Variable Speed Conveyer System Using E.M.F. Sensing Controlled Linear Stepper Motor

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Abstract: **In automatized factories the conveyers have the capabilities of not only carrying products, but also positioning accuracy at the target point at variable speeds. For these purposes the outer magnet type hybrid linear stepper motor is well suited. An improved control strategy is proposed, based on the E.M.F. sensing of the un-energized motor coil. Three control methods are compared by means of digital simulation based on a coupled circuit-field mathematical model. A typical positioning task of the conveyer system is simulated, too.**

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See attached the scan of the paper

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VARIABLE SPEED CONVEYER SYSTEM USING E.M.F. SENSING CONTROLLED LINEAR STEPPER MOTOR

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ABSTRACT

In automatized factories the conveyers have the capabilities of not only carrying products, but also positioning accuracy at the target point at variable speeds. For these purposes the outer magnet type hybrid linear stepper motor is well suited. An improved control strategy is proposed, based on the E.M.F. sensing of the un-energized motor coil. Three control methods are compared by means of digital simulation based on a coupled circuit-field mathematical model. A typical positioning task of the conveyer system is simulated, too.

1. INTRODUCTION

It is an increasing brisk to automate the factories using robots. The robots are required to carry out varieties of physical tasks either to replace or assist human beings. For example the conveyer used in a self-operated factory for automatic processing must have the capabilities of not only carrying products but also positioning accuracy at the target point at variable speeds.

For such a conveyer drive the hybrid linear stepper motor is well suited because of its high positioning accuracy at significant speeds and its capability of developing great linear thrust. It is suitable for precise acceleration, deceleration, and stopping at arbitrary points. There are no complications involved in using a rotary motor in addition to rotary to linear gearing (wear, losses and backlash, in addition to the associated extra costs).

Variable speed and high precision positioning are the two basic and fundamentally conflicting requirements for the motion controller which coordinates the variable speed conveyer system.

In open-loop drive mode of the linear stepper motor the operating frequency of the coil current pulses is given by an external source. However, if the load is varying and the frequency is not getting to accord to the load modifications, the step capability of the motor is exceeded. Dynamic instabilities and loss of synchronism between the motor position and excitation sequence changes are resulting, and the mover vibrations are amplified.

The total positioning capabilities and dynamic performances of the motor can be improved by operating under closed-loop control via a method based on E.M.F. (electrical motive force) sensing of the un-energized motor coil. This control method offers the possibility to maintain a prescribed motor speed not depending of the load, of course in certain limits. In this case the operating frequency will depend only on the capability of the motor to realize a step under given conditions, as load and input source limits.

The conveyer controller ensures in step mode a controlled motion over a preset distance. In position target mode the motor can be moved to a well-specificated location, and in true speed mode it provides the ability to run the motor at a constant speed irrespective of changing loads. The controller operates in position maintenance mode, too, when the motor position is held to within a closed tolerance under load fluctuations.

The authors suggest and analyze by computer dynamic simulation a closed-loop variable speed drive system for conveyer applications using the above mentioned control method.

2. THE HYBRID LINEAR STEPPER MOTOR

The hybrid linear stepper motor, shown in figure 1., is a variable reluctance, permanent magnet excited synchronous motor. It is operated under the combined principles of variable reluctance motors (tending to move towards the aligned teeth position in which magnetic reluctance is minimum), and of permanent magnet motors (having life-long excitation).

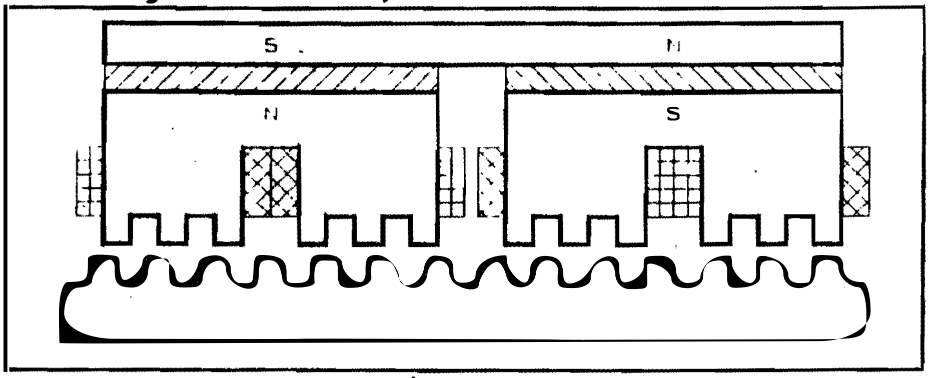

Figure 1

The moveable armature (the mover) consists of two electromagnets with coils and a permanent magnet on their top. Each electromagnet, made of insulated low-loss lamination, has two poles, and all poles have the same number of teeth. A command coil is placed on each pole. The back iron closes the motor magnetic circuit. The mover is suspended over a fixed stator (the platen), a toothed ferromagnetic structure having the same fine teeth pitch with the moveable armature.

The above presented motor construction has some advantages over the classical sandwich magnet type motor [1]. In the sandwiched magnet type motor the permanent magnet shape is simple and the motor can act with only one permanent magnet piece. As the flux path of the outer pole is longer than that of the inner pole, the permanent magnet flux of the outer pole is less than that of the inner pole. It follows that the produced thrust at the outer and inner poles are not equal, and thrust imbalance occurs, causing step errors and undesirable vibrations. In the outer magnet type hybrid linear motor the magnetic flux path of both poles becomes equal. In this case thrust imbalance does not occur, but the motor mass and height is greater due to the back iron.

The hybrid linear stepper motor presents high tracking force to volume performance, mainly because of the small air gap and good magnetic circuit utilization [2]. It has the ability to hold fix position under applied load. The motor is characterized by high servo stiffness which is essential for quick move-and-settle applications as conveyer drives. For these purposes direct drive mode of mounting can be adopted, the load being directly attached to the moving armature. This feature is an attractive solution because all transmission mechanisms are eliminated from the system. High reliability without any backlash, and additional inertia are ensured.

3. CONTROL STRATEGY

The conveyer system requires absolute step integrity at maximum speed and high load. Therefore a closed-loop control system (shown in Figure 2.) must be used. This is more expensive than the open-loop control system because of the required feedback loops, but enables significant motor efficiency, eliminates mechanical resonances, allows stable operation at high speed.

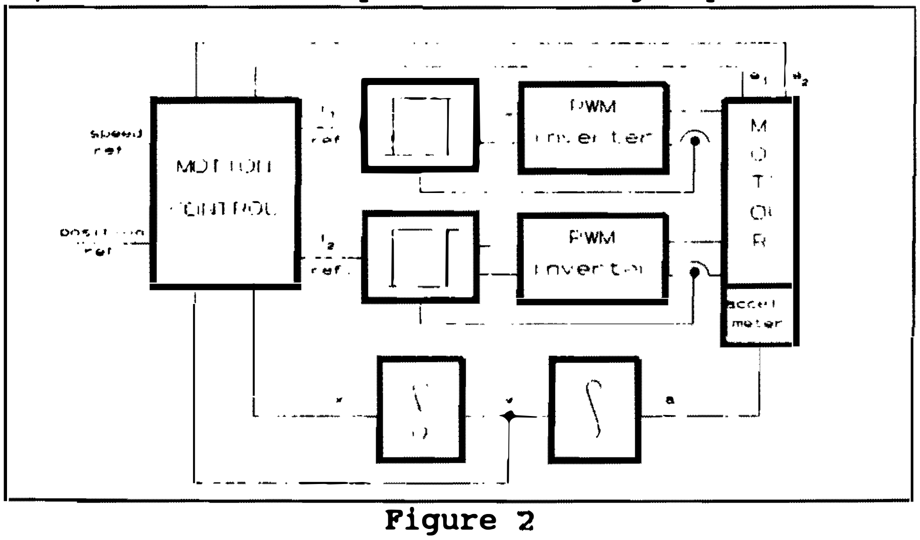

Figure 2

The proposed intelligent motion controller is based on the quadrature field-oriented control method of the linear hybrid stepper motor described in detail in [3]. The back E.M.F. generated in the un-energized coil of the motor is monitored in order to determine the current commutation moment. Integrating the acceleration signal obtained from a piezoelectrical accelerometer disposed on the mover, the actual speed of the motor can be determined. By integrating the speed signal the motor displacement is obtained.

The measured E.M.F. divided by velocity is compared with a prescribed reference. When these two values are equals the command current is commuted to an other coil with the necessary polarization. This way step integrity is guaranteed under all load conditions, because the start of each step is delayed until the previous step has been satisfactorily completed.

The controller compares the prescribed speed and position with the actual motor speed and displacement. The information thus collected provides the reference currents for the hysteresis current controllers. The motor command coils are fed by constant voltage PWM inverters.

For high efficiency the commutation of the command currents must be made in a way as to keep the medium value of the tracking force at maximum value. For this reason the current must be commuted before the mover is reaching an intermediate equilibrium position (point B in Figure 3.). In the equilibrium position the tangential force developed by the pole in which the magnetic flux was maximized is near nil. After commutation the tangential force (plotted by dashed line in Figure 3.) of the pole, in which the permanent magnet flux is concentrated, is at its greatest value. The best commutation moment is in point A, where the tangential forces before and after commutation are equal. This way the tangential force ripple is as small as possible for this type of motor.

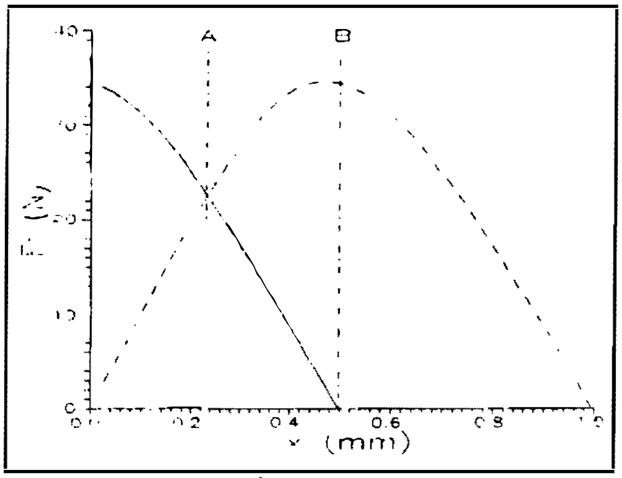

Figure 3

4. DYNAMIC SIMULATION OF THE CONTROL SYSTEM

The main reason for simulating any system through software is to verify that the design concept is optimal and provides the best balance of price and performance. The computer simulation of the above mentioned conveyer system, performed by a combined circuit-field mathematical model, offers the possibility to calculate the motor parameters.

The dynamic behavior of the linear hybrid stepper motor can not be covered accurately by an usual mathematical model because of the complex toothed configuration of the motor armatures, the magnetic saturation of iron parts and the permanent magnet operating point changes due to air-gap variable reluctance and control amperturns. The coupled circuit-field model was described in detail in several papers, [2] and [4].

The combined field-circuit model is conceived to be solved by means of computer, and the computational process consists of an iterative calculation. The computer program based on the proposed model offers the possibility to calculate all the motor characteristics (such as forces, acceleration, velocity, displacement, back E.M.F. etc.).

The model is well-suited for the simulation of both static and dynamic behavior of the described variable speed conveyer system. The digital simulation is an accurate tool for designers because they can try out many different control algorithms without prototyping hardware.

5. RESULTS AND CONCLUSIONS

Some of the geometrical dimensions and parameters of the motor under study are listed in Table 1.

ITEM	SPECIFICATION
tooth width	1 mm
slot width	1 mm
tooth pitch	2 mm
nr. of teeth per pole	5
airgap	0.1 mm
permanent magnet type	VACOMAX-145
residual flux density	0.9 T
coercive force	650 KA/m.
nr. of coil turns	200
motor width	40 mm

Table 1.

In order to emphasize the differences which does exist between different control strategies, the motor velocity, the tangential force and the mover displacement were plotted against time. In Figure 4. are shown the results for open-loop control mode. In this case the velocity is very low, having great variations due to the modifications of the tangential tracking force. The mover has a very small displacement.

Results of digital simulation for closed-loop control modes, using E.M.F. sensing, are presented in the next two figures. In Figure 5. are shown the results for the control system based on the detection of the minimum un-energized coil E.M.F. In this case the command currents are computed in the intermediate equilibrium positions. In this case the tangential force hasn't any negative values, the speed is increasing constantly and the motor displacement is uniform.

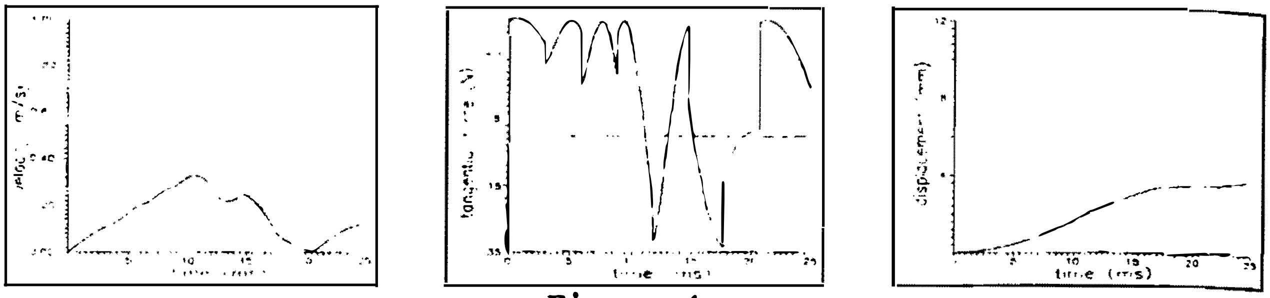

Figure 4.

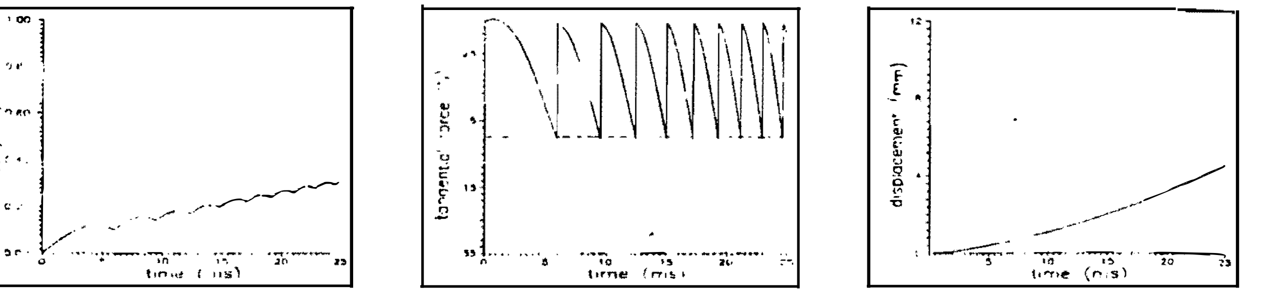

Figure 5.

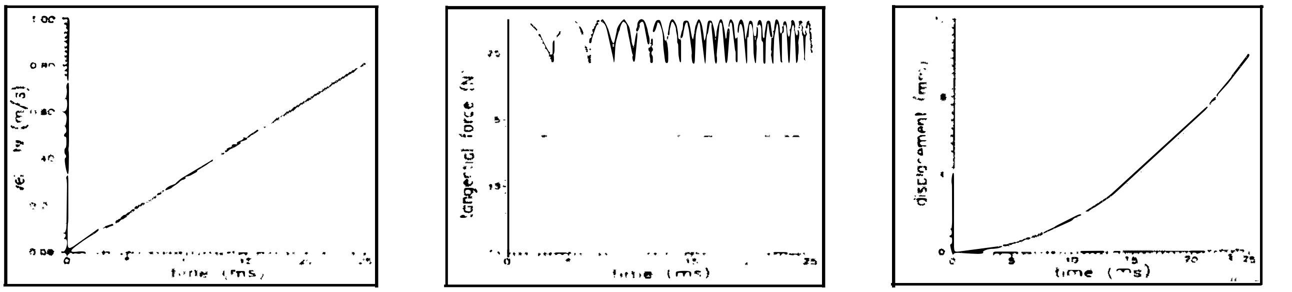

Figure 6

The best results (shown in Figure 6.) were obtained for the control strategy proposed in this paper. If the command currents are commuted before the mover is reaching its equilibrium position, the tangential force ripple is the smallest that can be achieved for the given motor type. The velocity is very high and is increasing near linearly resulting in a linear mover displacement.

CONTROL METHOD	Open-loop	Closed-loop commutation in A	Closed-loop commutation in B
max. tang. force [N]	35.46	35.46	35.46
min. tang. force [N]	-34.55	-0.75	21.78
max. velocity [m/s]	0.33	0.48	0.87
medium tang. force [N]	3.31	19.92	31.15
medium velocity [m/s]	0.05	0.33	0.59
final displacement [mm]	4.11	4.63	12.02

Table 2.

In Table 2. are presented some computed results obtained by simulating the above mentioned control methods. In all of the cases the motor was fed by 1.15A current pulses and a 25ms run was studied.

By evaluating the results obtained on computer model is quite clear that the best results were obtained for the proposed control method.

In Figure 7. are presented some results of dynamic simulation of a conveyer system controlled by the proposed E.M.F. detection based control method: the velocity, the command current in coil 1., the tangential force, the acceleration and the mover displacement versus time. The simulated task for the system was the following: the motor moves 5mm to the right with no-load at a speed of 0.8m/s. It stays stopped 10ms. After this the motor is moved 3mm with a 0.5kg load at a lower (0.5m/s) speed. Trapezoidal velocity profiles were adopted.

As it can be seen from the results the imposed task was successfully fulfilled.

The command current has great values during the two accelerations. The resulting thrust is high and the acceleration is relatively constant during the accelerations. When the motor is moving at slew speed, the tangential force is constant and the acceleration is nil. In order to decelerate the motor negative tangential forces are applied. During the movement the displacement is near linear.

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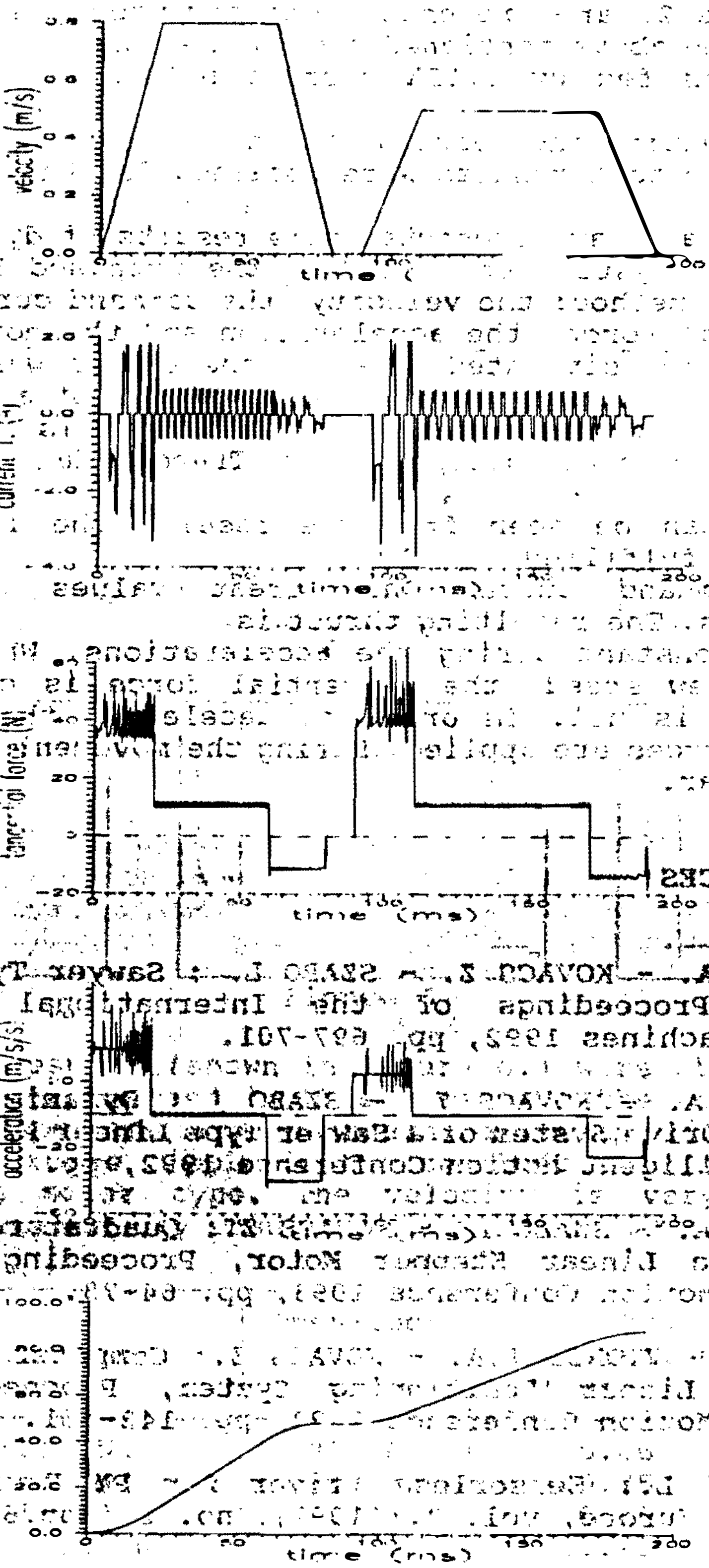

velocity (m/s)
current
tangential force (N)
time (ms)
acceleration
displacement (mm)
time (ms)

Figure 7.