TECH NOTE 120-3: Labeling Machine Motion Control System

Labels are applied on virtually every product, such as bottles, boxes and alike. A label is often pre-printed on a web (plastic or paper material) and supplied as rolls. Then, the labeling machine attaches the labels to the product (i.e. glued on box or bottle or stretch-fit over a bottle). Typical labeling speeds can be anywhere from 600 labels/minute (100 msec cycle time per label) to 3000 labels/minute (20 msec cycle time per label).

Components of the motion control system are as follows (Fig.1):

1. HMI
2. PLC/Motion Controller with EtherCAT Master and Slave I/O Interface module
3. Two axis servo drive and motor system (or one servo drive and motor plus a Master Encoder)
4. Sensors: two proximity sensors

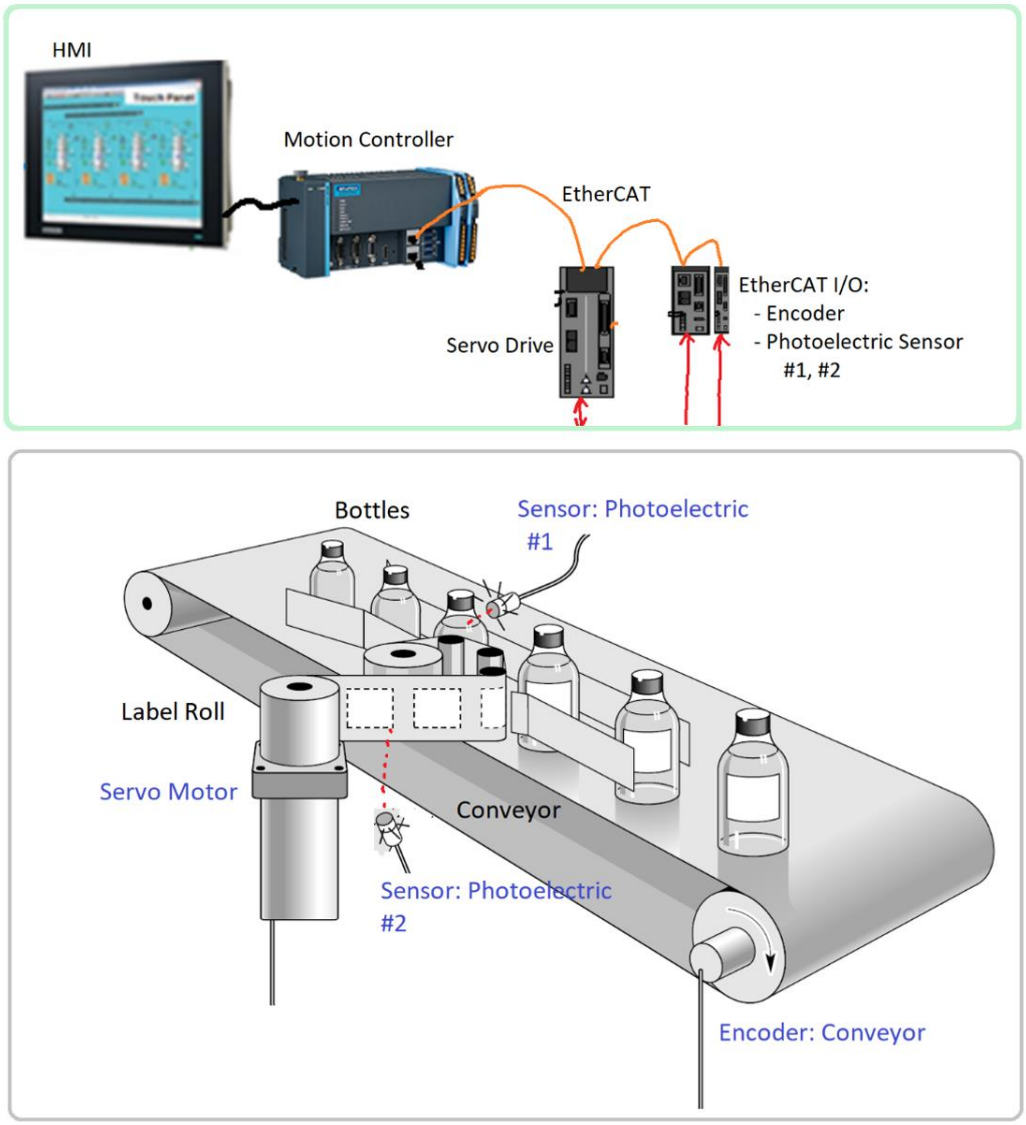

Fig. 1 – Labeling machine automation: two axis servo control system – one master encoder or conveyor drive servo motor, and one servo motor for label roll feed motion.

Number of motion axes: The key motion control task is to place the label on the product at the right position (that is the relative position of the label and the product must be correct when they start the contact), then until the label application is completed, the label and product translational speed must be matched. Hence there are two independently actuated, but coordinated, motion axes:

- an axis that moves the products such as bottles. This axis may be servo driven or driven by another control system but we have an position feedback in the form of a "Master Encoder". Product moves over a conveyor or a rotating indexer.
- an axis that moves the label relative to the product. This is a servo drive, motor with encoder axis.

If two servo axes are used, then each drive is simply interfaced to the controller as EtherCAT Slave Servo Drive. If one of them is Master Encoder, then is it interfaced to the PLC/Motion Controller as an EtherCAT Slave IO Interface Module for Encoder.

Sensors: Two (2) photoelectric ON/OFF sensors; one for the label detection, and one for the product box detection.

The PLC/motion controller is used to control the two-axis coordinated motion.

An **HMI** PC are used for operator interface.

This machine involves two axes of motion: Conveyor axis and Label axis. Conveyor does not have to be servo driven, although it would be desirable for it to be servo driven. Given the measurement of conveyor motion, i.e. encoder feedback signal from the conveyor drive motor or a Master Encoder attached to the conveyor, the servo drive system for the Label is controlled as a Slave to the conveyor motion (Master .

The system have two ON/OFF detection sensors: one for product (box) and one for label. If labels are already well placed accurately on the label feed-web and the variations in their position is negligible, and we have a way of accurately homing it, "Sensor #2" for Label can be omitted. Again, it is better to have this sensor against label placement error on the label feed web and against any position drifts (Fig. 2).

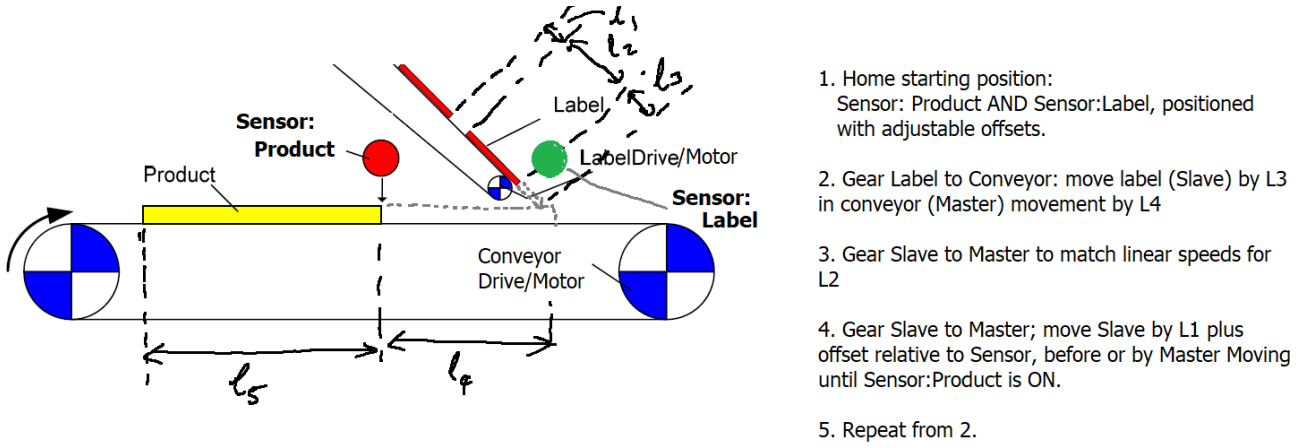

Fig. 2 – Labeling in packaging applications: electronically geared master-slave motion coordination plus registration sensor based position control.

A labelling machine generally includes a label supply roll which has the web of pre-printed labels and a conveyor system which moves-in and moves-out product (container boxes or bottles). In addition, it has a label application motion mechanism station where label and box/bottle are brought together and label is applied to the box/bottle. It is the control of this station that is critical for the successful application of the label. The label and box/bottle must be positioned together at the right position and translational speeds must be matched so that while both are moving, relative motion between them is zero (as if we apply the label while both box and label are in stationary condition). The basic principle of coordinated motion control is “electronic gearing” between the two axis of motion; box/bottle axis and label axis, plus a position adjustment based on a registration sensor in each label application cycle to make sure they are in the right position relative to each other.

In larger scope of a complete labeling machine, there would be three conveyors for moving the product (i.e. bottles, boxes, Fig. 3);

1. infeed conveyor, 2. labeling machine conveyor, and 3. outfeed conveyor.

Infeed and outfeed conveyors may operate under the control of the same PLC/Motion Controller or another controller. In either case, **our controller is able to adjust to the infeed and outfeed rates** on demand.

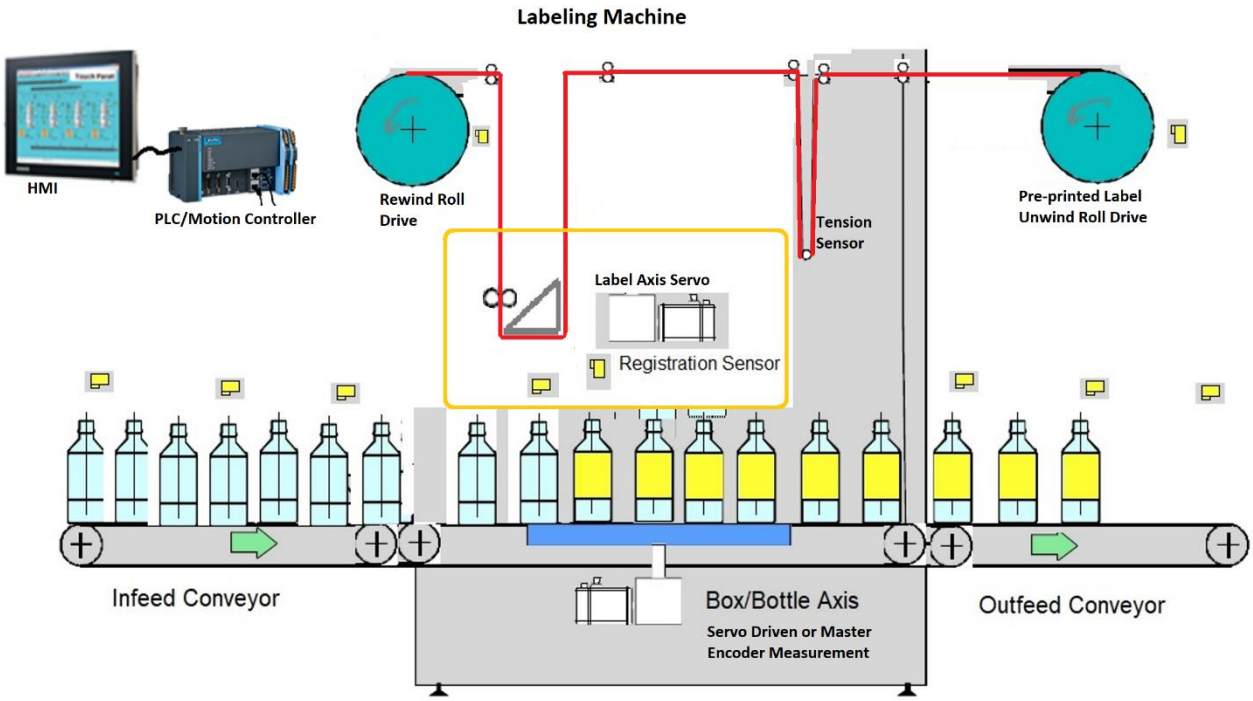

Fig. 3 - Bottle labeling machine control system.

As a good example, we have **three sensors on infeed conveyor** to indicate three different levels of low supply on infeed conveyor. Similarly, we have **three sensors on the outfeed conveyor** to indicate low level of products on the outfeed conveyor. Based on these sensors, i.e. when any one or a combination of they turn ON, we an increase or decrease the speed of the label application station and eventually even stop it.

The label handling system also may include **tension controlled unwind roll, and speed** controlled **rewind rolls. The control type can be reverse; speed controlled unwind roll and tension controlled rewind roll.** We have **two level (ON/OFF) sensors at the label supply** (unwind) roll to indicate label low or label supply zero (or very low) levels.

The label application station fits between the infeed and outfeed conveyor, plus the label rolls (unwind and rewind).

The key servo motion control of the machine involves two axis servo system minimally: the container/conveyor (box/bottle) feed axis and label feed axis. There is an HMI device and a motion controller. There is also a registration mark sensor on the label supply system to capture the position of the label. Product (box or bottle) position is controlled by the product feed axis which may take the shape of a carousel. In that case, the position of the container is known exactly from the closed loop position information of the container (carousel) motion control. If the product (boxes, bottles) are not fixed on the conveyor axis and may slip in position, then we would need to use the Product Detection Sensor.

There are also other inputs which are not critical for synchronized motion control, but they are part of the machine control logic. Components of the motion control system are

1. HMI (Human Machine Interface) Panel
2. PLC/Motion Controller
3. Two axis servo motor/drive: one for label and one for container box/bottle
4. Registration mark sensor to sense a registration mark on the label, capture the position of the label, compare it to where it should be, and make a corrective additional positional move.
5. Infeed conveyor motor/drive speed/position control system (either controlled by our controller or separate controller which communicates with our controller)
6. Outfeed conveyor motor/drive speed/position control system (either controlled by our controller or separate controller which communicates with our servo motion controller)
7. Label supply roll motor/drive (or brake/clutch) with tension control (either locally controlled or controlled by our servo motion controller).

Based on an set of ON/OFF sensors and operator commands, there is a simple logic to take appropriate action (PLC logic functions) as follows:

8. Three ON/OFF sensors (photoelectric) on infeed conveyor to indicate supply level. These sensors are used to slow-down (33%, 66%, STOP) the motion of the label application station, in coordination with sensors from outfeed conveyor.
9. Three ON/OFF sensors (photoelectric) on outfeed conveyor to indicate level. These sensors are used to speed-up (33%, 66%, 100%) the motion of the label application station, in coordination with sensors from infeed conveyor.
10. Two ON/OFF sensors on the label supply roll to indicate “label supply LOW” and “Label supply ZERO”. Based on the “Label Supply LOW” sensor, we give a warning message to operator to prepare for label roll change soon, i.e. in the next 15 minutes. Based on “Label Supply ZERO”, we stop the machine after a finite number of counts of label application cycle (number of available labels between the sensor location which senses the last label on the supply roll and where the label application occurs).
11. Label Jam Sensor: when ON, stop the machine
12. Infeed Conveyor Jam Sensor: when ON, stop the machine

13. Outfeed Conveyor Jam Sensor: when ON, stop the machine
14. Machine Guard Open Sensor: when ON, stop the machine

Operator HMI will have many input/output functions. Controller will perform the appropriate actions for each command button pressed at the operator HMI in three modes:

The HMI device provides three main windows:

1. Setup Mode
2. Manual Mode
3. Auto Mode

In Setup Mode, the operator/system integrator configures the parameters (data) of the application software. There are multiple (at least two) levels of access control with different password protection. In that menu, we enter the desired gear ratio, desired relative positions on registration sensor trigger, home motion types and its parameters (speed, offset, sensor source), jog (slow/fast, one axis at a time, multiple axis at a time, speed, direction) etc.

In the Manual Mode, the machine is moves in preparatory mode by individual commands by the operator. Motions include, in response to operator commands via HMI interface, we can move the machine axes:

1. Home motion
2. Jog : for each selected axis, fast/slow, direction
3. Index: incremental, selected axis, direction, selected index with predefined parameters (distance, speed, accel/decel rates etc)
4. Ability STOP motion at anytime; as a result of HMI command and application logic.
5. Execute a single cycle of Auto Mode at reduced speed, i.e. 10% of normal Auto Mode speed

In Auto Mode, upon the Start Auto Motion command, automatic motion cycles starts and continues until it stops based on software logic, sensory inputs or operator command.

1. Start Cycle
2. Stop Cycle
3. Pause Cycle
4. Resume Cycle

The motion control algorithm is an electronic gearing plus registration mark sensor based offset position adjustment. In principle, this is the same as printing with registration application. Container feed axis is master axis. Label feed axis is slave axis. Label feed axis position command is generated as a Slaved gear ratio to the actual position of the Container feed axis, plus for every label it makes an offset adjustment position (also referred as "incremental index") motion based on the registration sensor. Based on the mechanical dimensions of the machine, the desired gear ratio is calculated and entered as part of the machine setup in the application software. We also need to know in advance "when the registration mark sensor trigger signal is ON, where is the relative position of the two axes should be", then for each label we capture that relative position and make corrective offset position motion to make the relative positions equal to the desired value by the amount of the sensed error.

Task 1: Configure slave axis to follow the master axis at a defined gear ratio, once in setup

Define Gear Ratio: Slave Axis to the Master Axis

Configure capture position of slave or master axis on registration mark sensor ON: what position to capture when registration sensor is ON.

Define the desired relative position between master and slave when the Registration sensor is ON (desired = ideal)

Task 2:

A. Electronic Gearing Motion (execute once at the beginning of Auto Mode) : Enable the electronic gearing follower mode of operation of the slave axis closed loop motion

B. Registration Correction Motion (execute on every registration mark sensor ON in Auto Mode), as interrupt handler:

Read captured position

Calculate relative position

Calculate position error

Limit the maximum error correction per cycle (saturate)

Command additional position motion on top of electronic gearing of the slave axis

Control algorithm Inputs:

Control algorithm Outputs:

Control Algorithm Parameters:

Control Algorithm Logic:

CODESYS Application Software in PLC/Motion Controller using Function Blocks:

Demo Video:

References:

Cetinkunt, S., Mechatronics with Experiments, John Wiley and Sons, 2012, Second Edition, pp. 717-748.

Conveyor tracking by Yaskawa: https://www.youtube.com/watch?v=cWa8evbwSkI