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Pneumatic, PLC Controlled, Automotive Gear Shifting Mechanism

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Abstract: In this study, a gear shifting mechanism was designed and applied to make the shifting process faster and less destructible for the driver. The new device must be reliable, has a small dimensions, low construction and maintenance cost. This paper aims to improve gear shifting process using devices as: a manual four speed gear box, four pneumatic double acting cylinders, four pneumatic two position five ways directional control valves, Programmable Logic Controller (PLC) LOGO unit, an electrical motor, an electrical clutch, a belt, two pulleys, limit switches, push buttons, bulbs, a table (holder) and power supply. According to suggested gear_ shifting method the driver can select the transmission gear ratio without moving his hands from the steering wheel by putting the gear shifting push buttons on the steering wheel. Using this method leaves to the driver the excitement of choosing the shifting moment.

Key words: Directional control valve, gearbox, gear shifting mechanism, pneumatic cylinder, Programmable Logic Controller (PLC), solenoid valve

INTRODUCTION

This study describes in detail in an understandable way to how to convert the traditional manually gear shifting mechanism to a semi-automated gear shifting mechanism by using the Programmable Logic Controller (PLC).

Increasing demands on performance, quality and cost are the main challenge for today's automotive industry, in an environment where every movement, component and every assembly operation must be immediately and automatically recorded, checked and documented for maximum efficiency.

Automotive technology has been developed in many areas, like ABS system, active steering system and other safety systems, which are implemented to increase the passenger safety and comfort. The development has concluded also the gearbox, which became much smoother and produces less noise. Gear shifting mechanism must be easy to use and workable, these demands are very important especially for small cars used by special needs people.

MATERIALS AND METHODS

Steps, components and analysis: This work was achieved at the Department of Mechanical Engineering, Faculty of Engineering Technology, Al-Balqa' Applied University within 2009.

For some drivers, the gear shifting can cause some confusing at driving specially at critical situations. A crowded road on a hill or a sudden detour makes a lot of tension on the driver. One of the difficulties in this situation is to choose the right reduction ratio and engaging it at the right time (Brejcha *et al*., 1993; Okada *et al*., 2002; Taguchi *et al*., 2003; Yi, 1998).

This design helps the driver to increase his focusing on the road. Also reduces the time needed to engage the required reduction ratio, which increases the vehicles' response.

This design may be considered as an educational model for gear shifting mechanism. so, we pointed to the following:

- The suitable dimensions for the main components holder. Keeping in mind the addition of other parts for enhancement and development.
- A manual, 4-frontal speeds and one reverse speed gear box which is used in Mercedes-Benz automobile, rare wheel drive is chosen for this design because it is easier to modify.
- An electrical motor is used to create mechanical power instead of an internal combustion engine, which is difficult to be placed there. It is also used to make the engagement process easier.
- A manual clutch is replaced there by an electrical clutch. This uses electrical power from car battery (Fig. 1).
- A couple of pullies and a belt are used to transmit power from the electrical motor to the gear box. Both pullies are the same diameter and the belt is V type one (17 600) size.

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- To avoid binding in the input shaft caused by the radial force, we used a bearing fixed on the holder.
- We used four pneumatic, double acting cylinders, with different diameters, two are for the front and the rear motion the other two cylinders are for lateral sliding motion.
- Four (five ways, two positions) directional control valves are used to change the compressed air direction. Every directional valve has 12V solenoid that converts electrical power to magnetic power, which attracts the spool inside the valve; this action changes the compressed air direction.

Model components:
- A manual 4- speed gearbox
- Double acting pneumatic cylinders
- PLC LOGO unit
- 4-pneumatic 2 position 5 way directional control vales.
- An electrical motor (to simulate a combustion engine rotation).
- An electrical clutch (Fig. 1).
- Two pulleys
- A belt
- Pipes
- Wires
- Five limit switches
- Six PB
- Five bulbs
- Stand
- 12 Volt DC power supply

Components description:
The holder: The holder is made of cast iron. It consists of two groups, fixed one and movable one. The fixed group is the lower one. It holds the batteries (electrical source), the gearbox, the limit switches, the sliding cylinders and the electrical motor. The movable group is the upper one. It holds the PLC control unit, the buttons and indication lamps board, directional control valves and front and rear motion cylinders.

The holders' dimensions:
Length 0.9 m
Width 0.5 m
Height 0.9 m

The gearbox: The manual gearbox is a synchronizer type with helical gears. It has one input shaft and one output shaft. It has three shifting arms, one for first and second speeds, the second one for the third and fourth speeds and the last one for reverse one as shown in (Fig. 2). There are three Connecting rods one for each arm. Every connecting rod connects its shifting arm with a common shifting lever. Figure 3 shows the view above the plate and the view under the plate.

Fig. 1: Electrical clutch

Fig. 2: Gearbox shifting arms

Fig. 3: Gearbox common shifting lever

The common arm is 80 mm length with ability of sliding and axial motions. The axial motion is 35 mm forwards and 35 mm backwards (35mm↑.35mm). The sliding motion is 15 mm to the left and 15 mm to the right (15mm←15mm→). The arm is connected from the top with the front and rear pistons rod.

At the end of the gearbox input shaft there is a bearing. The outer side of the shaft is fixed in the bearing and the inner side is attached with the gearbox input shaft as shown in Fig. 4.

Fig. 4: The bearing

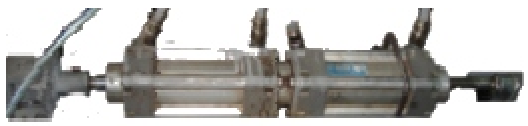

Fig. 5: Shifting cylinders

Fig. 6: Pivot joint connection

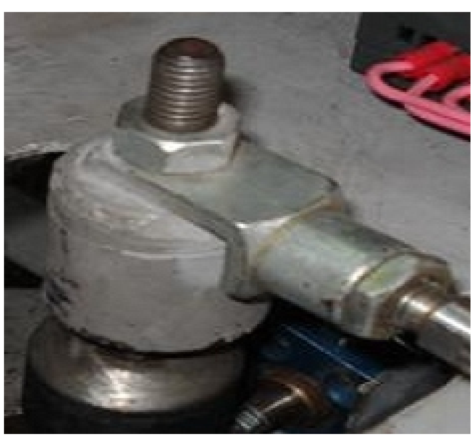

Fig. 7: Ball joint connection

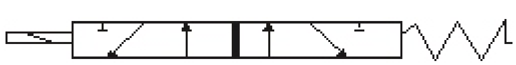

Fig.8: Directional control valve scheme

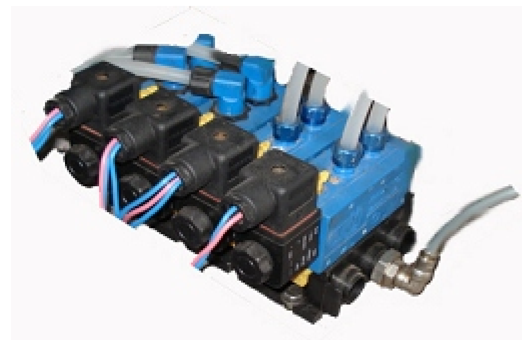

Fig. 9: Control valve hardware

Pneumatic cylinders: One of the problems we faced is how to stop the shifting lever at the mid point. The compressibility of air makes it difficult to stop the piston at a certain point. To solve this problem we used two cylinders for each mid point desired. For front and rear motion, the cylinders used are 35 mm stroke length and 32 mm bore diameter.

The cylinders are connected back-to-back (Taguchi *et al.*, 2003; Brejcha, 1993; Glielmo *et al.*, 2006) as shown in Fig. 5. By doing so, we get three positions of the shifting lever. The first position when the two cylinders are extracted. The second position when one is extracted, the other one is retracted and the final position is when the two cylinders are retracted. One end of the cylinders is connected to the frame by a pivot joint as shown in Fig. 6.

This joint allows the cylinders group to move with the shifting lever in lateral sliding movement (for example: shifting from the second gear to the third gear). The other end is connected with the shifting lever by a ball joint as shown in Fig. 7. This joint used to keep only the tangential force and eliminates any force on the cylinder rod.

For the sliding motion we used also two cylinders connected back to back to achieve the mid point. Here the piston diameter is not important because the force needed is negligible. The stroke for one cylinder is 15 mm as mentioned before, one end is connected with the frame holder and the other end is connected with the shifting lever.

Directional control valves: To control the direction of the compressed air passing to the cylinders, four directional control valves are used. They are compounded in one common input connected to the air pressure source, and two common exhaust ports that opened to ambient. Fig. 8 illustrates the directional control valve (Brejcha 1993; Glielmo *et al*, 2006; Inalpolat and Kahraman, 2008) scheme. It has a solenoid actuator and spring. Figure 9 shows the directional control valve hardware.

Fig. 10: PLC LOGO type

Fig. 11: Indication bulb panel

Fig. 12: Limit switch for the first gear indication bulb

Control unit: The used control unit is PLC LOGO with eight inputs and four outputs by Clements-Jewery and Jeffcoat, (1996). The inputs are connected with PB and outputs are connected to the DCV solenoids. Figure 10 shows the controller hardware. LOGO is the simplest device in the PLC families. It is called programmable relay. LOGO PLC has relays, timers and counters. Some types have real time operation. It can be used for simple operations; it also a reliable and durable device.

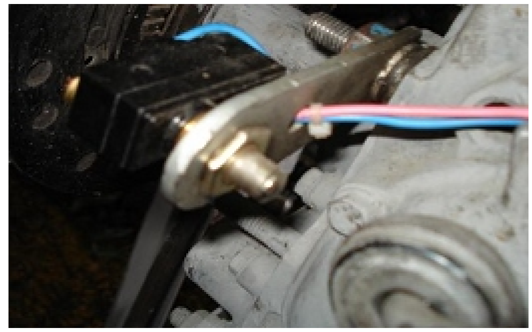

Fig. 13: Limit switch for the reverse gear indication bulb

The PBs are placed on a plate, under each PB there is a bulb that indicates the engaged gear. The neutral position has its own indication bulb. The reverse gear has a buzzer in addition to the indication bulb as shown in Fig. 11. The green bulb indicates the power on. The other bulbs are connected with limit switches. So we used five limit switches, one for each gear as shown in Fig. 12 and 13.

CALCULATIONS

First, we experimentally measured the required force needed to engage the synchronizer, the force was almost 150 (N). The pressure source is about four bars. Piston diameter is 32 mm.

For the engaging motion cylinder:
The piston area A:

$$A = \frac{\pi D^2}{4} = \frac{\pi (32 \times 10^{-3})^2}{4} = 8.04 \times 10^{-4} m^2$$

The connecting rod cross sectional area a:

$$a = \frac{\pi d^2}{4} = \frac{\pi (10 \times 10^{-3})^2}{4} = 7.85 \times 10^{-5} m^2$$

The net area A'

$$A' = A - a = 8.04 \times 10^{-4} - 7.85 \times 10^{-5}$$
$$= 7.25 \times 10^{-4} m^2$$

The extracted force F_{EX}

$$F_{EX} = p \times A = 4 \times 10^5 \times 8.04 \times 10^{-4} = 321.6N$$

The retracted force F_{RE}

$$F_{RE} = p \times A' = 4 \times 10^5 \times 7.25 \times 10^{-4} = 290N$$

Here, P-The air source pressure, P = 4 bars, The sliding force required is 70N

For the sliding motion cylinder:
The piston area A:

$$A = \frac{\pi D^2}{4} = \frac{\pi (20 \times 10^{-1})^2}{4} = 3.14 \times 10^{-4} m^2$$

The connecting rod cross sectional area a:

$$a = \frac{\pi d^2}{4} = \frac{\pi (8 \times 10^{-1})^2}{4} = 5.02 \times 10^{-5} m^2$$

The net area A'

$$A' = A - a = 3.14 \times 10^{-4} - 5.02 \times 10^{-5}$$
$$= 2.63 \times 10^{-4} m^2$$

The extracted force F_{EX}

$$F_{EX} = p \times A = 4 \times 10^5 \times 2.63 \times 10^{-4} = 105.2N$$

The retracted force F_{RE}

$$F_{RE} = p \times A' = 4 \times 10^5 \times 2.63 \times 10^{-4} = 105.2N$$

As we can see, the forces exerted by the cylinders are enough to move the shifting levers.

Diagrams:
Pneumatic diagram: As Fig. 14 shown, cylinder I is extracting when a signal comes to valve B the cylinder will retract. The same thing happens to cylinder III, which connected to valve C. Cylinder II, connected to valve A, and cylinder IV (connected to valve D) are retracting when the signal appears, the cylinder will extract.

Logic shifting map: Figure15 shown the sequence of the shifting procedure, For example, if we are driving at the first gear, we cannot engage the third gear without engaging the second gear. The reverse gear can be only engaged from the neutral position and always returns to neutral. Programming PLC LOGO unit to realize the algorithm shown in Fig. 15.

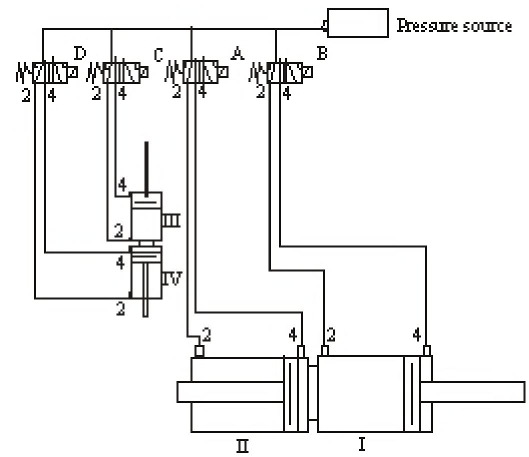

Fig. 14: Pneumatic diagram for gear shifting mechanism

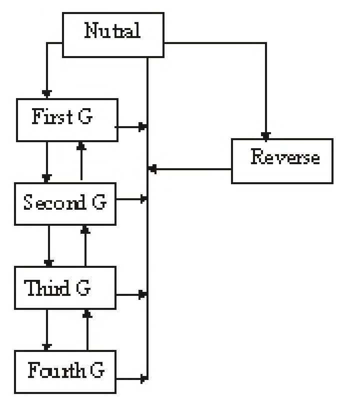

Fig. 15: The logic diagram for the gear shifting

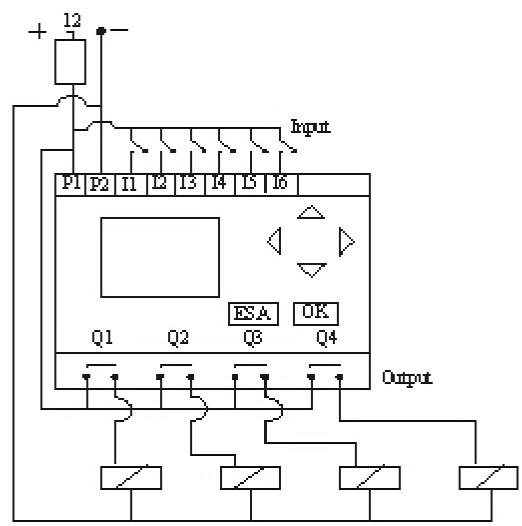

Fig. 16: Electrical diagram for the PLC

Electrical diagram: The output signals of the control unit activate relays, needed to operate the directional valves' solenoids. Fig. 16 shows the electrical connections (Clements-Jewery and Jeffcoat, 1996).

RESULTS AND DISCUSSION

Operation sequence:

Neutral position: In this position all controller outputs are zeros. Cylinders I and III are extended and cylinder II and IV are retracted.

Pressing the neutral button at any engaged gear the controller outputs will be changed to zeros. Also in any gearshift procedure the controller puts the gear in the neutral position first and then engages the desired one, as shown in Table 1 and 2. Table 1 describes the inputs;Table 2 describes the outputs for the neutral position. The directional control valves situations are shown in Table 3.

First gear: Here, cylinder II extends while the other cylinders stay at the previous position. This action pushes the gear stick foreword. Table 4 shows the directional control valves situation for the first gear.

Second gear: After controller reaches the neutral position, cylinder I is retracted. This action pulls the gear stick backward engaging the second gear. Table 5 shows the directional control valves situation for the second gear.

Third gear: After controller reaches the neutral position cylinder III will retract to allow the gear stick to engage the third gear position. Then, cylinder II extends pushing the gear stick and engages the third gear. Table 6 shows the directional control valves situation for the third gear.

Fourth gear: As in third gear, cylinder III is retracted. Then cylinder I will retract too to engage the fourth gear. Table 7 shows the directional control valves situation for the fourth gear.

Reverse gear: From neutral position, cylinder IV extends then cylinder II extends too. At this position, all cylinders are extended. Table 8 shows the directional control valves situation for the reverse gear.

Table 1: The inputs for the neutral position

Input	Description
I1	PB (first gear shift)
I2	PB (second gear shift)
I3	PB (third gear shift)
I4	PB (fourth gear shift)
I5	PB (reverse gear shift)
I6	PB (neutral position)

Table 2: The outputs for the neutral position

Output	Description
Q1	SV (A)
Q2	SV (B)
Q3	SV (C)
Q4	SV (D)

Table 3: Valves situation at neutral position

D.C.V	PORT 2	PORT 4	Solenoid
A	Pressure	Exhaust	0
B	Pressure	Exhaust	0
C	Pressure	Exhaust	0
D	Pressure	Exhaust	0

Table 4: Valves situation at first gear

D.C.V	PORT 2	PORT 4	Solenoid
A	Exhaust	Pressure	1
B	Pressure	Exhaust	0
C	Pressure	Exhaust	0
D	Pressure	Exhaust	0

Table 5: Valves situation at the second gear

D.C.V	PORT 2	PORT 4	Solenoid
A	Pressure	Exhaust	0
B	Exhaust	Pressure	1
C	Pressure	Exhaust	0
D	Pressure	Exhaust	0

Table 6: Valves situation at third gear

D.C.V	PORT 2	PORT 4	Solenoid
A	Exhaust	Pressure	1
B	Pressure	Exhaust	0

Table 7: Valves situation at fourth gear

D.C.V	PORT 2	PORT 4	Solenoid
A	Pressure	Exhaust	0
B	Exhaust	Pressure	1
C	Pressure	Exhaust	0
D	Exhaust	Pressure	1

Table 8: Valves situation at reverse gear

D.C.V	PORT 2	PORT 4	Solenoid
A	Exhaust	Pressure	1
B	Pressure	Exhaust	0
C	Exhaust	Pressure	1
D	Pressure	Exhaust	0

CONCLUSION

- According to the achieved results, the suggested mechanism is realizable and workable.
- Using the simplest PLC and required hardware enables to convert the old traditional gear shifting mechanism to semi utomatic one.
- The application of this mechanism leads to make the driving process easier, reduces the risk of destabilizing the car, the lap/stage time, and the chance of miss shifting.

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