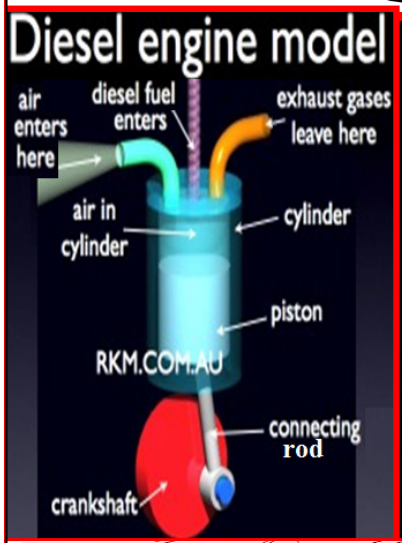
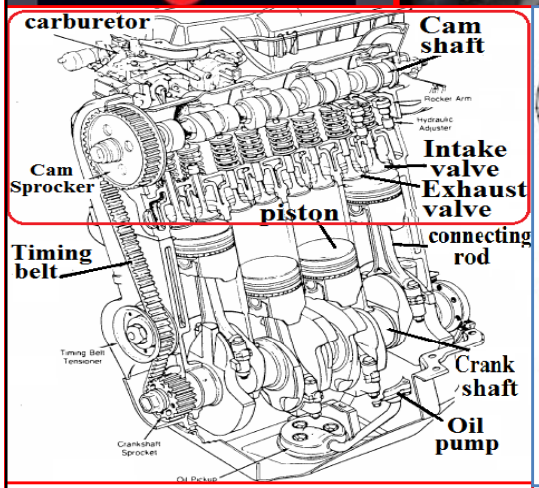
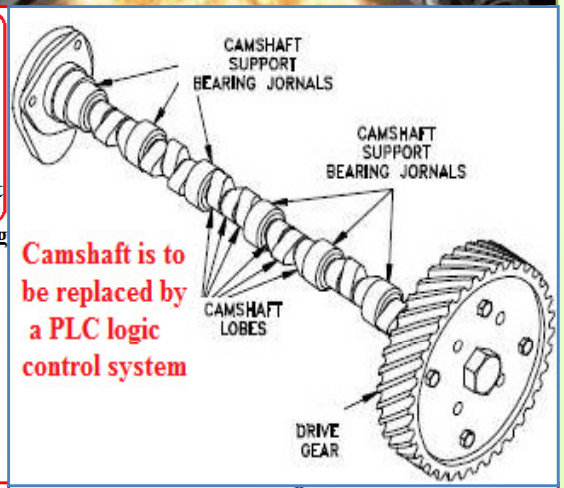
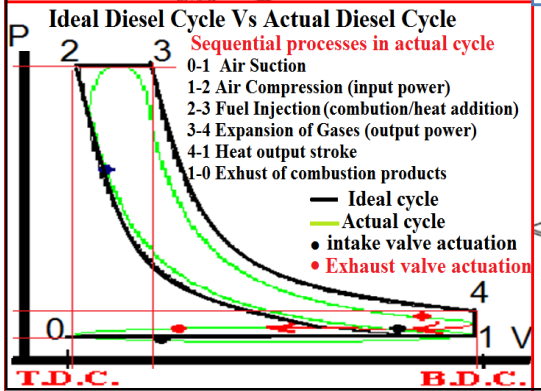
Cairo University
Faculty of Engineering
Mech. Power Department

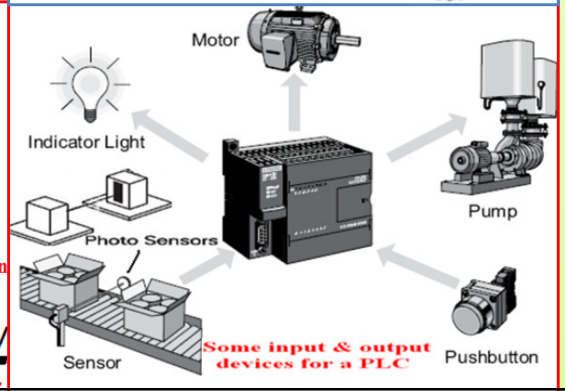
دبلوم تطبيقات التحكم الأوتوماتيكى فى نظم القوى الميكانيكية











MEP 599 Diploma Design Project-3 Summer 2017/2018

Application of PLC System for Industrial Diesel Engines

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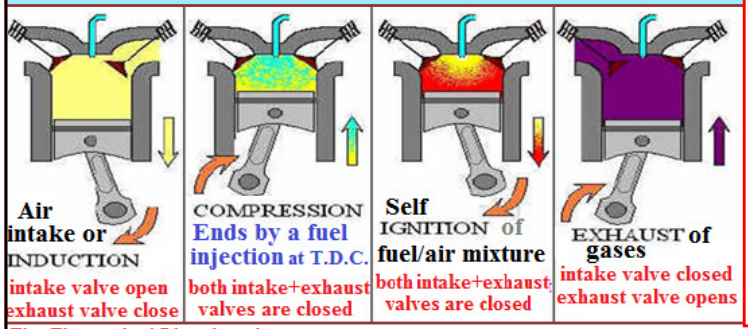
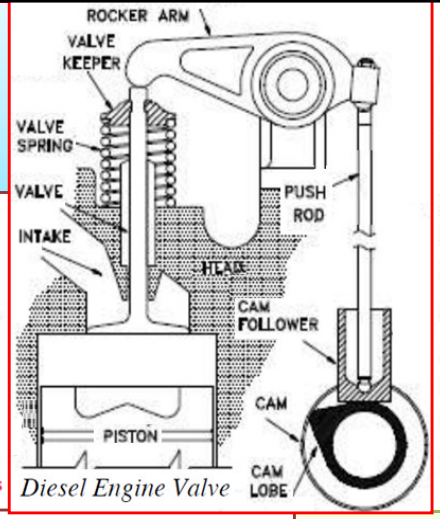
Mechanical Power Engineering Department

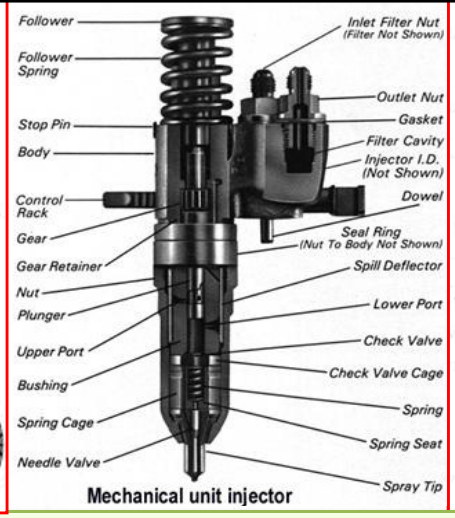
Abstract: **Our objective is to practice doing an applied-full design fora sequential PLC control system.Our project exercise is performing PLC logic fora4stroke Diesel engine toreplace anexisting cam-shaft &timing-belt control system in real engine. Cam-shaft controls all the sequence of opening/closing of intake&exhaustvalves and fuel injection process also to ensure efficient&safe operation of engine. Our designrequired to fully understandtypes, parts, operation cycle& speed control of Diesel engine. Different specific sequential steps in actual Diesel cycle are defined on a P-V chart (asseen on fig.below). All thermal/work processes are defined foreach step. Requirementsfor eachvalve actionrelative to both T.D.C.& B.D.C. positions are determined. Timing of fuel injection process is also examined to simulate having variable rpm speed as in real Diesel engine.**

Control Part: **PLClogicrequires todefineall input/output signals existing in a system. The P-Vchart is also used to define variousconditions of all I/O transitions between all cycle steps (as seen on fig.below).We defined also all number of input sensors&output actuators needed to replace the cam-shaft &timing-belt jobs to run one-cylinder only (as is the scope of our exercise). One solenoid actuated-spring return hydraulic cylinder is used to open/close each of intake/exhaust valves. To implement our PLC control system design, a detailed SFC (sequential function/flow chart) is drawn.The SFCdefined all control steps in addition to all the transition conditions existing before & after each step to prevent a signal trapping during the system operation. Educational/training PLC software (called TRiLOGI) is used to write the required PLC-LAD program needed to convert SFCinto functioning logic control system. The simulator section of TRiLOGI is also used to compile, test&run simulation of the project complete LAD program. Analysis of simulation results relative to each input or output signal should assure propercycle performance& having correct operation of intake/exhaust valves& timing of fuel injection pump.**

Major Components of Diesel Engine: **To understand how diesel engine operates, understanding of major components & how they work together is necessary as seen on fig.2 for 4-stroke, supercharged, diesel engine with inlet ports and exhaust valves.**







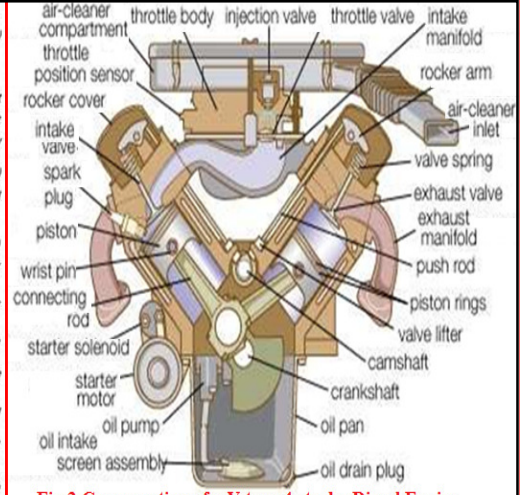
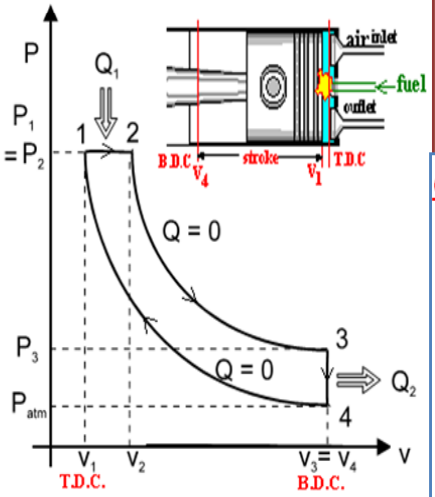


Fig.2 Cross-section of a V-type 4 stroke Diesel Engine

The Theoretical Diesel cycle:

Theoretical Diesel cycle is realized in compression-start type engines (i.e.,cycle compresses fresh-air only without fuel up to T.D.C. in adiabatic process 4-1 as on p–v diagram). After compression 4-1, piston is at T.D.C., a volume v_1 of compressed air is in physical state (1) at both high pressure P_1 & temperature T_1. If we inject a certain amount of finely atomized liquid fuel oil to come in good contact with air, that fuel ignites &burns with the hot compressed air at a constant pressure because the gas volume will increase as consequence of piston movement downwards. During constant pressure process 1–2, combustion will give the heat added quantity: $Q_1 = c_p \cdot (T_2 - T_1)$. At pt 2 gases will expand adiabatically up to point 3 (B.D.C.) where it is discharged to atmosphere at P_4. The pressure will instantaneously drop from P_3 to P_4 in transformation at constant volume represented by line 3-4. The heat rejected quantity is equal to: $Q_2 = c_v \cdot (T_3 - T_4)$. At point 4, a new air quantity is reintroduced and it is compressed adiabatically up to point 1 where the cycle restarts. The ratio $C = (V_4/V_1)$ is called compression ratio. Because compression 4-1 is done on the air only, the compression ratio (and therefore P_1&T_1) for the Diesel cycle is higher than the corresponding values for the Otto cycle. For the Otto cycle, the compression is done on a mixture of air & fuel where we have to keep T_1 below the self flashing of the fuel before reaching the T.D.C.

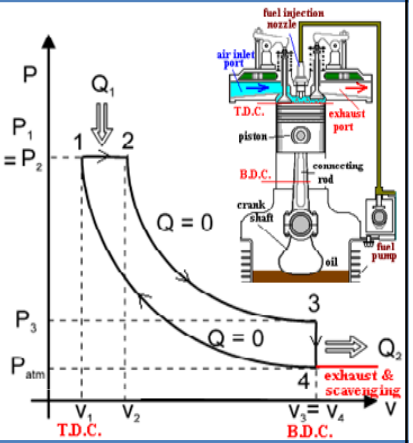


How Does Diesel Engine Work? **(as on above fig.) 1.Intake valve opens up to get air into cylinder. 2.Compression: piston moves back up and compresses trapped air. 3. Fuel injection: As piston reaches TDC, fuel is injected into cylinder. 4.Combustion: At just right moment, fuel is self ignited by heat from compression, forcing piston back down to BDC. 5.Exhaust: piston moves up to TDC, pushing exhaust gases created from combustion out of exhaust valve.**

Control Sequence of Theoretical 4 stroke Diesel Cycle:

It is assumed that the processes of compression 4-1, the combustion 1-2 and the exhaust 3-4 of the working cycle begin and end in correspondence with dead centers. We assume that the opening and closure of inlet air valve and exhaust valve is instantaneous and that fuel injection is instantaneous too. Combustion is assumed at constant pressure while expansion and compression are reversible-adiabatic. Moreover, we note that the distribution camshaft executes half of the revolutions of engine shaft (1 cycle = two revolutions).

We will follow the four processes succession on the engine working diagram and on the work cycle diagram. At the same time it is possible to follow also the distribution circular diagram; this one presents the relative positions of the handle in correspondence with distribution gear.



For the following figures, each one represents a 90° of the crank shaft rotation angle.

Fig.1: Suction starts at constant pressure:

Engine functioning diagram: **At T.D.C., inlet valve opens and piston starts moving down to B.D.C. and starts suction of air into cylinder (exhaust valve is closed-there is no scavenge process).**

Theoretical cycle diagram: **The line at constant pressure changes to red.**

Distribution Diag.: **The covered arc changes to red.**

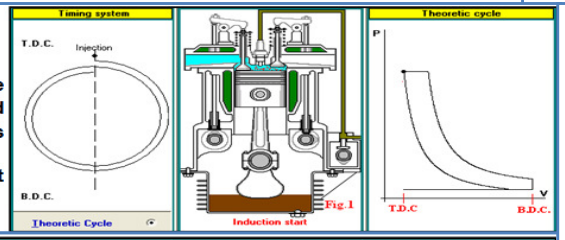


Fig.2: Suction goes on at constant pressure:

Engine functioning diagram: **Inlet valve keeps open and the piston keeps moving down to the B.D.C. and suction of fresh air into the cyclinder goes on(exhaust valve is closed-there is no scavenge process).**

Theoretical cycle diagram: **The line at constant pressure changes to red.**

Distribution Diag.: **covered arc changes to red.**

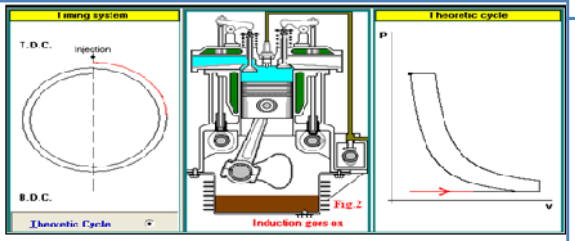


Fig.3: Const. Press. suction ends at B.D.C.:

Engine functioning diagram: **Inlet valve closes when the piston reaches the B.D.C. and suction of fresh air into the cyclinder is complete (exhaust valve is closed).**

Theoretical cycle diagram: **The line at constant pressure changes to red.**

Distribution Diag.: **covered arc changes to red.**

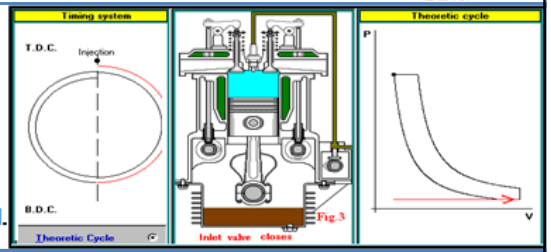


Fig.4: Adiabatic Compression starts at B.D.C.:

Engine working diagram: **Adiabatic compression starts at B.D.C.,The suction valve is closed. After B.D.C. piston keeps going up till reaching the T.D.C. where the compression ends**

Theoretical cycle diagram: **The adiabatic compression changes to red.**

Distribution diagram: **covered arc changes to red.**

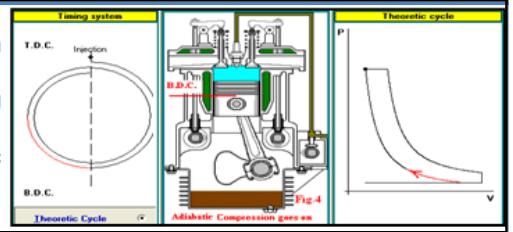


Fig.5: Adiabatic Compression ends at T.D.C.:
Engine working diagram: The suction valve closes, starting from bottom dead center, the piston begins to go up.
Theoretical cycle diagram: The compression adiabatic changes to red.
Distribution diagram: The covered arc changes to red.

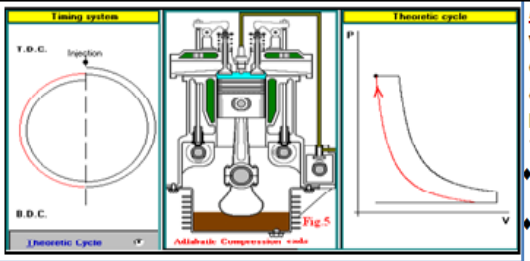


Fig.6: Injection of liquid fuel oil:
Engine working diagram: The piston is at T.D.C., the injection of liquid fuel oil takes place into the hot compressed air.
Theoretical cycle diagram: The circle relative to the injection changes to red on the diagram.
Distribution diagram: The circle relative to the injection changes to red on diagram.

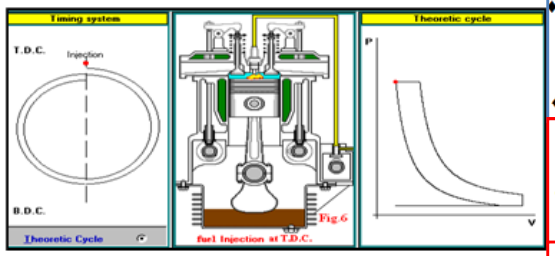


Fig.7: Starting of both combustion & Expansion
Engine working diagram: Starting from T.D.C., piston moves down starting combustion (at pressure=c) afterwhich an adiabatic expansion starts.
Theoretical cycle diagram: The combustion line at constant pressure and the adiabatic expansion change to red.
Distribution diagram: The covered arc changes to red.

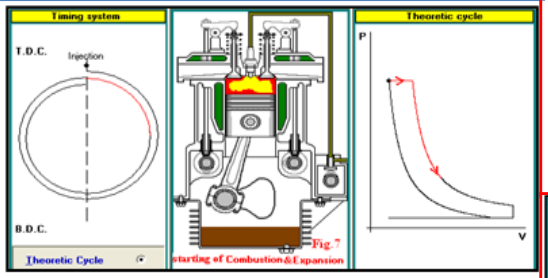


Fig.8: Expansion ends at B.D.C.&Exhaust starts
Engine working diagram: Piston keeps going down till B.D.C. where the adiabatic expansion ends & exhaust starts.
Theoretical cycle diagram: All the combustion line at constant pressure and the adiabatic expansion change to red.
Distribution diagram: covered arc changes to red.

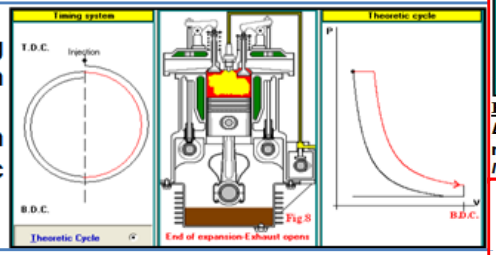


Fig.9: Spontaneous exhaust at B.D.C.:
Engine working diagram: As piston reaches B.D.C., the exhaust valve opens & the exhaust starts at constant volume.
Theoretical cycle diagram: The exhaust line at constant volume changes to red.
Distribution diagram: covered arc changes to red

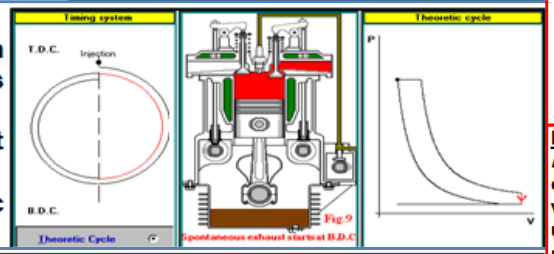
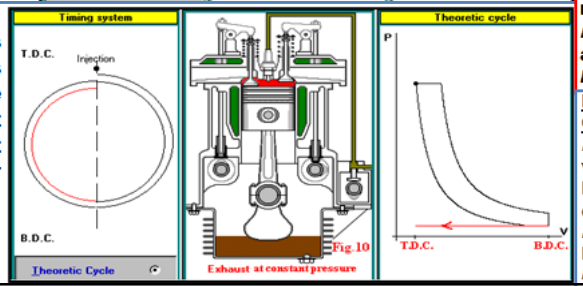
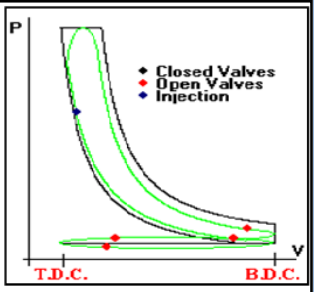


Fig.10: Exhaust goes on at const. pressure:
Engine working diagram: Exhaust valve is opened, starting from B.D.C., piston moves up. Exhaust goes on at constant pressure till the piston reaches T.D.C where outlet valve closes ending the exhaust process. At T.D.C., inlet valve opens to draw fresh air into cylinder to repeat the cycle (as in fig.1).
Theoretical cycle diagram
Line at constant pressure changes to red.
Distribution diagram: covered arc changes to red



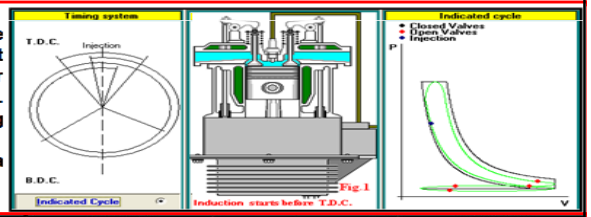
Indicated or actual cycle: Real cycle presents many differences in comparison with theoretical one; to show it better, the real cycle (shown in green) is placed on top of the theoretical cycle (shown in black). Moreover the opening priming & closure delays of valves are indicated with some circles (red if valve is open, black vice versa). Blue circle carries out same function for injection of fuel oil. The pumping area is visible. Shifting from the theoretic cycle is due mainly to:

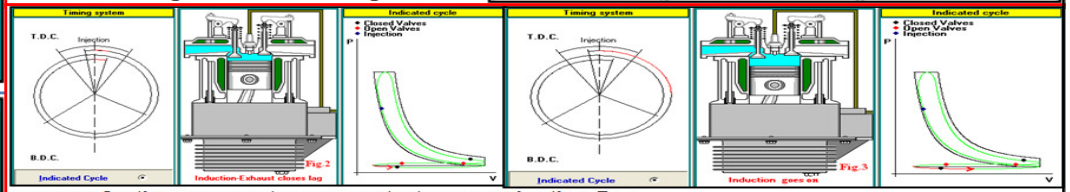
- 2 processes of expansion & compression are not adiabatic, but, because of heat loss by cylinder walls, polytropic of lower exponent ($Pv^n=c$; $n < \gamma$).
- Injection takes place late due to time between instant at which pump begins delivery to sprayer& instant at which effective injection into cylinder begins.
- Combustion is not instantaneous, but requires certain time, because of flame front propagation. It occurs, 1st, almost at constant volume and, subsequently almost at constant pressure; ♦ Valves don't open&close instantaneously at dead centers, but they open with certain priming & close with certain delay;
- **Increase of specific heats&CO_2 dissociation cause decrease of temperature & so of combustion pressure.**



Important Notice: In order to show every action in indicated cycle & due to those early and delays timing actions in indicated cycle, sequence of figures in the flowing does not correspond to 90° for each figure as we have seen for the theoretical cycle. We have here 14 figures for the indicated complet cycle (instead of 10 figures for theoretical cycle). Because of non-90° angles for the crankshaft, the lower part of the engine that includes the crankshaft and the lubricating oil is covered and thus is not shown on the 4-stroke indicated cycle.

Fig.1: Suction starts before T.D.C.:
Engine functioning diagram: Before reaching T.D.C., inlet valve open to start induction of fresh air into cyclinder when piston moves down to B.D.C. (exhaust valve is also open allowing scavenge process to take place).
Indicated cycle diagram: The line at a non constant pressure changes to red.
Distribution Diag.: covered arc changes to red.





Figs.2&3: Suction goes on at a non-constant pressure les than P_{atm}:
Engine functioning diagram: Exhaust valve closes lag after T.D.C. ending the scavenge process. Piston moves down to B.D.C. and suction of fresh air into cyclinder goes on.
Indicated cycle diagram: Line at non constant pressure changes to red. *Distribution Diag.:* covered arc changes to red.

Fig.4: Nonconst. Press. suction up to B.D.C.:
Engine functioning diagram: Piston reaches B.D.C. & suction of fresh air into the cyclinder is complete but inlet valve does not close. Delay closing takes place after B.D.C.
Indicated cycle diagram: The line at a non constant pressure changes to red.
Distribution Diag.: covered arc changes to red.

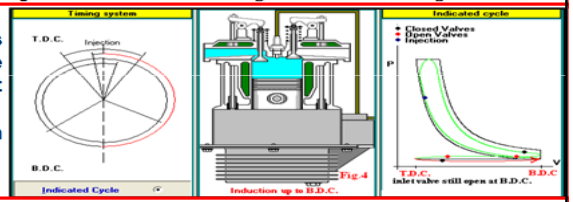


Fig.5: nonadiabatic Compression starts at B.D.C.
Engine working diagram: Non-adiabatic compression starts at B.D.C., The suction valve will close lag after B.D.C. Piston keeps going up till reaching the T.D.C. where the nonadiabatic compression ends
Indicated cycle diagram: The start of a non-adiabatic compression changes to red.
Distribution diagram: covered arc changes to red.

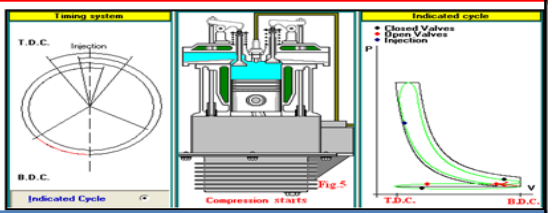


Fig.6: Inlet valve closes while a non-adiabatic Compression goes on:
Engine working diagram: The suction inlet valve closes lag after passing through the B.D.C. while the piston keeps going up to complete the nonadiabatic compression.
Indicated cycle diagram
Nonadiabatic compression changes to red.
Distribution diagram: Covered arc changes to red.

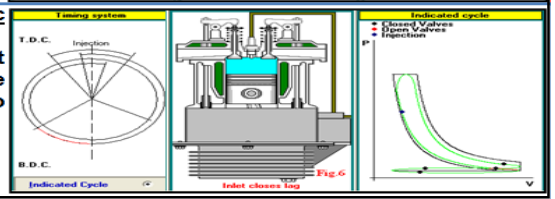


Fig.7: Injection of liquid fuel before T.D.C.:
*Engine working diagram:*Compression goes on. Before piston reaching T.D.C., advanced injection of liquid fuel takes place into hot compressed air.
Indicated cycle diagram: circle relative to injection changes to red on the diagram.
*Distribution diagram:*Circle relative to the injection changes to red on the diagram.

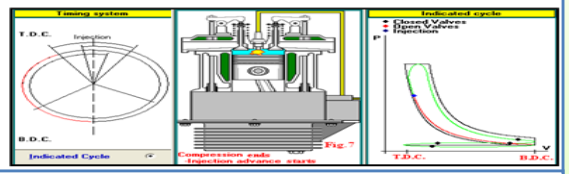


Fig.8: Advanced combustion starts before T.D.C.
*Engine working diagram:*Advanced combustion starts while the piston goes up towards T.D.C. afterwhich the piston moves down starting combustion process at a nonconstant pressure.
*Indicated cycle diagram:*Combustion line changes to red.
Distribution diagram: covered arc changes to red

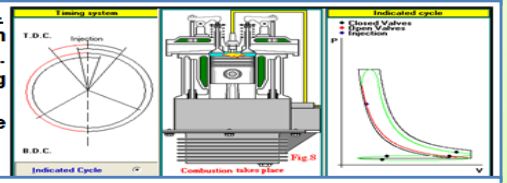


Fig.9:Both combustion & Expansion goes on
*Engine working diagram:*Starting from T.D.C., the piston moves down starting a nonconstant pressure combustion after which the nonadiabatic expansion starts.
Theoretical cycle diagram: combustion line and nonadiabatic expansion change to red.
Distribution diagram: covered arc changes to red.

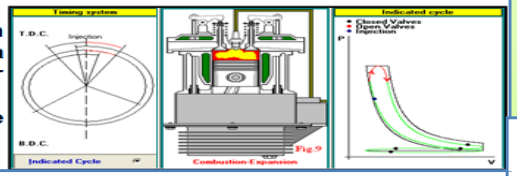


Fig.10: Expansion goes on & Exhaust starts
*Engine working diagram:*As piston keeps going down, a nonadiabatic expansion takes place. Before reaching B.D.C. outlet valve opens in advance starting exhaust at nonconstant volume process.
*Indicated cycle diagram:*nonadiabatic expansion changes to red.
Distribution diagram: covered arc changes to red.

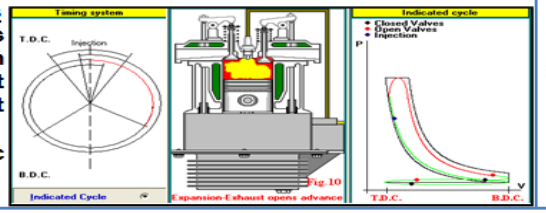


Fig.11:End of expansion&Exhaust starts before BDC:
*Engine working diagram:*Nonadiabatic expansion ends before piston reaches B.D.C., the exhaust valve opens & the exhaust starts at constant volume.
Indicated cycle diagram: exhaust line at constant volume changes to red.
Distribution diagram: covered arc changes to red

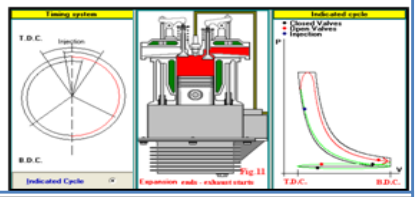


Fig.12: Exhaust at nonconstant pressure:
*Engine working diagram:*Exhaust valve is opened, before B.D.C., piston moves up. Exhaust goes on at nonconstant pressure till the piston reaches T.D.C.
Indicated cycle diagram: line at non constant pressure changes to red.
Distribution diagram: covered arc changes to red

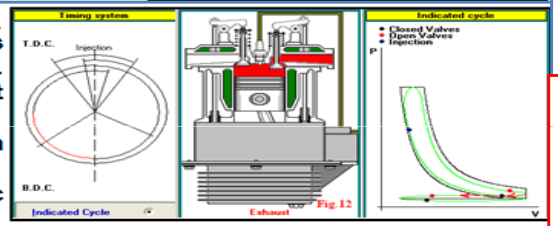


Fig.13: Exhaust goes on&inlet fresh air helps scavenge:
*Engine working diagram:*Exhaust valve is kept opened before T.D.C., piston keeps moving up. Exhaust goes on at nonconstant pressure. Before T.D.C., inlet valve opens in advance so that fresh air helps scavenge of exhaust gases.
Indicated cycle diagram: line at non constant pressure changes to red.
Distribution diagram: covered arc changes to red

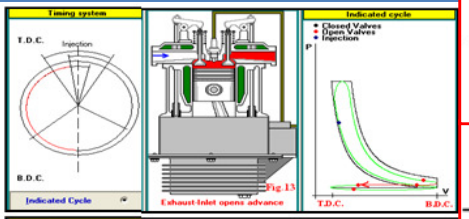
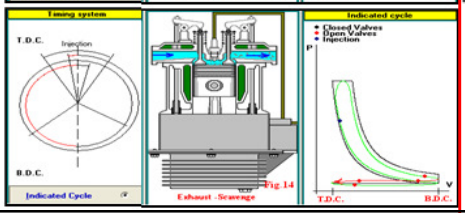
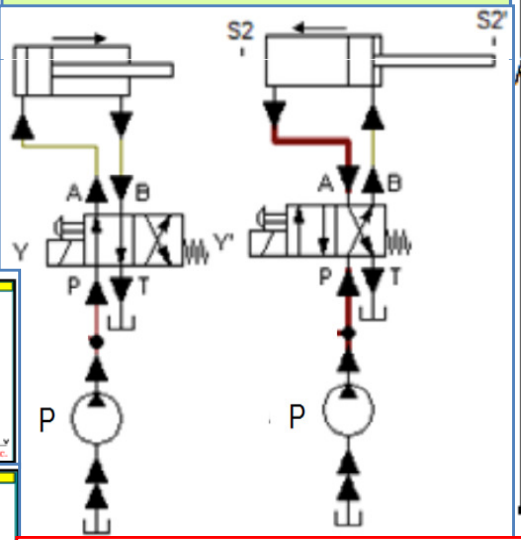


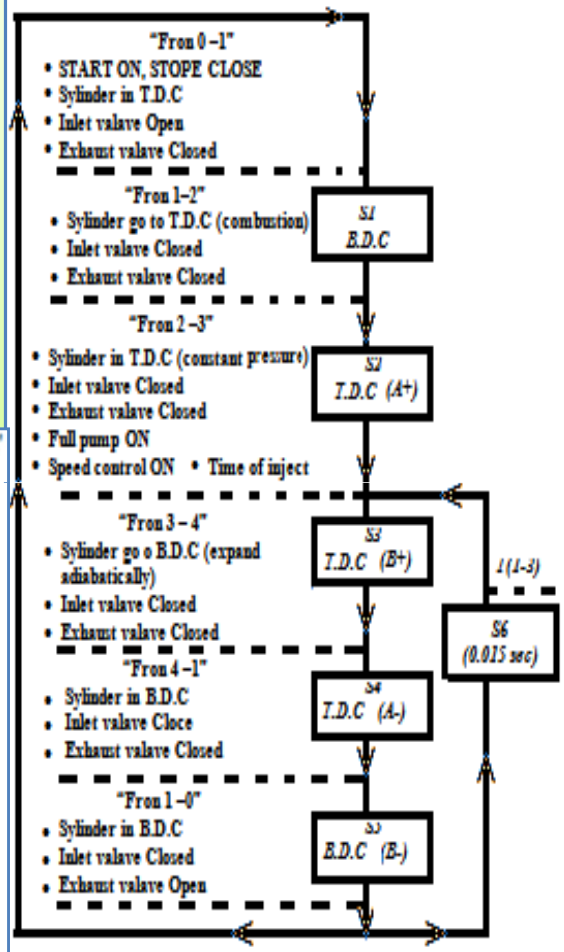
Fig.14: Inlet fresh air helps scavenge:
*Engine working diagram:*At T.D.C., inlet & exhaust valves are openD.C., piston moves up. Exhaust goes on at non constant pressure. Before T.D.C., inlet valve opens in advance and fresh air helps scavenge of exhaust gases. This completes the cycle to start a new cycle (with Fig.1 as shown before).
Indicated cycle diag: line at non constant pressure changes to red.
Distribution diagram: covered arc changes to red

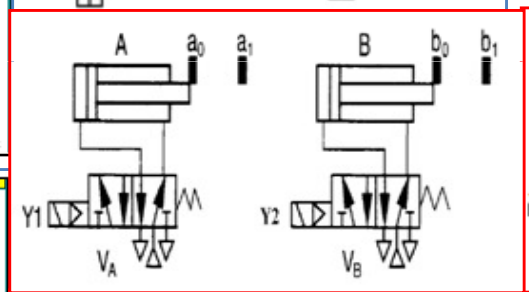


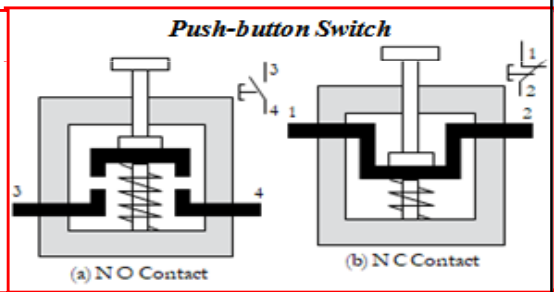
Hydraulic circuit: *In the electrical actuation of a hydraulic valve, the necessary actuating force is obtained electrically with the help of a solenoid. The off-centre core of the solenoid coil is pulled towards the centre of the coil when the electric current is passed through it. This discrete movement of the core is used to actuate the solenoid valve. The solenoid valve in an electro-hydraulic system acts as an interface between the hydraulic part and the electrical part of the system.*

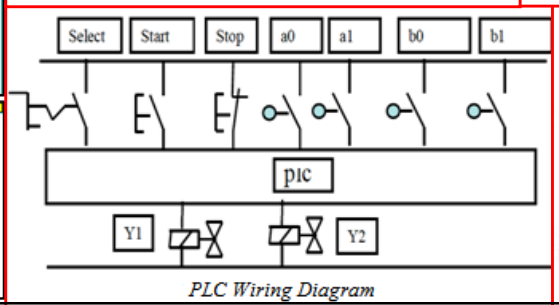


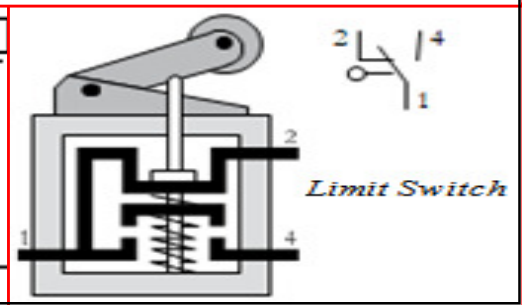
Using the Sequential Function Chart SFC

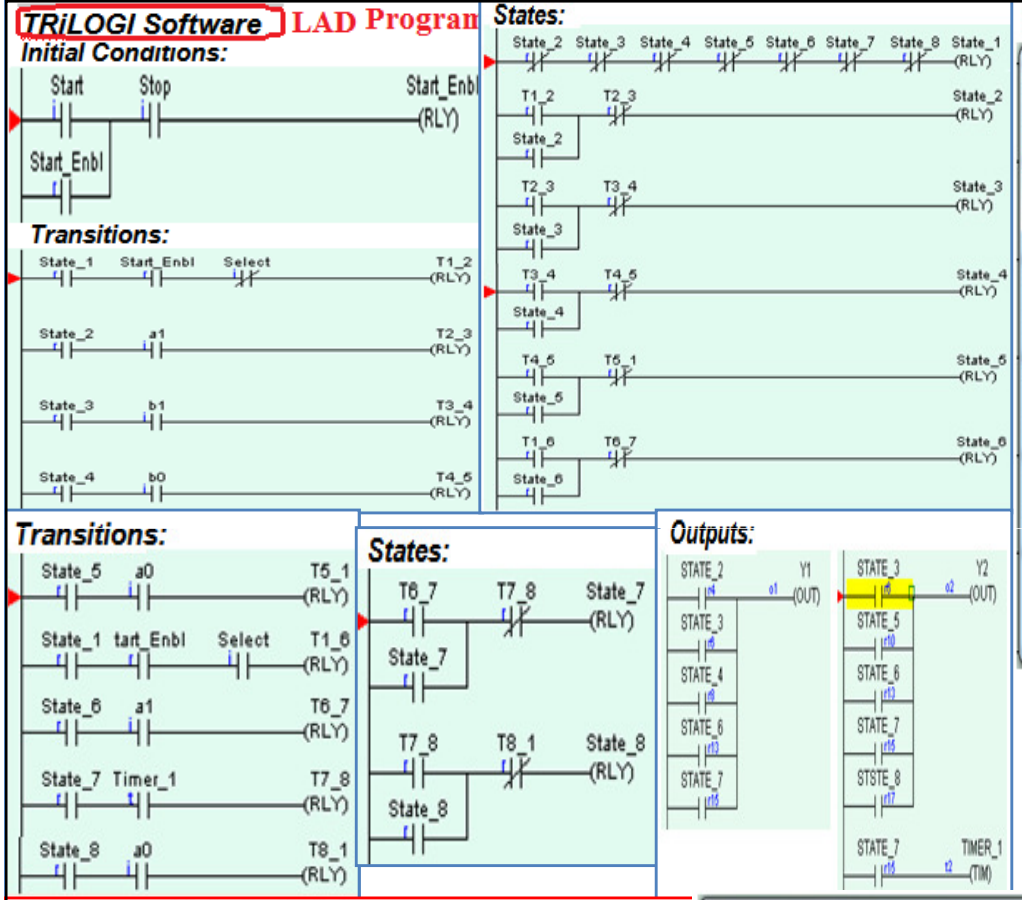


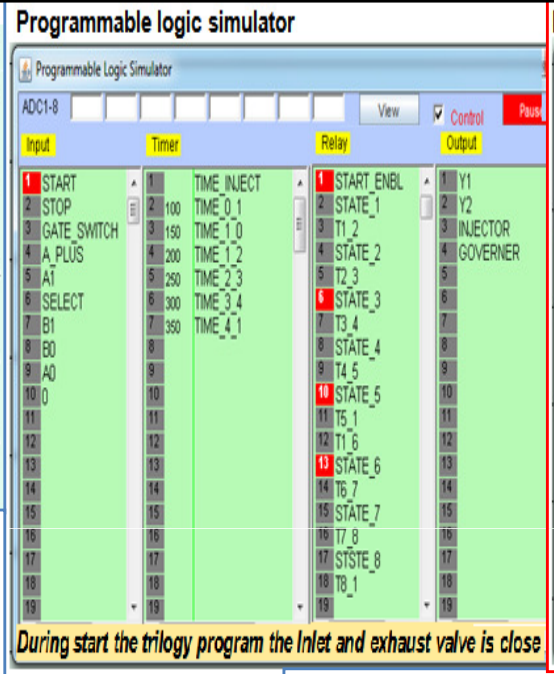


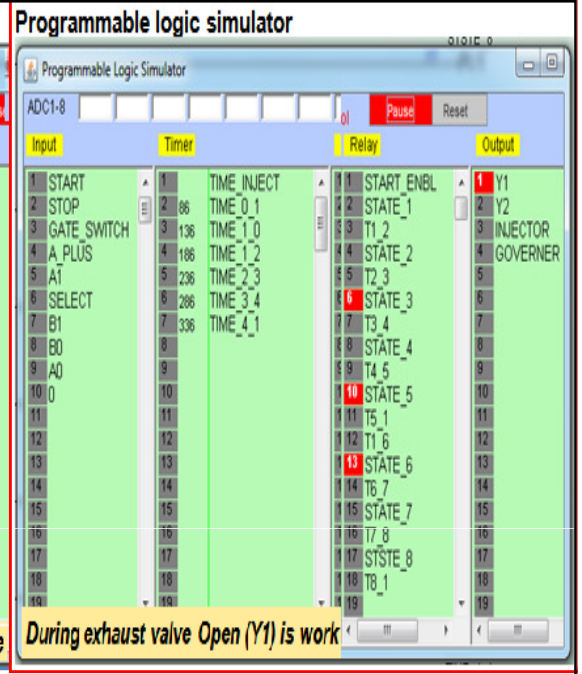


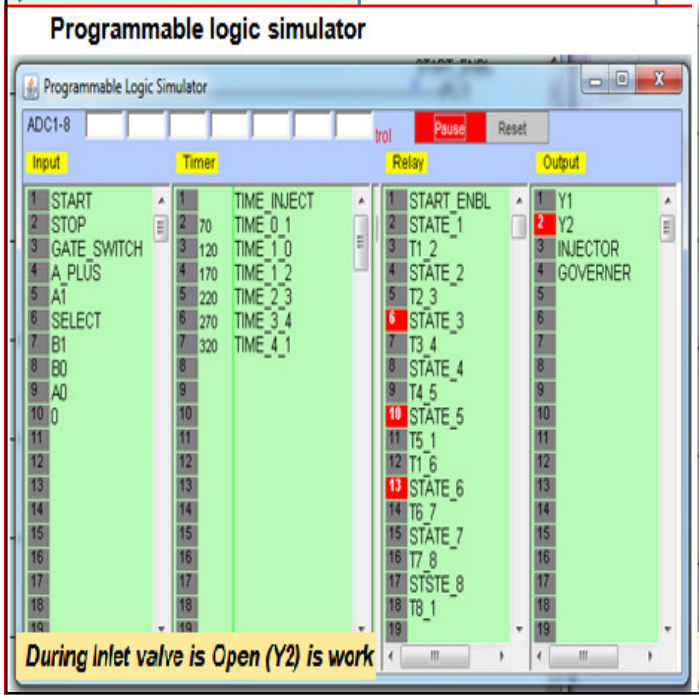


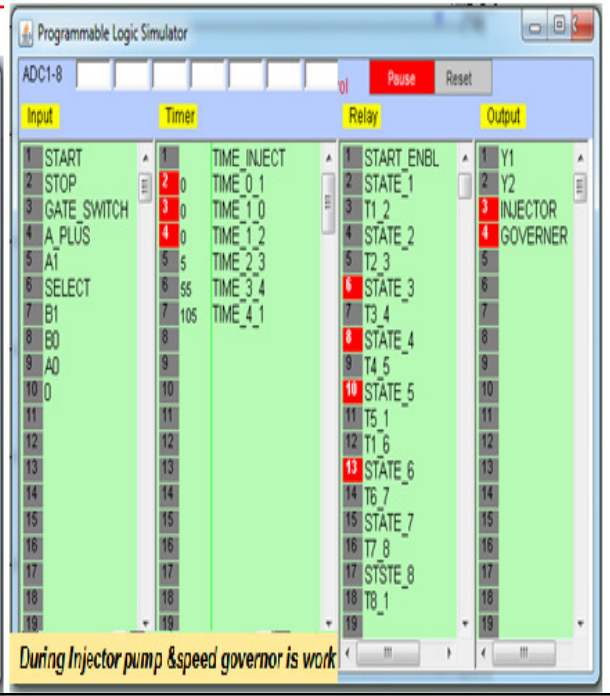












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