Diyala Journal of Engineering Sciences

ISSN 1999-8716

Printed in Iraq

Vol. 05, No. 01, pp.88-102, June 2012

A STUDY FOR CONVERSION OF MECHANICAL CONTROL SYSTEM TO ELECTRICAL CONTROL SYSTEM

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(Received:7/2/2011 ; Accepted:30/6/2011)

ABSTRACT:- This paper study the conversion of the mechannical control system to electrical control system for the softdrink machine which use gears as timers in the process of counting the number of the bottles and in the process of controlling the level of the softdrink in the bottle. The electricl control system use electronical components such as integrate circuits (counters , timers , LCD display) , using the counter to count the number of the bottles with the use of the photosensor (in our paper counting every four bottles)and adjusting the level of the fluid by one of the following methods. The first method of controling the level of the liquid is by the timer which is fixed at time which is required to fill the bottle to the adequate level and it is adjustable according to the volume of the bottle. The Second method for conteroling the level of the liquid is the ultrasonic device which use the ultrasonic sensor to control the level of the fluid and it is adjustable according to the distance between the sensor and the bottle. The results of the electrical and mechanical models achived the satisfication results .

Keyword : US Tx – ultrasonic transmiter, US Rx – ultrasonic reciever, SONAR – sound navigation and ranging, Radar – radio detection and ranging, LCD –liquid crystal display, PLC – Programmable Logic Controller.

2. MECHANICAL ANALYSIS

2.1 Introduction

Gears are used to transmit torque and angular velocity in a wide variety of applications. There are also a wide variety of gears types to be selected (1).This paper will deal with the simplest type of gear, the spur gear using in filling machine. This machine is working under old mechanical system component from three mean parts AC motor, simple gear box, and Guide rotating shaft.

2.2 AC motor

The AC motor is usied to supply the rotating motion to the system, the motor has 1215 rpm. The electric specification of the motor are unimportant in this paper .

2.3 Gear box

2.3.1 Gears dimension

This section will discuss the kinematics of gear tooth theory, and gear trains of compound system. Spur gears, are used in model illustrated in Fig.1, have teeth parallel to the axis of rotation and are used to transmit motion from one shaft to another, parallel shaft[(2)] . The derivation of the equations that describe the gear geometry and turn ratio translations can be found in many textbooks [Norton 1999; Shigley's 2008; and others] in this paper the data used from Reference 2. The terminology of spur-gear teeth is illustrated in Fig. 1. The pitch circle is a theoretical circle upon which all calculations are usually based; its diameter is the pitch diameter. The pitch circles of a pair of mating gears are tangent to each other. A pinion is the smaller of two mating gears. The larger is often called the gear. The circular pitch p is the distance, measured on the pitch circle, from a point on one tooth to a corresponding point on an adjacent tooth. Thus the circular pitch is equal to the sum of the tooth thickness and the width of space. The module **m** is the ratio of the pitch diameter to the number of teeth. The customary unit of length used is the millimeter. The module is the index of tooth size in SI. The diametral pitch **P** is the ratio of the number of teeth **N** on the gear to the pitch diameter. The addendum **a** is the radial distance between the top land and the pitch circle. The dedendum **b** is the radial distance from the bottom land to the pitch circle. The whole depth **ht**

is the sum of the Addendum and the Dedendum. The clearance circle is a circle that is tangent to the addendum circle of the mating gear. The clearance c is the amount by which the Dedendum in a given gear exceeds the addendum of its mating gear. The backlash is the amount by which the width of a tooth space exceeds the thickness of the engaging tooth measured on the pitch circles. You should prove for yourself the validity of the following useful relations .The pressure angle $\emptyset$ is defined as the angle between the axis of transmission or line of action (common normal) and the direction of velocity at the pitch point. Pressure angles of gears sets are use in the old mechanical system is 20°[(2)].
The following useful relations are:

$$P = \frac{N}{d} \tag{1}$$

$$m = \frac{d}{N} \tag{2}$$

$$p = \frac{\pi d}{N} = \pi m \tag{3}$$

$$p\,P = \pi \tag{4}$$

Where
P = diameter pitch, teeth per inch
N = number of teeth
d = pitch diameter (inch or mm).
m = module, mm
d = pitch diameter (mm).
p = circular pitch.

The velocity ratio can by dreived from the fundamental law of gearing , the angular velocity m_v ratio between the gearset remains constant throughout the mesh **Eq.5**.[(1)]

$$m_v = \frac{\omega_{out}}{\omega_{in}} = \frac{d_{in}}{d_{out}} \tag{5}$$

Substituting **Eq.1** in to **Eq.5** with diametral pitch are same.

$$m_v = \frac{N_{in}}{N_{out}} \tag{6}$$

This can by generalized for any number of gears in the train as:

$$m_v = \frac{product\ of\ number\ of\ teeth\ on\ driver\ gears}{product\ of\ number\ of\ teeth\ on\ driven\ gears} \tag{7}$$

Table (1) content list of properties of gear box used in the compound gears system calcelated from **Eq .1, 2, 3, and 4**. With asuume the presser angle $\emptyset$ equal 20^o for all gears and number of teeth equal to 15 and 45 in pinion and gears respectively.

2.3.2 Gear box analysis

The gear box used in the filling machine consist of five stages to transmute the angular velocity from 1215 r.p.m. to 5 r.p.m. the simulation of mechanical system accomplish by using a three software packed program of FEM technical *GearTeq2010*, *SolidWork2010*, and *COSMOSMotion*. The simulation begin from *GearTeq* program for setting all dimansion of profiel of gears see Tabel 1. and create a profile of gears only (notsolid part), without compiond,and show simple of first Stage of transulation turn in gear box see fig.2. second step used *SolidWork assembly* program for a arrangement the gears and shaft for bulding a gearbox see fig.3 , the Third (final) step running a *COSMOSMotion* program in solidwork environment for simulatiom the the inlet and outlet rotational velocity , this software solve the overall model process, the analyzing a mechanism consists of three main steps: model generation, analysis (or simulation), and result visualization (or post-processing).

2.3.3 Guide rotating shaft

A rotating guide shaft fig.4, is one of the important parts in the mechanical system , Its adjust the time for counting and filling the product .The guide shaft has number of pins on its surface which can be adjusted at deferent angles which leads to the adjustment of time , because the velocity of the shaft is constant. For the old machanical model in this paper , the machine needs to count four element in 2 sec, the filling time is about 3 sec. for the given data :

- Guide shaft diameter = 50 mm
- Time of 4^{th} speciment inter TI = 2 sec.
- Time of filling TF = 3 sec.
- Total time of one cycle T.T= TI+TF
- Angular velocity of shaft = 5 rpm (constant)

We must Adjust the shaft as following :

By simple elgebra , The time of one cycle is 12 sec. also any 30^o on the shaft take one second and 15^o take 0.5 second , from this first pine can be adjusted at 0^o , and other pine fixed after a 60^o (which equals the time for counting four elements) , other pine fixed at 150^o (time for fiiling of element) see fig.5. Repeating this prosedure around the shaft take 8 elements per 210^o of shaft. for the different time can by rearrangement the pin at circumference of shaft.

3. ELECTRICAL ANALYSIS

3.1 Introduction

There are a large number of applications which depends on using the sensors, at the same time we have a large number of different sensors (limit switch , Inductive proximity , Capacitive proximity , Photoelectric proximity , Ultrasonic sensors). Choosing a sensor depends on many factors such as scan mode , operating voltage , ambient , and output configuration, exact positioning , speed of detection . Most of these sensors can be used with some or all scan techniques (thru-beam , reflective , and diffuse scaning) . In special cases we need to use specialized sensors such as Fiber optics which is ideal for small sensing areas or small objects , or Laser sensors in order to detect extermely small objects at a distance , or color sensors (which can differentiate between different colors to check labels and to sort packages by color mark) . Some sensors have a feature which is known as Teach In (This feature allows the user to teach the sensor what shoud it detect). There are a selection guides In order to determine the right sensor(3, 4).

3.2 Technical Preview :

Sensors are devices used to provide information on the presence or absence of an object There are different types of sensors which can be divided into:

*Contact Sonsors (there is a physical contact between the sensor and the parameter it measures) .

* Non-contact sensors(also its called proximity sensors(12), they indicates that the object is near , but contact is not required) . Also sensors can be divided into:

* Digital sensors (which have two states On/Off) , Digital sensors includes ((switches , Inductive, Capacitive , Ultasonic , optical (photoelectric) , encoders)) .

* Analog (which senses continuous variables such as temprature, pressure and provides a continuous linear voltage or current according to an input/ output transfer function) .

These sensors can be packaged in a various configurations to meet practically any requiremenet needed in industrial and commercial applications(5, 6).

4. EXPERIMENTAL VALIDATION

Hint: All the work is achieved and simulated with the use of program National Instruments Circuit Design Suite 10.0 (Multisim) (7) .

In one industrial application we have a soft drink machine which is controlled mechanically , the sequence of work is as below :

The operator of the machine turn the machine On by turnning the strat switch to On position , an AC motor which speed is controlled by a Frequency Inverter will start running , the worker will put the bottles on the conveyer , every fourth bottle the motor will stop mechanically , then a electromagnetic valve will begin to fill the softdrink into the four bottles at the same time , the time is controlled and adjusted by a mechanical timer (guid shaft) , after that the sequence will continue . It is requested to change the mechanical steps with electrical steps because it is easy and economical and have less disadvantages than the mechanical , the procedure of electrical controling (new model) as following: The worker put the bottles on the conveyer each bottle have a hole to put it on , a photosensor (thru - beam mode) will be set at the start point of the machine as shown in the diagram above Fig.6 , this sensor will change his state when the bottle cut the beam of the light . From schematic diagram Fig.7, Fig.8 we see that pulses coming from the photosensor will feed a decade counter U1 which is adjusted so that every fourth bottle (pulse) will have an output pulse ,

this pulse is feed to a timer U10 (monostable) as trigger pulse to the pin (2) of the LM555 so the timer geneate a pulse which is period (T) is adjusted by a potentiometer R1.The period is determined by the formula :

$$T=1.1(R*C) \quad (8)$$

So if R = 1MΩ the period will be $T = 1.1 (10^6\Omega * 1.10^{-6} F) = 1.1\ sec$

And if R = 3MΩ $T = 1.1 (3.10^6\Omega * 1.10^{-6} F) = 3.3\ sec$

So the relay K2 will be activated , the normal open contact of K2 will change now and will activate relay K1 and the electromagnetic valve , relay K1 with NC contact will now be activated and the AC supply will be cut from the frequency inverter and the motor will stop so the convyer will stop , so the juice will be infused in the four bottles at the same time , The timer is set to an adequate time enough to fill the bottles.

When there is no output from the timer , transistor Q1 is off and K2 is off and there is no supply to the K1 and electromagnetic valve , if K1 is off the frequency inverter supply will be feed and the motor will run and so on .

From the photosensor S1 we will feed a decade counter U2, 4, 5, 6 so the output of these counters is connected to a DCD- HEX-DEG display so we will count the number of the bottles is produced .

From Fig . 8 , the first waveform shown indicate the input of U1 (pin 10), U2 (pin 14) they represent a decade counter , this diagram is the pulses coming from the photosensor , the second waveform represent the output of the counter U1 (pin 4) which change his state every fourth bottle , this output pulse of U1(pin 4) will trigger the timer U10 (pin 2) and a square pulse will be generated, the third waveform represent the output of the timer which will control relay K2 , when the square pulse from U10 reach the relay K2 this relay will be activated and output voltage of his contact (29) will activate relay K1 which will cut the supply from the frequancy inverter and stop the conveyer , and at the same time electromagnetic valve will be activated , and the fluid will flow .

The second solution for determining the level of the fluid is to use ultrasonic device Fig.10 instead of timing , this device can determine the level of the fluid in the botlle as it is required and it could be adjustable for different types of bottles (different volumes) .The schematic diagram of the ultrasonic device consist of ultrasonic transmitter UTx and ultrasonic reciever

URx which operats on frequancies (40kHz) which is higher than the hearing frequancy for the human (20 Hz – 20kHz) [3,8,9,10] .The principle of the ultrasonic device is similar to the pinciple of the Radar (the transmitter generates pulses and transmitte these pulses through the air , the time between two transmitted pulses is the receiving period for the pulses reflected from an object , knowing the speed of the signal (light speed) we can determine the distance between the object and the radar) . In our case we have the speed of the sound (346.3 m/s for air temprature 25º C) which can be calculate from the equation :

$$C = \sqrt{\gamma * R * T} \quad (9)$$

Where

C: Speed of sound (m/s)

γ : Ratio of specific heats (γ = 1.4 for dry air)
R: Gas constant (R = 286,9 N.m/(kg.K))
T: Absolute temperature (Kelvin – where 0ºC = 273.16 K)

So the speed of the sound at room temperature (25º C , 71.6º F) will be **:**

$C = \sqrt{1.4\ (25 + 273.16)(286.9)} = 346.3$ m/s .

More values for sound speed for different values of temperature refer to Table .2 and Fig.9 Knowing the speed of sound and the time between the transmitted pulse and the received pulse we can calculate the distance between the ultrasonic device and the object. The SONAR generates sound signals and transmitte them through the air , when these signals hit the surface of the fluid a portion of the signal reflect back and received by the US Rx, amplified by operation amplifier , and used as enable signal for the decade counter , a NC relay will be activated and will stop the flowimg of the fluid , at the same time NO contact will operate the frequancy inverter and the convyer will work again.

From the schematic Fig. 10 [11, 12], for the ultrasonic device we can determine the frequancy of the oscillator U3D by using the equation :

$$f = \frac{1}{T} = \frac{1}{R*C} \tag{10}$$

For max value of R9 = 50 kΩ the frequancy is :

$$f1 = \frac{1}{R*c} = \frac{1}{(50+5.6)*10^3\Omega*10*10^{-9}F} = 0.00179\ \text{MHz}$$

For min value of R9 = 0 kΩ the frequancy is :

$$f2 = \frac{1}{R*c} = \frac{1}{(5.6)*10^3\Omega*33*10^{-9}F} = 0.0178\ \text{MHz}$$

The output of the decade counter pin(3) is a pulse which its frequancy is is divided by ten :

$f1 = 179.85\text{Hz}$

$f2 = 1780\text{Hz}$

So the duration of the pulse is :

$$\mathbf{T1} = \frac{1}{f1} = \frac{1}{179.85Hz} = 0.0055\ \text{sec}$$

$$\mathbf{T2} = \frac{1}{f2} = \frac{1}{1780Hz} = 5.617\ .10^{-4}\ \text{sec}$$

So the distance from device to the fluid :

$$T = \frac{2*R}{c} \quad \text{or} \quad D = \frac{c*R}{2} \tag{11}$$

Where
D : Distance from the device to the object.
C: sound speed = 346.3 m/sec
So

$$D1 = \frac{T1*c}{2} = \frac{0.0055*346.3\ m/sec}{2} = 0.962\ m$$

$$D2 = \frac{T1*c}{2} = \frac{5.617\ .10^{-4}*346.3\ m/sec}{2} = 0.0969\ m\ .$$

For more details about the distance see table 3 .

When the counter U1 counts four bottles (in our research) the supply to the ultrasonic device is fed , so the ultrasonic sensor will be on and it transmittes pulses, at the same time the supply to the electromagnetic valve is fed so the fluid will flow untill the adjusted distance is reached a relay K3 with NC contats(at the output of the ultrasonic device) will be activated so his NC contacts will change to NO and cut the supply from the electromagnetic valve , in other word when the distance between the device and the fluid is 0.0969 m the electromagnetic valve will stop filling the bottle , and at the same time will reset the counter ,so it will repeat the procedure again.

5. CONCLUSIONS AND RECOMMENDATION

5.1 ConclusionS

1 – The mechanincal control system which use gears has many disadvantages (power losses , high coast , regular maintenance , low resolution …etc so the electronical control system is the best solution which solve these problems .
2 - By using sensors we can have an adequate control components which are practical , economical , have high response time , and they are simple to maintain .
3 - All kinds of sensors have different types of scanning , different operating modes , different packages but they all indicates the absence and presence of the object .
4 – As comparsion between the electrical parts and mechanical system used in the research we have the following results:

Sensor type	Advantages	Disadvantages
Photosensor	*Sense all kinds of materials *long life *longest sensing range *Very fast response time	*Lens subject to contamination *Sensing range affected by color and reflectivity of target
Ultrasonic	*Sense all materials	*Resolution *Repeatability *Sensitive to temperature changes
Mechanical system	*heavy duty . *resistive to ambiant conditions .	*weight *noise *maintenece *high power *large size

5.2 Recommendations and future work

1 - As modification and for more resolution , simple control , and less components , less maintenance , we can replace classical components (counter , timer … etc) with the use of the PLC which will use sensors as input device and contactor , motor as output device

this device (PLC) use microprocessor , and the procedure of the control will be represented as software which can be written by PC , also can be modified by PC [13,14] .

2 – The ulrasonic device also can be modified and minimized , by the use of the MCU (MicroContrller Unit) which is more accurate , low price , high speed response (because of the use of crystal oscillator) .

6. REFERENCES

1. Robert L. Norton , 2006 ,"MACHINE DESIGN An Integrated Approach", 3ed Edition , Prentice Hall .
2. Shigley, 2006 , " Mechanical Engineering" Eighth Edition, MCGRAW-HILL Primis.
3. Ian R.Sinclair , 2001 " Sensors and Transducers" third edition , MCGRAW-HILL
4. .www.eandm.com (Siemens STEP 2000 Course – Basics Of Sensors) .
5. Industrial Sensors-1, 2006 (Industrial Control systems – MME 486 – Fall) .
6. Sensor Foresight , 2004 , technology and market (Technovation 24) .
7. National Instruments Circuit Design Suit 10.0 (Multisim) .
8. Donald P . Massa "Automatic Ultrasonic Bowling Scoring System." Sensor .Vol .4, No.10 .
9. Donald P . Massa "Choosing an Ultrasonic Sensor for Proximity or Distance Measurement Part 2:
10. Luis Puebla Palma , 2008, " Ultrasonic Distance Measurer " Freescale Semiconductor .Document No.AN3481, Rev.0.02 .
11. www.proximon.com .
12. .www.riccibitti.com / Good Old Sonar .
13. Nebojsa Matic " Introduction to PLC controllers (www.mikro.com/en/books/plcbook.htm) ".
14. Mohammad Aqil, 2007 " programmable Logic Controllers ITCE Introduction to PLCs chapter 1", Alazhar University – Faculty of Engineering&information Technology "

Table (1): Properties of gear box**.**

No.	Types	No. of teeth N	Circular Pitch diameter (d) mm	Circular pitch (p_c)mm	Presser angle (θ) degree	Module (m) mm	R.P.M	State
1	P_1	15	10.8	2	20	0.6	1215	input
2	G_1	45	32.4	2	20	0.6	405	Stage 1
3	P_2	15	10.8	2	20	0.6	405	Stage 2
4	G_2	45	32.4	2	20	0.6	135	Stage 2
5	P_3	15	10.8	2	20	0.6	135	Stage 3
6	G_3	45	32.4	2	20	0.6	45	Stage 3
7	P_4	15	10.8	2	20	0.6	45	Stage 4
8	G_4	45	32.4	2	20	0.6	15	Stage 4
9	P_5	15	10.8	2	20	0.6	15	Stage 5
10	G_5	45	32.4	2	20	0.6	5	output

Table(2): Temperature vs sound speed.

Temperature	Speed
-20º C	319.3 m/s
0º C	331.6 m/s
5º C	334.5 m/s
10º C	337.5 m/s
15º C	340.6 m/s
20º C	343.8 m/s
25º C	346.3 m/s
40º C	355.3 m/s
60º C	366.5 m/s
80º C	377.5 m/s

Table(3): Variation of distance with respect to frequency.

C	R	T	f	1/10f	T	D
1.00E-08	5.60E+03	0.000056	17857.14	1785.714	0.00056	0.096964
1.00E-08	1.00E+04	0.0001	10000	1000	0.001	0.17315
1.00E-08	1.50E+04	0.00015	6666.667	666.6667	0.0015	0.259725
1.00E-08	2.00E+04	0.0002	5000	500	0.002	0.3463
1.00E-08	2.50E+04	0.00025	4000	400	0.0025	0.432875
1.00E-08	3.00E+04	0.0003	3333.333	333.3333	0.003	0.51945
1.00E-08	3.50E+04	0.00035	2857.143	285.7143	0.0035	0.606025
1.00E-08	4.00E+04	0.0004	2500	250	0.004	0.6926
1.00E-08	4.50E+04	0.00045	2222.222	222.2222	0.0045	0.779175
1.00E-08	5.00E+04	0.0005	2000	200	0.005	0.86575
1.00E-08	5.50E+04	0.00055	1818.182	181.8182	0.0055	0.952325
1.00E-08	5.56E+04	0.000556	1798.561	179.8561	0.00556	0.962714

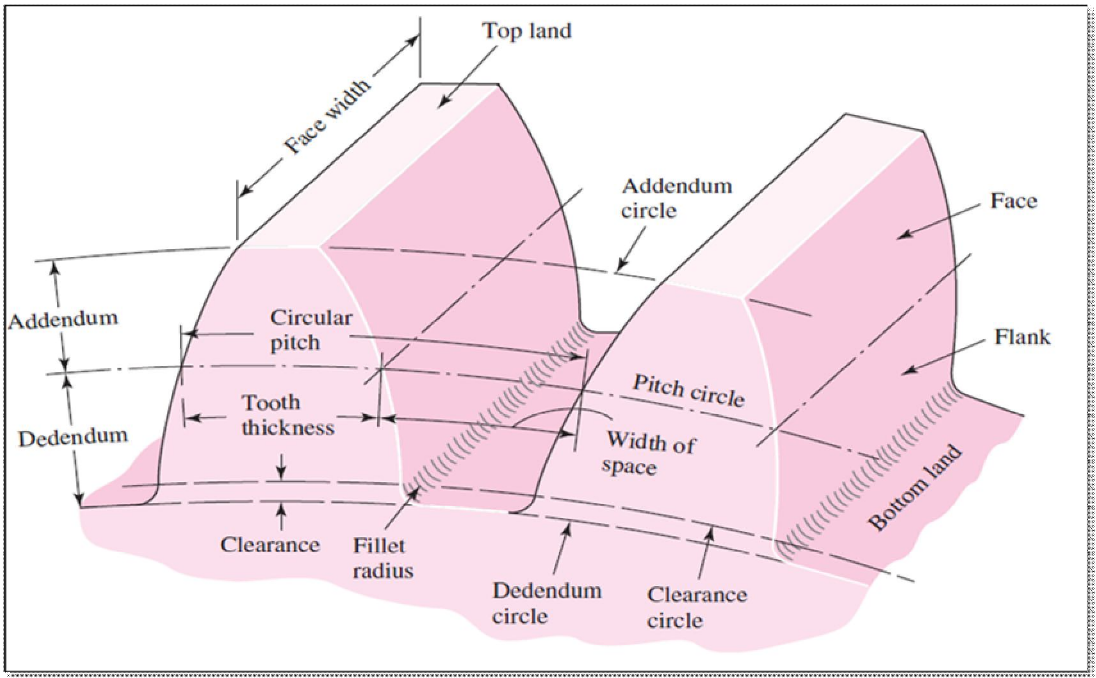

Fig.(1): profile of gears**.**

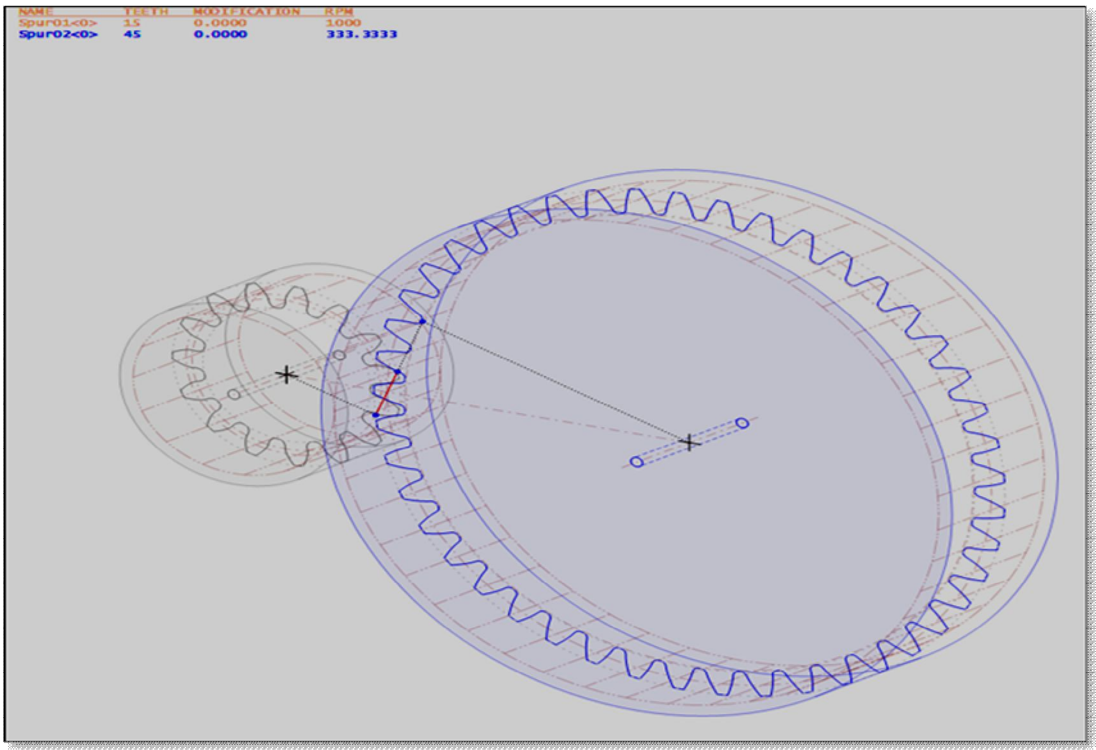

Fig.(2): Gear and Pinion model in GearTeq program(G_1 X P_1).

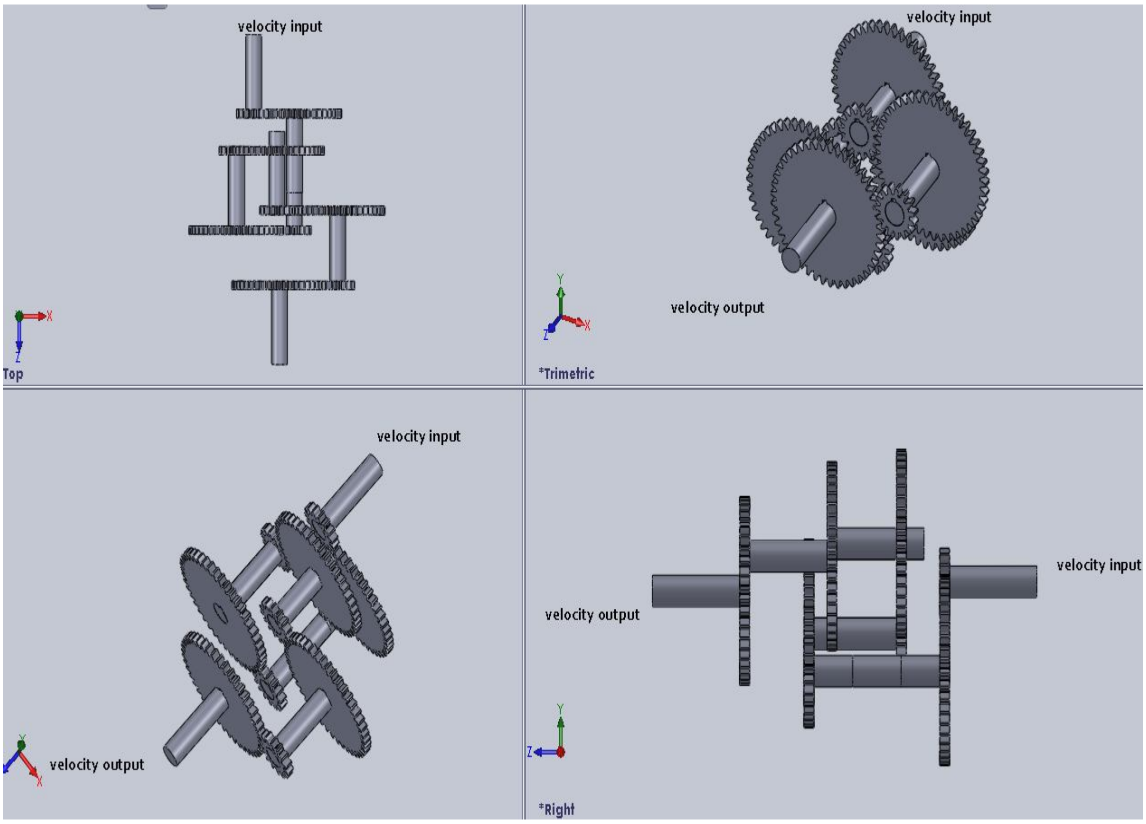

Fig.(3): mechanical control system**.**

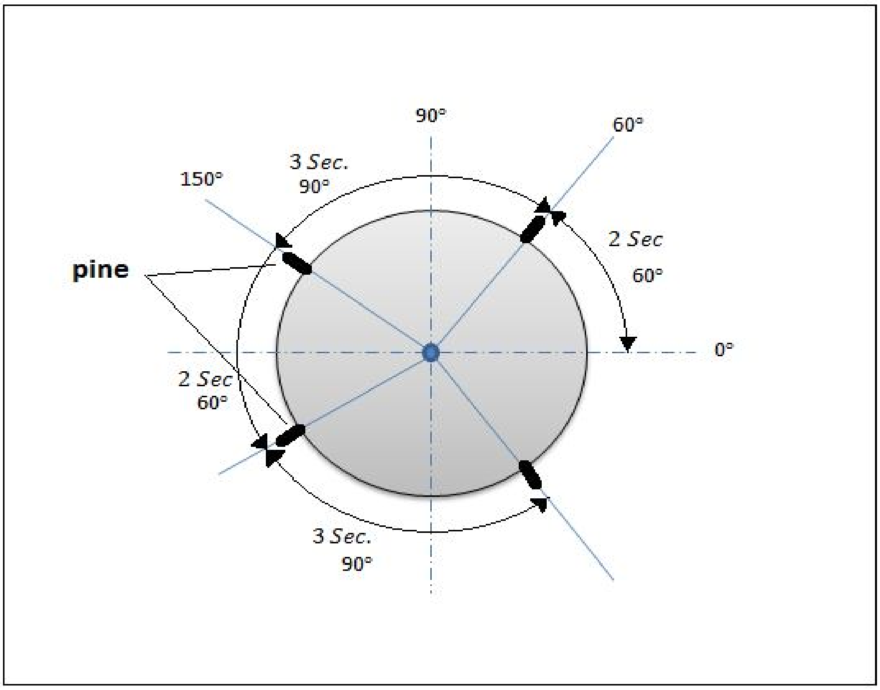

Fig.(4): C.S.A of guide rotating shaft.

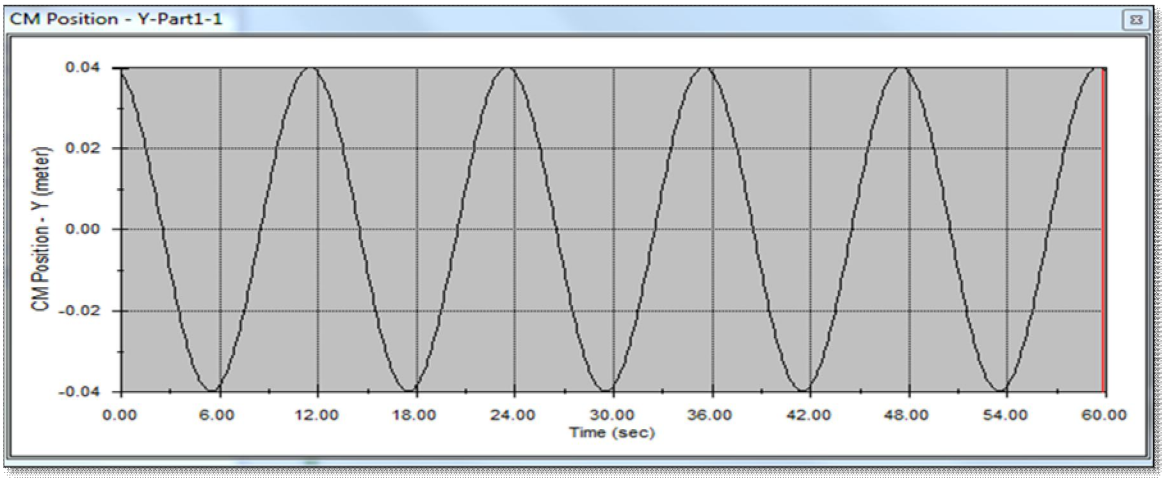

Fig.(5): waveform of the signals of mechanical control system.

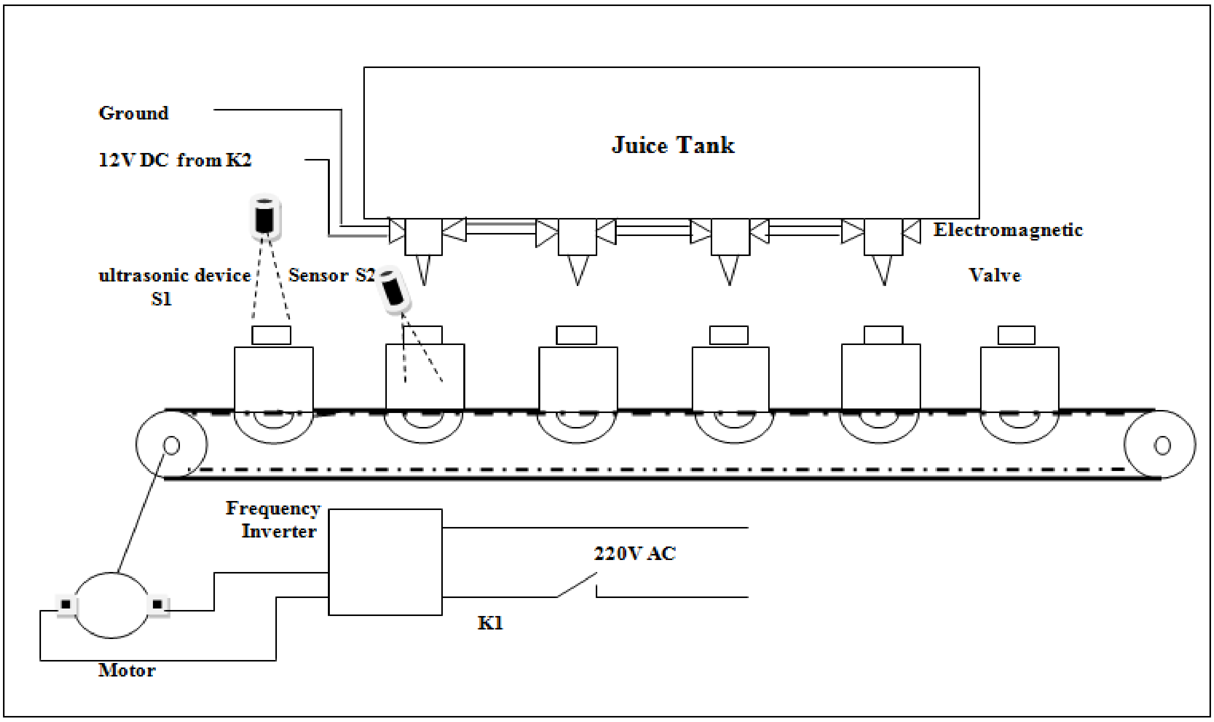

Fig.(6): block diagram for the machine.

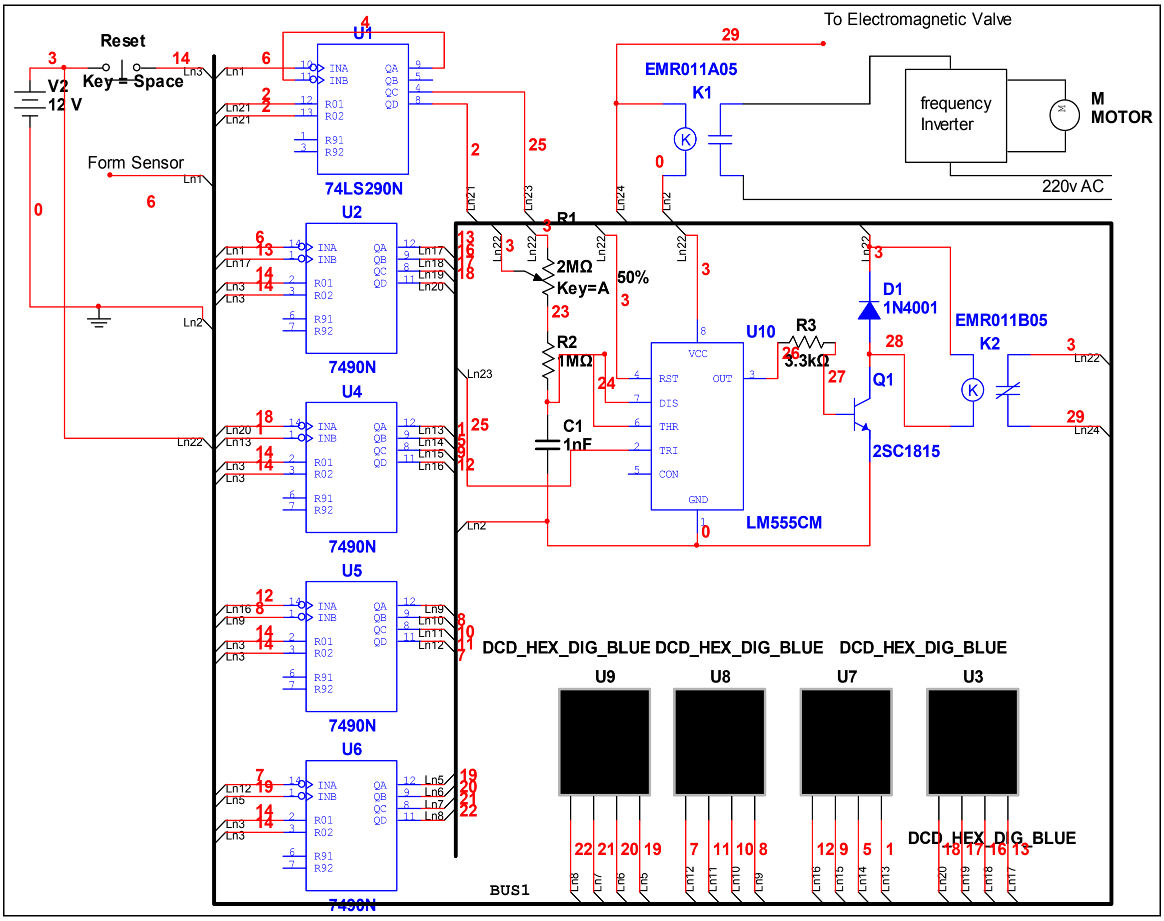

Fig.(7): schematic circuit for the electrical control system.

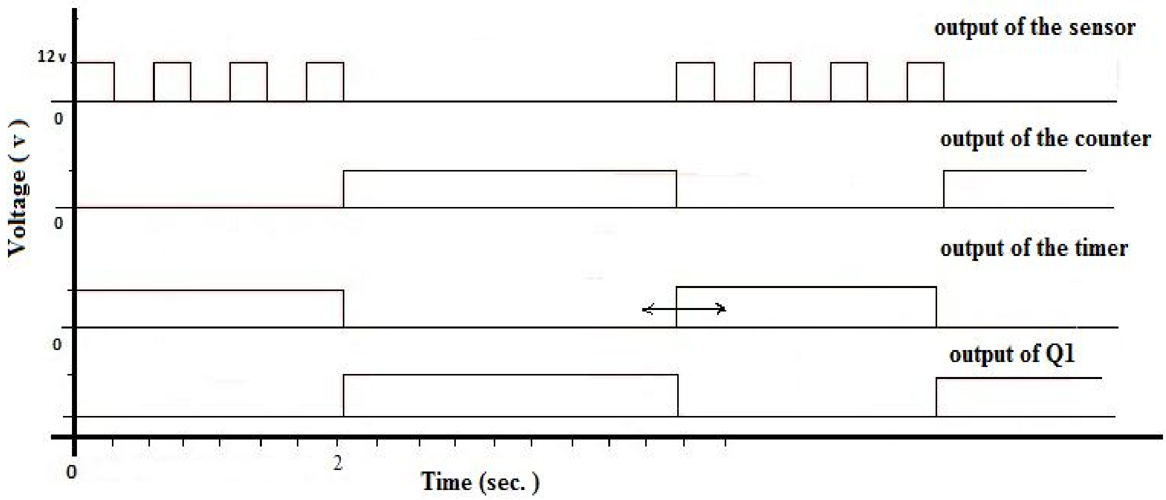

Fig.(8): waveform of the signals of electrical control system.

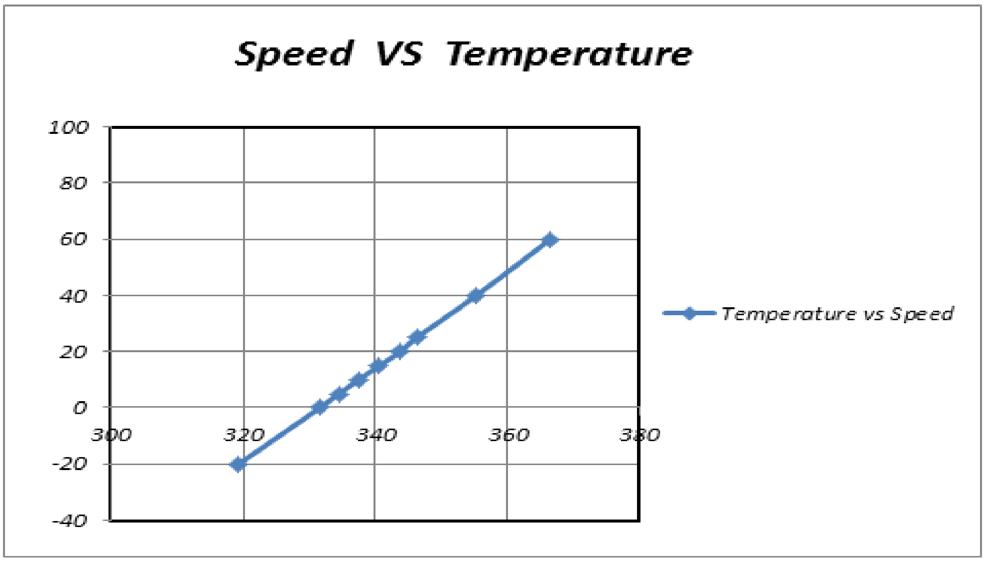

Figure 9 :(variation of speed with respect to temperature)

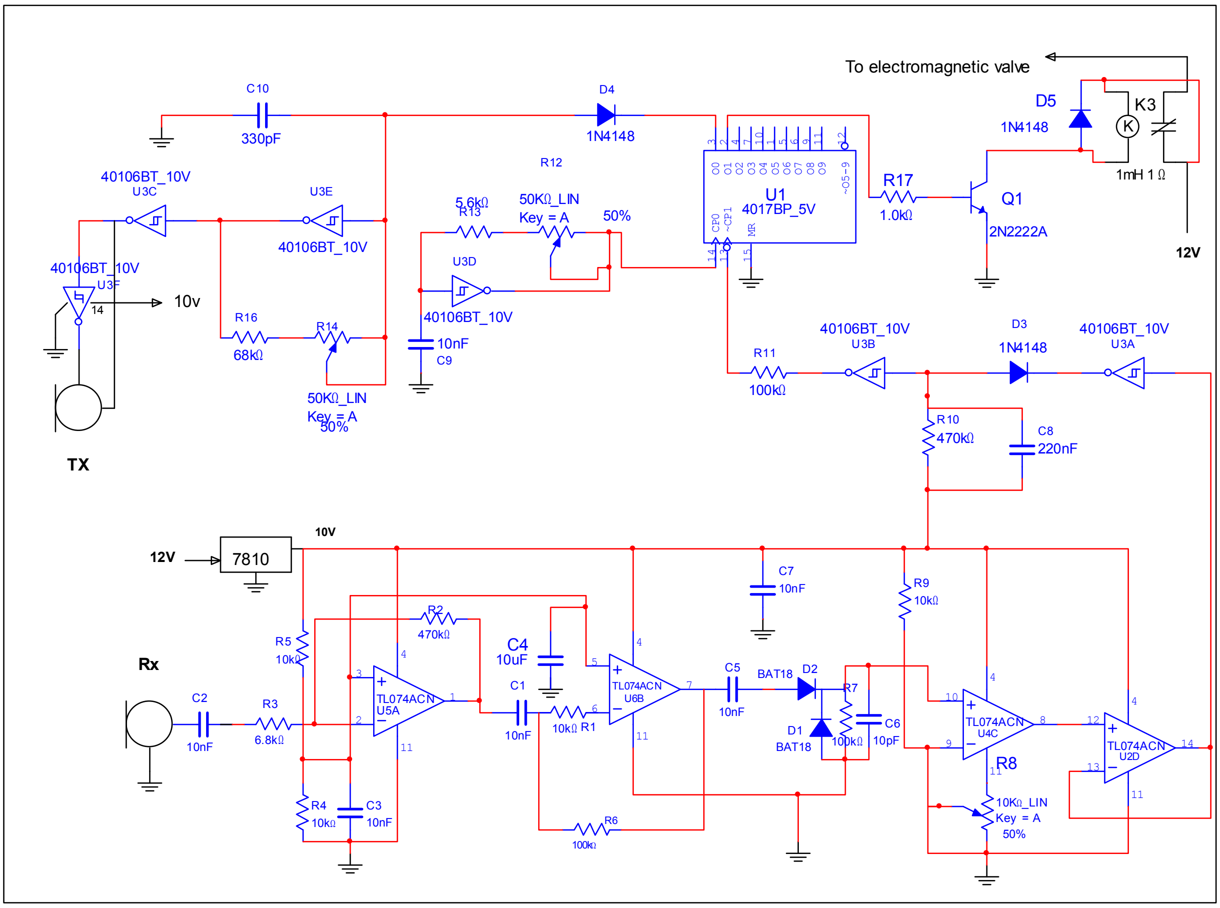

Fig.(10): ultrasonic control system.

دراسه تحويل منظومه السيطرة الميكانيكيه الى منظومه السيطرة الكهربائيه

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الخلاصة

في هذة الدراسه تمت مناقشه تحويل منظومه السيطرة الميكانيكيه الى منظومه السيطرة الالكترونيه الخاصه بماكنه المشروبات الغازيه والتي تستخدم المسننات كمؤقت في عمليه عد القناني و في عمليه السيطرة على مستوى السائل في القنينه منظومه السيطرة الالكترونيه تستخدم العناصرالالكترونيه مثل الدوائر المتكامله (العدادات ،المؤقتات ، وشاشات العرض البلوريه) ، تستخدم العدادات لعد عدد القناني و أعتمادا على الحساسات الضوئيه (نتناول هنا عد كل أربع قناني) ، أما السيطرة على مستوى السائل فتتم بأحدى الطريقتين .الطريقه الاولى يتم السيطرة على مستو ى السائل في القنينه بواسطه المؤقت والذي يكون فيه الزمن قابل للتغيير نسبه الى حجم القنينه .الطريقه الثانيه هي بأستخدام الحساسات فوق الصوتيه حيث يتم السيطرة على مستوى السائل أعتمادا على المسافه بين الحساس الفوق صوتي و مستوى السائل والتي يمكن تغييرها نسبه الى حجم القنينه ، وكانت النتائج مقبوله في كلا المنظومتين الميكانيكيه و الكهربائيه .