systems without any modification of the hardware setup. The effectiveness of the proposed method was proven by experiments carried out with an actual belt driven system. The accuracy of the simulation study based on numerical methods was also verified with the analytical solutions derived.

Selezneva [5] studied the use of belt for high precision applications that became appropriate because of the rapid development in motor and drive technology as well as the implementation of timing belts in servo systems. Belt drive systems provide high speed and acceleration, accurate and repeatable motion with high efficiency, long stroke lengths and low cost. Modelling of a linear belt-drive system and designing its position control were examined in the research work. Friction phenomena and position dependent elasticity of the belt were analyzed. Computer simulated results showed that the developed model was adequate. The PID control for accurate tracking control and accurate position control was designed and applied to the real test setup. Both the simulation and the experimental results demonstrated that specifications. The designed controller met the specified performance specifications.Musselman and Djurdjanovic [10] in their research on improvement of belt tension monitoring in belt-dive automated material handling system, carried-out experimental study of belt dynamics which indicated that transverse belt vibrations were sensitive to changes in belt length, belt tension, belt misalignment, and excitation location. Based on these findings, a novel device was developed to always excite the belt vibration in the material handling system with reduced vibrations in belt length and initial location.In order to effectively increase printing speed, [2] two employed an approach such that the controller for the printer previews the printable data in each swath to obtain the maximum acceleration time from the present carriage position and moves the carriage within the time frame to print at the referenced speed.

III. METHOD

In this section, the mathematical equations of a printer belt drive system is obtained and a controller is designed for the system using Matlab software. The mathematical equations are transformed into transfer functions representing the DC motor and the printer belt and pulley system. The DC motor and the printer belt pulley system are integrated with the designed controller to form a closed-loop control system which employs a light sensor with a unit feedback gain.

1.1 Dynamic Equations of Printer Belt Drive

Figure 1 shows a typical printer belt drive system for a computer. In Fig.1, R is the motor circuit resistance, L is the inductance of motor armature, τ is the rotational torque of the motor shaft, v_b is the back induced electromotive force (e.m.f), J is the total inertia of the printer belt drive, v_a is the applied voltage, $i(t)$ is the current of the motor circuit, θ the angular positioning of the motor of the motor shaft and θ_p is the angular positioning of the pulley.

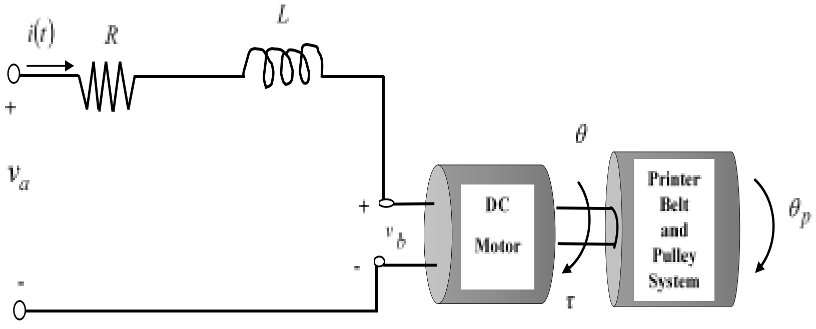

Figure 1: A typical printer belt drive system

Two basic components make-up the printer belt drive system shown in Figure 1. These are: the electrical components of the DC motor and the mechanical components of the printer belt and pulley system.

1.1.1DC Motor Dynamics

The DC motor converts electrical energy it receives from electrical supply system to mechanical energy for driving the belt and pulley arrangement. The electrical components of the DC motor of the printing device is shown in Fig.2. It is assumed in this context that the field current of the armature- controlled DC motor is constant.

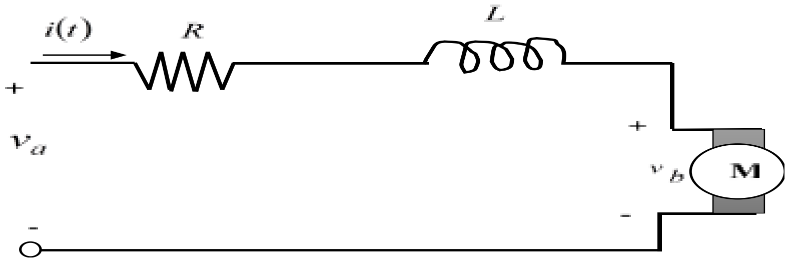

Figure 2: DC motor electrical circuit

In this way, it acts as an actuator. Applying Kirchhoff's voltage law to the DC motor circuit gives:

$$v_a(t) = Ri(t) + L\frac{di(t)}{dt} + v_b(t) \qquad (1)$$

The angular positioning of the shaft θ and the angular speed of the shaft ω are related as follows:

$$\omega(t) = \frac{d\theta(t)}{dt} \qquad (2)$$

The back e.m.f $v_b(t)$ is directly proportional to the angular speed of the motor shaft. This is given as:

$$v_b(t) = k_m\frac{d\theta(t)}{dt} \qquad (3)$$

where k_m is the motor torque constant. Substituting Eq. (3) into (1) gives:

$$v_a(t) = Ri(t) + L\frac{di(t)}{dt} + k_m\frac{d\theta(t)}{dt} \qquad (4)$$

Equation (4) is expressed in Laplace transform as:

$$V_a(s) = RI(s) + LsI(s) + k_m s\theta(s) \qquad (5)$$

The rotational elements of the DC motor shaft are represented by:

$$\tau(t) = J\frac{d^2\theta(t)}{dt^2} + f\frac{d\theta(t)}{dt} \qquad (6)$$

The rotational torque of the motor shaft is:

$$\tau(t) = k_m i(t) \qquad (7)$$

Substituting Eq. (7) into Eq. (6) and expressing the resulting equation in Laplace transform gives:

$$k_m I(s) = Js^2\theta(s) + fs\theta(s) \qquad (8)$$

Elimination of $I(s)$ from Eq. (5) and Eq. (8) gives:

$$G(s) = \frac{\theta(s)}{V_a(s)} = \frac{k_m}{s\left[(Js+f)(R+sL)+k_m^2\right]} \qquad (9)$$

Equation (9) is the DC motor transfer function.

1.1.2 Printer Belt and Pulley System

A typical printer belt and pulley drive arrangement is shown in Fig. 3. The belt is attached to two pulley system such that the tension, T_1 and T_2, adjusts the flexibility of the belt. The belt has elastic constant, k, the radius of the pulley is r, and the angular positioning of the pulley is θ_p. It is assumed in this context that the mass of the printing device, m attached to the belt and pulley system, and its position $c(t)$ is fed to a feedback light sensor which measures it. The output of the sensor is compared with an input (referenced) voltage and the error signal is fed into the controller.

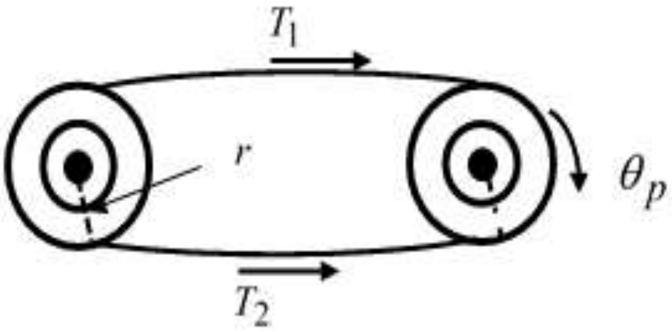

Figure 3: Printer belt and pulley arrangement

In order to model the printer belt and pulley system, the following equations are developed.
Let the output of the printing device be:

$$c(t) = r \times \theta_p \qquad (10)$$

The tension, T_1 is: $$T_1 = k(r\theta - r\theta_p) \qquad (11)$$

The tension, T_2 is: $$T_2 = k(r\theta_p - r\theta) \qquad (12)$$

Substituting Eq. (10) into Equations (11) and (12) yields:

$$T_1 = k[r\theta - c(t)] \qquad (13)$$

$$T_2 = k[c(t) - r\theta] \qquad (14)$$

The resultant tension acting on the printing device of mass, m is given by:

$$T_1 - T_2 = m\frac{d^2c(t)}{dt^2} \qquad (15)$$

Also $$T_1 - T_2 = k[r\theta - c(t)] - k[c(t) - r\theta] = 2[r\theta - c(t)] \qquad (16)$$

Equating (15) and (16) yields:

$$m\frac{d^2c(t)}{dt^2}+2c(t)=2r\theta \qquad (17)$$

Taking the Laplace transform of Eq. (17) yields:

$$ms^2C(s)+2C(s)=2r\theta(s) \qquad (18)$$

The transfer function of Eq. (18) is:

$$\frac{C(s)}{\theta(s)}=\frac{2r}{ms^2+2} \qquad (19)$$

Equation (19) is the dynamic equation of the printer and pulley system.

In order to perform simulation so as to check performance characteristics of a printer belt device for computer system considered in this paper, the following parameters are adopted from [1].

Table 1: Parameters of a typical printing device [1]

Parameter	symbol	value	unit
Mass	m	0.2	kg
Light sensor	-	1	V/m
Radius	r	0.15	m
Inductance	L	0	H
Viscous force	f	0.25	Nms/rad
Resistance	R	2	Ω
Motor torque constant	k_m	2	Nm/A
Inertia	J	0.01	Kg/m^2

It should be noted that the total inertial of the system is equal to the sum of the inertial of the DC motor (a typical 1/8 hp DC motor) and the pulley given by:

$$J=J_{motor}+J_{pulley} \qquad (20)$$

1.2 System Configuration and Controller Design

The configuration of the printer belt drive system integrating a controller is shown in Fig. 4. The system is a single input single output (SISO) system.

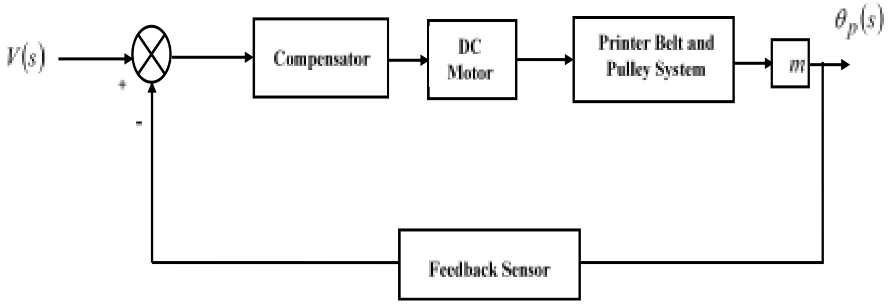

Figure 4: Performance control loop of a printer belt drive system

In order to design the controller, Matlab software is used. An optimal performance tuning is employed such that a differentiator, lead phase compensator and real zero are combined to give a hybrid compensator whose gain is 121. Equation (21) gives the designed hybrid compensator C:

$$C=121\frac{s(1+0.4s)(1+s)}{(1+0.1s)} \qquad (21)$$

IV. SIMULATION RESULTS AND DISCUSSION

4.1Simulation Results

In this paper, simulations are performed considering two conditions. First, the system is simulated without compensator in the in the closed loop as shown in Fig. 5. Then simulation is performed when the designed compensator is integrated into the forward path of the system, and the plot obtained is shown in Fig. 6.

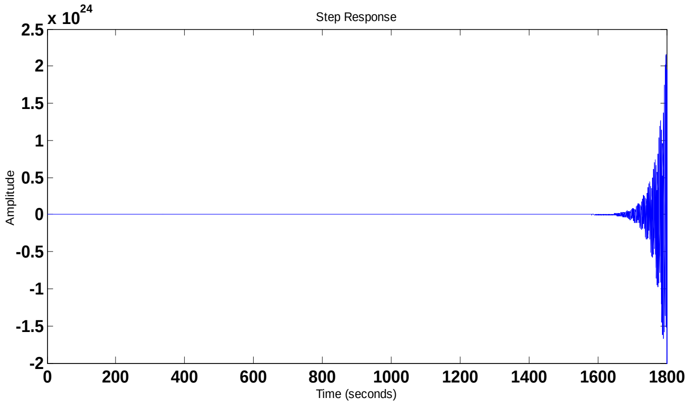

Figure 5: Step response without compensator

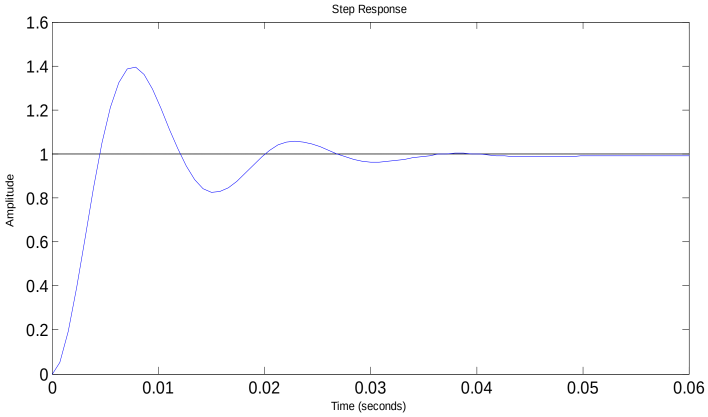

Figure 6: Step response with compensator

Table 2: Achieved performance result

Characteristic	Value	Unit
Rise time	0.00577	s
Settling time	0.0338	s
Overshoot	20	%

V. DISCUSSION

Two simulations were performed as at the time the compensator was not in the printer belt drive closed loop system and when the compensator was in the loop. In the first case as shown in Fig. 5, the response (or output) of the system shows a high degree of instability. The characteristics of the system is undesirable. In this case, the positioning and speed performance of the printing device will be poor and inaccuracy in printing will set-in. This required a system that will improve the positioning and speed performance of the printer for effective printing and accuracy. Incorporating the hybrid compensator into the printer belt loop gives an improved system with effective and accurate positioning and speed performance whose response (or output) is shown in Fig. 6. Table 2 shows the achieved performance result obtained for the improved system. It can be seen that the system rise time is 0.00577s, settling time is 0.0338s, and overshoot is 20%. By this, the positioning and speed performance of a printer belt drive system considered in this paper is highly improved.

VI. CONCLUSION

This paper has presented performance improvement of printer belt drive for a computer system. The dynamics of DC motor, printer belt and pulley system were obtained. A hybrid compensator was designed using

Matlab software. The designed compensator was integrated with the DC motor, printer belt and pulley system to form a single-input single-output closed loop system. The designed compensator was able to improve the positioning and speed performance of a printer belt drive system considered in this paper.

REFERENCES

[1]. Richard, C.D., and R.H., Bishop, Modern Control Systems, 12th Edition, Prentice Hall, Upper Saddle River, NJ, 2011.
[2]. J.L.K. Chan and A.B. Tan. Variable-Duration PrinterCarriageMotorAccelerationMethod and Apparatus, U.S. Patent: 5,627,947, Hewlett-Packard Co., Palo Alto, CA USA, May 6, 1997.
[3]. Mathias J. and Hubert G. Dynamic Modeling and Flatness Based Control of a Belt Drive System. Vol. 14, Issue 1, 2014, DOI: 10.1002/pamm. 201410424, pp 887-888.
[4]. Yusong P. Intelligent Belt Conveyor Monitoring and Control. Department of Electrical Engineering, Taiyuan University of Technology geborenteChangzhi, Shanxi Province, China, 2(7), 2010. pp 39-42.
[5]. Selezneva, A. Modeling and Synthesis of Tracking Control for the Belt Drive System. A Master of Science Thesis, Department of Electrical Engineering Lappeenranta University of Technology, 2(6), (2007). pp 29-31.
[6]. Doug Harriman. Control Systems Challenges in the HP Personal Ink Jet Printing Application. 2005 American Control Conference. June 8-10, 2005. Portland, OR, USA
[7]. J. Parkkinen ; M. Jokinen ; M. Niemela ; T. Lindh ; J. Pyrhonen. Motion synchronization of two linear tooth belt drives using cross-coupled controller. Sept. 2013. DOI: 10.1109/EPE.2013.6634434. ISBN: 978-1-4799-0116-6.
[8]. Grzegorz, Domek.Motion Analysis of Timing Belt Used in Control Systems.American Journal of Mechanical Engineering 1.7 (2013): 208-211.
[9]. Jayawardene, T. S. S., Nakamura, M., and Goto, S. Accurate Control Position of Belt Drives under Acceleration and Velocity Constraints.International Journal of Control, Automation and Systems .1(4), (2003). 474–483.
[10]. M. Musselman and D. Djurdjanovic. Improvement of Belt Tension Monitoring in a Belt-Drive Automated Material Handling System. Advances in Sustainable Manufacturing pp 135-140. May 2011

NjokuDonatus "Performance Improvement of Printer Belt Drive For A Computer System." American Journal of Engineering Research (AJER), vol. 6, no. 12, 2017, pp. 67-73.