DESIGN AND CONSTRUCTION OF A PSEUDO CONTINUOUS SINGLE STATION AUTOMATED CELL

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ABSTRACT

This paper presents the work implemented and experience gained in designing, constructing and operating a pseudo continuous automatic drilling machine in which the drilling head acts as a two degrees freedom manipulator. The manipulator carries out a complex planer movement to drill parts being transported by a continuously moving conveyor belt. The produced machine works as a single station automated cell that drills single model wooden parts. The cell is currently utilized in the Production Processes Lab of the Industrial Engineering Department at An-Najah National University. The experience gained in designing and constructing such a Mechatronics system was found to be successful in terms of obtaining a properly working automated cell, as well as enhancing the students' abilities to understand the concepts of design and construction of an automatic machine in particular and Mechatronics systems in general.

1. INTRODUCTION

Single station Manufacturing cells are used for either processing or assembly operations. They can be designed for single, batch, or mixed model production. In fact, there are two types of single station manufacturing cells; single station manned cell, and single station automated cell [1].

In general, automatic machines consists of five building blocks: Feeding, Functional, Checking, Transporting, and Discharge blocks. Generally speaking, there are two main approaches to combine building blocks when designing an automatic machine; one leads to periodically acting machine and the other leads to continuously acting machine [2]. In a periodically acting automatic machine the transporting device moves in an interruptive (movement and pause) manner, hence the feeding, functional, and discharge blocks can only act during the pause period of the transporting device. On the other hand, continuous process automatic machines are more effective since in which transportation and processing of parts are performed continuously and simultaneously.

An alternative and intermediate approach is to combine the two main approaches together. In other words to design an automatic machine in which transportation, feeding, inspection, and discharge are all continuous but processing is periodic, such a machine is known as pseudo continuous automatic machine [2].

This paper presents the work implemented and experience gained in designing, constructing and operating a pseudo continuous automatic drilling machine in which the drilling head acts as a two degrees of freedom manipulator. The manipulator drills parts being transported by a continuously moving conveyor belt. Part of the cycle time of the manipulator is inactive time during which the drilling head requires to return to its initial position to start a new cycle.

The produced machine is an integrated mechanical system controlled by micro switches, photo electric sensor, and PLC. Contactors and relays were used as actuators, and the drivers are DC and AC motors.

In this project, the work was carried out in three stages, the first was the design stage, in which all designs and calculations were completed based on single model product specifications. The second was the construction stage, in which all elements including mechanical, electrical, and electronics were fabricated and/or assembled in the local engineering workshop of An-Najah National University. The last was the operating stage, in which the cell was tested and calibrated.

Although the project was academic oriented project, however the experience gained in designing and constructing this Mechatronics system was found useful.

2. STAGES OF THE PROJECT

The work in this project was carried out in three stages; the first was the design stage, the second was the construction stage, and the last was the operating and testing stage. The following subsections present the details of these three stages.

2.1 The Design Stage

All designs and calculations of the different mechanical, electrical and electronic components were conducted based on single model product specifications. The product was specified to be wooden cylindrical parts having 25 mm diameter and 50 mm length with 6 mm diameter side blind hole centered along the length of the part, the depth of the hole is to be 20 mm.

2.1.1 Drilling Head Kinematic Analysis

Figure 1 below represents schematically the proposed pseudo continuous drilling operation in which the drilling head (No.4) acts as a two degrees of freedom manipulator. The manipulator drills work parts (No.3) being transported inside pockets (No.2) by a continuously moving conveyer belt (No.1). The conveyer moves with linear speed v mm/sec. The path of the drilling head for one cycle is described as (a-b-c-d-a). Actual processing (drilling) takes place between b and c.

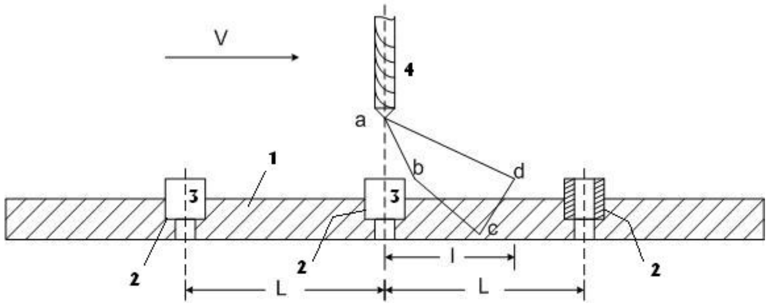

Fig. 1: Schematic Representation of Pseudo Continuous Drilling Operation

With reference to Figure 1 above, the following assumptions and considerations were first stated for design purposes:

1- The drilling head reaches the work part during (a-b), drilling it during (b-c), returns back to its surface during (c-d), and goes back home during (d-a). The drilling head moves along this path (a-b-c-d-a) with one single feed rate equals to (f_r), which equals to the vertical component of the drilling head velocity.
2- The cycle time (T) was taken to be T = 42 seconds, where T is the total time needed for the drilling head to move a loge the path (a-b-c-d-a).
3- The (active) time during the path (a-b-c-d) is denoted by (t) and was taken to be 2/3 of (T).
4- The initial height of the drilling head is 50 mm above the surface of the work piece.
5- The distance between every two successive pockets (parts) is 420 mm.

The velocity of the drilling head has two components one vertical and one horizontal. The horizontal component during the forward stroke (a-b-c-d) is denoted by $(v_x)_{a-d}$ while denoted by $(v_x)_{d-a}$ during the back stroke (d-a), $(v_x)_{a-d}$ and $(v_x)_{d-a}$ are not equal. Also, the vertical component during the forward stroke (a-b-c) equals to the feed rate (f_r) which also equals to $(v_y)_{c-a}$ during the back stroke (c-d-a).

Now with reference to Figure (1) the values of the velocity components can be determined as follows:

$$(v_x)_{a-d} = v = \text{Distance between pockets (L) / Cycle time } (T)$$

$$(v_x)_{a-d} = 420 \text{ mm} / 42 \text{ sec} = 10 \text{ mm/sec}$$

The active time (t) equals to 2/3 of the cycle time, so that

$$t = (2/3)*T = (2/3) * 42 = 28 \text{ sec}$$

The forward stroke (l) of the drilling head can be calculated as

$$l = (v_x)_{a\text{-}d} * (t)$$

$$l = (10\text{mm/sec}) * (28 \text{ sec}) = 280 \text{ mm}$$

Now, the feed rate (f_r), which also equals to $(v_y)_{c\text{-}a}$, can be found as

$$f_r = (v_y)_{c\text{-}a} = \text{Total vertical distance during the path (a-b-c-d-a) / Cycle time}$$

$$f_r = (50 + 20 + 20+50) \text{ mm} / 42 \text{ sec} = 3.33 \text{ mm/sec}$$

Similarly, $(v_x)_{d\text{-}a}$ can be found from

$$(v_x)_{d\text{-}a} = l / (T\text{-}t)$$

$$(v_x)_{d\text{-}a} = 280 \text{ mm} / (42\text{-}28 \text{ sec}) = 20 \text{ mm / sec}$$

2.1.2 Design of the conveyor system

The conveyor system consists mainly of conveyor 'belt', two slotted drums, supporting frame, and the pulley-belt system.

The conveyor 'belt' used in here consists of several plates made of stainless steel, each two successive plates are connected together by an interconnecting pin. Plate dimensions are 3X50X80 mm, the overall length of the conveyor 'belt' is 2100 mm.

Two slotted drums are used, the first is the driver drum used to drive the conveyer 'belt'. The driver drum is connected to the driving motor through a speed reduction pulley-belt system. The second drum is a supporting drum that supports the conveyor 'belt' at its other end.

A supporting frame is used to hold the conveyor 'belt', it mainly consists of the following components:

1- A couple of opposite U-beams.
2- A couple of holding Legs to hold the U-beams.
3- Four adjustable drum-holding plates used to hold the drums by 4 side bearings.

A speed-reduction pulley-belt system was properly designed to reduce the speed of the available AC motor (ω_m) and give the driver drum the necessary angular speed (ω_d) needed to drive the conveyor 'belt' with the specified linear velocity $v = (v_x)_{a\text{-}d}$.

It is known that the speed relation between two directly connected pulleys is given by [3]

$$\omega_1 * R_1 = \omega_2 * R_2 \qquad (1)$$

Where ω_1 and ω_2 are the speeds in (rad/sec), and R_1 and R_2 are the radii of pulley one and pulley two respectively. In our case the speed of the available AC motor is known and equals to 25 rpm. Therefore, the required speed of the driver drum (ω_d) can be calculated as

$$\omega_d = (v_x)_{a\text{-}d} / R_d$$

Where R_d is the drum radius. In our case the radius of the available drum is R_d = 74.5 mm including the thickness of the conveyor 'belt'. Hence, ω_d = 0.134 rad/sec which equals to 1.282 rpm.

Based on equation (1) a set of four pulleys having diameters: D_1 = 55 mm, D_2 = 202 mm, D_3 = 38 mm, and D_4 = 202 mm were designed to transform the input motor speed from 25 rpm to the required drum speed of 1.282 rpm. Pulley 1 is connected to the motor, pulley 4 is connected to the driver drum, and the remaining two are connected to an intermediate shaft as shown in Figure 2 below. The AC motor was purchased with the specifications of 0.25 hp and 25 rpm output speed.

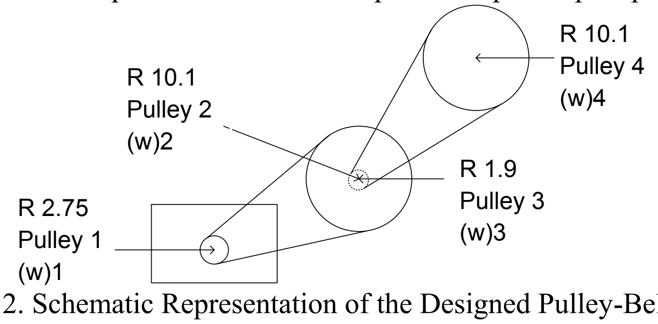

Figure 2. Schematic Representation of the Designed Pulley-Belt System.

Figure 3 below shows the designed conveyer system with its four major components; namely the conveyor 'belt', the drums, the supporting frame, and the pulley-belt system.

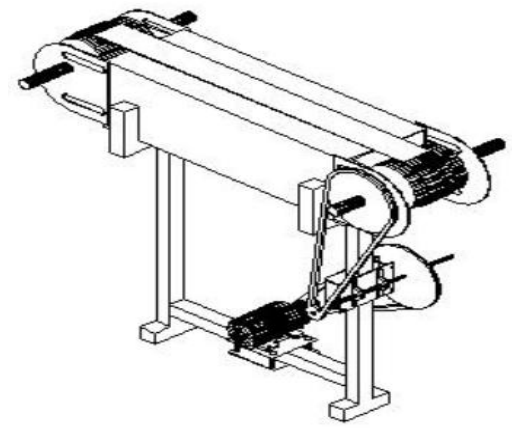

Figure 3. The Designed Conveyer System

2.1.3 Design of the Drilling Head Mechanism

The drilling head mechanism consists mainly of two power screws one vertical and one horizontal. The drilling head it self is directly fixed to the nut of the vertical screw, while the supporting frame of the vertical screw is directly fixed to the nut of the horizontal screw. Note also that the supporting frame of the horizontal screw is rigidly clamped to an adjustable holding column.

The complex motion of the drilling head is therefore obtained as a result of the motion of the two perpendicular power screws. There are two DC motors used to drive the two power screws; one for each. Of course power screws, as all we know, transform rotational motion into rectilinear translational motion.

The rotational speeds of the horizontal and vertical screws determine respectively the horizontal (v_x) and vertical (v_y) components of motion of the drilling head. The rotation of the horizontal screw is controlled in a way to give the two specified horizontal velocity components $(v_x)_{a\text{-}d}$ and $(v_x)_{d\text{-}a}$, and also the rotation of the vertical screw is controlled to give the specified value of (f_r) = $(v_y)_{c\text{-}a}$. The supporting frames of the two screws were fabricated using 12 mm thick Aluminum plates. Figure(4) below shows both the side and top views of the horizontal screw together with its supporting frame, the horizontal screw is connected with its DC motor using a sprocket-chain system in order to obtain the required torque at relatively small speeds. In fact, two DC motors, each of (12 V), were used to drive the drilling head mechanism. To reduce the cost, the motors attached to the vertical and horizontal screws were, respectively, second hand car-wiper motor and car-cooling-fan motor.

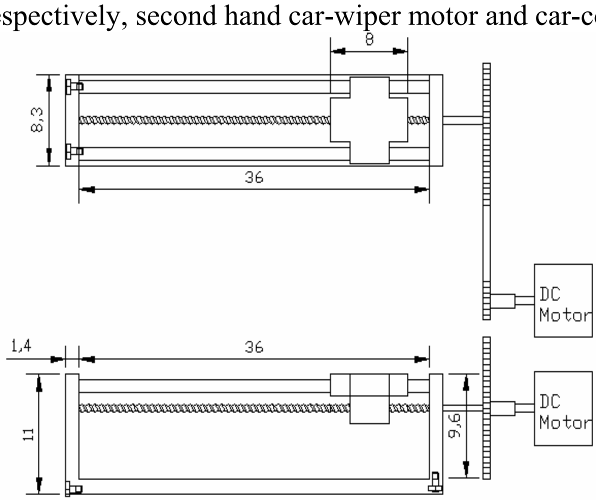

Figure 4. Side and Top Views of the Horizontal Screw Mechanism, Dimensions are in cm

The drilling head used for drilling the work parts is obtained by making use of a portable electrical drilling machine. The drilling head and its power electric circuit were the only parts taken from that drilling machine.

2.1.4 Kinematic Analysis of Power Screws

The lead of both vertical and horizontal screws is same and equals to 2.3 mm per revolution. The angular speed of the vertical motor needed to obtain the specified feed rate (f_r) = 3.2 mm/sec can be calculated as:

Speed of Vertical Motor during the entire path (a-b-c-d-a) = (3.33 mm/sec)/ (2.3 mm/rev) = 1.44 rev/sec = 86.86 rpm, but the motor during (a-b-c) rotates in opposite direction of that during (c-d-a).

For the horizontal screw, it was very difficult for us to find a DC motor that has the required torque at relatively low speeds, the only available motor was having a speed of 2400 rpm. Therefore, a speed-reduction sprocket-chain system (with two sprockets) was used to connect the horizontal screw with its motor. The diameter of the first sprocket connected to the screw = d_s = 130 mm and the diameter of the other sprocket connected to the motor = d_m = 35 mm. The used sprocket-chain system increases the motor's output torque by 3.7 times of its original value, in which 3.7 equals to d_s/ d_m.

Now, the angular speed of the horizontal screw needed to obtain $(v_x)_{a\text{-}d}$ = 10 mm/sec can be calculated as:

Speed of Horizontal screw during (a-b-c-d) = (10 mm/sec)/ (2.3 mm/rev) = 4.35 rev/sec = 261 rpm

Similarly, the angular speed of the horizontal screw needed to obtain $(v_x)_{d\text{-}a}$ = 20 mm/sec can be calculated as:

Speed of Horizontal screw during (d-a) = (20 mm/sec) / (2.3mm/rev) = 8.7 rev/sec = 522 rpm

Therefore, the speed of the horizontal motor during (a-b-c-d) = (261 rpm)(3.7) = 965.7 rpm, and during the back stroke (d-a) = (522 rpm)(3.7) = 1931.4 rpm.

2.1.5 Feeding Mechanism Design

A vertical box hopper with a sleeve was used as the feeding mechanism. The cylindrical wooden work parts moves down the hopper through the sleeve by their own weight. A cantilever spring controls the lower outlet of the sleeve. The feeder is directly fixed above the left end of the conveyer, the hook at each bucket hooks one work part from the sleeve as it passes its lower outlet. Note that the clearance (Δ) in the longitudinal direction between the part and the sleeve was calculated using the following equation [2]:

$$\Delta = \left(\sqrt{D_P^{\,2} + L_P^{\,2}} \Big/ \sqrt{1+\mu^2}\right) - L_P$$

Where D_P and L_P are respectively the diameter and length of the work part, and μ equals to the tangent of the seizure angle.

2.1.6 Control System Design

The DC Motors:

As mentioned before, two 12V DC motors were used to drive the drilling head mechanism, the vertical and horizontal motors were, respectively, second hand car-wiper motor and car-cooling-fan motor. Such motors are usually easy to be controlled since their speed is directly proportional to armature voltage and inversely proportional to the magnetic flux produced by the poles, adjusting the armature voltage and/or the field current will change the rotor speed, also it is easy to change its direction by commutating the direction of the current flow through inverting its polarity.

The PLC:

The used PLC is one type of DELTA DVP-SS (family) which is a micro PLC that offers two main processing units and several extension units. The main processing units have 14 points and the extension units offer 8-16 points. The maximum input or output points may be extended up to 128 points (total of 256 points). In our case the used PLC consists of 8 inputs and 6 outputs.

The Controlling Circuits:

Simple controlling circuits were built, they consist mainly of relays, contactors, potentiometers to change the voltages of the motors and hence change the speeds (DC V. Bridges), Fuses, and transformers.

The conveyer system was designed to be switched on or off using a single bar knob (Rotary Switch). Figure 5 below shows the controlling circuit of the horizontal motor in the drilling head mechanism.

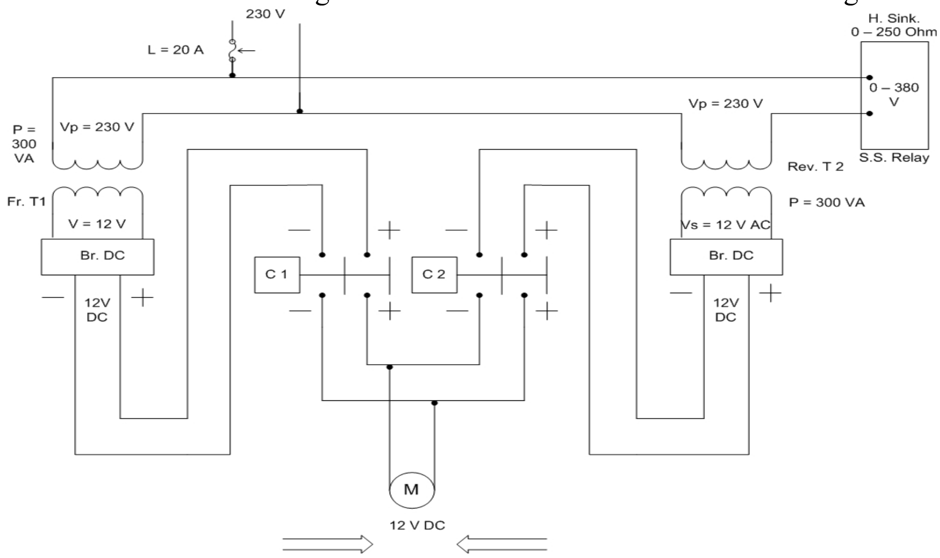

Figure 5. the Controlling Circuit of the Horizontal Motor

It is seen that there are two transformers and two potentiometers in order to get two different speeds for the motor, one for the forward stroke and the other for the back stroke, the speeds can be calibrated manually by hand. Note that the inputs come from the limit switches on the left and right ends of the horizontal screw.

Similarly, Figure 6 below shows the controlling circuit of the vertical motor in the drilling head mechanism

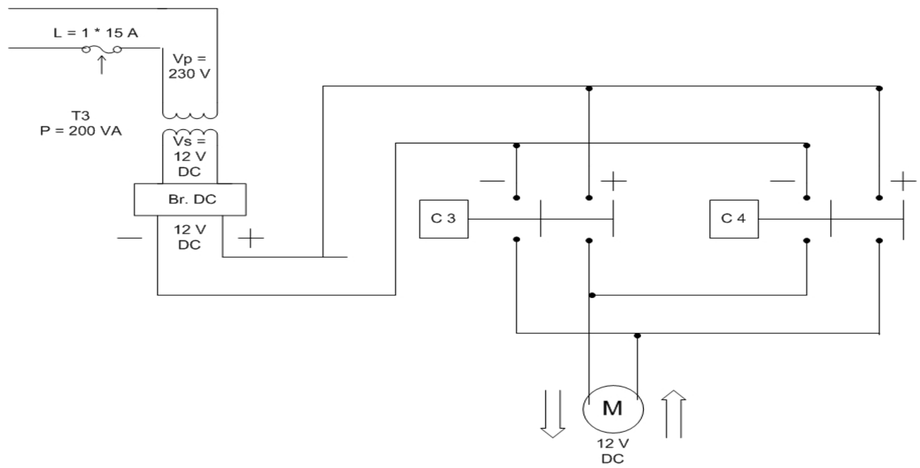

Figure 6. the Controlling Circuit of the Vertical Motor

The inputs of the PLC to command the contactors are the limit switches at the top and bottom ends of the vertical screw.

The AC motor which drives the conveyor system is not controlled by the PLC because it moves with a constant speed to give $v = (v_x)_{a\text{-}d} = 10$ mm/sec .

The motor of the drilling head itself is a small 12 V DC motor that receives its current directly through a 200 VA 12V DC transformer via a contactor. This small motor is not controlled by the PLC, it rotates only in one direction with a constant speed.

PLC Load Design:

Figure (7) below describes how is the PLC connected to the other hardware and clarifies what is meant by each input and output.

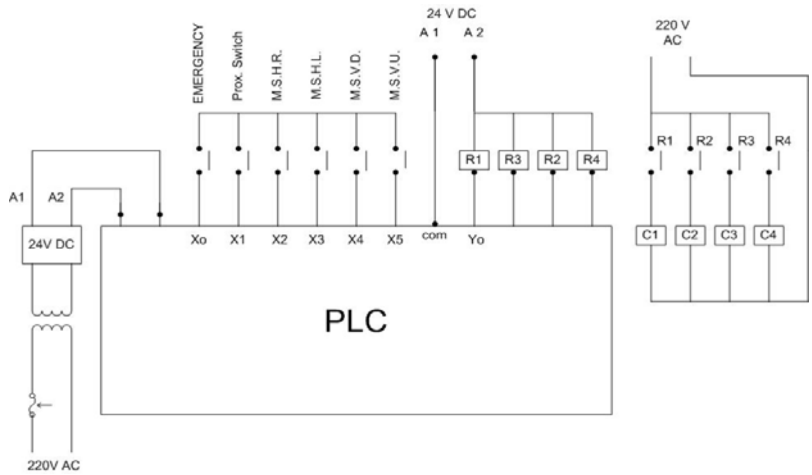

Figure 7. PLC Connection with Other Hardware

PLC Programming:

The PLC system program was written as follows:

00000	LD	X1	00017	OR	M3
00001	OR	M1	00018	AND	X0
00002	AND	X0	00019	ANI	X3
00003	ANI	X2	00020	ANI	M1
00004	ANI	M3	00021	OUT	M3
00005	OUT	M1	00022	LD	M3
00006	LD	M1	00023	OUT	Y2
00007	OUT	Y0	00024	LD	X4
00008	LD	X1	00025	OR	M4
00009	OR	M2	00026	AND	X0
00010	AND	X0	00027	ANI	X5
00011	ANI	X4	00028	OUT	M4
00012	ANI	M4	00029	LD	M4
00013	OUT	M2	00030	OUT	Y3
00014	LD	M2	00031	END	
00015	OUT	Y1			
00016	LD	X2			

Such that:

X0: Refers to the emergency switch
X1: Refers to the proximity switch
X2: Refers to the horizontal right limit switch
X3: Refers to the vertical down limit switch
X4: Refers to the horizontal left limit switch
X5: Refers to the vertical up limit switch
M1: Horizontal motor moves from right to left
M2: Vertical motor moves from up to down
M3: Horizontal motor moves from left to right
M4: Vertical motor moves from down to up

This program describes the following logic:

Once the system is started, the AC motor rotates with a constant speed, then when the proximity switch senses a part the PLC command the horizontal motor to move the drilling head in the forward stroke with a speed equal to that of the conveyor. At the same time, the vertical motor moves the drilling head from up to down with the feed rate (f_r).

When the drilling head touches the right limit switch of the horizontal screw, the motor changes its speed and direction and returns to its initial position and stops as it touch the left limit switch waiting another response from the proximity switch.

For the vertical motor, as the drill touches the bottom limit switch of the vertical screw the motor directly changes its direction to move the head back to its initial position with the same speed (f_r).

The Ladder Diagram:

Figure 8 below presents the ladder diagram of the used PLC

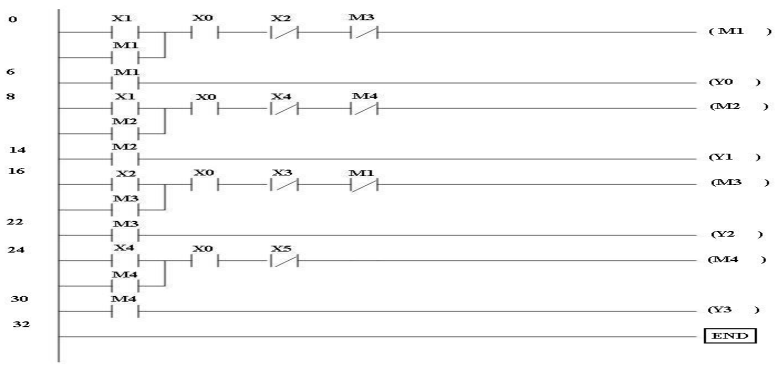

Figure 8. The Ladder Diagram

2.2 The Construction Stage

In this project most of the components used in constructing the machine were fabricated and assembled in the workshop of the Engineering Faculty at An-Najah National University. The main manufacturing processes used were: Cutting, Welding, Bending, Turning, Milling, Shaping, Drilling, Grinding, Threading, Internal Threading, Thermoforming, and Assembly. As an example, Figure 9 below presents the process flow diagram for constructing the drilling head mechanism.

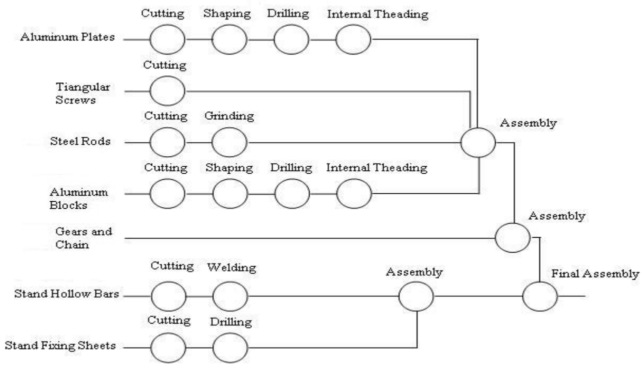

Figure 9. Process Flow Diagram of Constructing the Drilling Head Mechanism

2.3 Operating and Testing Stage

The system was operated and tested after being assembled. Different tests were conducted to each subsystem separately, then the entire system was tested to ensure that all its components work together uniformly and effectively. The basic parameters to be tested were the speed of the conveyer and the velocity components (horizontal and vertical) of the drilling head. Some miner deviations were detected between actual and theoretical speed values. This deviation was mainly because of the friction and human errors. This deviation problem was solved by using the appropriate lubricant and by further tuning of potentiometers.

The sequence of operations in this automated cell starts by switching on the AC motor of the conveyer, then the hook at each bucket hooks one work part from the outlet of the feeder, the feeder is rigidly fixed at the left end of the conveyer. Once the first full bucket passes the proximity switch the switch sends signals to both horizontal and vertical DC motors to rotate with the necessary angular speeds. Limit switches are used to give the necessary signals needed to inverse the direction of rotation and change the magnitudes of the angular speeds of the DC motors. A new cycle of the drilling head starts directly as the next full bucket passes the proximity switch. The finished parts are simply discharged by their own weight at the right end of the conveyer.

3. CONCLUSIONS

In this project a single station automated cell was designed and constructed, a worker is required to be at the machine periodically to load and unload parts or to change the drill as it wears out. In fact, while constructing the system we tried to make use of cheep second hand mechanical parts to reduce the total cost, this is because the project was academic oriented project. The direct cost of the entire system was about 1500$. The system is currently utilized in the Production Processes Lab of the IE department at An-Najah University. We found the experience gained in designing and constructing this Mechatronics system successful in terms of obtaining a properly working single station automated cell, as well as enhancing the students' abilities to understand the concepts of design and construction of an automatic machine in particular and Mechatronics systems in general.

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