High Performance Linear Actuation Systems

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Abstract –To achieve high precision linear movements, most actuators use a standard rotary motor and couple it to a mechanical rotary to linear translator. However, this is not the most optimum method. For high precision and high speed linear motions, this paper proposes to use dedicated direct-drive linear actuator with intelligent controller to accomplish the job. This type of implementation has the advantages of simple mechanism, easy maintenance, and low operation cost. This paper will explore several types of linear drives, including Permanent Magnet Synchronous Linear Motor, and Linear Switched Reluctance Motor.

INTRODUCTION

Most advanced manufacturing processes require high-speed and high-precision assembly machines for material transfer, packaging, assembly, and electrical wiring. Examples are the surface mounting of electronic components, the wire bonding of semiconductor chips, and the assembly of watches and jewelry. To achieve precise motion control, most of these machines use rotary electrical motors as their prime motion actuators, and couple their output shafts to mechanical motion translators (e.g. reduction gear, belt, ball screw, etc.). Though this is the most widely used method, it has disadvantages of reduced accuracy, complex mechanical structure, difficult adjustments, high production cost, and low reliability.

In this paper, the author proposes a new direction in high performance automated machine design, and suggests that future high performance motion systems should be designed through the philosophy of "simplifying the mechanics through direct-drive actuators and advanced control methodologies" [1, 2]. This paper will look at the present traditional linear slides and highlight its inadequacy, and then it will explore the direct drive linear actuators, and describe how these actuators can overcome these inadequacies.

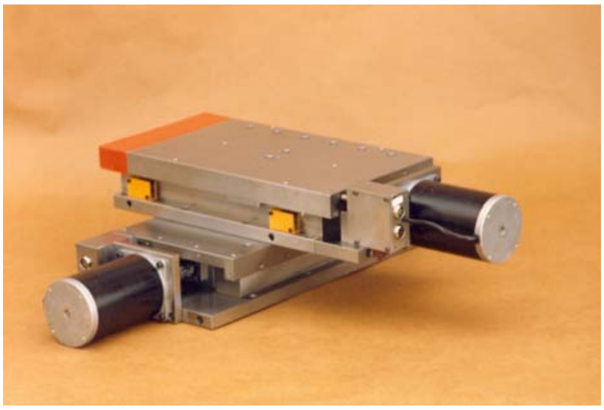

Fig. 1 A traditional linear slide using rotary motor and mechanical translator.

PROBLEMS OF PRESENT LINEAR MOTION SYSTEMS

Most of these machines require high position accuracy, high repeatability, and high accelerations and decelerations.

To achieve these tasks, most machines employ rotary permanent magnet brushless motors, shaft couplers and rotary/linear mechanical translators, and reduction gear to design the machine. The control of this type of machine is relatively easy, and in most cases, standardized motion components are used. However, its manufacturing and maintenance cost are relatively expensive, due to its complex mechanical parts. Also, this type of machine also suffers from complicated alignment procedure, backlash problems, low reliability, and unable to operate in harsh environments.

Fig. 1 shows the mechanical layout of a conventional linear slide, cascaded on top of each other to form a 2 dimensional X-Y table. This kind of arrangement may lead to inaccuracies and the performance reductions. This is mainly due to the coupler alignment, the straightness of the ball screw, the coupling between the ball screw and nut, and the parallel alignment between the linear guides, the ball screw, and the motor. As the complexity of manufacturing product increases, the precision requirement of machines to manufacture these devices also needs to increase. Normally, the cost of a Cartesian robot increases exponentially with its precision. Most of the increase in cost goes to the higher precision mechanical components, the mechanical alignment procedure, and the regular maintenance effort. Therefore, the complexity in the mechanical translators and couplers has lead to expensive and hard to maintain machines.

THE LIMITED STROKE VR ACTUATOR

Fig. 2 shows the diagram of a limited stroke VR solenoid. Primarily it is used for on off control of fluids. The structure is very robust, and the cost of such a device is very low. However, this device can be used as a proportional valve in hydraulic servo systems, if it is controlled in a proportional manner.

By measuring the nonlinear characteristics [3], and embed these nonlinear control characteristics into the control strategy, the above proposition can be accomplished. Furthermore the position of the plunger can be estimated by a sensorless position technique, and the feedback position sensor can be eliminated from this device.

By using advanced control method, the low-cost on-off solenoid can replace some types of proportional valves which have much higher costs and less reliability.

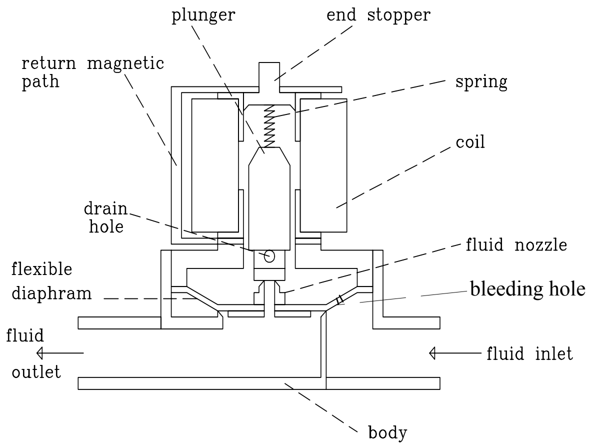

Fig. 2 The limited stroke VR actuator

DIRECT DRIVE LINEAR ACTUATORS

To combat the above mention ed problems, this paper proposes to use direct drive linear actuators and intelligent controllers to provide the linear motion, rather than using the traditional method.

The linear direct-drive actuator has a simple and robust structure with low inertia and direct drive capability, and is particularly suitable for high precision and high speed manufacturing machinery. Due to the simple structure, manufacturing of the actuator is simple and low cost. Since the actuator's track is extendible, the actuator is suitable for precision travel over long distances.

Unlike other types of motion actuators, mechanical couplings, lead screws are not required in linear actuator. Special mechanical adjustments or alignments are also not necessary.

This paper will introduces two types of linear actuators: the Permanent Magnet Linear Synchronous Motor (PMLSM) and the Linear Switched Reluctance Motor (LSRM).

THE PERMANENT MAGNET LINEAR SYNCHRONOUS MOTOR (PMLSM)

Fig. 3 shows the photo of the Linear Permanent Magnet Synchronous Motor.

The LPMSMs are of brushless type motors; therefore another electronic means of commutation (AC driving) is needed when controlling the motor [6].

With the continual advancement of microelectronics, powerful electronic devices and micro controller units, such as the IGBT power drivers & DSP processors, are readily available. This allows the building of the high efficient digital driver at a very competitive cost and high performance. In addition, the complexity associates with controlling an ac drive are readily being overcome.

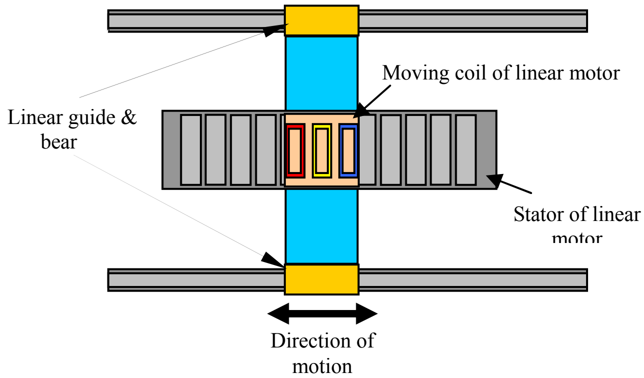

Fig. 3 A Permanent Magnet Linear Synchronous Motor (PMLSM)

The Linear Permanent Magnet Synchronous Motor can eliminate:

(a) The rotary bearing,
(b) The mechanical coupler
(c) The ball-screw & nut
(d) The extra rotary encoder for the commutation control and position control of the motor.

Therefore the resulting driving system consists of less mechanical parts and this has made the design more simple, straightforward and less costly. In practice, for a 5m accuracy 6"x6" X-Y table, cost reduction of up to 80% is possible with the replacement of the rotary system by the linear one. Besides the overall mechanical friction in the system is a lot smaller, less audible noise will be generated and the motor can move faster. In addition, the position sensor is attached very close to the load; the position of the load can be more accurate. Furthermore, the system is virtually free of maintenance and this means a more robust and reliable motion system is possible.

THE LINEAR SWITCHED RELUCTANCE MOTOR (LSRM)

Linear switched reluctance motor (LSRM) has never been a popular choice for high precision and high-speed motion actuator because of its high force ripples and highly nonlinear control characteristics. Current applications of LSRM are focused on transportation systems and printer mechanisms. There is not much in recent literature, which concerns with high-accuracy position control (down to micrometer resolution) and high-speed control of switched reluctance linear drive systems. Until recent years, a general surge of interest in the switched reluctance motor is found. [7]

This paper describes a novel, high performance, direct drive LSRM for precision manufacturing applications [4,5]. The actuator is based on switched reluctance technology with flux de-coupled windings. The LSRM has a simple and robust structure with low inertia and direct drive capability, and is particularly suitable for high precision and high speed manufacturing machinery. Manufacturing of the actuator is simple, and it is suitable for precision travel over long distances. Special mechanical adjustments or alignments are also not necessary. Comparing to permanent magnet linear motor, the proposed actuator has a much simpler structure and is less expensive. It is also more robust and more fault tolerant, and has less overheating problem.

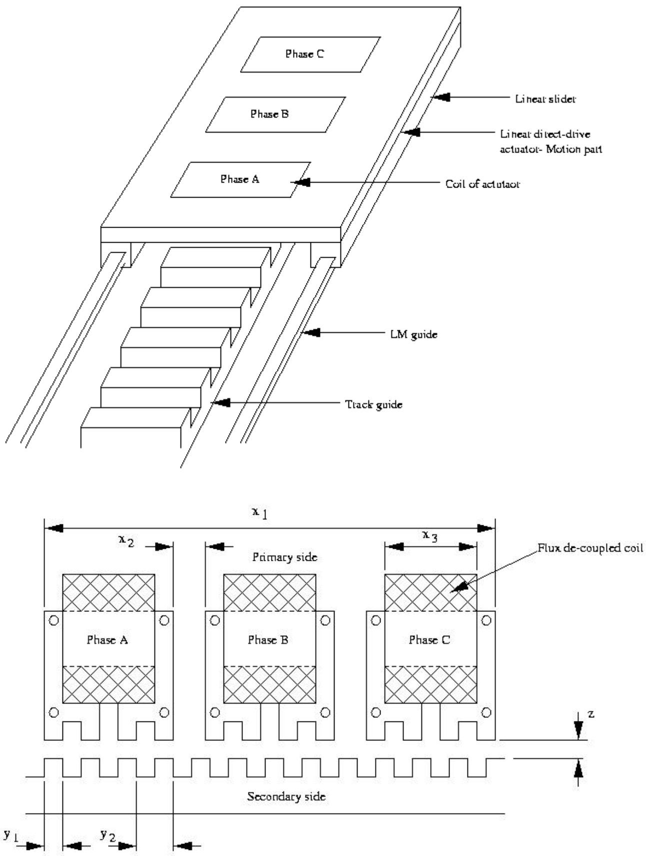

Fig. 4 Schemetic Diagram of the Linear Switched Reluctance Motor (LSRM) and the Decoupled Coil Arrangement)

Fig. 4 shows the schematic diagram of the LSRM and Fig. 5 shows the actual motor. The motor is optimised for (i) high power-to-size ratio, (ii) low force ripple, (iii) low leakage and eddy current loss, and (iv) fast current dynamics. The motor is integrated on a precision linear motion slider. In order to provide an accurate position feedback for the LSRM, a 0.5 um resolution linear optical encoder is mounted on the motion actuator to observe the motion profile and provides the position feedback. [8,9,10]

The proposed LSRM is constructed in longitudinal configuration. Three phase coils are assembled on a moving platform with 120 electrical degree separations. As the motor windings are flux de-coupled, the three phase circuits are completely independent and there is no mutual inductance between phases.

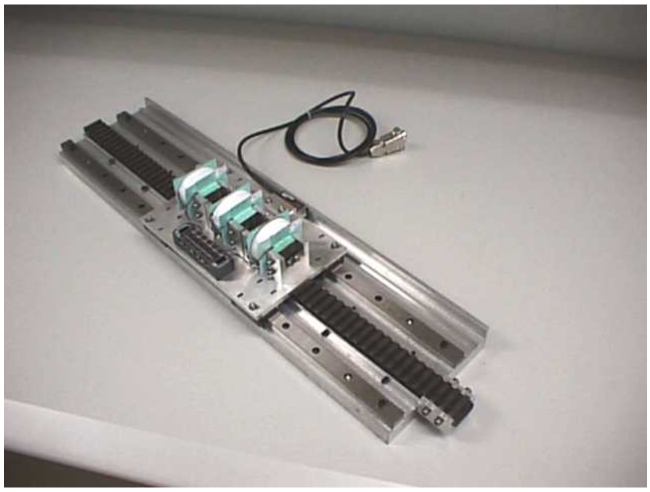

Fig. 5 The actual Appearance of the Linear Switched Reluctance Motor

CONCLUSION

The actuators described in this paper are robust, reliable and have little mechanical adjustments. These actuators will be applied to many new, high end applications which were not possible before. It will also have a tendency to replace many traditional X-Y tables which operate by rotary motors and mechanical lead screws. It will break the traditional domination of traditional X-Y tables in many high speed and high precision motion applications. It will also open new applications of precise motion travels over long distances and under harsh environment.

Overall, the highly reliable, low cost and ease of application of linear actuation systems will make a significant contribution towards advanced manufacturing automation, when this project's knowledge is widely available to the industrialists and engineers.

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