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REDUCTION OF FUEL CONSUMPTION IN MULTICYLINDER ENGINE BY CYLINDER DEACTIVATION TECHNIQUE

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Abstract:
The four stroke Spark Ignition (SI) engine's P–V diagram contains two main parts. They are the high pressure loop (compression–combustion–expansion) and the low pressure (exhaust-intake) loops. The main reason for efficiency decrease at part load conditions for these types of engines is the flow restriction at the cross sectional area of the intake system by partially closing the throttle valve, which leads to increased pumping losses. This can be rectified by implementation of cylinder deactivation in four cylinder SI engine by developing proper control system.
Keywords:
SI engine, Part load, Pumping loss, Pressure loop, Cylinder Deactivation.

1. INTRODUCTION:

The non renewable energy sources such as fossil fuels like petrol, diesel, etc. are continuously under depletion. Even though the renewable energy sources exist, the utilization of such energy resources is very low due to high cost involved in utilization of such resource. Hence the fossil fuel must be effectively utilized. The internal combustion engine has been the predominant power plant in the automobile for nearly a century. Although a century of development has lead to a highly refined technology, there is still some opportunity for further fuel efficiency gains [1].

The four stroke SI engine is a widely applied power source in transportation and other power generation units. However, with the increasing number of such applications, air pollution caused by exhaust emissions has become of primary significance due to its environmental impact. During the past forty years, with the pressure of governmental policies and enormous research activity in this area, the emission (NO_x, CO and HC) levels have been decreased significantly. In the future, a considerable decrease in emission levels due to further improvement in engine technology is expected. Reducing the fuel consumption and related CO_2 emission is increasingly important these days. Typically, internal combustion engines operate more efficiently when the engine load is high [1-3]. However in daily life, most of the time the engine is operated in lower efficiency region. Better matching of real engine load with optimum engine load can be obtained by applying cylinder deactivation [3]. By deactivation of cylinder, the load of the still activated cylinder is increased with improved efficiency.

Thomas Tsoi-Hei Ma used a multi-cylinder spark ignition internal combustion engine having two groups of cylinders, and developed disabling means for selectively deactivating one group of cylinders by cutting off its fuel supply while continuing to receive air. The exhaust system includes an NO_x trap to store NO_x gases while the exhaust gases contain excess air. During part load operation, the engine is run with one bank of cylinders disabled most of the time during which NO_x gases are stored in the NO_x trap. In order to permit the trap to be regenerated or purged periodically, both bank are fired at is the same time for short intervals to supply a stoichiometric or reducing mixture to the exhaust system. Michael Ralph Foster *et al.*, invented a controller and cylinder deactivation system to regenerate an exhaust after treatment device for a multicylinder engine that operates primarily at an air/fuel ratio that is lean of stoichiometry. The invention uses the cylinder deactivation system to control temperature and air/fuel ratio of an exhaust gas feed stream going into an after treatment device. The invention also increases the amount of fuel delivered to each non-deactivated cylinder by an amount sufficient to maintain operating power of the engine. The regeneration action includes desorbing NO_x from a NO_x adsorber catalyst, desulfating the NO_x adsorber catalyst, and purging a diesel particulate trap. Tyler M. Nester *et al.*, designed, implemented and tested crankshaft-mounted pendulum absorbers used for reducing vibrations in a variable displacement engine. The engine can run in V8 and V4 modes, and without absorbers it experiences significant vibration levels, especially in V4 idle. The absorbers are tuned to address the dominant second order vibrations, and are slightly overtuned to account for nonlinear effects. The absorbers were designed to replace the large counterweights at the ends of the crankshaft, and thus serve for both balancing and vibration absorption. The engine was placed in a vehicle and tested for vibration levels at idle under various load conditions, and these results were compared with results obtained from a similar vehicle without absorbers. The tests demonstrate that these absorbers offer an effective means of vibration attenuation in variable displacement engines. Wang Y *et al.*, implemented model-based control methodology utilizes position feedback, a nonlinear observer that provides virtual sensing of the armature velocity and current, and cycle to cycle learning for actuating electromechanical valve actuator. An electro mechanical valve actuator model was developed and experiments were used to identify unknown model parameters and functions and to validate the model predictions. Osman Akin Kutlar *et al.*, investigated the methods for increasing efficiency at part load conditions and their potential for practical use. M. Sellnau *et al.*, designed a 2-step variable valve actuation system and integrated on a 4-valve-per-cylinder 4.2 litre inline-6 engine and also used simulation tools to develop valve lift profiles for high fuel economy and low NO_x emissions. A 2-step valvetrain mechanism was developed that features hydraulically-actuated switchable rocker arms and hydraulic lash adjusters. The engine management system was modified for control and calibration of 2-step VVA, and to realize the full fuel economy potential of the system.

From the literature survey it is clear that more focus is required on development of control system which helps to change the mode from normal mode to deactivated mode or vice versa while engine running without fluctuation in engine speed with respect to time.

2. METHODOLOGY:

- The thermal inefficiency due to pumping loss in 4 stroke multicylinder SI engine during part load will be thoroughly understood.
- This inefficiency will be reduced by cylinder deactivation which means stopping fuel supply to certain cylinders in a multicylinder engine.
- The operating speed range and load range for deactivated mode will be determined from performance curve (torque- speed curve) obtained by conventional testing method.
- The throttle angular position for normal mode and deactivated mode at various load and speed where the mode change is planned will be determined using stepper motor interfaced to PC with LabVIEW software through DAQ card.
- A mathematical model for change in throttle angular position required during mode change will be developed based on experimental result and will be incorporated into the LabVIEW program.
- The load cell and proximity sensors will be interfaced to PC with LabVIEW software through DAQ card.
- The performance of the control system will be experimentally evaluated by plotting speed-time curve to observe the fluctuations in speed during mode change.

3. CYLINDER DEACTIVATION:

3.1. Pumping losses:

The four stroke, spark ignition (SI) engine pressure–volume diagram (P–V) contains two main parts. They are the compression–combustion–expansion (high pressure loop) and the exhaust-intake (low pressure or gas exchange loop) parts that are shown the Figure 1. The main reason for efficiency decrease at part load conditions for these types of engines is the flow restriction at the cross sectional area of the intake system by partially closing the throttle valve, which leads to increased pumping losses and to increased low pressure loop area on the p–V diagram [5- 8].

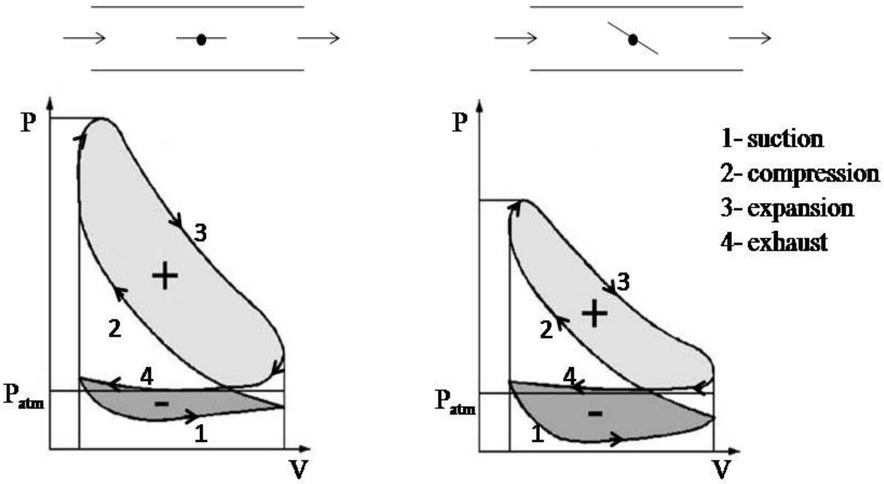
3.2. Need for cylinder deactivation:

Cylinder Deactivation refers to cutting of fuel supply to selected cylinders in a multicylinder engine so that the active cylinders which have fuel supply are operated near to full load [6].

When the engine is operated at part load condition with half the number of cylinders (two cylinders) deactivated, the throttle valve is widely opened compared to normal mode (four cylinders are operated). Hence the pumping loss is reduced in deactivated mode during part load condition. Therefore the total fuel consumption of the engine in deactivated mode is reduced.

3.3. Advantages of cylinder deactivated engines

- Increased fuel efficiency (10-20%).
- Decreased emissions from deactivated cylinders.
- Better breathing capability of the engine, thereby reducing power consumed in suction stroke.



Full load part load

Figure 1. Schematic diagram showing throttle valve position and P-V diagram for full load condition and part load condition

4. FEASIBILITY OF PROJECT WORK:

The morse test rig is used to investigate the feasibility of cylinder deactivation in four cylinder SI engines. In order to check the feasibility, the total fuel consumption of the engine has to be calculated in normal mode (four cylinders mode) and in deactivated mode (two cylinders deactivated).

4.1. Manual testing in four cylinder mode:

The engine is operated at normal mode. The fuel consumption (in kg) is measured for a constant time period using an electronic weighing machine. The total fuel consumption (in kg/hr) is measured at various speeds by constant load test. The experiment is repeated for different loads and the readings are tabulated in Table 1.

4.2. Manual testing in two cylinder mode:

The engine is operated at deactivated mode. The fuel supply to two selected cylinders is cut-off by switching off the electrical pulses to the fuel injectors of those cylinders.
The total fuel consumption is measured by using the same procedure followed for the normal mode. The total fuel consumption is measured and tabulated in Table 2.

4.3. Comparison of TFC between two modes:

The percentage reduction in fuel consumption when the engine is operated in two cylinder mode is calculated with respect to normal mode and tabulated in Table 3.The average percentage reduction in fuel consumption is 22.71 %.
From Table 3, it is clear that the cylinder deactivation in 4 cylinder SI engine reduces total fuel consumption. Hence the project is feasible.

Table 1. Total fuel consumption (kg/hr) in four cylinder mode

Speed (rpm) / Torque (Nm)	1200	1400	1600	2000	2200	2500
0	1.2	0.96	1.25	1.67	1.81	1.92
6	0.96	1.44	1.92	1.68	2.16	2.4
12	1.2	1.44	1.68	1.92	2.64	2.16
18	1.44	1.92	2.16	2.16	2.88	3.12
24	1.92	2.16	2.4	2.64	2.88	3.36
32	1.68	1.92	2.4	2.88	3.12	3.12

Table 2. Total fuel consumption (kg/hr) in two cylinder mode

Speed (rpm) / Torque (Nm)	1200	1400	1600	1800	2000	2200	2500
0	0.69	0.84	0.85	0.92	1.02	1.45	1.50
6	1.02	0.76	1.09	1.61	1.65	1.49	1.91
12	1.08	1.29	1.44	1.52	1.58	1.91	2.09
18	1.12	1.21	1.35	1.66	1.82	2.30	2.39

Table 3. Percentage reduction in fuel consumption

Torque (Nm) \ Speed (rpm)	1200	1400	1600	2000	2200	2500
0	42.86	12.02	32.24	39.17	19.96	21.81
6	-6.03	46.95	43.10	1.97	30.84	20.59
12	9.86	10.67	14.23	17.82	27.75	3.15
18	22.22	37.14	37.52	15.69	20.17	23.42

5. SCHEMATIC DIAGRAM OF SETUP:

The LabVIEW software necessary to interface DAQ card with PC is installed on the computer. The various sensors and stepper motor are connected as shown in Figure 2. The relays are used to cutoff the signals from ECU to the injectors.

The 5V supply required to energize the relay coil is supplied from digital output of the DAQ card. When the mode change torque or speed is reached, the labVIEW program supplies power through digital output. The relay is energized in such a way that the signals to alternate cylinders in firing order.

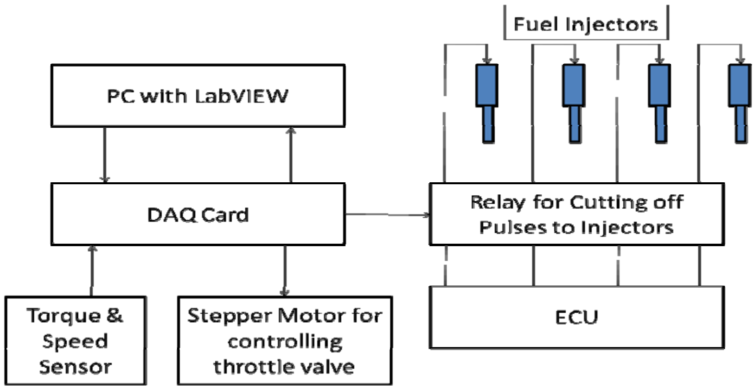


Figure 2. Block diagram showing connection between various elements

6. DESIGN OF THROTTLE ACTUATING MECHANISM:

6.1. Need for stepper motor:

The stepper motor is used to actuate the throttle valve. The actuation of throttle valve is done using stepper motor because while changing the mode, the throttle valve position is to be altered automatically so that there is no drop in speed of the engine. When the mode is changed from normal mode to deactivated mode, the throttle valve has to be opened wider. Similarly when the mode is changed from deactivated mode to normal mode, the throttle valve has to return to original position.

6.2. Working of stepper motor:

The commonly used stepper motor is four coil unipolar type as shown in Figure. 3. They are called unipolar because they require only that their coils be driven ON or OFF. If the stepping sequence is forward (coil 1-2-3-4), the stepper motor rotates clockwise. If the stepping sequence is reversed (coil 4-3-2-1), the stepper motor rotates counter clockwise [17].

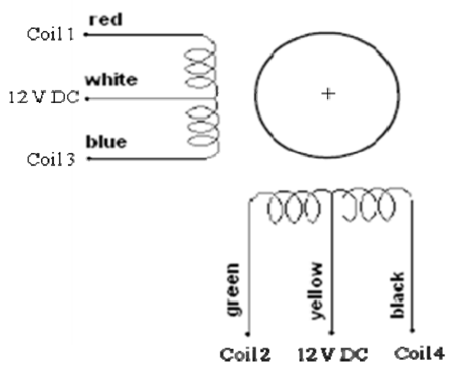


Figure 3. Schematic diagram of stepper motor showing various terminals

6.3. Interfacing stepper motor with PC:

The stepper motor is controlled by PC through NI-USB6009 DAQ card of National Instruments. The control program required to control the stepper motor is developed using LabVIEW software. The selected stepper motor requires a supply voltage of 12V and the coil current of 1.2 A/Phase. For each step it can turn 1.8 degrees.

The maximum output of DAQ card is 5 V. But the stepper motor requires 12 V. Hence the output of DAQ card has to be stepped up to 12 V. This is achieved by using ULN 2003 IC. The ULN 2003 IC requires a supply voltage of 12V DC which is given from power supply unit or battery. It is recommended to connect a 12V zener diode between the power supply and V_{DD} (Pin 9) on the chip, to absorb reverse (or "back") EMF from the magnetic field collapsing when motor coils are switched off [17].

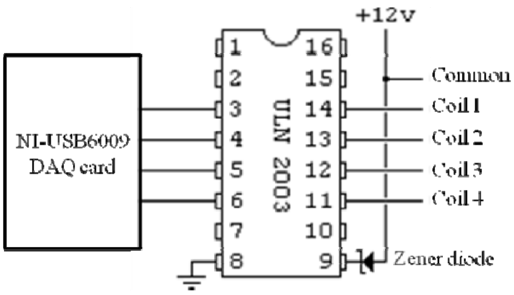


Figure 4. Schematic diagram showing connection between stepper motor coil and DAQ card through ULN 2003 IC

7. PROGRAMMING IN LABVIEW:

The stepper motor is controlling VI consist of a front panel as shown in Figure 5 and a block diagram shown in Figure 6. The stepper motor rotates based on the number of rotations and speed given as input.

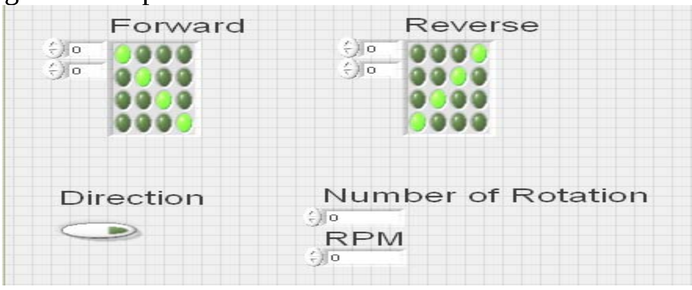


Figure 5. Front panel of stepper motor control LabVIEW program

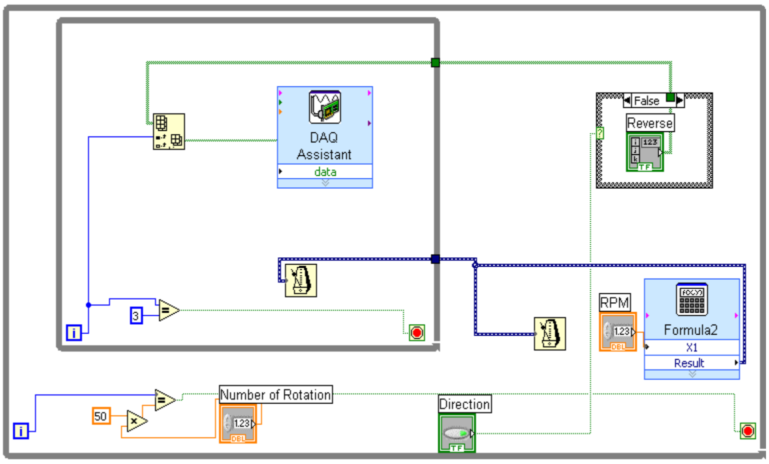


Figure 6. Front panel of stepper motor control LabVIEW program

8. CONCLUSION:

The fuel economy benefit for four cylinder engine was evaluated using cylinder deactivation technique. The maximum fuel economy benefit is achieved when the load on the engine is nearer to full load of two cylinder mode. The average percentage reduction in fuel consumption was experimentally found to be 22.71 %. The mechanism and program for actuation of throttle valve controlled by labVIEW program was designed and developed. It was also observed that the usage of high precision stepper motor had ensured a good response to mode change with less speed fluctuation.

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