CONDITION MONITORING OF SEAL DEFECTS IN PNEUMATIC CYLINDERS

by

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September, 2006

İZMİR

CONDITION MONITORING OF SEAL DEFECTS IN PNEUMATIC CYLINDERS

A Thesis Submitted to the
Graduate School of Natural and Applied Sciences of Dokuz Eylül University
In Partial Fulfillment of the Requirements for the Degree of Master of Science
in Mechanical Engineering, Machine Theory and Dynamics Program

by
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M.Sc THESIS EXAMINATION RESULT FORM

We have read the thesis entitled **"CONDITION MONITORING of SEAL DEFECTS in PNEUMATIC CYLINDERS"** completed by **FEYZ M. NOORANİ** under supervision of **PROF. DR. HİRA KARAGÜLLE** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

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This thesis is dedicated to my parents and I thank them for their patience and sacrifice in making me what I am today.

Feyz M. NOORANİ

CONDITION MONITORING OF SEAL DEFECTS IN PNEUMATIC CYLINDERS

ABSTRACT

The aim of this study is to determine the possible seal defects before they occur in pneumatic cylinders and to eliminate the sudden system shut downs. An extra program is downloaded to the programmable logic controller (PLC) and the possible defects can be promptly realized. The possible defects are determined by vibration analysis and velocity calculation. Two proximity switches are mounted to the lowest and highest limit of the cylinder. Time of the stroke movement is measured and the velocity is calculated by the measured data. Also a 5 cm long aluminum beam with a piezo-electric sensor bonded on it, is installed to the cylinder body. By this sensor the vibration data are routed to the PLC as a low voltage signal. It is observed that the extent of the seal defect in pneumatic cylinders is proportional to the stroke time, vibration amplitude and vibration energy .

Keywords : Condition monitoring, pneumatic cylinder, seal defect, vibration measurement.

PNÖMATİK SİLİNDİRLERDEKİ SIZDIRMAZLIK ELEMANI ARIZALARININ İZLENMESİ

ÖZ

Bu çalışmanın amacı, pnömatik silindirlerdeki sızdırmazlık elemanlarında oluşabilecek muhtemel arızaları önceden tespit ederek, ani sistem durmalarını önlemektir. Programlanabilir lojik kontrolöre (PLC) ek bir program yazılarak, arıza oluşumları otomatik olarak algılanır. Arıza durumu, titreşim analizi ve hız ölçümü yöntemleriyle araştırılmıştır. Pnomatik silindirin alt ve üst son noktalarına birer adet yaklaşım sensörü monte edilerek, hareketin süresi ölçülmüş; ve dolayısıyla strok hızı hesaplanmıştır. Ayrıca pnomatik silindir gövdesine 5 cm ‘lik aluminyum bir çubuk monte edilmiş ve çubuk üzerine yapıştırılan piezo elektrik elemanla titreşim bilgileri düşük voltajlı bir sinyal şeklinde PLC ‘ye iletilmiştir. Yapılan çalışmada, hareket süresinin, titreşim genliklerinin ve enerjisinin, sızdırmazlık elemanındaki arıza derecesi ile orantılı olarak değiştiği görülmüştür.

Anahtar sözcükler :Arıza izlenmesi, pnömatik silindir, sızdırmazlık elemanı arızası, titreşim ölçümü.

CONTENTS

CHAPTER ONE
INTRODUCTION

1.1 Condition Monitoring in Mechanical Systems

Numerous components in a mechanical system involve periodic motion. Gears, rotating electric motors and generators, and AC-powered systems all exhibit some periodicity in operation. A defect in these systems can manifest itself as a periodic abnormality in the repetitive pattern of operation or as a short-time-duration "glitch" in an otherwise repetitive pattern.

Through modern technology it is relatively easy to measure the characteristics of periodic motion and, more importantly, to detect variations in repetitive patterns. Small, low-cost sensors allow efficient measurement of mechanical vibrations that occur in known directions. Numerous voltage dividers, current transducers, and high-gain antennas are available for measuring electrical voltages and currents as well as electric and magnetic fields, including electromagnetic waves. Fast digitization of electrical signals can be accomplished with digitizing oscilloscopes and with low-cost analog-to-digital converters installed in inexpensive, portable computers. In addition, extensive digital signal processing is now possible using available hardware and software.

Thus, detection of abnormalities and patterns of deterioration in periodic systems is relatively easy. Of particular significance to aging mechanical system is the fact that many subsystems are powered by electric motors, and electric motors can be utilized as transducers of the mechanical load being driven. A variation in load will often manifest itself as a variation in drive current. This effect is particularly strong in systems driven by small DC motors and becomes weaker with increasing rotor mass; however, with careful application of signal-analysis techniques, much information on the load can be extracted from analysis of the motor current.

The overall goal of “the condition monitoring in mechanical systems” is the development and implementation of practical monitoring systems that are capable of predicting the end-of-life of system components in sufficient time that repair or replacement can be accomplished before a mission becomes compromised. Such systems would allow extension of the time interval between replacement of some components and would decrease maintenance costs while increasing system reliability.

1.2 Condition Monitoring in Fluid Power Systems

Fluid power systems are widely used in industry, aerospace and agriculture and are becoming more complex in construction and in function. Reliability of the systems must be supported by an efficient maintenance scheme. Due to component wear or failure, some system parameters may change causing abnormal behaviour in each component or in the overall circuit. Research in this area has been substantial, and includes specialized condition monitoring studies on artificial fault simulations.

The failure of the components and the systems occur either suddenly or with slow progress. Both of these usually neverthless come unexpectedly and can induce major problems and costs. The time points of the sudden faults are practically impossible to predict, only some statistical estimates can be given, even if the condition of the components or system were continuously monitored. Instead, the slowly progressing faults are possible to detect by continuous monitoring of the quantities at issue. When the failure mechanisms of these slowly progressing multifunctions for separate components are modeled, the models can be used together with component or system models and the monitoring data to track the state of components or systems and to recognize faults beforehand. By this model-based diagnostic method it is possible to predict the proper time point when action should be taken to avoid major damages and to reach minimum maintenance costs.

1.3 Research Works on Condition Monitoring of Fluid Power Systems

Below is a partly list of research works carried out for the condition monitoring and fault diagnosis of fluid power systems.

- Oil Condition Monitoring in Hydraulic Machines: ”Institute for Fluid Power Drives and Controls - IFAS dealt with developing sensors that determine the condition of the oil” (2005).
- Condition Monitoring of Axial Piston Pump: “In this study, wear ‘and hence leakage’ between the pistons and cylinder bores in the barrel was of interest. Researchers at the University of Saskatchewan, as well as at other research institutions, have been involved in studies to detect wear in pumps using a variety of condition monitoring algorithms” (*Zeliang Li**,** 2005).*
- Condition Monitoring of a Water Hydraulic Actuator: “This project is concerned with the condition monitoring and fault diagnosis of fluid power systems. A water hydraulics and an oil hydraulics test rig have been commissioned and tested. The conditions are monitored via vibration signatures, linked to a data acquisition and control system using LabVIEW, a general purpose graphical programming language. An oil hydraulics experimental rig which comprises a power pack, valves, a cylinder, and a programmable logic controller which is used to control the operation of the hydraulic motor and cylinder is set. Work is in progress to incorporate the effect of loading to the motor and the incorporation of mechanical faults to the systems.” *(Chua, P.S.K. & Lim, G.H.,1999).*
- Condition Monitoring of Hydraulic Systems, Automated Modelling and Energy Saving Control of Programmable Valves: “Research is directed towards the design of on-board condition monitoring systems for electro-hydraulic systems. The methods under development are directed towards indicating impending failure of hydraulic systems. The model-based methods utilize standard sensory information present on common hydraulic equipment. The objective of these methods is the development of a condition monitoring algorithm to detect faults at an early stage, allow for just in time

maintenance and help in replacement of failed critical components." *(Dr. Bin Yao,2006).*

- Condition Monitoring of a Hydraulic Valve and Performance of Passive Vibration Control: "The main objectives of this research are to evaluate the effect of parameter inaccuracy on the results of virtual testing, to test the parameter sensivity of the main fluid power component model parameters, to apply knowledge on parameter uncertainty on condition monitoring of a hydraulic valve and performance of passive vibration control. Methods to be used are measurements and differential-algelbraic and statistical modeling." *(Prof. Matti Juhala,2003).*
- Using Wavelet Analysis for Condition Monitoring Purposes in Proportional Directional Control Valves: "The main objectives of this research are to find the failure mechanisms of the key components in fluid power, to define the mechanisms of the internal and external leakage, to develop a method to prevent external leakage, to create virtual sensors for the needs of condition monitoring, and to construct a model based condition monitoring method to key components of the fluid power system. Methods to be used are measurements and differential-algelbraic modeling." *(Prof. Matti Juhala,2005).*

1.4 Condition Monitoring of Seal Defect in Pneumatic Cylinder

Pneumatic cylinders often form a critical part of production processes. The reliable operation of the systems is extremely important as the economic consequences of a system failure seldom are limited to the cost of replacing the failed components. Compared to conventional scheduled maintenance, needs based maintenance is generally considered more cost effective in achieving reliable operation. The decisions on service operations or component replacements are based on condition monitoring and fault diagnosis, not on pre-determined intervals.

The method in this thesis is monitoring by continuous measurement of quantities such as vibration and velocity. In model-based maintenance, diagnostics is additionally supported by computer models based on physical principles and component test data. By comparing computer predictions with monitoring data it is possible to diagnose the system and detect incipient failures.

The goal of this project is to investigate failure mechanisms of seals in pneumatic cylinders, and to incorporate the knowledge obtained into computer models that can be used for predicting the behaviour of the systems under various operating conditions. The model-based diagnostic method can help avoiding major equipment damages and also facilitate production planning by predicting the time point when maintenance actions should be taken to reach minimum costs.

For this porpose, artificial faults are simulated to the seal of a pneumatic cylinder and system performance and data are collected working with different loads in an experimental rig. According to these, a study for the condition monitoring and fault diagnosis of seal defects in pneumatic cylinders is completed.

CHAPTER TWO
MODELING of VIBRATION SENSOR

2.1 Vibration Sensor

For the condition monitoring of seal defects in pneumatic cylinders, it is proposed to use a piezo electric sensor which will create a low voltage signal according to the vibration amplitute. Working with a 5 cm aluminum beam, with a piezo electric sensor bonded on it, the max., min., peak to peak vibration amplitute and vibration energy, occuring as a result of the impact of the loads hitting the ends of cylinder body can be measured.

The PZT sensor (BM532) of SENSORTECH is bonded onto an aluminum beam. The aluminum beam is designed to be 5 cm long. The beam is modeled with dimensions of 50mm lenght, 20 mm width and 1.5 mm thickness, embedded rigidly 10 mm from the piezo electric sensor and initial displacement is applied to 5 nodes on z axis. as shown in Figure 2.1. The solutions are obtained according to this model.

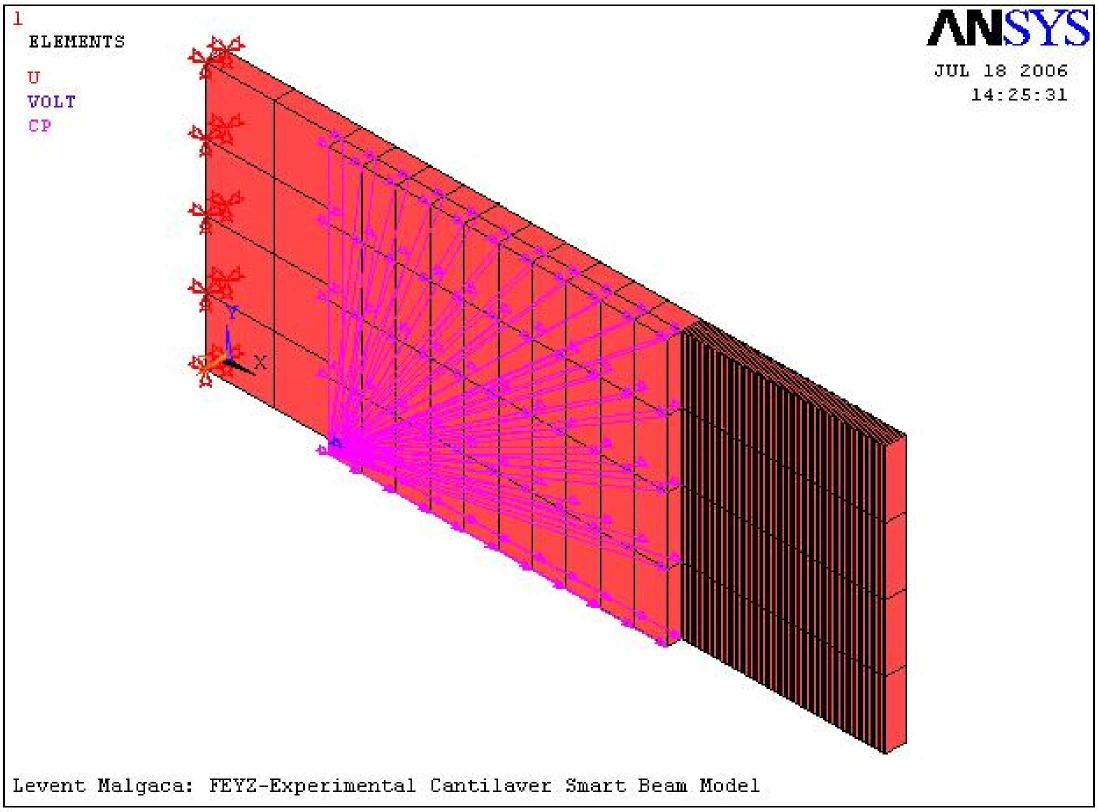

Figure 2.1 Ansys modeling of vibration sensor bonded on a 5 cm long aluminum beam

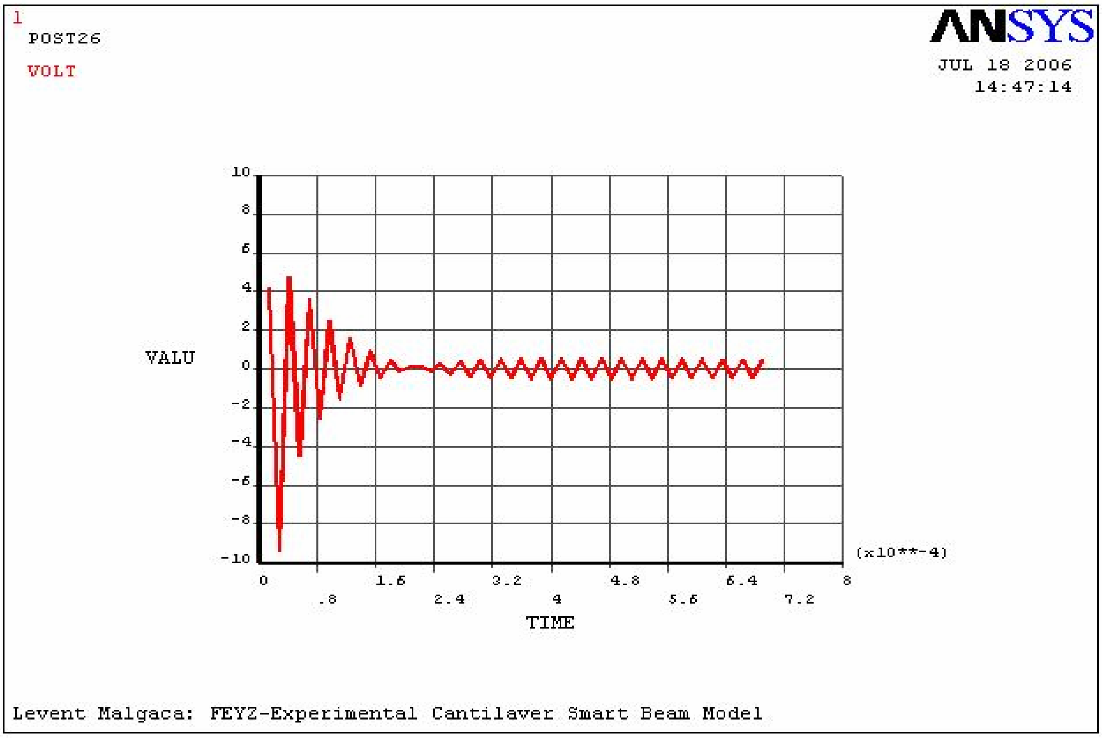

Figure 2.2. x(t) graph derived from ansys modeling of vibration sensor bonded on a 5 cm long aluminum beam

After the application of 1mm initial displacement to 5 nodes on z-axis, it is observed from the outcome of the modeling and the solution as shown in figure 2.2. The sensor response to this initial displacement is 4V. The x(t) curves derived from the 5 cm long beam and piezo electric sensor, are sufficiently selective to perform the experiments and compare the vibration behaviour under different levels of seal defects.

2.2 Modeling and Analysis Program of the Vibration Sensor

2.2.1 Modeling Program

The ANSYS modeling program of the vibration sensor is shown in Figures 2.3, 2.4 and 2.5. The dimensions and physical properties of the aluminum beam and piezo electric sensor can be changed in order to obtain a distinctive variation in vibration signals.

The modeling program is benefitted from H. Karagülle, L. Malgaca, H. F. Öktem, 13 (2004) 661-667. August-2004 .

```
/prep7
/title,Levent Malgaca: FEYZ-Experimental Cantilaver Smart Beam Model
!Parameters for Smart Structure
npzt= 1                                  ! Number of PZT : (0.No PZT, 1.SENSOR )
!------------------------------------------------
l1=50e-3                                 ! Length of Metal Beam
b1=20e-3                                 ! Width
h1=1.5e-3                                ! Height
l2p=25e-3                                ! Length of PZT
b2p=b1                                   ! Width of PZT
h2=1e-3                                  ! Height of PZT
l1s=10e-3                                ! Length of space to locate PZT
!------------------------------------------------
nebx=83                                  ! Number of elements in X direction for Metal
nepx=10                                  ! Number of elements in X direction for PZT
nepy=4                                   ! Number of elements in y direction for PZT
nebsx=2                                  ! Number of elements in X direction for Space
nebsy=0                                  ! Number of elements in y direction for Space
!------------------------------------------------
!Material Properties
!------------------------------------------------
et,1,solid45
et,2,solid5,3
mp,ex,1,68e9                             ! Elasticity modulus for metal
mp,dens,1,2770                           ! Density
mp,nuxy,1,0.32                           ! Posisson's ratio
mp,dens,3,7350                           ! Density for piez. material
mp,perx,3,15.03E-9                       ! Permittivity in x direction
mp,pery,3,15.03E-9                       ! Permittivity in y direction
mp,perz,3,13E-9                          ! Permittivity in z direction
tb,piez,3                                ! Define piez. table
tbdata,16,17                             ! E16 piezoelectric constant
tbdata,14,17                             ! E25
tbdata,3,-6.5                            ! E31
tbdata,6,-6.5                            ! E32
tbdata,9,23.3                            ! E33
tb,anel,3                                ! Define structural table
tbdata,1,126E9,79.5E9,84.1E9             ! C11,C12,C13
tbdata,7,126E9,84.1E9                    ! C22,C23
tbdata,12,117E9                          ! C33
tbdata,16,23.3E9                         ! C44
tbdata,19,23E9                           ! C55
tbdata,21,23E9                           ! C66
!TBLIS,ALL
!-----------------------------------
cory=0
corz=0
dist=0
*do,ind,1,n1ny
n,ind,corx,cory,corz
 *repeat,nnbsx,n1ny,dxs
*if,ind,ge,nnbsy,and,ind,lt,n1ny-nebsy,then
n1ex=nebx+nepx+nebsx                     ! Total elements number in X direc.
n1ey=nepy+2*nebsy                        ! Total elements number in y direc.
dxp=l2p/nepx
dyp=(b2p/nepy)
b1s=(b1-nepy*dyp)/2                      ! Width of space to locate PZT
dxs=l1s/nebsx
*if,nebsy,eq,0,then
 dys=0
*else
 dys=b1s/nebsy
*endif
l1b=l1-(l1s+l2p)
dxb=l1b/nebx
dyb=dyp
nnbsx=nebsx+1                            ! Number of nodes for space
nnbsy=nebsy+1
n1nx=n1ex+1                              ! Number of nodes in X direc. as total
```

Figure 2.3 The ANSYS Modeling Program of aluminum beam and piezo electric sensor (Part1)

```
n1ny=n1ey+1
nnpx=nepx+1                                          ! Number of nodes for PZT
nnpy=nepy+1
!---------------------------------
type,1                                               ! Modeling Metal structure
mat,1
corx=0

dist=dyp
*else
 dist=dys
*endif
 cory=cory+dist
*enddo
nodp1=nnbsx*n1ny+1                                   ! Node in lower surface for dx/dz increment
corx=l1s+dxp
cory=0
corz=0
dist=0
*do,ind,nodp1,nodp1+n1ey
n,ind,corx,cory,corz
*repeat,nepx,n1ny,dxp
*if,ind,ge,nodp1+nebsy,and,ind,lt,nodp1+nebsy+nepy,then
 dist=dyp
*else
 dist=dys
*endif
 cory=cory+dist
*enddo
nodb1=nodp1+nepx*n1ny
corx=l1s+l2p+dxb
cory=0
corz=0
dist=0
*do,ind,nodb1,nodb1+n1ey
n,ind,corx,cory,corz
*repeat,nebx,n1ny,dxb
*if,ind,ge,nodb1+nebsy,and,ind,lt,nodb1+nebsy+nepy,then
 dist=dyb
*else
 dist=dys
*endif
 cory=cory+dist
*enddo
nodl=n1nx*n1ny                                       !Number of nodes in lower-surface
corx=0
cory=0
corz=h1
dist=0
*do,ind,nodl+1,nodl+n1ny
 n,ind,corx,cory,corz
 *repeat,nnbsx,n1ny,dxs
*if,ind,ge,nodl+nnbsy,and,ind,lt,nodl+1+nebsy+nepy,then
dist=dyp
*else
dist=dys
*endif
cory=cory+dist
*enddo
nodp2=nodl+nodp1                                     ! Node in lower surface for dx/dz increment
corx=l1s+dxp
cory=0
corz=h1
dist=0
*do,ind,nodp2,nodp2+n1ey
n,ind,corx,cory,corz
*repeat,nepx,n1ny,dxp
*if,ind,ge,nodp2+nebsy,and,ind,lt,nodp2+nebsy+nepy,then
dist=dyp
*else
dist=dys
*endif
 cory=cory+dist
*enddo
nodb2=nodp2+nepx*n1ny
corx=l1s+l2p+dxb
cory=0
corz=h1
```

Figure 2.4 The ANSYS Modeling Program of aluminum beam and piezo electric sensor (Part2)

```
dist=0
*do,ind,nodb2,nodb2+n1ey
n,ind,corx,cory,corz
*repeat,nebx,n1ny,dxb
*if,ind,ge,nodb2+nebsy,and,ind,lt,nodb2+nebsy+nepy,then
 dist=dyb
*else
 dist=dys
*endif
cory=cory+dist
*enddo
nodu=2*nodl                                             !Number of nodes in Metal
en,1,1,n1ny+1,n1ny+2,2,nodl+1,nodl+n1ny+1,nodl+n1ny+2,nodl+2
egen,n1ey,1,1,n1ey
egen,n1ex,n1ny,1,n1ex
nsel,S,LOC,X,(0)
d,all,ux,0
d,all,uy,0
d,all,uz,0
nsel,all
/view,1,1,1,1
/ang,1
/rep,fast
eplot
/PBC,ALL, ,1
*if,npzt,eq,0,then
*go,:label1
*endif
!--------------------------------------------------------------------
*if,npzt,eq,1,then
type,2                                                  ! Modeling PZT #1 as a SENSOR
mat,3
corx=l1s
cory=nebsy*dys
corz=h1+h2
*do,ind,nodu+1,nodu+nnpy
 n,ind,corx,cory,corz
 *repeat,nnpx,nnpy,dxp
 cory=cory+dyp
*enddo
nbs=nodp2+nebsy-n1ny                                    ! Starting coupled node number in Metal
nps=nodu+1                                              ! Starting node number of PZT
npend=nodu+nnpx*nnpy                                    ! Ending node number of PZT
nes=n1ex*n1ey                                           ! Number of elements in Metal
e1=0
e2=0
e3=0
*do,ind,1,nepx
en,nes+1+e2,nbs+e1,nbs+n1ny+e1,nbs+n1ny+1+e1,nbs+1+e1,nps+e3,nps+nnpy+e3,nps+nnpy+1+e3,nps+1+e3
*repeat,nepy,1,1,1,1,1,1,1,1,1
e2=e2+nepy
e1=e1+n1ny
e3=e3+nnpy
*enddo
nxinc=nbs
*do,i,1,nnpx
nsel,s,node,,nxinc,nxinc+nepy
nxinc=nxinc+n1ny
cp,1,volt,all
*if,i,eq,1,then
*get,nsv0,node,0,num,min
*endif
*enddo
nsel,all
nsel,s,node,,nps,npend
cp,2,volt,all
*get,nsv,node,0,num,min
nsel,all
*endif
:label1
finish
```

Figure 2.5 The ANSYS Modeling Program of aluminum beam and piezo electric sensor (Part3)

2.2.2 Analysis Program

The ANSYS analysis program of the vibration sensor is shown in Figures 2.6 and 2.7. The initial displacement can be changed according to the practical values read from oscilloscope screen.

The analysis program is benefited from H. Karagülle, and others, 13 (2004) 661-667. August-2004 .

```
/input,feyzm,txt
/prep7
!Parameters for analysis
!-------------------------------------------------
ns=100
d0= 1e-3                                    ! Initial displacement (m)
f0= 1
alpha=2e-4                                  ! Rayleigh damping
ansel=2                                     !******* Select Analysis *******
                                            ! 1- Static analysis
                                            ! 2- Modal analysis
nf=nepy/2+1
nr=nodu-nepy/2
*if,ansel,eq,1,then
!-------------------------------------------------------------
/SOLU
antype,static                               ! Static analysis
d,nf,uz,d0                                  ! Apply force to PZT
!f,nf,fz,f0                                 ! Apply force to PZT
d,nsv0,volt,0                               ! Ground to bottom of PZT
solve
finish
/POST1
PLNSOL,U,Z,1,
*get,Vsensor,node,nsv,volt
finish
*elseif,ansel,eq,2,then
!-------------------------------------------------------------
alphad,alpha
betad,alpha
/solu
d,nsv0,volt,0
d,nsv,volt,0
ANTYPE,MODAL,NEW                            ! Modal Analysis
MODOPT,QRDAMP,5
MXPAND,5
solve
finish
/POST1
SET,LIST
finish
*elseif,ansel,eq,3,then
!-------------------------------------------------------------
/solu
d,nsv0,volt,0
d,nsv,volt,0
alphad,alpha
betad,alpha
ANTYPE,MODAL,NEW                            ! Transient Analysis
MODOPT,LANB,5
solve
*get,f1,mode,1,freq
finish
```

Figure 2.6 The ANSYS Analysis Program of aluminum beam and piezo electric sensor (Part1).

```
dt=1/f1/20
ts=ns*dt
u0=10e-6
/solu
ddele,nsv,volt
antype,trans,new
outres,all,all
kbc,0
tintp,,0.25,0.5,0.5
timint,on,ALL
trnopt,FULL
deltim,dt
d,nf,uz,u0
time,dt
solve
d,nf,uz,0
time,2*dt
solve
time,ts
solve
finish
/post26
nsol,2,nsv,volt
plvar,2
*endif
```

Figure 2.7 The ANSYS Analysis Program of aluminum beam and piezo electric sensor (Part2).

CHAPTER THREE
THE EXPERIMENTAL RIG

After modeling the vibration sensor, an experimental rig is set. In the experimental rig, a PC, PLC, cable connection card and two proximity switches are added and proximity switches are mounted to the lowest and highest points of the total stroke length for the measurement of time during the movement of the load, leaving the first point and facing the other one for a total of 20 strokes.

The experimental rig consists of the following parts as shown in figure 3.1.

- Rigid body
- Flange mounting
- Pneumatic cylinder
- Deteachable loads (1 kg, 3 kgs, 5 kgs)
- Piezo electric sensor
- Two proximity switches
- PC, PLC and Oscilloscope
- Cable connection card

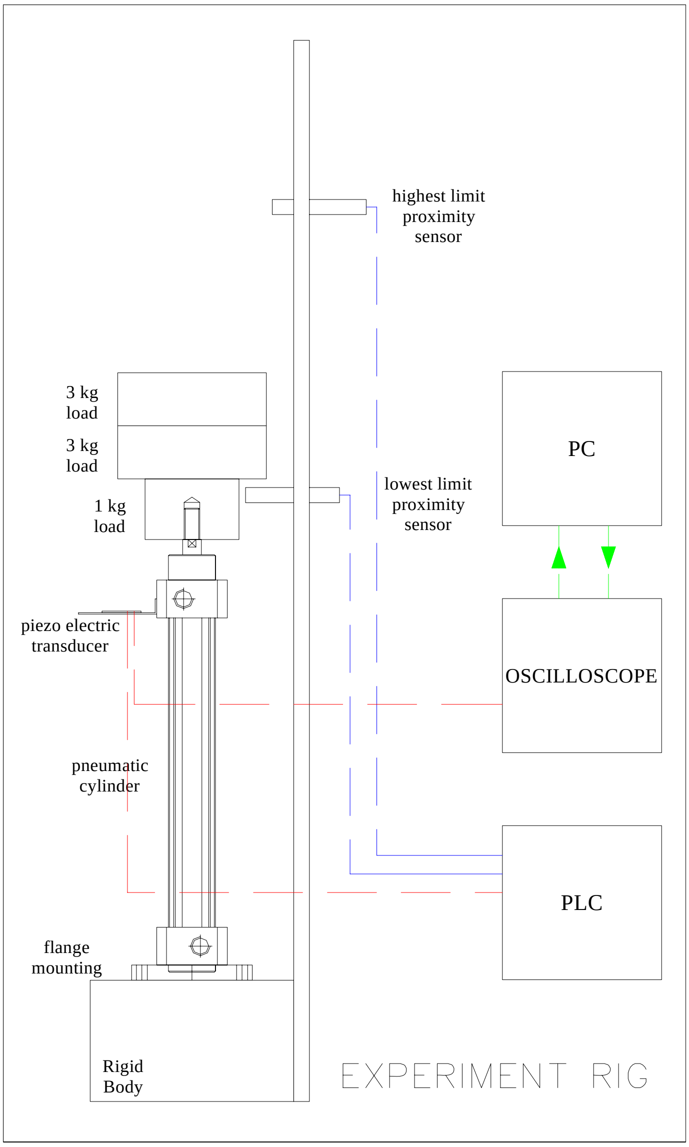

Figure 3.1 The experimental rig

The tests are performed with undamaged, level 1 damaged and level 2 damaged seals in the test rig and data from the system are collected under the loads of 1kg, 3kg and 5kg.

The data collected from the system are total movement time for 20 up and down strokes, vibration amplitute and vibration energy (rms).

3.1 Experimental Procedure

There are two proximity switches mounted to the lowest and highest points of the total stroke length and a 12V DC signal is routed to the PLC from the relay outputs of the proximity switches when the load is facing to these limit points. By the program downloaded to the PLC, the time during the movement of the load, leaving the first point and facing the other one is measured for a total of 20 strokes.

Working with a 5 cm beam, with a piezo electric sensor bonded on it, the max., min., peak to peak vibration amplitute and vibration energy, occuring as a result of the impact of the loads hitting the ends of cylinder body, are measured. Initially the low voltage signal from the piezo electric sensor is collected by the oscilloscope. Then the curves on the oscilloscope screen are transfered to PC with the help of a Visual BASIC program. The vibration curves transfered to PC are saved and max., min., peak to peak vibration amplitude and vibration energy data are compared for the seals with different levels of damages.

3.2 Cable Connections Between Experimental Rig Components

A cable connection card is utilized for putting every input/output signal and power cables of the test rig components, in order. For supplying a 12V DC main power voltage, a 10W 220V AC to 12V DC adaptor is used. All signal cables between the components and power cables are shown in figure 3.2. A LED lamp, which is energised by PLC when a vibration amplitute exceeding the threshold value received, is installed on the card. The lamp is set to be lit for 2 seconds when energised by PLC program in order to visually alarm the operator. The cable connection ports are named from 1 to 22 and these ports are listed in table 3.1

Table 3.1 Cable Connection Card Port Descriptions

Port Number	Description
1 & 2	12V DC main supply power from 10W adaptor
3 & 4	12V DC main power for the highest level proximity switch (HLPS)
5	12V DC signal created by HLPS during it faces the load
6 & 7	12V DC main power for the lowest level proximity switch (LLPS)
8	12V DC signal created by LLPS during it faces the load
9 & 10	0 –10V DC analog signal created by piezo electric transducer routed to PLC
11 & 12	12V DC main power for 5/2 directional valve energised by PLC relay output
13 & 14	12V DC main power for the PLC
15	12V DC digital input of PLC (signal received from HLPS)
16	12V DC digital input of PLC (signal received from LLPS)
17	0-10V DC analog input of PLC (signal received from piezo elec. transducer)
18 & 19	12V DC relay output of PLC energises 5/2 directional valve
20 & 21	12V DC relay output of PLC energises LED lamp on cable connection card
22	Not used

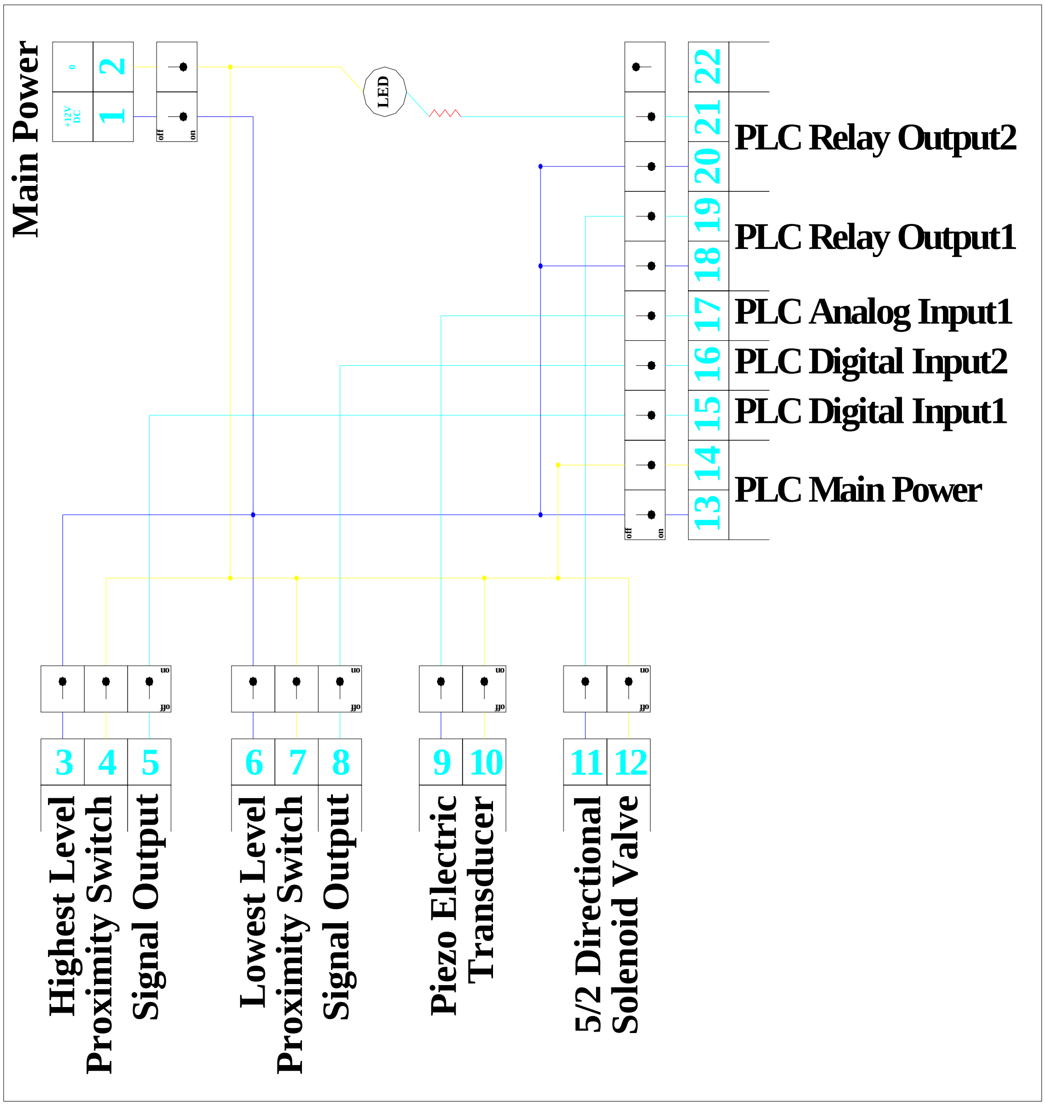

Figure 3.2 Cable Connection Card

3.3 Programmable Logic Controller - PLC

Control engineering has evolved over time. In the past humans were the main method for controlling a system. More recently electricity is used for control and early electrical control was based on relais. These relais allow the power to be switched on and off without a mechanical switch. It is common to use relais to make simple logical control decisions. The development of low cost computer has brought the most recent revolution, the Programmable Logic Controller (PLC). The advent of the PLC began in 1970s, and began the most common choice in manufacturing controls.

PLCs have been gaining popularity on the factory floor and will probably remain predominant for some time to come. Most of this is because of the advantages they offer.

- Cost effective for controlling complex systems
- Flexible and can be reapplied to control other systems quickly and easily.
- Computational abilities allow more sophisticated control.
- Troubleshouting aids make programming easier and reduce downtime.
- Reliable components make these likely to operate for years before failure.

3.3.1 Mounting and Wiring of the PLC

A mounting and wiring example and hardware configuration of Siemens brand PLC used in this thesis are shown in figures 3.3 and 3.4.

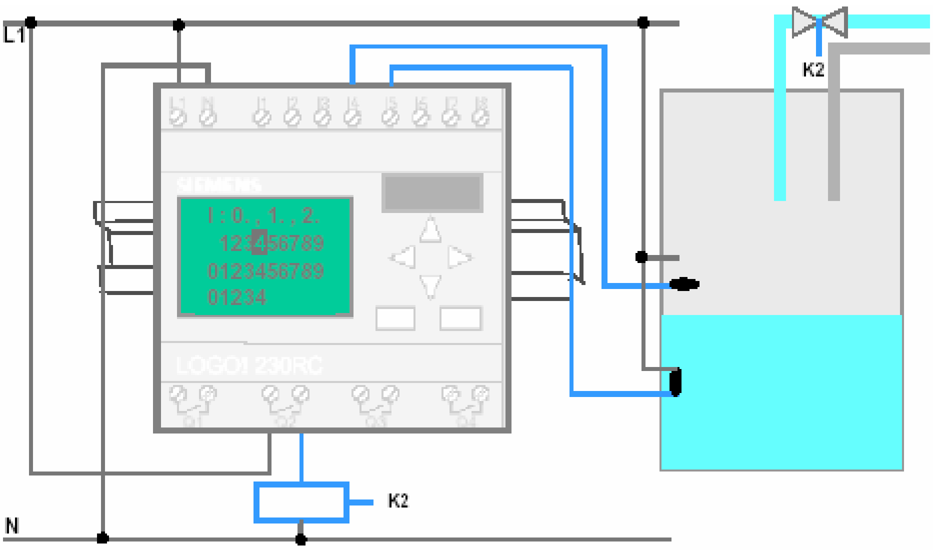

Figure 3.3 Mounting and wiring example

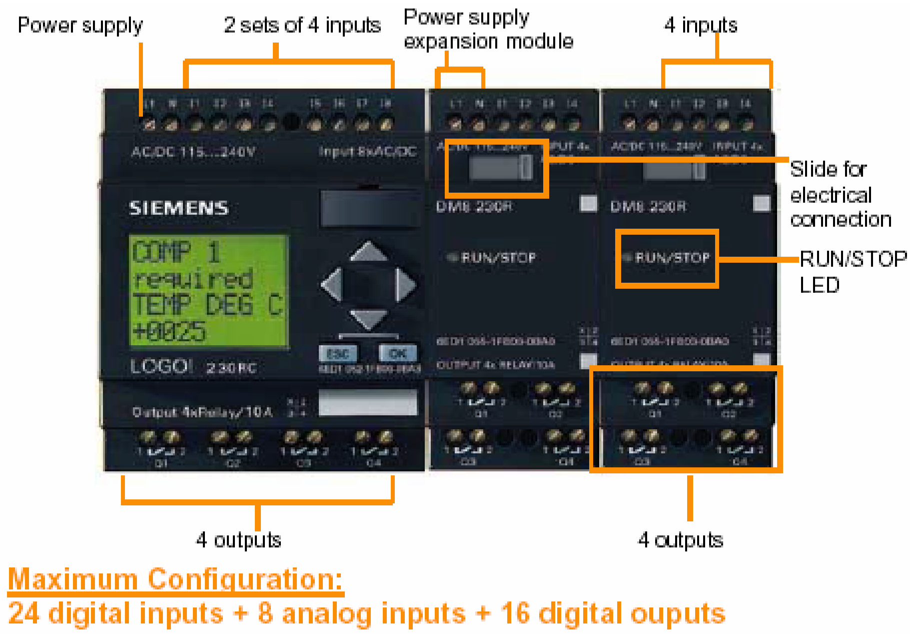

Figure 3.4 Hardware configuration of PLC

PLC can be connected to the power supply from the screw adaptors namely L1 and N indicating live and neutral.

Sensors are connected to the inputs namely I1, I2..., I8. Sensors include contact push buttons, contact switches, temperature, pressure, ultrasonic sensors etc.

Different loads can be connected to the outputs namely Q1, Q2, ...,Q4; such as lamps, motors, contactors etc. Maximum switch current is 10A for output relais. For higher currents, auxilary relais which can be energised by PLC outputs have to be used.

As means of improving productivity with fewer resources, PLC based control is increasingly becoming the choice of more manufacturers. The benefits of using PLCs are realized through the ease of use, the decrease in maintenance, service and down time on the factory floor. According to all those advantages, today PLC based automations take part in many processes. Also for the future PLCs will keep on being widely used instruments in many both simply and complex automatic control applications.

3.3.2 Automation Program of the Test Rig

In almost every industrial applications of pneumatic and hydraulic elements, the systems are automated with a controller such as PLCs or microprocessors and defect monitoring program can be downloaded to that controller. In this thesis, for the automation of the experimental rig a SIEMENS brand PLC with 12V DC supply voltage is utilized.

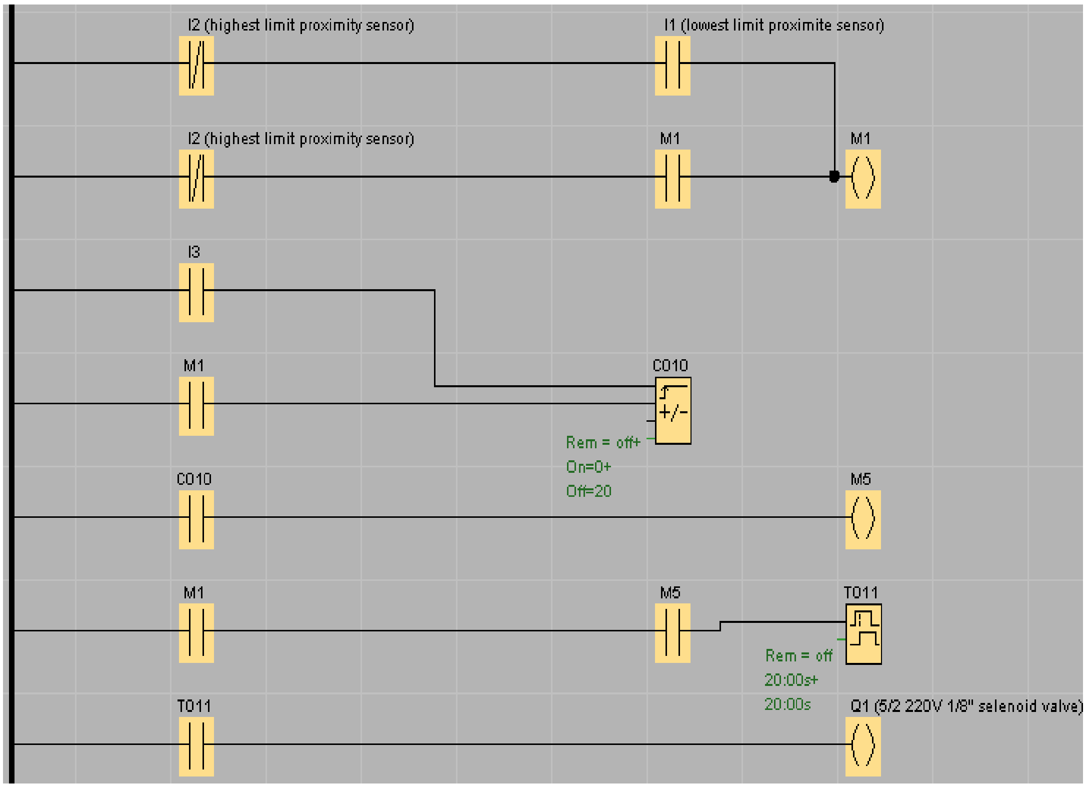

Figure 3.5 Automation program of the test rig downloaded to PLC in ladder format.

As shown in figure 3.5, the automation program of the test rig is downloaded in ladder format. Below is the list of outputs, inputs, auxilary relais and counters used in ladder of the program.

Q1	: Output of the PLC to energise 5/2 selenoid directional valve.
T011	: Delay timer used for letting the vibration be totally damped.
C010	: Counter used for counting a total of 20 up and down strokes.

I1 : Input received from lowest limit proximity sensor when faces the load.

I2 : Input received from highest limit proximity sensor when faces the load.

M1 & M5 : Auxilary relais

3.3.3 Total Movement Time Calculation Program

Two digital inputs of the PLC are used for total movement time calculation of total 20 up and down strokes. With 12V DC signals received during the load facing proximity switches, a timer is used to measure the time of movement between two limit points. The total time of a total of 20 up and down strokes is noted from that timer. When the load reaches the highest or lowest limits, another delay timer is used for waiting the vibration to be damped totally and this delay timer set not to energise the total movement timer.

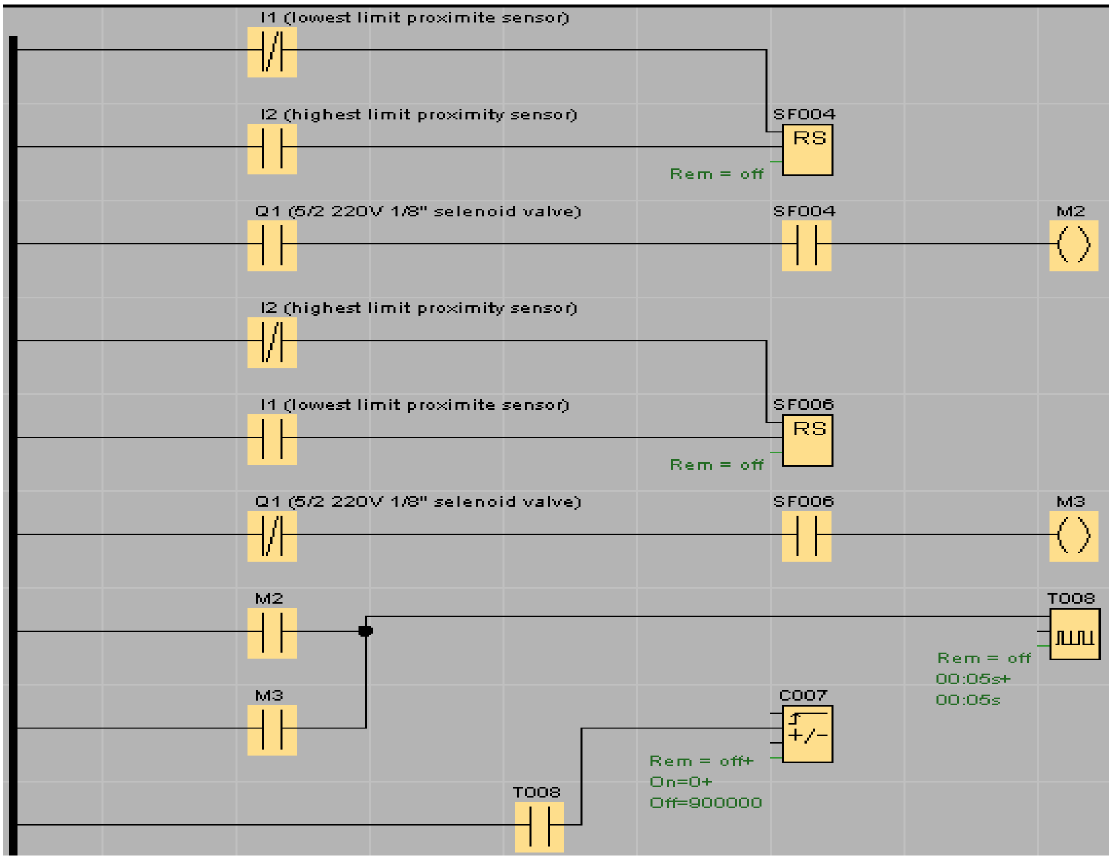

Figure 3.6 Total movement time calculation program for 20 upwards and downwards stroke

As shown in figure 3.6, the total movement time calculation program downloaded in ladder format. Below is the list of outputs, inputs, auxilary relais and counters used in ladder of the program.

I1 : Input received from lowest limit proximity sensor when faces the load.
I2 : Input received from highest limit proximity sensor when faces the load.
SF004 & 006 : Relais energised when the load is moving down or up respectively.
M2 & M3 : Auxilary relais energised by SF004 & SF006
T008 : Timer creates a pulse signal, when M2 or M3 energised. This pulse is sent to C007 in every 0.1 second.
C007 : Counter energised by T008 timer to calculate time of a total of 20 up and down strokes.

3.3.4 Vibration Data Evaluation Program

An analog (0-15V) input created by the piezo electric sensor is used for collecting vibration data. The piezo electric sensor sends a low voltage signal ranging between 0 to 15V to the analog input of PLC. This low voltage signals occur because of the vibration resulting from the impact of the load hitting the end points of cylinder body. A threshold value of vibration amplitude is set to PLC program. The total number of vibration amplitudes exceeding this threshold, is counted for every seal defect level by using PLC counter during a total 20 strokes movement.

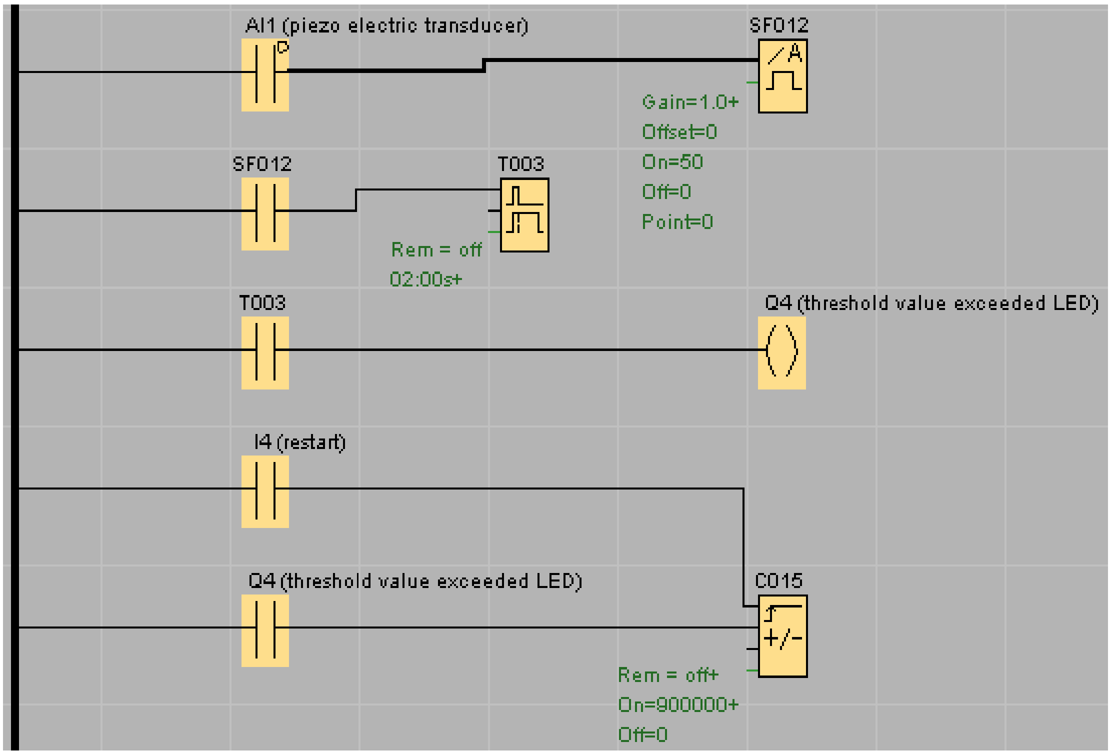

Figure 3.7 The program used to obtain the number of vibration amplitutes exceeding the threshold value.

As shown in figure 3.7, vibration data evaluation program is downloaded in ladder format. Below is the list of outputs, inputs, auxilary relais and counters used in ladder of the program.

AI1 : Analog input created by piezo electric sensor.

SF012 : This relay is energised when a current higher than the set threshold value is created by piezo electric sensor and sent to PLC analog input.

Q4 : Relay output of PLC to energise visually alarming LED when an analog signal exceeding the set threshold value is received.

T003 : An off-delay timer to keep the LED on for a few seconds.

C015 : The counter which gives the number of vibrations exceeding the threshold value during the period of total 20 up and down strokes.

I4 : A digital PLC input sent by a push switch to reset the C015 counter.

3.4 Transmission of the Vibration Data from Oscilloscope to PC

Ansys modelling of the 5 cm beam with a piezo electric sensor bonded on it, is solved and an experimental rig is set to perform the test. The automation of the experimental rig is completed by PLC and test started to run.

Firstly the low voltage signals from the piezo electric sensor is directed towards both oscilloscope and PLC. And then the vibration curves read from oscilloscope screen are transmitted to a PC by using a Visual BASIC program as shown in figure 3.8 and 3.9. The data transmitted to PC are saved and later compared according to the seal defect level.

```
Dim b1 As String, b2 As String, b As String, ndelay As Integer, nport As Integer
Dim fl As String, kfile As Integer
Dim nd As Integer, y(512) As Single, fl0 As String
Dim tmin, ymax As Single
Dim kv, kt As String
Private Sub Command1_Click()
Form1.Cls: Picture1.Cls: Print "   PLEASE WAIT ..."
MSComm1.PortOpen = True: MousePointer = 11
MSComm1.Output = "ST1" + Chr(13): Sleep ndelay: b1 = MSComm1.Input
MSComm1.PortOpen = False: MousePointer = 1: n = Len(b1)
'Print Len(b1): Print b1
GoSub 200
'-----
   For i = 1 To n
   xc = Mid(b1, i, 1): If xc = "#" Then GoTo 105
   Next i
105 xa = Mid(b1, 1, i - 2): xt = Mid(b1, i + 4, n - i - 5)
   nd = Len(xt) - 2
   For k = 1 To nd: y(k) = Asc(Mid(xt, k, 1)): Next k
   ymax = 4 * dv: ymin = -4 * dv: dt1 = 10 * dt / (nd - 1)
For k = 1 To nd
  y(k) = (ymin - ymax) * (y(k) - 255) / (-255) + ymax
Next k
'    ymax = 255: ymin = 0: dt1 = 10 * dt / (nd - 1)
 Print n, ymin; "  "; ymax; ""; kv, 10 * dt; "  "; kt
    Picture1.Scale (0, ymax)-(10 * dt, ymin): Picture1.PSet (0, y(1)): t = 0
    For k = 2 To nd: t = t + dt1: Picture1.Line -(t, y(k)): Next k
'----------
Exit Sub
200 '------ read scales: dv,kv, dt,kt
For i = 1 To n
 If Mid(b1, i, 1) = "," Then nv = i: GoTo 201
Next i
201 n1 = 5: nl = nv - n1 - 1: kv = "v" ' volt
   If Mid(b1, nv - 2, 1) = "m" Then kv = "mv": nl = nv - n1 - 2
   xc = Mid(b1, n1, nl): dv = Val(xc)
'---------
For i = nv + 1 To n
If Mid(b1, i, 1) = "," Then nv2 = i: GoTo 206
Next i
206 n1 = nv + 1: nv = nv2: nl = nv - n1 - 1: kt = "s"
   If Mid(b1, nv - 2, 1) = "m" Then kt = "ms": nl = nv - n1 - 2 '
   If Mid(b1, nv - 2, 1) = "u" Then kt = "us": nl = nv - n1 - 2 '
   xc = Mid(b1, n1, nl): dt = Val(xc)
'------------
'Print dv, kv, "   ", dt, kt, nd
Return
End Sub
```

Figure 3.8 Visual Basic program (part1) for the transmission of vibration data measured by oscilloscope to PC.

```
Private Sub Command2_Click()
xc = InputBox("File name"): If xc = "" Then Exit Sub
fl1 = fl0 + xc + ".txt": Print fl1
Open fl1 For Output As 1
Print #1, Str(ymax) + "," + kv + "," + Str(10 * dt) + "," + kt
For k = 1 To nd: Print y(k): Print #1, y(k): Next k
Close #1
End Sub

Private Sub Command3_Click()
ymin1 = y(1): ymax1 = ymin1
For k = 2 To nd
  If ymin1 > y(k) Then ymin1 = y(k)
  If ymax1 < y(k) Then ymax1 = y(k)
Next k
Print "min,max,p2peak : "; ymin1, ymax1, ymax1 - ymin1
rms = 0
vtrig = 0.2: k1 = 0
For k = 1 To nd
 If Abs(y(k)) > vtrig Then k1 = k1 + 1: rms = rms + y(k) ^ 2
Next k
rms = Sqr(rms / k1): Print "rms = ", vtrig, k1, rms
End Sub

Private Sub Form_Load()
fl0 = "d:\tez\feyz\"
MSComm1.CommPort = 1: ndelay = 3000
WindowState = 2: Form1.Caption = "Data Transfer from Gould 400 Oscilloscope"
Command1.Caption = "Transfer Data"
Command2.Caption = "Save Data"
Command3.Caption = "Process"
End Sub
```

Figure 3.9 Visual Basic program (part2) for the transmission of vibration data measured by oscilloscope to PC.

CHAPTER FOUR
TEST RESULTS

4.1 Parameters Measured by Oscilloscope and PLC

The parameters (data), measured from the experimental rig and compared according to the seal defect level, are given below .

- Max. vibration amplitude
- Min. vibration amplitude
- Peak to Peak vibration amplitude
- Vibration energy (rms)
- Total movement time
- Number of the vibration amplitutes exceeding the threshold value (analog counter)

The results of these measured parameters are displayed on PLC screen or PC screen. Below table 4.1 shows the screen on which the results are read from.

Table 4.1 Test parameters and the screens on which the results are displayed

PARAMETERS	RESULT SCREEN
Max. vibration amplitute	Displyed on PC screen
Min. vibration amplitute	Displyed on PC screen
Peak to Peak vibration amplitute	Displyed on PC screen
Vibration energy (rms)	Displyed on PC screen
Total movement time	Displyed on PLC screen
Number of the vibration amplitudes exceeding the threshold value	Displyed on PLC screen

These parameters are compared under 3 different loads and for 3 different defect levels, and the results are shown in sections 4.2 and 4.3.

4.2 Vibration Results Received by Oscilloscope

The vibration curves on oscilloscope screen are sent to PC and saved as a notepad file. As shown in figures 4.1, 4.2, and 4.3 vibrations under same load but with 3 different damage levels are compared by Miscrosoft Office – Excel program.

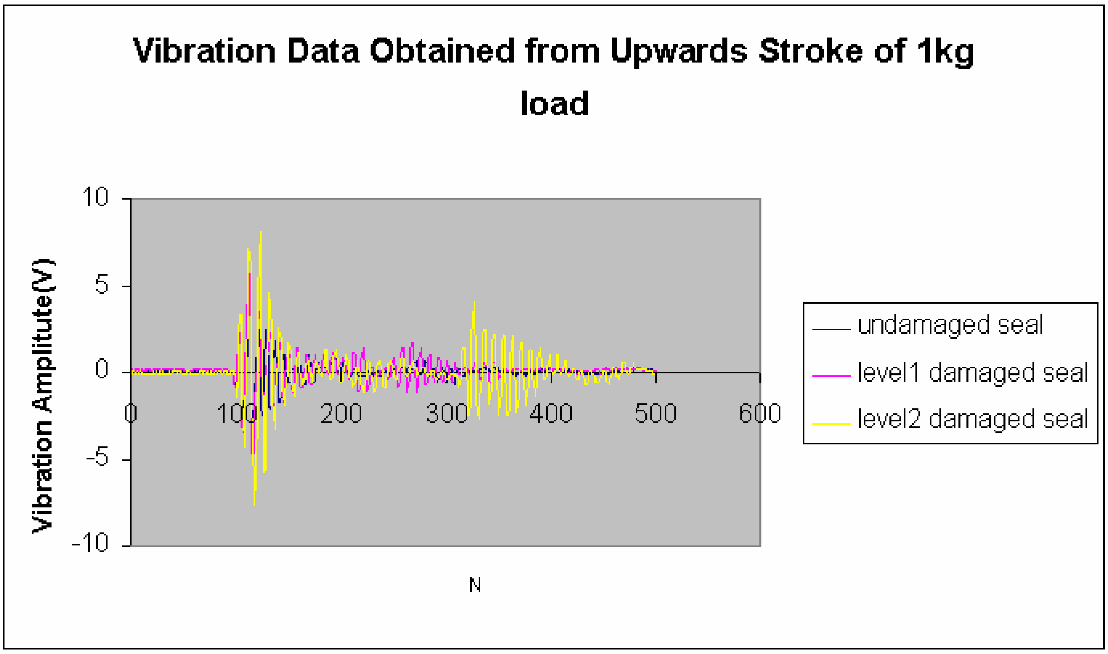

Figure 4.1 Vibration data obtained from upwards stroke of 1 kg load

As it can be seen from figure 4.1, max. vibration amplitute occured when working with a level2 damaged seal (from curve in yellow colour) is around 8V. The vibration amplitutes decreases to 5.5V approximately when working with level1 damaged seal (from curve in dark blue colour) and it is less than 3V during the test with undamaged seal.

When we increased the working load, the measurement of seal defects by vibration analysis becomes much selective. As shown in figure 4.2, max. vibration amplitute occured when working with a level2 damaged seal is around 15V. The vibration amplitutes decreases to 9V approximately when working with level1 damaged seal and it is less than 7V during the test with undamaged seal.

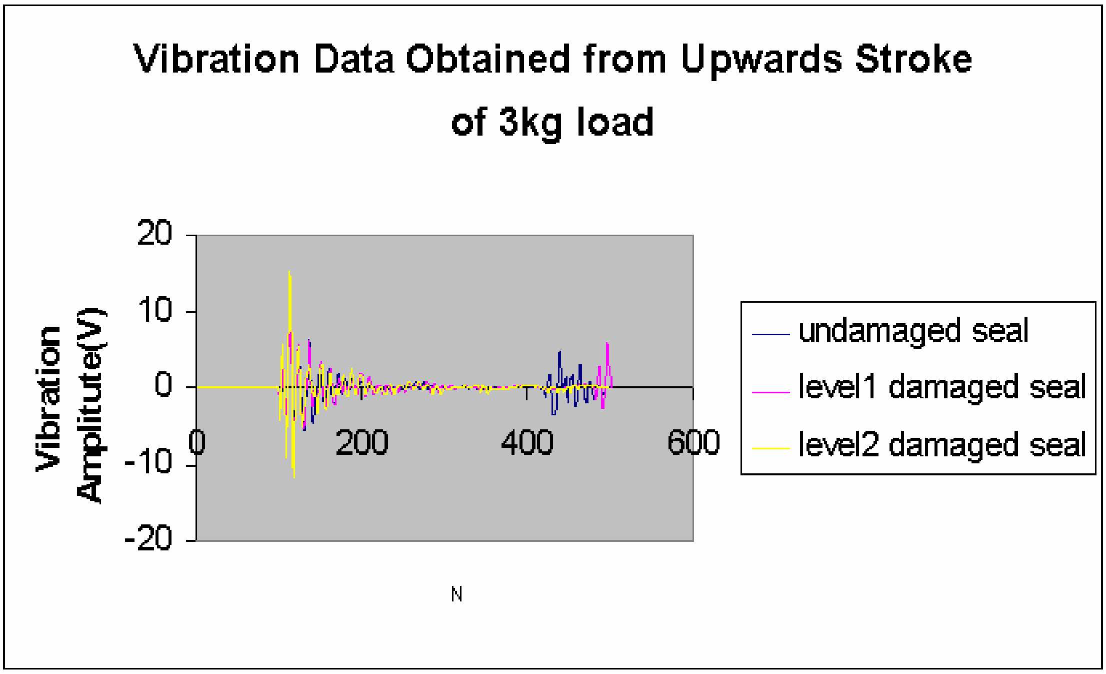

Figure 4.2 Vibration data obtained from upwards stroke of 3 kg load

Both tests with 1 and 3 kgs loads are performed under a constant 6 bar compressor pressure. This pressure is reduced to 4 bar and again kept constant for test under 5 kg loads.

As shown on figure 4.3, vibrations analysis is again selective even in working with 3 bar air pressure. Max. vibration amplitute occured when working with a level2 damaged seal is around 6V. The vibration amplitutes decrease to 4.2V approximately when working with level1 damaged seal and it is less than 2V during the test with undamaged seal.

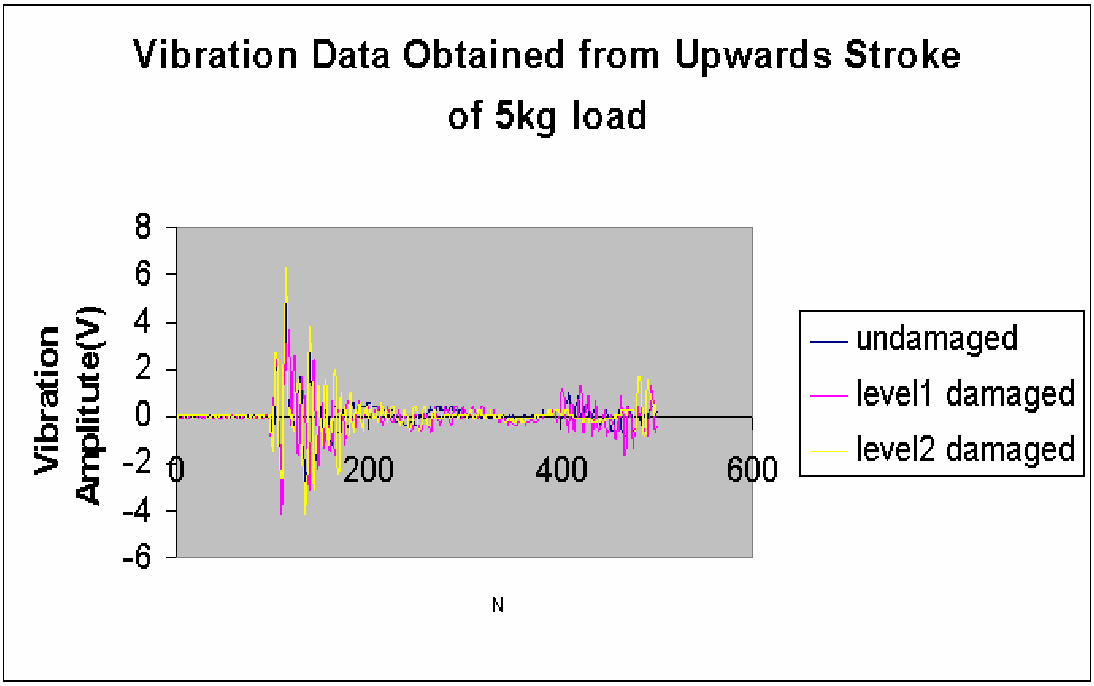

Figure 4.3 Vibration data obtained from upwards stroke of 5 kg load

Also the vibration results on figures 4.1, 4.2 and 4.3 are quite similar to the solution obtained by ansys modeling and analysis in chapter 2.

4.3 Complete Results Compared According to the Extent of Seal Defect

All of the results, measured by vibration analysis or velocity calculation methods and displayed on PLC or PC screens, are compared according to the seal defect level on figures 4.4, 4.5 and 4.6.

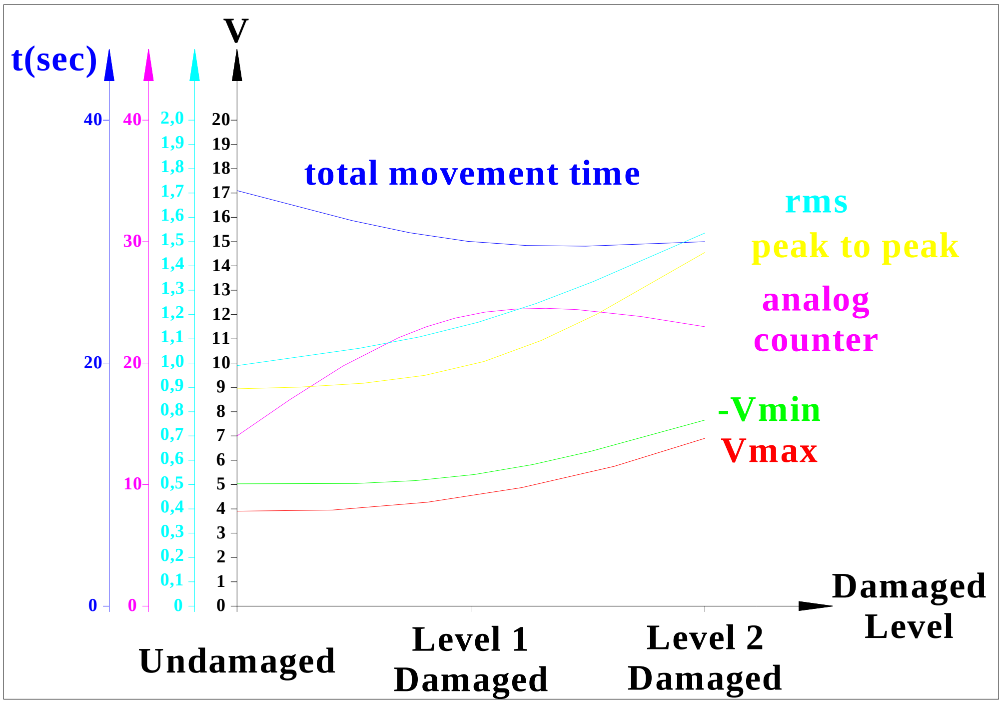

Figure 4.4 Parameters compared at 1kg load according to the extent of the seal defect.

Curves namely total movement time and analog counter are formed by the results read from PLC screen. They show that the total movement time reduces with respect to increase in seal defect level and the number of vibration amplitudes exceeding the threshold value increases with the increase in seal defect level.

Also the results of min., max., peak to peak vibration amplitutes and rms value are compared according to seal defect level. This shows that vibrations with greater amplitutes occur when working with seals with increased defect level.

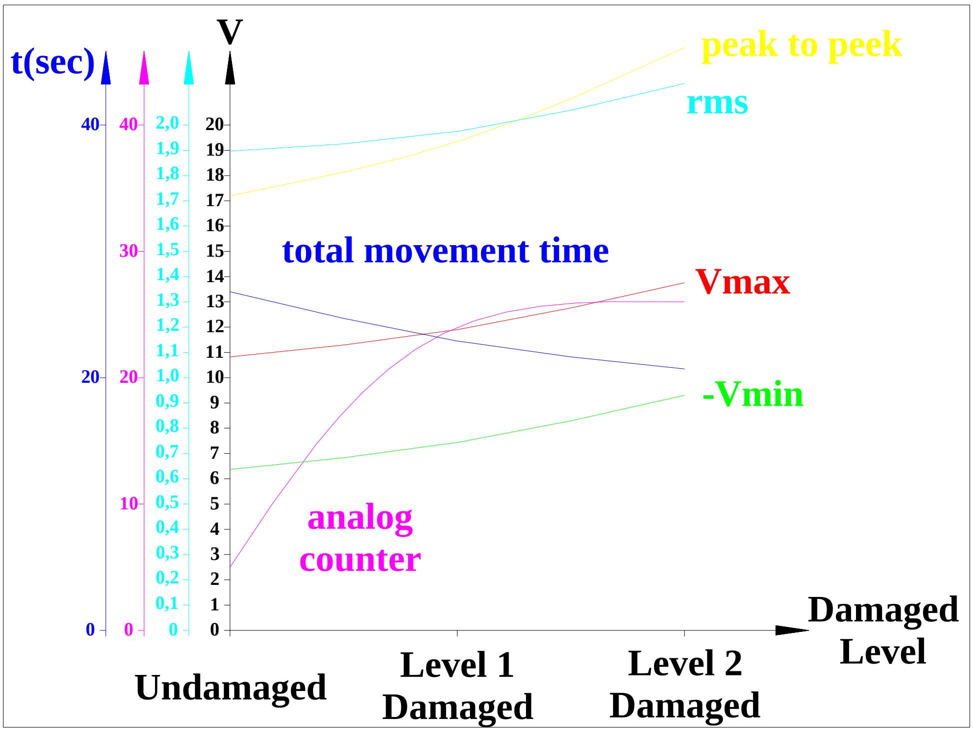

Figure 4.5 Parameters compared at 3kg load according to the extent of the seal defect

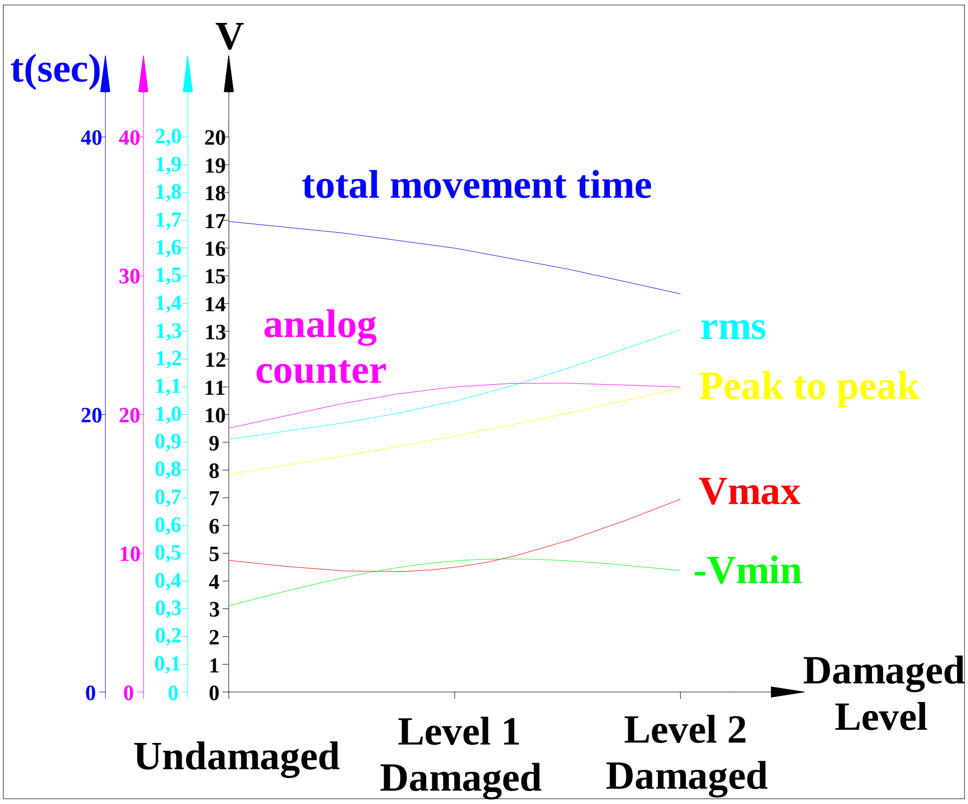

Figure 4.6 Parameters compared at 5kg load according to the extent of the seal defect

CHAPTER FIVE
CONCLUSIONS

A condition monitoring system of seal defects in pneumatic cylinder is set by using low cost sensors. Tests are performed on an experimental rig from which vibration data and stroke durations are obtained and saved.

The results are compared. It can be seen easily from the test results that 6 different test parameters such as max., min., peak to peak amplitude, rms, analog counter and total movement time change proportional to the extent of seal defect in pneumatic cylinder.

By studying signals from vibration sensor and proximity switches of pneumatic cylinder in faulty and healthy states under different operating conditions, we get the results that there is a distinctive variation in vibration signals, and average stroking duration. The results imply that PLC program can be written to set warning levels and trigger an alarm when a fault is impending.

A defect monitoring system which is economical and also practical is formed.

The sudden system shut downs and resulting injuries and manhour losses, can be minimized if this kind of studies are employed for the other types of pneumatic and hydraulic elements.

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Appendix – A
SIEMENS PLC - LOGO

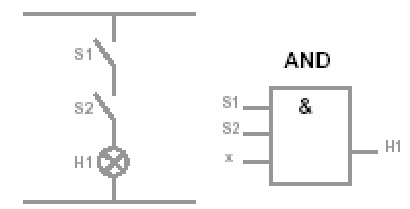
A.1. Basic Functions of Siemens PLC

Siemens Logo has 8 basic functions namely “AND” , ”OR” , “NOT” , “NAND” , “NOR” , “XOR” , “AND edge” , “NAND edge” .

A.1.1 AND Logic Operation

Referring to the circuit diagram, it can be seen that lamp H1 illuminates only if S1 and S2 switched are both closed. There is a dependancy between the input and output states.

The circuit shown in figure 3 is referred to as AND logic operation. This means that S1 and S2 switches must be energised in order for lamp H1 to illuminate. Symbolically this operations is represented by &. The state of the AND output = 1 only if the state of all inputs=1. An unconnected input block in this block is automatically assigned state = 1.



Logic Table for AND Block:

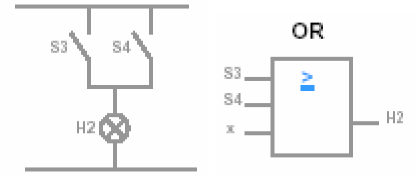
Input 1	Input 2	Input 3	Output
0	0	0	0
0	0	1	0
0	1	0	0
0	1	1	0
1	0	0	0
1	0	1	0
1	1	0	0
1	1	1	1

Figure A.1 Series circuit with normally open contacts

A.1.2 OR Logic Operation

For lamp H2 to illuminate, switch S3 or S4 must be closed. This dependancy of the output state is referred as OR logic operation. This means that at least one of the two switches –S3 or S4- must be closed in order for lamp H2 to illuminate. The symbol for this operation is ≥1 .

The state of the OR output = 1 if the state of at least one input =1. An unconnected input pin in this block is automatically assgned state=0.



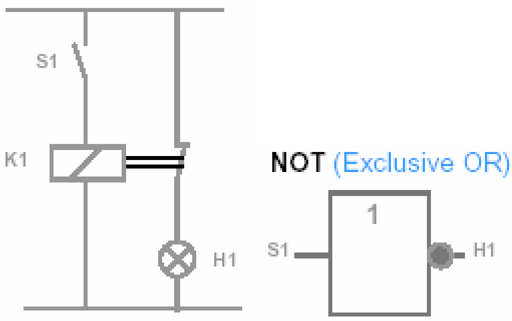
Logic Table for OR Block:

Input 1	Input 2	Input 3	Output
0	0	0	0
0	0	1	1
0	1	0	1
0	1	1	1
1	0	0	1
1	0	1	1
1	1	0	1
1	1	1	1

Figure A.2 Parallel circuit with normally open contacts

A.1.3 NOT Logic Operation

Referring to the circuit diagram, it can be seen that lamp H1 is only illuminated if switch S1 is not activated. The circuit diagram in figure 5 implements a NOT logic operation. The symbol for this operation is 1. The state of the output = 1 if the input = 0, that is NOT inverts the input state. One advantage of the NOT operation is that normally closed contacts are no longer needed for PLC. A normally open contact is used and is converted to a normally closed contact with the NOT operation. An unconnected input pin in this block is automatically assigned state =1.



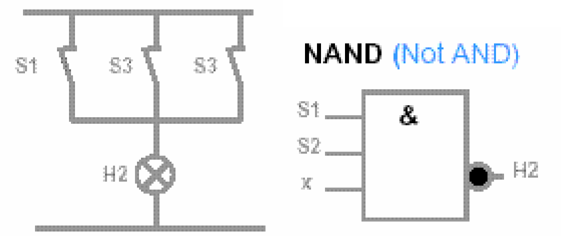
Logic Table for NOT Block:

Input 1	Output
0	1
1	0

Figure A.3 Only one switched circuit with normally closed contact

A.1.4 NAND Logic Operation

Referring to the circuit diagram, it can be seen that lamp H2 is always illuminated unless all of the switches are activated. The circuit shown below is referred to as a NAND (not AND) logic operation. This means that switches S1, S2 and S3 must be activated in order for lamp H2 not to be illuminated. The symbol for this operation is &◂ .The state of the NAND (not AND) output = 0, only if the state of all inputs =1. An unconnected pin in this block is automatically assigned state=1.



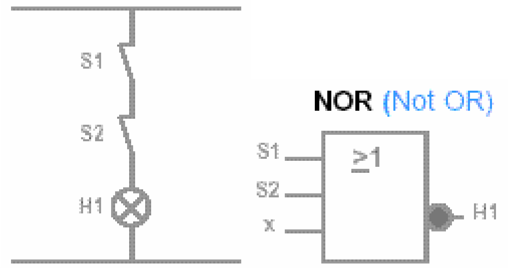
Logic Table for NAND Block:

Input 1	Input 2	Input 3	Output
0	0	0	1
0	0	1	1
0	1	0	1
0	1	1	1
1	0	0	1
1	0	1	1
1	1	0	1
1	1	1	0

Figure A.4 Parallel circuit with normally closed contacts.

A.1.5 NOR Logic Operation

Referring to the circuit diagram, it can be seen that lamp H1 is illuminated only if normally closed switches S1 and S2 are not activated. The circuit diagram shown below is referred to as a NOR (not OR) logic operation. This means that if at least one of the switches S1 or S2 is activated, lamp H1 is not illuminated. The symbol for this operation is ≥1◄. The state of the NOR (not OR) output = 1 only if the state of all inputs =0. As soon as any input is switched on (state=1) , the output is switched off. An unassgned input pin in this block is automatically assigned state = 0.



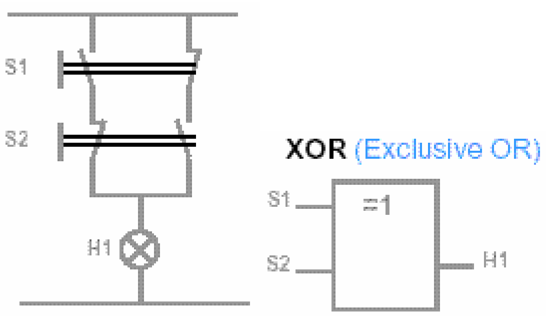
Logic Table for AND Block:

Input 1	Input 2	Input 3	Output
0	0	0	1
0	0	1	0
0	1	0	0
0	1	1	0
1	0	0	0
1	0	1	0
1	1	0	0
1	1	1	0

Figure A.5 Series circuit with normally closed switches.

A.1.6 XOR Logic Operation

Referring to the circuit diagram, it can be seen that H1 is not illuminated only if all of the switches are activated. The circuit diagram below is referred to as an XOR (exclusive OR logic operation). This means that either S1 or S2 is activated, lamp H1 will illuminate. The symbol for this operation is =1. The state of XOR (exclusive OR) = 1 if the state of the inputs is different. An unconnected pin in this block is automatically assgned state = 0.



Logic Table for XOR Block:

Input 1	Input 2	Output
0	0	0
0	1	1
1	0	1
1	1	0

Figure A.6 Both Series & Parallel circuits with normally closed and open contacts in XOR logic operation.

A.1.7 AND with EDGE Evaluation

The state of the output of the AND with Edge Evaluation operation = 1 only if the state of all inputs = 1 and the state of at least one input during the previous cycle = 0. An unconnected input pin in this block is automatically assigned state = 1.

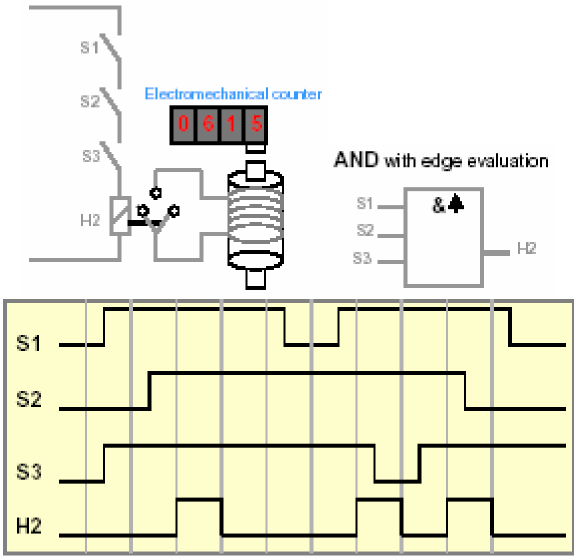


Figure A.7 Circuit,operation block and signal diagram explaining AND with edge evaluation

A.1.8 NAND with EDGE Evaluation

The state of the output of the NAND (not AND) with Edge Evaluation operation = 1 only if the state of at least one input = 0 and the state of all inputs during the previous cycle = 1. An unconnected input pin in this block is automatically assigned state = 1.

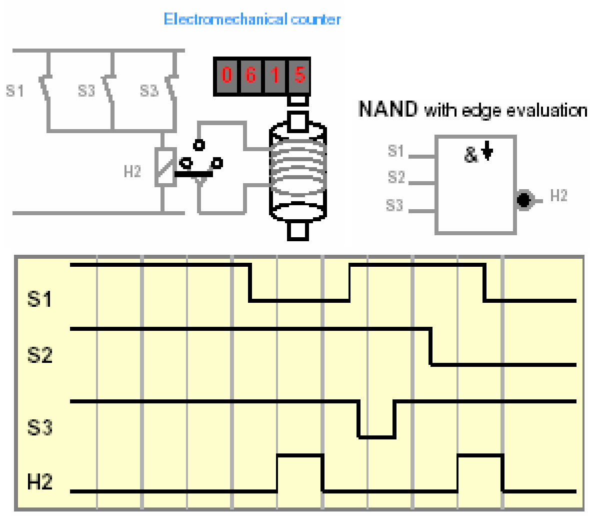


Figure A.8 Circuit,operation block and signal diagram explaining NAND with edge evaluation

A.2. Special Functions of Siemens PLC

Siemens Logo has 19 special functions namely “On-Delay” , ”Off-Delay” , “On/Off Delay” , “Retentive On-Delay” , “Internal time delay relay” , “Edge-Triggered Internal time delay relay” , “Asynchronous Pulse Generator” , “Random Generator” , “Weekly Timer” , “Yearly Timer” , “Up/Down Counter” , “Elapse Time Counter” , “Latching Relay” , “Message Text” , “Pulse Relay” , “Frequency Threshold Switch” , “Staircase Lighting Time Delay” , “Multifunction Switch” , “Symmetrical Clock Pulse Generator”

A.2.1 On – Delay

Referring to the circuit diagram, it can be seen that the motor starts running only after the set time delay expires. This function is referred to as an on – delay. This means that the motor is switched on after a set time delay. If the state on input trigger changes from 0 to 1, the timer starts running. If the state at input trigger = 1 for a sufficient amount of time, the output is set to 1 once time T expires. There is a delay in switching on the output as compared to the input. The output is reset to 0 if the state at input Trg=0. If the state at input Trg changes back to 0 before time T expires, the timer is reset. The expired timer is reset after a power failure.

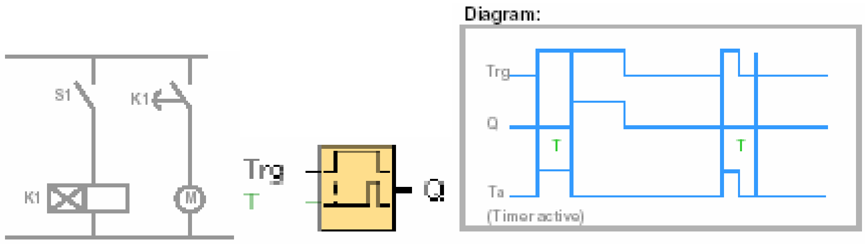


Figure A.9 Circuit,operation block and signal diagram explaining On-Delay Operation

A.2.2 Off – Delay

Referring to the circuit diagram, it can be seen that the motor is switched off only after the set time delay expires. This function is referred to as an off – delay. This means that the motor is switched off after a set time delay. The state at input Trg = 1, the state at output Q switches immediately to 1. If the state at input Trg changes from 1 to 0, the timer in PLC is activated and output state is retained. When the timer reaches the value set using T (Ta = T), the state at output Q is reset to 0. If the input Trg is switched on and off again, time Ta is restarted. Time Ta and output are reset using input R (reset) before time T expires.

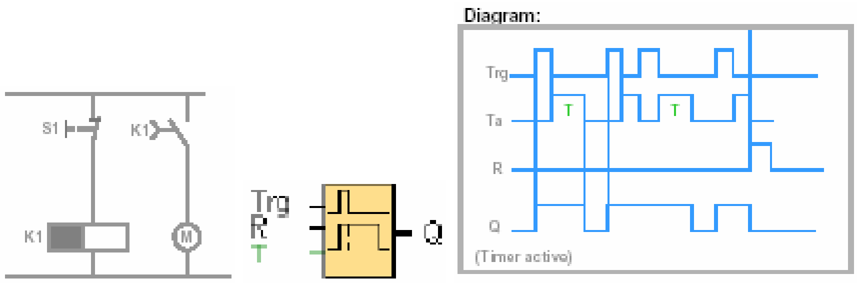


Figure A.10 Circuit,operation block and signal diagram explaining Off-Delay Operation

A.2.3 On/Off Delay

Referring to the circuit diagram, it can be seen that: if S1 is closed, contact K1 closes after a time delay and the motor runs. If S1 is opened, contact K2 opens after a time delay and the motor stops. This functions is referred to as an on/off delay. This means that the motor is switched on and off after a set time delay. If the state at input Trg changes from 0 to 1, time TH runs. If the state at input Trg remains 1, the output is set to 1 once the time TH expires. If the input state changes back to 0, time TL runs. If the state at input Trg remains 0 for the duration of time TL, the output is set to 0 once time TL expires.

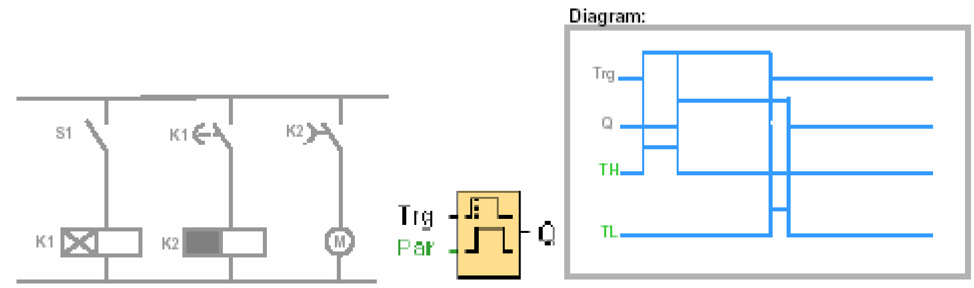


Figure A.11 Circuit,operation block and signal diagram explaining On/Off Delay Operation

A.2.4 Retentive On Delay

Referring to the circuit diagram, it can be seen that motor M runs after a set time delay following activation of momentary contact push button S1. Momentary contact push button S2 (normally closed) causes motor to switch off again. This function is referred to as retentive on-delay. If the state at input Trg changes from 0 to 1, the current time Ta starts running. When time Ta reaches time T, the state at output Q is set to 1. Output Q is reset to 0 only when the state at input R = 1. Further switching actions at input Trg have not influence on output Q.

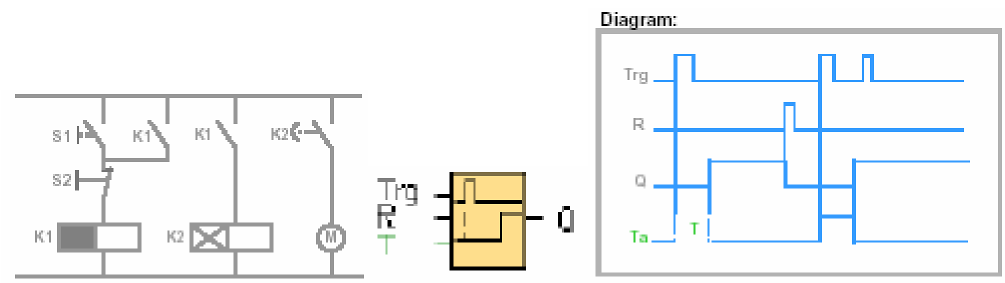


Figure A.12 Circuit,operation block and signal diagram explaining Retentive On-Delay Operation

A.2.5 Interval Time – Delay Relay / Pulse Output

Referring to the circuit diagram, it can be seen that lamp H1 is illuminated only if maintained contact switch S1 is closed, but at most for the time period set ont timer T1. If the state at input Trg = 1, the state at output Q immediately switches to 1. Simultaneously, current time Ta starts in PLC, and output setting is retained. When Ta reaches the value set using T (Ta=T), the state at output Q is reset to 0 (pulse output). If the state at input Trg changes from 1 to 0 before the specified time expires, the state at the output also changes immediately from 1 to 0.

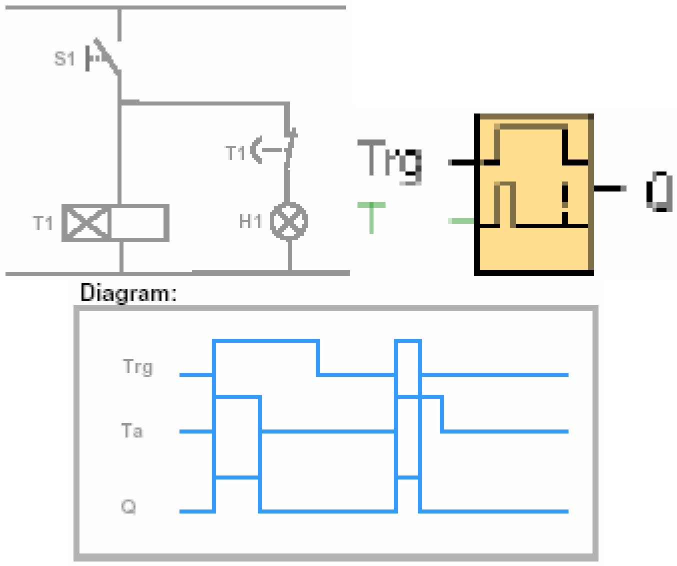


Figure A.13 Circuit,operation block and signal diagram
explaining interval time – delay relay / pulse output operation

A.2.6 Edge Triggered Internal Time – Delay Relay

Referring to the circuit diagram, it can be seen that lamp H1 illuminates for a period of time set in timer T1 when maintained contact switch S1 is activated. If the state at input Trg = 1, the state at output Q switches to 1. Simultaneously time Ta starts. When time Ta reaches the value set using T (Ta=T), the state at output Q is rest to 0 (pulse output). If the state at input Trg changes back from 0 to 1 before the specified time expires (retriggering), time Ta is reset and the output remains switched on.

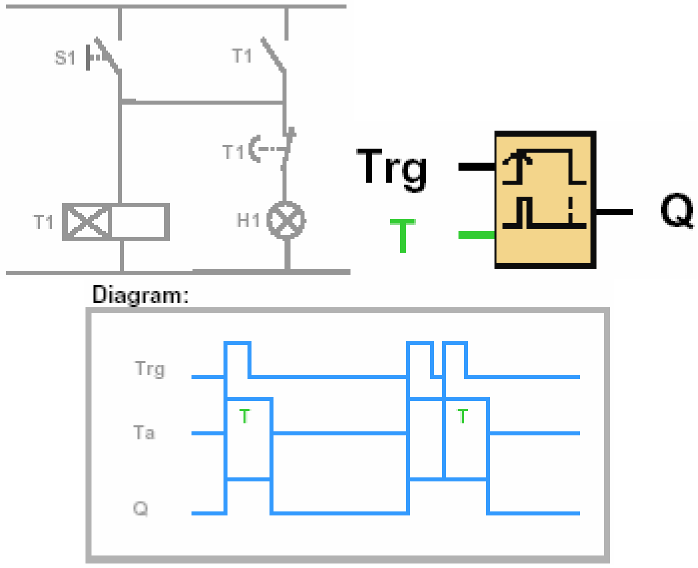


Figure A.14 Circuit,operation block and signal diagram explaining edge triggered internal time – delay relay operation

A.2.7 Asynchronous Pulse Generator

The pulse for of the output can be modified by means of the assignable pulse/pause ratio. Pulse length and pause length can be set by means of parameters. The time base can be divided into seconds, minutes or hours. Both parameters have the same time basis, and a different setting is not possible. Input Inv causes the output to be inverted if the block is enabled bu means of EN.

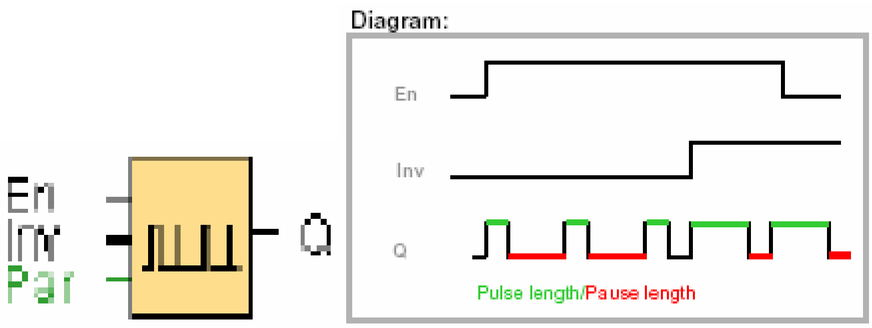


Figure A.15 Circuit,operation block and signal diagram explaining asynchronous pulse generator

A.2.8 Random Generator

The random generator switches the output on or off within an assignable time. If input En changes from 0 to 1, a random time between 0 to 10 seconds is started. If En=1 for at least the duration of the on delay time, the output is set to 0 when the on delay time expires. If the state at input En changes back to 0 before the on delay time expires, the time is reset. If input En changes from 1 to 0, a random time (off delay time) of between 0 to 15 seconds is started. If En=0 for at least the duration of the off delay time, the output is set to 0 once the off delay time expires. If the state at input En changes to 1 before off delay time expires, the time is reset.

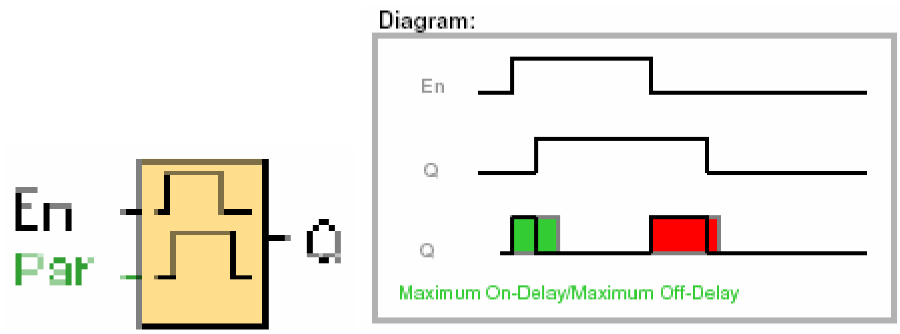


Figure A.16 Circuit,operation block and signal diagram explaining random pulse generator

A.2.9 Weekly Timer

The output is controlled by means of an assignable on and off date. Any combination of weekdays is supported. Active weekdays are selected by removing inactive weekdays. Each weekly timer has three cams which can be used to assign parameters for each time window. The on and off times are specified using cams.

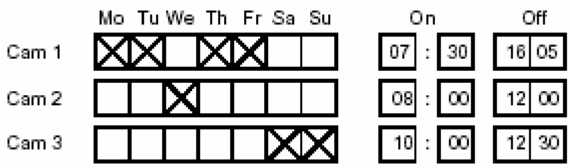


Figure A.17 Diagram explaining weekly timer

A.2.10 Yearly Timer

Each yearly timer has an on and off time. The yearly timer switches the output on at a specified on time and switches off at a specified off time. The off date identifies the day when the output is to be reset to 0.

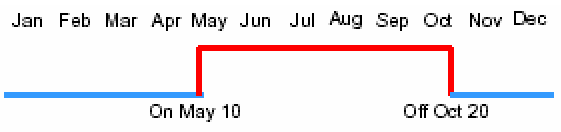


Figure A.18 Diagram explaining yearly timer

A.2.11 Up/Down Counter

Referring to the circuit diagram, it can be seen that the time pulse is generated with maintained contact switch S1. Maintained contact switch S2 determines whether the counter counts up or down. If the counter content has a value ≥10, the lamp is switched on. For every rising edge at input Cnt, the internal counter counts up by one (Dir=0) or down by one (Dir=1). If the internal counter value is equal to or greater than the value specified using Par, output Q is set to 1. The internal value and the output can be reset to 0 using input R. As long as R=1, the output is 0 and pulses at input Cnt are not counted.

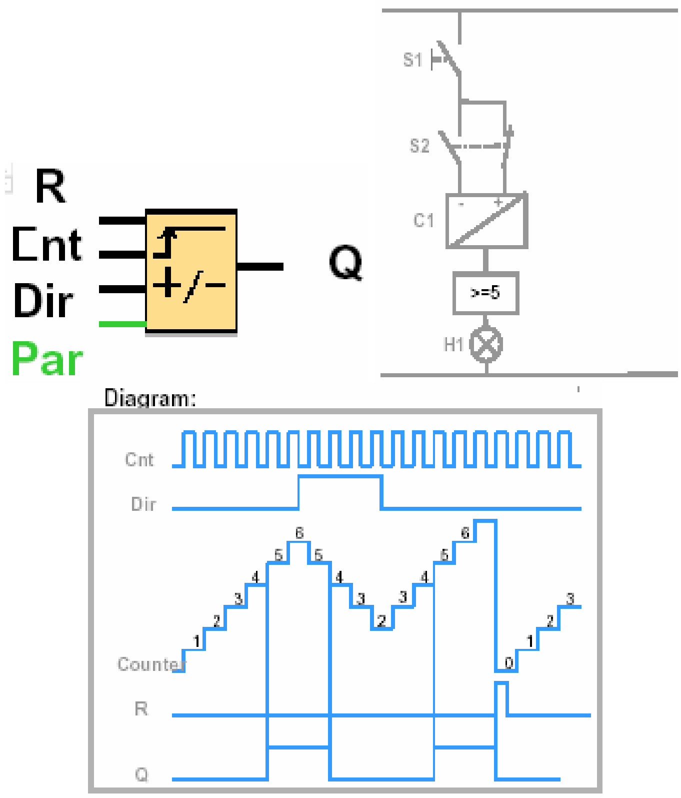


Figure A.19 Circuit,operation block and signal diagram explaining Up/Down Counter

A.2.12 Elapse Time Counter

The elapse time counter monitors input En. As long as the value at this input = 1, PLC quatifies elapse time OT and remaining residual time MN. PLC indicates the times in parameter assignment mode. If the remaining residual time MN=0, output Q is set to 1. The reset input R is used to reset output Q and to set the counter for residual time to the specified value MI. Internal counter OT resumes counting. The reset input Ral is used to reset output Q and to set the counter for the residual time MN to the specified value MI. The internal counter OT is reset to 0.

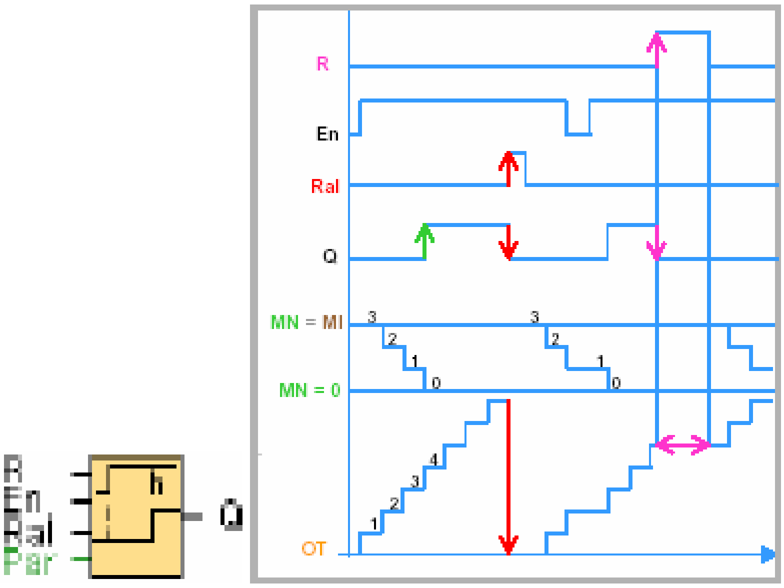


Figure A.20 Operation block and signal diagram explaining elapse time counter

A.2.13 Latching Relay

Referring to the circuit diagram, it can be seen that coil K1 is energised with momentary contact push button S1, causing maintained contact switch K1 to close (latching). This function is referred to as a latching relay. Output Q is set by means of input S; output Q is reset by means of a second input R.

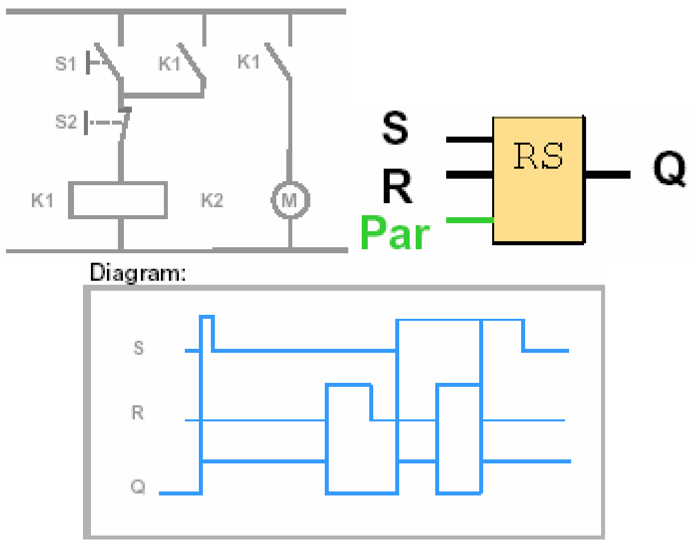


Figure A.21 Circuit,operation block and signal diagram explaining Latching Relay

A.2.14 Message Text

Display of and assigned message text in RUN mode. If the input state changes from 0 to 1, the appropriate message text is output ont the display during RUN mode. If the input state changes from 1 to 0, the message text is removed. If more than one message text has been triggered with En=1, the highest priority message is displayed. It is possible using ▲ and ▼ keys to toggle between the standart display and the message text display. If “acknowledge message” is selected, the corresponding message text is removed only after pressing a button on PLC, provided En=0.

A.2.15 Pulse Relay

Referring to the circuit diagram, it can be seen that lamp H1 can be switched on and off with momentary contact pushbuttons S1 and S2. This function is referred to as a pulse relay. This means that lamp H1 is switched on off by a brief pulse in S1 or S2, respectively. Each time that the state at input Trg changes from 0 to 1, output Q changes its state, i.e the output is switched on and off. The state of the latching relay is set to 0 using input R.

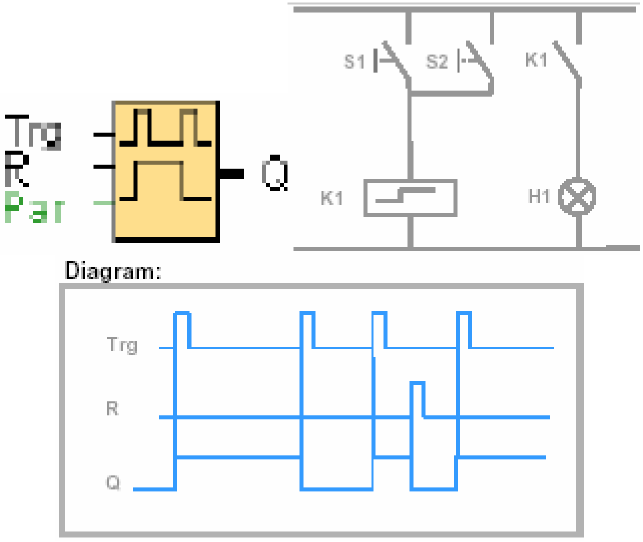


Figure A.22 Circuit,operation block and signal diagram explaining Pulse Relay

A.2.16 Frequency Threshold Switch

The output is switched on and off depending on two assignable frequencies. The threshold switch measures the signals at input Fre. The pulse are detected over an assignable time period (peak time). If during the peak time, the measured values are greater than the upper threshold value, output Q switches on. Output Q switches off again when the measured values are less than the lower threshold value.

SWOn is the on threshold. The permitted range is 0000 to 9999.

SWOff is the off threshold. The permitted range is 0000 to 9999.

Peak time is the time interval during which the pulses at Fre are measured. The permitted range is 0,05 seconds to 99,95 seconds.

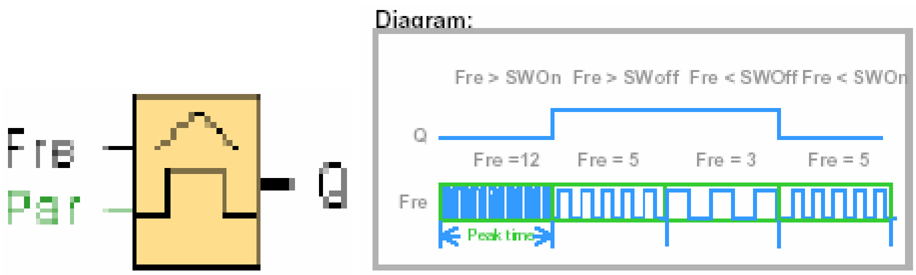


Figure A.23 Operation block and signal diagram explaining Frequency Threshold Switch

A.2.17 Staircase Lighting Time Delay

An assignable time runs following an input pulse (edge triggering). The output is reset after the time expires. An early shutdown warning is issued 15 seconds before the time expires. If the state at input Trg changes from 0 to 1, the current time Ta runs and output Q is set to 1. Fifteen seconds before Ta reaches time T, output Q is reset to 0 for 1 second. Further switching actions at input Trg while Ta is running resets Ta (retriggering option).

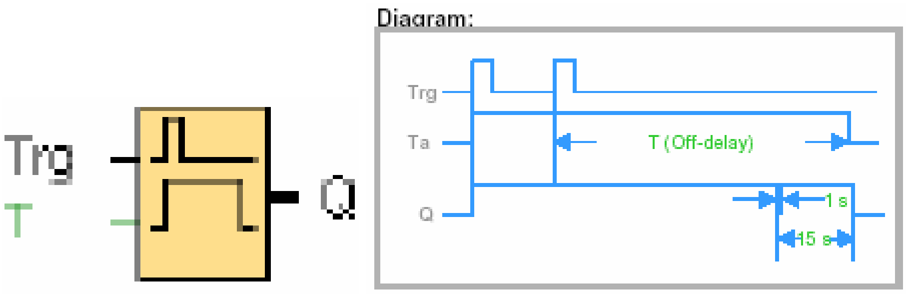


Figure A.24 Operation block and signal diagram explaining Staircase Lighting Time Delay

A.2.18 Multifunction Switch

Switch with two different functions.

- Pulse switch with off delay.
- Switch (steady light)

If the state at input Trg changes from 0 to 1, output Q is set to 1. If input Trg changes back to 0 before the steady light time expires, the output is reset to 0 after a time delay of 5 seconds. If the state at input Trg changes from 0 to 1 and remains 1 for at least 20 seconds, the steady light functions is enabled and output Q is switched on for the duration. Further switching actions at the input Trg from 0 to 1 and back to 0 causes output Q to switch off.

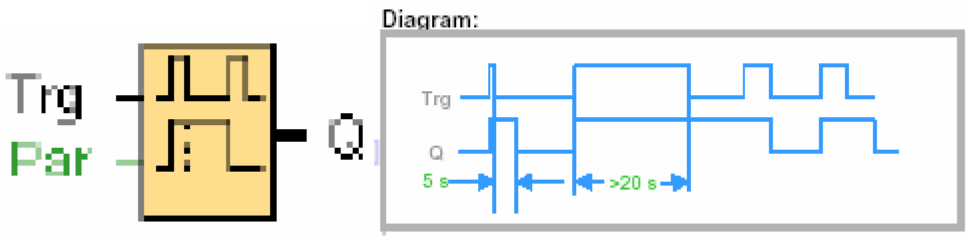


Figure A.25 Operation block and signal diagram explaining Multifunction Switch

A.2.19 Symmetrical Clock Pulse Generator

Referring to the circuit diagram, it can be seen that lamp H1 flashes with a pulse time set using a clock pulse generator when maintained contact switch S1 is activated. Parameter T is used to specify the length of the on and off time. En is used to switch the clock pulse generator on. The clock pulse generator sets the output to 1 for time T, and then to 0 for time T, and so on, until En=0 at the input. The time T specified must be >0,1 seconds at all times.

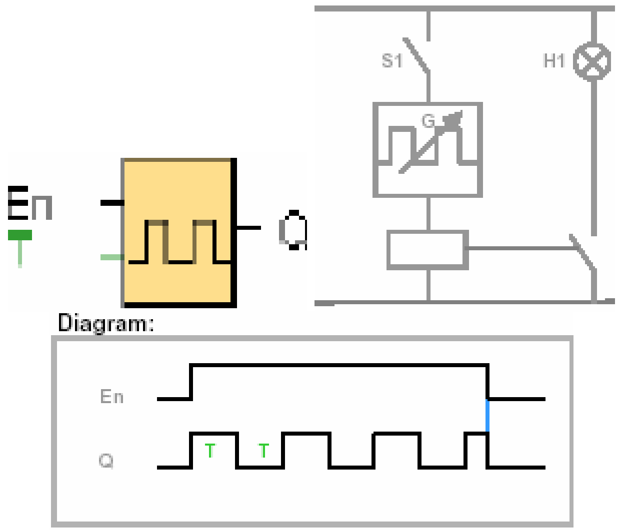


Figure A.26 Circuit, operation block and signal diagram explaining Symmetrical Clock Pulse Generator

A.3. Typical PLC Applications

A.3.1 Application 1 – Water Tank Filling and Discharge Control

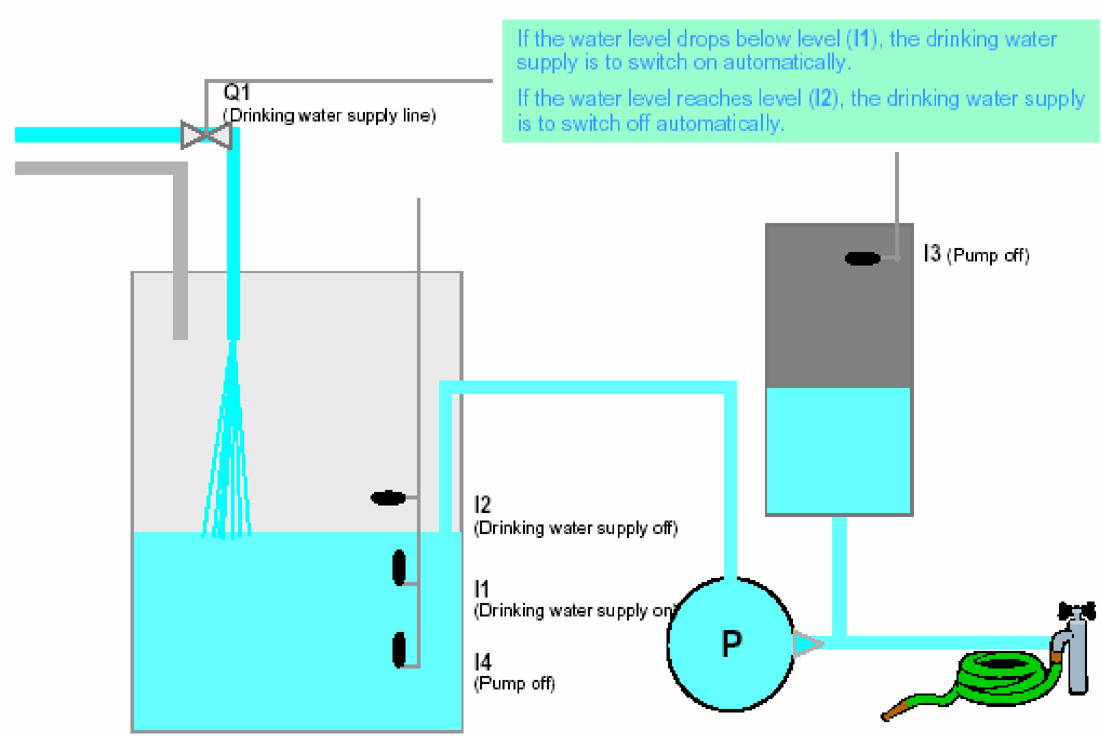


Figure A.27 Typical PLC Applications – Application 1

There are 4 inputs and 2 outputs needed to program this application with a PLC.

Inputs : I1, I2, I3, I4

Outputs : Q1, Q2 for drinking water supply valve and discharge pump respectively.

First we have to design the circuit for this application.

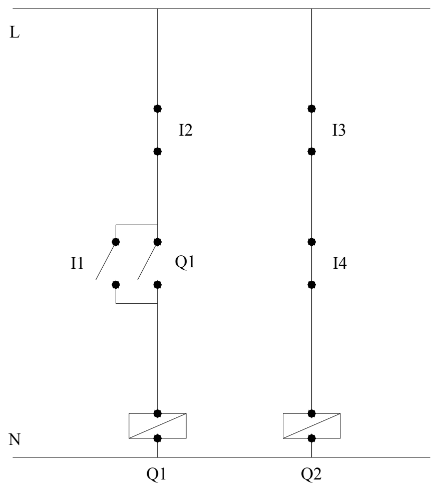


Figure A.28 Circuit of Application 1

Then block diagrams have to be formed according to the circuit diagram.

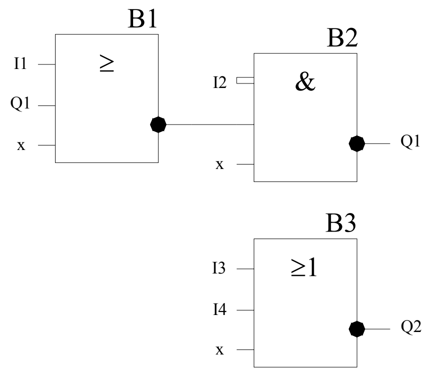


Figure A.29 Block Diagrams of PLC application 1

This block diagram can be entered in PLC menu and desired automation can be exercised.

A.3.2 Application 2 – Conveyor Band Control

A bottle filling machine is to be controlled.

Part 1: The conveyor motor is switched on or off using (I1). When the conveyor, the motor for the conveyor belt runs (Q1). The motor is able to be switched off at any time by means of (I3).

Part 2: When the sensor (I2) detects a bottle, the motor is switched off for 3 seconds (filling operation). Afterwards, the motor starts running again.

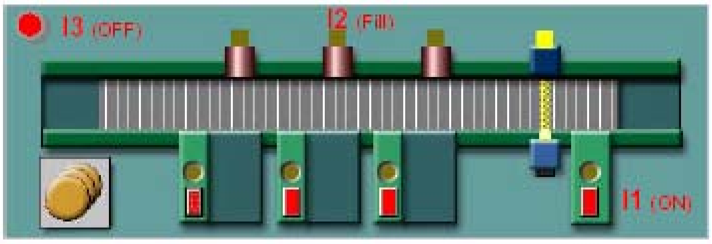


Figure A.30 Typical PLC Applications – Application 2

There are 3 inputs and 1 output needed to program this application with a PLC.

Inputs : I1, I2, I3

Outputs : Q1 for conveyor motor

First we have to design the circuit for this application.

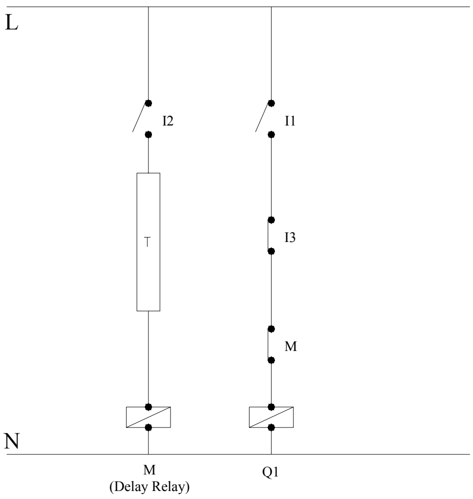


Figure A.31 Circuit of Application 2

Then block diagrams have to be formed according to the circuit diagram.

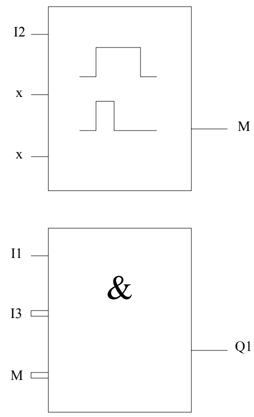


Figure A.32 Block Diagrams
of PLC application 2

This block diagram can be entered in PLC menu and desired automation can be exercised.