# MANAGEMENT AND MOTION CONTROL OF BALL SCREW ACTUATORS APPLIED IN THE ROBOTIC STRUCTURES



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# MANAGEMENT AND MOTION CONTROL OF BALL SCREW ACTUATORS APPLIED IN THE ROBOTIC STRUCTURES

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**Abstract:** The ball screw transmission can perform, in general, a continuous motion of constant velocity or a limited and controlled motion of variable speed. In this paper for the management and motion control a linear actuator, with high performance in movement and positioning, will be used. A linear actuator is composed out of a DC motor and a system of movement transmission and transformation (ball screws and a movable/sliding table – working point). The linear actuator is driven and controlled by an electronic automation system. This paper aims to present a series of programming and control elements for the ball screw transmission actuator. Experimental researches were performed based on an experimental stand, which contains a precise mechanical chain transmission driven and controlled by a programmable logic controller PLC. This system can be therefore used for programming, in a flexible manner, the axial positioning of the robotic modules by using the ball screw actuators.
**Keywords:** linear actuator, ball screw transmission, preload system, programmable logic controller**.**

## 1. Introduction

A ball screw is a mechanical mechanism that transforms rotation into linear motion with very low friction losses. A threaded shaft provides a helical raceway for ball bearings which acts as a precision screw. Besides being highly precise it is able to apply or withstand high thrust loads with minimum internal friction. They are manufactured with close tolerance and are therefore suitable for use in situations in which high precision is necessary. The ball assembly acts as the nut while the threaded shaft is the screw. The closed circuit of the balls is provided by the mechanism of recirculation balls.

For a ball screw assembly, preloading is a method of eliminating backlash. Preloading increases stiffness (resistance to deflection) and provides for accurate positioning with very little increase in applied torque or load capability. This is a requirement when positioning accuracy and repeatability must be maintained for the ball screw mechanism.

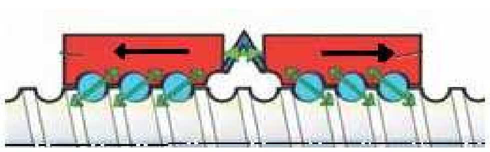

**Fig. 1.** Preload double nut system

Preloaded ball screw assemblies consist of two standard ball nuts joined by an adjustable preload package containing a collar, coupler and bevel or helical springs (Fig 1).The preload package has been designed to exert an axial separating force between the adjacent ball nuts thereby generating the requisite preload. Preloaded ball screw assemblies are required when positioning accuracy and repeatability must be maintained [1].

**Fig. 2.** Preloaded ball screw assemblies

The preload force on the ball screw has high influence in movement and positioning accuracy. Usually, preload force $F_{pr}$ has the following expression:

$$F_{pr}=X_{pr}.C \tag{1}$$

Where $F_{pr}$ - internal axial load due to the preload [N]; X - preload factor (0,02-0,1); C - dynamic load rating [N]
If the axial load of transmission $F_n$ has expression:

$$F_n \leq 2,8\ F_{pr} \tag{2}$$

Effective force that loads one nut is:

$$F_{eff} = \left( \frac{F_n}{2,8F_{pr}} + 1 \right)^{\frac{3}{2}} F_{pr} \tag{3}$$

It is very important to know the axial load, $F_n$ of the system in every moment for being able to determine and set the preload force in system. This way the force $F_{eff}$ acting on a nut may be known in real time. If necessary, a device for automatic adjustment of force $F_{pr}$ depending on axial load $F_n$ [5] can be used.

## 2. Programming and Control of the System

### 2. 1. Drive system - Experimental Stand

The experimental stand simulates a linear actuator with ball screw transmission in form and conception (Fig. 3).

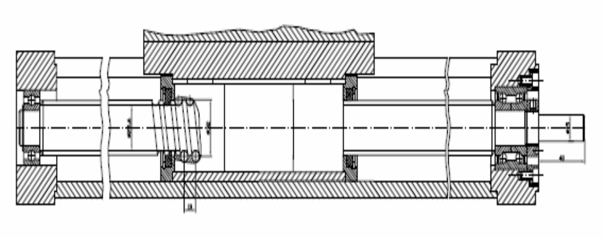

**Fig. 3.** Ball screw transmission

Ball screw transmission (Fig 2), is an important subset of the experimental stand (Fig 8), it contains a screw with special end bearing and a double nut with preload system. The preload system is an adjustable mechanism; the tension that appears is due to the effect of helical spring deformation (Fig 1). It is possible to measure the preload force.

The drive system – actuator (Fig.4), is a DC electric motor (2000 rot/min), that contains, as a compact system, a worm gear speed reducer, transmission ratio 39.

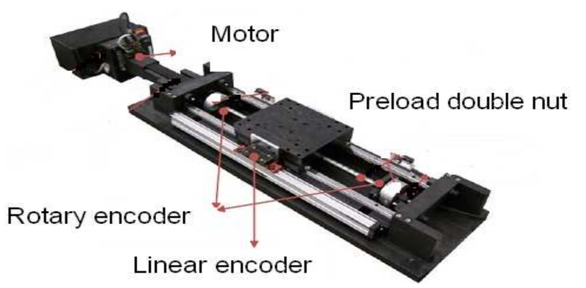


**Fig. 4.** Ball screw actuator

### 2.2. PLC Versus PC and Microcontrollers

The architecture of a PLC's CPU is basically the same as that of a general purpose computer; however, some important characteristics set them apart. First, unlike computers, PLCs are specifically designed to survive the harsh conditions of the industrial environment. A well-designed PLC can be placed in an area with substantial amounts of electrical noise, electromagnetic interference, mechanical vibration, and non-condensing humidity. A second distinction of PLCs is that their hardware and software is designed for easy use by plant electricians and technicians.

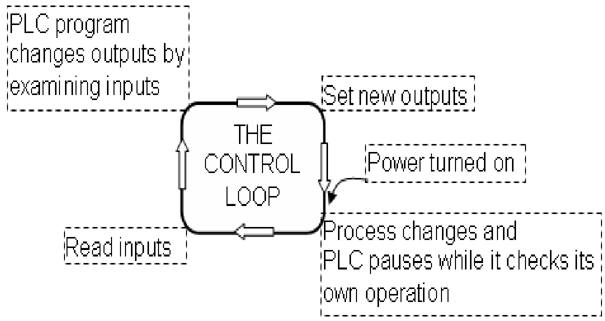


**Fig. 5.** Steps in execution operations of a PLC

The hardware interfaces for connecting field devices are actually part of the PLC itself and are easily connected. The modular and self-diagnosing interface circuits are able to pinpoint malfunctions and, moreover, are easily removed and replaced. Also, the software programming uses conventional relay ladder symbols, or other easily learned languages, which are familiar to plant personnel. Whereas computers are complex computing machines capable of executing several programs or tasks simultaneously and in any order, the standard PLC executes a single program in an orderly, sequential fashion from the first to the last instruction, (Fig. 5). The personal computer, however, is being used as the programming device of choice for PLCs in the market, where PLC manufacturers and third-party PLC support developers come up with programming and documentation systems for their PLC product lines. Personal computers are also being employed to gather process data from PLCs and to display information about the process or machine (i.e., they are being used as graphic user interfaces, or GUIs). However, some control software manufacturers, utilize PCs as CPU hardware to implement a PLC-like environment. The language they use is based on the International Electro technical Commission (IEC) 1131-3 standard, which is a graphic representation language (sequential function charts) that includes ladder diagrams, functional blocks, instruction lists, and structured text. These software manufacturers generally do not provide I/O hardware interfaces; but with the use of internal PC communication cards, these systems can communicate with other PLC manufacturers' I/O hardware modules. Communication and transmission of the signal within the sensing system is generally processed in digital form after digitization of the analog input signal. The analog transmission of the sensed signal prior to digitization requires special care, as the quality of the signal transmission directly influences the quality of sensing. The analog signal is easily deteriorated by the noise signal surrounding the transducers/sensors and the signal transmission cables. The high-frequency noise signals coming from the power circuits including the motors, the digital devices, etc., as well as those coming from the power supply can be major sources of noise signals. Programming and control of the system is possible by using a programmable logic controller (PLC). The positioning of the mobile parts of the chain transmission is possible by using proximity sensors like inductive ones. The sensors provide signal for the inputs of PLC. The numbers of inputs are six digital and two analogical. In our application we use digital inputs. The level of the signal for digital inputs consists of 24 V DC. Outputs from PLC like a relay are four and are used for building an H-bridge. The software from inside the PLC is written in ladder diagram by a PC.

The drive system is driven by a DC Motor connected to the outputs of the PLC (Fig. 7). Q1 and Q4 allow screw ball movement in one direction, Q2 and Q3 in opposite direction. For system operation, two power supplies are required, one for the PLC and the second one for the DC motor. The switching between left and right displacement is managed by the PLC outputs Q1, Q2, Q3 and Q4.

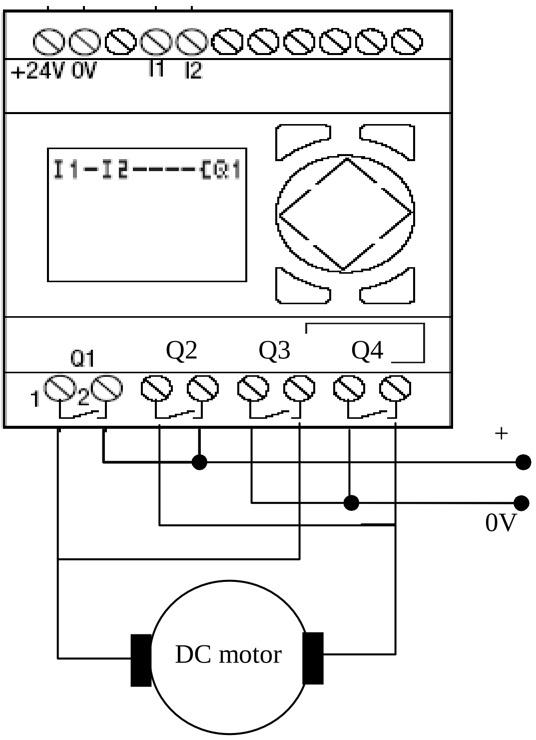


**Fig. 6.** Control of the DC motor

For the creation of the program in ladder diagram we use V4.0 STEP7 MicroWIN software. Proximity sensors PS1 and PS2 (Fig. 8) provide signals for automatic replay. PS1 connected to input I0.5 will stop the left displacement and restart the right displacement. PS2 connected to input I0.4 will stop the displacement to the right and restart the one to the left. The software for the system control is presented in (Fig.8). The number of lines of the program depends on the number of temporal phases of the chain actuator.

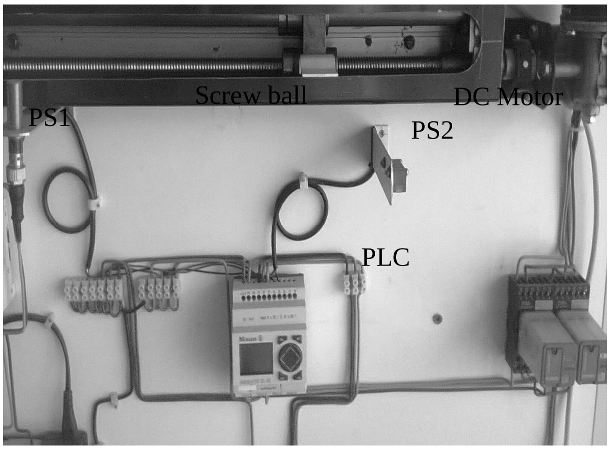


**Fig. 7.** Experimental set

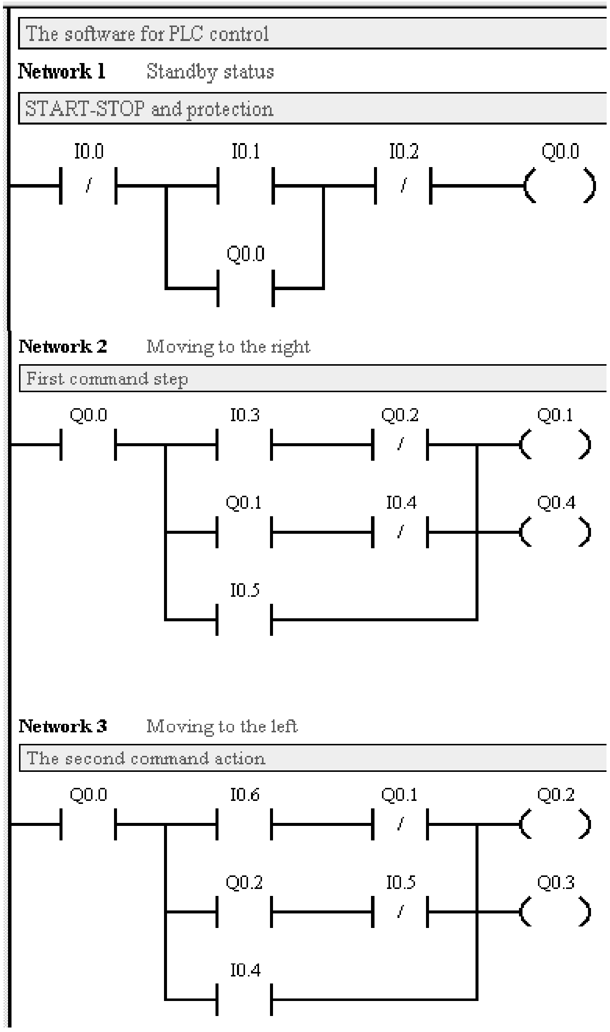


**Fig. 8.** Software in Ladder diagram

The software with explicit instructions is presented in figure 9.

```
The software for PLC control
Network 1    Standby status
START-STOP and protection
LDN     I0.0
LD      I0.1
O       Q0.0
ALD
AN      I0.2
=       Q0.0

Network 2    Moving to the right
First command step
LD      Q0.0
LD      I0.3
AN      Q0.2
LD      Q0.1
AN      I0.4
OLD
O       I0.5
ALD
=       Q0.1
=       Q0.4

Network 3    Moving to the left
The second command action
LD      Q0.0
LD      I0.6
AN      Q0.1
LD      Q0.2
AN      I0.5
OLD
O       I0.4
ALD
=       Q0.2
=       Q0.3
```

**Fig. 9.** Software in Instruction list form

The status of inputs and outputs of the PLC is presented in figure 10. The internal oscilloscope of the PLC permits to establish inputs and outputs for visualizing the dependence between them. The software offers possibilities to count the number of displacements of the cinematic chain. For counting the number of displacements the PLC receives digital inputs from the proximity sensor PS1 and PS2. In case of endurance testing or precision evaluating one or more counters are programmed. Routine counters may be set for cycling left to right and vice versa. The system offers the possibility to establish the precision for positioning the ball screw actuators.

## 3. Concluding and Remarks

1. Ball screw actuators may be used in the realization of high precision displacements. The PLC controllers offer possibilities to program and control the movements.
2. The system can be used for programming, in a flexible manner, the axial positioning of the robotic modules by using the ball screw actuators
3. For testing in endurance modus the system offers the possibility to plan the number of successive movements using a simple counter as a simple routine.

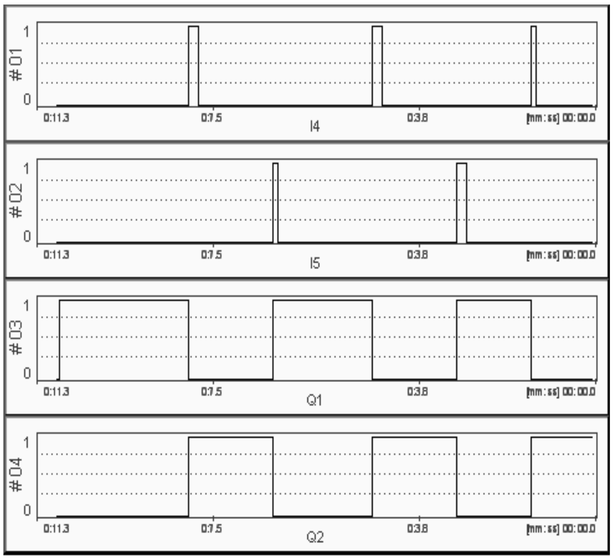


**Fig. 10.** The status of inputs and outputs

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## Personal notes

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