Experimental analysis of faults of automobile starting

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Abstract

In a vehicle operation, engine start is an important phase and it influences emission and drivability of the vehicle. The main function of the starting system is to supply cranking torque to the crankshaft of the engine until a sustainable rpm is achieved. A warm engine will normally take only two revolutions of the crankshaft and a cold engine may have to be cranked for a little longer to start. It is essential to disengage the pinion from the engine crankshaft to protect the starter motor against over speed and prevent excessive wear. The continuous attempt to start the engine may increase contact resistance which results in various starting system faults like brush fault, armature fault, field winding fault, short circuit fault, battery fault and open circuit fault. The conventional methods which are in practice to detect various faults of automobile starting system have the limitations that an expert can detect the fault with his previous experience and intelligence or by measuring certain electrical parameters by conducting tests. Both are time consuming as well as laborious process. Those conventional techniques cannot meet all of the demands. Fault detection and diagnosis is getting more importance in recent days. Based on the experimental data, fault diagnosis system can be developed to monitor the starting system before they occur. The developed fault diagnosis system can be used by the manufacturers and service providers.

Keywords: Starting system; Peak cranking current; Cranking attempts; Starter motor faults; Contact resistance

1. Introduction

In a vehicle operation, engine start is an important phase and it influences emission and drivability of the vehicle. The main function of the starting system is to supply cranking torque to the crankshaft of the engine until a sustainable rpm is achieved. A warm engine will normally take only two revolutions of the crankshaft to start. A cold engine may have to be cranked for a little longer up to a minute is not uncommon [1]. As soon as the internal combustion engine starts to generate its own torque and results in increasing speed of rotation, even though this is not sufficient for starting in all cases. The starter motor may have to continue to assist the internal combustion engine to reach the minimum sustained operation speed. After only a few ignition cycles, the engine accelerates so sharply that the starter motor can no longer match its speed and is outrun. At this point, it is essential to disengage the pinion from the engine crank shaft to protect the starter motor against over speed and prevent excessive wear.

The amount of current that passes through the winding determines the amount of torque the motor shaft can produce. Since the series field is made of large conductors, it can carry large amounts of current and produce large torques. The starter motor used to start an automobile engine is a DC series type and it may draw up to 500 A when it is turning the engine’s crankshaft on a cold conditions [2]. The series motor can safely handle large currents since the motor does not operate for an extended period. In most applications the starter motor will operate for only a few seconds while this large current is present. The rated voltage of the starting system for light duty motor vehicle is 12 V system and for heavy duty vehicles is a 24 V system. The starting system with 24V system requires half the current needed with a 12 V system to produce same power. Also it reduces the voltage drop considerably in the wiring as the length of wires used in commercial vehicles are much greater than in passenger cars.

The DC series type starter motor cannot be permanently locked with the crankshaft during cranking. If it is locked with the engine crankshaft permanently during cranking, the inertia of the rotor of the starter motor will be increased ten times greater than required torque and finally damage the starter motor armature, which is reflected in the motor current, finally affects the contact resistance of the starting system [3].

Unexpected breakdown of vehicle due to starting system faults causes both monetary losses and replacement of its parts before its service life. Since starting system of a vehicle is a typical mechanical and electric device relating to efficiency and safety of vehicle start process, it may get damaged because of improper operation and hence decrease its service life [4].

Starting system failures are due to mechanical faults (like wear, seizure or fractures of moving parts) or electrical failures like short or interrupted circuit and contact resistance increase [5]. Among the electrical faults, short and open circuits faults as well as deterioration of brushes and commutator are very common. In mechanical faults, damaged pinion gear provides torque during starting manifest themselves as
mechanical vibrations, acoustic noise and current transients is the most common.

The connectors for automotive applications are often subjected to harsh environmental conditions. Long term exposure to extreme levels and rapid variation, humidity and temperature deteriorate the connectors, increases the contact resistance and hence reduces reliability. However, the ability of the connectors to withstand high temperatures has become critical since the engine compartment which experiences ambient temperatures has slowly decreased in size because of the more compact and low hood line design. Though it is very difficult to simulate the exact conditions of the automobile connectors encounter in real life, it is possible to study the effect of certain conditions and to correlate their influence on the extent of temperature variation and in turn to predict the reliability of connectors by controlling the contact resistance [5].

No study to date, has studied the influence of changes of contact resistance of connectors used in starting system. In last years, several electrical systems are installed in modern cars in order to satisfy the needs of comfort, security, performance and to reduce the fuel consumption. Consequently, the demand in electrical power increases.

High current leads to increase contact temperature due to the generation of the Joule heat and can produce metallurgical changes such as softening or even melting of the conducting areas. This requires the minimization of electrical contact resistance and contact temperature, which requires the conception of new power connectors and minimization of electrical contact resistance and contact temperature for the high currents. Moreover, high currents need lower electrical contact resistance \( C R < 1 \text{ m\Omega} \). If the contact resistance increases, the losses increase and the starter output drops [5]. The total contact resistance of the starting system determines the quality of start.

In this study, the peak cranking current and voltage drop across the starting system during cranking was measured using a tong tester (clamp meter). Light duty car (diesel and petrol) vehicles, medium and heavy duty vehicles were taken as test vehicles and tests were conducted on the same as shown in the Fig. 1. In this study, test vehicles with defective starter motor and new starter motor with new and low charged battery, the peak cranking current and voltage drop during cranking were measured and compared. Reliable and safe operation can be accomplished by detection, classification and monitoring of faults in very early by suitable diagnosis methods and taking proper corrective action at right time [6].

Starting system failure detection is a complicated process and requires high level of expertise. The conventional methods which are in practice to detect various faults of automobile starting system have the limitations that an expert can detect the fault with his previous experience and intelligence or by measuring certain electrical parameters by conducting tests. Both are time consuming as well as laborious process. The available test rigs have the limitations that it can be used to test the starter motor alone after overhauling the same. It cannot be used to detect entire starting system faults of a vehicle, therefore the conventional methods of detecting starting system faults leads to financial losses. Therefore an electronic control unit (ECU) can be developed based on the peak cranking current and voltage during cranking at different fault conditions to detect the starting system faults by transferring human expertise into a computer and stored in a suitable form. Then the system can make inferences and arrive at a specific conclusion to give advices and explains, if necessary, the logic behind the advice to the user [7].

2. Measurement of Current and Voltage of Faulty Starting System

The various starting system fault conditions of both petrol and diesel vehicles were observed and studied the causes for them. The test vehicles considered in this study are light duty petrol and diesel cars, medium and heavy duty diesel vehicles.

A tong tester (clamp meter) was used to measure the momentary current drawn by the starter motor during cranking; Simultaneously voltage drop across the battery terminals were also measured using volt meter. The test set up used to measure the current and the voltage drop during cranking at various starting system fault conditions is shown in Fig. 1. The cranking test was conducted as per SAEJ544 test procedure. Five cranking attempts were made with time interval of 3 seconds to start the engine and the corresponding open circuit voltage, voltage drop and peak cranking current during cranking were measured. Similarly, used starter motor of the same vehicle was replaced by a new starter motor, the same test procedure was followed and the corresponding open circuit voltage, voltage drop and peak cranking current during cranking were measured.

A set of tests were conducted for measurement of peak cranking current and voltage drop during cranking with various fault conditions. Different starting system faults of test vehicles like brush fault; Battery fault, open circuit fault, armature fault, field winding fault and short circuit faults were measured. The testing of light duty vehicle (petrol and diesel), medium duty diesel and heavy duty diesel vehicles are shown in Fig. 2. The current drawn by the starter motor and the voltage drop during cranking of internal combustion engine with new starter motor and new battery, starter motor with various faults with new battery and faulty starting system circuits were measured by conducting a set of tests. The specifications of the test vehicles, light duty vehicle (petrol and diesel), medium duty diesel and heavy duty diesel vehicles are shown in Table 2.1

The measured values of peak cranking current and voltage at various conditions of starting systems of light duty vehicle (petrol and diesel), medium duty diesel and heavy duty diesel vehicles are shown in Table 2.2
Figure 1. Test set up to measure current and voltage

(a) Light duty vehicle (diesel)  
(b) Light duty vehicle (petrol)  
(c) Medium duty diesel vehicle  
(d) Heavy duty diesel vehicle

Figure 2. Testing of vehicles

Table 1. Specifications of Test Vehicles

<table>
<thead>
<tr>
<th>SL.No.</th>
<th>Vehicle type</th>
<th>Engine Power (HP)</th>
<th>Engine Torque (Nm)</th>
<th>Battery Capacity (Ah)</th>
<th>Starter motor Power (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Light duty petrol</td>
<td>37.00</td>
<td>59.00</td>
<td>50.00</td>
<td>2.00</td>
</tr>
<tr>
<td>2</td>
<td>Light duty diesel</td>
<td>42.70</td>
<td>102.00</td>
<td>70.00</td>
<td>2.20</td>
</tr>
<tr>
<td>3</td>
<td>Medium duty diesel</td>
<td>71.30</td>
<td>200.00</td>
<td>88.00</td>
<td>2.00</td>
</tr>
<tr>
<td>4</td>
<td>Heavy duty diesel</td>
<td>145.00</td>
<td>470.00</td>
<td>120.00</td>
<td>2.00</td>
</tr>
</tbody>
</table>
The experiments were conducted on the starting systems of the test vehicles fitted with 50% worn out brushes and new batteries. The measured peak cranking current and the corresponding voltage drop during cranking are measured. The maximum peak cranking current of the light duty petrol, light duty diesel, medium duty diesel and heavy duty diesel vehicles are 96A, 165 A, 166 A and 272 A respectively. Engine took long cranking time for starting, at the same time sparks were occurred between the starter motor commutator and the brushes.

2.3. Armature fault

The experiments were conducted on the starting systems of the test vehicles in which the armatures of the starter motors were replaced by a damaged armature with good condition battery. The measured peak cranking current and the corresponding voltage drop during cranking are measured.

The maximum peak cranking current of the light duty petrol, light duty diesel, medium duty diesel and heavy duty diesel vehicles are 215 A, 308 A, 356 A and 415 A respectively. It is observed that the starting system drew high current.
2.4. Battery fault

The biggest cause of the starting system failure is low battery voltage which causes the problems for the starting system and faulty starter motor causes battery problem. The experiments were conducted on the starting systems of the test vehicles with new starter motor and the battery which was not having 100% charge but able to support the starting system were mounted. The measured peak cranking current and the corresponding voltage drop during cranking are measured. The maximum peak cranking current of the light duty petrol, light duty diesel, medium duty diesel and heavy duty diesel vehicles are 132 A, 185 A, 218 A and 317 A respectively.

It is noted that the solenoid switch makes a series of rapid clicks. When the starter motor begins to turn, the battery voltage decreases rapidly to a point where the windings in the solenoid switch can no longer hold the solenoid disc against the contacts. This releases the load made by the starter motor on the battery, therefore the solenoid gets enough voltage to operate again making click sound [2].

2.5. Field winding fault

The experiments were conducted on the starting systems of the test vehicles in which the field windings of the starter motors were replaced with faulty field windings and good condition battery. The measured peak cranking current and the corresponding voltage drop during cranking are measured. The maximum peak cranking current of the light duty petrol, light duty diesel, medium duty and heavy duty diesel vehicles are 245 A, 345 A, 388 A and 472 A respectively.

It is observed that, as the number of attempts increases, the battery voltage decreases and the starter motor drew high current. The starter motor was not running in this condition because the magnetic field was very low.

2.6. Open circuit fault

The good conditions of starting system of the test vehicles were ensured by starting the engine in one attempt. The starting system circuits were set for loose connection to have an open circuit fault. The peak cranking current and the corresponding voltage drop during cranking are measured. The maximum peak cranking current of the light duty petrol, light duty diesel, medium and heavy duty diesel vehicles are 155 A, 235 A, 276 A and 350 A respectively.

The engine was able to start only when holding the cable connections are in proper tight condition during cranking, when there is cross section reduction in connection cable, the loose cable connection or the loose battery pole, the starting system was not developing the required torque to start the engine [2].

2.7. Short circuit fault

The experiments were conducted on the starting systems of the test vehicles in which the field winding of starter motors were replaced with short circuited field winding and good condition battery. The measured peak cranking current and the corresponding voltage drop during cranking are measured. The maximum peak cranking current of the light duty petrol, light duty diesel, medium and heavy duty diesel vehicles are 390 A, 395 A, 453 A and 545 A respectively.

As the number of cranking attempts increases, the battery voltage decreases, at the same time it drew high current. In this condition the starter motor was not running because there was not enough magnetic field. It is observed that in both field winding fault and short circuit fault, even though the starter motor drew high current, the starting system was not developing the required torque due to weaker magnetic field.

It is observed from the experimental results that if any fault occurred in the starting system or the starter motor, the peak cranking current and voltage drop during cranking are changed. It is observed that the voltage drop and the peak cranking current of each fault are different for light duty (petrol and diesel), medium and heavy duty diesel vehicles.

3. Comparison of Peak Cranking Current and Voltage

3.1 Comparison of different faults of light duty vehicle

The comparison of peak cranking current and voltage drop at different faults of light duty petrol vehicle is shown in Fig. 3. The peak cranking current developed by the starting system in good condition is 187 A. The peak cranking current developed by the same starting system in brush fault, battery fault and open circuit fault conditions are 96 A, 132 A and 155 A respectively. It is noted that these peak cranking current are lower than that of normal condition.

The peak cranking current developed by the starting system in armature fault, field winding fault and short circuit fault conditions are 215 A, 245 A and 390 A, respectively. It is noted that these peak cranking current are higher than that of normal condition. The starting system drew high current.

3.2 Comparison of different faults of light duty diesel vehicle

The comparison of peak cranking current and voltage drop at different faults of the light duty diesel vehicle is shown in Fig. 4.

The peak cranking current developed by the starting system in good condition is 285 A. The peak cranking current developed by the same starting system in brush fault, battery fault and open circuit fault conditions are 165 A, 185 A and 235 A.
respectively. It is noted that these cranking current are lower than that of normal condition. The engine took long cranking time for starting, at the same time sparks were occurred between the starter motor commutator and the brushes.

The peak cranking current developed by the starting system in armature fault, field winding fault and short circuit fault conditions are 308 A, 345 A and 395 A respectively. It is noted that these peak cranking current are higher than that of normal condition. The starting system drew high current.

3.3. Comparison of different faults of medium duty diesel vehicle

The comparison of the voltage drop and the peak cranking current at different faults of medium duty diesel vehicle is shown in Fig. 5.

The peak cranking current developed by the starting system in good condition is 305 A. The peak cranking current developed by the same starting system in brush fault, battery fault and open circuit fault conditions are 166 A, 218 A and 276 A, respectively. It is noted that these peak cranking current are lower than that of normal condition. The peak cranking current developed by the starting system in armature fault, field winding fault and short circuit fault conditions are 356 A, 388 A and 453 A respectively. It is noted that these peak cranking current are higher than that of normal condition. The starting system drew high current.

3.4. Comparison of different faults of heavy duty diesel vehicle

The comparison of peak cranking current and voltage drop at different faults of heavy duty diesel vehicle is shown in Fig. 6. The peak cranking current developed by the starting system in good condition is 392 A. The peak cranking current developed by the same starting system in brush fault, battery fault and open circuit fault conditions are 272 A, 317 A and 350 A respectively. It is noted that these peak cranking current are lower than that of normal condition.

The peak cranking current developed by the starting system in armature fault, field winding fault and short circuit fault conditions are 415 A, 472 A and 545 A, respectively. It is noted that these cranking current are higher than that of normal condition. The starting system drew high current.

![Figure 3. Comparison of different faults of light duty petrol vehicle](image-url)
Figure 4. Comparison of different faults of light duty diesel vehicle

Figure 5. Comparison of different faults of medium duty diesel vehicle

Figure 6. Comparison of different faults of heavy duty diesel vehicle
4. Discussion

In automobile starting system, the cranking torque produced by starter motor is directly proportional to the current consumed by it from the battery during starting. In different faulty conditions of starting system, the cranking current and voltage drop were measured through experiments. In a good condition starter motor, the signal peaks of current and voltage drop were noted in every attempt and it is observed that the required cranking torque was produced by consuming sufficient amount of current from the battery.

The engine didn’t start when the starter motor was fitted with worn out brush because it consumed less current than that of starter motor in good condition. The reasons are due to unsMOOTH contact of the brushes, consumed brush life, dirty collector or brushes, unadjusted brush pressure springs, and oval shaped collector. In these conditions, the starter motor drew less current hence required cranking torque was not developed by it. The cranking attempts were made repeatedly until the engine starts, which increased the internal resistance of the battery, hence service life of both the starter motor and the battery is reduced.

In armature fault condition, there may be a short circuit in armature windings, damaged armature bearing, and open circuits of armature windings. The starter motor runs erratically when short circuit is occurred in the armature and the current drawn also increased. Since there is a short circuit in the armature winding, one of the armature windings of the starter motor was cancelled. In this case, the motor runs without developing the required torque. When the brush comes across this broken winding, the engine was not started.

The engine didn’t start when the same starting system was fitted with low charged battery; it is observed that the revolution of the motor was too low; this may be due to low charge of the battery or may be due to problem in charging system. When the number of attempts increases, this may increase the internal resistance of the battery, thereby results in reduced service life of the battery. In battery fault condition, the starter motor drew less current than that of normal condition. The starter motor draws twice the current, hence battery voltage is dropped to half. When the battery voltage was less than 6 V, the starter motor was not working, due to fully discharged battery or there is a problem in charging system, at these stages the revolution of the starter motor was too low.

In open circuit fault condition, the starter motor draws more current due to decrease in the cross section of cable, when the cable cross section reduction is more, which cause effect on revolution. If there is loose connection, results in increasing contact resistance thereby starter motor current goes up. If there is an open circuit between solenoid switch and starter motor contact terminals will affect the current carrying capability of the starting system, hence poor torque will be generated by the starter motor. The reasons for open circuit fault are loose or dirty connections which cause excessive voltage drop and increased contact resistance thereby starter motor current goes up. Increased voltage drop also due to resistance of lengthy cables used.

Damaged starter motor and battery terminals will draw more current from the battery which will affect the service life of the battery. If there is short circuit in armature of the starter motor, it will draw heavy current and the starter motor can be seen as working properly; however the required torque was not developed by it. When the brush comes across this broken winding, the motor does not start. In this condition, the current drawn by the starter motor is depending on the largeness of short circuit but the starter motor does not turn the flywheel due to insufficient magnetic fields.

In both short circuit and armature in broken coil condition, the starter motor draws more current than that of normal condition, results in arcing, hence affects service life of the starter motor. The reasons for armature fault are short circuit in armature windings, damaged armature bearing, and open circuits of armature windings. The reasons are due to short circuit between own windings, therefore the starter motor turns but the torque developed was not uniform due to non-existence of enough and smooth magnetic field. The current drawn by the starter motor depends on the magnitude of short circuit.

In field winding fault condition, the current carrying capability of the stator is increased which leads to change in magnetization, therefore flux generated by the stator circuit gets increased, hence results in ripple torque generation by the starter motor. The other reason for the field winding fault may be short circuit between own windings, therefore the motor turns but the torque developed will not be uniform due to non-existence of enough and smooth magnetic field.

5. Conclusion

In brush fault condition, the starter motor drew less current than that of normal condition. The brush fault is predominant problem in starting system of all types of vehicles. In a starting system, if there is any problem, brush will get damaged since the current is passing through it. In armature fault condition, the starter motor drew higher current than that of normal condition. In field winding fault condition, the starter motor drew higher current than that of normal condition. In short circuit fault condition, the starter motor drew higher current than that of normal condition. In both field winding fault and short circuit fault, the starter motor drew higher current than that of normal condition. In open circuit fault condition, the starter motor drew less current than that of normal condition.

The peak cranking current and voltage drop in brush fault, battery fault and open circuit fault conditions are lesser than that of in normal working condition by the starting system of all test vehicles. Similarly the peak cranking current and voltage drop in armature fault, field winding fault and short circuit fault conditions are higher than that of in normal working condition. Different fault conditions of starting system will lead to multiple cranking attempts by the user, which will
increase the contact resistance of the starting system circuit.

Since, the peak cranking current and voltage drop at normal working condition and different fault conditions of light duty (petrol and diesel), medium duty diesel and heavy duty diesel vehicles are different; these values can be used to develop a diagnosis system of automobile starting system. The proposed fault diagnosis system can be used by the manufacturers in their production unit and service providers to save time, monetary loss and unexpected breakdown.

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**References**


