Hydraulic Starting System for Automobile

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***Absract* - Starting system of an automobile is a very important system, supplies energy to perform suction, compression & exhaust stroke and to overcome frictional forces of rotating parts. Majority of automobiles are having electrical starter which draws electrical energy from electrical battery. These electrical batteries are suffering from major drawbacks like environmental pollution, less life, cold weather starting, high price, frequent replacement. Now a day's, many vehicles are having hydraulic system for functionality purpose. Hydraulic motors are having advantages of less weight, bulk & cost and high torque. Theses motors are maintenance free and having long life. Moreover, hydraulic energy can be supplied form on board hydraulic system helps to reduce capacity of electrical battery. Present work is oriented to develop system to start the IC engine using hydraulic motor in conjunction with onboard hydraulic system.**

Keywords: Automobile starting system; Electrical starter motor; Hydraulic motor

INTRODUCTION

All IC engines are suffering from major drawback of requirement of external energy source to start itself. Once started, they rely only upon fuel energy supplied.[1] Majority of starting energy required is used by suction, compression, exhaust strokes, lubrication system, cooling system, fuel supply system, ignition system, Inertia & friction between moving parts. Hence apart from fuel energy, there is always another source of energy to run the IC Engine.[2] Earlier vehicles are having hand cranking system that will be powered by human to start IC engine as This system has major drawbacks of limiting compression ratio, discomfort to alone woman, kick back, hill starting etc.[16] Instead of such difficulties vehicles produced during 17th and 18th centuries were using hand cranking system. In the year 1911, Charles Kettering has invented self starting system. No matter what many inventions, in general, starting energy is stored in form of electrical batteries for majority of vehicles while very few IC engines rely on hydraulic/pneumatic/mechanical form of energy.[3]

Further developments in starting systems were related to coupling between starter pinion and flywheel. In distinct innovation,Valeo developed integrated starter alternator technology, where alternator works as starter motor that eliminates need for another electric motor and resulted in improved performance in criteria like weight, fuel consumption and emission of system.[16]

Further Innovation in a great amount of starting devices was proposal and analyzed, including springs, compressed air, hydraulic and inertial starter engines. Only in 1910 batteries with enough capacity of storage had started to be produced, making feasible the use of electric motors as starter motors. The basic project of the starter motor was elaborated a long time ago. In market, nowadays, there is a continuous necessity for improvements in the performance and reduction of cost. The sum of these factors is the incentive for this project.[14]

A new methodology found to circumvent this issue and it is, by evaluating the strain experienced by the pinion and drive mechanism, engine starting torque demand can be evaluated
at any temperature. By this process, starting system design can be made to suit the correct requirements of the engine starting[12]

Major Requirements of Starting System:

1. Continuous readiness for starting
2. Sufficient starting power at different Temperatures
3. Long service life for high number of starts
4. Robust design to withstand meshing, cranking, vibration, corrosion, dampness and dirt,
5. Low weight and small size weight and small size
6. Longest possible maintenance free service life.

DESCRIPTION OF CONCEPT

Proposed system aimed to develop for automobiles with on board hydraulic system. Major components of hydraulic system are hydraulic accumulator, hydraulic pump, power take off, direction control valve, oil reservoir and hydraulic device. The vehicle selected to test the concept is TATA ACE HOPPER TIPPER. Important engine specifications of the vehicle are described in Table 1. Starter motor fitted in TATA ace vehicle is producing 800 W at 2500 rpm. The pinion meshes with flywheel through bendix mechanism. Important specification of starter motor of TATA ace hopper tipper vehicle are mentioned in Table 2. Analogy between hydraulic starter and electrical starter is described in Table 3.

Table 1. Engine specification of TATA ace

Parameter	Specification
Engine Type	4 stroke, naturally aspirated, indirect injection diesel engine
Compression ratio	22.8:1
Capacity	702 cc
No of cylinder	2
Max. Power	16 bhp@3200 rpm
Max Torque	38 Nm@2000 rpm

Table 2. Starter specification of TATA ace

Parameter	Specification
Engine starting rpm	200-250 rpm
Starting power	800 W
No of teeth on pinion	12
No of teeth on flywheel	121
Starting time	0.5 – 1.5 s

Table 3. Electrical-hydraulic starter analogy

Parameter	Electric Starter	Hydraulic Starter
Energy storage	Electric battery	Hydraulic accumulator
Cranking device	Electric motor	Hydraulic motor
Energy transmit	Conductor cables	Hoses
Cranking switch	Starter relay	Direction control valve
Energy generator	Alternator	Hydraulic pump
Coupling mechanism	Bendix drive	May be magnetic clutch

DESIGN METHODOLOGY

Elementary design parameters considered are based on electrical starter motor. In present vehicle starter motor power rating is noted. Engine cranking rpm recorded with the help of tachometer. To prevent engine starting fuel supply was disconnected. To account for effect of various parameters on engine starting several test run carried out under different starting conditions. Cold starting, hot starting rpm recorded at different battery states of charge. The results are recorded and higher values are considered for design and described in Table 4 and Table 5 respectively. During cold starting conditions engine rpm recorded were higher than hot starting conditions as reduced heat loss to coolant result in more power transfer to piston and efficient use of heat energy. Battery SOC has less effect on engine cranking rpm.

Table 4. Recording of elementary parameters

Parameter	Cold start 1	Cold start 2	Hot start 1	Hot start 2
Engine (rpm)	235	249	219	225
Starting time (s)	2.0	1.8	1.7	1.5
Parameter	100% SOC	75% SOC	100% SOC	75% SOC
Engine (rpm)	245	239	220	218
Starting time (s)	1.9	2.0	1.8	1.8

Table 5. Optimum values considered for design

Sr no	Parameter	Design value
1	Engine starting rpm	250
2	Starter power W	800
3	No of teeth on pinion – $t_{starter}$	11
4	No of teeth on flywheel - $t_{flywheel}$	113
5	Starting time - s	2

Design of hydraulic starter motor

Considering higher starting RPM is 250. Further, considering starter and flywheel gear ratio, starter RPM will be as following:

$$N_{Flywheel} \times t_{Flywheel} = N_{Starter} \times t_{Starter}$$

$$250 \times 113 = N_{Starter} \times 11$$

$$N_{Starter} = 2568.18 \sim 2569\ RPM$$

Now, to calculate starter torque following equation can be used:

$$Power\ (W) = \frac{2\,\pi\, N_{Starter}\ T_{Starter}}{60}$$

$$800 = \frac{2 \times 3.14 \times 2569 \times T_{Starter}}{60}$$

$$T_{Starter} = \frac{800 \times 60}{2 \times 3.14 \times 2569}$$

$$T_{Starter} = 2.97\ Nm@2569\ RPM$$

According to speed and torque of starter, Hydraulic motor has to be selected from supplier/market. To reduce overall cost, manufacturing and design field seeks available components/assembly from market. While selecting or choosing such component, if perfect matching of specification is not available than higher parameters are selected. Here, in this case, selected motor should produce torque of 2.97 Nm@2569 rpm or higher. Table 6 describes specification of hydraulic motor selected. Figure 1 shows hydraulic motor with gear to engage with flywheel.

Table 6: Specification of hydraulic motor

Sr no	Parameter	Design value
1	Running[rpm]	1550
2	Hydraulic motor power [W]	2400
3	Displacement [cc/rev]	12
4	Maximum pressure drop [bar]	10

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Figure 1. Hydraulic motor

Design of hydraulic pump

Test vehicle is not fitted with hydraulic accumulator. Hence, hydraulic pump must be used to supply oil under pressure. To design pump it must supply power than required by hydraulic motor. Based on hydraulic motor selected hydraulic pump selected from market has specification described in Table 4.16

Table 7: Specification of hydraulic pump

Sr no	Parameter	Design value
1	Pump type	3020
2	Nominal displacement [cc/rev]	6.07
3	Nominal delivery [lpm]	9.1
4	Maximum continues pressure [bar]	207
5	Speed at max. cont. pressure [bar]	3500

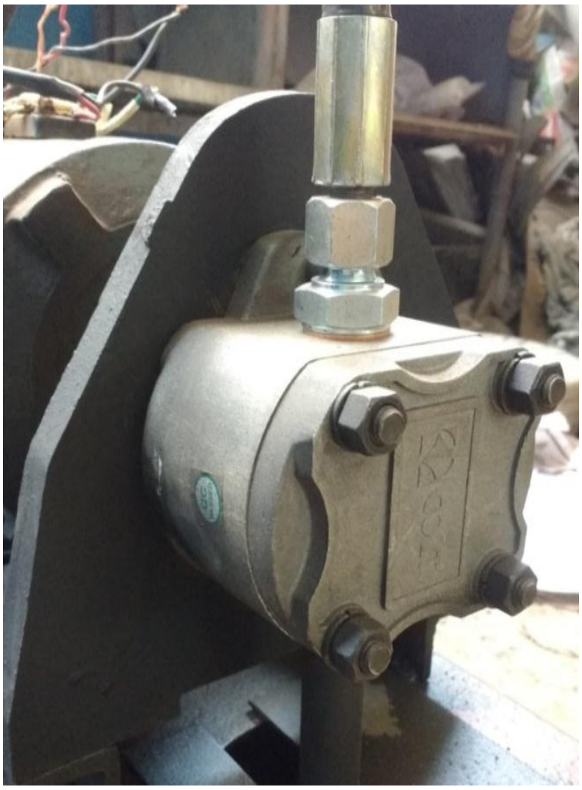

Figure 2. Hydraulic Pump

EXPERIMENTAL SETUP

Schematic of experimental set up is shown in figure To start engine, initially power is supplied to electric motor which drives hydraulic pump. Hydraulic pump sucks low pressure oil from oil reservoir tank and supplied to direction control valve through high pressure hose. As pressure is reached to designate value direction control valve is operated and now oil under high pressure is directed to hydraulic motor. Hydraulic motor is coupled with flywheel and once oil is supplied it starts rotating flywheel and thus cranking of engine starts. Low pressure oil is directed to oil reservoir tank through low pressure hydraulic hoses. Once engine is started direction control valve stops the supply to hydraulic motor. In the mean time supply to electric motor is stopped which brings hydraulic pump to rest. Hydraulic motor is disconnected from flywheel and engine is allowed to run.

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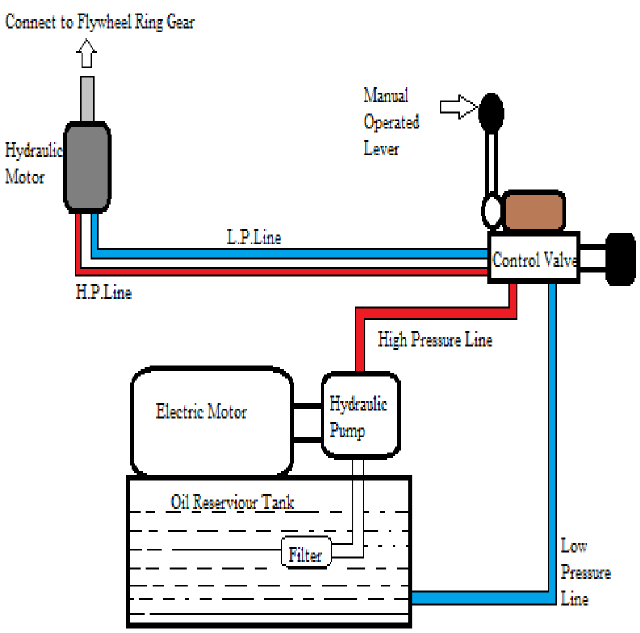

Figure 3. Schematic of Experimental Setup

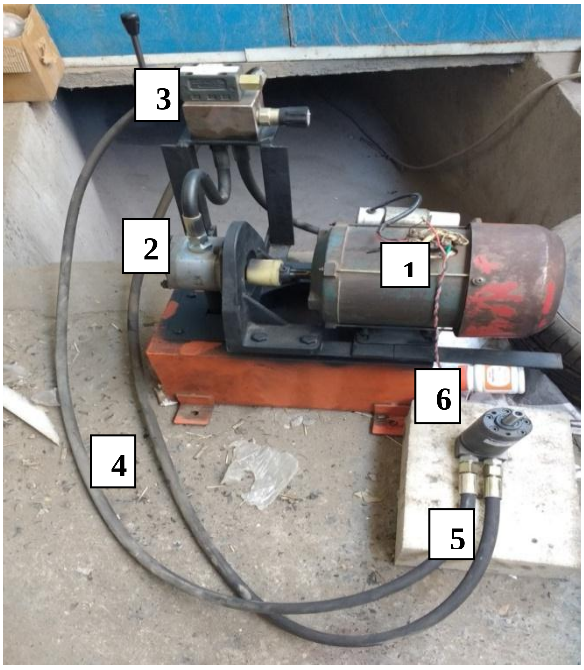

Figure 4. Actual Experimental Setup

1	Electric motor	4	High pressure line
2	Hydraulic pump	5	Low pressure line
3	Direction control valve	6	Hydraulic motor

Experimental procedure

To carry out experiments following procedure is used.

- Disconnect fuel supply to prevent engine from starting
- Mount hydraulic motor to flywheel
- Operate direction control valve to supply high pressure oil to motor
- Record time consumed for cranking
- Record maximum engine rpm during cranking
- Operate direction control valve to stop oil supply to hydraulic motor
- Repeat above steps with fuel supply to ensure engine starting

To reduce errors in reading cranking process is done with following considerations

- For each condition 5 readings to be noted and average time should be considered
- Experiments should involve cold starting and hot starting

OBSERVATION AND RESULTS

As per experimental procedure mentioned above, experiments are carried out and results are tabulated in observation table as following. Cold cranking start is considered when starting engine after night halt and coolant temperature is ambient. Hot starting is engine condition when vehicle is ran for 15 km approx. and coolant temperature is nearly 90℃. Results recorded on two different days i.e. on 1st may 2017 and 8th may 2017. Results of cold cranking engine rpm & hot cranking rpm vs. cranking time on date 1st may 2017 are shown in Table 7 and Table 8 respectively. Results of cold cranking engine rpm & hot cranking rpm vs. cranking time on date 8th may 2017 are shown in Table 9 and Table 10 respectively.

Table 8: Cold cranking rpm and time recorded on 1st may 2017

Parameter	Cold crank 1	Cold crank 2	Cold crank 3	Cold crank 4	Cold crank 5
Engine (rpm)	275	278	283	276	274
Cranking time (s)	1.5	1.4	1.6	1.5	1.5

Table 9: Hot cranking rpm and time recorded on 1st may 2017

Parameter	Hot crank 1	Hot crank 2	Hot crank 3	Hot crank 4	Hot crank 4
Engine (rpm)	294	296	292	301	299
Cranking time (s)	1.0	1.1	1.2	1.1	1.1

Table 10: Cold cranking rpm and time recorded on 8th may 2017

Parameter	Cold crank 1	Cold crank 2	Cold crank 3	Cold crank 4	Cold crank 5
Engine (rpm)	273	279	274	275	272
Cranking time (s)	1.6	1.5	1.5	1.4	1.4

Table 11: Hot cranking rpm and time recorded on 8th may 2017

Parameter	Hot crank 1	Hot crank 2	Hot crank 3	Hot crank 4	Hot crank 4
Engine (rpm)	298	297	293	298	297
Cranking time (s)	1.1	1.2	1.1	1.0	1.0

Results of cold starting engine rpm & hot starting rpm vs. cranking time on date 1st may 2017 are shown in table 5.5 and table 5.5 respectively. Results of cold starting engine rpm & hot starting rpm vs. cranking time on date 8th may 2017 are shown in table 5.7 and table 5.8 respectively.

Table 12: Cold starting engine rpm and time recorded on 1st may 2017

Parameter	Cold start 1	Cold start 2	Cold start 3	Cold start 4	Cold start 5
Engine (rpm)	235	234	237	232	235
Starting time (s)	1.5	1.5	1.4	1.5	1.5

Table 13: Hot starting engine rpm and time recorded on 1st may 2017

Parameter	Hot start 1	Hot start 2	Hot start 3	Hot start 4	Hot start 5
Engine (rpm)	210	208	201	216	210
Starting time (s)	1.4	1.4	1.4	1.3	1.4

Table 14: Cold starting engine rpm and time recorded on 8th may 2017

Parameter	Cold start 1	Cold start 2	Cold start 3	Cold start 4	Cold start 5
Engine (rpm)	234	237	236	234	237
Starting time (s)	1.4	1.5	1.4	1.4	1.5

Table 15: Hot starting engine rpm and time recorded on 8th may 2017

Parameter	Hot start 1	Hot start 2	Hot start 3	Hot start 4	Hot start 5
Engine (rpm)	209	209	208	214	212
Starting time (s)	1.4	1.4	1.3	1.3	1.4

DISCUSSION ON RECORDING RESULTS

(1) Cold and hot cranking performance From the tables 5.1, 5.2, 5.3 and 5.4 above, average cold cranking rpm and cranking time for both the days are 276 rpm and 1.5 s respectively while cranking with hydraulic motor. Whereas average hot cranking rpm and cranking time for both days are 297 rpm and 1.1 s respectively. The hot cranking rpm are 7.6% higher than cold cranking rpm. The reason behind increase in rpm may be reduced friction forces during hot cranking results in less effort and reduced time for cranking. During cold cranking lubrication oil has not reached all the components. In addition hot surfaces are smoother than cold surfaces. Hot cranking time is 0.4 seconds less compared to cold cranking time. This shows the reduction of 26.67 % of cranking time in hot cranking compared to cold cranking time.

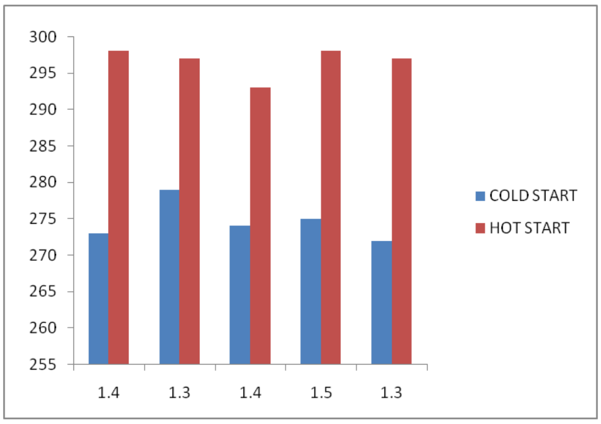

Figure 5: Engine Rpm Vs Cranking Time on 8th May

(2) Cold and hot starting performance
Average cold starting rpm and time with hydraulic motor are 235 rpm and 1.5 s respectively for both the days. Average hot starting rpm and time with hydraulic motor are 210 rpm and 1.4 s respectively for both the days. Hot starting rpm are 10.63% less than cold starting rpm. Again, less friction forces with addition of less heat loss results in lower starting rpm during hot engine condition. However, time required for starting is nearly same for both shows that heat losses may have more impact during hot starting condition. With electric starter, cold starting rpm and time recorded are 241 rpm and 1.9 s respectively. Further, with electric starter, hot starting rpm and time is 222 rpm and 1.6 s respectively. State of battery charge does not have considerable impact when 100% and 75% charge. But may be result in considerable change in cold climate as battery performance deteriorate with fall in environmental temperature. With hydraulic motor starting rpm is 1 % less than electric motor may be due to minimum engine speed required to start the engine. Though very minor change in starting rpm, reduction in starting time with hydraulic starter is 20 % less this is very useful in vehicles with start stop system. During hot starting with hydraulic motor engine starts at 210 rpm which is 5.4 % lower than hot engine starting with electric motor. Hydraulic motor is capable of hot engine starting earlier by 0.2 s compared to electric starter.

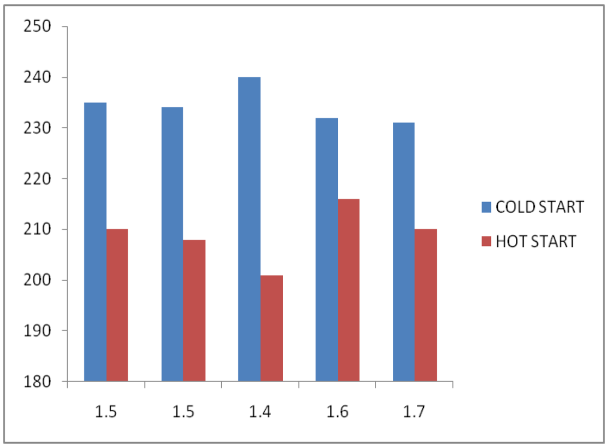

Figure 6: Engine Rpm Vs Starting Time on 8th May

COST ANALYSIS

From annexure 1, addition of cost with hydraulic motor seems to be Rs.25000/-. However, in actual additional cost is for hydraulic motor, hoses and direction control valve has to be added because hydraulic pump and reservoir are already installed on vehicle. This additional cost comes out to be Rs. 12480/- which is very comparative to electric starter having cost of approx. Rs. 9000/-. Hence, actual cost difference will be Rs. 3480/- only. Moreover, maintenance required by electric starter is more than hydraulic starter. In addition, battery required with electric starter needs higher capacity and higher voltage with all cells should be in working condition. Whereas with hydraulic starter battery capacity is reduced and even works fine with one of the cell is damaged. Weight and bulk of hydraulic motor is lower than conventional electric starter helps to design compact engine system and vehicle. Battery contains hazardous pollutants like lead. With hydraulic starter motor battery life improves as for starting power is not fetched from battery and even in case of one of any cell is damaged battery continue to perform satisfactory. With reduced capacity battery cost, bulk and weight of engine compartment reduces and may result in overall gain in spite of additional cost and components.

CONCLUSION

Based on recorded results and literature references following conclusions are drawn.

- Cold engine cranking time is 7.6% higher than hot engine cranking time with hydraulic motor.
- Cold starting time with hydraulic starter is 1.5 s compared to 1.9 s of electric starter and is 21.05% lower than electric starter.
- Hot starting time with hydraulic starter is 1.4 s compared to 1.6 s of electric starter and is 12.5% lower than electric starter.
- Initial cost with hydraulic starter is higher by Rs. 3480/- compared to electric starter but considering initial and running cost hydraulic motor may be cheaper than electric starter.
- Battery life is more with hydraulic starter and results in reduced environment pollution.
- Hydraulic starter is more suitable for vehicles with start stop system.

SUMMARY

- Cold engine cranking time is higher compared to hot engine cranking time may be due to higher friction forces with lack of lubrication.
- Hydraulic starter can easily start engine compared to electric starter.
- Hydraulic starter is more suitable for vehicles with start stop system.
- Hydraulic starting system is more compact, low weight and less bulky than electric starting system.
- Hydraulic starting system has less maintenance cost and higher life compared to electric starter.
- Vehicles with hydraulic system on board can be easily modified with hydraulic starter.

FUTURE SCOPE

This research work has following future scopes

- Hydraulic starter motor with inbuilt pinion engagement and disengagement system can be developed.
- Research work on using engine oil pump as starter seems to be more beneficial option.
- Combination of technology like reducing cranking torque and hydraulic starter should be researched.
- Effect of ambient temperature on new starting system can be new area of research work.

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